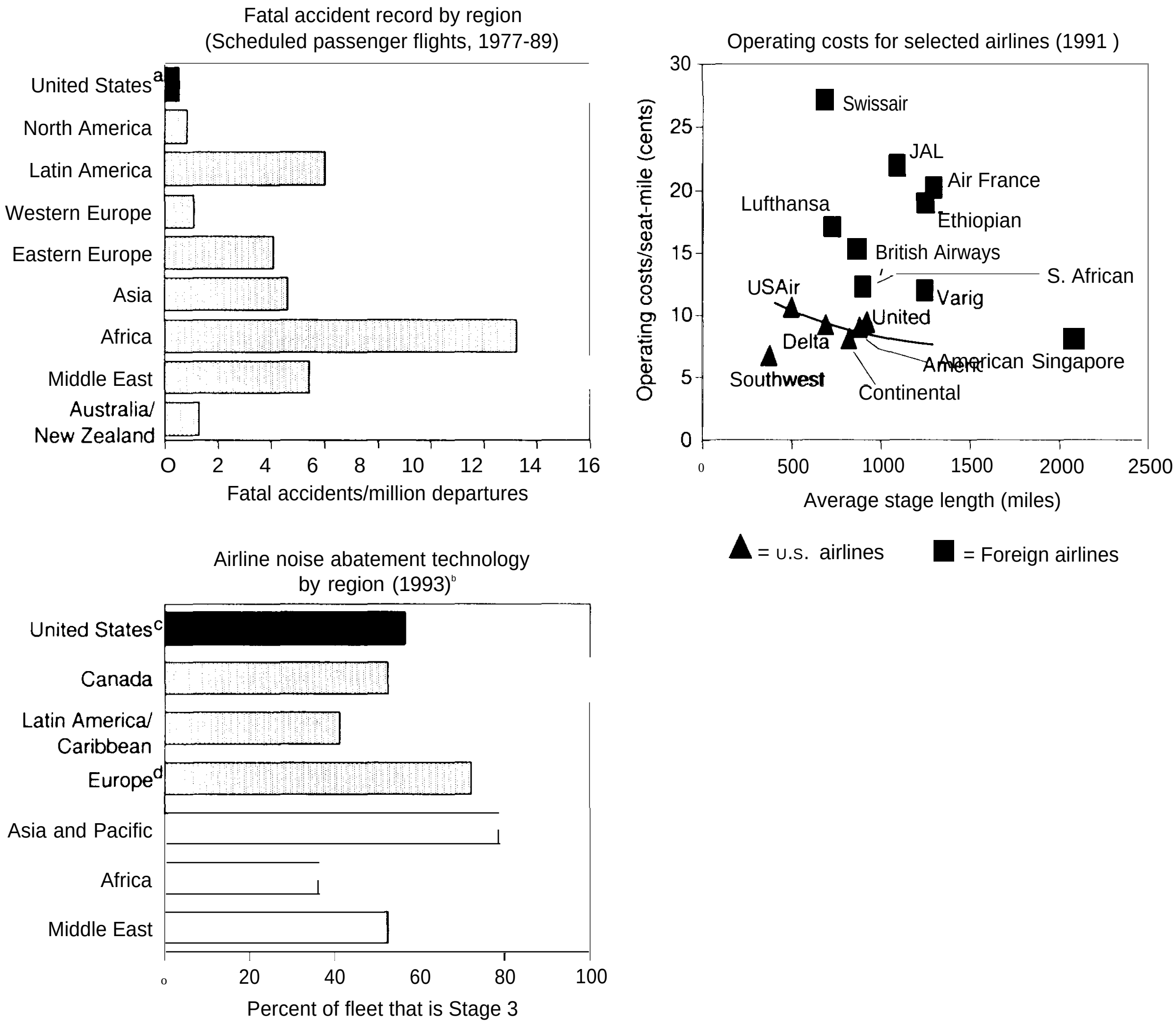
Summary and Policy Conclusions 1

Americans have extremely high, and often conflicting, expectations for air transportation. We want plenty of flights to many destinations, but have little tolerance for aircraft noise above our homes; we insist that airlines be as safe as possible, but demand ever lower ticket prices; and many of us want to leave or arrive at similar times, but are annoyed by congested roads and terminals and delayed flights.

