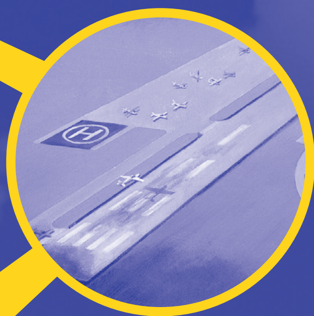
SPECIAL REPORT 263

Future Flight

A Review of the Small Aircraft Transportation System Concept



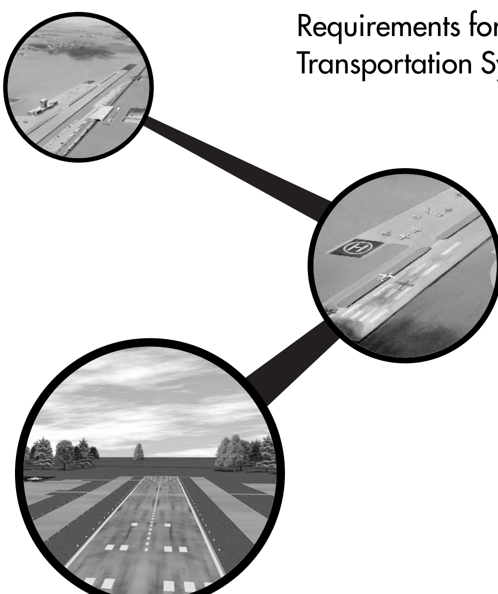
Transportation Research Board
THE NATIONAL ACADEMIES

SPECIAL REPORT 263

Future Flight

A Review of the Small Aircraft Transportation System Concept

Committee for a Study of Public-Sector Requirements for a Small Aircraft Transportation System



Transportation Research Board
National Research Council

National Academy Press
Washington, D.C.
2002

Transportation Research Board Special Report 263

Subscriber Category
V aviation

Transportation Research Board publications are available by ordering individual publications directly from the TRB Business Office, through the Internet at www.TRB.org or national-academies.org/trb, or by annual subscription through organizational or individual affiliation with TRB. Affiliates and library subscribers are eligible for substantial discounts. For further information, contact the Transportation Research Board Business Office, National Research Council, 2101 Constitution Avenue, NW, Washington, DC 20418 (telephone 202-334-3213; fax 202-334-2519; or e-mail TRBsales@nas.edu).

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competencies and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to the procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

The study was sponsored by the National Aeronautics and Space Administration.

Library of Congress Cataloging-in-Publication Data

National Research Council (U.S.). Transportation Research Board. Committee for a Study of Public-Sector Requirements for a Small Aircraft Transportation System.
Future flight : a review of the small aircraft transportation concept / Committee for a Study of Public-Sector Requirements for a Small Aircraft Transportation System, Transportation Research Board, National Research Council.
p. cm.—(Special report / Transportation Research Board, National Research Council ; 263)
ISBN 0-309-07248-4
1. Local service airlines—United States. 2. Aeronautics, Commercial—United States—Planning. 3. Air travel—United States. I. Title. II. Special report (National Research Council (U.S.). Transportation Research Board) ; 263.

TL724 .N38 2002
387.7′3′0973—dc21

2002019966

THE NATIONAL ACADEMIES

Advisers to the Nation on Science, Engineering, and Medicine

National Academy of Sciences
National Academy of Engineering
Institute of Medicine
National Research Council

The **National Academy of Sciences** is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. On the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Bruce M. Alberts is president of the National Academy of Sciences.

The **National Academy of Engineering** was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. William A. Wulf is president of the National Academy of Engineering.

The **Institute of Medicine** was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, upon its own initiative, to identify issues of medical care, research, and education. Dr. Kenneth I. Shine is president of the Institute of Medicine.

The **National Research Council** was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both the Academies and the Institute of Medicine. Dr. Bruce M. Alberts and Dr. William A. Wulf are chairman and vice chairman, respectively, of the National Research Council.

The **Transportation Research Board** is a division of the National Research Council, which serves the National Academy of Sciences and the National Academy of Engineering. The Board's mission is to promote innovation and progress in transportation by stimulating and conducting research, facilitating the dissemination of information, and encouraging the implementation of research results. The Board's varied activities annually engage more than 4,000 engineers, scientists, and other transportation researchers and practitioners from the public and private sectors and academia, all of whom contribute their expertise in the public interest. The program is supported by state transportation departments, federal agencies including the component administrations of the U.S. Department of Transportation, and other organizations and individuals interested in the development of transportation.

Committee for a Study of Public-Sector Requirements for a Small Aircraft Transportation System

H. Norman Abramson, Southwest Research Institute, San Antonio, Texas, *Chair*
Donald W. Bahr, GE Aircraft Engines (retired), Cincinnati, Ohio
Marlin Beckwith, California Department of Transportation (retired), Sacramento
Max E. Bleck, Raytheon Corporation (retired), Benton, Kansas
Daniel Brand, Charles River Associates, Inc., Boston, Massachusetts
Walter S. Coleman, Regional Airline Association (retired), McLean, Virginia
James W. Danaher, National Transportation Safety Board (retired), Alexandria, Virginia
John J. Fearnsides, George Mason University, Fairfax, Virginia
John D. Kasarda, University of North Carolina, Chapel Hill
Charles A. Lave, University of California, Irvine
Nancy G. Leveson, Massachusetts Institute of Technology, Cambridge
Robert G. Loewy, Georgia Institute of Technology, Atlanta
James G. O'Connor, Pratt & Whitney Company (retired), Coventry, Connecticut
Herbert H. Richardson, Texas A&M University System, College Station
Daniel T. Wormhoudt, Environmental Science Associates, San Francisco, California

NATIONAL RESEARCH COUNCIL STAFF

Thomas R. Menzies, Jr., Study Director, Transportation Research Board
Alan Angleman, Senior Program Officer, Aeronautics and Space Engineering Board
Michael Grubbs, Research Assistant, Transportation Research Board

Preface

In August 1999, the Transportation Research Board (TRB) held a workshop at the request of the National Aeronautics and Space Administration (NASA) to examine its Small Aircraft Transportation System (SATS) concept. Individuals from the aviation, transportation infrastructure, public policy, research, and finance communities were invited to participate in the 2-day event, during which managers from NASA's Office of Aerospace Technology described their ongoing efforts to advance the state of technology in general aviation and to further the development and use of advanced small aircraft as a means of personal transportation.

Workshop participants were tempered in their response to the SATS concept and NASA's plans to pursue it. They asked many questions—about the transportation needs that such a system would meet, the practicality of trying to define and plan a transportation system far in advance, and the rationale for NASA's involvement in transportation system planning. Nevertheless, most participants were impressed by the advanced technologies and capabilities described and urged NASA to sponsor a more comprehensive assessment of the SATS concept by TRB and the National Research Council (NRC). NASA agreed, funding this study during spring 2000. The study Statement of Task is presented in Box P-1 and discussed in more detail in Chapter 1.

Following usual NRC procedures, TRB assembled a committee with a range of expertise and a balance of perspectives on issues pertaining to the study topic. H. Norman Abramson, Executive Vice President Emeritus of the Southwest Research Institute, chaired the committee, which included 15 members with expertise in aircraft engineering and manufacturing, airport management and planning, air traffic control, aviation safety, economic development, demographics, transportation system planning, and travel demand analysis. Committee members served in the public interest without compensation.

The committee convened six times during a 16-month period. As noted in the Foreword, all of these meetings except the last occurred before the September 11, 2001, terrorist airline hijackings and attacks. The committee spent much of its time gathering and evaluating data relevant to the SATS concept, and these empirical findings underpin the study conclusions and recommendations. The committee did not, however, have sufficient time to examine the security implications of SATS in a similarly thorough manner in light of the concerns raised by the September terrorist attacks. The most it could do is offer its expert judgment of potential implications,

Box P-1
Statement of Task

This study will address the following two key questions:

1. Do the relative merits of the SATS concept, in whole or in part, contribute to addressing travel demand in coming decades with sufficient net benefit to warrant public investment in technology and infrastructure development and deployment?
2. What are the most important steps that should be taken at the national, state, and local levels in support of the SATS deployment?

In addressing these questions, the committee will:

- Review the validity of the assumptions about future travel demand and transportation capacity challenges presented by the aviation hub-and-spoke system, highway congestion, freight growth, and frequency spectrum management that underlie the justification for the public-sector investment requirements in SATS;
- Consider whether future use of SATS aircraft would be of sufficient magnitude and benefit to warrant public investment in airports and air traffic management technologies;
- Identify key public policies (finance, safety, environmental) that would need to be addressed for SATS to be realized; and
- Consider whether the benefits of SATS warrant accelerated institutional changes in regulation and certification policies and practices as related to SATS technologies.

The committee's report will include findings regarding the SATS concept in terms of the need, potential benefits, feasibility issues, and effectiveness. It will then offer guidance regarding changes in public policies, laws, funding arrangements, and public education required for a Small Aircraft Transportation System to be realized.

which are provided in a brief Afterword. The committee believes that many of the security issues relevant to general aviation today would also apply to SATS. The Federal Aviation Administration and other federal agencies are now in the process of examining ways to reduce the potential for terrorism involving both commercial and general aviation. NRC is contributing to these efforts and has convened a special panel to identify how science and technology can aid in countering terrorism involving aviation and other transportation modes. The chairman of this committee is a member of that special panel.

Most of the early meetings of the TRB SATS study committee were open to the public. During the first meeting, NASA research managers briefed the committee on the SATS concept, relevant research under way, and plans for additional research and technology projects. NASA arranged for other experts to assist with the briefings, including John Bartle, University of Nebraska; George Donohue, George Mason University; Ken Wiegand and Keith McCrea, Virginia Department of Aviation; Andres Zellweger, Embry Riddle Aeronautical University; Jim Rowlette and Jeff Breunig, Federal Aviation Administration; and William Hammers, Optimal Solutions. Samuel L. Venneri, Associate Administrator for NASA's Office of Aerospace Technology, gave the committee an overview of how the SATS concept and research program relate to the broader goals of aeronautics research and technology development at NASA.

In conjunction with the committee's second meeting, held in Williamsburg, Virginia, the committee visited the NASA Langley Aeronautics Research Center for detailed briefings and technology demonstrations by NASA researchers Mark Ballin, Tom Freeman, Charles Buntin, Paul Stough, Ken Goodrich, Michael Zernic, and Bill Willshire, as well as NASA's SATS research partners at the Research Triangle Institute, Hampton Roads, Virginia. Between the first and second meetings, several committee members also visited the Experimental Aircraft Association's Air Venture 2000 in Oshkosh, Wisconsin, visiting the exhibits of many developers and suppliers of new and advanced general aviation aircraft and supporting systems.

During the Williamsburg meeting, the committee organized several panel discussions that shed light on a number of relevant issues, such as the relationship between demographics, economics, and travel demand; human factors and automation; pilot performance, training, and general aviation safety; air traffic control procedures and the capacity of the national airspace system; and airport use, expansion, and community noise concerns. These discussions provided much information and insights that were referred to repeatedly by the committee during its subsequent deliberations. The committee wishes to thank the following panel discussants for their important contributions to the study: Steven J. Brown, Associate Administrator for Air Traffic Services, Federal Aviation Administration; Brian M. Campbell, President, Campbell-Hill Aviation Group; Thomas Chappell, President and CEO, Chappell, Smith & Associates; C. Elaine McCoy, Professor and Chair, School of Aviation, Ohio University; Eric Nordling, Vice President for Market Planning, Atlantic Coast Airlines; Clinton V. Oster, Jr., Professor of Economics, School of Public and Environmental Affairs, Indiana University; and John S. Strong, Professor of Economics and Finance, School of Business Administration, College of William and Mary.

During its third meeting, the committee met with representatives of several companies that are designing advanced small aircraft and their components. Vern Raburn, President and Chief Executive Officer of Eclipse Aviation, described his company's plans to design, certify, and manufacture a lower-cost twin-engine jet aircraft for use in general aviation. Bruce Hamilton, Director of Sales and Marketing, Safire Aircraft Company, discussed his company's plans to do the same. George Rourk, Director, Business Development, and Ray Preston, Vice President of New Business

Development at Williams International Company, described compact and lightweight turbofan engines being developed to power a new generation of small jet aircraft. Michael Schrader, Director of Sales at The Lancair Company, discussed his company's new, high-performance piston-engine airplanes, which have incorporated several advanced features and technologies, including integrated cockpit displays developed partly through public-private consortia sponsored by NASA. During this meeting, the committee also discussed potential uses for these technologies in applications other than passenger transport. Robert Lankston, Managing Director of the Supplemental Air Operations for Fedex Express, provided insights in this regard by describing his company's use of small aircraft for express package delivery services. The committee thanks all of these participants for their important contributions to this study.

In addition, special appreciation is expressed to NASA's Bruce Holmes, Manager of the General Aviation Program Office, and David Hahne, Integration Lead, SATS Planning Team. They were the committee's main points of contact with NASA. They attended most of the committee's meetings, provided detailed explanations and updates of the SATS program, and furnished numerous reports and planning documents at the request of the committee. Thanks are also due to other General Aviation Program Office staff for assistance with information requests and for planning numerous presentations and demonstrations for the committee.

Thomas R. Menzies, Jr., managed the study and drafted the final report under the guidance of the committee and the supervision of Stephen R. Godwin, Director of Studies and Information Services. Alan Angleman assisted with committee meetings, data collection, and the composition of initial draft report sections. Michael Grubbs also provided assistance with data collection and analysis.

The report was reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by NRC's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process.

Appreciation is expressed to the following individuals for their review of this report: Linden Blue, San Diego, California; Anthony J. Broderick, Catlett, Virginia; Jack E. Buffington, University of Arkansas, Fayetteville; Frank S. Koppelman, Northwestern University, Evanston, Illinois; Maria Muia, Indiana Department of Transportation, Indianapolis; Agam Sinha, MITRE Corporation, McLean, Virginia; and Charles F. Tiffany, Tucson, Arizona. Although these reviewers provided many constructive comments and suggestions, they were not asked to endorse the committee's findings and conclusions, nor did they see the final report before its release. The review of this report was overseen by Richard M. Goody, Harvard University (emeritus), Cambridge, Massachusetts, and Lester A. Hoel, University of Virginia, Charlottesville. Appointed by NRC, they were responsible for making certain that an independent examination of this report was carried out in accordance with institu-

tional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

Suzanne Schneider, Associate Executive Director of TRB, managed the report review process. The report was edited and prepared for publication by Norman Solomon under the supervision of Nancy Ackerman, Director, Reports and Editorial Services. Alisa Decatur prepared the manuscript. Jocelyn Sands directed project support staff. Special thanks go to Amelia Mathis and Frances Holland for assistance with meeting arrangements and correspondence with the committee.

Contents

Foreword

The study committee convened six times between June 2000 and October 2001. It met for the final time 5 weeks after the September 11, 2001, terrorist hijackings of four U.S. airliners. The tragic consequences of these hijackings and the subsequent restrictions imposed on aircraft operations in the commercial and general aviation sectors were therefore apparent to the committee. Many of the security restrictions were lifted before the committee completed its report, while some remained in effect. Although the longer-term implications of the terrorist threat to aviation remain unclear, the potential for aircraft to be misused will endure as a major public safety and national security concern.

Because the committee completed most of its deliberations and analyses before the attacks of September 11, it had limited opportunity to reflect on how new safety and security concerns might affect the Small Aircraft Transportation System concept and program. These reflections, which are offered in an Afterword, do not conflict with the main conclusions of this report; rather, they validate the committee's overarching concern about the wisdom of trying to preconceive and promote a fully defined transportation system for the future. Events since September 11 demonstrate that needs and circumstances change over time—sometimes abruptly—and that we cannot have the foresight to predict such changes with specificity.

Executive Summary

The Small Aircraft Transportation System (SATS) program has been established by the Office of Aerospace Technology in the National Aeronautics and Space Administration (NASA). In the initial 5-year phase of the program, NASA is working with the private sector and university researchers, as well as other federal and state governmental agencies, to further various aircraft-based technologies that will

- Increase the safety and utility of operations at small airports lacking traffic control towers, radar surveillance, or other conventional ground-based means of monitoring and safely separating aircraft traffic in the terminal airspace and on runways and taxiways;
- Allow more dependable use of small airports lacking instrument landing systems or other ground-based navigation systems that are now required for many nighttime and low-visibility landings; and
- Improve the ability of single-piloted aircraft to operate safely in complex airspace (that is, at airports and in airways with many and diverse operators).

Guiding this program is a longer-range SATS vision of the routine use of advanced, small fixed-wing aircraft—of a size common in general aviation (GA) (4 to 10 passengers)—for personal transportation between small communities. NASA envisions tens of thousands of advanced small aircraft being used in this role. Key to this guiding vision are advances anticipated by NASA in technologies and processes that will make small aircraft much less expensive to produce, maintain, and operate; more environmentally acceptable; and much easier, safer, and more reliable to fly than are small GA aircraft today.

NASA envisions that such a transportation system, once developed and deployed, could reduce congestion and delays in the commercial aviation sector by diverting passenger traffic from large airports and could improve transportation service in many more communities by making better use of the nation's small airports and least-traveled airways. Currently, NASA's SATS technology research program is being justified on the basis of these anticipated benefits and the expectation that major challenges to the development and deployment of such a system—from technological and economic considerations to safety and environmental requirements—can be met.

NASA asked the Transportation Research Board to convene a study committee to review the plausibility and desirability of the SATS concept, giving special consideration to whether its potential net benefits—from user benefits to overall environmental and safety effects—are sufficiently promising to warrant public-sector investment in SATS development and deployment (see Box P-1 of the Preface for the statement of task). The absence of credible examinations of SATS by NASA compelled the committee to undertake its own analyses of the concept's plausibility and desirability, which are presented in Chapter 4. The committee's conclusions and advice derived from these analyses are provided in detail in Chapter 5; they are summarized in the following paragraphs.

The committee does not share NASA's vision for SATS, nor does the committee support the use of this vision to guide technology development and deployment investments. Numerous findings, summarized below, suggest that such a system is neither likely to emerge as conceived nor to contribute substantially to satisfying travel demand. **Nevertheless, the committee endorses NASA's efforts to develop and demonstrate technologies that can help further the highly desirable outcomes listed in the three bullets above.** To help achieve these outcomes, **the committee urges NASA to prioritize, without regard to the SATS concept, the capabilities and technologies now being pursued in the 5-year program according to a clearly delineated set of civil aviation needs (such as improved GA safety) that these new capabilities and technologies can help meet.**

NASA has a traditional and vital role in advancing aeronautics technologies that can enhance civil aviation safety, capacity, accessibility, and environmental compatibility. Technological capabilities to reduce the probability of air traffic conflicts in more places, permit more reliable and safe operations during inclement weather at more airports, and enhance the safety of single-pilot operations could improve the safety and utility of the nation's civil aviation system. The full-scale SATS concept, however, should not be used to guide the R&D program because it presents an unlikely and potentially undesirable outcome. Analyses of the concept suggest the following:

- Limited potential for the use of SATS aircraft to be affordable by the general public. The aircraft envisioned for SATS would need to be far more advanced and sophisticated than even the highest-performing small GA aircraft of today to achieve the standards of safety, ease of use and maintenance, and environmental friendliness that would attract large numbers of users. The committee found no evidence to suggest that such aircraft could be made affordable for use by large numbers of people and businesses.
- Limited potential for SATS to attract large numbers of users because of its orientation to travel markets outside the nation's major metropolitan areas. Most people and businesses are located in metropolitan areas, which are the origins and destinations of most time-sensitive business travelers and most intercity passenger trips overall. The expectation that large numbers of people will use advanced small aircraft to fly between airports in small, nonmetropolitan communities runs counter to long-standing travel patterns and demographic and economic trends.
- Limited appeal to price-sensitive leisure travelers, who use the automobile for most short or medium-length intercity trips. Most intercity travelers are highly sensitive to the price of travel, especially in the short- to medium-length trip markets

envisioned for SATS. Leisure travelers, who account for the majority of all intercity trips under 1,000 miles, usually travel by automobile, largely because of the versatility it offers and the low additional cost per passenger.

• Significant obstacles to SATS deployment because of infrastructure and ancillary service limitations at small airports, as well as potential environmental concerns at such airports, including increases in aircraft noise and air pollutant emissions. Most of the country's 5,000 public-use airports have minimal infrastructure and support services, which limits their suitability for frequent and routine transportation usage. About half of all public-use airports have a paved runway that is at least 4,000 feet long and thus potentially capable of handling small jet aircraft; yet, most of these airports would likely require further infrastructure investments.

• The implausibility of expeditious and nonevolutionary deployment of SATS technologies because of technical challenges and the need for high levels of safety assurance that have been notably neglected in the SATS program. Safety is paramount in aviation, particularly for passenger transportation. Hence, any changes in aviation, from new methods of air traffic control and pilot training and certification procedures to new aircraft materials and manufacturing processes, are subject to intense and thorough safety evaluations and validations that can take much time. The idea that many nonevolutionary changes in aircraft design, propulsion, flight control, communications, navigation, surveillance, and manufacturing techniques could emerge at about the same time and be accepted as safe by users, manufacturers, insurers, and regulators is highly questionable.

• A genuine potential for many undesirable congestion, safety, and environmental effects from SATS deployment. If SATS does not access major metropolitan markets, it will likely have little, if any, meaningful effect on operations at the nation's busiest and most capacity-constrained large airports, where most delays in the commercial air transportation system occur. Yet, if SATS does access these markets, the mixing of SATS with non-SATS aircraft in heavily used, controlled airspace and airports could create significant traffic management challenges. Moreover, a well-used SATS could have negative net effects on aviation's environmental compatibility by shifting travelers from larger aircraft, each carrying dozens of travelers, to smaller aircraft, each carrying a handful of travelers.

More generally, the committee believes that positing any such preconceived system, in which a single and definitive vehicle concept is used to guide research and development, could inhibit the evolution of alternative outcomes that may result from technological opportunities and economic and social needs. The heightened emphasis on aviation security in recent months (discussed in the Afterword to this report) is an example of how difficult it is to accurately predict change in the aviation sector. NASA's strength in civil aeronautics is in technology research and development, and not in defining, developing, and promoting new transportation systems.

Although it does not share NASA's vision for SATS, the committee commends NASA for using its resources and expertise to leverage and stimulate private-sector investment in civil aeronautics research and development. Indeed, it is essential that NASA researchers work closely with commercial developers and users, since the private sector understands the current market for technologies and can provide guidance on applications that appear likely. Furthermore, NASA must seek the active involvement of the Federal Aviation Administration (FAA) and state and local agencies in the technology program. Their involvement is necessary in reaching an understanding of the constraints on technology deployment, such as environmental, safety, and public finance concerns.

To ensure the continuation of forward-looking aeronautics R&D, **the committee urges NASA to join with other relevant government agencies, led by the Department of Transportation, in undertaking studies of future civil aviation needs and the opportunity for technology advancements to meet them and potentially stimulate new uses for civil aviation.** Working with FAA, the National Transportation Safety Board, and other governmental agencies with operational and technological expertise should give NASA a better understanding of such needs and opportunities. The capabilities and technologies being developed under the SATS program may prove useful in ways that are not now apparent; for instance, they may benefit many different users by increasing the safety and utility of both general and commercial aviation. Indeed, many system and vehicle configurations that are not envisioned for the current SATS concept may prove useful. The committee urges NASA to keep such possibilities in mind.

The committee commends NASA for requesting and sponsoring this review, which offers the opportunity for the perspectives and advice of experts in transportation and other disciplines not involved in the conception of SATS to be brought to bear. Such external reviews are a valuable means of obtaining fresh perspectives on R&D program goals, plans, and accomplishments, and additional policy-level and technical reviews are desirable as the restructured program proceeds.

1 Study Overview and Aims

Background information on the general aviation (GA) technology research programs of the National Aeronautics and Space Administration (NASA), including its Small Aircraft Transportation System (SATS) concept and plans to further it through a 5-year technology development and demonstration program, is provided in this chapter. As a key part of its SATS concept, NASA envisions small aircraft being flown between small airports in currently lightly used airspace to provide an increasingly larger share of the nation's intercity personal and business travel. The approach taken in this study to examine the SATS concept vision and the 5-year program to advance it are then described.

BACKGROUND ON THE SATS VISION

Aviation, which had a niche role in transportation before World War II, has grown to become a central part of the nation's transportation system, providing long-distance passenger service that links thousands of communities scattered across the United States. Perhaps more than any other mode of transportation, aviation has benefited from a constant stream of technological innovations, which at times have had revolutionary effects on air travel. Only 25 years passed between Charles Lindbergh's 33-hour transatlantic flight in 1927 and the introduction of the first commercial jet airliner, the De Havilland Comet, in 1952. The larger, faster, and better-designed passenger jets that followed the Comet dramatically increased travel speeds, cutting the time of transcontinental flights by more than half. Between 1955 and 1970—the year after Boeing introduced the 550-seat 747 "jumbo" jetliner—the number of passengers flying on U.S. airlines more than quadrupled, from 40 million to nearly 175 million per year as the jet age took hold (*TR News* 1996). A decade later, air travel was transformed again by economic deregulation of the airline industry. Now free to extend and reconfigure their route systems, airlines formed hub-and-spoke networks, offering many more flights between many more cities. The number of air travelers increased sharply beginning in the 1980s, and any visions of the wide-body jetliner coming to dominate transcontinental passenger service ended abruptly as airlines shifted to smaller narrow-body jets better suited to short and medium-length domestic hub-and-spoke routes.

By and large, the revolutions in air transportation have been unanticipated, often the culmination of many technological advances interacting and coinciding with economic, demographic, and political developments. The jet engine, which was developed for military use during the 1930s and 1940s, became practical for commercial use by the early 1950s. However, many other technological advances had to occur during this period to enable the transformation to the jet age, such as stability augmentation systems and the adoption of swept-wing designs. The shift in U.S. population westward spurred demand for faster transcontinental airline service, making private investment in more expensive jet airliners feasible. Likewise, the revolution in airline operations that followed industry deregulation in the 1980s coincided with a revolution in computing and information technologies, allowing the development of equipment management, scheduling, and computer reservations systems that made the operation of complex hub-and-spoke networks much more practical and efficient.

The technological advances and innovations in air transportation, and aviation in general, have emerged from a mix of military, industrial, university, and other public and private sources. NASA and its predecessor organization, the National Advisory Committee for Aeronautics, have made many significant contributions to aviation's advancement, from more efficient wing and airframe designs obtained from years of aerodynamics and structures research to occupant protection improvements obtained from crash studies.[1] NASA analytical tools and test facilities, such as wind tunnels, simulators, and acoustic laboratories, have provided valuable data for designing safe, efficient, and environmentally acceptable aviation systems.

NASA continues to have a prominent role in the advancement of aeronautics research and technology. Much of its research is aimed at developing capabilities that can be applied to many different classes and configurations of aircraft. For example, NASA researchers are working on ways to improve icing detection and mitigation, engine and airframe material durability, and the fuel efficiency of wing designs. Through its aviation safety and weather information programs, NASA is seeking to develop more effective pilot training procedures and aids, improved tools for turbulence forecasting, and materials and technologies that reduce the incidence and severity of postcrash fires.

In recent years, NASA has identified several goals to help guide and inspire its aeronautics research programs:[2]

- Reduce the aircraft accident rate by a factor of 5 within 10 years and by a factor of 10 within 25 years.
- Reduce oxides of nitrogen emissions of future aircraft by 70 percent within 10 years and by 80 percent within 25 years, and reduce carbon dioxide emissions of future aircraft by 25 percent and by 50 percent in the same time frames.
- Reduce the perceived noise levels of future aircraft by a factor of 2 (10 decibels) within 10 years and by a factor of 4 (20 decibels) within 25 years.
- Reduce the cost of air travel by 25 percent within 10 years and by 50 percent within 25 years.
- Double the capacity of the aviation system within 10 years and triple its capacity within 25 years.

[1] For examples of NASA research and technologies used in at least one aviation sector, GA, see Appendix C, General Aviation Task Force Report, prepared for NASA, September 1993.
[2] See www.aerospace.nasa.gov/goals/ra.htm.

• Reduce door-to-door travel time by half within 10 years and by two-thirds within 25 years. Reduce transcontinental travel time by half within 25 years.

Whether or not these ambitious goals can be achieved as targeted, NASA's research and technology programs are undoubtedly contributing toward the overall objective of improving aviation capacity, efficiency, safety, and environmental compatibility. As is often the case with research, however, progress in accomplishing these goals can be difficult to perceive when the potential systems in which they may be used are so diverse. NASA has thus sought to organize some of its research activities around specific segments of aviation, including GA. NASA's General Aviation Program Office works closely with GA manufacturers, suppliers, and users to better understand their research and technology needs and to find opportunities for NASA to help meet them.

GA Research at NASA

The civil aviation sector consists of two major components: commercial aviation and GA. Commercial aviation comprises mainly scheduled airlines and charter operators, which carry most of the passengers and cargo moved by air. Nearly all the country's large civilian jets are operated by commercial airlines, which provide for-hire passenger and freight transport services. Aircraft used for all other purposes—such as recreational flying and corporate jet travel—are classed as GA.

GA is the oldest segment of aviation, predating scheduled air service by more than two decades. Beginning in the early 1980s, however, the GA industry in the United States experienced a sharp and sustained drop-off in demand for new aircraft, especially smaller piston-engine aircraft normally used for personal flying. Some long-standing GA aircraft manufacturers, such as Piper Aircraft, went out of business, while many others dramatically changed their product lines, shifting away from piston-engine airplanes to turboprops and jets used for corporate travel and commercial applications. The causes of this decline, occurring during a period of increased air passenger travel generally, have engendered much debate. Changes in tax laws, attrition among private pilots trained during World War II, and high product liability costs are often cited. Another cause cited is that the GA industry had become stagnant technologically. Many aircraft manufactured in the 1970s and 1980s were based on designs that were two to three decades old, having been modified only slightly over time.

Concern over the magnitude of the decline in demand for small private aircraft during the 1980s and 1990s prompted concerted efforts by the public and private sectors to enhance the utility and appeal of GA aircraft. In passing the General Aviation Revitalization Act of 1994, Congress sought to reduce the cost of producing GA aircraft by limiting manufacturer liability. To boost demand further, the GA industry began sponsoring national programs to promote GA flying for business and recreation.[3] NASA then began to examine how its own research and technology programs

[3] For instance, see "Be-A-Pilot" Foundation (www.beapilot.com), which is aimed at encouraging more student pilots and is sponsored by GA flight schools, manufacturers, and industry associations.

could aid GA. At the time, NASA was sponsoring work on cockpit systems intended to be more user oriented; low-cost aircraft design and manufacturing methods; and propulsion systems that are quiet, produce less exhaust emissions, and provide a comfortable ride. The application of these advances to GA, however, had been given little direct consideration.

NASA convened a General Aviation Task Force to advise on ways to better coordinate and target research to the benefit of the GA sector. Composed mostly of GA aircraft manufacturers, the task force noted that NASA had long worked with the Federal Aviation Administration (FAA), other public agencies, and private industry and universities to meet civil aviation needs—for instance, by seeking to enhance aviation safety, reduce aircraft noise, and increase the capacity of the airspace system. It urged NASA to undertake more focused research on aerodynamics, propulsion, flight systems, and materials and structures that have the potential for application in smaller, less expensive GA aircraft. It also urged NASA to make available its tools and test facilities to the GA community and to work more closely with GA manufacturers and suppliers through public-private R&D partnerships.[4]

In response to these recommendations, NASA's General Aviation Program Office created two new public-private partnerships—the Advanced General Aviation Transport Experiments (AGATE) program in 1995 and the General Aviation Propulsion (GAP) program in 1996. AGATE members, including more than 70 companies, universities, industry associations, and state aviation departments, have shared expertise and resources to develop affordable new airframe and avionics technologies for small airplanes, enhanced certification and manufacturing processes, improved weather information and navigation displays, and easier-to-operate flight controls. GAP participants have likewise shared public- and private-sector expertise and resources in an effort to improve the reliability and maintainability of reciprocating engines and develop lower-cost turbine propulsion systems.

Both of these consortia were created for a fixed period of 5 years and are now nearing completion with some notable accomplishments, such as the development of a lightweight turbofan engine that offers the potential for high thrust with low emissions and fuel consumption.[5] The purpose of having a fixed program life was to help turn around the nation's GA industry by focusing activities on those technologies with the potential to be commercially viable within a short time frame. NASA's longer-range goal in establishing the partnership programs was to lay the groundwork for a technological revolution that would transform the GA industry into a central element of the nation's transportation system.

Genesis of the SATS Concept

The promise of technological advances making small aircraft safer, easy to operate, and more affordable for transportation dates back to the "auto-planes" that were conceived even before World War II. Yet, the fact that widespread public use of small aircraft has not emerged as anticipated can be traced to many factors—among them the flexibility and cost advantages provided by the automobile and airlines for most

[4] See pp. 4–5, General Aviation Task Force Report, September 1993.
[5] See Williams International's FJX-2 turbofan engine at www.williams-int.com.

trips, the reluctance of many people to fly in small aircraft because of safety concerns, and an inability to devote the time and resources necessary to learn how to pilot small aircraft and to maintain skills. Many of the technological advances that have made large aircraft more efficient and safer for passenger transportation—from inertial guidance systems to fully coupled autopilots—have not filtered down to the smaller GA aircraft used for personal and recreational flying, largely because of the high costs associated with acquiring, maintaining, and learning how to use them.

Thus, NASA set forth as central goals of both the AGATE and GAP programs not only the development of affordable advanced technologies, but also the development of a whole new generation of small aircraft that are less expensive to manufacture, maintain, and fly than are small aircraft today. AGATE was charged with developing more efficient small aircraft manufacturing processes and low-cost materials, as well as faster and less expensive means of training private pilots and maintaining proficiency. GAP was charged not only with developing more reliable and quieter small aircraft propulsion systems, but with developing systems that are much less expensive to build, maintain, and operate than those used by existing small aircraft.

Indeed, AGATE first conceived of a small aircraft transportation system as a "decision-making framework" for its research and technology planning. AGATE planning documents[6] describe the following key goals that would need to be achieved for advanced small aircraft to become practical and popular for use in personal and business transportation:

- Safety rates comparable with those of commercial airlines,
- Portal-to-portal costs and times per trip that are competitive with those of cars and airlines for mid-range travel,
- Operational reliability similar to that of cars,
- Availability in low-visibility conditions through the GA infrastructure,
- Complexity of operations and time and cost to achieve operator proficiency that are commensurate with a cross section of user abilities and needs, and
- Features that increase the comfort of travel to a level comparable with travel by automobile and airline.

Recognizing that two 5-year R&D programs focused primarily on vehicle technologies could make only limited progress toward such far-reaching goals, NASA and other AGATE and GAP participants began discussing ways to further the SATS concept and build acceptance by FAA, the broader GA community, and state and local transportation officials.

NASA's General Aviation Program Office devised a "General Aviation Road Map" laying out a 25-year strategy for the development of a national small aircraft transportation system through a series of public and private partnerships.[7] The early (10-year) goal would be to make conventional GA safer, more reliable, and more

[6] See pp. 6–9, "Small Aircraft Transportation System Concept Document," AGATE, Reference No. WP12.0-1200070-065, July 1996.

[7] General Aviation Road Map, document presented to study committee by B. Holmes, NASA General Aviation Program Office Manager, June 7, 2000.

useful through improvements in small aircraft avionics, airframes, pilot training, navigation and control systems, and engine technologies. The longer-range (25-year) goal would be to create new markets for small aircraft by developing and integrating features and capabilities that make small aircraft safer, more affordable, and easier to operate. In particular, NASA envisioned flights of advanced, self-piloted small aircraft between the thousands of GA airports located across the country, using the nation's uncontrolled airspace. This system, NASA postulated, could reduce congestion and delay in the commercial air transportation system and greatly expand travel options for people and businesses located in communities without convenient access to commercial air services (SAIC 2001).

To better understand the opportunities and challenges facing this transportation system vision, NASA commissioned a series of precursor studies of possible economic, engineering, environmental, and other issues likely to affect the development and introduction of SATS. As a guide for these studies, NASA developed a SATS Operational Concept, which defined desirable characteristics of a mature small aircraft transportation system 25 years hence. The kinds of capabilities that NASA envisioned for SATS and how these capabilities would be applied are portrayed in Box 1-1, which is derived from the Operational Concept.

The precursor studies were completed between 1999 and 2001, as NASA sought congressional funding for a 5-year program to advance the concept by developing and demonstrating key airborne technologies for the precision guidance of small aircraft at small airports. The topics covered in several of these initial studies, many of which evolved into exercises designed to promote the concept, are summarized in Box 1-2.

In October 2000, Congress appropriated $9 million to be used for

> operational evaluations, or proofs of concept where operational evaluations are not possible, of four new capabilities that promise to increase the safe and efficient capacity of the National Airspace System [NAS] for all NAS users, and to extend reliable air service to smaller communities. These capabilities are: high-volume operations at airports without control towers or terminal radar facilities; lower adverse weather landing minimums at minimally equipped landing facilities; integration of SATS aircraft into a higher en route capacity air traffic control system with complex flows and slower aircraft; and improved single-pilot ability to function competently in complex airspace in an evolving NAS.[8]

Congress further directed NASA to undertake the program in a collaborative manner by encouraging industry and university teams to compete for awards by involving FAA aircraft certification, flight standards, air traffic, and airport personnel in planning the evaluations. It noted that NASA will "develop and operationally evaluate these four capabilities in a five-year program [with subsequent funds to be considered in future appropriation legislation] which will produce sufficient data to

[8] House Report 106-988, accompanying Public Law 106-377, Departments of Veterans Affairs and Housing and Urban Development, and Independent Agencies Appropriations Act, 2001.

Box 1-1

SATS Operational Capabilities: Concept Envisioned for 2025 (SAIC 2001)

- Aircraft will be capable of operating in low-visibility conditions (visibility of 1/4 mile) at small, rural (nonmetropolitan) airports with runways 2,400 feet or longer and without radar cover or assistance from air traffic control towers. Aircraft will require neither ground-based navigation aids nor approach lighting.
- Aircraft operations will be contained within existing airport terminal areas and protection and noise exposure zones. Operations will be environmentally compatible with communities near airports. Most of the nation's 5,000 public-use airports will be able to accommodate SATS operations.
- Operators will vary widely in training, experience, and capability, having skills ranging from those required to pilot an airline to those required to drive an automobile. Automation will replace human manipulation and decision making as primary control inputs, although operators will be able to exert varying degrees of control. Onboard computers will provide realistic, real-time tutorials and training, even during flight.
- Digital data link capabilities will provide the operator and aircraft with real-time and integrated weather, traffic, and airport information for dynamic modifications to flight plans.
- Interactions with air traffic management and control will be largely automated and will not require positive control. Aircraft will operate autonomously, providing guidance for self-separation from other aircraft and obstacles. SATS users will interface with air traffic services only to the extent that they operate in controlled airspace and airports. A fully digital communication system will be in place, alleviating frequency congestion difficulties. Aircraft separation and sequencing will be accomplished by interaction of aircraft systems using the Global Positioning System (GPS) and automatic dependent surveillance and broadcast messages (ADS-B).
- Primary navigation service will be provided by GPS at all altitudes. Terrain and obstacle databases with data up-link capabilities, automation, and intuitive displays of the information in the cockpit will aid operators in avoiding collisions. Dynamic approach procedures will be calculated by onboard computers in real time to any runway end or touchdown point.
- New materials and engine and airframe designs, as well as mass production of aircraft, will allow for greatly reduced aircraft acquisition, maintenance, and operating costs. Ride-smoothing and envelope-limiting protections will ensure ride comfort and safety.
- Aircraft will be used for on-demand and scheduled passenger transportation by individuals (owner-operators), air taxis, businesses, and corporate flight departments for trips ranging from 150 to 1,200 miles. Trips may include as many as 10 passengers, depending on aircraft size and configuration.

Box 1-2

SATS Precursor Study Topics

1. User needs: Researchers modeled the life-cycle cost of acquiring and operating various sizes and types of small aircraft (piston-engine, turboprop, turbofan) under different ownership (individual ownership, shared ownership leased, private) and usage (private, corporate) scenarios. Using Orlando, Florida, as a case study, they tried to assess how SATS would affect travel speeds for users and whether SATS operations would prompt delays in commercial airline service. They also sought to examine how the availability and reliability of SATS operations might compare with those of commercial airlines by comparing the number of people living within a 30-minute drive of a commercial airport in Florida with the number living near smaller, noncommercial airports.

2. Market potential: More than 70 businesses in Virginia were queried about their potential use of SATS. Ten of the respondents were selected for further study and shown a video of the SATS concept that both explained and emphasized its positive aspects, while pointing out the problems associated with existing transportation options. The respondents were then asked to judge their potential use of a new small aircraft transportation system and their willingness to pay for it.

3. Consequential economic benefits: An order-of-magnitude estimate of the potential national economic benefits derived from the introduction of a new small aircraft transportation system was sought. For illustrative purposes, it was estimated that if SATS increases annual growth of gross domestic product by 0.01 to 0.05 percent, national income gains on the order of $3 billion to $15 billion per year would result. Other conjectural estimates were provided for illustration.

4. Noise effects: Two noise studies were conducted at airports in Virginia to provide benchmarks to compare noise levels around airports today with those anticipated after the introduction of a small aircraft transportation system. One, a study of Newport News/Williamsburg International Airport, concluded that GA was the dominant source of the noise footprint at the airport and that SATS aircraft, if quieter than existing GA aircraft, would likely reduce overall noise levels and be welcomed by residents. A more thorough study of Manassas Regional Airport noted that air traffic growth as a result of SATS, especially jet traffic, could raise noise levels and require abatement. However, the report also noted that as both the population near the airport and GA traffic grow, noise concerns are likely to increase, which the quiet-aircraft technologies introduced as part of SATS could mitigate.

support FAA decisions to approve operational use of the capabilities, and FAA and industry decisions to invest in the necessary technologies."

The initial phase of the 5-year program is under way, and a plan for the staging of operational evaluations is being developed, as described in the next section.

SATS 5-YEAR PROGRAM PLAN

In carrying out the congressional charge, NASA intends to develop technologies and procedures that can be used to demonstrate the potential for the following four capabilities:[9]

1. Higher-volume operations at nontowered, nonradar airports;
2. Lower landing minimums at minimally equipped landing facilities;
3. Increased single-pilot crew safety and mission reliability; and
4. En route procedures and systems for integrated fleet operations.

NASA is seeking industry and university partners to help plan and stage the demonstrations. SATS program managers have established tentative goals to guide these plans and criteria to judge the program's success in demonstrating each of the four capabilities. The target goals—accompanied by more ambitious "stretch" goals—and the metrics for judging the success of the demonstrations are given in Table 1-1.

The target for the first capability is to demonstrate technologies and procedures that can enable at least two aircraft to operate simultaneously[10] in instrument meteorological conditions—that is, during limited visibility—at an airport that does not have conventional radar surveillance or a traffic control tower for safely directing and separating aircraft. Presumably, this capability would allow minimally equipped small airports to remain open for landings and takeoffs during lower-visibility conditions and allow some small airports to handle even more flights during good weather when demand is high. For many operators of GA aircraft, the option of being able to use more airports with fewer contingencies for weather and traffic could make flying easier, safer, and more useful. In the context of an envisioned small aircraft transportation system, the ability of many airports to handle multiple operations is essential for a convenient system that encompasses most desired origins and destinations.

The target for the second capability is to demonstrate technologies and procedures that can give approach and landing guidance that is nearly as reliable (in terms of weather minimums) as that provided by conventional ground-based landing systems. Presumably, this aircraft-based capability would make it possible for more pilots to fly between more airports, on a more reliable and planned basis, without the public expense of constructing and maintaining instrument landing systems and other airport-based guidance systems. Systems that employ the Global Positioning System are already being deployed that offer such capabilities, but mainly for skilled, professional pilots operating advanced aircraft at large airports. For GA pilots with more limited skills, the emergence of additional technologies that offer the ability to access more airports under more weather conditions—and be assured of this access—

[9] The information in this section is derived from the SATS Program Plan, Version 8.
[10] For instance, allowing one aircraft to take off while another is approaching for landing.

Table 1-1 Goals and Objectives for NASA's SATS Technology and Demonstration Program

Objective	Current Situation	Stretch Goal	Minimum Success Requirement
1. Higher-volume operations at nontowered, nonradar airports	Current regulations and procedures require ATC to maintain "procedural separation" between aircraft in IMC in nonradar airspace, which results in one operation (in terminal airspace at landing facilities) at a time (about three landings per hour)	Demonstrate the use of vehicle-to-vehicle collaborative sequencing and self-separation algorithms and automated flight path management systems to allow 10 operations at a time in nonradar airspace (about 30 landings per hour)	Demonstrate the ability to eliminate "procedural separation" requirements in IMC in nonradar terminal airspace and allow two or more simultaneous operations at a time (more than six landings per hour)
2. Lower landing minimums at minimally equipped landing facilities	Current airports without navigation aids or instrument approach procedures are limited to VFR minimums for ceiling and visibility, which can be as restrictive as 1,000 feet and 3 miles, respectively. Access to airports with instrument approaches (precision and nonprecision) can be limited to higher minimums	Demonstrate the ability to provide near-precision approach and landing guidance that requires no new land acquisition, no approach lighting, and minimal new ground-based equipment with no ceiling requirements and a visibility requirement of $\frac{1}{4}$ mile at a currently VFR-only airport	Demonstrate the ability to provide near-precision approach and landing guidance that requires no new land acquisition, no approach lighting, and minimal new ground-based equipment with minimum ceiling and visibility requirements of 200 feet and $\frac{1}{2}$ mile, respectively, at a currently VFR-only airport
3. Increased single-pilot crew safety and mission reliability	The current baseline is a single instrument-rated pilot flying with current instrumentation ("steam" gauges and basic radio navigation avionics)	Demonstrate single-pilot precision, safety, and mission reliability equal to that of two air transport crew members with current instrumentation	Demonstrate single-pilot precision, safety, and mission reliability equal to that of a single air transport pilot with current instrumentation
4. En route procedures and systems for integrated fleet operations	It is not currently possible to analyze the impact of operations enabled by SATS technologies on higher en route air traffic flows or terminal airspace operations in the current NAS	Show, through analysis, that operations enabled by SATS technologies have no negative impact on higher en route air traffic flows or terminal airspace operations in the current NAS	Show, through analysis, the potential impact of operations enabled by SATS technologies on higher en route air traffic flows and terminal airspace operations in the current NAS

NOTE: ATC = air traffic controllers; IMC = instrument meteorological conditions; VFR = visual flight rules.
SOURCE: SATS Program Plan, Version 8.

would enhance the utility of flying small aircraft. With regard to the envisioned small aircraft transportation system, the ability to reliably access many small airports helps ensure a convenient system with wide reach.

The target for the third capability is to demonstrate technologies and procedures that can enable single, nonprofessional pilots to operate with a level of precision, safety, and reliability equivalent to that of a single professional pilot today using conventional instrumentation. Such an outcome, if achieved, would confer safety benefits on much of the GA community, since many GA accidents involve aircraft operated by private pilots and are caused by errors in pilot performance and decision making. In the context of an envisioned small aircraft transportation system, the achievement of this capability would bring nearer the day when more individuals will fly advanced small aircraft for their own transportation.

Finally, rather than seeking to develop a specific technology or procedure to demonstrate the fourth capability, NASA will undertake a study of how the first three capabilities, if achieved, would affect aircraft operations in the higher en route air structure where most commercial airliners and private jets operate, as well as in other airspace frequented by aircraft that do not have the new capabilities. While limited use of the three operating capabilities in GA might have minor effects on the operations of commercial airliners and other nonequipped aircraft, the widespread use of these and other capabilities envisioned for SATS would raise many important questions about the integration of SATS and non-SATS users.

NASA's plan for the program consists of three phases. In the first phase, researchers will identify and develop candidate airborne technologies to achieve the desired capabilities listed above. One development project will focus on instrument panel and flight deck technologies with the potential to improve the safety and efficiency of single-pilot operations by integrating the pilot-aircraft interface and underlying flight systems using visually intuitive, multifunction cockpit displays and software-based controls. Another development project will focus on automated flight path management technologies that can make small airports easier, safer, and more reliable to use by enabling collaborative sequencing and self-separation of aircraft and conflict detection. Candidate technologies for the two projects include

- Self-separation and collaborative sequencing algorithms—software that allows pilots and avionics to maintain appropriate separation without controller direction;
- Highway-in-the-sky guidance—graphical depictions of flight path guidance for en route and terminal procedures that are intuitive to pilots;
- Emergency automated landing controls—computer-based flight control systems for fail-safe recovery of aircraft and occupants following pilot incapacitation or other emergency situations; and
- Software-enabled controls—simplified flight controls and autopilot functions integrated in graphical displays that reduce the complexity of controlling aircraft attitudes, power settings, and rates of motion, while also providing limited flight path control and compliance with clearances that ensure traffic separation.

Promising technologies in each of the two projects will be screened and selected for further development using simulations, flight tests, and other means, including benefit-cost analyses.

In a follow-up phase, the selected technologies will be integrated to demonstrate each of the capabilities requested by Congress. This initial series of demonstrations will be conducted through a combination of simulations, flight tests, and other means in the third and fourth years of the program. In the final year of the program, NASA anticipates a larger demonstration that integrates promising technologies relevant to all of the capabilities; this integrated demonstration will be staged for the public and will include flight demonstrations.

Concurrent with the technology development and demonstration phases of the program, NASA plans to sponsor a series of "transportation system analyses" studies. These studies, scheduled for completion in the final year of the program, will examine the economic viability, market potential, environmental impacts, and community acceptance of a small aircraft transportation system. The results will be used to identify changes needed in regulations, certification procedures, and airport and airspace design to enable the SATS concept.

During the final stages of this National Research Council study, NASA was in the process of examining proposals from four teams comprising members from the public and private sectors to develop plans for the flight demonstrations. It was also seeking a single consortium manager to act as the interface between NASA and the planning teams.

STUDY AIM AND APPROACH

At its most elementary level, the SATS concept is an envisioned outcome of the use of small aircraft to fly between small airports in currently uncontrolled airspace to provide a much larger share of the nation's intercity personal and business travel than is now the case.

The influence of this vision is manifest throughout the 5-year technology program. It provides inspiration for the program, compatible with NASA's strategic goals (cited earlier) to dramatically reduce the cost of air travel; increase travel speeds; and enhance the safety, capacity, and environmental compatibility of the aviation system. It is also helpful in promoting the technology program in a competitive environment for government R&D funding. As the central element of NASA's GA research program, the SATS vision has come to define the goals of the General Aviation Program Office.

More specifically, however, the long-range SATS vision has clearly influenced the kinds of capabilities and technologies being pursued in the program. In the program plan,[11] NASA states the following:

> The technologies targeted for development are aimed at small aircraft used for personal and business transportation missions within the infrastructure of small airports through the nation. These missions include transportation of goods and travel by individuals, families, or groups of business associates. Consequently, the aircraft are of similar size to typical automobiles and vans used for non-commercial ground transportation. . . . The technology investments are selected and prioritized for the purpose of trans-

[11] SATS Program Plan, Version 8, p. 2.

> portation of people, goods and services. . . . The program focuses on airborne technologies that expand the use of underutilized airports (those without precision instrument approaches) as well as underutilized airspace (such as the low-altitude, non-radar airspace below 6,000 ft and the en route structure below 18,000 ft).

Hence, NASA appears to be looking beyond early uses of the new capabilities and viewing them as components of a new and much different kind of small aircraft transportation system. Its interest in developing systems such as emergency automated landing and highway-in-the-sky guidance, which hold the promise of making flying easier for the general public, and self-sequencing and separation capabilities, which are relevant to higher-density operations at small airports, is a reflection of the program's orientation toward the longer-term SATS vision. Absent from the program is an explanation of how these desired capabilities might prove useful to GA as it is used today, which is most likely the way it will be used in the future without the highly uncertain and ambitious SATS. Presumably, an assessment of the probability of SATS, if made, would influence the array of capabilities and technologies being pursued in the program; hence, the absence of such a probability assessment is notable.

Likewise, the plan to integrate the capabilities in flight demonstrations reflects the emphasis placed on SATS as the intended outcome of the technology program. Although each capability has potential utility, the SATS vision emphasizes the integration of many capabilities in a class of aircraft. A central aim of the integrated demonstrations themselves and the involvement of industry, FAA, and state and local officials in these demonstrations is to spur interest in the concept and prompt necessary changes in certification processes, regulations, and supporting infrastructure. Indeed, a stated goal of the program is to "provide the technical and economic basis for national investment and policy decisions to develop a small aircraft transportation system," including the "coalescing of private sector segments into SATS architectures" and "the coalescing of state authorities to support and advocate implementation of SATS technologies."[12]

An important reason for taking a closer look at the merits of the SATS vision is the influence of the vision on the NASA GA technology program. Another important reason, however, is that in promoting the SATS outcome NASA anticipates large public benefits—benefits that are not self-evident and that warrant more careful consideration. NASA's initial aim in creating AGATE was to help rejuvenate the GA industry. In establishing the SATS R&D program, NASA's aim is much more comprehensive—to prompt the creation of a new kind of transportation system benefiting the general public. In particular, the widespread use of advanced small aircraft operating between small airports is perceived by NASA as a means of increasing overall transportation system capacity and transportation options for underserved small communities. These are the key benefits NASA anticipates from SATS; they are the justification for using government funds to develop and demonstrate technologies aimed at achieving SATS.

[12] SATS Program Plan, Version 8, p. 5 (SATS Goals).

The aims of this study are to examine more closely the rationale for promoting and pursuing the SATS vision and to offer NASA recommendations on the suitability of this vision as a guide for research and technology programming. The study was undertaken at the request of NASA, which specifically asked the study committee to address the following questions pertaining to the SATS concept and its relevance for technology development and deployment planning:[13]

- Do the relative merits of the SATS concept, in whole or in part, contribute to addressing travel demand in coming decades with sufficient net benefit to warrant public investment in technology and infrastructure development and deployment?
- What are the most important steps that should be taken at the national, state, and local levels in support of the SATS deployment?

The committee interprets the first question as a request for an assessment of whether the small aircraft transportation system envisioned and being pursued by NASA is sufficiently plausible and desirable to justify a focus of government resources on development and deployment of enabling technologies and infrastructure. If the concept in its entirety does not justify such an investment, then NASA asks whether aspects of the SATS concept—assumed to mean individual capabilities and technologies—merit public investment in development and deployment. The second question, predicated on an affirmative answer to the first, asks for recommendations on steps that should be taken at various levels of government to further the advent of SATS and the development and deployment of the individual capabilities and technologies.

While specific advances in technology cannot be predicted with certainty, the overall magnitude of the technological challenge ahead for the emergence of SATS can be surmised, given what is understood about the factors influencing the nature and pace of technology development and deployment in the air transportation sector. Likewise, it is possible to gain an understanding of the practical challenges facing the system by examining such factors as the number, condition, and location of small airports and their ability to accommodate SATS operations and attract large numbers of users.

Whether the SATS outcome holds the promise of net public benefits and is indeed desirable will depend on more than its technical feasibility and potential to meet transportation demands. This outcome must also be compatible with other public policy goals, such as ensuring transportation safety and environmental acceptability, which are key considerations in this study.

REPORT ORGANIZATION

The remainder of this report consists of four chapters. In the next two chapters, background and statistical information are provided; the committee's analyses and assessment of SATS are given in the final two chapters.

An overview of the aircraft, infrastructure, and use characteristics of the current civil aviation sector in the United States, including recent and emerging trends in air

[13] The statement of task that contains these two questions, including several secondary questions and tasks, is provided in the report preface.

transportation, is provided in Chapter 2. This information is helpful in understanding the terminology and issues covered in the report. The key capacity, service, safety, and environmental challenges facing the aviation sector today and for some time into the future are examined in Chapter 3. An appreciation of these challenges is important, because the aim of SATS is to help meet them. Although a close review of these two chapters is not essential for readers with a general understanding of the U.S. aviation and air transportation sectors, many of the statistics and findings that are cited in the later analytical sections of the report appear there.

The study committee's analyses of the SATS concept's plausibility and desirability are described in Chapter 4. Consideration is given to the probability of NASA's SATS vision emerging in light of what is known about (*a*) the influence of safety assurance requirements on aviation technology development, affordability, and deployment; (*b*) the physical condition and operational characteristics of the nation's airport and airspace infrastructure; and (*c*) intercity travel demand and the factors that influence it. The desirability of the system and potential effects on overall transportation system capacity, accessibility, safety, and environmental compatibility are also examined.

The committee's responses to the questions and its recommendations, which are based on the findings of these analyses, are given in Chapter 5.

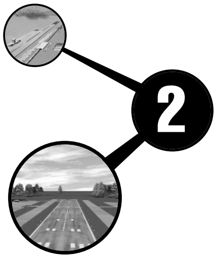
REFERENCES

Abbreviation

SAIC Scientific Applications International Corporation

SAIC. 2001. *Small Aircraft Transportation System (SATS) Operational Concept Update.* Version 4. AGATE Document NCA1-183, WBS 7. March.

TR News. 1996. The Revolution in Passenger Aviation. No. 182, Jan.–Feb., p. 25.



U.S. Civil Aviation Fleet, Airport, and Airway Use Characteristics

The U.S. civil aviation sector is large and diverse. It consists of about 190,000 aircraft, 5,000 airports open to the public, and 600,000 pilots. In this chapter, an overview of the basic types of aircraft in the fleet, their uses in transportation, the system of airports and airways they operate in, and the qualifications and characteristics of the pilots that fly them is provided. Much of the discussion is background, helpful for understanding the terminology and issues presented in subsequent sections of the report. In addition, much of the factual information and many of the statistics are referenced in later analyses of the Small Aircraft Transportation System (SATS) concept. Inasmuch as the SATS vision postulates a radical transformation in civil aviation, an understanding of the structure, scale, and uses of civil aviation today is helpful in better gauging the prospects for such dramatic change.

Several pertinent findings emerge from this overview; they are summarized at the end of the chapter. In general, the data indicate

- Trends in demand for small aircraft, how they are being used, and the kinds of aircraft that are most popular for transportation;
- The condition, capacity, and location of small airports in the United States, and the factors that influence their use; and
- How small aircraft operate in the national airspace system, the wide-ranging skills and qualifications of the pilots that fly them, and long-term changes taking place in the U.S. pilot population.

U.S. AIRCRAFT FLEET

The U.S. civil aircraft fleet consists of about 182,000 fixed-wing and nearly 7,000 rotary-wing aircraft (see Table 2-1).[1] There are many ways to classify these 189,0000 aircraft; the most common groupings are by type of wing (fixed-wing or rotary-wing) and power and propulsion (piston- or turbine-engine and propeller- or jet-driven). The fleet is described in these terms below. The description is followed by a discussion of how the aircraft are used for transportation and other purposes, such as law enforcement, emergency airlift, crop dusting, aerial photography, sightseeing, and recreation.

[1] Another 19,000 civil aircraft are classified as gliders, dirigibles, balloons, and experimental aircraft. These aircraft are not considered here.

Table 2-1 U.S. Aircraft Fleet by Aircraft Type and Use, 1998–2000 (FAA 2000b; RAA 1999; RAA 2000)

		Air Carrier				
Aircraft[a]	General Aviation (Including Air Taxi)	Major Passenger Airlines	Major Cargo Carriers	Commuter Passenger Airlines	Regional Cargo Carriers	Total
Fixed-wing						
Single-engine piston	144,662	–	–	284	55	145,001
Multiengine piston	16,219	–	–	196	544	16,959
Total piston	160,881	–	–	480	599	161,960
Turboprop	5,857	–	–	1,759	790	8,406
Turbofan (jet)	6,071	4,176	1,022	412	169	11,850
Total turbine	11,928	4,176	1,022	2,171	959	20,256
Total fixed-wing	172,809	4,176	1,022	2,651	1,558	182,216
Rotary-wing						
Piston-engine	2,259	–	–	–	–	2,259
Turbine-engine	4,668	–	–	3	–	4,671
Total rotary-wing	6,927	–	–	3	–	6,930
Total	179,736	4,176	1,022	2,654	1,558	189,146

[a] Excludes approximately 19,000 gliders, dirigibles, balloons, and experimental aircraft.

Fixed-Wing Aircraft

Piston-Engine Airplanes

Piston-engine propeller airplanes make up about 80 percent of the fixed-wing fleet. A large majority of these airplanes are very small, having six or fewer seats, weighing less than 5,000 pounds when fully loaded, and equipped with a single reciprocating engine. Single-engine aircraft account for about 90 percent of piston-engine airplanes in the civil fleet (see Table 2-1). With few exceptions, large multiengine piston aircraft, once common in the U.S. commercial fleet, have been displaced by more reliable and powerful turbine aircraft, which require less maintenance in heavy-duty use.

Most small piston-engine aircraft have normal cruise speeds of 120 to 175 mph and maximum ranges of between 500 and 1,200 miles, depending on fuel capacity, weight, cruising altitude, and other design and use characteristics.[2] Some high-performance single-engine piston aircraft, such as the Mooney Bravo, can cruise at more than 250 mph, and some twin-engine aircraft, such as the Beech Baron, can fly for more than 1,500 miles. Piston-engine aircraft are seldom flown higher than 10,000 to 15,000 feet above sea level, since few are pressurized or designed for efficient operations at high altitudes. Small piston-engine aircraft have the advantage of needing only 750- to 2,500-foot runways for takeoff and landing.

Over the past two decades, demand for new piston-engine aircraft has declined overall, although in recent years it has grown slightly. Domestic sales fell from 10,500 units in 1980 to fewer than 1,000 in 1995 and about 1,700 in 1998 (see Figure 2-1). There has been much speculation about the causes of this dramatic decline, from rising interest rates and product liability costs to changes in tax policy and a shrinking population of private pilots interested in recreational flying. Because many piston-engine aircraft are used sporadically—on the average, less than 150 hours per year (FAA 2000b, V-7)—there is an ample supply of used aircraft, which has contributed to the limited demand for new aircraft. The average age of a piston-engine aircraft is 30 years (GAMA 1999a; GAMA 1999b). Hence, despite the major drop in production beginning in the 1980s, the size of the fleet has fallen by only 15 percent since 1980 because of the large number of older and reconditioned aircraft still in operation.

Faced with declining demand, a number of general aviation (GA) manufacturers have failed over the past two decades, and many others have had to revamp their product lines to attract a new base of customers. New manufacturers, such as Cirrus Design Corporation and Lancair Company, have emphasized ease of operation, advanced avionics, and modest prices to appeal to customers interested in aircraft for both personal and business uses.[3] Cirrus even includes a whole-airframe parachute as a safety attraction for its four-seat SR20. Long-time GA manufacturers such as Raytheon Aircraft Company and Cessna Aircraft have increasingly emphasized speed and styling in their new piston-engine designs, promoting them as affordable, comfortable, and practical for business travel.

---

[2] Detailed information on aircraft dimensions, specifications, and performance characteristics can be found in the *Aerospace Source Book,* published annually by *Aviation Week,* McGraw-Hill. The most recent edition, January 15, 2001, was referenced in this chapter.

[3] See aircraft company and product information at www.lancair.com and www.cirrusdesign.com.

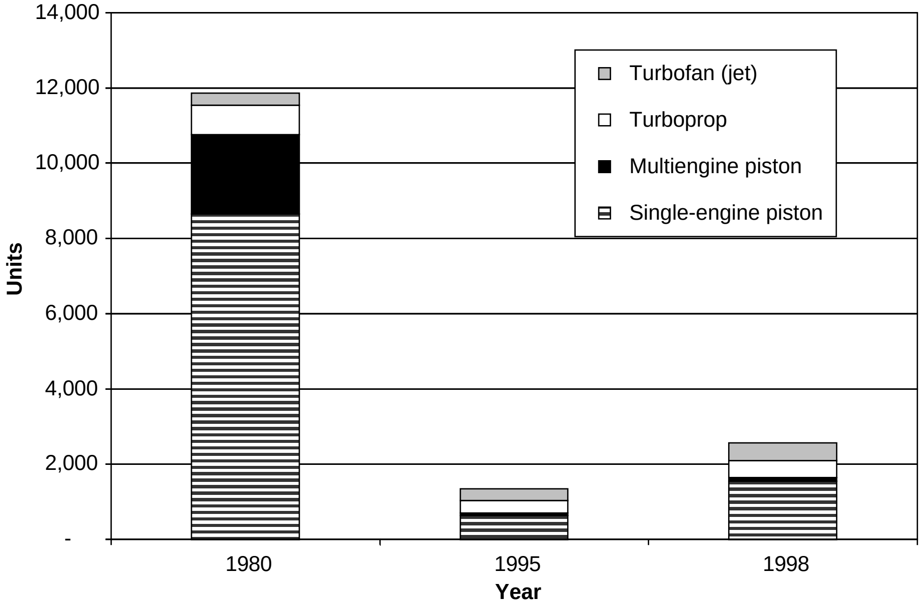


Figure 2-1 Shipments of new general aviation aircraft in the United States from domestic and foreign manufacturers, 1980, 1995, and 1998 (GAMA 1999b).

Piston-engine aircraft sales have increased in recent years; about 1,000 more new aircraft were sold in 1998 than in 1995, when Cessna—the largest domestic maker of GA aircraft—reintroduced its line of piston-engine airplanes (see Figure 2-1). The average price of a new piston-engine aircraft in 1998 was $220,000 (GAMA 1999a; GAMA 1999b). This price is low compared with that of turbine aircraft but still high relative to used piston-engine airplanes, which can be purchased at a fraction of this price.

Turbine-Engine Airplanes

The two general classes of turbine-powered aircraft in the civil fleet are turboprop and turbofan designs. A turboprop aircraft uses a gas turbine to drive a shaft and propeller that provide thrust forces to propel the airplane. In the turbofan aircraft, the gas-air mixture exiting from the rear of the turbine engine produces thrust pushing the aircraft forward.[4] Although both types of aircraft use gas turbine technology, the latter type is normally referred to as jet aircraft. Turbine engines are more reliable than piston engines, having fewer moving parts, and they require less frequent maintenance and downtime for overhauls. They also burn readily available grades of kerosene fuel, which are generally less expensive than the aviation-grade gasoline

[4] Jet aircraft in the civil fleet, designed for subsonic flying, almost always have turbofan engines, which have greater fuel efficiency than turbojets. Pure turbojets are relegated mostly to high-speed military aircraft.

used in piston engines. These are especially important attributes to aircraft operators; however, among the main attractions to passengers of turbine aircraft are their ability to fly faster, at higher altitudes (above most weather-related turbulence), and for longer distances than piston-engine aircraft. In addition, passengers experience less noise and vibration. All jet aircraft and most turboprop aircraft are pressurized and capable of flying more than 250 mph at altitudes above 18,000 feet.

A deterrent to the use of turbine engines is that they are much more expensive to manufacture than piston engines. They also tend to burn more fuel in a given time to produce the same horsepower. However, because of their performance advantages, turbine engines have displaced piston engines on nearly all aircraft in which reliability and payload capacity are important.

Turboprops There are about 8,400 turboprop airplanes in the U.S. civil fleet (see Table 2-1). These airplanes vary widely in size, seating, and cargo capacity. Most weigh more than 10,000 pounds when loaded and can seat 6 to 30 people. Some are much larger, especially those used for passenger transportation. Large turboprops used by commuter airlines, such as the De Havilland Dash 8, can weigh more than 60,000 pounds loaded and seat 70 or more people. Turboprops usually have cruising speeds of 200 to 350 mph and ranges in excess of 1,200 miles. They tend to be most efficient when flown at 15,000 to 30,000 feet above sea level. Although even the smallest turboprops can cost $1 million to $4 million (GAMA 1999a, 6; RAA 1999, 37–42), they are generally less expensive to manufacture than jet aircraft. Turboprops can also be used on shorter runways than turbofan and turbojet aircraft because they produce more static thrust for a given horsepower. Some are designed to be used on unpaved fields and in amphibious configurations. A powerful turbine engine coupled to a propeller provides for the efficient generation of thrust, particularly at lower airspeeds, so that single- and multiengine turboprops have found utility in short-haul passenger service and cargo hauling. The multipurpose Cessna Caravan, Beech 1900, and Embraer Brasilia are examples of the latter.

Growth in domestic sales of turboprop airplanes has been modest over the past two decades. The number of turboprop aircraft in the civil fleet is up by about 10 percent since 1990 (FAA 1989; FAA 2000b). The most rapid growth in turboprop sales occurred during the 1970s, as these aircraft replaced multiengine piston aircraft in many commercial uses. Between 1975 and 1985, an average of 445 new turboprop aircraft entered the U.S. fleet each year, compared with an average of 247 since 1986 (GAMA 1999a, 6). Commuter airlines invested heavily in these aircraft during the 1970s and early 1980s; however, during the past 15 years, both airline and business users have shown a preference for jets. The sale of new turboprops used for GA is down 45 percent since 1980, although sales have risen by 25 percent since the low in 1995 (see Figure 2-1). The Federal Aviation Administration (FAA) predicts that the GA fleet of turboprops will increase by only 10 to 15 percent over the next decade, while the airline fleet of turboprops remains stable (FAA 2000b). The average price of a new turboprop used in GA was $2.8 million in 1998 (GAMA 1999a; GAMA 1999b).

Turbofan Jets There are about 11,900 jet airplanes in the U.S. civil fleet. They range from 10,000-pound (loaded) business jets that carry 5 or 6 people to wide-body jet airliners that weigh more than 800,000 pounds loaded and can seat more than 500. Jet aircraft offer high performance, including speed, reliability, low maintenance, and ride comfort (less cabin noise and vibration) qualities that exceed those of piston-engine and turboprop aircraft. Normal cruise speeds are 475 to 600 mph. Most jets have ranges exceeding 2,000 miles and are designed for cruising altitudes above 25,000 feet. However, the turbofan engines—which require extensive quality control in fabrication and material selection—are expensive to manufacture, raising the price of even small jet aircraft to several million dollars. Jet aircraft also require longer runways than propeller aircraft because of the extra distance necessary to accelerate to flight speeds.[5] In general, runways used by jets must be long, hard-surfaced, reasonably level, free of debris, and otherwise well maintained.

Large jet airliners, used for passenger and cargo transport, can carry passengers and weigh more than 100,000 pounds fully loaded. Their range is usually at least 1,500 miles, and some have a range exceeding 7,000 miles. They usually require 6,000 feet or more of runway for takeoff and landing (depending on factors such as load weight, elevation, and air temperature).[6] Medium-sized jets with seating capacities of 32 to 100 and gross weights of 50,000 to 80,000 pounds are now being used by many airlines. Commonly referred to as regional jets (RJs), these aircraft have become increasingly popular for scheduled air service. Although some jets designed for 100 or fewer passengers have been used by airlines for many years, such as the Fokker 100 and the four-engine BAE-146, the recent growth in RJs has centered on 50- to 70-seat jet aircraft, such as the Bombardier Canadair RJ 200 and 700 series and the Embraer ERJ-135 and 145. RJs generally require runways that are 5,500 to 6,500 feet long.

Somewhat smaller jets, such as the Dassault Falcon, Raytheon Hawker Horizon, and Citation 10, are configured to seat 8 to 19 passengers and are typically used for corporate aviation. These midsize business jets, weighing 30,000 to 60,000 pounds loaded, have ranges exceeding 3,500 miles and cabin amenities such as lavatories and compact galleys, which are valued for longer trips. Growth in demand for even smaller jets for use in business transportation has prompted GA manufacturers to increase jet production over the past decade. In doing so, they have introduced smaller, entry-level business jets, such as Cessna's Citation CJ series and Raytheon's new Premier 1. These smaller jets are certified for single-pilot operations and can seat four to seven passengers. When fully loaded, they weigh between 10,000 and 12,500 pounds and generally require at least 3,000 feet of runway for takeoff. These small jets sell for $5 million or more new, depending on their many customized features.

[5] FAA aircraft certification rules stipulate that an aircraft must be able to reach takeoff speed, decelerate, and stop safely on the runway, as may be necessary in an aborted takeoff because of an engine failure. Alternatively, the aircraft must be able to continue to climb safely under the power of other functioning engines if an engine fails after the aircraft reaches the speed at which it can safely stop on the remaining available runway length. The runway length required to achieve this requirement is the aircraft's FAA-certified takeoff field length; aircraft are certified to operate only on runways with sufficient length to meet this standard. For aircraft used in air carrier operations, an additional runway safety margin is required, as noted later.

[6] For illustration, newer-model narrow-body turbofan aircraft such as the Boeing 737-800 (160 passenger) and Airbus 320-200 (150 passenger) require 6,200 to 7,600 feet of runway for takeoff, while an older Boeing 727-200 (145 passenger) requires 10,000 feet.

Still smaller private jet aircraft are in various stages of planning, design, and development. For instance, the start-up Eclipse Aviation Company is designing and seeking to certify for manufacture a twin-engine jet airplane (Eclipse 500) that weighs less than 5,000 pounds loaded and has a wingspan and fuselage that are about one-fifth shorter than those of existing small jets. Eclipse anticipates that its aircraft will require about 2,500 feet for takeoff and accommodate up to six people, including crew.[7] Safire Aircraft Company, another start-up, is likewise planning a small twin-engine jet (the S-26) with comparable features and capabilities.[8] Anticipating the development of low-cost jet engines, as well as advances in electronics and manufacturing systems, both companies have targeted sales prices of about $1 million for their new aircraft. By dramatically reducing small-jet prices, these companies expect much greater use of such aircraft for business, and even personal, travel.

FAA predicts continued growth in the jet fleet for both private aviation and airline uses (FAA 2000b). The number of shipments of new GA jet aircraft was 45 percent higher in 1998 than 1980 (see Figure 2-1). The GA jet fleet grew by one-third from 1995 to 2000 (from about 4,600 to 6,100), and it is expected to grow by another 80 percent during this decade. Meanwhile, FAA predicts that airlines will continue to invest heavily in RJs. It expects the RJ fleet to increase from about 400 to more than 1,500 aircraft in 10 years (FAA 2000b).

Rotary-Wing Aircraft

There are about 6,900 rotary-wing aircraft in the U.S. fleet (see Table 2-1). About 60 percent of these aircraft use gas turbine engines, and the remainder use piston engines. FAA estimates that the number of rotorcraft will increase by about one-third over the next decade, contingent in part on the development and introduction of technologies that improve nighttime and all-weather flying, while reducing maintenance requirements and environmental impacts—mainly external noise—that limit routing, landing, and takeoff options (FAA 2000b).

Civilian tiltrotor aircraft are being developed. These aircraft can take off vertically like a helicopter but fly like fixed-wing aircraft when airborne; hence, they can greatly increase the range, speed, and comfort of rotorcraft by flying above most weather and at speeds exceeding 250 mph. A major attraction of these aircraft is that they do not require runways, so service can be provided with little land area and with limited noise impacts by reducing the ground surface areas flown over during climbing and descent. These aircraft achieve versatility by combining many of the components otherwise unique to helicopters on the one hand and fixed-wing aircraft on the other. This combination, however, requires more parts and therefore higher manufacturing cost and—in all probability—higher maintenance costs.

FLEET USE CHARACTERISTICS

Most turbine and many piston-engine aircraft in the civil fleet are used to transport people and goods from point to point. However, transportation is only one of several uses of civil aircraft. These transportation and nontransportation applications are discussed in this section.

[7] See www.eclipseaviation.com.

[8] See www.safireaircraft.com.

Aircraft Uses in Transportation

In regulating air transport operations and flight standards, FAA has long distinguished between "for-hire" and "private" service. Aircraft operators who provide for-hire transportation are defined as air carriers and are subject to comprehensive federal regulations governing operating procedures, aircraft maintenance, and pilot training and eligibility. In contrast, owners and users of private aircraft are subject to more general operating and flight regulations. The rationale for this differing treatment is that customers of for-hire carriers do not have direct control over or responsibility for their own safety; therefore, the government must assume a more prominent role in ensuring airworthiness and safe operations.[9]

This broad regulatory distinction and the nature of air transportation demand itself have led to differentiation in the types of for-hire and private air transportation providers. The primary types include (*a*) major airlines, which fly large jet aircraft for mainline passenger and cargo services; (*b*) commuter airlines, which fly RJs, turboprops, and some piston-engine aircraft on short to medium-length routes for scheduled passenger and cargo services; (*c*) air taxis, which use small jets, turboprops, and piston-engine aircraft for short- to medium-haul, on-demand passenger and cargo transportation; and (*d*) corporations and other private entities, which own, lease, and operate aircraft used for in-house transportation purposes that are incidental to their main line of business.

Major Airlines

Major passenger and cargo airlines operate about 5,200 aircraft domestically, including most of the narrow- and wide-body jet passenger airliners and freighters in the U.S. fleet (see Table 2-1). About three-quarters of these aircraft are used in scheduled passenger service. Charter airlines operate about 5 percent of jet airliners, and large cargo carriers operate about 20 percent. Some of the scheduled airlines (e.g., low-fare airlines such as Frontier and Spirit Airlines) provide large-jet service over a limited number of business or vacation routes. However, most large jet airliners are used by carriers with nationwide route networks (e.g., Delta Airlines, United Airlines, American Airlines).

The major airlines have found that jet aircraft with 100 to 250 seats are particularly well suited to their domestic networks, which have been structured into hub-and-spoke systems since deregulation of the industry nearly 25 years ago. Most major airlines configure their routes around two or three large connecting ("hub") airports (such as Dallas, Denver, Atlanta), two or three regional hubs (such as Charlotte, Cincinnati, Salt Lake City), and international gateways (such as Miami, San Francisco, Washington Dulles). The major airlines fly mainly between these two dozen or so connecting hubs and about 125 other large and medium-sized destination, or "spoke," airports. Narrow-body (single-aisle) jet airliners such as Boeing 737s, MD- 80s, and Airbus 320s work well on the 400- to 1,200-mile flight segments, although desired flight frequencies, traffic volumes, and distances in individual city-pair markets dictate the most suitable aircraft. Markets with a preponderance of business travelers, who tend

[9] FAA has recently reiterated its rationale for this distinction in a Notice of Proposed Rulemaking for fractional ownership programs and on-demand operations (*Federal Register* 2001).

to prefer a choice of departure options throughout the day, are often served by smaller RJs that can operate with higher frequency (and more easily meet economic passenger load factors) than larger aircraft. About half the passengers on major airlines are business travelers. RJs now constitute about 5 percent of the major airline fleet, and FAA expects this share to double by 2010 (FAA 2000b).

Since 1980, the fleet of jet aircraft operated by major passenger and cargo airlines has doubled. The increased number of flights brought about by hub-and-spoke systems has contributed to the increase in fleet size; however, the main source of growth has been escalating passenger demand. Major airlines enplaned about 665 million domestic passengers in 2000, a 40 percent increase over passenger enplanements a decade earlier. Included in this number are connecting enplanements, which account for about one-fourth of all enplanements (FAA 1989; FAA 2000b).[10] Thus, excluding connections, airlines accommodated about 500 million passenger trips in 2000.[11]

The volume of air cargo carried in jet aircraft has also increased significantly over the past decade because of the growing demand for express package services and the emergence of all-cargo carriers. Air cargo traffic, including shipments carried in passenger aircraft, has increased by 50 percent since the early 1990s (measured in ton-miles) (FAA 2000b).[12]

Commuter Airlines

A key distinction between major and commuter airlines is that the latter operate fleets composed primarily of aircraft that have 60 or fewer seats. Another difference is that commuter airlines seldom fly distances greater than 500 or 600 miles. They are sometimes referred to as regional carriers because their networks are usually confined to a single region of the country, rather than extending nationwide as do the networks of major airlines. Commuter carrier networks are typically configured to provide service between large hub airports and smaller communities within 75 to 600 miles of the hub.

Commuter airlines provide scheduled service in about 450 airports in the contiguous United States, performing more than 4 million departures per year.[13] Commuter airlines account for between 15 and 80 percent of operations at the country's largest 150 commercial airports, and they provide all scheduled service at about 280 smaller airports. Altogether, nearly 100 commuter airlines operate in the United States. They deploy about 4,200 aircraft, including about 1,600 all-cargo aircraft (see Table 2-1). The top 25 commuter airlines (in terms of passenger enplanements) operate most of the 2,600 aircraft used in passenger service. All large commuter airlines are affiliated with one or two major airlines; they share flight codes, aircraft paint schemes, baggage handling, ticketing, and other service and marketing functions.

[10] In addition, see industry statistics collected by the Air Transport Association (www.air-transport.org).

[11] These trips are generally referred to as true origin-to-destination (O&D) trips; a traveler on a round-trip ticket generates two O&D trips (one trip for each direction of travel) regardless of the number of connecting legs.

[12] In addition, see the Air Transport Association website (www.air-transport.org).

[13] The statistics cited in this subsection are from the Regional Airline Association's annual fact book (RAA 1999; RAA 2000) and Internet website (www.raa.org).

The commuter airlines provide important feeder service to the major airlines at their hub airports. Although some passengers on commuter flights are heading directly to the hub, most are transferring to larger aircraft for mainline transportation to a more distant city. Indeed, about one in five passengers on major airlines uses a commuter airline on one or more legs of the trip.

Commuter airlines enplaned about 85 million passengers in 2000. Most passengers on commuter airlines—about two-thirds—travel for business purposes. FAA predicts that passenger traffic on commuter airlines will increase by about 20 percent over the next 5 years (FAA 2000b). By affiliating with major airlines, the commuter airlines have been able to increase their passenger traffic substantially, allowing for the efficient use of large aircraft. Consequently, nearly all commuter passengers are now being carried on turbine aircraft—either turbojet or turboprop. About 16 percent of the commuter passenger fleet consists of regional jets, 66 percent of turboprops, and 18 percent of piston-engine aircraft. [Regional airline fleet data are provided by the Regional Airline Association (RAA 2000)]. However, because turbine aircraft have many more seats than piston aircraft and operate on the densest routes, they account for more than 95 percent of the passengers carried on commuter airlines. Outside Alaska, few piston-engine aircraft are used in scheduled commuter service.

The commuter airline industry has undergone considerable change over the past two decades. In 1980, 60 percent of the commuter fleet consisted of aircraft with fewer than 20 seats (FAA 1989; FAA 2000b; RAA 1999; RAA 2000). At the time, more than 200 commuter airlines operated throughout the country, averaging less than 150 miles per flight and using aircraft with an average of only 15 seats. Commuter carriers were just then beginning to affiliate with major airlines and, accordingly, to structure their networks around connecting hubs. Today—with passenger volumes six times greater than in 1980—most commuter airlines operate aircraft with 30 or more seats. RJs now account for about 40 percent of passengers carried by commuter airlines.

FAA predicts that RJs will account for half the fleet by 2010—mainly by replacing turboprops and opening new, longer-haul markets to commuter airlines (FAA 2000b).

Air Taxis

Air taxis operate the smallest aircraft used in the for-hire segment of air transportation. In what are essentially charter operations, these companies typically operate aircraft with fewer than 10, but sometimes up to 30, seats. Air taxis are certificated as an air carrier by FAA but are subject to operating requirements different from those applicable to the scheduled carriers using larger aircraft. For instance, because of the nature of their services and the kinds of aircraft they operate, air taxis can often use single-pilot crews and access GA airports that do not provide on-site safety and security services—such as rescue and fire fighting, passenger and baggage screening, and weather reporting—required for scheduled operations. Of course, air taxis also operate in the large commercial airports.

According to the National Air Transportation Association, there are some 3,000 air taxi operators nationwide (NATA 1999). They provide services ranging from passenger and cargo transportation to air ambulance services. These services are often provided by fixed-base operators (FBOs) at commercial and GA airports. FBOs sell and store aircraft, provide aircraft maintenance and fuel, and offer flight instruction. Many have modest fleets of aircraft that can be rented by private pilots or chartered in air taxi service. FBOs sometimes manage aircraft for corporations and charter the aircraft when they are not being used for corporate aviation.

Because they are often used for multiple purposes, the aircraft used in air taxi service are usually counted as part of the GA fleet even though air taxi companies are regulated as "air carriers." FAA estimates that about 5,000 GA aircraft are used in air taxi service (FAA 2000b). Turboprop aircraft are frequently used, as are smaller piston-engine aircraft. Small and midsize jets have become more popular to charter, especially in business markets. As measured by hours flown, air taxi service is the leading application for rotorcraft, accounting for about 30 percent of their service hours, including more than two-thirds of the total hours flown by turbine rotorcraft (FAA 2000b).

Air taxis flew about 2.4 million hours in 1999, accounting for nearly 10 percent of the total hours flown in GA (FAA 2000b). There are no national-level statistics on the number of passenger trips by air taxi. Most air taxi companies operate aircraft with fewer than 10 seats. If it is assumed that each flight averages 1 hour and carries six passengers, the total number of passengers carried by air taxi is on the order of 15 million per year (2.4 million $\div$ 1 $\times$ 6 = 14.4 million).

Air taxis normally charge hourly rates that vary by the type and size of the aircraft. For instance, a Cessna CE 340 twin piston-engine airplane, which accommodates up to four passengers, may have an hourly rate of about $400, while a Beech King Air C90A turboprop that seats up to seven passengers costs $1,000 per hour.[14] Jets are the most expensive to charter. A Cessna Citation Jet CE255 that seats up to six can cost $1,500 or more per hour. Ultimately, the utility and expense of air taxi service must be judged on the basis of its cost, safety, and convenience relative to other forms of travel, factoring in the potential savings in time, lodging, and ground transportation and the additional business opportunities that such direct service can provide.

Business Aviation and Fractional Ownership

Aircraft are used in business aviation in many different ways. For example, a private pilot may periodically rent a small piston-engine airplane to meet with a client, and a corporate flight department may employ professional flight crews and own dozens of turbine aircraft used to transport executives and managers. Most corporations that operate business aircraft use turbine aircraft with fewer than 20 seats. These aircraft are typically flown by professional pilots (usually by two pilots) whose exclusive responsibility is to fly company aircraft.

On-demand service and accessibility are important reasons why businesses own or lease aircraft. Operators of private aircraft for business aviation can fly to more airports than for-hire air carriers, including many air taxis. Private aircraft have better access to some airports because they are not subject to the same safety restrictions on

[14] For examples of hourly charter rates by aircraft see www.bizcharter.com (accessed August 2001).

runway length and other airport capabilities and services (such as weather reporting and emergency maintenance) that can limit air carrier access. From a regulatory standpoint, private aircraft used in business aviation are treated like other kinds of GA aircraft.

Owning and operating private aircraft can be inefficient if the aircraft are not used regularly. Consequently, some companies are gaining access to private aircraft through fractional ownership programs, in which aircraft are owned by several individuals or companies and pooled with similar fractionally owned equipment. A private company that manages the fleet ensures that the owners have access to the pool aircraft and that they are ready for use as needed.

The National Business Aviation Association (NBAA) estimates that more than 9,300 companies in the United States operate business aircraft.[15] The 6,300 NBAA members, which include most corporate fleet operators, own approximately 8,700 aircraft. About half of these aircraft are jets. Turboprops account for about 20 percent, while piston-engine airplanes, turbine-powered aircraft, and helicopters account for the remaining 30 percent. By comparison, fractional ownership programs managed approximately 500 aircraft on behalf of about 3,500 owners.

The number of jets in the business fleet is growing—especially the number of small and midsize private jets. Currently, two-thirds of jets in the business fleet weigh (empty) less than 30,000 pounds. The total number of jets sold for business aviation has doubled over the past 5 years, while deliveries of new turboprops have declined. The speed, comfort, and reliability of jet aircraft have proved to be major advantages in business aviation.

NBAA estimates that about 7.2 million hours were flown by business aviation aircraft in 1999. As with air charter operators, there are no national estimates of the number of passenger trips. If it is assumed, as with air taxis, that each flight takes 1 hour and carries six people, the total number of passenger trips per year amounts to 40 million to 45 million (7.2 million $\div$ 1 $\times$ 6 = 43.2 million).

Other Uses of GA Aircraft

GA aircraft are used in many ways other than for transportation. FAA estimates that less than 30 percent of GA flight hours are for air taxi service and corporate and business transportation purposes (see Table 2-2). Most flights in GA airplanes are for other local activities, including flight instruction, aerial observation, chemical application, and sightseeing. Personal flying for recreation is another major use of GA airplanes, accounting for more than 40 percent of hours flown by piston-engine aircraft; in contrast, turbine aircraft are seldom used for such flying. Nontransportation civilian uses of GA rotorcraft include emergency rescue and medical services, police surveillance, and traffic monitoring and reporting.

It is important to note that the safety record of GA in nontransportation activities tends to be worse than that of GA in air carrier and corporate transportation. GA safety is examined in the discussion of the challenges facing air transportation in Chapter 3.

[15] Statistics in this section on business aviation are from the *Business Aviation Factbook 2000* (NBAA 2000).

Table 2-2 Annual Hours Flown (Thousands) by Fixed-Wing Aircraft in the U.S. GA Fleet by Aircraft Type and Use, 1997 (GAMA 1999a; FAA 2000b)

	Piston-Engine	Turboprop	Turbofan (Jet)	Total	Percent of Total Flight Hours	Average Flight Hours per Aircraft by Primary Use
Number of Aircraft in GA fleet (1997)	156,056	5,619	5,178	166,853	N.A.	N.A.
Total flight hours by primary use (thousands)						
Corporate transportation	552	676	1,435	2,663	11	268
Other business transportation	2,786	86	24	2,896	12	109
Air taxi	921	410	121	1,452	6	379
Personal	8,542	75	19	8,636	36	86
Instructional	4,707	10	1	4,718	20	351
Government	411	107	74	592	2	237
Other[a]	2,661	289	25	2,975	12	279
Total hours	20,580	1,653	1,699	23,932	100	N.A.
Average flight hours	131	294	328	143	N.A.	N.A.

NOTE: Gliders, experimental aircraft, rotorcraft, and lighter-than-air aircraft are excluded. N.A. = not applicable.
[a] Includes aircraft used for aerial observation, chemical application, sightseeing, external load carrying, and other nontransportation functions.

Table 2-3 Runway Characteristics of U.S. Civilian Airports

	Airport Type[a]		
	Public Use	Private Use	Total
Total number of airports	5,025	9,433	14,458
Airports with paved runway			
Number	3,870	849	4,719
Percent	77	9	33
Airports with lighted runway			
Number	3,970	755	4,725
Percent	79	8	33
Airports without paved or lighted runway			
Number	754	8,585	9,339
Percent	15	91	65
Airports with longest runway length			
Less than 3,000 feet	1,181	6,855	8,036
3,000 to 3,999 feet	1,390	1,163	2,553
4,000 to 4,999 feet	914	364	1,278
5,000 to 5,999 feet	776	152	928
6,000 feet or more	764	57	821

[a] Some (1,012) public-use airports are privately owned but open to the public.
SOURCE: Data provided to Transportation Research Board by Airport Planning and Programming Office, Federal Aviation Administration, August 2001.

AIRPORTS

FAA has identified 19,245 civil (including joint civil/military) landing facilities in the United States, including 4,013 public and 10,445 private airports (in addition to heliports and seaplane bases). This total includes 5,025 airports that are open to the public, including 1,012 private airports (see Table 2-3).

The United States averages one public-use airport for every 50,000 people, or about one every 700 square miles. However, as discussed below, these airports differ significantly in their physical condition and capacity, how they are used, where they are located, and how they are funded.[16]

Airport Condition and Capacity

An airport has airside and landside facilities. The airside comprises runways, taxiways, apron areas, aircraft parking positions and maintenance buildings, hangars, refueling stations, air traffic control facilities, and navigational aids. The landside comprises terminal and cargo buildings, access roads, automobile parking lots, and other facilities for passengers and other airport users. Some general indicators of airport functional capabilities include the presence of (*a*) runways that are paved, lighted, and sufficiently long and well-maintained to accommodate a variety of aircraft operations; (*b*) navigation aids, traffic control facilities, and safety services; and

[16] Much of the data and description in this section are derived from the *2000 Aviation Capacity Enhancement Plan* (FAA 2000a).

(*c*) passenger facilities and amenities. The condition of these facilities is also relevant to an airport's functional capabilities.

Runways

Among the 5,025 public-use airports, 77 percent have at least one paved runway and 79 percent have at least one lighted runway. By comparison, only 9 percent of private-use airports have a paved runway, and only 8 percent have a lighted runway—which is understandable since many of these facilities are turf landing strips used for specialized activities such as crop dusting and banner towing. Thus, altogether there are about 4,700 airports in the United States with at least one runway that is paved or lighted (or both), about 3,900 of which are open to the public (see Table 2-3).

About 30 percent of public-use airports, or about 1,500, have runways that are at least 5,000 feet long, and about half of these airports have runways longer than 6,000 feet (see Table 2-3). About one-quarter of public-use airports have runways less than 3,000 feet long, and another 28 percent have runways that are less than 4,000 feet long. As might be expected, private-use airports tend to have limited runway capacity. Very few private-use airports—209—have runways that are at least 5,000 feet long; indeed, most private-use airports do not have a runway as long as 3,000 feet. Altogether, about 3,027 public- and private-use airports have runways that are at least 4,000 feet long, including 1,749 with runways at least 5,000 feet long.

Runway length and condition are critical factors for jet operations. A 5,000-foot paved runway is the typical minimum for jet operations, although longer runways are generally required for the jets used by air carriers, and somewhat shorter lengths (seldom less than 4,000 feet) can be used by very light jets. As noted earlier, aircraft are certified by FAA as having minimum takeoff and landing distances. For jet aircraft, takeoff distances are usually the critical factor. An aircraft must be able to accelerate to takeoff speed and then abort the takeoff and stop safely on the runway in an emergency; multiengine aircraft must have enough thrust to continue climbing away under power after a single engine failure. This is known as the "accelerate-to-stop" rule, and the critical takeoff speed is known as the "V-1" speed. Because high-performance jet aircraft have higher V-1 speeds than propeller aircraft, they require longer runways. To increase safety margins for for-hire transportation, FAA requires that the safe stopping distance be no longer than 60 percent of the runway length for aircraft used by air carriers, including air taxis. Hence, pursuant to FAA requirements, a jet aircraft that is certified to operate on a 3,000-foot runway when used in private (e.g., corporate) service must operate on a 5,000-foot runway when used in air carrier service.

Navigation Aids, Traffic Control, and Safety Services

Airport features other than runway length are important for scheduled air service. Nearly all 450 U.S. airports with regularly scheduled air service have air traffic control towers and runways equipped with instrument landing systems (ILS) for precision approaches, as well as a runway lighting system that provides pilots with a visual glide path to the runway (these landing aids are discussed in more detail later in this chapter). Although instrument approaches and departures can be made at airports without an ILS, the ability to land in reduced visibility and a low ceiling improves trip reliability and planning. Reliability is especially important to scheduled airlines, but it is also important to air taxi and business aviators, who place a high value on time.

As an added safety measure, FAA requires commercial airports that serve air carriers to comply with numerous standards governing runway signing and lighting, fire and rescue, deicing and snow removal, ground operations, field security, fuel storage, and traffic and weather reporting. The majority of public-use airports do not meet the standards for commercial aviation; for instance, few GA airports have on-site rescue and fire services or aircraft deicing capabilities. Airports that serve scheduled operations of large air carrier aircraft and meet these standards are issued a "full" certificate for air carrier operations. Approximately 430 airport operators hold such certificates. Because they provide mostly seasonal scheduled service, another 135 airports hold limited certificates for air carrier operations and are subject to fewer restrictions.

Passenger Facilities and Amenities

Most airports with scheduled air service have terminal buildings with passenger lounges, baggage handling, and ticketing counters, as well as ground transportation (e.g., car rental, taxi, and limousine services). The largest 150 airports served by major airlines have the most extensive passenger facilities, and even the smallest airports with scheduled service and business aviation facilities have such amenities, which are now expected by travelers on commuter airlines affiliated with major carriers.

Airport Uses

FAA has designated approximately 3,300 airports as part of the national airport system (National Plan of Integrated Airports). As such, these public airports, which are owned primarily by local governments, are eligible for federal assistance for infrastructure improvements. The national airport system contains three major types of airports classed according to use: 526 "commercial-service" airports, 258 "reliever" GA airports, and 2,543 other GA airports (see Table 2-4). Commercial-service airports, followed by relievers, receive federal funding priority. The purpose of these airport classifications is to concentrate aid for airports and air traffic control infrastructure at the most heavily used airports to maximize system safety and efficiency.

Commercial-Service Airports

Commercial-service airports are located in the largest and smallest communities in the country—including New York City and Alamosa, Colorado (population 15,000). The 526 commercial-service airports handled 99.9 percent of the nation's airline passenger traffic in 2000. A large majority of this traffic was handled by the 213 commercial-service airports with more than 100,000 annual enplanements (see Table 2-4). Of the remaining 313 smaller commercial-service airports, slightly more than half (159) are located within 75 miles of one of these larger commercial-service airports.

Commercial-service airports serve as bases for all of the approximately 9,400 aircraft used by airlines, plus about 38,000 other GA aircraft—or about one-quarter of

Table 2-4 Number of Based Aircraft and Annual Enplanements at Public-Use Airports in the National Plan of Integrated Airports, 2000

	Airports		Based Aircraft		Airline Enplanements	
	Number	Percent of Total	Number	Percent of Total	Number	Percent of Total
Commercial-Service Airports						
Airports with at least 100,000 annual airline enplanements	213	6.4	26,991	14.4	667,863,478	98.8
Airports with less than 100,000 annual enplanements but located less than 75 miles from 100,000-enplanement airport	159	4.8	14,592	7.8	4,169,163	0.6
Airports with less than 100,000 annual enplanements but located at least 75 miles from 100,000-enplanement airport	154	4.6	6,190	3.3	3,274,029	0.5
Subtotal	526	15.8	47,773	25.5	675,306,670	99.9
General Aviation Airports						
Metropolitan reliever airports	258	7.8	59,143	31.5	120,578	0.0
Other GA airports located less than 75 miles from 100,000-enplanement airport	1,783	53.6	68,683	36.6	371,271	0.1
GA airports located at least 75 miles from 100,000-enplanement airport	760	22.8	11,981	6.4	132,786	0.0
Subtotal	2,801	84.2	139,807	74.5	624,635	0.1
Total	3,327	100.0	187,580	100.0	675,931,305	100.0

SOURCE: Data provided to TRB by Airport Planning and Programming Office, Federal Aviation Administration, August 2001.

the total civilian aircraft fleet (see Table 2-4). Even at the largest commercial-service airports, GA aircraft can account for between 15 and 50 percent of takeoff and landing operations (FAA 2000b).

Metropolitan Reliever Airports

All large metropolitan areas have GA reliever airports. They have been designated as reliever airports by FAA because they can divert GA traffic from congested commercial airports. To be designated as a reliever, the airport must have at least 25,000 itinerant (point-to-point) operations per year and 100 or more based aircraft and must reside in a metropolitan location with 250,000 or more people. These airports tend to be the most intensely used, and hence the best equipped, of the country's GA landing facilities. Many reliever airports have runways with ILS, control towers, passenger waiting areas, provision of rescue and fire-fighting equipment, and other infrastructure that can support their intense use for air transportation.

Reliever airports are conveniently located and well equipped and often capable of handling the kind of aircraft used by commuter airlines. Nevertheless, these airports are seldom used by scheduled commuter airlines, which prefer to operate from nearby larger hub airports, where a large percentage of their passengers can make connections to other destination cities. By definition, all reliever airports are located near a larger commercial-service airport in a metropolitan area; however, without the benefit of mainline connecting traffic, commuter airlines are generally reluctant to operate from GA reliever airports in metropolitan areas. In doing so, they would need to use smaller passenger aircraft than they do now, fly at reduced frequencies, and charge higher fares to make up for the lost feeder traffic.

Nevertheless, reliever airports in large metropolitan areas handle a large number of GA operations (FAA 2000b). Some large relievers, such as Teterboro near New York City and Centennial near Denver, average more than 1,000 operations per day. Dekapounds-Peachtree Airport near Atlanta is second only to Atlanta-Hartsfield in daily operations in Georgia.

Reliever airports are used extensively for local aviation services, recreational flying, and on-demand air taxi and business aviation. They house almost one-third of all civil aircraft in the United States (see Table 2-4).

Other GA Airports

GA airports must meet certain minimum criteria to enter the national airport system and thus become eligible for federal aid. For instance, an airport must have at least 10 based aircraft. For the most part, the 2,543 GA nonreliever airports within the national airport system have paved runways and runway lighting and are the best-maintained and best-equipped GA airports, after the relievers.

As part of its Essential Air Service program, the U.S. Department of Transportation estimates the proximity of all GA airports to commercial-service airports with 100,000 or more passenger enplanements per year. According to these data, 1,783, or 70 percent, of the 2,543 GA nonreliever airports in the national airport system are located within 75 miles of an airport with more than 100,000 enplanements per year (see Table 2-4). These 1,783 GA airports serve as bases for more than 35 percent of the GA fleet. Altogether, more than 90 percent of the U.S. civil aircraft fleet is based at or within 75 miles of commercial-service airports with 100,000 or more passenger enplanements per year.

Airport Funding

Airport development is funded by a combination of private and public sources. Major sources include the federal Airport and Airway Trust Fund's Airport Improvement Program (AIP), passenger facility charges (PFCs), state and local funding programs (e.g., publicly and privately funded bonds), and airport concessions, rents, and parking charges.

Although it operates air traffic control towers at fewer than 10 percent of public-use airports, the federal government has an important role in financing infrastructure at thousands of airports. In fact, federal AIP aid is second only to the municipal bond market as a source of financing for airport development. In FY 2001, the federal government provided states and localities with more than $3 billion in capital grants obtained from the trust fund. This aid can be used for a variety of purposes, including the improvement of runways, taxiways, navigation aids, and air traffic control infrastructure; the construction of access roads; and the implementation of noise abatement programs.

Most trust fund revenues are derived from taxes and other levies on commercial airlines (FAA 2000c, 17–25). Airline passengers pay a 7.5 percent federal tax on the price of their tickets plus a flight segment fee, which accounts for more than half of trust fund revenues. About three-quarters of trust fund revenues are generated through passenger taxes. Air carriers are exempt from federal taxes on the purchase of aviation gasoline and jet fuel; these taxes are paid mainly by GA users and account for less than 10 percent of trust fund revenues.

Between 15 and 30 percent of the capital spending at commercial-service airports is federally financed (FAA 2000c, 17–25). Many large commercial-service airports receive federal aid on a continuing basis, with one or more capital projects under way at any given time. In addition, each year about 1,000 reliever and other GA airports receive federal grants for infrastructure, which are often administered through state agencies. These airports depend more heavily on federal aid for capital improvements, since they generate little income from users and have only limited access to other funding sources such as bonds. Federal aid accounts for about 40 percent of capital expenditures by the roughly 3,000 reliever and other GA airports in the national airport system.

PFCs, capped at $4.50 per flight segment, are an important source of capital funds for the largest U.S. airports; however, they are irrelevant for small airports that do not have air carrier service (FAA 2000b; FAA 2000c). Smaller airports must depend instead on user charges, bonds, and state and local aid for most of their capital and operating needs. The issuance of revenue bonds is the primary means of financing airport development projects at larger commercial-service airports, where airline rents, service concessions, parking fees, and landing fees can be used to generate revenues to finance the debt. For most small community airports, state and local aid remains the primary source of revenue for improvements, because other revenues are insufficient to finance the levels of debt required for capital development programs. State and local funds are often used to match or supplement federal grants. For the most part, user charges at small airports cover only operating expenses.

Airports receiving federal aid are subject to additional federal environmental requirements, including environmental review to determine whether proposed airport development would result in significant impacts pursuant to the National Environmental Policy Act, as well as state requirements where applicable. Environmental statutes and regulations, both federal and state, can be key factors in the decision to expand an airport, whether the expansion involves a new or modified runway or the construction of access roads, parking facilities, or other airside and landside infrastructure. Noise and other environmental considerations also affect how often and in what manner an airport is used, potentially affecting its capacity. For instance, noise abatement procedures for an airport can reduce available capacity during certain hours of the day and restrict the use of departure and approach paths that pass over residential areas. Airport environmental issues are discussed in greater detail in Chapter 3.

AIRSPACE SYSTEM

Charged with providing for the safe, orderly, and expeditious flow of air traffic, FAA is responsible for designing and operating the national airspace system. The system consists of terminal and en route airspace and a complex network of navigation, surveillance, and communications systems that are used to guide and control traffic within the airspace and on the ground at airports.[17]

Controlled Terminal and En Route Airspace

The airspace in the United States includes all altitudes from the ground up to 60,000 feet above sea level. This space is divided into two broad sectors: traffic-controlled and uncontrolled. Over the years, FAA has divided the controlled airspace into different classifications, each with its own set of rules for aircraft operations. Thus, within the controlled space are several subclassifications, from Class A through Class E (see Figure 2-2). The least controlled airspace is referred to as Class G space. Operations anywhere in the United States below 18,000 feet, except near large airports, can be conducted under visual flight rules (VFR), providing the weather is good. Most airspace up to 1,200 feet above the ground is Class G, including the space above most small airports without traffic control towers. Because there are only 450 control towers nationwide, most of the country's 5,000 public-use airports are under Class G uncontrolled airspace.[18]

Controlled Terminal Airspace

Towered airports can fall into one of three categories of controlled airspace. At a minimum, all airspace within a 5-mile radius of a towered airport is Class D terminal airspace. This airspace is cylindrical in shape and typically extends up to 2,500 feet above the ground. Most towered airports, including most with light to moderate

---

[17] Much of the data and description in this section are derived from the *2000 Aviation Capacity Enhancement Plan* (FAA 2000a).

[18] As discussed below, however, the higher-altitude airspace (above 1,200 feet) above many GA airports is controlled if they are located within 5 to 30 miles of a busy commercial-service airport with a control tower.

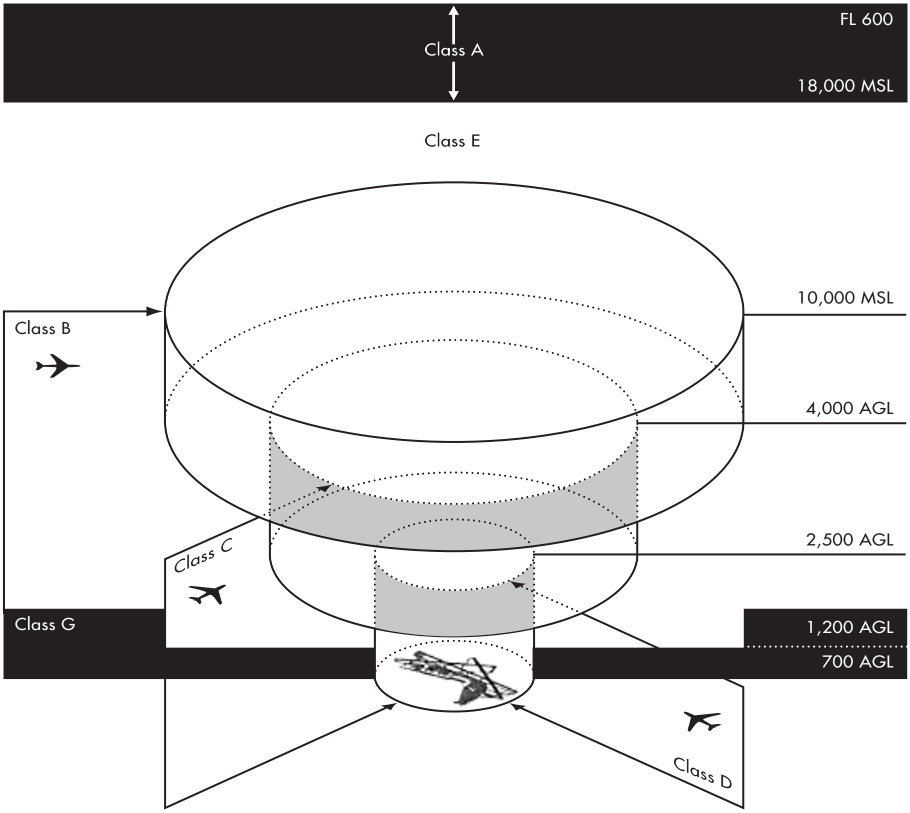


Figure 2-2 Airspace structure in the United States (see text for definitions of airspace Classes A through G) (FAA 2000a). Note: AGL = above ground level; FL = flight level; MSL = maximum sea level.

scheduled air carrier service, are subject to FAA rules governing Class D airspace. Radio contact before entering this controlled airspace, known as the Airport Traffic Area, is mandatory. Few Class D airports have their own radar surveillance systems, although the radar facility at a nearby larger airport may cover the Class D airport and transmit information to its tower. Most Class D airports broadcast recorded weather advisories to pilots. The tower, when open,[19] is responsible for regulating all aircraft maneuvers in the local airspace and approving all aircraft for takeoff and landing. A separate ground controller may be used to clear aircraft movements on taxiways and onto runways. FAA has designated approximately 200 airports as subject to Class D airspace restrictions. These airports account for about 5 percent of all passenger enplanements on scheduled airlines.

A more restrictive category of controlled terminal airspace is Class C, which surrounds most of the airports of the country's midsize cities—generally the middle

[19] Many control towers at small and medium-sized airports have limited hours of operation.

40 to 175 busiest commercial-service airports. These airports account for about 25 percent of the country's enplanements on scheduled airlines. In addition to having airspace controls within a 5-mile radius of the airport extending up to 2,500 feet above the ground, Class C airports are subject to controls on the approach-level airspace extending from 2,500 to 4,000 feet above the ground within a 10-mile radius of the airport.

Class B airspace surrounds the busiest 40 airports in the country. At its core it extends from the ground to an altitude of 10,000 feet above sea level. Because Class B airspace is designed to meet the specific needs of the airport, its size and structure differ from place to place. The radius of the core airspace is usually 5 to 10 miles long, and the outermost layer of restricted space can have a radius of 20 to 30 miles extending outward from the airport center and upward to from 4,000 to 10,000 feet above sea level. The pilot in command of an aircraft operating in Class B airspace must hold at least a private pilot certificate and have specific equipment for air traffic control surveillance and communications. Operations within this controlled terminal airspace must receive air traffic control clearance and separation services. Airports subject to Class B airspace restrictions account for about 70 percent of all air carrier passenger enplanements. In general, all airports that have at least 3.5 million passenger enplanement per year or a total airport activity of 300,000 or more annual operations are subject to Class B airspace restrictions. Moreover, traffic at all other airports within a 20- to 30-mile radius of the Class B airport, including most of the high-capacity GA reliever airports in metropolitan areas, is subject to operational restrictions. Aircraft operating in Class B terminal airspace are generally separated from other aircraft by at least 3 miles horizontally and 1,000 feet vertically.[20]

En Route Airways

The final two categories of airspace are Classes A and E, which comprise the en route structure. Class E airspace extends from the top of the very low-altitude Class G uncontrolled airspace to 18,000 feet above sea level. Airways in Class E airspace are charted and can be used for en route travel by pilots flying under VFR or instrument flight rules (IFR). Each of these two traffic types is assigned an altitude level (in 500- to 1,000-foot increments staggered according to directional flow) in the Class E corridors, which are normally 8 miles wide and guided by navigation aids. A typical navigation aid is a very-high-frequency omnidirectional radio signal (VOR). Pilots operating under VFR can fly between Class G airports without ever being controlled by an air traffic center or tower, if they keep within the Class E altitudes set aside for VFR and approach the destination airport under 1,200 feet if in the vicinity of controlled terminal airspace. This freedom ends, however, when landing, taking off, or entering Class B, C, or D terminal airspace. Aircraft flying at IFR altitudes in Class E airways are subject to air traffic control monitoring, instructions, and clearances to change altitudes and headings. For the most part, the low-altitude Class E en route airways are used by piston-engine and turboprop aircraft.

[20] On approaches and departures, separation standards are modified when different types of aircraft are following one another to limit the impact of wake turbulence. In general, light aircraft must extend separation distances when following behind much heavier aircraft.

Class A airspace consists of all airspace between 18,000 and 60,000 feet above sea level. All operations in this airspace are IFR, subject to direct FAA controls. The mid-structure of Class A airspace (24,000 to 45,000 feet) contains the nation's major jet routes. Aircraft flying in this en route domain are separated from other aircraft by 5 to 10 miles horizontally and 1,000 to 2,000 feet vertically, depending on the altitude and radar coverage reliability.

In addition to the controlled airspace in Classes A through E, FAA has established Special Use Airspace designed for military users. Most of these spaces require altitude changes or detours to bypass.

Air Traffic Control Facilities

Three basic kinds of controllers direct aircraft through the airspace system, each during a different phase of the flight. In the towers of commercial-service airports and some large GA airports, local air traffic controllers together with ground controllers handle aircraft movements. The tower controller directs runway operations (takeoff and landing clearances), and the ground controller directs surface movements between the gates, taxiways, and runways. Approximately 450 airports have control towers, which manage traffic within approximately 5 miles of the airport up to an altitude of about 3,000 feet.

Departure and approach controllers at terminal radar approach control (TRACON) facilities handle departing aircraft from takeoff to cruising altitude and arriving aircraft during the approach phase. More than 185 TRACONs sequence and separate aircraft as they approach and depart all airports in major metropolitan areas. They typically control air traffic within a 30-mile radius of the airport, exclusive of the local core area managed directly by airport towers. TRACONs also guide high-altitude traffic that is flying over the area. Terminal airspace is usually divided into sectors that can be modified on the basis of runway configurations in use by the airports in the TRACON airspace. All Class B airspace and most Class C airspace is under the control of TRACONs.

Twenty-one air route traffic control centers (ARTCCs) monitor and control aircraft in transit over the United States. Each center handles a different region of the country, and some also control aircraft over the ocean using radio communication. The airspace controlled by each of these centers usually covers several states. Each ARTCC has controllers who guide the lower-altitude airways (Class E and lower-altitude Class A) used by turboprops and piston-engine airplanes and the higher-altitude airways used mainly by jets. The Air Traffic Control System Command Center in Herndon, Virginia, coordinates the actions of the various local and regional control centers and airline operating centers. Normally, the federal air traffic control system handles 30,000 to 45,000 flights per day.

Other Traffic Control Equipment and Navigational Aids

An extensive network of facilities, generally known as navaids, supports aircraft movement in the airways. The main navaids that define the system, the VOR airway stations, transmit signals to guide traffic in designated airways. Pilots can use these signals, which are transmitted from more than 1,000 stations, for bearing information. Radar surveillance also aids controllers in monitoring en route aircraft, allowing them to better advise pilots on navigation. All aircraft used by airlines and many of the GA aircraft used for long-distance transportation are equipped with transponders that transmit aircraft identification and altitude information to air traffic control.

Other navaids help pilots descend from cruising altitude to prepare for landing. Visual and radar navigation cannot be used for precision approaches in poor visibility. This capability is provided by ILS, which consists of a localizer for horizontal guidance and a glide slope for vertical guidance. The localizer is placed beyond the stop end of the runway, aligned with the centerline. The glide slope is located beside the runway, near the touchdown point. There are currently about 1,300 ILS-equipped runways in the country, including multiple ILS runways in large airports. Other navaids that assist pilots with approach and landing include precision path lighting systems and runway end lights.

FAA is transitioning from this system of ground-based navigation aids to the satellite-based Global Positioning System (GPS). Radar and other ground-based navaids limit the amount of airspace available and can increase travel distance, since aircraft must follow one navigational fix to another. Under GPS, several sequenced satellites orbiting the earth each transit an omnidirectional signal that reaches a receiver on the aircraft, which with precise timing information calculates a radius of distance from each satellite. The intersection of at least three spherical surfaces allows for the automated calculation of the aircraft's position. This process provides highly accurate information for en route navigation. GPS is already being used for navigation in oceanic and en route airspace.

To enhance the accuracy and reliability of GPS so that it can be used as a primary means of navigation and nonprecision approaches, FAA has been augmenting the system with a nationwide network of reference stations that will receive and refine signals from the GPS satellites. Known as the Wide Area Augmentation System (WAAS), these enhancements will allow so-called "differential" GPS to be used as a primary means of navigation for en route travel and nonprecision approaches in the United States, as well as near-precision approaches. WAAS will also allow a pilot to determine a horizontal and vertical position within 6 to 7 meters, compared with the 100-meter accuracy available today from the basic GPS service. FAA is also testing other applications of GPS, such as Automatic Dependent Surveillance-Broadcast (ADS-B),[21] as part of its transition from central control to "Free Flight" concepts. The aim of Free Flight is to give pilots greater flexibility to determine optimal routes and speeds, thereby improving the overall efficiency and capacity of the airspace system. Though promising, such capacity-enhancing systems require more than FAA certification and investment; they require the installation of appropriate equipment in airports and aircraft, the training of pilots, the availability of safe and certifiable avionics, and other private-sector commitments and investments.

Finally, FAA maintains approximately 75 Flight Service Stations at its air traffic facilities. These stations provide pilot briefings and en route communications, and

[21] ADS-B is a surveillance system that continuously broadcasts GPS position information, aircraft identification, altitude, velocity, vector, and direction to all other aircraft and air traffic control facilities in the area. The information is displayed in the cockpit to provide greater situational awareness. Controllers will also receive ADS-B transmissions, providing them with more timely and accurate traffic information.

they assist aircraft in emergency situations. They also relay air traffic control clearances, originate pilot advisories (Notices to Airmen), broadcast weather reports, and receive and process IFR flight plans.

This complex airspace system has come under scrutiny in recent years as demand for air transportation has escalated. Much of the concern has centered on flight delays and the slow pace of national airspace system modernization and capacity enhancement. The factors that influence system capacity and delay are discussed in more detail in Chapter 3.

AIRCRAFT OPERATORS

About 620,000 people are licensed to fly in the United States, representing about 0.25 percent of the country's adult population. By comparison, there are 325 licensed automobile drivers for every pilot. Thus, pilots are rare. Moreover, they have become even rarer in recent years as the pilot population has declined, mostly because of a drop in the number of private, as distinguished from professional, pilots. The total population of pilots is down by 12 percent since 1990 and by 19 percent since 1981 (see Figure 2-3). Trends in the number of private pilots and other pilot types are discussed in more detail below.

Private Pilots

The shrinking number of private pilots has been a main reason for the decline in total pilots over the past two decades. The "private pilot" certificate qualifies a person to act, without compensation, as a pilot-in-command of an aircraft carrying passengers. The number of private pilots fell from 328,000 in 1981 to 247,000 in 1998 (see Figure 2-3). Attrition in the historically large civilian population of aviators trained in the military (from World War II through the Vietnam War) is one reason for the long-term decline. Other likely factors include the time and expense associated with pilot training and maintaining proficiency, as well as the cost of owning (or renting) and operating small aircraft. In metropolitan areas with heavy air traffic and much controlled airspace, the need for private pilots to obtain a thorough familiarity with radio communication techniques adds to the overall training and proficiency requirements. According to the Aircraft Owners and Pilots Association,[22] the cost of obtaining a private pilot license is $3,000 to $5,000, and a student training 2 to 3 days per week can obtain a license in about 4 months, flying 40 to 65 hours.[23] The rental charge for even a small trainer airplane at a GA airport tends to begin at $50 to $75 per hour. Most private pilots are rated to fly only under VFR; earning and maintaining an IFR rating is an added expense, as discussed below.

Whatever the cause, the number of students seeking pilot licenses is much lower today than two decades ago. New student certificates issued each year have fallen sharply during the period, from more than 110,000 issued in 1981 to fewer than 63,000 issued in 1998 (GAMA 1999a). The total number of student pilots fell by nearly half between 1981 and 1998 (see Figure 2-3).

[22] The discussion of pilot training requirements in this section was derived from W. L. Gruber, "Beyond the Private: How to Ascend the Aviation Hierarchy," Aircraft Owners and Pilots Association (www.aopa.org).
[23] Although FAA rules require the student to log 35 to 40 hours, most students will require more hours to obtain the necessary proficiency.

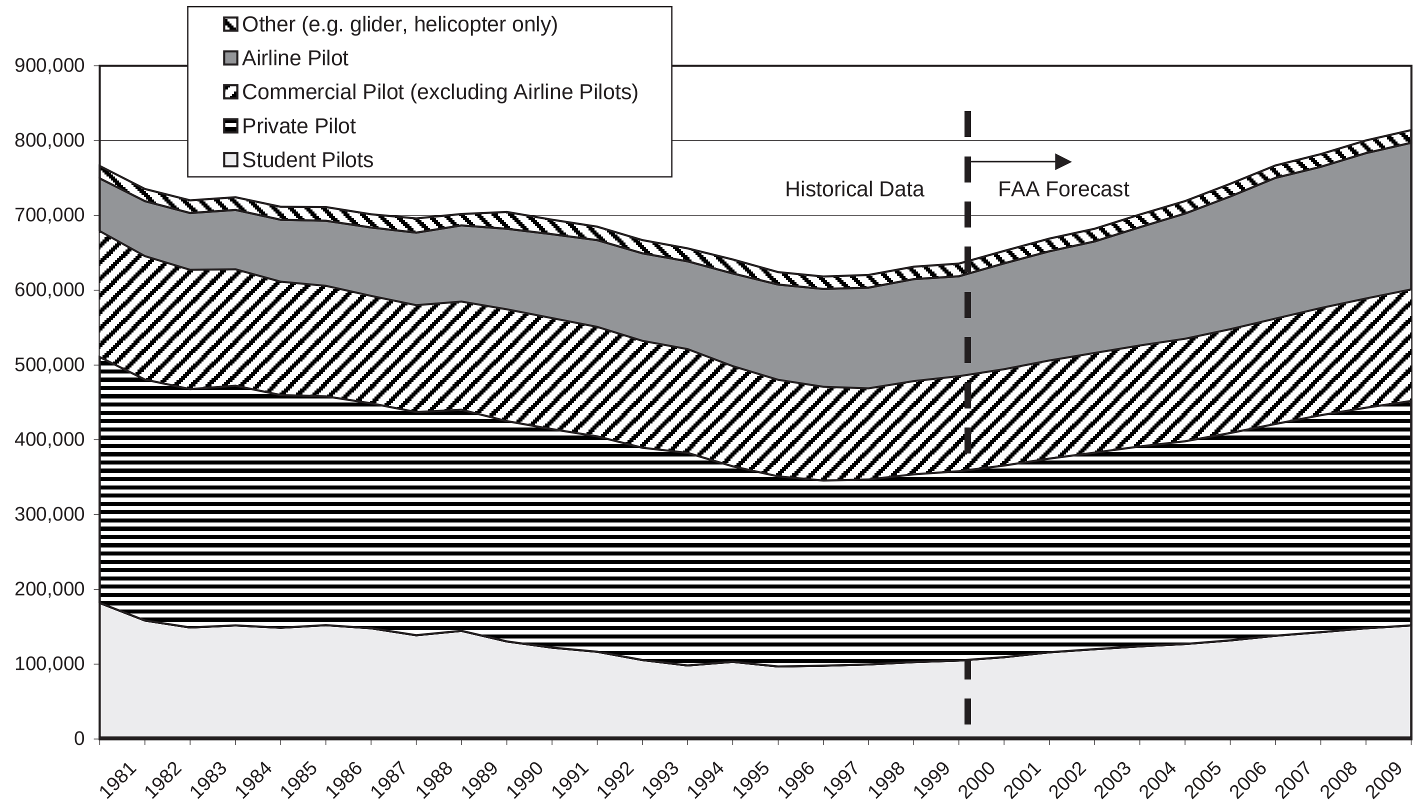


Figure 2-3 Historical trends and FAA predictions, U.S. pilot population by type, 1981–2011 (FAA 2000b).

Commercial and IFR-Rated Pilots

While the total pilot population has fallen, the number of commercial-rated pilots has continued to grow (see Figure 2-3). For the most part, these pilots have instrument ratings, which allow them to fly by referring to instruments on board the aircraft. About 15 percent of private pilots also have instrument ratings, on the basis of data from the General Aviation Manufacturers Association (GAMA 1999a, 19). The number of IFR-rated pilots has increased by about 25 percent since 1981. An instrument rating offers greater flexibility and utility, since flight plans do not have to be contingent on specific weather conditions. Pilots qualified to fly only under VFR can only operate when the cloud ceiling is no lower than 1,000 to 3,000 feet above ground level and when visibility is at least 3 miles, and they must remain clear of clouds. Because such visual conditions cannot be relied on for flight planning, professional pilots must have instrument ratings as a practical matter. Applicants for commercial pilot's licenses are now required to have an instrument rating.

Students who train 2 days per week can expect to obtain the instrument rating in about 5 months after obtaining a VFR rating, at an additional cost of $3,000 to $4,000; they first must log at least 50 hours of nonstudent VFR flying (equivalent to about $2,500 in aircraft rental). IFR-trained pilots may go on to obtain their commercial certificates, at an added expense of $2,000 to $2,500, plus 75 hours of additional IFR flying time (250 hours minimum). Commercial pilots can be compensated for their services, and many become flight instructors in order to log more hours to obtain higher-paying airline positions.

Airline Pilots

The number of pilots certified for airline operations (the air transport certificate) has continued to grow over the past two decades, both in absolute and relative terms. Airline pilots now make up about 20 percent of all pilots, compared with 8 percent in 1981 (see Figure 2-3). The air transport certificate qualifies a pilot to act as a pilot-in-command of an airline's aircraft. The pilot must be IFR-qualified and have logged 1,500 hours of flight time to become eligible to pursue the certificate. Furthermore, to operate a jet or other aircraft weighing more than 12,500 pounds, a pilot must be type rated in the particular aircraft, which can take several additional weeks of training (e.g., type training on a Boeing 737 takes 3 weeks and costs about $7,000).

Airline pilots must also pass more rigorous periodic medical exams than private and other commercial pilots. A Class 3 medical certificate is required for private pilot duties, and it must be obtained every 2 to 3 years. Every year, commercial pilots must obtain a Class 2 medical certificate, which has additional physical and mental health requirements. Air transport pilots must obtain a Class 1 certificate, which has additional requirements, every 6 months.

Pilot Forecasts

Despite the recent trend toward fewer private pilots, FAA anticipates an expanding base of pilots and predicts 20 to 30 percent growth in student and private aviators over the next decade (see Figure 2-3). It expects that continued economic growth will increase the number of people who can afford pilot training and that GA industry programs will spur interest in learning to fly.[24] FAA also anticipates that many of these new pilots will further their training and predicts an increase of 15 to 20 percent in the number of IFR-rated pilots by 2010 (FAA 2000b).

The demographic characteristics of the current pilot population, however, suggest the significant challenge involved in expanding the pilot population and bring into question FAA predictions of significant growth in the pilot population over the next decade. The average age of all pilots currently is 44 and has been increasing over time for all pilot categories; even the average age of a student pilot is 35.[25] One-third of all pilots, including student pilots, are more than 50 years old, and more pilots are 55 to 59 than are 25 to 29. The time commitment and out-of-pocket cost of pilot training, which are too high for many younger individuals, may explain this distribution. Moreover, women account for a very small share of all pilots. Despite a doubling of the number of women airline pilots from 1989 to 1998, the total number of women aviators fell by 15 percent during the period. Women now account for less than 6 percent of all pilots. Progress in expanding the demographic base of pilots beyond middle-aged men has been slow, and the obstacles to further expansion—apart from the expense and time required for training—are not well understood.

RELEVANT FINDINGS

The aviation system in the United States in general is covered in this chapter. The following points and findings from the discussion are especially relevant for analyzing the SATS concept, and they are cited again in the analyses of Chapter 4.

Small Aircraft and Their Use

- The vast majority of the U.S. civil aircraft fleet is composed of small GA aircraft. Most of these aircraft are piston-engine airplanes used mainly for personal and recreational flying. There has been a large decline in demand for these propeller airplanes over the past 20 years as the number of private pilots has fallen sharply. There is little evidence to suggest that either trend will change dramatically in the near future.
- GA manufacturers have focused their attention on meeting the needs of business aviation, producing increasingly sophisticated jet aircraft flown mostly by professional pilots. The experience of business aviation and commuter airlines indicates that travelers prefer flying on jet aircraft because of their higher levels of safety, speed, reliability, and ride comfort. Business travelers, in particular, value the fast, on-demand, and direct service that private jets can provide. Nevertheless, most business travelers fly on commercial airlines; by consolidating traffic through their hub-and-spoke systems and affiliating with commuter carriers, airlines can offer frequent service, including jet service, between many points.
- Small jet aircraft are much more expensive to produce than are small piston-engine aircraft. The smallest jets in production are 10 to 30 times more expensive than

[24] These include the "Be-A-Pilot" program, established by the General Aviation Manufacturers Association and other industry groups, which claims to have increased student starts by 14 percent since program inception in 1996.

[25] Data on pilot demographics obtained from the General Aviation Manufacturers Association (1999a, 15–19).

new piston-engine aircraft. Jet aircraft require runways that are longer (4,000 feet or more) and in better condition than do piston-engine aircraft. The higher-performing jet aircraft also require more pilot training.

Small Airport Condition, Capacity, and Use

- Approximately 5,000 airports are open to the general public for GA operations. About 3,000 of these airports have a paved and lighted runway that is at least 4,000 feet long, and about half these airports have a 5,000-foot runway. Jet aircraft require hard-surface runways and seldom operate on runways shorter than 5,000 feet. About 1,200 airports have a runway with an ILS, which allows for precision landing during low-visibility conditions.
- FAA has identified about 3,300 airports as part of the national airport system. By and large, these are the highest-quality public-use airports. About 550 of these airports are certified for commercial service, having procedures, facilities, and equipment required for safe air carrier operations. The remaining 2,750 serve only GA traffic. About 10 percent of these airports have sufficient infrastructure and services (such as ILS) to accommodate a wide range of aircraft, including small jets, under most weather conditions. These top GA airports are mainly located in major metropolitan areas and have been designated by FAA as “relievers” because they supplement the large commercial-service airports. Altogether, about three-quarters of all GA airports in the national airport system are located within 75 miles of a commercial-service airport with regular air carrier service.
- The federal government has a prominent role in airport funding. Funding is provided through the Airport and Airway Trust Fund, which is financed largely by taxes on the passengers flying on airlines; hence, a large share of the fund is used to improve infrastructure in commercial-service airports. The general philosophy of FAA is to concentrate aid for airports and air traffic control infrastructure at the most heavily used airports to ensure their safe and efficient performance.
- The airspace system is heavily used in and around the nation’s major metropolitan areas, and thus it is heavily restricted and complex. Many small airports, including most of the nation’s busiest and best-equipped GA reliever airports, are located under restricted airspace.

Small Aircraft Operations in the Airspace System

- Most of the small aircraft in the civil fleet are used primarily by private pilots for recreation. The population of private, nonprofessional pilots in the United States has declined markedly over the past 20 years, and despite recent stability there is little indication that the number of pilots will grow substantially during the next decade or longer. The large commitments of time and expense required to train for and obtain a license and to maintain proficiency are deterrents to growth in the number of private pilots; however, the full array of factors influencing pilot supply and demand are not well understood.
- An instrument rating is essential for operating aircraft as a reliable means of transportation. Proficiency in flying under instrument conditions is important for planning trips with reliability. The number of instrument-rated professional pilots has been increasing. Growth in commercial passenger and cargo activity and the use of

jet aircraft for business aviation have increased demand for professional-grade pilots. Substantially greater effort and expense are required to attain and maintain the necessary proficiency levels for piloting jet aircraft than are required for private pilots operating small, piston-engine aircraft.

REFERENCES

Abbreviations

FAA	Federal Aviation Administration
GAMA	General Aviation Manufacturers Association
NATA	National Air Transportation Association
NBAA	National Business Aviation Association
RAA	Regional Airline Association

FAA. 1989. *Aviation Forecasts Fiscal Years 1989–2000*. U.S. Department of Transportation, Washington, D.C.

FAA. 2000a. *2000 Aviation Capacity Enhancement Plan*. U.S. Department of Transportation, Washington, D.C.

FAA. 2000b. *Aerospace Forecasts Fiscal Years 2000–2011*. U.S. Department of Transportation, Washington, D.C.

FAA. 2000c. *Annual Report 2000*. U.S. Department of Transportation, Washington, D.C.

Federal Register. 2001. Vol. 66, No. 138, pp. 37,520–37,561.

GAMA. 1999a. *1999 General Aviation Statistical Databook*. Washington, D.C.

GAMA. 1999b. *GAMA Almanac: A Look at the Past 10 Years of General Aviation Production Airplane Shipments and Billings*. Washington, D.C.

NATA. 1999. *Aviation Businesses and the Services They Provide*. Washington, D.C.

NBAA. 2000. *Business Aviation Factbook 2000*. Washington, D.C.

RAA. 1999, 2000. *RAA Annual Report*. Washington, D.C.

3 Air Transportation Challenges: Enhancing Capacity, Service, Safety, and Environmental Compatibility

As discussed in Chapter 1, the Small Aircraft Transportation System (SATS) concept originated as a guide for the general aviation (GA) technology programs of the National Aeronautics and Space Administration (NASA). NASA foresees the application of advanced technologies to small aircraft to make them much easier to pilot, more reliable, safer, and less expensive to own, maintain, and operate than high-performance GA aircraft today. It envisions tens of thousands of advanced small aircraft being flown in the nation's uncontrolled airspace for personal transportation between thousands of small GA airports that are lightly used today. More than envisioning such a system, NASA is promoting it through research and technology partnerships with industry, universities, the Federal Aviation Administration (FAA), and state and local aviation authorities. The main rationale for promoting SATS is that it could help alleviate congestion and delay in the commercial aviation sector and increase transportation options for people and businesses residing in many small and remote communities with limited access to airline service.

Reducing congestion and delay in the air transportation system is a decades-long public policy goal that has become more urgent in recent years as air travel demand has escalated. Likewise, access to more reliable, convenient, and affordable air transportation has been a long-standing aim of many small communities eager to attract economic development but unable to afford or justify large public investments in airport infrastructure. The prospect of increasing aviation system capacity and coverage through advanced technologies applied to private small aircraft with minimal public infrastructure investment is appealing, but it warrants more careful review.

In this chapter, the sources and magnitude of the congestion and capacity challenges facing the air transportation industry are examined. To better judge whether SATS can help increase system capacity and reduce congestion—and thus lessen the need for future public investments to expand airport and airspace capacity—it is necessary to understand the nature of the congestion problem and the quality and coverage of the service now being provided.

The challenges facing the air transportation sector extend beyond the need to alleviate congestion and enhance service quality and coverage. Two particularly important challenges are the need to ensure air transportation system safety and environmental compatibility. The individual technologies and capabilities being furthered by NASA and its research partners have the potential to improve safety and environmental aspects of GA. Whether the envisioned system has the potential for overall improvements in the safety and environmental compatibility of air transportation, however, must be examined before concluding that the SATS concept is a desirable outcome.

In this chapter, the following four aviation challenges are reviewed: alleviating congestion and delay in commercial air transportation, improving small-community access to air transportation service, enhancing aviation safety, and ensuring aviation's environmental compatibility. This information is used in Chapters 4 and 5 to analyze the SATS concept.

CONGESTION AND DELAY IN COMMERCIAL AIR TRANSPORTATION

While ensuring security is the foremost challenge facing the aviation sector, the efficient use and allocation of the nation's airspace and airport capacity remain as long-term public policy imperatives. During the past decade, flight delays caused by system congestion and other factors have been a chronic source of frustration and cost for air travelers and the aviation industry. Delays are the most common passenger complaint received by the U.S. Department of Transportation (DOT), accounting for about 40 percent.[1] According to DOT's Inspector General, roughly one flight in four in 2000 was delayed, canceled, or diverted for reasons ranging from airport and airway congestion to severe weather and aircraft mechanical problems (DOT 2000). More than 1.3 million flights arrived late at their destinations—52 minutes late on average—adversely affecting about 160 million passengers. FAA and the Air Transport Association, which represents major airlines, estimate that airlines and their passengers incurred more than $5 billion in delay-related costs.[2]

Recurrent delays and the unpredictability of schedules in the commercial aviation system are major problems for airlines and air travelers. The growing popularity of business jets and the introduction of fractional ownership programs are attributable in part to the desire of some travelers to obtain more reliable service and, in some cases, to avoid the crowds and congestion at major airports. Whereas the incidence of delay varies by individual airport, city, and region of the country, delays in one location can have effects that cascade throughout the entire system, since aircraft and passenger flows are interconnected. Understanding the causes of delay is complicated because of the large number of possible causes and the interconnectivity of the system; nevertheless, such an understanding is essential for devising solutions.

Tracking the Incidence, Severity, and Source of Delays

To monitor the performance of its air traffic management system, FAA collects data on flight delays through its Operations Network (OPSNET). FAA personnel manually record aircraft that are delayed for 15 minutes or more relative to their planned flight times[3] after coming under FAA's air traffic control (for instance, once the pilot has requested FAA clearance to taxi out for departure). Delays are recorded for arrival, departure, and en route operations; delays attributable to an airline's own

[1] DOT *Air Travel Consumer Report*, available on DOT's website (www.dot.gov/airconsumer).

[2] See DOT's *Audit Report* (DOT 2000) and the Air Transport Association's website (www.air-transport.org).

[3] That is, relative to airline flight plan times with FAA, which may differ from the times listed in published schedules.

operations, such as aircraft maintenance, passenger boarding, or a late-arriving flight crew, are not recorded since they do not pertain to air traffic control performance. Likewise, canceled flights, from whatever cause, are not counted in OPSNET.

Using OPSNET data, FAA defines an airport as suffering from significant delays when 3 percent or more of flights in the air traffic control system are delayed on arrival or departure for at least 15 minutes. Of the 31 busiest U.S. airports (in terms of passenger enplanements) in 2000, 8 exceeded this threshold (in some instances by a wide margin), accounting for two-thirds of all OPSNET-recorded delays at these 31 airports (see Figure 3-1). The eight airports handled nearly one-quarter of total U.S. passenger enplanements in 2000 (see Figure 3-1). By FAA's measure, however, most of the country's largest airports did not suffer from recurrent delays related to air traffic control.

FAA records OPSNET delays as caused by one of five factors: (*a*) weather, (*b*) air traffic control or airport equipment problems, (*c*) closed runways or taxiways, (*d*) high flight volumes in the terminal area or regional traffic control center, or (*e*) "other." Such classifications are complicated by the fact that delays are sometimes attributable to multiple causes and contributors. For instance, when inclement weather requires changes in air traffic control procedures, high traffic volumes can leave little, if any, margin for adjustment without incurring delays that propagate throughout the system, affecting flights in locations without severe weather. Weather is in fact the main source of flight delays associated with air traffic control, causing more than two-thirds of departure and en route delays in 1999 and 1998 (see Figure 3-2). The next most common cause, high traffic volume, is the primary source of delay in 12 percent of delayed flights. Because FAA's OPSNET data do not include late flights (or flight cancellations) caused by delays in refueling, passenger boarding, baggage loading, maintenance, or other airline-related activities, the data do not fully reflect the experience of travelers. To derive a more complete picture of delays at the nation's largest airports, DOT compares actual departure and arrival times with those published in airline schedules. Flights are reported as delayed when they do not pull back from the gate within 15 minutes of the scheduled departure time or to the gate within 15 minutes of scheduled arrival time. Although airlines have increased the time shown between arrivals and departures ("block times") in their published schedules to better reflect actual experience, the DOT data show how airports differ in the incidence of delay. Whereas FAA's OPSNET data indicate that delays affect 1 to 10 percent of operations at most large airports, the on-time performance data collected by DOT indicate that delays affect 15 to 30 percent of flights.[4] These data suggest that air traffic control and capacity shortcomings account for only a portion of delays and that other factors, including airline operations, are important causes. Hence, improvements in airport infrastructure and air traffic control performance could reduce delays but would not affect all—or even most—flight delays.

The use of hub-and-spoke systems affects the incidence and severity of delays. Although these systems have proved to be highly efficient in configuring air transportation networks, they contribute to the strains placed on the national airspace

[4] See April 2001 release of DOT's *Air Travel Consumer Report,* available on DOT's website.

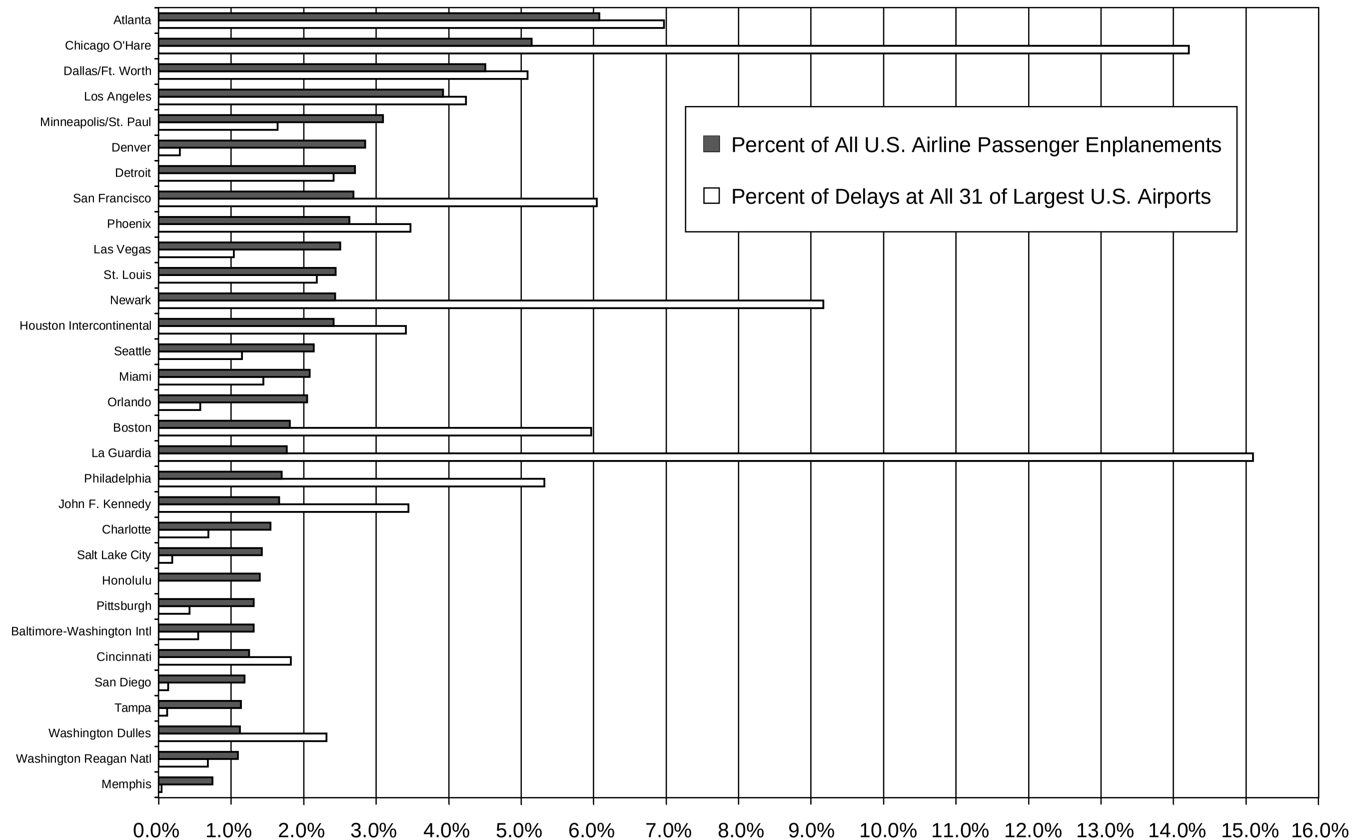


Figure 3-1 Flight delays and passenger enplanements at 31 busiest U.S. airports, percent of total by airport. (Source: FAA 2001.)

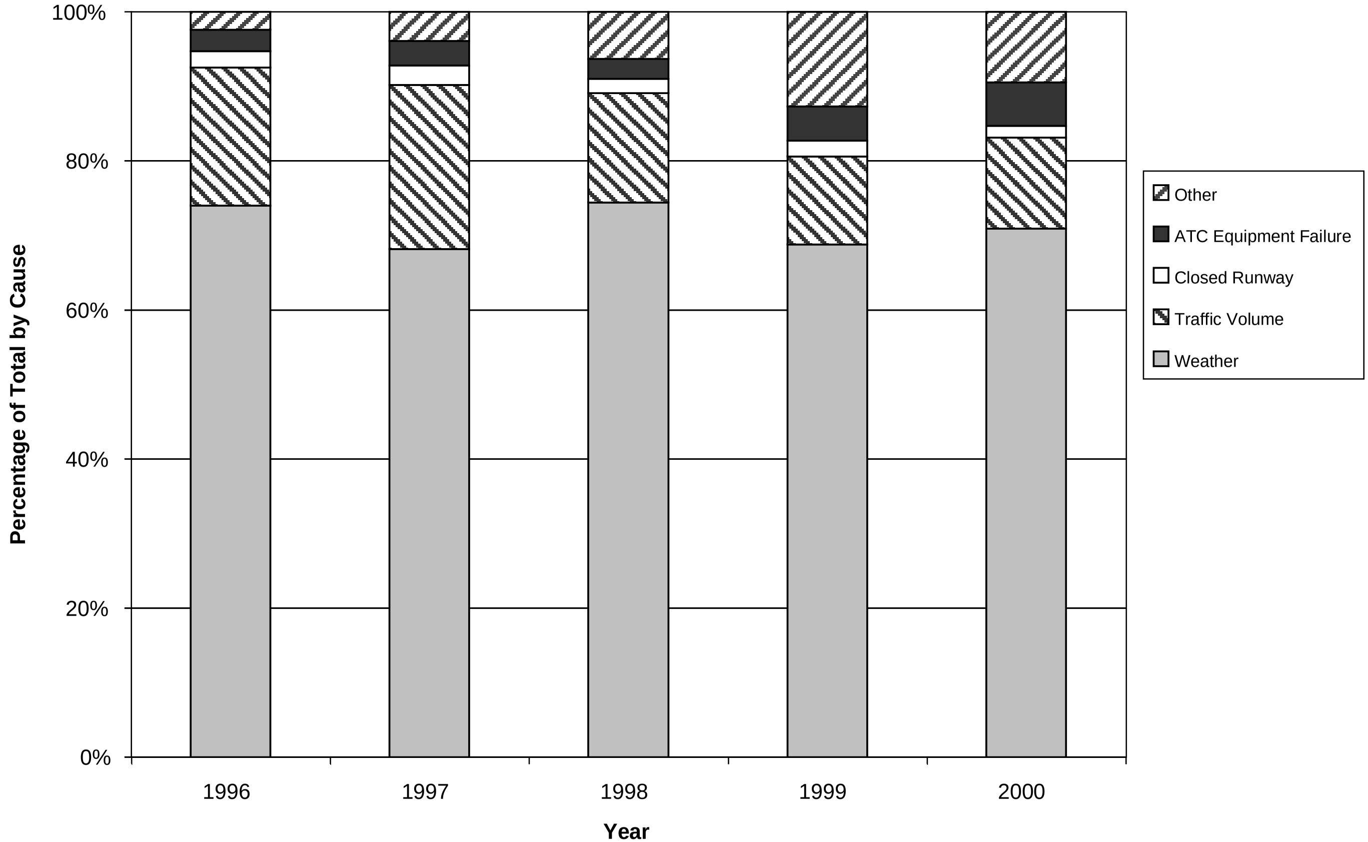


Figure 3-2 Causes of flight delays in the national air traffic control system, 1996–2000.
[Source: OPSNET data (FAA 2000a).]

system, particularly at some of the major hub airports that serve as transfer points for much of the traffic in the system. As explained in Chapter 2, nearly all airlines funnel most of their flights and passengers through a small number of large hub airports. The largest transfer hubs handle more than 2,500 departures and landings and enplane more than 75,000 passengers per day. Indeed, on any given day, about 30 percent of all people flying on domestic airlines will arrive or depart on a flight at one of four airports: Chicago O'Hare, Los Angeles, Dallas–Fort Worth, or Atlanta. About 150,000 travelers begin or end their trips at one of these airports each day (representing 13 percent of all passenger trips), and another 210,000 pass through them on their way to other destinations.

The occurrence of these clustered transfers, known as connecting banks, creates an uneven distribution of demand on the hub airports. Flights arrive and depart in waves that can exceed runway, taxiway, gate, and air traffic control capacity, especially if combined with inclement weather or other conditions that restrict capacity. Figure 3-3 shows the fluctuation in morning arrivals at Dallas–Fort Worth. Many of the peaks, occurring in 15- to 30-minute intervals, exceed optimal throughput capacity, which can force some arrivals to be delayed to nonpeak times. When runway capacity is severely diminished at a large hub airport, air traffic controllers often institute "ground holds" that can delay aircraft departing from scores of other airports.

Challenges

Since 1990, the number of domestic airline enplanements has increased by more than 40 percent. FAA expects airline passenger traffic to grow another 1.5 to 5.5 percent per year in the nation's largest airports over the next 15 years, resulting in a 40 percent increase in total passenger enplanements by 2015 (FAA 1999; FAA 2000b). Likewise, the number of airline operations managed by traffic control towers is expected to rise by 30 percent in total and at even higher rates at several major airports, such as Atlanta, Minneapolis, Las Vegas, and Seattle.

Escalating passenger traffic raises the prospect of greater demands on scarce runway space at major airports and on air traffic control, which could exacerbate system congestion and delay. It is important to recognize, however, that worsening aviation congestion because of traffic growth has been a concern for decades and that the aviation system has, by and large, responded without crises. Severe congestion at Washington's National, Chicago's O'Hare, and New York's John F. Kennedy and La Guardia Airports during the late 1960s prompted the federal government to limit the number of daily landings and takeoffs at these airports. Airports elsewhere have been able to adapt without such artificial restraints because of continued enhancements in their operational capabilities and those of air traffic control and airlines. In the meantime, airports in fast-growing cities like Orlando, Las Vegas, and Charlotte have become major points of origin and destination, absorbing much of the growth in the system, which handles four times more passengers today than it did 30 years ago.

Future strategies for enhancing system capacity to meet growing traffic demand are likely to center on the removal of chronic bottlenecks in the system, which would be achieved through targeted improvements in airport infrastructure, air traffic control

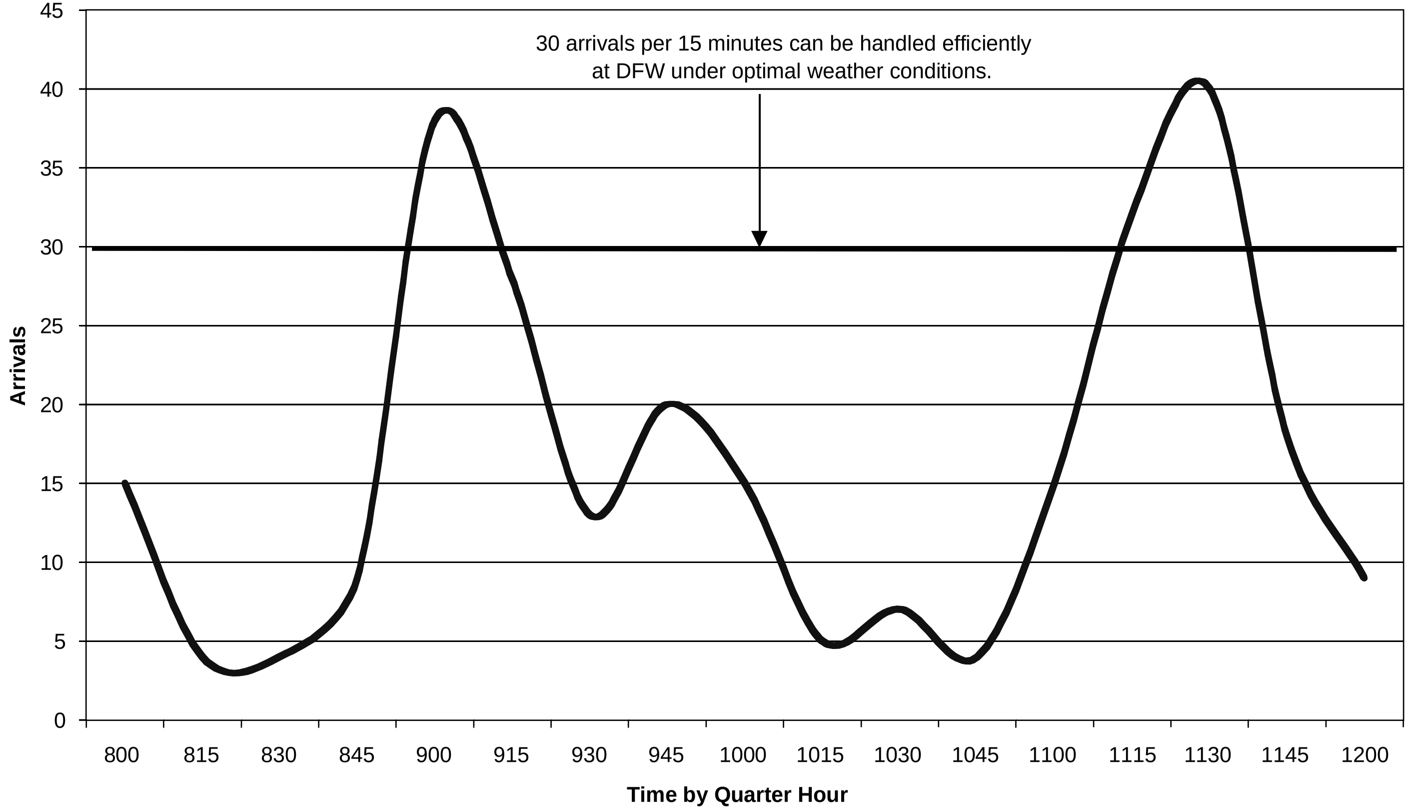


Figure 3-3 Distribution of morning flight arrivals at Dallas–Fort Worth (DFW) International Airport.
(Source: FAA 2000a.)

capabilities and procedures, and airline operating practices.[5] For example, increasing runway capacity at San Francisco International Airport (SFO), one of the busiest airports in the country, would do much to reduce flight delays throughout the system. SFO, which suffers from one of the highest occurrences of delay among major airports, accommodates about the same number of airline operations per year as Pittsburgh (PIT); yet PIT, which suffers relatively little delay, can handle many more operations per hour (see Figure 3-4). A particular problem for SFO is that it loses nearly one-third of its runway capacity during inclement weather, which is a frequent occurrence. FAA expects passenger traffic at SFO to grow by more than 60 percent during the next 15 years; hence, addressing its capacity problems—as well as those of several other large airports with similar problems—is considered critical to controlling the incidence and severity of delays in the wider system.

One of the most effective ways to increase national airspace capacity is to construct additional runways and associated taxiways and gates in those heavily used airports in which limited infrastructure capacity is a recurrent problem. Runway investments have the greatest potential to reduce congestion and delay in high-demand airports prone to adverse weather patterns that can severely restrict use of existing runways because of their configuration, geometry, length, and other characteristics. However, new runways are expensive to build and difficult to modify once built. The construction of new runways at major airports has proved to be a costly and time-consuming process, largely because of noise and environmental concerns, as well as the lack of sufficient land at some older, urban airports. These difficulties have prevented all but seven major airports from adding new runways during the past 10 years.

The redesign of airspace and the modification of air traffic control procedures and technologies are other options being pursued by FAA for enhancing capacity at the bottlenecks. For instance, consideration is being given to increasing capacity by modifying air traffic control rules and technologies affecting approach procedures during instrument conditions. Because safety is the paramount concern, the focus of air traffic control is on separating aircraft in time and space.[6] These traffic spacings—which are designed to reduce the adverse safety effects of wakes in good and bad weather—are more often applied during inclement weather, when air traffic controllers do not give pilots visual clearances. As a practical matter, the spacings tend to reduce runway capacity at some busy airports. Inclement weather can also limit the simultaneous use of parallel runways, which can substantially reduce operational capacity at some major airports.

Certain improvements in air traffic control technologies and procedures are being advocated because of their purported ability to increase the capacity of terminal airspace

[5] FAA's Airport Capacity Benchmarking and National Choke Points initiatives are both examples of the agency's intentions to enhance capacity through targeted improvements in airports and air traffic control operations.

[6] Traffic in terminal airspace, where aircraft are moving more slowly, must be separated from other aircraft by at least 3 miles and 1,000 feet. The specific separation minima depend on the type of aircraft in the queue, considering aircraft design, performance characteristics, and weight. For instance, to protect smaller and slower planes from wake turbulence and because of different runway occupancy times, the in-trail arrival separations between small and large aircraft must be greater than those for two large aircraft with comparable characteristics.

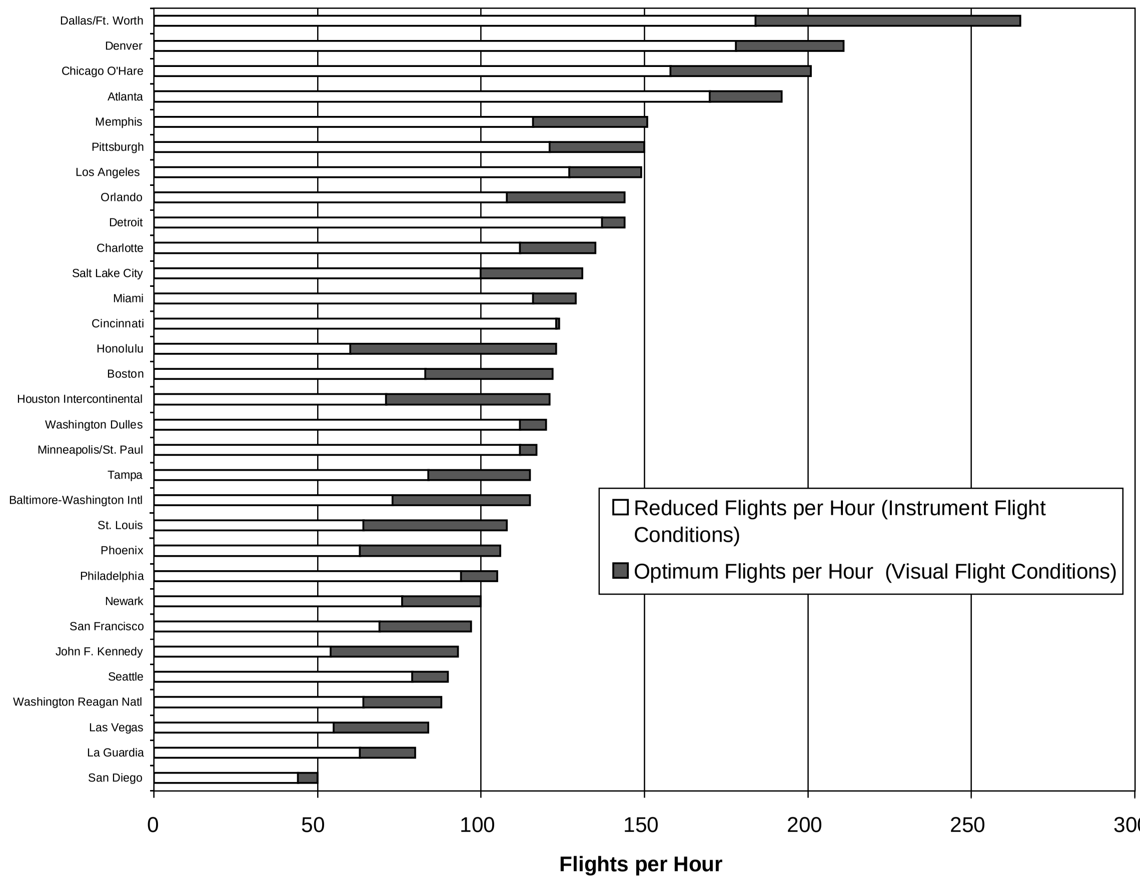


Figure 3-4 Capacity benchmarks for 31 largest U.S. airports. (Source: FAA 2001.)

and airports under optimal and reduced visibility without impairing safety. These include Automatic Dependent Surveillance-Broadcast (ADS-B, mentioned in Chapter 2) coupled with cockpit displays of traffic information, which can help the pilot maintain desired separation more precisely; tools that assist the controller in better assigning runways and sequencing aircraft; and radar systems that permit simultaneous instrument approaches on parallel runways. Such changes offer the potential for only incremental improvements in capacity at most airports and terminal areas. Nevertheless, FAA believes they could increase capacity by 10 percent or more in several important airports with significant delay problems, such as Newark, La Guardia, and Philadelphia (FAA 2001).

Finally, despite overall growth in traffic, the airspace system often has excess capacity during much of the day. Volume-related congestion and delays at airports tend to occur during the most convenient arrival and departure times. La Guardia, for instance, is heavily used by business travelers, who tend to prefer flights arriving and departing during the most convenient morning and evening hours. To increase travel flexibility, they also prefer departure and arrival options at frequent intervals during these peaks. Airlines, competing with one another for high-fare business travelers, have learned to schedule flights at close intervals at La Guardia, often using smaller jets (such as 60-seat regional jets) because they are economical for such service. The tendency to increase schedule density at peak times, however, has exacerbated congestion at this capacity-constrained airport, which is the most delay-ridden in the country (see Figure 3-1).

Similar problems occur in San Francisco, Boston, Philadelphia, and other business markets. Thus, it is clear that an understanding of the nature of the demand for air travel is necessary to address the factors that contribute to congestion and delay. Demand management techniques to smooth the peaks and valleys in use are increasingly being considered as options for relieving chronic congestion at high-demand airports with limited capacity. Though they may not be practical or politically feasible today, the use of congestion-based landing fees and other economic incentives may become more acceptable over time to relieve congestion and reduce costs resulting from travel delay.

Relevant Findings

Recurrent delays in airline flights have prompted much debate about how to alleviate this problem and make air travel more reliable and convenient for passengers. Sharp growth in demand for air travel has contributed to congestion and to the flight delays and schedule disruptions that ensue. Because more people are flying, more are affected by canceled, delayed, and diverted flights. It is important to recognize, however, that most large commercial airports and nearly all smaller airports are not congested and have much idle capacity. Sustained growth in passenger traffic can be accommodated throughout much of the system.

Ameliorating congestion that occurs repeatedly at particular airports is critical to alleviating flight delays that propagate widely. Improvements in airport runways, air traffic control procedures and technologies, and demand management techniques are the most likely remedies for congestion problems at these bottlenecks. Such improvements would have positive effects on the incidence and severity of delays throughout the system. Congestion, however, is not the source of all flight delays and schedule disruptions. Many of the delays experienced by travelers are caused by airline practices, equipment problems, labor actions, and other factors, including severe weather, and are unrelated or only indirectly linked to traffic volume.

SMALL-COMMUNITY ACCESS TO AIR TRANSPORTATION

Ever since the emergence of aviation as a mode of intercity transportation during the 1930s, rural and small communities located far from major urban airports have expressed concern about having limited access to air transportation and the benefits that such service can confer. To address these concerns, the federal, state, and local governments have taken steps to foster air service in small communities, whether through subsidization of scheduled airline service or the provision of aid for improvements in small-airport infrastructure.

Early in the development of commercial aviation after World War II, it was widely believed that subsidies were necessary for air service to be extended to communities too small to generate sufficient traffic volumes to attract airlines. Accordingly, the federal government, which then regulated airline fares and service areas, approved the establishment of several local-service airlines (e.g., Piedmont, Ozark, Frontier) to provide supplemental service between small communities and large airports served by the mainline carriers. The local carriers used revenues generated on their most profitable feeder routes, to which they were given exclusive rights, to cross-subsidize required service on low-volume routes. The regulated carriers, however, often scheduled flights in the smallest markets at inconvenient times and intervals so they could use the equipment on profitable routes during the peak periods (Meyer and Oster 1984). On the eve of airline deregulation in 1978, about 150 communities were receiving service from local-service carriers, often by jet airliners, as required by federal regulators.

Once deregulated and given the freedom to adjust their route systems and compete with larger airlines, most local-service carriers moved their larger jet aircraft to mainline routes and abandoned the unprofitable smaller markets. Regional and commuter airlines, however, quickly filled most of the service vacancies by using lower-cost turboprop airplanes. Within a few years after deregulation, more than 100 regional and commuter airlines, most nonexistent a decade earlier, were offering scheduled air service in hundreds of small, medium, and large airports. Moreover, Congress, concerned about the potential withdrawal of airline service from small communities, established the Essential Air Service (EAS) program in the wake of deregulation. More than 100 small communities located farther than 75 miles from a larger commercial-service airport were eligible for the program, which provided federal subsidies to commuter airlines to provide minimum levels of scheduled service.

Small-Community Service Today

The EAS program continues today; about 80 airports receive subsidized scheduled service. Altogether, commuter airlines serve more than 500 airports across the country, most of which receive no public subsidy. As explained in Chapter 2, most of the more than 500 commercial-service airports in the United States are served primarily by commuter airlines that operate a mix of turboprops and regional jets. In the smallest 200 of these airports, the commuter airlines provide between 4 and 16 flights per day, mostly using 20- to 30-seat turboprops. Most flights of most commuter airlines are into or from one or two hub airports. About 3 percent of all passenger trips by commercial airline originate at airports that do not offer large-jet service, and about 1 in 10 of these trips originates in the very smallest 200 commercial airports (see Figure 3-5).

The emergence of airline hub-and-spoke systems has been the most significant factor in increasing small-community air service during the past two decades. Small cities linked as “spokes” in these networks derive significant benefits by being connected, via the hubs, to hundreds of other cities, large and small. And the larger a hub-and-spoke system grows, the more likely it is to encompass more small cities. This outcome is the result of the creation of thousands of city-pair markets in large networks; thus, even small cities with limited passenger traffic to any one destination may generate sufficient traffic to support scheduled flights carrying passengers through the hub to numerous final destinations. Although each city-pair market by itself will have little passenger traffic (perhaps only a handful of passengers per year), the large number of points in the network raises the total volume of traffic.

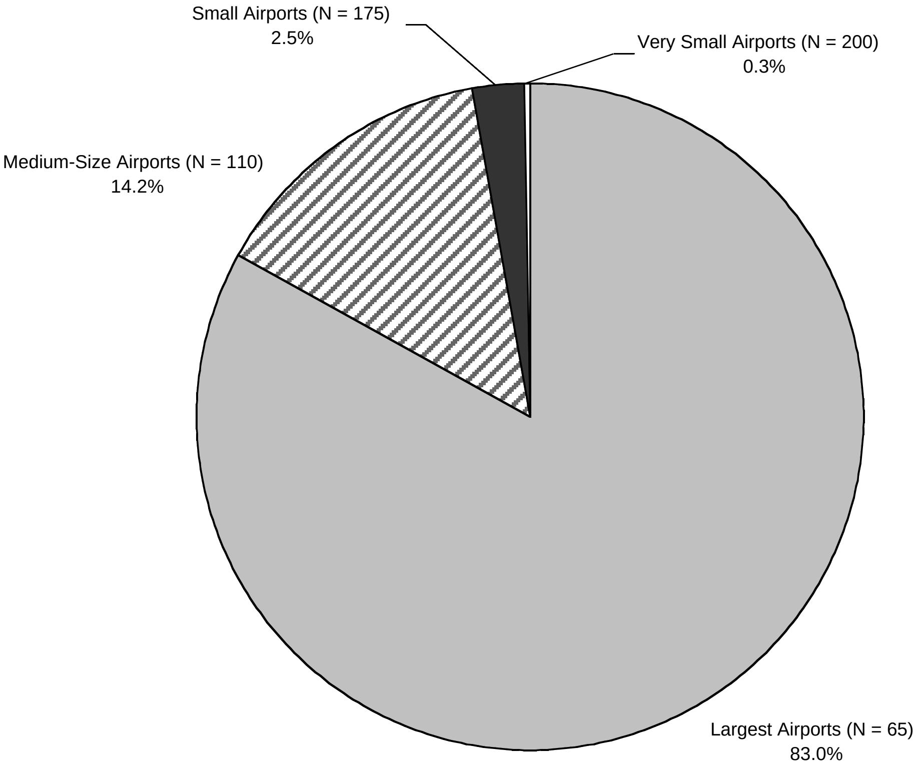


Figure 3-5 Percent of all airline passenger trips originating from commercial airports of varying size. (Data sources and definitions are provided in Table 4-3.)

Moreover, the increased traffic volume can make it economical for the airline to schedule additional flights to and from small cities and to introduce regional jets, which can attract even more travelers because of the increased speed, safety, and comfort of travel.

Challenges

Although most evidence suggests that small markets are, in general, better served today as a result of hub-and-spoke systems, not all small communities and travelers in small markets are satisfied with the service they receive. The need to change airplanes at hubs in order to access most destinations—even those 200 or 300 miles away—is a drawback because such connections make the travel time from origin to destination much longer than would be the case for a nonstop flight. Whereas the hub-and-spoke system allows for increased flight frequencies and creates more city-pair options through connections, more time is spent waiting in transit and flying on more circuitous routings. To illustrate, Table 3-1 shows the service from five small airports to the largest cities located within 300 miles and at a distance of 301 to 500 miles. In all cases, the largest city within 300 miles is a large hub airport, and travelers in these small communities tend to have frequent and fast service to these hubs (usually 4 to 16 departures per day). In contrast, none of the five small cities has nonstop service to the largest city that is between 301 and 500 miles distant. For these longer trips, all air travelers must change planes at the hub airport. Although travelers have many flights to choose from during the day, the elapsed travel time required for the connecting service greatly reduces average travel speeds from origin to final destination in most cases.

Another source of dissatisfaction for travelers in some small communities is that they must travel to other small communities or nearby larger cities for airline service, largely because it is often uneconomical for an airline to serve multiple airports that are near one another or to serve very small communities that cannot provide minimum traffic volumes. There are more than 1,200 cities in the United States with a population of 20,000 or more (Gaguin and Littman 1999). In addition, about 350 of the nation's 3,100 counties have a population of 50,000 or more. Many of these counties and cities are adjacent, and they often share an airport with scheduled air service because of the economies that such consolidation can generate. To illustrate, the southern Texas cities of Brownsville, Harlingen, and McAllen are comparable in population and are located within 60 miles of one another. They each have an airport with scheduled service; however, centrally located Harlingen has large-jet service and enplanes more passengers than the other two airports combined.[7] By concentrating operations and passenger flows, the airlines are able to use larger aircraft, offer more frequent service and lower fares, and provide more extensive airport facilities to the benefit of all travelers in the region. In contrast, more remote smaller cities and counties, such as Elko, Nevada (which is more than 250 miles from the nearest large city), tend to have scheduled commuter service at their local

[7] This information is based on TRB analyses of DOT's quarterly survey of airline passenger tickets (Databank 1A) for the second quarter of 1999.

Table 3-1 Scheduled Flight Options from Five Small Cities to Larger Cities

Origin to Destination (Small City to Large City)	Average No. of Passengers (True O-D) per Day Each Way	No. of Scheduled Flights per Day (Each Way)	Average Elapsed Time (Scheduled)[a]	No. of Flight Segments[b]	Aircraft Equipment	Average Speed (mph) for Trip (Origin Airport to Destination Airport)
Destination City Is Largest City Within 300 Miles of Small City[c]						
Brunswick, GA, to Atlanta (238 miles)	23	4	1:20	1	EM2 (turboprop)	179
Chico, CA, to San Francisco (153 miles)	9	5	0:59	1	EM2 (turboprop)	155
Elko, NV, to Salt Lake City (200 miles)	19	6	0:59	1	EM2 (turboprop)	212
LaCrosse, WI, to Chicago (215 miles)	16	4	0:58	1	ERJ (jet)	222
North Platte, NE, to Denver (227 miles)	1	4	1:06	1	BE1 (turboprop)	206
Destination City Is Largest City Between 301 and 500 Miles of Small City[c]						
Brunswick, GA, to Miami (383 miles)	1	4	4:19	2	EM2/B-767	89
Chico, CA, to Los Angeles (446 miles)	8	4	3:15	2	EM2/B-737	137
Elko, NV, to Los Angeles (496 miles)	4	6	3:49	2	EM2/B-757	130
LaCrosse, WI, to Detroit (416 miles)	7	10	3:32	2	EM2/B-757	118
North Platte, NE, to Minneapolis (459 miles)	1	3	4:16	2	BE1/733	108

NOTE: To illustrate, travelers in Brunswick have four flights to Atlanta to choose from each day. An average of 23 travelers fly from Brunswick to Atlanta as their final destination. The nonstop flight, on a turboprop, takes an average of 1 hour 20 minutes. On average, one person flies from Brunswick to Miami each day. The traveler has four flights to choose from, all connecting to a hub airport. The first leg is on a turboprop, and the second leg from the hub to Miami is on a Boeing-767 jet. The total trip time averages 4 hours 19 minutes.

[a] For trips from the small city to the largest city within 300 miles, this is the time scheduled for the flight. For trips from the small city to the largest city between 301 and 500 miles of the small city, this is the time scheduled for the entire trip.

[b] A trip with two flight segments requires one connection.

[c] Great circle miles.

SOURCES: Official Airline Guide (www.oag.com) and Databank 1A (U.S. Department of Transportation).

airports. Indeed, most remote small communities with at least 20,000 people generate sufficient traffic to support commuter airline service.

The concentration of commercial air traffic in roughly 500 airports in the United States generally represents an efficient use of airport infrastructure investments. The need for accessible and convenient service is reasonably well balanced with the advantages of consolidating passenger flows into a limited number of airports. The provision of air service to more airports in a region would undoubtedly require more infrastructure investments to upgrade the airports to achieve desired levels of safety, security, and service. The resulting lower passenger volumes at each airport would make such investments difficult to justify and finance.

Nevertheless, some small cities lacking airline service at their local airport worry that economic development will be hindered, even if such service is available within the region. Consequently, many have made significant investments in their local airports to accommodate GA business aircraft and even to attract scheduled airlines. As discussed in Chapter 2, there are about 3,300 airports in the national airport system, including about 2,800 that serve only GA. About three-quarters of these airports, however, are located within 75 miles of a commercial-service airport with 100,000 or more passenger enplanements per year, while most of the rest are located in rural areas with limited populations. As a practical matter, few of these 2,800 airports are candidates for regular air service.

The two-decade-long experience with the federal EAS subsidy program, which is designed to foster airline service in small cities, itself raises questions about the relationship between economic development and airline service. While EAS cities have received subsidized commuter airline service for years, most average only a handful of passengers per day, even with subsidies that average between $100 and $300 per passenger.[8]

Relevant Findings

More than half the commercial airports in the United States are in small cities that receive scheduled air service through commuter airlines. For the most part, this service is oriented toward providing feeder traffic to larger airports served by major airlines operating national hub-and-spoke route networks. Travelers in small markets benefit from the connecting service these hubs provide to hundreds of destinations. By funneling more passengers through the larger hubs, the commuter airlines can offer more frequent flights and use larger aircraft, to the benefit of the small-community traveler.

Airlines have learned to balance the public's desire for convenient and accessible local air service with the desire for lower fares, more frequent flights, faster and more comfortable aircraft, and amenities and services at airports. Many small local airports, therefore, do not have scheduled airline service because it is more efficient to concentrate flights and passenger flows in one or two regional airports, usually within a

[8] For a complete listing of EAS communities and data on the subsidy amounts and passenger enplanements at each community's airport, see Senate Report 106-309, Department of Transportation and Related Agencies Appropriations Bill, 2001 (June 14, 2000), pp. 16–21. According to these data, the average EAS subsidy in FY 2000 was $195 per passenger, and 80 EAS airports averaged fewer than 10 passengers per day.

50- to 100-mile drive. By concentrating passenger traffic in a regional airport, airlines can schedule more frequent flights on larger aircraft and offer lower fares. In contrast, remote small cities with at least 20,000 residents tend to have scheduled airline service at their local airports, since larger airports are too distant to be competitive.

Because business travelers place a high value on time, some small communities without scheduled air service worry that other cities in their region with such service have an advantage in competing for businesses and economic development. Spreading passenger traffic over many small airports in a region, however, could lead to no single airport having sufficient traffic volumes to support frequent and comfortable air carrier service or minimum safety services, passenger facilities, or other amenities.

CIVIL AVIATION SAFETY

Aviation safety has improved markedly over the past 40 years. However, a gradually declining accident rate can still yield an increase in the absolute number of accidents because of growth in the number of flights. Since the use of jet aircraft became widespread in the 1960s and as more safety-oriented regulations, procedures, and technologies have been introduced, the aviation accident rate has declined sufficiently to keep the total number of accidents in check. Nevertheless, each air transportation crash is a high-profile event and influences the public's perception of aviation safety. Hence, continued progress in reducing accident rates is critical to ensuring public confidence in the system.

The National Transportation Safety Board (NTSB) investigates all civil aviation accidents, including all GA accidents that involve a death, serious injury, or substantial damage.[9] In this section, trends in commercial aviation and GA safety as indicated by NTSB data are reviewed, along with the factors cited as causing and contributing to accidents. As is noted, pilot performance is a major factor in aviation accidents, especially in GA. Reducing pilot error as a source of accidents in GA and bringing GA safety performance closer to that of air carriers are long-standing challenges.

GA Safety

Trends

In 2000, GA aircraft, excluding air taxis, were involved in 1,835 accidents, including 341 that led to 592 fatalities.[10] The GA accident and fatal accident rates were 6.0 and 1.1, respectively, for every 100,000 hours flown—the lowest rates ever. The improvement was not an aberration; the GA accident rate has declined steadily during the past two decades. From 1975 to 1978, the accident rate hovered above 12.0 per 100,000 flight hours; since 1989 it has been under 9.0 every year, and since 1996 it has not risen higher than 7.7 (see Figure 3-6). Likewise, the fatal accident rate has declined from an average of more than 2.0 during the late 1970s to less than 1.5 during the past 5 years.

[9] According to NTSB, "substantial damage" means any damage or failure that affects the structural strength, performance, or flight characteristics of the aircraft and that would normally require repair or replacement.

[10] The data referred to in this section are from NTSB's review of aircraft accident data for 1997 (NTSB 2000) and NTSB online data reports (www.ntsb.gov).

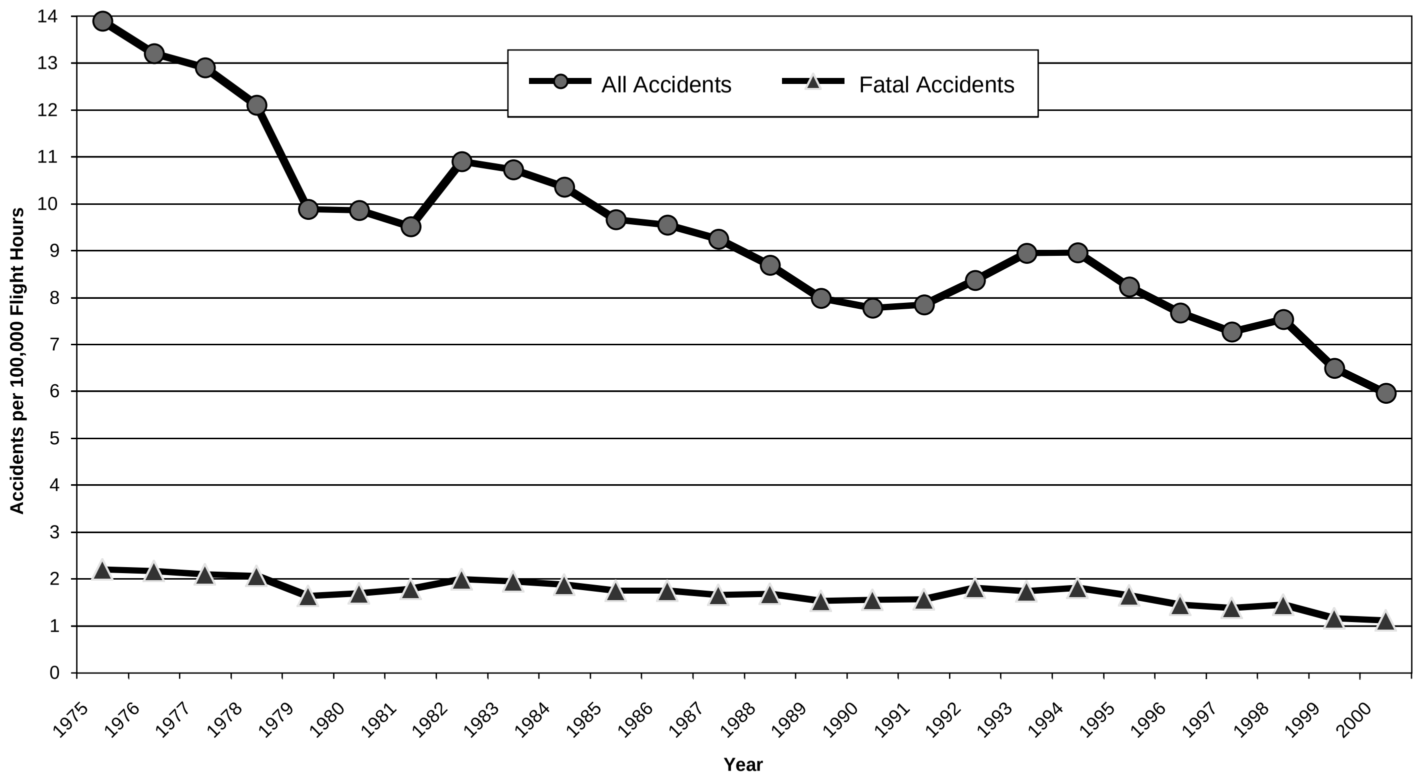


Figure 3-6 Trends in GA accident rates, 1975–2000. Note: flight hours are estimated by FAA. Accidents per departure (as opposed to accidents per flight hour) are not available because of limited data on GA departures. [Sources: NTSB 2000; NTSB online Table 10 (www.ntsb.gov/aviation/Table10.htm).]

Accident Occurrences

The most recent detailed compilations of NTSB aviation accident investigations is for 1997. A large majority of GA accidents that year (as in all previous years) involved single-engine piston airplanes, which accounted for three-quarters of all GA accidents. These aircraft, which also comprise a majority of the GA fleet, averaged 8.1 accidents per 100,000 flight hours, which was the highest among all fixed-wing aircraft. Turboprop and turbofan jet airplanes averaged 4.5 and 1.1 accidents per 100,000 flight hours, respectively. Rotorcraft had the highest accident rates, in part because these aircraft have the shortest flights and the highest ratio of landings and takeoffs (when many accidents occur) per hour flown.

About 60 percent of all accidents and two-thirds of fatal accidents involved aircraft used for personal flying. Instructional flights accounted for about 15 percent of accidents, followed by aerial applications (such as crop dusting), which accounted for 6 percent. About 4 percent of accidents involved business-related flying, excluding corporate flights. Private aircraft used for corporate transportation, which are almost always operated by professional flight crews, accounted for fewer than 1 percent of GA accidents, and their accident rates were 10 to 20 times lower than those of GA as a whole.

Altogether, student and private pilots accounted for more than half of all accidents in 1997. Commercial pilots flying GA aircraft, who log many more flight hours than private pilots, accounted for about 45 percent of accidents.

Accident Causes and Contributing Factors

For the 5-year period 1993 to 1997—the most recent period for which NTSB has published detailed time-series data—NTSB cited probable causes and contributing factors in more than 9,700 GA accidents, including 1,885 with fatalities. Such determinations, as NTSB notes, require many assumptions and judgments, since the events leading up to an accident are often difficult to reconstruct. Because pilot decisions affect the course and severity of most aviation accidents, pilot performance is frequently cited as an accident cause or a contributing factor. Indeed, NTSB cited pilot performance as a causal or contributing factor in 82 percent of all GA accidents from 1993 to 1997. By comparison, the environment and aircraft were cited as factors in 45 and 40 percent of GA accidents, respectively.

Weather is the most significant environmental factor contributing to GA accidents, although it is seldom cited as a "cause," under the presumption that pilots are trained to make safe decisions when operating in inclement weather. In 1997, weather was a contributing factor in 20 percent of all GA accidents investigated by NTSB, including nearly one-quarter of fatal accidents. Fog and low ceilings were the most commonly cited adverse weather conditions.

Through its Safer Sky Program, FAA is working to identify and address the highest-priority accident causes such as runway incursions, controlled flight into terrain, weather, and uncontained engine failures. The idea is to use NTSB reports and other accident and incident data more systematically to identify the more common accident problems, causes, and precursors in order to determine how best to allocate agency safety resources.[11]

[11] See the FAA website for more information on this initiative (www.faa.gov/apa/safer_skies).

Air Carrier Safety

NTSB compiles accident investigation records for air carriers according to type of service: large carriers, scheduled commuter airlines, and air taxis.[12] Over the past dozen years, large carriers have had the lowest accident rates, which have ranged from 0.15 to 0.40 per 100,000 hours flown, while the fatal accident rate has ranged from 0.02 to 0.10.[13] Because many commuter airlines are affiliated with major airlines and use some of the same kinds of equipment, their accident records have recently been grouped with those of larger airlines, making it difficult to distinguish any differences in accident patterns or trends. In general, however, air taxis, which provide unscheduled air service using smaller GA aircraft, have the highest accident rates among certificated air carriers. Between 1989 and 2000, air taxis had 80 to 160 accidents per year; the number involving fatalities ranged between 38 and 83 per year. Over this span, the air taxi industry has averaged about 3.8 accidents per 100,000 hours flown, including 1.0 fatal accidents. Accident rates for air taxis, therefore, have been about half of those for GA as a whole but higher than those of corporate aviation (see Figure 3-7). It is important to note that many air taxis (unlike corporate aircraft) operate in Alaska, which has an operating environment (e.g., terrain, weather, landing facilities) that is much more challenging than elsewhere in the country; hence, about one-third of all air taxi accidents occur in Alaska.

In a compilation of air carrier accidents spanning 1986 to 1996, NTSB cited airline pilot performance as a causal or contributing factor in 32 percent of the 287 large-carrier accidents. The performance of other persons outside the aircraft (such as maintenance workers and air traffic control personnel) was the most frequently attributed factor, cited in 42 percent of accidents; weather conditions were attributed in 30 percent of accidents. The pilot was cited as a factor in a much higher share of air taxi accidents during the period—75 percent of the more than 1,000 air taxi accidents investigated.

Challenges and Relevant Findings

Individual aviation accidents can significantly affect the public's overall perception of aviation safety. As air travel has grown over the past 40 years, both the rate and the number of civil aviation accidents have declined, tending to raise public confidence in aviation for transportation. Accident rates have declined for both commercial aviation and GA, although rates for the former remain much lower. The experience in both sectors is that professionally piloted aircraft used in transportation, often turbine aircraft, have far lower accident rates than aircraft flown by private pilots.

Pilot performance is a more significant factor in GA accidents than in commercial airline accidents. Whereas crew factors generally appear in a minority (though still large percentage) of airline accidents, they account for a large majority of GA and air taxi accidents. It is noteworthy that airline and corporate aircraft, which have the lowest accident rates, are typically two-pilot operations, unlike most GA and air

---

[12] The "large carrier" grouping includes major passenger and cargo airlines with scheduled service, as well as any other carriers using large aircraft for scheduled and charter passenger or cargo service.

[13] The data referred to in this section are from NTSB's review of aircraft accident data for 1996 (NTSB 1999) and NTSB online data reports (www.ntsb.gov).

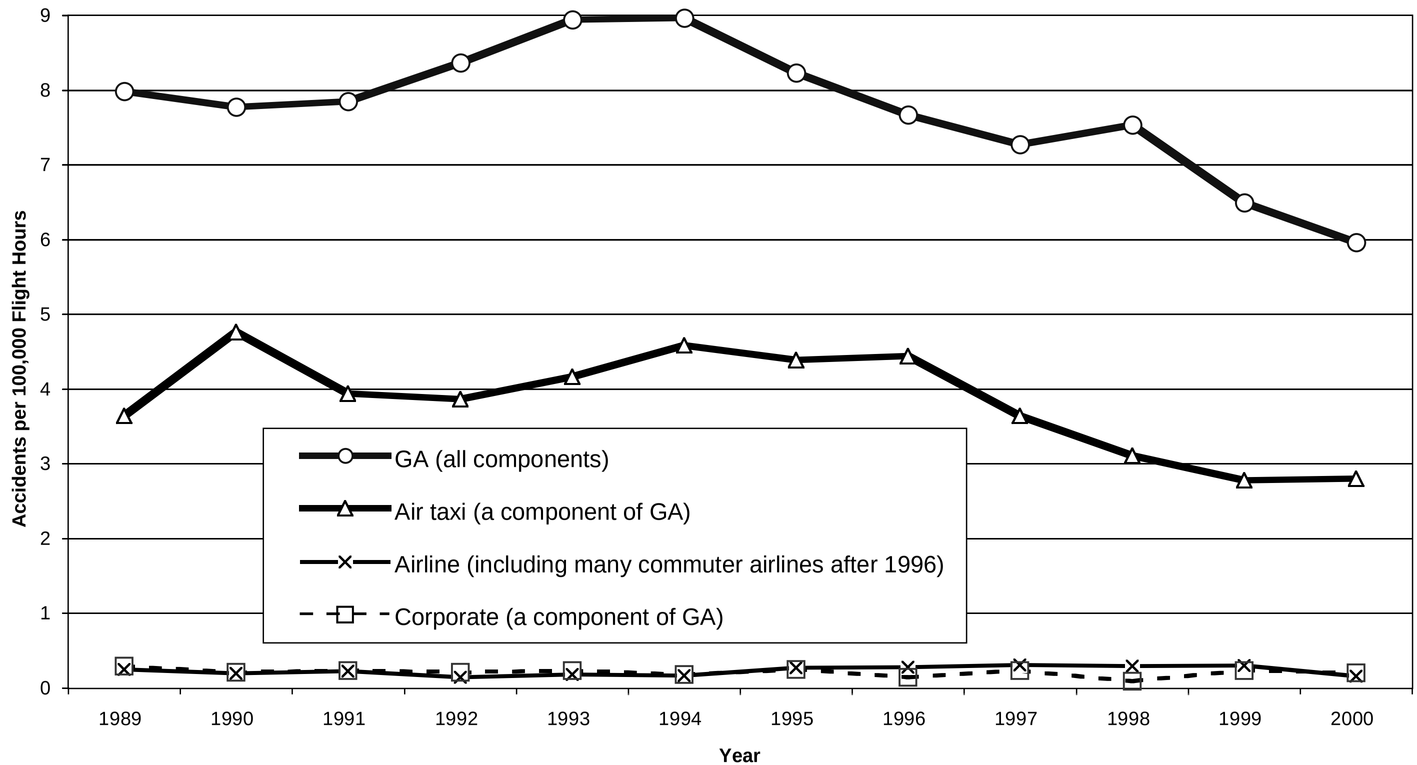


Figure 3-7 Accident trends by segments of aviation industry, 1989–2000. Note: flight hours are estimated by FAA. Accident rates based on departures are not available because of limited data on GA departures. [Sources: NTSB 1999; NTSB 2000; NTSB online Tables 9 and 10 (www.ntsb.gov/aviation); NBAA 2000.]

taxi operations. Progress in improving GA pilot performance, though not necessarily to the extent of equaling the safety record of two-pilot professional crews, continues to be an important safety need in the GA sector.

ENVIRONMENTAL COMPATIBILITY

Airports have long been a focus of environmental concern. Because of their size, functional requirements, and use in transporting passengers and high-value cargo, airports tend to be located on large, flat sites near populated areas. Suitable sites are often found on the shores of rivers, lakes, and oceans, or in wetlands or other types of landscape thought to have little economic value when originally selected for airport development. These sites, however, often support important ecological systems whose disturbance can affect plant and animal communities and humans.

With passage of the National Environmental Policy Act (NEPA) and similar state environmental laws during the 1970s and 1980s, airport planning and development projects became subject to much greater scrutiny by the U.S. Environmental Protection Agency (EPA), other federal agencies (such as the U.S. Army Corps of Engineers), and state environmental agencies. FAA also established a number of programs and guidance aimed at reducing the array of environmental effects at and near airports receiving federal aid. The programs have ranged from studies to resolve land use compatibility and noise-related problems at airports to the preparation of manuals for airport personnel to use in managing wildlife hazards at airports. Likewise, many states have developed planning and impact assessment guidelines for local jurisdictions and airport authorities to lessen the environmental impacts from airport operations and construction projects.

The types of environmental impacts associated with the development and operation of airports are varied. They generally fall into two categories: "footprint" and "operational" effects. Footprint effects are those resulting from the location, size, and configuration of airport facilities and may include effects on water quality (surface and subsurface), wetlands, floodplains, species habitats, and land uses (farmland, parks and recreational areas, and protected landscapes, such as coastal zones). Operational effects are those attributable to changes in the volume of aviation operations and the composition of the aircraft fleet, which may result in increases in aircraft noise and pollutant emissions, as well as other social externalities such as increased highway traffic congestion.

It is generally true that operational activity at large commercial airports affects more people and larger areas than does that at smaller GA airports. Nevertheless, operational effects are not negligible in many GA airports. For instance, in some locations even a modest increase in the number of nighttime operations at a GA airport—an increase that would barely be noticed at a large airport—may be perceived negatively by neighboring residents, generating significant public opposition and even legal challenges. Moreover, the severity of an airport's environmental footprint can have little relation to airport size, since location is a critical factor. For instance, a 1,000-foot runway extension at a GA airport situated near wetlands can engender more environmental scrutiny than the construction of a new runway at a much larger hub.

As commercial aviation activity has increased dramatically, so has concern about the environmental impacts associated with airport footprints and operational activity. Community opposition to new airport development projects on environmental grounds has escalated in recent decades, often becoming a significant factor in delaying or preventing project implementation.

Among operational impacts, aircraft noise during takeoff and arrival has historically been by far the most prominent concern. However, local air quality, which is affected by emissions from aircraft and surface traffic activity at and near airports, is growing in importance. On a larger scale, the effects of aircraft emissions on regional air quality, and potentially on global climate change and stratospheric ozone depletion, have received more attention during the past two decades. Footprint impacts also constrain airport development because of such concerns as the filling of wetlands (subject to the review and approval of the Corps of Engineers), impairment of water quality in surface and underground sources resulting from the use of hazardous substances at airports, and adverse effects on the habitats of species protected and given other special status by federal and state statutes.

Aircraft Noise

As airport activity increased and larger jets began operating in the nation's urban airports during the 1960s, the communities near airports became increasingly effective in conveying their concerns about noise. Organized reactions by neighborhoods have led to strong political pressure to control aircraft noise. Heavier aircraft have tended to attract the most concern because they require more thrust during takeoff and create proportionally more noise and vibration than smaller aircraft, unless treated. Likewise, the operation of helicopters, which can have a distinctive noise profile caused in part by blade "slapping," has proved particularly problematic. They often fly lower and slower than fixed-wing aircraft and can land and take off outside large airports; hence, their noise effects can be more intrusive and longer-lasting.

Aircraft noise is surely an annoyance, but one that is difficult to measure since noise characteristics vary by source and people differ in their tolerance and reaction. NEPA requires an environmental impact assessment when federal action, such as funding aid or airport layout approval, is associated with an airport improvement or other change.[14] Because most U.S. airports receive federal aid or require federal action in connection with airport development programs, they must undertake such assessments, and noise is one of the factors they must consider. EPA, which enforces and sets standards for NEPA compliance, has established methods for measuring and analyzing noise in and around airports. Airport noise exposure, expressed in terms of the day-night annual average noise level (DNL), is calculated on the basis of cumulative noise levels over the course of the day and the intensity and duration of each noise event. FAA uses a DNL value of 65 decibels as a threshold of noise impact significance for sensitive land uses (e.g., residential areas) under ordinary circumstances.[15]

To limit the unacceptable noise footprints, many airports have paid large sums for noise mitigation. Measures include the soundproofing of nearby homes and the purchase of land on the perimeter of the airports, which sometimes requires the relocation of households. Some airports have purchased easements from homeowners

[14] State laws may require similar or additional environmental assessments.

[15] According to FAA rules, 60 decibels may be used under some circumstances as a screening threshold.

to ensure that residents will not object to increases in airport activity. Most airports want to avoid curfews and limits on airport use. Many airport operators, however, have had to make changes to limit objectionable noise; for instance, by requiring aircraft operators to throttle back engines during climb out, limiting flight paths, and rotating runways in use. Such restrictions can affect the airport's capacity to handle traffic, especially during inclement weather.

Aircraft noise is a worldwide concern, as evidenced by the fact that the International Civil Aviation Organization (ICAO) is charged with recommending aircraft noise exposure standards worldwide. FAA has adopted ICAO standards requiring the phasing out of noisier jet aircraft and their replacement by quieter so-called Stage III aircraft. In general, newer aircraft are better designed to suppress or reduce engine noise.

Still, noise concerns continue to constrain airport use and expansion in the United States and abroad. Although technology has helped reduce the maximum noise of single events, growth in aircraft traffic activity has often led to increases in the frequency, duration, and level of noise and to the expansion of noise exposure areas. It has become increasingly clear that standard noise metrics may not be accepted as measures for all aspects of community concern and that controversies about how noise is evaluated are likely to continue. For instance, intermittent or startling sounds can create community concerns, and it is well known that residents complain about aircraft movements they can see, even if they cannot hear them. It appears that even when noise is measurably reduced or contained, the sight of aircraft can provoke public outcry, partly out of concern about the risk of overflying aircraft crashing into residential areas (NSTC 1999, 51–60). Moreover, automobile traffic in the vicinity of airports, much of it generated by airport operations, may add to aircraft noise to create cumulative noise impact issues.

Other Local Environmental Effects

The federal Clean Air Act (CAA) requires EPA to identify National Ambient Air Quality Standards to protect public health and welfare. Standards have been established for various air pollutants including ozone, carbon monoxide, nitrogen dioxide, sulfur dioxide, suspended particulate matter, and lead. These substances are called "criteria" pollutants because standards have been established for each of them to meet specific public health and welfare criteria set forth in the CAA. (States have adopted their own ambient air quality standards, which may be more stringent, for the criteria air pollutants.) EPA has classified air basins or portions of air basins as either "attainment" or "nonattainment" for each criteria air pollutant on the basis of whether the criteria standards have been achieved. In nonattainment areas, CAA requires states to develop plans defining strategies for achieving attainment; these plans are referred to as state implementation plans (SIPs).

Many of the metropolitan areas of the United States are located in air basins designated as nonattainment for one or more criteria pollutants. Within urban air basins designated as nonattainment, airports are significant sources of criteria pollutant emissions, from both stationary sources (fuel storage and distribution systems, boilers) and mobile sources (aircraft, on-road vehicles, ground support equipment). Consequently, increases in emissions associated with growth in aviation activity are a concern to the regulatory agencies responsible for monitoring and improving air quality and to the general public. For this reason, development projects at major air carrier airports are typically subject to detailed analyses of how development-related increases in air passenger and cargo activity affect air quality. Moreover, airport development projects that require action by FAA, such as approval of funding or airport layout plans, must be in conformity with the applicable SIPs before FAA can approve the project.

In general, if modest increases in criteria pollutant emissions are anticipated from an airport project requiring federal action or approval and FAA determines that the applicable thresholds for particular pollutants would be exceeded, additional analysis or mitigation may be required to secure acceptance. For instance, it may be necessary to offset projected increases in emissions through reductions in airport-related emissions or the purchase of emissions "credits" from nonairport sources (e.g., local stationary sources). Because identifying acceptable and cost-effective mitigations is often difficult, even the finding of modest increases in criteria pollutants from an airport project can seriously delay or preclude its implementation.

Air quality concerns are also changing as more is learned about the generation and effects of pollutants. Public health agencies in recent years have increasingly focused on air pollutants known to have short-term (acute) or long-term (chronic or carcinogenic) adverse human health effects but for which no ambient standards have been established. Examples are formaldehyde, benzene, and xylene. Their emissions at airports are generated from the combustion of fuel in the engines of aircraft, on-road vehicles, and ground support equipment, among other sources. While many scientific uncertainties remain about the generation and dispersion of these substances, particularly from aircraft and other nonroad mobile sources, some states require their examination as part of the environmental documentation needed for airport development approvals.[16]

Air quality concerns can be significant issues for development and activity changes even at small GA airports, depending on their location and the nature of the planned changes. Even a relatively minor change that requires federal action (or in some cases, state action), such as modifications to the airport's layout, can trigger the need for air quality impact evaluations and other environmental assessments. Although smaller aircraft generate smaller amounts of pollutants than larger aircraft per operation, increases in total aircraft operations and changes in the types of aircraft using an airport—for instance, a shift from piston-engine to turbine-engine aircraft—can change the airport's emissions profile. Such changes may be subject to assessment and action by public agencies. This process can generate public scrutiny and perhaps challenges from nearby residents concerned about health risks from air pollutants and suspicious of possible changes in the activity patterns at the airport. An improvement in air quality at a larger airport resulting from the diversion of air traffic to an expanded smaller GA airport may not be perceived as a net air quality benefit. The

[16] For example, the California state environmental documentation for the proposed expansion of Los Angeles International Airport includes an analysis of hazardous air pollutant emissions and a health risk assessment to determine whether exposure to the emissions generated by the expansion could increase the incidence of cancer or other illnesses.

deterioration in air quality near the GA airport may be proportionately much greater than the improvement at the larger commercial airport.

Global Environmental Concerns and Energy Use

Aircraft in flight have environmental effects. They can contribute to the buildup of greenhouse gases and particulate matter in the atmosphere, which can affect the earth's radiative balance and contribute to the buildup of gases in the stratosphere that can deplete the earth's protective ozone layer. Like other transportation vehicles that burn fossil fuel, aircraft produce carbon dioxide, which is the most plentiful and lasting of the greenhouse gases that threaten to cause a change in the earth's climate. Aircraft flying in the troposphere also emit aerosols (microscopic airborne particles) and water vapor that can create cirrus clouds, which reflect incoming solar radiation and can have a cooling effect on surface temperatures (World Meteorological Organization 1995). The emission of oxides of nitrogen and other substances from aircraft flying at high altitudes (40,000 feet above sea level or higher) may destroy ozone in the stratosphere, which is naturally present and is an important protection against ultraviolet light penetration (Intergovernmental Panel on Climate Change 1996).

Federal and ICAO regulations governing large aircraft set standards for the emission of certain substances (criteria air pollutants) during landing and takeoff cycles. There are no U.S. or international standards governing the exhaust emissions of aircraft at cruising altitudes, partly because of insufficient scientific information on which to base such standards. However, the scientific and aviation communities have begun to take seriously the atmospheric effects of aircraft emissions. Changes in the types of aircraft and where they fly in the atmosphere—for instance, an increase in the number of aircraft entering the upper troposphere and lower stratosphere—are of interest to scientists evaluating the current and prospective atmospheric effects of aviation.

The risk of global environmental effects related to the combustion of fossil fuel is one reason to seek improvements in the energy efficiency of aviation. A more immediate reason for improving energy efficiency is that fuel is a major cost item for airlines and other aircraft operators. Aircraft fuel efficiency is extremely important to air carriers and private jet operators, since it is often second only to labor as an operating cost. Many older aircraft, such as the Boeing 727 and DC-9, have been retired in recent years in favor of more fuel-efficient, later-model versions of aircraft such as the Boeing 737. The airline industry has made great strides in improving energy performance, and fuel use per passenger mile has been cut in half since 1970. Airlines continue to seek changes in operating practices, especially air traffic routings and control procedures that will produce additional savings in fuel consumption.

At the same time, the conversion to turbine aircraft in the business aviation and commuter airline industries has had implications for fuel usage, since turbine aircraft use several times more fuel per operating hour than do piston-engine aircraft. On a passenger-mile basis, however, the faster turbine aircraft, which travel farther per hour flown, are a fuel-efficient means of transporting people over long distances. Because takeoff and low-altitude operations use a disproportionate share of jet fuel, turbine aircraft are most energy-efficient (on a passenger-mile basis) on longer flights, during which cruising altitudes are maintained for a larger portion of the flight. In addition, for the same level of turbine engine and aircraft technologies, small aircraft are inherently less fuel-efficient on a passenger-mile basis than are larger aircraft.

Challenges and Relevant Findings

Environmental issues impose a fundamental limitation on growth in the aviation sector. Aircraft noise will likely continue to be a major impediment to the expanded use of many airports, despite technologies that have made aircraft quieter. Increases in operations, even by quieter aircraft, continue to prompt concern by neighboring communities. Public and regulatory agency concerns about pollutant emissions have increased in recent years, and air quality has become as significant an environmental issue at many airports as aircraft noise.

Other environmental effects also pose constraints on aviation: the effects of aircraft and airport operations on local water quality, special-status species habitats, and sensitive land uses. Aircraft emissions in the atmosphere that could result in far-reaching environmental effects are likely to be a source of increasing scientific and public concern. These effects are being addressed through regulation and research in varying degrees. Changes in the nature, location, and magnitude of aviation activity will undoubtedly lead to new understanding of and concerns about the global environmental effects of aviation.

FINDINGS RELEVANT FOR ANALYZING SATS

The following chapter findings are relevant for examining the SATS concept. They are referred to again in the assessment of the rationale and justification for SATS given in Chapter 4.

Alleviating Air Transportation Congestion and Delay

Future growth in air travel demand could exacerbate congestion and increase the incidence and severity of flight delays. Much of the delay experienced by passengers is attributable to bottlenecks in the system, which often result from capacity shortages at a small number of large airports with limited infrastructure and heavy passenger demand. Most commercial airports in the United States have excess capacity, even during peak travel times. General efforts to curb overall growth in passenger traffic—for instance, through diversion of travelers to other modes—hold limited potential to alleviate delay problems. While it is important to develop systemwide strategies to enhance airport and air traffic capacity, remedies that are targeted to removing system bottlenecks are essential.

Small-Community Access to Air Transportation

Hundreds of small cities and remote rural communities receive scheduled air service from commuter airlines affiliated with major airlines. Travelers in these small markets gain from being linked to major airline hub-and-spoke networks that create thousands of city-pair markets. Not all small and remote communities, however, have scheduled service at their local airports; travelers in these communities often must drive to other airports in the region for access to scheduled service. Airlines have learned to balance the traveling public's preference for convenient and accessible local air service with the desire for frequent flights, faster and more comfortable aircraft, and ample amenities and services at airports. By concentrating passenger traffic in a regional airport, airlines can schedule more frequent flights on larger aircraft and offer lower fares. Spreading passenger traffic over many small airports in a region raises the prospect of no single airport generating passenger volumes sufficient to support frequent flights or minimum facilities and services.

Aviation Safety

Aircraft accidents, especially by air carriers, are often high-profile events, affecting the public's overall perceptions of aviation safety. Government and industry, recognizing that even small degradations can cause a loss of public confidence in flying, have gone to great lengths to ensure safety. FAA's central mission in regulating aviation and providing air traffic control service is to ensure safety. Commercial airline transportation, which is subject to the most comprehensive government interventions, has performed with high levels of safety—several times higher than the safety performance of GA. Pilot performance tends to be a more significant factor in GA accidents than it is in commercial airline accidents. Improved pilot performance continues to be a key safety need in GA.

Environmental Compatibility

Environmental issues constrain growth in the aviation sector. Aircraft noise and, increasingly, air quality concerns are major impediments to the expanded use of many airports, despite technologies that have made aircraft engines quieter and reduced pollutant emissions. Growth in the overall number of aircraft operations has been associated with increases in cumulative noise and air pollutant levels. Changes in an airport's infrastructure and use characteristics, including changes in the mix of aircraft using the airport, are therefore likely to continue to attract scrutiny, and the issues raised will require remediation.

REFERENCES

Abbreviations

DOT	U.S. Department of Transportation
FAA	Federal Aviation Administration
NBAA	National Business Aviation Association
NSTC	National Science and Technology Council
NTSB	National Transportation Safety Board

DOT. 2000. *Audit Report: Air Carrier Flight Delays and Cancellations.* Report CR-2000-112. Office of Inspector General, Washington, D.C., July.

FAA. 1999. *Terminal Area Forecast Summary, FY 1999 to 2015.* Office of Aviation Policy and Plans, Washington, D.C., Nov.

FAA. 2000a. *2000 Aviation Capacity Enhancement Plan.* U.S. Department of Transportation, Washington, D.C.

FAA. 2000b. *Long Range Aerospace Forecasts, FY 2015, 2020, and 2025.* Office of Aviation Policy and Plans, Washington, D.C., June.

FAA. 2001. *Airport Capacity Benchmark Report 2000.* U.S. Department of Transportation, Washington, D.C.

Gaguin, D. A., and M. S. Littman. 1999. *County and City Extra: Annual Metro, City, and County Data Book,* 8th ed. Bernan Press, Washington, D.C.

Intergovernmental Panel on Climate Change. 1996. *Climate Change 1995: The Science of Climate Change. Contribution of Working Group II to the Second Assessment Report.* Scientific Assessment of the Atmospheric Effects of Stratospheric Aircraft, Reference Publication 1381. Washington, D.C.

Meyer, J. R., and C. V. Oster. 1984. *Deregulation and the New Airline Entrepreneurs.* MIT Press, Cambridge, Mass.

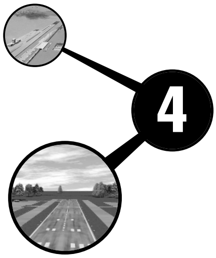
NBAA. 2000. *Business Aviation Factbook 2000*. Washington, D.C.

NSTC. 1999. *National Research and Development Plan for Aviation Safety, Security, Efficiency, and Environmental Compatibility*. Committee on Technology, Executive Office of the President of the United States, Washington, D.C., Nov.

NTSB. 1999. *Annual Review of Aircraft Accident Data, U.S. Air Carrier Operations, Calendar Year 1996.* Report NTSB/ARC-99/01. Washington, D.C., July.

NTSB. 2000. *Annual Review of Aircraft Accident Data, U.S. General Aviation, Calendar Year 1997.* Report NTSB/ARG-00/01. Washington, D.C., Sept.

World Meteorological Organization. 1995. *Scientific Assessment of Ozone Depletion: 1994*. Report 37. Global Ozone Research and Monitoring Project, Geneva, Switzerland.



4 Analysis of Small Aircraft Transportation System Concept

As explained in Chapter 1, the statement of task asks the study committee to answer the following two questions:

- Do the relative merits of the Small Aircraft Transportation System (SATS) concept, in whole or in part, contribute to addressing travel demand in the coming decades with sufficient net benefit to warrant public investment in technology and infrastructure development and deployment?
- What are the most important steps that should be taken at the national, state, and local levels in support of SATS deployment?

Under the SATS concept, highly advanced small aircraft would be operated as a means of personal transportation in airspace and at airports that are now used only lightly. The committee interprets the first question as asking broadly whether the concept is sufficiently plausible and desirable to serve as a guide for general aviation (GA) research and technology programs and as a basis for government investments in the development and deployment of supporting infrastructure. The committee interprets the second question as a request for specific advice on what, if any, steps the National Aeronautics and Space Administration (NASA) and other public agencies ought to take to further the development of such a system or its constituent capabilities and technologies.

The committee's answers to these questions and its advice on NASA's GA research and technology program are offered in Chapter 5. The supporting analyses are presented below. First, the likelihood that many novel and advanced aviation technologies can be developed, integrated, tested, and adopted in a manner that ensures safe performance and user affordability is examined. Consideration is then given to the ability of the nation's small airports and uncontrolled airspace to accommodate such a system, which will depend in part on the kinds of aircraft envisioned for SATS and their utility and performance characteristics. The potential for significant user interest in such a system is then examined given what is known about travel demand trends, patterns, and the factors that influence them.

While such analyses are helpful in judging the likelihood of such a system emerging as anticipated, they do not address its social desirability. Important considerations deserving closer scrutiny are the safety and environmental effects of SATS. For instance, how will a shift from travel in larger airplanes to smaller airplanes affect overall transportation safety, energy use, and emissions? How will a shift in traffic from large to smaller airports affect aviation safety, environmental compatibility, and overall settlement patterns? By serving mainly small airports in nonmetropolitan areas, how will SATS affect traffic volumes, capacity, and congestion in the larger commercial air transportation system? Before promoting SATS as a socially desirable outcome, it is important to consider these and other issues.

PROSPECTS FOR TECHNOLOGY DEVELOPMENT AND DEPLOYMENT

For the small aircraft transportation system that NASA envisions to emerge, many new technologies and systems would have to be developed, validated, and integrated for production and use. While future technologies cannot be predicted with certainty, it is possible to surmise the overall magnitude of the technological challenge facing SATS given a general understanding of factors that influence product development and deployment in aviation. The success of SATS would require many significant advances in small aircraft propulsion, flight control, communications, navigation, surveillance, landing, and manufacturing systems; no attempt is made here to explore the various technical challenges in each of these areas. What must be considered, however, is whether so many coordinated advances could be planned for and achieved in an aviation environment in which safety assurance and affordability are key, and often conflicting, constraints.

Safety Assurance

Nearly all aspects of aviation are subject to extensive government and industry standards, advisories, and procedures aimed at ensuring safety—from pilot training and proficiency requirements to criteria for aircraft and airport design, maintenance, and inspection. The public's expectations for safety are high because the consequences of mistakes can be fatal, so emphasis is placed on avoiding accidents through exacting design, material, and manufacturing standards; multiple backup systems and redundancies; standard operating procedures; and training and qualification standards for pilots, maintenance personnel, air traffic controllers, and many others involved in the aviation sector. To ensure these high levels of performance, the introduction of new aviation technologies, components, and systems must be preceded by extensive analysis and evaluation. Through this multilayered process, most new technologies and procedures are incorporated into the aviation system gradually.

The expeditious and orchestrated development and introduction of many new aviation technologies and systems on the scale required by SATS is unprecedented. The current safety assurance system, though deliberate and slow-paced, has been accompanied by continual improvements in aviation safety over the course of many decades. Because of the overriding importance of safety, the prospect that SATS would emerge quickly and with sufficient user, regulator, and industry confidence appears highly questionable. Moreover, given that SATS is envisioned to appeal to a new kind of small aircraft user—including many novice pilots with limited experience and skills—the magnitude of this safety challenge appears to have been greatly underestimated.

Affordability

Central to the SATS vehicle concept is that technological advances can reduce the cost of owning and operating small aircraft even as the attributes of these aircraft—

including safety—are enhanced greatly. The idea is that a combination of lower aircraft costs and increased performance and utility will spur user interest.

The history of technological development is replete with examples of large reductions over time in the cost of products, even as their performance and capabilities increase. However, this has seldom been the case for high-performing production aircraft. Indeed, the increasingly sophisticated small jet aircraft produced in the GA sector since the 1960s (with the introduction of the six-place Learjet) have become more expensive over time relative to consumer purchasing power (see Figure 4-1). In 1998, the 415 jet airplanes produced by GA manufacturers cost an average of $11.5 million each, which is about twice as much per unit as in 1980, when 326 new jets sold for an average price of $5.1 million each, adjusted for inflation.

The number of small jets produced in any given year is only in the hundreds, and they are highly customized and individually crafted. Under the SATS concept, however, high user demand is assumed to prompt large reductions in unit price, primarily because of increases in the number of aircraft manufactured and distributed. Some prospective aircraft manufacturers, such as Eclipse Aviation and Safire Aircraft Company (see Chapter 2), are anticipating levels of jet aircraft production several times higher than that of all GA manufacturers today. These companies anticipate the emergence of volume-related production economies and improved manufacturing methods. Such developments, the companies believe, will allow them to sell their aircraft (with mostly conventional avionics) for about $1 million per unit—a price that can make small jets more practical and economical to a significant portion of the public.

To date, there is little evidence of the potential for such economies in small-aircraft manufacturing, and such an outcome would run counter to recent industry trends. The U.S. GA industry today produces fewer than 3,000 aircraft per year, a figure that represents the aggregate output of more than a dozen manufacturers for all types of GA aircraft (GAMA 1999). Even at its peak during the 1970s, the industry never produced more than 20,000 aircraft of all types per year, and it has not produced more than 4,000 aircraft in any year since 1982. Fewer than 500 of the most sophisticated jet aircraft are manufactured each year, and no single GA manufacturer produces more than 150 to 200 small jets per year. Since the SATS concept rests on assumptions—so far undemonstrated—about the manufacture of increasingly sophisticated and safe small aircraft at a cost substantially less than that of conventional aircraft today, it appears to be mostly speculative.

AIRPORT AND AIRSPACE COMPATIBILITIES

Another central feature of the SATS concept is that advanced small airplanes will be able to make much better use of the country's thousands of small GA airports and vast amounts of lightly used airspace. NASA's SATS Program Plan maintains that "most of the U.S. population lives within a 30-min. drive of over 5,000 public-use airports. . . . an untapped natural resource for mobility."[1] It also identifies the "non-radar airspace below 6,000 ft and the en route structure below 18,000 ft" as underutilized airspace that the airborne technologies of SATS aircraft can put to better use. These elements

[1] Small Aircraft Transportation System Program Plan (Version 6), NASA Office of Aerospace Technology, p. 3.

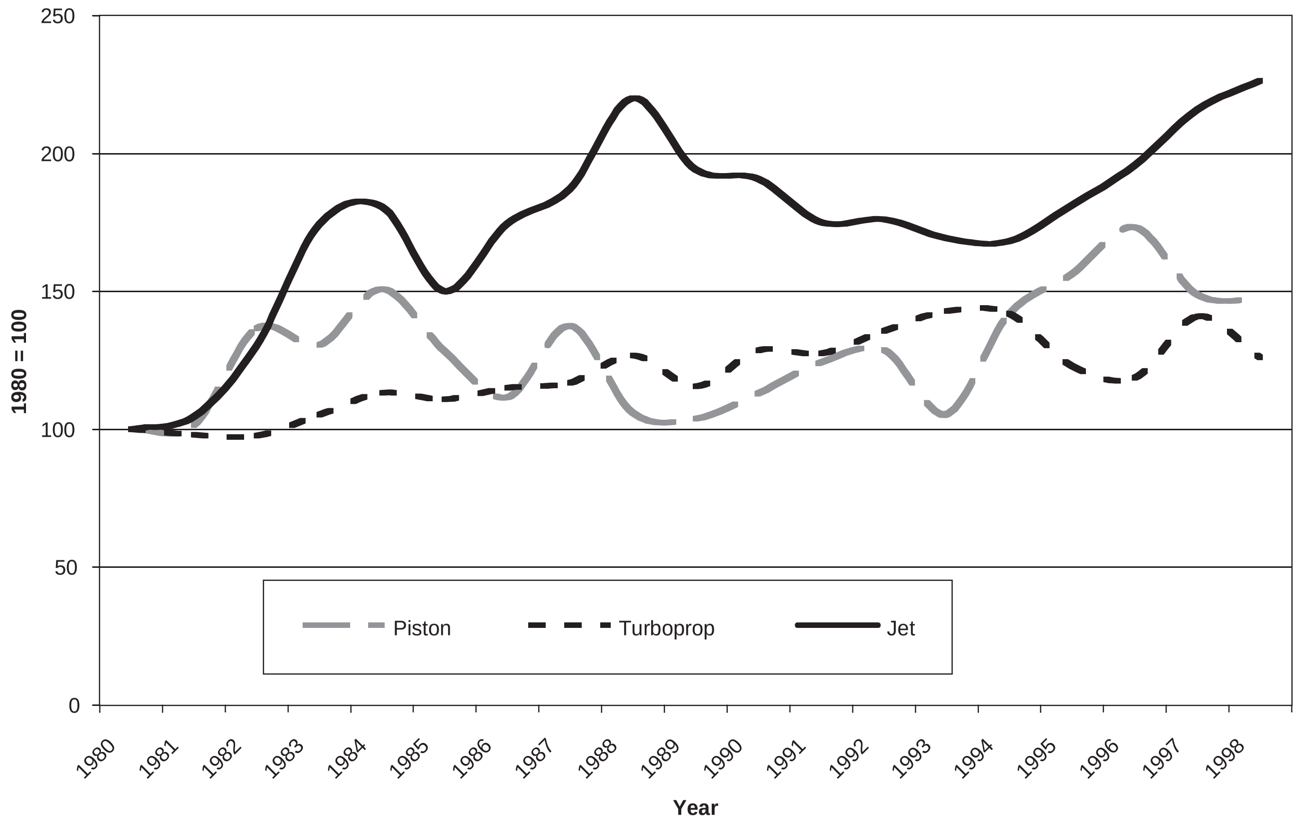


Figure 4-1 Inflation-adjusted index of changes in average price of new GA aircraft, 1980–1998.
Note: price adjusted using the Consumer Price Index (Census Bureau 1998). Value of new GA aircraft shipments derived from GAMA (1999, p. 6).

of the nation's airspace system are seen as offering a ready infrastructure for the use of advanced small aircraft in transportation, requiring little additional public investment.

The assumption of available infrastructure needs to be examined, which requires an understanding of the basic kinds of aircraft postulated for such a system. So far, NASA's SATS program plan simply envisions "fixed-wing aircraft applications."[2] It is possible that multiple vehicle types, including piston-engine, turboprop, and turbofan jet aircraft, would be accommodated in such a system. However, piston-engine and turbine aircraft have differing capabilities, from the speeds and altitudes at which they cruise most efficiently to their landing and takeoff characteristics. These differences have implications not only for the kinds of technological advances needed to make small aircraft more useful and desirable for transportation, but also for the extent to which airport and airway infrastructure can accommodate SATS vehicles. Some of the implications for just two of many possible aircraft types are considered next.[3]

SATS Jet Aircraft

Jet aircraft require longer runways than propeller aircraft with comparable passenger (or payload) capacity. In general, the runways must be well maintained and have a paved surface. As reported in Chapter 2, 3,027 public- and private-use airports in the United States have at least one runway that is at least 4,000 feet long, and 1,749 of these airports have a runway that is at least 5,000 feet long. Today's small jet aircraft operate mostly from the latter 1,749 airports with longer runways and night lighting. In particular, they operate in the roughly 1,200 of these airports that have a precision instrument landing system (ILS) on at least one runway. ILS allows for dependable operations during periods of low visibility. Radar coverage, which is not always coupled with ILS, allows for the safe separation of aircraft during instrument flight rule (IFR) operations—a capability that is indispensable in airports with a large amount of traffic. However, ILS is expensive to install and maintain. As discussed in Chapter 2, new technologies such as ADS-B and WAAS have the potential to substitute for or supplement ILS in the near future, reducing the cost of low-visibility operations substantially.

All jet aircraft are equipped for ILS approaches, and as a practical matter, all jet operators are IFR-qualified to use these systems. The 1,200 ILS-equipped airports include nearly all of the country's 526 commercial-service airports and about 258 metropolitan reliever airports. Advanced technologies that allow for precision approaches without the installation and maintenance of ILS will expand the number of airports available for low-visibility jet operations by instrument-rated pilots.[4]

[2] Small Aircraft Transportation System Program Plan (Version 6), NASA Office of Aerospace Technology, p. 2.

[3] The SATS program plan does not mention the potential role of other types of aircraft apart from fixed-wing airplanes, such as STOL/VTOL, tilt-wing, and even autogyros. Technological advances over the 25-year period envisioned for SATS deployment could presumably improve the performance and reliability of these aircraft to make them more acceptable and practical as a means of short- to medium-distance transportation.

[4] Although it is conceivable that advanced technologies will eventually allow lesser-trained (e.g., non-IFR and single-engine rated) operators to fly jet aircraft under low-visibility conditions, it is not possible to know what infrastructure would be needed for such operations. Longer runways might be needed, for instance.

Airports with paved 5,000-foot runways not equipped with ILS would be initial candidates for jet operations, although some airports with smaller runways, 3,000 feet long or longer, might be usable by the smallest jet aircraft. To illustrate the implications for small jet access, Figure 4-2 shows the location of commercial-service airports in and around Georgia, as well as the location of other GA airports having ILS and those having 5,000-foot runways without ILS. Of the state's 109 public-use airports,

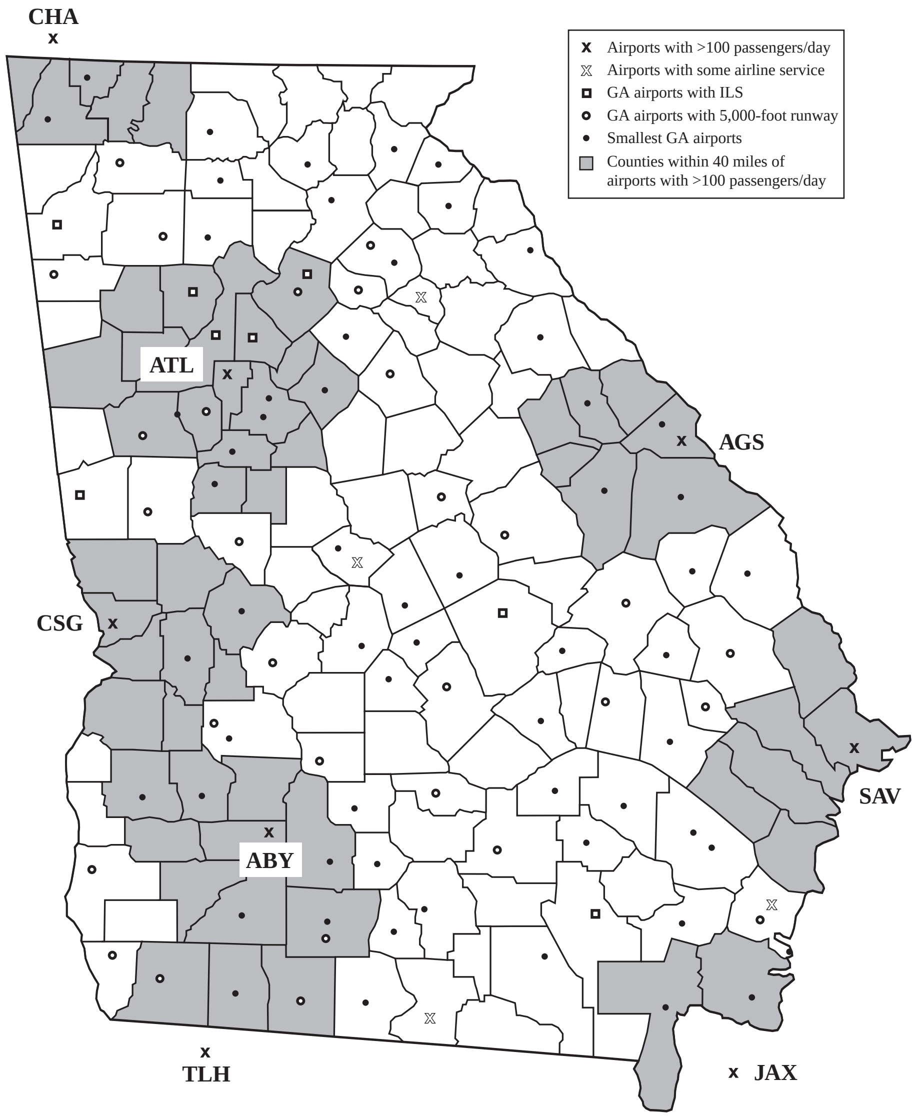


Figure 4-2 Geographic distribution of all public-use airports in Georgia and major commercial-service airports in other states near Georgia border.

46 have at least one runway that is 5,000 feet long or more, including 30 that do not have ILS or offer commercial service.

Assuming that most current runways that are now equipped with ILS are at least 5,000 feet long, advanced technologies would give jet operators dependable access to about 550 more airports that have 5,000-foot runways but no ILS. If additional technological advances allowed more small jet aircraft to operate safely on 4,000-foot runways, an additional 1,300 non-ILS-equipped airports would become candidates for jet operations. Conceivably, further advances in the short-field takeoff and landing capabilities of small jet aircraft could expand access to another 2,600 public- and private-use airports with 3,000- to 3,900-foot runways. In practice, however, the number of airports that could handle small jet aircraft on a regular basis is sure to be smaller than these figures suggest, especially in the absence of significant airport investments. The need to control noise and pollutant emissions would undoubtedly compel many of these airports to purchase additional land around the airport and take other actions to control noise and air quality impacts. Many would also have to improve the condition of their runways and upgrade their runway maintenance programs to handle jet aircraft.

The low-altitude structure (below 18,000 feet) envisioned for SATS may be incompatible with the usual design of jet aircraft to fly fast at high altitudes. Designing jet aircraft to fly at lower altitudes would offset the important speed advantages offered by jet aircraft, as well as the critical advantage of flying above inclement weather. However, at the higher altitudes, all airspace is highly controlled (Class A). Whether SATS jet aircraft would be used in the existing controlled jetways or in other lightly used portions of the controlled, high-altitude structure is unclear. The intended pattern of use, however, would have important implications for the technologies needed to ensure compatibility with other non-SATS air traffic.

SATS Propeller Aircraft

NASA's SATS Program Plan does not explicitly identify propeller (piston-engine or turboprop) aircraft as the main type of aircraft envisioned for SATS. However, this can be inferred through the emphasis placed on the ability of SATS users to access 5,000 more public-use airports with little or no infrastructure modification, affordability of SATS aircraft by a large segment of the public, and confinement of SATS operations mainly to the uncontrolled low-altitude airspace structure.

Propeller aircraft, and especially piston-engine aircraft, have advantages in each of these areas. Most can land on short, unpaved runways and therefore can land and take off at all small airports without modification to runways. A conventional, high-performance piston-engine aircraft can be produced today at a fraction of the cost of even the least expensive turbine-engine aircraft. Piston-engine aircraft, and to a lesser degree turboprops, routinely operate in the lower-altitude uncontrolled airspace (Class G) and at airports without ILS, and cabin pressurization could increase the altitudes at which piston-engine aircraft can regularly fly (e.g., from 12,000 to perhaps 18,000 feet; however, such a capability adds significantly to an aircraft's production cost). While many IFR-rated pilots operate these aircraft, large numbers of private pilots without an IFR rating also fly them. Piston-engine aircraft are easier to learn to fly and maintain proficiency in than higher-performance, higher-cost turbine-engine aircraft; hence, the potential exists for training more pilots at reasonable expense.

The deployment of piston-engine or even turboprop aircraft as the primary SATS vehicle raises a number of obstacles. Propeller aircraft flying at the level of weather present significant challenges in meeting the public expectations of safety (both real and perceived), ride comfort, reliability, and travel speed. Moreover, the extent to which the public would benefit from more reliable (low-visibility) access to 5,000 public-use airports is questionable.

ASSESSING USER DEMAND

Forecasting long-range user demand for any mode of transportation is difficult because demographics, preferences, technologies, and other factors affecting travel demand and mode choice can change over time. This difficulty is compounded when the characteristics of the mode of transportation lack definition. Central to the SATS concept is the idea that advanced small airplanes will have reliable access to many more small airports in the country. As discussed above, however, the SATS concept does not define the type of small aircraft that will predominate, apart from an emphasis on fixed-wing, small aircraft. The committee has been asked to estimate demand for SATS. Without more specific information on vehicle characteristics, it is difficult to begin estimating the pool of potential users, since the general aircraft type affects, among other things, the speed, comfort, reliability, and cost of service; the mix of locations that can be served; and operator training and proficiency requirements. Given the many technical, demographic, and economic uncertainties, the committee questions the ability of anyone to offer such detailed and definitive information on future vehicle characteristics; yet, it is difficult to gauge the prospective demand for SATS without it.

The ability to attract travelers to jet and propeller aircraft is likely to vary markedly because of large differences in the cost and performance characteristics of each aircraft type. Moreover, there is an implicit, but unexamined, assumption that small airports, if made more accessible, would divert large numbers of users from highway travel to air travel. This assumption is critical not only in assessing potential user demand, but also in evaluating the desirability of SATS from safety and environmental standpoints.

Demand for Travel by SATS Jet and Propeller Aircraft

As detailed above, jet aircraft differ fundamentally from piston-engine aircraft in their operating characteristics and requirements. Not only are the former much more expensive to produce, they require more extensive pilot training and proficiency and longer, better-maintained runways. Aircraft equipped with jet engines may produce more noise, and therefore they are often subject to restrictions on where they can fly. Small jets may produce more air pollutant emissions than small piston-engine aircraft, raising air quality concerns in the vicinity of the airports they operate from. At the same time, travelers have shown a much stronger preference to travel by jet than by propeller aircraft. Jets, which fly above most weather, are more reliable and more comfortable to fly in (passengers experience less turbulence and interior noise and vibration). Jets are much faster, are designed to have greater range than propeller aircraft, require more skilled pilots, and have achieved a better safety record.

Over the past 20 years, the use of propeller aircraft, including turboprops, in business aviation and commercial airline transportation has declined and has shown little potential for significant growth in intercity transportation applications. The persistence and magnitude of this trend suggest that any anticipated SATS emphasizing propeller aircraft would have limited user demand. As discussed in Chapter 2, about 70 percent of GA airports are located within 75 miles of one or more of the country's 525 commercial-service airports, many of which have commercial jet service or can accommodate private jet operations. In addition, most of the 260 GA reliever airports can accommodate jet aircraft. As estimated, 1,800 to 3,000 public- and private-use airports could accommodate small jet aircraft. Therefore, it is reasonable to question whether the greater accessibility of propeller aircraft, which can operate on shorter airfields, is likely to generate any additional user demand, particularly given the apparent reluctance of many travelers to fly in such aircraft.

Although preference for travel in jet aircraft is clear, constraints on the large-scale production and deployment of new small jet aircraft remain. Small jet aircraft are expensive to produce and operate and may raise substantial environmental concerns in communities exposed to the effects of increased jet operations. In a transportation system oriented toward small jets, fewer airports would be accessible than in one oriented toward propeller airplanes. Nevertheless, limitations on the use of some small airports may be offset by the performance attributes of jet aircraft that appeal to travelers. In contrast, the challenge with regard to propeller aircraft, particularly piston-engine aircraft, is in making them more comfortable, faster, reliable, and safer—characteristics closer to those of jet aircraft.

Given the dissimilarities between jet and propeller aircraft, it is surprising that the SATS program emphasizes GA aircraft and thus far has made little distinction between aircraft types. The program has supported equally the development of both kinds of GA aircraft and their use in such a transportation system without acknowledging the significantly different challenges and opportunities each presents. Without large reductions in the cost of producing and operating jet aircraft and large gains in the ride quality, speed, and safety of propeller aircraft, whether either type of aircraft would attract significant user demand is questionable.

Traveler Demand in Small Cities and Nonmetropolitan Markets

An important consideration in assessing demand for SATS is the extent to which expanded access to small, nonradar airports is likely to attract large numbers of users. For the most part, airports with radar are located in metropolitan areas. Radar contributes to the safe separation of IFR traffic, allowing reliable operations under poor visibility. Large commercial-service airports require such controlled separation of traffic, and even small airports within large metropolitan areas are located under controlled airspace. The emphasis in the SATS concept on providing access to radarless small-city and nonmetropolitan airports results from NASA's recognition of the challenge of integrating SATS operations with those of commercial airlines in about 175 urban areas under Class B and C airspace in the United States. This limitation on the scope of SATS is understandable because of the complexity of urban air traffic patterns, but it raises questions about the likelihood of SATS generating much user demand.

The most recent American Travel Survey conducted for the U.S. Department of Transportation (DOT) indicates that in 1995 Americans made more than 1 billion domestic intercity trips of 100 miles or longer (from point of origin to final destination). Eighty-three percent of these trips began or ended in one of the nation's 160 largest metropolitan areas with populations of more than 250,000 (see Figure 4-3). These urban areas contain about two-thirds of the country's population. Thus, only 17 percent of trips both began and ended in one of the country's 170 smaller metropolitan or nonmetropolitan areas, despite the fact that about one-third of the population resides in these areas. For the most part, Americans travel to or from large urban areas. Indeed, 60 percent of all trips involve one of the country's 50 most populated metropolitan areas, where about 55 percent of U.S. population lives. These data suggest that if SATS aircraft do not access airports in large metropolitan areas, the potential of that system to attract significant numbers of users will be greatly limited.

A key promise of SATS is on-demand transportation service. This capability can be especially important to business travelers, who place a high value on time and schedule flexibility. Yet business travelers—who make about one-fifth of all intercity trips—are even more likely than others to be traveling between large metropolitan areas: 65 percent of all business trips involve a metropolitan area among the 50 most populous as point of origin or destination, and 86 percent involve one of the country's largest 160 metropolitan areas. If the emphasis in the SATS concept is on serving small cities and nonmetropolitan areas, then significant demand for SATS services is required from leisure travelers, who account for 87 percent of the trips taken in small-city and nonmetropolitan markets. Yet, leisure travelers—who plan their trips relatively far in advance—are usually more concerned about the price of travel than the schedule flexibility permitted by on-demand service of the type that SATS vehicles might provide.

Larger metropolitan areas also account for a disproportionately high share of intercity trips because they contain important business locations and because their residents tend to have higher incomes than do residents of smaller metropolitan and nonmetropolitan areas. The 50 largest metropolitan areas in the United States have average household incomes that are 10 to 25 percent higher than those in the rest of the country (Census Bureau 1998, Table 729). Intercity travel increases as household incomes rise, and travel by air is highly correlated with income (see Figure 4-4). Hence, the travelers having the highest propensity for air travel, urban travelers, may have the least to gain from a SATS that emphasizes nonmetropolitan service.

It is reasonable to question whether these recent travel patterns are reliable indicators of future travel trends, especially if Americans move farther away from metropolitan areas as communications and transportation systems continue to enhance personal mobility. The notion that innovations in communications technology have fostered a population shift from urban to rural areas is not confirmed by demographic data. While central cities have lost residents and businesses over the past half-century, their suburbs have boomed, as most metropolitan areas have gained population overall. According to Census Bureau data, nearly 80 percent of the U.S. population lived in the country's 330 metropolitan areas in 1998 (see Figure 4-5). Another 11 percent lived in nonmetropolitan areas that are adjacent to metropolitan areas. Only 9 percent lived in other nonmetropolitan areas. By comparison, in 1970, 73 percent of the population lived in metropolitan areas, 14 percent lived in adjacent metropolitan areas, and nearly 13 percent lived in nonmetropolitan areas far from cities. Most population growth has occurred in the suburbs of metropolitan areas as incomes have risen.

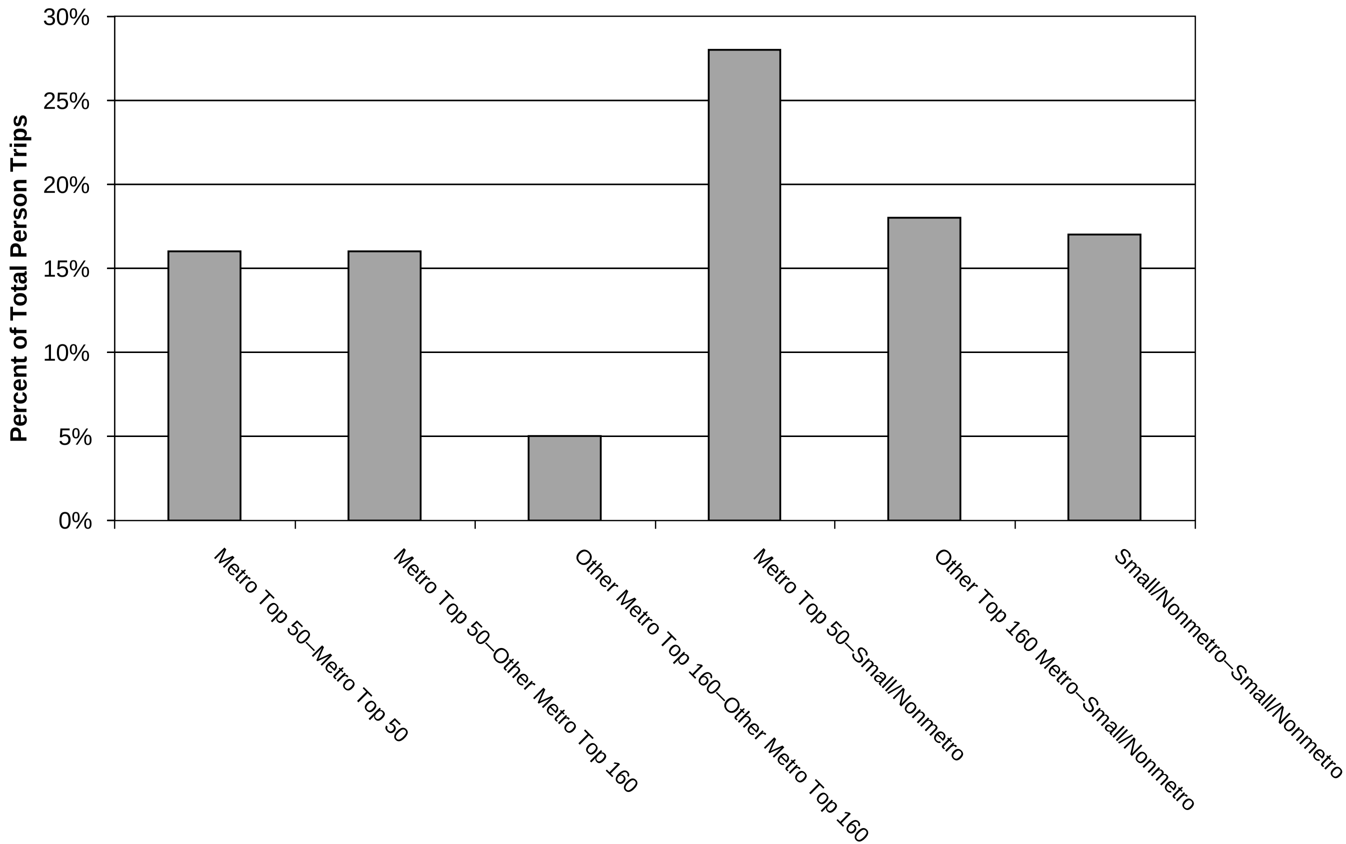


Figure 4-3 Intercity person trips involving metropolitan and nonmetropolitan areas by all modes, American Travel Survey, 1995.

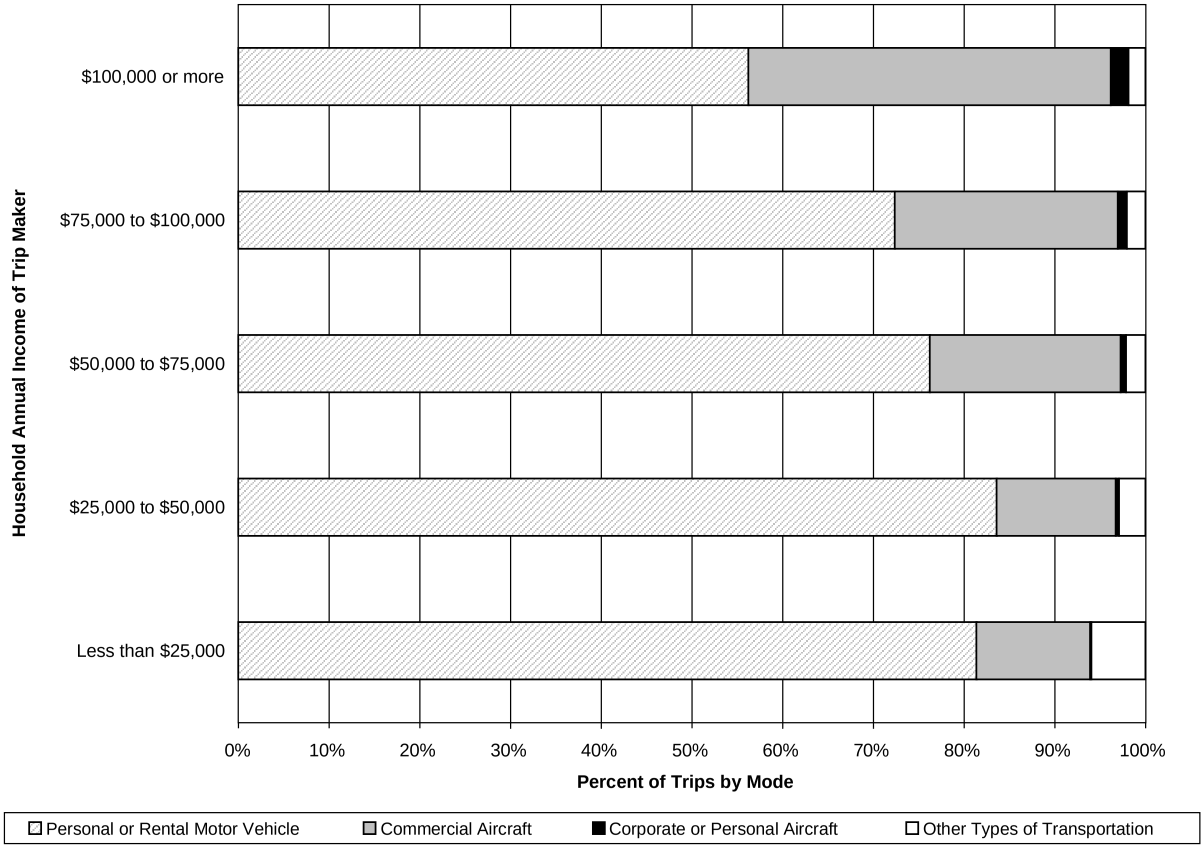
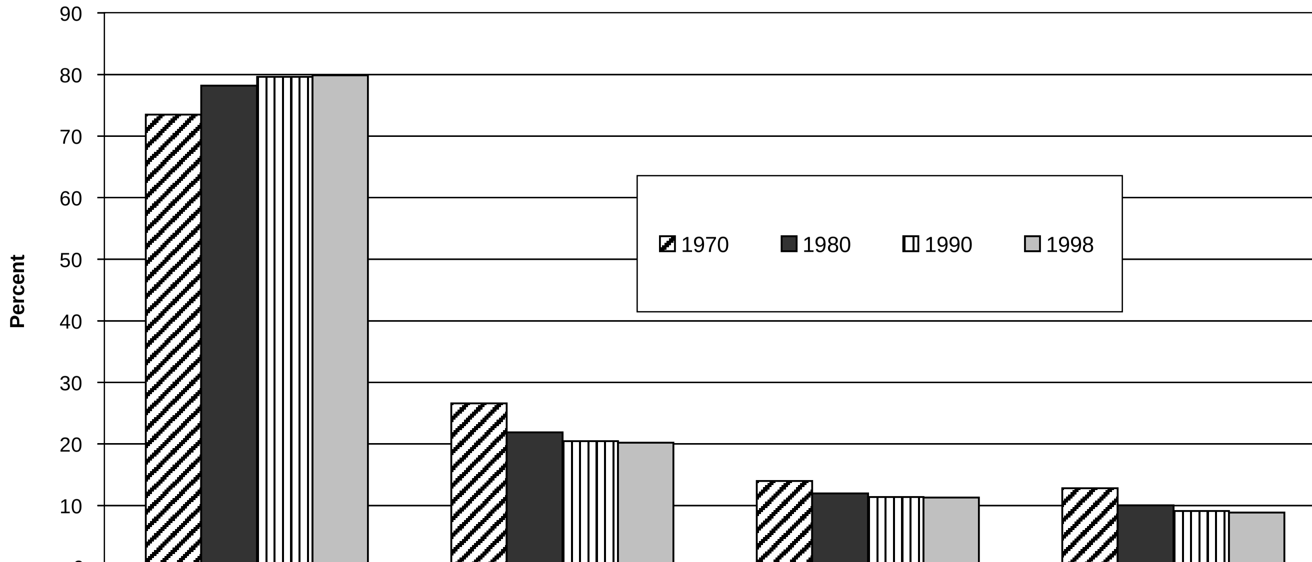


Figure 4-4 Transportation mode shares by household income for intercity person trips of 200 to 1,000 miles, American Travel Survey, 1995.



	Metropolitan	All Nonmetropolitan	Nonmetropolitan Adjacent to Metropolitan Area	Nonmetropolitan Not Adjacent to Metropolitan Area
1970	73.41	26.59	13.97	12.8
1980	78.12	21.88	11.9	9.98
1990	79.57	20.43	11.32	9.11
1998	79.87	20.13	11.28	8.85

Figure 4-5 Trends in the percentage of U.S. population in metropolitan and nonmetropolitan areas, 1970–1998. (Source: analyses of census data by J. D. Kasarda, Kenan Institute of Private Enterprise, University of North Carolina, Sept. 2000.)

Competition with the Automobile

About 45 percent of all the intercity trips taken by Americans in 1995 were for 200 to 999 miles, which is the one-way distance envisioned for most SATS uses. Three-quarters of these trips were taken by personal motor vehicle and fewer than 20 percent by air (see Table 4-1). Not until trip distances exceed about 800 miles does air transportation surpass motor vehicle transportation as the primary mode of intercity travel.

The tendency of people to drive on intercity trips is especially strong for leisure travelers, who use personal motor vehicles on most of their trips under 900 miles (see Figure 4-6). Leisure travelers driving their automobiles have lower values of time (about $20 per hour for intercity automobile trips under 500 miles), meaning that they are less willing to pay for air travel that may save them a few hours in door-to-door travel time (Brand 1996). Because leisure travelers also tend to have longer stays at their destinations, the added travel time by automobile is less important than it is for business travelers, who tend to make trips of shorter duration. The automobile also offers the advantage of being inexpensive for family or group travel, because the marginal cost of additional passengers is miniscule and because the automobile can be used at the destination for local transportation.[5]

Business travelers, by comparison, travel by air on nearly one-quarter of their trips between 200 and 300 miles (see Figure 4-7). They place a high value on time and are thus willing to pay more for the time savings that air travel can provide. The value of time of business travelers traveling by automobile is about $30 per hour for intercity trips under 500 miles (Brand 1996).

These data indicate the different challenge of competing with motor vehicles for travel on most short to medium-length intercity trips, particularly for nonbusiness travel. The hourly cost of a small piston-engine airplane, such as a Cessna 310, is about $400 (see Chapter 2), and the airplane travels at an average speed of 200 mph. The automobile, by comparison, has a perceived out-of-pocket cost of about $0.10 per mile,[6] or $20 for the 200-mile trip. Thus, with a cost differential of $380 for the 200-mile trip ($400 minus $20), the air alternative would have to be more than 12 hours faster for business travelers to choose it ($380 ÷ $30 per hour), even assuming that no time or additional costs are incurred in accessing and egressing the airports at either end of the trip. For nonbusiness travelers, the air alternative would have to about 10 hours faster ($380/2 ÷ $20 per hour).

Of course, these time savings would have to be subtracted from the approximately 4 hours needed to drive 200 miles, meaning the small airplane would have to make the trip in minus 8 or minus 6 hours to be preferable for business or nonbusiness travel, respectively. Moreover, the fact that nonbusiness travelers are also more likely to travel in groups (average group size of two) means that air fares on commercial carriers are effectively doubled, while the out-of-pocket cost of automobile travel effectively remains the same. The result, as shown in Figure 4-7, is that commercial air carriers are at an even greater disadvantage with respect to the automobile for short-distance leisure trips than they are for short-distance business trips. For slightly longer trips of 400 miles, which would take 2 hours on the small plane

[5] The average group size for leisure travel is about two, but close to one for business travel.

[6] A survey of the literature on automobile operating costs is given by Levinson and Gillen (1998).

Table 4-1 Number of Person-Trips by Principal Means of Transportation and Trip Distance, American Travel Survey, 1995

	Person-Trip Origin-Destination Distance (Miles)			
	200 to 299	300 to 399	400 to 499	500 to 599
Personal motor vehicle				
Number	168,793,987	72,623,610	36,389,326	22,721,633
Percent of total	37.9	16.3	8.2	5.1
Commercial airplane				
Number	13,555,496	14,211,426	11,677,991	8,452,965
Percent of total	3.0	3.2	2.6	1.9
Other airplane				
Number	668,615	670,617	344,313	272,331
Percent of total	0.2	0.2	0.1	0.1
All other (bus, train, ship, ferry, bicycle, other)				
Number	6,653,463	3,422,320	2,048,411	1,403,671
Percent of total	1.5	0.8	0.5	0.3
Total	189,671,561	90,927,973	50,460,041	32,850,600
Percent of total	42.6	20.4	11.3	7.4

at a cost of $800, the time savings to make air travel preferable to automobile travel would be essentially double that for the 200-mile trip. However, fares on commercial carriers are usually lower than $800 for a 400-mile trip. This is why the percentage of travelers using airlines increases as distances and time savings increase, particularly on discount airlines (e.g., Southwest), whose fares are specifically designed to compete with automobile travel.

Hence, a small aircraft transportation system that is oriented to 200- to 1,000-mile passenger trips must compete with the automobile at a substantial cost disadvantage. The higher travel speeds of small aircraft suggest that, despite the cost disadvantage, SATS vehicles could compete with automobiles at the middle to the high end of the range of trip distances, especially for time-sensitive travel (e.g., business trips). For shorter distances, however, the automobile is extremely difficult to compete with because of its advantage in not requiring transfers to and from other modes, which can be inconvenient, especially when carrying baggage.

If SATS is oriented toward serving small and rural communities that are not currently well served by commercial airlines, the competition with automobile transportation becomes even more challenging because of the lower average household incomes in nonmetropolitan areas. Using Georgia again as an example, Table 4-2 and Figure 4-2 show that about 31 percent of the state's residents live in counties that are 40 miles or farther from a commercial-service airport either in the state or in an adjoining state. The average household income for these counties is about 25 percent lower than the average for counties located near commercial-service airports.

600 to 699	700 to 799	800 to 899	900 to 999	Total
15,005,049	10,488,152	7,880,562	5,991,263	339,893,582
3.4	2.4	1.8	1.3	76.4
11,453,109	8,715,163	9,188,492	9,008,074	86,262,716
2.6	2.0	2.1	2.0	19.4
304,181	130,156	241,740	101,185	2,733,138
0.1	0.0	0.1	0.0	0.6
958,981	678,036	565,731	484,365	16,214,978
0.2	0.2	0.1	0.1	3.6
27,721,320	20,011,507	17,876,525	15,584,887	445,104,414
6.2	4.5	4.0	3.5	100.0

As might be expected, intercity travelers are much more likely to travel by airplane for longer trips, since the low travel speed of the automobile accumulates a substantial time penalty. Indeed, 70 percent of person trips are by aircraft for distances exceeding 1,000 miles. At these distances, the challenge facing a SATS aircraft is the competition from the commercial airline industry. According to the Air Transport Association, the average ticket cost per passenger-mile for jet airline travel on journeys of 1,200 miles (one-way) was about \$0.12 in 2000. The cost to carry four people the same distance in a small jet airplane, such as a Cessna Citation jet, would be between \$0.75 and \$1.25 per passenger-mile.

Uncertainties in Predicting Demand for Future Transportation System Concepts

As the above discussion illustrates, predicting user demand for a new transportation concept is a difficult task. It is made more complicated if the attributes of the envisioned system (e.g., vehicle type, markets served) are only partially defined and not expected to emerge for many years, or even decades. Demand for any given mode of transportation is influenced by many factors, including individual preferences and the availability of alternative modes and technologies, that can change over time. The longer the time frame, the more difficult it becomes to estimate future demand with any reliability. Box 4-1 contains a brief description of how demand studies are typically carried out when facing such uncertainty.

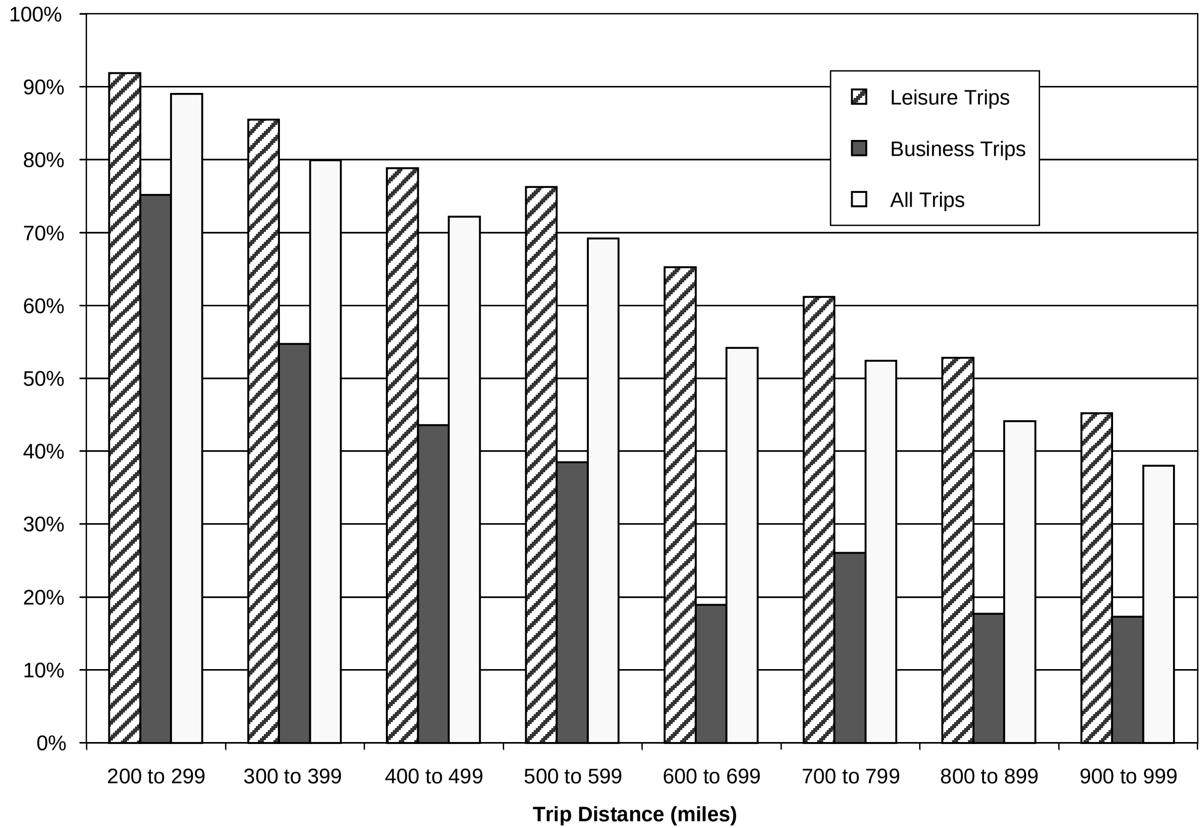


Figure 4-6 Share of intercity person trips made by personal motor vehicle for business and leisure travel, American Travel Survey, 1995.

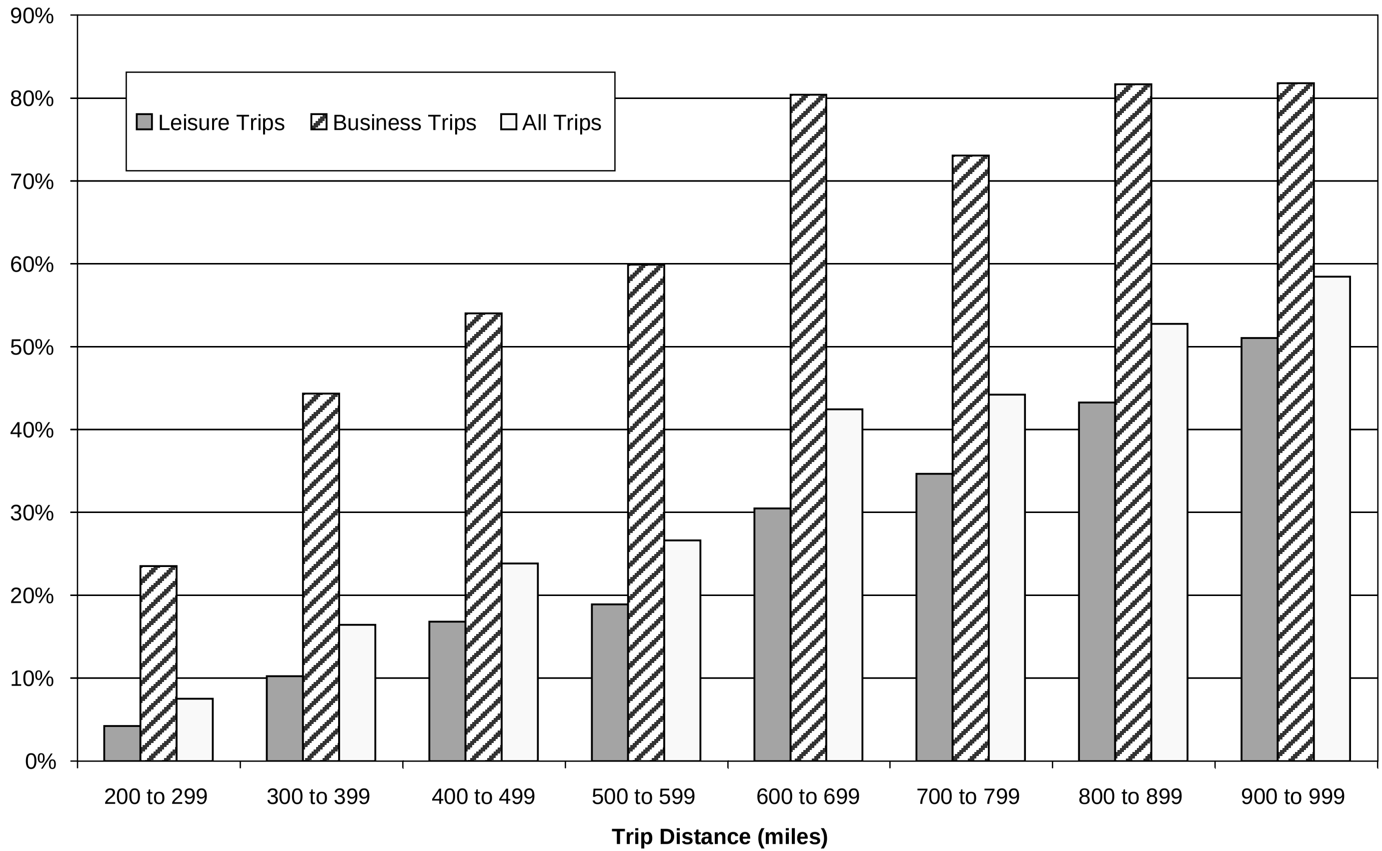


Figure 4-7 Share of intercity person trips made by air transportation (commercial and private) for business and leisure travel, American Travel Survey, 1995.

Table 4-2 Passenger Traffic on Scheduled Airlines at Largest Airports in and near Georgia, 1999, Second Quarter

Airport Code	City	Passengers (O&D) per Day (Each Way)	People Living in Georgia Within 40 Miles of Airport with Scheduled Service	Number of Counties	Percent of Georgia State Population	Median Household Income, 1997 ($)
Airports in Georgia with More Than 100 Passengers per Day Each Way						
ATL	Atlanta	37,600	3,555,000	15	45.6	43,000
SAV	Savannah	2,200	460,000	8	5.9	33,700
AGS	Augusta	650	357,000	7	4.6	34,400
CSG	Columbus	240	336,000	11	4.3	31,500
ABY	Albany	120	266,000	10	3.4	29,000
Nearby Airports in Bordering States with More Than 100 Passengers per Day Each Way						
JAX	Jacksonville, FL	6,800	91,000	3	1.2	32,200
TLH	Tallahassee, FL	1,200	92,000	3	1.2	26,800
CHA	Chattanooga, TN	800	213,000	4	2.7	33,800
Subtotal		49,610	5,370,000	61	69.0	39,390
Rest of state		230	2,418,240	99	31.0	29,650
State total		49,840	7,788,240	160	100.0	36,366

NOTE: O = origin; D = destination.
SOURCE: U.S. Department of Transportation Databank 1A (10 percent fare sample).

Box 4-1

Brief Primer on Transportation Demand Studies

Demand studies are used to evaluate the market for transportation technologies in particular applications. In general, these studies develop and apply models that estimate the utility of the transportation technology to all potential users. The estimated benefits can be used as inputs in more comprehensive benefit-cost evaluations to support public and private decisions about the merits of investing in the particular technology and its associated infrastructure. The information can also be used to improve the design of the technology to maximize private and social benefits. For the latter, demand models are often employed in combination with engineering studies of possible external effects of the technology that are not perceived by the user, such as noise, environmental effects, and safety performance.

Demand equations measure the volume of usage by an individual or group of individuals at any given price. The term "price" in this context is the set of variables representing those attributes that explain the decision to travel on the particular mode; for instance, travel time, schedule convenience, fare levels, and ride comfort. The mix of variables and their influence on demand usually differ among particular market segments, most notably between nonbusiness (leisure) and business travelers.

Demand equations are developed in a variety of ways. For existing travel modes, data are collected on the *observed behavior* of users, including characteristics of the travelers (such as their income, occupation, and travel group size), the trip purpose (vacation, business activity), and the characteristics of the travel mode itself and alternative modes (travel time, schedule convenience, access/egress convenience). For new or anticipated modes, data are usually collected using *stated preference* survey methods. Survey respondents believed to be representative of potential user groups are asked to choose between transportation options for particular trips they currently make. The options differ in the mix of attributes, such as travel time, schedule convenience, ride comfort, and fare levels. Either type of data (observed behavior and stated preference) or a combination of the two can be used with regression or other statistical techniques to develop demand equations that allow for particular variables to be weighted with respect to their influence on demand. For instance, the model can be used to estimate how changes in travel time will affect the number of trips on a given mode, holding the values of all other variables constant.

Much is known about the factors that influence demand for air travel on the basis of observations from the commercial airline, air taxi, and business aviation sectors. The effects on demand from new technologies that marginally improve certain aspects of air travel—for instance, that permit on-demand service without raising fares—can be estimated by using demand models based on empirical,

(continued)

Box 4-1 *(continued)* • **Brief Primer on Transportation Demand Studies**

or observed, data. However, if many variables affecting demand are dramatically changed because of, say, changes in technology, observed responses may have to be supplemented by stated preference surveys. To be reliable, such surveys must be carefully designed so that respondents are placed as much as possible in realistic choice situations and asked to enumerate their preferences after being given information on all the attributes of all their choice alternatives, including other transportation options. It is important that the surveyer not influence respondent choices by promoting one option over another, for example, by providing more information on the new option than on current options.

Finally, even demand models that are based on sound empirical and survey data must be applied with caution in forecasting user interest in a transportation mode that is not likely to emerge for several decades and that has attributes that can only be partially defined. A particular problem with predicting user demand for transportation systems that are not expected to be operational for several decades is that both observed and stated preference data reflect current consumer choices affected by existing conditions and technologies. Over time, one can expect—but not necessarily anticipate—changes in income levels, demographics, consumer preferences, availability of other transportation options, and other factors that can influence the demand for any given mode of transportation. However, in such cases, demand modeling can be useful in illuminating the many assumptions that must be examined in planning a system.

Central to most transportation demand studies are observations of how people behave when presented with various travel options. In this regard, the SATS concept is difficult to examine, because there is no real-world SATS experience to observe. Nevertheless, more general observations of travel patterns and preferences can provide some idea of the scale of potential demand. For instance, observations on demand gleaned from the commuter airline, air taxi, and business aviation sectors indicate that a large portion of the public prefers travel by jet aircraft over travel by propeller aircraft, for reasons cited earlier. This information suggests that a small aircraft transportation system dominated by propeller aircraft would require major improvements in vehicle ride quality, travel speed, reliability, and safety performance to generate user interest. Small jet aircraft are more likely to appeal to many travelers, but these vehicles have proved to be too expensive for use by most travelers, few of whom fly in private jets or charter publicly available air taxis. Small jets, to attract significant demand, would need to become much less expensive to produce and operate than they are today, especially for short-range application.

Regardless of vehicle type, a SATS oriented toward short- to medium-range intercity trips would need to compete for travelers, especially leisure travelers, not only with airlines but also with the automobile. Air taxi services have had little success in attracting these travelers, largely because the automobile offers so much utility at a relatively low cost of operations. The greatest appeal of SATS would therefore appear to be among time-sensitive business travelers who use commercial air taxis on an occasional to regular basis. As discussed earlier, however, most small airports and most people are located within areas served by commercial airlines. Even a cursory review of these data, commonly used in transportation demand studies, suggests that SATS would need to serve large markets in order to have more than a niche role in the nation's transportation system.

DESIRABILITY OF A SMALL AIRCRAFT TRANSPORTATION SYSTEM

In the previous section, consideration was given to the plausibility of the SATS concept emerging as planned. Many uncertainties were exposed, including a questionable potential for significant user demand. Yet, even if its plausibility could be affirmed, the desirability of such a transportation system would warrant closer scrutiny. The promise of SATS is that it will help reduce congestion and delay in commercial aviation and extend air service to more communities throughout the country. The potential for SATS to achieve these two goals and the possible effects of such a system on aviation safety and environmental quality are examined in this section. Whether the envisioned SATS is indeed desirable as an outcome warranting government promotion will depend to a large extent on its ability to meet its anticipated goals without having counteracting safety and environmental effects.

SATS and Decongestion

An anticipated benefit of the SATS concept is that full-scale deployment will help alleviate congestion and flight delays at commercial airports and in the nation's controlled airspace by diverting some passenger traffic and flights to smaller GA airports. The idea is that this system, in addition to inducing new travel, would absorb a substantial portion of air travel that would otherwise have been accommodated by airlines. This shift could free up additional capacity in the commercial aviation system and, at a minimum, keep the system from becoming more congested. The public would benefit from such an outcome not only because of reduced congestion and associated flight delays, but also because of the reduced need to invest in more conventional airport and air traffic control capacity. This assumes that SATS deployment would require only limited public investment in supporting infrastructure.

The most far-reaching SATS vision postulates that this new transportation system will combine with other advances in communications and information technology to cause a growing number of people and businesses to move outside large metropolitan areas, often referred to as "exurbia." If SATS facilitates demographic changes that limit urban-oriented growth, it would also ease congestion pressures on the commercial aviation sector at major metropolitan airports. In this regard, SATS is viewed as a potential contributor to increasingly dispersed, or scattered, settlement patterns in the United States. Yet, demographic trends do not point to the emergence of such patterns, despite repeated predictions of exurban growth for the past two or three decades.[7] As noted earlier, the trend in the United States, as in all

[7] See, for instance, Naisbitt (1982).

developed countries, has been toward increased urbanization, leading to the expansion of metropolitan areas in both population and land area.

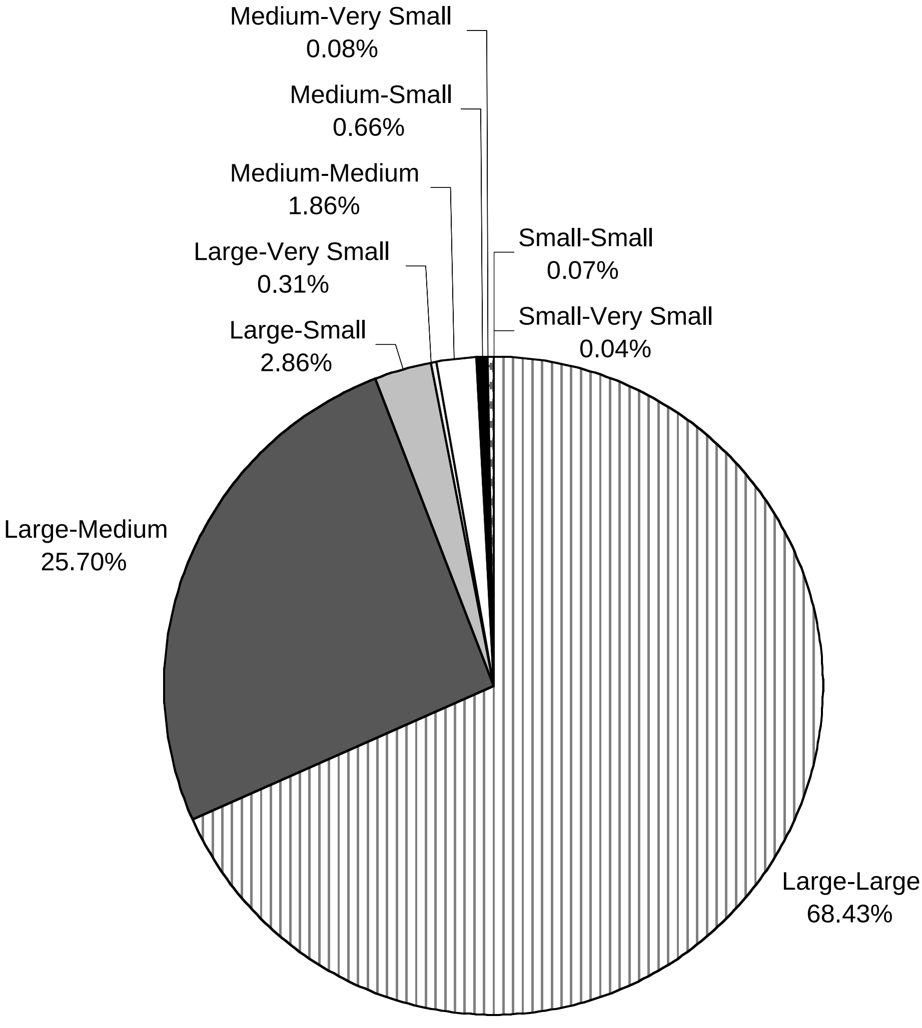
Another anticipated outcome is that SATS will shift passenger traffic out of the hub-and-spoke system by diverting connecting passengers from these systems. The idea is that many passengers from small cities could use SATS to fly directly to their intended destination without making a transfer at a large hub airport; for instance, by flying straight from Erie to Allentown, Pennsylvania, without having to change planes in Pittsburgh.

The decongestion effects of this expected outcome are open to question for several reasons. For one, the number of travelers in small-city airline markets—that is, those who begin and end their trips in small commercial-service airports—accounts for a very small percentage of all airline passengers, as shown in Figure 4-8 and in Table 4-3. Most passengers originate or end trips in large airports. A system that has little influence on passenger volumes in these markets has limited ability to affect congestion in the national airspace system.

In this regard, it is important to note that flights from small cities to the hub airports of larger cities carry many passengers making connections to other cities, often on jet airliners. Since SATS service is not a substitute for these trips, to the extent that SATS vehicles are used at all they may not reduce the number of commuter flights from small cities to hubs, but only the size of the aircraft flying from these cities. The replacement of larger, faster aircraft by smaller, slower aircraft, including turboprops for regional jets, could result in poorer service in some smaller cities. Thus, the use of such aircraft could even reduce capacity at hub airports by increasing congestion (e.g., because of the need to increase the spacing of smaller aircraft and larger jet aircraft in the traffic streams of terminal areas).

Another reason to question the decongestion promise of SATS is that capacity constraints are not a problem throughout the commercial air transportation system, but mainly at a few key airports that contribute to delays elsewhere in the system. If SATS has little effect on passenger traffic and flight volumes in these bottleneck airports, as appears likely, then SATS holds only limited potential to relieve congestion and reduce flight delays in the entire system. Moreover, many delay episodes are caused by severe weather, such as thunderstorms. The incidence and severity of weather-related problems, as well as delays caused by other factors such as aircraft mechanical problems, are affected only indirectly by the volume of passengers passing through the system.

Finally, another anticipated means by which SATS might shift passenger traffic out of the hub-and-spoke system is by allowing some travelers who normally fly from large commercial airports to fly from smaller reliever airports located in the suburbs of large metropolitan areas. Some travelers might be attracted by the convenience of these airports, some of which have passenger amenities and are generally less crowded and served by relatively uncongested roadways. For SATS to serve these satellite airports, however, the aircraft must be able to function within the already heavy and complex air traffic over large metropolitan areas. As described in Chapter 2, the airspace over the country's largest metropolitan areas, the origin and destination points for most air travelers, is closely controlled. The proximity of reliever airports to major metropolitan areas raises the possibility that SATS activity at relievers will have the unintended effect of changing the mix and increasing the



Total passenger trips per day = 1,150,000

Figure 4-8 Share of daily passenger trips on scheduled airlines by size of origin and destination airports, 1999, second quarter. Note: "Large-Large" means that the airports on both ends of the trip (origin and final destination) are large airports (handling 5,000 or more outbound trips per day). See definitions, data, and sources in accompanying Table 4-3.

Table 4-3 Domestic Airline Passenger Trips by Market Size and Distance, 1999 Second Quarter

		Passengers per Day Each Way for Trip Length (Miles)							
Airport Pair Market	Number of Markets	75 to 200	201 to 400	401 to 600	601 to 900	901 to 1,200	1,201 to 3,000	Total	Percentage
Large to large	1,892	15,387	64,682	50,271	69,257	68,085	125,499	393,181	68.43
Large to medium	6,076	8,882	39,490	18,071	24,659	22,500	34,043	147,645	25.70
Large to small	7,128	1,557	2,207	1,748	2,722	3,013	5,170	16,417	2.86
Large to very small	3,377	190	323	191	294	315	466	1,779	0.31
Medium to medium	4,194	84	1,454	2,271	3,149	1,614	2,127	10,699	1.86
Medium to small	6,560	276	790	759	721	425	837	3,808	0.66
Medium to very small	1,572	84	96	65	76	53	72	446	0.08
Small to small	1,744	12	78	80	60	70	118	418	0.07
Small to very small	477	137	10	9	13	19	19	207	0.04
Total	33,020	26,609	109,130	73,465	100,951	96,094	168,351	574,600	100.00
Percentage		4.63	18.99	12.79	17.57	16.72	29.30	100.00	

NOTE: Passenger data are based on 10 percent ticket sample by DOT. Connecting passenger enplanements are not included in origin and destination (O&D) counts.
Only large carriers are required to report these data to DOT; however, because of code sharing agreements between large and small carriers, many trips on commuter carriers are included.
Large airport = 50,000 to 5,001 outbound domestic passengers (O&D) per day—from Los Angeles (LAX), Atlanta, and Chicago O'Hare to Omaha, Tucson, and Oklahoma City. About 65 airports in total.
Medium airport = 5,000 to 501 outbound domestic passenger trips (O&D) per day—from Buffalo, Tulsa, and Anchorage to Bozeman, MT; Lafayette, LA; and Traverse City, MI. About 110 airports in total.
Small airport = 500 to 51 outbound domestic passenger trips (O&D) per day—from Erie, PA; Charlottesville, VA; and Fayetteville, AR, to Clarksburg, WV; Dubois, PA; and Brainerd, MN. About 175 airports in total.
Very small airport = 50 to 5 outbound domestic passenger trips (O&D) per day—from Staunton, VA; Pierre, SD; and Manhattan, KS, to Jonesboro, AR; Sidney, MT; and Bluefield, WV. About 200 aiports in total.

complexity of the airspace around major metropolitan airports, thus further taxing capacity in the commercial aviation sector.

SATS and Air Service in Small Communities

As discussed in Chapter 2, there are about 550 commercial-service airports in the United States, and more than half of these airports are in small cities. The smallest 200 small-city airports have 4 to 16 departures per day, usually on turboprop aircraft flown by scheduled commuter airlines. The commuter airlines fly mainly to large hub airports, where travelers from small markets can make connections to their final destinations. In being connected to large hub airports, travelers in small markets gain access to hundreds of city-pair markets to a degree that is not possible through direct, point-to-point service. For reasons explained in Chapter 2, the introduction of hub-and-spoke systems over the past two decades has been especially beneficial to travelers in lightly traveled markets. The consolidation of traffic flows at hub airports allows for more scheduled flights and the use of larger aircraft, since travelers originating from and headed to many different locations can share aircraft for parts of their trips. A problem with this system is that travelers in small markets often must make time-consuming connections, even for short trips.

Airlines have a strong economic incentive to add markets to their hub networks to maximize passenger flows. The number of city-pairs served increases with the square of the number of spokes,[8] adding more potential customers. Although many of the individual city-pairs created may have only a few passengers per year, the sheer number of such markets created increases the volume of traffic heading to and from the small city. At the same time, airlines recognize the need to avoid duplicative operations in small markets that would result from serving multiple airports in the region. The goal is to provide convenient scheduled service without spreading passenger flows at any one airport so thinly that reasonable flight frequencies cannot be supported, increasingly smaller aircraft must be used, and basic airport services and amenities cannot be sustained.

To the extent that SATS aircraft are desirable to travelers (that is, they have characteristics that are generally acceptable) and can be produced and operated at low cost, commuter airlines could use them to provide more service to small airports, including some that are not served today. Commuter airlines serve mostly business travelers, who place a high value on airport convenience and frequent flights. The network of cities that commuter airlines serve represents a balance of business traveler demands for frequent flights, fast and comfortable service, and access to convenient locations. The economic constraints that govern the type of aircraft that are cost-efficient for the number of passengers and the extent to which airports can afford user-desired services and amenities are also taken into consideration. Although commuter airline service is geared to the time-sensitive and high-fare business traveler, leisure travelers often benefit from this service by filling unused seats at marginal cost. Introducing small jet aircraft that are easier to fly, perhaps requiring only one pilot, and much less expensive to produce than small jets today could alter this

[8] The number of city-pairs created in a hub-and-spoke network is equivalent to $\frac{1}{2}(x + x^2)$, where x is the number of spokes (Wheeler 1989).

balance, making more small airports economical to serve in the airlines' hub-and-spoke networks.

The idea that SATS aircraft could efficiently serve short- to medium-range small-city markets on a nonstop (point-to-point) basis presents a far more significant economic challenge for commercial airline service. For a scheduled commuter airline, or any airline operating a hub-and-spoke network, there is little to be gained from providing service that bypasses the network. The diversion of passengers depresses load factors on network flights, which could lead to service cutbacks. Such an outcome could be especially problematic for small cities if SATS aircraft were to siphon passengers from the hub-and-spoke system, leaving only those small-city passengers connecting for longer-distance flights. The efficiency of the hub-and-spoke system is contingent on the mixing of passengers headed to numerous places, both near and far.

Air taxi operators, rather than network airlines, are the most likely candidates to adapt such aircraft to their operations. Air taxis currently serve many small cities; however, most air taxi service is in large markets, including the nation's largest commercial-service airports and busy metropolitan reliever airports (see Chapter 2). In many respects, such a pattern is to be expected, since air taxis primarily serve business travelers, and most business is conducted in large urban areas. SATS could make air taxi service more economical for more travelers where it is in demand today; whether SATS would generate any significant demand outside the large business markets is unclear. As discussed above, small communities have relatively few business travelers, and leisure travelers are highly sensitive to the price of travel, especially for short or medium-distance trips that can be accomplished with an automobile. An aircraft that is easier and less costly to fly for on-demand service would have utility to some business travelers in small markets; however, its potential to compete with the automobile and efficient hub-and-spoke airline operations appears to be much more limited.

SATS and Air Transportation Safety

More than any other mode of transportation, air travel is highly regulated for safety assurance. Nearly all aspects of aviation, from the design and maintenance of individual aircraft parts to the training and retraining of pilots, are subject to stringent regulation aimed at ensuring and progressively improving aviation safety. One of the goals of the SATS research and technology program is to improve the safety of small aircraft operations, a long-standing concern. Many of the individual capabilities and technologies being pursued under the SATS umbrella could confer safety benefits on the conventional GA sector; for instance, by reducing pilot workload and improving the quality and timeliness of information for pilot decision making.

Whether the full-scale SATS concept could improve the overall safety of air transportation is a more complicated question. To predict net safety effects, it is first necessary to understand where the users are likely to come from—for instance, whether they would otherwise have flown on the larger aircraft of scheduled airlines, driven automobiles, used other modes of transportation, or not traveled at all. The anticipated role of SATS in alleviating congestion in the commercial aviation sector suggests that diverting passengers from larger airliners is an intended outcome. Whether this outcome would confer net safety benefits on the public is questionable, since the larger jets flown by airlines have safety records that are many times superior to those of GA (as discussed in Chapter 3). The replacement of a smaller number of larger airline-operated aircraft many smaller, albeit advanced, aircraft operated by nonprofessional pilots raises the possibility of a safety decrement, given the comparative safety performance of small and large aircraft.

Highway travel in general is considered less safe than air travel.[9] To the extent that SATS users would otherwise have driven automobiles on their intercity trips, transportation safety might be expected to improve for these travelers. However, for reasons discussed earlier, SATS appears to offer limited potential for traffic diversion from the automobile for short- to medium-range trips, largely because of the automobile's flexibility and low out-of-pocket costs.

SATS and Environmental Compatibility

As described in detail in Chapter 3, environmental concerns have important influences on the use and expansion of airports, both large and small. Communities near airports are often vocal and politically influential opponents of airport expansions, particularly because of noise concerns. Because aviation noise has proved to be so problematic (and widespread), the assumption that small airports could readily handle many more SATS aircraft without investing in costly noise mitigations (such as land purchases to create noise buffer zones) warrants more careful consideration. Moreover, as noted, residents near airports are known to object to increased aircraft flight activity for other reasons, including concerns over congestion on local roads leading to and from the airport and over the safety of aircraft flying over homes and other structures. Whatever the source of concern, such adverse responses should be expected and not underestimated.

Likewise, air quality concerns are certain to arise in connection with implementation of the SATS concept. Even if SATS aircraft engines emit fewer air pollutants than conventional small aircraft engines, increases in total operations and shifts in aircraft fleet mixes from piston-engine GA aircraft to more turbofan SATS aircraft may increase total pollutant emissions at small airports. Increases in these emissions are likely to compel assessment and action by public agencies and may prompt public opposition to SATS deployment, as well as the need for costly mitigations. Without more information on the specific circumstances (e.g., adjacent land uses, environmental sensitivities) of individual airports, it is reasonable to assume that prevailing use patterns are compatible with existing runway configurations, location, and physical infrastructure. Fundamentally different traffic mixes and levels would create other needs, including further environmental controls. Noise constraints on remote and rural airports might be less restrictive; however, such airports are least likely to have utility.

Finally, additional thousands, or even hundreds of thousands, of small aircraft cruising in the nation's airways are bound to have environmental effects that are not yet understood. One area of uncertainty is resultant changes in energy use and

[9] Although Evans et al. (1990) estimated, on the basis of data from the 1980s, that for trips up to 600 miles a business traveler (typified as a middle-aged male, sober, and wearing a seat belt) had a lower risk of fatality driving on a rural Interstate highway in daylight than flying in a piston-engine commuter airplane.

environmental implications. Small aircraft use less fuel per mile than large aircraft, but they are less fuel-efficient on a passenger-mile basis, particularly in the case of jets. As an example, a small 5-seat jet that consumes 100 gallons of fuel per flight hour covering 400 miles consumes 1 gallon of fuel for every 20 seat-miles. In comparison, a 50-seat regional jet that consumes about 500 gallons of fuel per hour consumes 1 gallon of fuel for every 40 seat-miles. Hence, the use of many more small aircraft to carry the same number of people once carried in larger aircraft could bring about much higher fuel usage. The environmental effects of such an increase in fuel consumption, including the atmospheric effects, warrant explicit examination.

KEY FINDINGS FROM ANALYSES

It is important to distinguish the individual capabilities and technologies being pursued under the SATS umbrella from the SATS concept itself. The specific capabilities and technologies can have merit individually or collectively—for instance, in improving aspects of GA safety—even if the full-scale SATS concept does not. The justification for promoting and planning a full-scale *system* is that it will confer large public benefits, primarily by helping to alleviate congestion in the national airspace system and extend much-needed air service to more communities. The SATS concept is thus being used to guide decisions about the various kinds of technologies that should be furthered through NASA research and development and, conversely, those that should not. It is also being offered as a guide for public investment decisions about airport and airspace infrastructure development and deployment. As such, the SATS concept deserves examination.

The analyses in this chapter raise many important questions about the SATS concept. For the concept to be plausible—that is, credible enough to promote and plan for—the following assumptions must hold:

- Many major technological advances in propulsion, flight control, communications, navigation, surveillance, and manufacturing techniques can be achieved and coordinated to occur at about the same time. They can be validated by producers and regulators to ensure a high degree of safety when used in a new operating environment and by operators having piloting skills and training that differ markedly from those of today's pilots.
- Much larger numbers of people will be both willing and able to serve as pilots.
- Growth in demand for SATS aircraft will prompt, and be propelled by, large reductions in the cost of producing advanced, high-performance small aircraft, primarily as a result of improvements in aircraft manufacturing and certification processes and scale economies not previously exhibited in the GA industry.
- Large numbers of travelers will accept propeller aircraft, including piston-engine airplanes, as a mode of intercity transportation, and these aircraft can be made much more comfortable to fly in, more reliable, faster, safer, and more affordable.
- Small jet aircraft can be produced in mass quantities at much lower cost than today's jet aircraft; designed to operate on shorter, lightly maintained runways; and made capable of operating efficiently on short-range trips and in lower-altitude, uncontrolled airspace that will not interfere with commercial flights.

• A small aircraft transportation system oriented toward short- to medium-range intercity trips (200 to 1,000 miles) can compete for travelers with the low-cost, adaptable automobile, particularly among price-sensitive leisure travelers who make most trips under 1,000 miles.

• Counter to current demographic trends, increasing numbers of people and businesses with a propensity for travel and a high value of time will locate outside metropolitan areas, causing GA airports in small and rural communities to become more convenient to more people. Alternatively, SATS aircraft can be made capable of operating in the complex and congested airspace in and around the nation's metropolitan centers, which is currently where most people live, most businesses are located, and most intercity travel demand occurs.

• Scheduled airlines, including commuter carriers that serve small cities, will not adapt these same advanced technologies effectively enough to make SATS less advantageous.

This is a long list of improbabilities. Failure of any of them puts the SATS concept at risk. Moreover, the total SATS concept would not address the causes of aviation congestion and delay because it would have little, if any, effect on capacity and operations in the nation's busiest and most congestion-prone airports and airways. Whether SATS would improve air service in small communities, to the benefit of the public and travelers in small markets, is likewise unclear. Scheduled commuter airlines now serve most small communities, though frequently at regional airports and with service oriented toward hub-and-spoke systems. The on-demand, nonstop, short-range service envisioned in the SATS concept would be a niche service, unlikely to be competitive with network carriers, which are themselves likely to adopt many of the advanced technologies to enhance their own service offerings.

The prospect of diverting passengers from larger commercial airliners to small aircraft operated by private pilots and to airports with limited safety services should be examined in light of long-standing goals to enhance transportation safety. The safety record of small aircraft has been improving but remains poor compared with that of aircraft operated by scheduled airlines. A high degree of utility from the use of small aircraft for transportation and the introduction of technologies that improve small aircraft safety might justify an emphasis on SATS; however, only the latter is evident. Likewise, the prospects of environmental gains from a SATS oriented toward more fuel-intensive vehicles flying with fewer occupants at low altitudes are not apparent. The net effect on the environment could be deleterious.

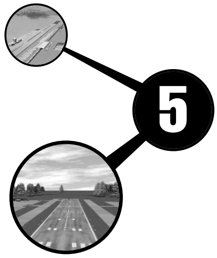
REFERENCES

Abbreviation

GAMA General Aviation Manufacturers Association

Brand, D. 1996. *The Values of Time Savings for Intercity Air and Auto Travelers for Trips Under 500 Miles in the U.S.* Office of the Secretary of Transportation, U.S. Department of Transportation, June.

Census Bureau. 1998. *Statistical Abstract*. Washington, D.C.
Evans, L., M. Frick, and R. Schwing. 1990. Is It Safer to Fly or to Drive?—A Problem in Risk Communication. *Risk Analysis,* Vol. 10, No. 2, pp. 239–246.
GAMA. 1999. *1999 General Aviation Statistical Databook*. Washington, D.C.
Levinson, D. M., and D. Gillen. 1998. The Full Cost of Intercity Highway Transportation. *Transportation Research D,* Vol. 3, No. 4, July, pp. 207–223.
Naisbitt, J. 1982. *Megatrends: Ten New Directions Transforming Our Lives*. Warner Books, New York.
Wheeler, C. F. 1989. Strategies for Maximizing the Profitability of Airline Hub-and-Spoke Networks. In *Transportation Research Record 1214,* TRB, National Research Council, Washington, D.C., pp. 1–9.



5 Summary Assessment and Advice

In this chapter, the National Aeronautics and Space Administration's (NASA's) concept of a Small Aircraft Transportation System (SATS) and the main elements of its 5-year program to evaluate and demonstrate technologies leading up to the envisioned system are summarized. The key findings from the analysis of the SATS concept are then described. On the basis of these findings, the committee offers its conclusions concerning the use of the SATS concept to guide technology development and deployment. Finally, recommendations on ways to improve the SATS program by making it more responsive to the needs of aviation users and the public are given.

RECAP OF SATS CONCEPT AND TECHNOLOGY PROGRAM

Among the overarching goals of NASA's Office of Aerospace Technology are to "revolutionize aviation," "enable people to move, faster and farther, anytime, anywhere," and "reduce inter-city doorstep-to-destination transportation time by 50 percent in 10 years and by 67 percent in 25 years."[1] With these goals in mind, NASA has set forth a vision under which advanced small aircraft, of a size commonly used in general aviation (GA) today, will be flown routinely between the country's small GA airports, transporting individuals, families, and groups of business travelers. The vision anticipates major advances in avionics, engines, airframes, flight control, manufacturing, communications, and navigation systems and their application to thousands of small fixed-wing aircraft over the next several decades. These advanced aircraft will be safer and easier to operate and much more comfortable, reliable, and affordable than GA aircraft today. The enhancements will make many more of the country's 5,000 small airports much more practical and available for intercity transportation without requiring large public investments in airport and air traffic control infrastructure.

To further this concept, NASA has received funding ($9 million for FY 2001) from Congress to begin a 5-year program to identify, develop, and demonstrate "key airborne technologies for precise guided accessibility in small aircraft in near all-weather conditions to virtually any small airport in non-radar, non-towered airspace."[2] Specifically, Congress has charged NASA with collaborating with the

[1] NASA Office of Aerospace Technology, Small Aircraft Transportation System Program, Version V0.8.

[2] NASA SATS Program Plan, V. 8, p. 1.

private sector to develop and evaluate technologies that can provide the following four capabilities:[3]

- High-volume operations at airports without control towers or terminal radar facilities,
- Lower adverse weather landing minimums at minimally equipped landing facilities,
- Integration of SATS aircraft into a higher en route air traffic control system with complex flows and slower aircraft, and
- Improved ability of single-pilot aircraft to function in complex airspace in an evolving national airspace system.

The SATS program to demonstrate these capabilities, which NASA estimates will require approximately $69 million in government funding over the 5-year period, is now under way. The program plan states that the goal of the public-private partnership program is to provide "the technical and economic basis for national investment and policy decisions to develop a small aircraft transportation system." The first phase will entail development of technologies pertinent to each of the congressionally identified capabilities, including technologies for aircraft separation and sequencing, software-enabled controls, emergency automated landing, and highway-in-the sky guidance. Candidate technologies in each area will be screened and selected for further development and evaluation. In the program's final year, NASA hopes to integrate technologies to exhibit three or more of the capabilities in a public demonstration that includes flight demonstrations. It also plans to assess the economic viability, environmental impacts, and community acceptance of an "end-state" SATS.

SUMMARY OF KEY FINDINGS

NASA has offered two main justifications for pursuing and promoting this concept. The first is that SATS would increase transportation system capacity by shifting travel demand from the most congested parts of the aviation system to more lightly used parts without requiring significant infrastructure investment. The second is that SATS would enhance and extend air service to many small communities. The committee's analyses of the potential for SATS to achieve these goals, while also meeting other public-interest goals such as ensuring transportation safety and environmental compatibility, raise many uncertainties and questions about the SATS premise and led to the following conclusions:

- **There is little evidence to suggest that SATS aircraft can be made affordable for use by the general public.** The aircraft envisioned for SATS would need to be far more advanced and sophisticated than even the highest-performing small GA aircraft of today to achieve the standards of safety, ease of use and maintenance, and environmental friendliness that would attract large numbers of users. The committee found no evidence to suggest that such aircraft could be made affordable for use

[3] See House Report 106-988 Appropriating Funds for NASA SATS Evaluations (October 2001).

by large numbers of people and businesses. The complexity and cost of manufacturing GA aircraft have typically increased as aircraft capabilities have improved and expanded. The aircraft industry has not yet demonstrated a strong potential for volume-related economies that might greatly lower the cost of producing such advanced aircraft in large quantities. Although they lack nearly all of the advanced capabilities envisioned for SATS, the smallest jet aircraft in the early stages of preproduction planning today are projected to sell for about $1 million each. The least expensive small aircraft—and those best suited for use in most small airports—are piston-engine propeller airplanes. These aircraft do not appeal to most travelers because of their interior noise and vibrations, inability to fly well above most weather, frequent maintenance, and poorer safety record than jets.

- **SATS has minimal potential to attract users if it does not, as conceived, serve the nation's major metropolitan areas.** The expectation that large numbers of people will use advanced small aircraft to fly between airports in small, nonmetropolitan communities runs counter to long-standing travel patterns and demographic and economic trends. Most people and businesses are located in metropolitan areas, which are the origins and destinations of most intercity passenger trips. These patterns have strengthened over time, even as transportation and communications systems have improved. Metropolitan areas account for a large majority of all business travelers, as well as higher-income households, which have a high propensity for air travel. The committee found no evidence, only speculation, to suggest that these patterns are changing or likely to change as a result of the emergence of a new transportation system centered on the use of small airports and advanced small aircraft. Because the nation's large metropolitan areas account for most commercial airline traffic, they present a highly complex operating environment for small, private aircraft—a significant challenge for SATS application. An intercity transportation system that does not serve these markets will, in effect, neglect the largest and most likely pool of prospective users.
- **SATS promises limited appeal to price-sensitive leisure travelers, who make most intercity trips.** Most intercity travelers are highly sensitive to the price of travel, especially in the short- to medium-length trip markets envisioned for SATS. Leisure travelers, who account for the majority of all intercity trips under 1,000 miles, usually travel by automobile, largely because of the versatility it offers and the low additional cost per passenger. In general, air service frequency, speed, and convenience are less important attributes to leisure travelers than they are to business travelers, who are often willing to pay a premium for such service, while leisure travelers will not. In addition to being inexpensive to operate, automobiles have other qualities that are highly valued; for instance, they can carry large amounts of baggage, provide door-to-door transportation, and offer a means of local transportation at the destination. Because SATS is envisioned as a common mode of transportation for short to medium-length trips, these competitive disadvantages relative to the automobile present major shortcomings.
- **Infrastructure limitations and environmental concerns at small airports are likely to present large obstacles to SATS deployment.** Most of the country's 5,000 public-use airports have minimal infrastructure and support services, which limits their suitability for frequent and routine transportation usage. About half of

public-use airports have a paved runway that is at least 4,000 feet long and thus potentially capable of handling small jet aircraft; yet, most of these airports would likely require further infrastructure investments. Few public-use airports, for instance, have on-site fire and rescue stations or intensive programs for monitoring and maintaining runway condition. While travelers appreciate airport proximity to their points of origin and destination, they also value airport services, such as ground transportation, automobile parking, and passenger waiting areas. Travelers are willing to sacrifice some proximity to obtain such services, which are costly and impractical to provide at airports with limited passenger volumes. Of the nation's 2,800 top-quality GA airports that receive federal aid, more than 70 percent are located within 75 miles of a commercial-service airport offering scheduled airline service and passenger facilities and services. Most GA airports with sophisticated infrastructure and services are located in large metropolitan areas and are heavily used. Most public-use airports located more than 75 miles from a commercial airport are situated in rural areas and have limited potential to attract users. Without information to indicate otherwise, it is reasonable to assume that these small airports are best suited to accommodate the level and mix of traffic activity existing today. Significant changes may require infrastructure modifications as well as investments to address noise and other environmental concerns that have proved to be major impediments to the expansion of airports of all sizes and types.

- **Many technical and practical challenges await the development and deployment of SATS technologies.** Safety is paramount in aviation, particularly for passenger transportation. Hence, any changes in aviation, from new methods of air traffic control and pilot training and certification procedures to new aircraft materials and manufacturing processes, are subject to intense and thorough safety evaluations and validations that can take much time. The idea that many nonevolutionary changes in aircraft design, propulsion, flight control, communications, navigation, surveillance, and manufacturing techniques could emerge at about the same time and be accepted as safe by users, manufacturers, insurers, and regulators is highly questionable. Assessing and ensuring the safety of any one of the new capabilities and advanced technologies envisioned for SATS would likely present many technical and practical challenges. The idea that many such changes could occur almost simultaneously in a new operating environment with a much different pool of pilots seems unreasonable without assuming a fundamental change in safety expectations and procedures. The magnitude of this safety assurance challenge alone, which has been largely neglected in the NASA program, is sufficient to call into question the plausibility of the SATS vision.
- **SATS has the potential for undesirable outcomes.** If SATS does not access major metropolitan markets, it will likely have little, if any, meaningful effect on operations at the nation's busiest and most capacity-constrained large airports, where most delays in the commercial air transportation system occur. Yet, if SATS does access these markets, the mixing of SATS with non-SATS aircraft in heavily used, controlled airspace and airports could create significant traffic management challenges. Moreover, a well-used SATS could have negative net effects on aviation's environmental compatibility by shifting travelers from larger aircraft, each carrying dozens of travelers, to smaller aircraft, each carrying a handful of travelers. Such a

shift, resulting in a net increase in aircraft operations to carry the same number of travelers, would almost certainly increase aggregate energy use as well as emissions of various pollutants and would have other environmental impacts, even if SATS vehicles offered considerable gains in fuel efficiency. A shift in aviation activity to small, currently underutilized airports could also result in increased impacts to natural resources in the vicinity of the airports, including bodies of water, wetlands, and sensitive habitat. These possible outcomes of SATS have gone largely unexamined.

CONCLUSIONS

NASA asked the study committee to answer the following two questions:

1. Do the relative merits of the SATS concept, in whole or in part, contribute to addressing travel demand in coming decades with sufficient net benefit to warrant public investment in technology and infrastructure development and deployment?
2. What are the most important steps that should be taken at the national, state, and local levels in support of the SATS deployment?

As explained in Chapter 1, the committee interprets the first question as a request for an assessment of whether the SATS concept is sufficiently plausible and desirable to serve as a guide for government investments in technology development and deployment. The second question asks how public investment in those aspects of the SATS concept that have merit—assumed to mean the component capabilities and technologies of SATS—can best be accomplished.

In answer to the first question, the committee finds that the full-scale SATS concept presents a highly unlikely and potentially undesirable outcome. The findings summarized above suggest that such a system is not likely to emerge as conceived or contribute substantially to satisfying travel demand. It is limited by the affordability of the conceived vehicles, the lack of demand between origin and destination points proposed in the concept, and complex system issues ranging from airspace design and management to safety and environmental effects. The potential for such a system to induce significant new travel demand is speculative. Moreover, the committee believes that the positing of any such preconceived system, in which a single and definitive vehicle concept is used to guide research and development, could inhibit the evolution of alternative outcomes that may result from technological opportunities and economic and social need.

In answer to the second question, the committee views favorably and endorses much of the technological research and development contained in the SATS program, as well as the approach of using NASA and other government resources and expertise to leverage and stimulate private-sector investment in aeronautics research and development. The committee does not, however, support public-sector investment in SATS deployment or the use of the SATS concept itself as a guide for making technology development and deployment decisions.

There is reason to believe that the component capabilities and technologies being pursued now under the SATS umbrella can enhance safety and confer other benefits on users of both general and commercial aviation. The committee's recommendations for better orienting these research and technology efforts toward achieving such public benefits are given in the next section.

RECOMMENDATIONS

Aviation has a crucial role in the nation's transportation system, and the public sector has a large influence on it. The federal government funds and operates the nation's airspace system and sets standards governing the design, manufacture, maintenance, and operation of aircraft. It works with state and local governments to help finance the nation's airports and to ensure aviation's safety and environmental compatibility. Therefore, the public sector has reason to have a keen interest in sponsoring research on technologies that can make civil aviation safer, reduce its potential harm to the environment, and improve its overall productivity and efficiency.

NASA has traditionally played an important role in supporting and conducting this research on behalf of the federal government. However, NASA's strength in civil aeronautics is in technology research and development, and not in defining, developing, and promoting new transportation systems. Accordingly, **the committee urges NASA to join with other relevant government agencies, led by the U.S. Department of Transportation, in undertaking forward-looking studies of civil aviation needs and opportunities to ensure that they are being addressed appropriately through government-funded technology research and development. Working with the Federal Aviation Administration (FAA), the National Transportation Safety Board, and other government agencies with operational and technological expertise, NASA should gain a better understanding of these needs and how to structure aeronautics research and development to help meet them.**

It is crucial that major elements of NASA's technology research be supported by a strong empirical understanding of important civil aviation needs. The technological capabilities now being pursued under the SATS program offer the potential to address some such needs; for instance, by allowing more reliable and safe operations during inclement weather at more small airports and by improving the accuracy, timeliness, and relevance of the weather, traffic, and airport information provided to GA pilots. Therefore, the committee believes that NASA should continue its efforts to advance these capabilities; however, it should orient the program goals toward toward realistic views of transportation operations and needs, rather than furthering the unpromising SATS concept. **Thus, the committee recommends that NASA prioritize the capabilities and technologies that are now being pursued in the SATS program according to a clearly defined set of civil aviation needs that these capabilities and technologies can help meet.** Progress in meeting such needs through advanced technology will likely have other positive effects such as improving the overall utility of small aircraft in transportation. However, such outcomes, which are uncertain, should not justify or guide the technology program. A safer, more efficient, and more environmentally acceptable GA sector is likely to have greater utility, whatever the specific form it takes.

To be sure, NASA ought to be concerned that the technologies that it does pursue are practical from the standpoint of commercialization and do not have unacceptable side effects. Thus, NASA should work closely with commercial developers and users. The private sector understands the market for technologies, at least in regard to current operations, and can provide guidance on applications that appear likely. The level of interest by commercial developers and users can help determine which technology developments merit further attention. Likewise, NASA must continue to involve FAA and state and local agencies in evaluating this technology program. Their involvement is essential to understanding constraints on technology deployment, such as noise, energy efficiency, air pollutant emissions, safety, public finance, and other environmental and social concerns.

CONCLUDING OBSERVATIONS

The SATS concept has been presented as a way to provide the public with benefits through an expansion of usable airport and airspace capacity without the need for large public-sector investments. The committee did not find justification for this expected outcome and therefore urges NASA to put aside the SATS concept and recommit the program to other, more achievable, goals. The capabilities and technologies being developed under the SATS program may prove useful in ways that are not now apparent. Indeed, many system and vehicle configurations not envisioned for the current SATS concept may emerge. The committee urges NASA to keep such possibilities in mind.

Finally, on the basis of the findings from the review of this program and reviews by others of similar activities,[4] the committee recognizes that technology research programs may become oriented toward justifying and furthering particular areas of research without adequately reflecting a connection with real-world needs. The committee commends NASA for requesting this review, which offers the opportunity for the perspectives and advice of experts in transportation and other disciplines not involved in the conception of SATS to be brought to bear. Additional external reviews of program goals and the technical progress toward achieving them are desirable as the restructured program proceeds.

REFERENCE

Abbreviation

TRB Transportation Research Board

TRB. 1998. *Special Report 253: National Automated Highway System Research Program: A Review*. National Research Council, Washington, D.C.

[4] For example, several committee members served on the National Research Council's Committee for a Review of the National Automated Highway System Consortium. That committee reached similar conclusions about the need for external reviews and noted their successful use for other research and development activities, including the Partnership for a New Generation of Vehicles (TRB 1998).

Afterword: Small Aircraft Transportation System and Aviation Security

Much has changed in the U.S. aviation sector since the September 11, 2001, terrorist hijackings of four U.S. jet airliners, and much remains in flux. At the time of the committee's final meeting, only weeks after the hijackings, the federal government had imposed emergency air traffic control rules restricting where pilots can fly, the operating procedures they must follow, and the kinds of flying activities they can undertake in designated areas. Thirty metropolitan areas were designated as having "enhanced" Class B terminal airspace[1] and were thus subject to additional operating restrictions on the airspace directly above and below the normal Class B structure. Most private aircraft flight operations were suspended in the enhanced Class B airspace over the Washington, D.C., New York City, and Boston metropolitan areas, while in 27 other metropolitan areas private aircraft operations were modified through requirements for the use of transponders and limitations on certain kinds of visual flight rule (VFR) operations. In addition, most foreign-registered aircraft were barred from operating under VFR in U.S. airspace.[2]

Most of these restrictions were lifted later in the year, although concerns remain over the use of aircraft, large and small, as a means of carrying out terrorist attacks. Whether these concerns subside will depend in large part on the nation's ability to counter the terrorist threat in general. Nevertheless, it seems reasonable to anticipate

- Flight restrictions in the airspace over many of the country's largest metropolitan areas;
- Restrictions and prohibitions on flying near sensitive facilities;
- Requirements for operators to file flight plans and use equipment that will allow air traffic controllers to monitor and communicate with aircraft and their operators from takeoff to touchdown;
- Enhanced security measures at airports—large and small—to protect travelers and to secure facilities, aircraft, and other aviation equipment;
- Increased screening and scrutiny of airport and air carrier personnel, suppliers, and service providers; and
- Increased scrutiny of pilot candidates and training centers, as well as new pilot eligibility and certification requirements.

---

[1] Enhanced Class B airspace is at least a 20-nautical-mile (22.7-statute-mile) radius around a major airport and extends from the ground to 18,000 feet.

[2] Canadian and Mexican aircraft were exempt from this restriction.

Specific restrictions on aviation will undoubtedly change in response to evolving security concerns. In all likelihood, elevated concerns over security will influence not only operations but also the kinds of technologies being funded and developed and how they are applied in both commercial and general aviation.

In light of these new aviation security concerns, a number of additional questions arise with regard to the Small Aircraft Transportation System (SATS) concept and the technological capabilities being pursued to advance it. Among them are the following:

- Will more stringent pilot eligibility requirements and more complex, security-oriented operating environments further limit the number of people capable of and interested in becoming private pilots?
- If more aircraft can be used at more airfields by more pilots, what steps can be taken to safeguard the airfields and prevent the misuse of aircraft?
- Can a distributed system of air traffic management, coupled with a much larger population of private aircraft, be made compatible with the need for a centralized authority both to monitor traffic near sensitive areas and to ground aircraft quickly in an emergency (e.g., during a threat from multiple aircraft)?
- If concerns over the safety and security of people and facilities on the ground prompt additional restrictions on the airspace over metropolitan areas, how will such restrictions affect the ability of SATS aircraft to serve the main market for air travel, that is, travel to and from urban areas?

As difficult as it is to foresee how today's aviation system will adapt to security concerns, it is even more difficult to anticipate how future aviation technologies and systems will be influenced by such concerns. For example, certain capabilities, such as highway-in-the-sky navigation systems, could prove helpful in ensuring secure flight operations by providing a means for operators to report and adjust their flight plans on a more timely basis, fly their courses more accurately, and obtain updated information on restricted and prohibited airspace for safe and predictable course adjustments. Alternatively, technologies that make it easier to fly may allow more people to operate aircraft for illegal and illegitimate purposes.

The attacks of September 11 and their uncertain ramifications underscore the difficulty of making accurate predictions of change in the aviation sector. Other major developments in aviation in recent decades, from the precipitous decline in demand for new GA aircraft to the emergence of hub-and-spoke operations after deregulation (which have had major implications for the kinds of aircraft used by airlines and the demands placed on air traffic control), have occurred almost entirely unexpectedly. Other unanticipated changes will undoubtedly follow. The aviation sector has always been highly dynamic and dependent on aggressive technology research and development. Such characteristics make the sector unsuited to a high level of specificity in long-range planning.

Study Committee Biographical Information

H. Norman Abramson, *Chair,* is Executive Vice President Emeritus of Southwest Research Institute. He is internationally known in the field of theoretical and applied mechanics. His specific area of expertise is in the dynamics of contained liquids in astronautical, nuclear, and marine systems. He began his career as an Associate Professor of Aeronautical Engineering at Texas A&M University and has served as Vice President and Governor of the American Society of Mechanical Engineers and Director of the American Institute of Aeronautics and Astronautics (AIAA). He is an AIAA Fellow and Fellow and Honorary Member of the American Society of Mechanical Engineers. As a member of the National Academy of Engineering (NAE), he served on its council from 1984 to 1990. He has been appointed to many other NAE and National Research Council (NRC) committees, including the Commission on Engineering and Technical Systems (CETS) Committee on R&D Strategies to Improve Surface Transportation Security, the Transportation Research Board's (TRB's) Research and Technology Coordinating Committee, and TRB's Committee on the Federal Transportation R&D Strategic Planning Process, all of which he served as chair. He served as a member of the U.S. Air Force Scientific Advisory Board from 1986 to 1990. Dr. Abramson earned a Ph.D. in engineering mechanics from the University of Texas.

Donald W. Bahr retired in 1994 as Manager of Combustion Technology, GE Aircraft Engines. He is an expert in gas turbine and ramjet technologies for both aircraft propulsion and industrial applications. His expertise includes small aircraft engine technologies, especially with regard to their pollutant emission characteristics and technologies for the abatement of these emissions. He began his career with GE in 1956 as a combustion chemical engineer and became Manager of Combustion Technology in 1968. He has served on several NRC committees and panels, including the CETS Committee on High Speed Research and the Commission on Geosciences, Environment, and Resources Panel on Atmospheric Effects of Aviation. He was a chair of the emissions project group of the Aerospace Industries Association and a member of the General Aviation Manufacturers Association's Environmental Committee. He was an industry delegate to the International Civil Aviation Organization's Committee on Aviation Environmental Protection. Mr. Bahr earned a master's degree in chemical engineering from the Illinois Institute of Technology.

Marlin Beckwith retired in 2000 as Manager of the Aeronautics Program in the California Department of Transportation (Caltrans). He began his career with Caltrans in 1964 and has held a series of administrative and management positions of increasing responsibility. As manager of the aeronautics program, he oversaw the state's airport grant and loan program and supervises the permitting and inspection of helicopter facilities and public-use airports. He also worked with local governments concerned about airport noise and was responsible for ensuring the integration of state and national aviation system plans. He earned a B.A. degree from the University of Idaho and was an officer in the U.S. Army before joining Caltrans.

Max E. Bleck retired in 1996 as President of Raytheon Corporation, a position he had held since 1991. From 1987 to 1991, he was President and Chief Executive Officer of Beech Aircraft Corporation. He was previously President of Cessna Aircraft Company and Executive Vice President and Chief Operating Officer of Gates Learjet Corporation. From 1968 to 1985, he held several top management positions at Piper Aircraft Company, including President, CEO, Chief Operating Officer, and Executive Vice President. Earlier in his career, he held several top management and engineering positions at Cessna, including General Manager and group Vice President. He began his career in 1950 at Stanley Aviation Corporation, where he attained the position of Vice President of Engineering. Mr. Bleck earned a B.S. in mechanical engineering from Rensselaer Polytechnic Institute.

Daniel Brand is Vice President of Charles River Associates, Inc. He has served as Undersecretary of the Massachusetts Department of Transportation, Associate Professor of City Planning at Harvard University, and Senior Lecturer in the MIT Civil Engineering Department. He was a member of TRB's Committee for a Study to Assess Advanced Vehicle and Highway Technologies and its Committee for High-Speed Surface Transportation in the United States. He has also chaired three TRB standing committees: the Committee on New Transportation Systems and Technology, the Committee on Passenger Travel Demand Forecasting, and the Committee on Intelligent Transportation Systems (ITS). He was a founding member of the Coordinating Council of ITS America and serves on three of its technical advisory committees. He was editor of *Urban Transportation Innovation* and coeditor of *Urban Travel Demand Forecasting*. Mr. Brand earned his bachelor's and master's degrees in civil engineering from MIT.

Walter S. Coleman recently retired as President of the Regional Airline Association (RAA), which represents U.S. regional and commuter airlines and suppliers of products and services that support the industry. He served as RAA's President for 8 years and before that was Director and Vice President of Operations for the Air Transport Association. From 1976 to 1981 he was Director of the Airline Reservation Center of the Airline Scheduling Committees. He began his airline career in 1968 with Pan American World Airways, serving as a pilot, flight engineer, and superintendent of schedule development. He was a pilot in the U.S. Navy from 1960 to 1968 and served in the U.S. Naval Reserve from 1970 to 1986. Mr. Coleman earned a B.A. degree in business administration from Ohio University.

James W. Danaher recently retired as Chief of the Operational Factors Division of the Office of Aviation Safety, National Transportation Safety Board (NTSB). He has more than 35 years of government and industry experience in the human factors and safety fields. After joining NTSB in 1970, he served in various management positions, with an emphasis on human performance in flight operations and air traffic control. He has participated in on-scene investigations of numerous accidents, public hearings, and the development of NTSB recommendations. He is a former naval aviator and holds a commercial pilot's license with single-engine, multiengine, and instrument ratings. Among other NRC assignments, he served on the Panel on Human Factors in Air Traffic Control Automation for the Commission on Behavioral and Social Sciences and Education. Mr. Danaher earned a master's degree in experimental psychology from Ohio State University.

John J. Fearnsides is a Professor of Public Policy at George Mason University and Senior Strategic Consultant with Lockheed Martin Corporation. Until 1999, he was Vice President and General Manager of the MITRE Corporation and Director of its Senior Center for Advanced Aviation System Development, which is sponsored by the Federal Aviation Administration. He worked at the U.S. Department of Transportation from 1972 to 1980, serving as Deputy Undersecretary and Chief Scientist, Executive Assistant to the Secretary, and Acting Assistant Secretary for Policy and International Affairs. He was a National Science Foundation Fellow and is a Fellow of the Institute of Electrical and Electronics Engineers and the National Academy of Public Administration. He has served as a member of several NRC and TRB committees, including the Committee for a Review of the National Automated Highway System Consortium Research Program. Dr. Fearnsides earned a Ph.D. in electrical engineering from the University of Maryland.

John D. Kasarda is a Kenan Distinguished Professor of Management of the Kenan-Flagler Business School and Director of the Kenan Institute of Private Enterprise at the University of North Carolina, Chapel Hill. He has published more than 60 scholarly articles and 9 books on aviation infrastructure, logistics, and competitiveness issues. He serves on the editorial boards of several professional journals and has served on a number of NRC committees. He has received grants and awards from the Federal Aviation Administration, the National Science Foundation, the U.S. Agency for International Development, and many other organizations. He is a Fellow of the American Association for the Advancement of Science and Senior Fellow and Trustee of the Urban Land Institute. Dr. Kasarda earned his B.S. and M.B.A. from Cornell University and a Ph.D. from the University of North Carolina.

Charles A. Lave is Professor of Economics and Director of the Graduate Program in Transportation Sciences, Associate Director of the Institute of Transportation Studies, and Faculty Assistant to the Chancellor at the University of California, Irvine. He was chair of the economics department from 1978 to 1983 and chair of the Faculty of Social Sciences from 1978 to 1984. He has been a visiting scholar at Harvard University, MIT, and Stanford University. His area of expertise is transportation economics, and he has served on two TRB standing committees: the Committee on

Transportation Data and Information Systems and the Committee on Energy Conservation and Transportation Demand. He has also served as a member of TRB's Committee for the Study of the Benefits and Costs of the 55-mph National Maximum Speed Limit, Committee for Guidance on Setting and Enforcing Speed Limits, and Committee for an International Comparison of National Policies and Expectations Affecting Public Transit. He has written extensively on highways, mass transit, and other modes of transportation. Dr. Lave earned a Ph.D. in economics from Stanford University.

Nancy G. Leveson is Professor of Aeronautics and Astronautics at the Massachusetts Institute of Technology, where she also heads the Software Engineering Research Laboratory. Before joining MIT in 1998, she was Boeing Professor of Computer Science at the University of Washington. Her work has focused on building software for real-time systems where failures can result in loss of life or property. She is a member of NAE and has served on several NRC committees. She is a member of CETS and chaired its Committee for a Study of the Space Shuttle Software Process. She was a member of TRB's Committee for a Review of the National Automated Highway System Consortium Research Program. She is a Fellow of the Association for Computing Machinery, which honored her with the 1999 Alan Newell Award for Cross-Disciplinary Research. In 1995, she was awarded the 1995 American Institute of Aeronautics and Astronautics Information Systems Award. Dr. Leveson earned a Ph.D. in computer science from UCLA.

Robert G. Loewy is the William T. Oakes Professor and Chair of the School of Aerospace Engineering, Georgia Institute of Technology. From 1978 to 1993 he was Institute Professor and from 1982 to 1993 he was Director of the Rotorcraft Technology Center at Rensselaer Polytechnic Institute. He previously served as Provost and Vice President of Academic Affairs there. He began his academic career at the University of Rochester, where he was Professor of Mechanical and Aerospace Sciences, Dean of the College of Engineering and Applied Sciences, and Director of the Space Science Center. He was Chief Scientist for the Department of the Air Force and chaired the National Aeronautics and Space Administration Advisory Committee and the U.S. Air Force Scientific Advisory Board. He has served on many NRC committees and most recently chaired the Aeronautics and Space Engineering Board's Committee for a Strategic Assessment of the U.S. Aeronautics Program. Dr. Loewy earned a Ph.D. in engineering mechanics from the University of Pennsylvania.

James G. O'Connor is former president of Pratt and Whitney, which designs and builds engines for commercial, military, and general aviation aircraft. He began his 34-year career with the company as an engineer and assumed positions of increasing responsibility in program management, manufacturing operations, and general management. He was promoted to CEO in 1989 and retired in 1993. He is currently chair of the Board of Trustees, Embry-Riddle Aeronautical University. He is a member of NRC's Aeronautics and Space Engineering Board and chaired its Committee on Aircraft Certification Safety Management. He is a member of the Connecticut Academy of Science and Engineering, the President's Advisory Council of Clemson University, and the Wings Club. He earned a master's degree in mechanical engineering from Rensselaer Polytechnic Institute.

Herbert H. Richardson is Director of the Texas Transportation Institute; Associate Vice Chancellor for Engineering, the Texas A&M University System; and Associate Dean of Engineering, Texas A&M University. He is also Regents Professor and Distinguished Professor of Engineering at the university. From 1991 to 1993 he was Chancellor of the Texas A&M University System. Before joining Texas A&M in 1984, he was Associate Dean of Engineering at MIT, where he began his academic career in 1955. He was head of MIT's Mechanical Engineering Department from 1974 to 1982. On leave from MIT, he was Chief Scientist for the U.S. Department of Transportation from 1970 to 1972. He has served on many NAE and NRC committees, including the Council of the NAE and the NRC Governing Board. He chaired TRB's Executive Committee, Committee for the Critique of the Federal Research Program on Magnetic Levitation Systems, and Committee for the Study of the Railroad Tank Car Design Process. He was Cochair of the TRB Committee for the Study of Geometric Design Standards for Highway Improvements and Vice Chair of the Committee for a Review of the National Automated Highway System Consortium Research Program. Dr. Richardson earned a Ph.D. in mechanical engineering from MIT.

Daniel T. Wormhoudt is Vice President of Environmental Science Associates (ESA) and Director of its Airports and Ports Facilities Business Group. Before joining ESA, he was president of MAP, Inc. Both firms specialize in environmental, land use, and transportation and energy facility siting issues. He has led several studies of the noise and other environmental impacts associated with both large and small airports. He is Chair of the TRB Task Force on the Environmental Impacts of Aviation and is active in many airport-related organizations, including the Airport Consultants Council. He earned a master's degree from the University of California at Berkeley.