Compared with aviation systems around the world, U.S. air transportation comes closest to meeting this wide range of exacting standards (see figure 1-l). Benefiting from decades of public and private research and technology investment, passengers and freight can travel by air across the United States today more safely, for less cost, and with less environmental impact than ever before (see figure 1-2). Research and technology development have contributed to these positive results and now promise further gains. **However, to better anticipate new safety and efficiency challenges to the aviation system and to promptly modernize the U.S. air traffic control (ATC) system federal aviation research and development (R&D) must encompass more than technology. The** early and continuing advice of operational experts must be part of this process, and operational issues, as well as technological ones, must be within its scope.

The Federal Aviation Administration (FAA) plays a pivotal role in improving the performance of the aviation system. FAA's

FIGURE 1-1: Comparison of Aviation Systems Around the World



[a] Data for the United States includes cargo flights
[b] Data are for western-built aircraft only
[c] By law, U S airline fleets must be all 'Stage 3 by the year 2004, i e meeting the most stringent noise requirements
[d] Does not Include members of the Commonwealth of Independent States

NOTE Curved line in "operating costs" graph is a best fit plot for U S airlines only

SOURCE Off Ice of Technology Assessment, 1994, based on accident data from Clinton Oster, Why *Airplanes Crash* (New York, NY Oxford University Press, 1992), Federal Aviation Administration, and National Transportation Safety Board, noise abatement data from Boeing and airline operating cost data from Global Aviation Associates, Ltd International Air Transport Association, and Air Transport Association of America missions to promote safety and foster air commerce[1] are incorporated in three key areas: 1) regulation, 2) infrastructure development, and 3) ATC operations. These missions are highly technical, and research and technology development are important to each. Federal R&D related to these missions occurs not only at FAA but at other agencies, including the National Aeronautics and Space Administration (NASA), the Department of Defense (DOD), the Department of Energy (DOE), and the Department of Commerce.

As regulator and ATC operator, FAA has ties to all segments of the aviation community. FAA's foremost obligation for aviation research and technology is to identify the long-term operational requirements for the aviation system. **In carrying out this responsibility, it is especially important for FAA to work with other federal agencies conducting research to ensure that the specific needs of aviation are addressed within other research programs.**

Federal aviation R&D programs are mostly technology-driven, and scientists and engineers at the federal laboratories have contributed to many critical elements of the modern aviation system, including radar, avionics, and advanced materials. However, policy makers expect more from these types of R&D programs than the programs alone can deliver in the regulatory and operational arenas. Policy and management decisions to improve aviation safety or air traffic operations that depend primarily on technology-driven R&D often fall short of objectives. Aviation safety and efficiency are system attributes, and a detailed understanding of how the aviation system operates on a day-(o-day basis is crucial to targeting R&D efforts and implementing the new technologies. The scientists, engineers, and administrators who staff federal research institutions rarely have this expertise.

The aviation system relies on a range of R&D efforts—from collecting safety inspection data and developing air traffic procedures, to scientific research and technology-centered projects. In addition, for both today's and future systems, a clear understanding of the problems that are to be addressed with R&D is essential; **it is here that FAA's role is most critical and in most need of strengthening.** The R&D process would be more effective if it drew more upon the diverse skills and experience of aircraft crews, air traffic controllers, technicians, manufacturers, and others.

This is especially true for ATC system development. The ATC system is not just equipment, but operating standards and procedures—the rules of the game, so to speak. And both parts of the system must be developed in concert. More so than in other fields, it is necessary to know clearly what the equipment is supposed to do before building it. To accomplish this, experienced operational personnel must also be an integral part of the technol -

[1] Section 103 of the Federal Aviation Act (Public Law 85-726, Aug. 23, 1958) provides [he declaration of policy that states:

In the exercise and performance of his powers and duties under this Act, the Administrator shall consider the following, among other things, as being in the public interest:

(1) The regulation of air commerce in such manner as to best promote development and safety and fulfill the requirements of national defense:

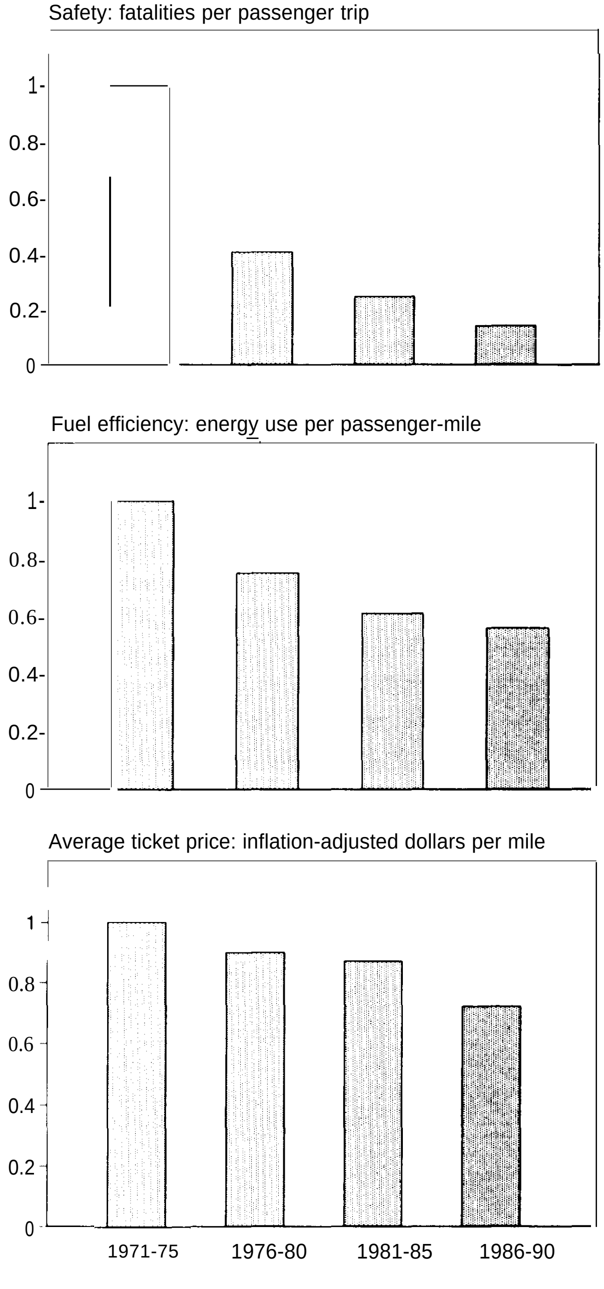
(2) The promotion, encouragement, and development of civil aeronautics;

(3) The control of the use of the navigable airspace of the United States and the regulation of both civil and military operations in such airspace in the interest of the safety and efficiency of both;

(4) The consolidation of research and development with respect to air navigation facilities, as well as the installation and operation thereof:

(5) The development and operation of a common system of air traffic control and navigation for both military and civil aircraft,

FIGURE 1-2: Commercial Aviation Trends for Safety, Fuel Efficiency, and Ticket Price



NOTE Calculations are for five-year averages, normalized to the 1971-75 data

SOURCE Off Ice of Technology Assessment, 1994, based on: Safety data from the Federal Aviation Administration and the National Transportation Safety Board fuel efficiency data from the Department of Energy Energy information Off Ice, and ticket price data from Boeing, 1993 *Current Market Outlook*

ogy development and engineering process. In addition, the research and engineering methodologies commonly used in developing technologies must be used in analyzing and advancing the operational standards, practices, and procedures for ATC systems. However, that generally has not been the case. **Modernization efforts have most often been held up by inadequate understanding of operational and procedural issues, rather than by insufficient technological expertise.**

Other challenges for the U.S. aviation system are international in nature. **Advances in aviation technology and less restrictive trade policies around the world are forcing globalization of aviation industries and infrastructure.** As the aviation industry becomes global, its operations will benefit from more uniform safety, environmental, and operating standards worldwide. But the current international framework for handling aviation technical issues is inadequate. While aircraft and ATC technologies can span oceans and continents, the institutions that regulate and operate the international air transportation system do not have the same reach.

The opportunity now exists for the United States to provide world leadership in the technical areas of aviation operations. U.S. expertise in aviation safety, environmental effects, and air traffic systems can be decisive factors in the deliberations of multinational aviation organizations. FAA is the agency best positioned to meet this global challenge, but needs a clear mandate to step up its efforts in the international arena.

Most important, satellite systems and digital communications will likely form the backbone of air traffic communications, navigation, and surveillance (CNS) systems in the near future. FAA's current efforts to implement such CNS systems for U.S. operations could potentially form the basis for an efficient international system.

Moreover, new technologies provide the opportunity for private or other nonfederal organizations to own and operate key elements of the CNS infrastructure. FAA will thus face new challenges in fulfilling its safety oversight responsibilities. Such opportunities and FAA challenges will exist

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

R&D Important to FAA's missions is also conducted at other federal agencies

regardless of the outcome of the Clinton Administration's proposal to establish a federal corporation to operate, maintain, and modernize the nation's ATC system (see box 1-1).

Congressional Interest and Scope of Study

Federally sponsored aviation research has received considerable congressional attention in the last decade due to the need to modernize and expand the U.S. airspace system. address aircraft safety and environmental issues. and respond to terrorism threats against air travelers. Congressional appropriations for R&D directed at these responsibilities go primarily to FAA and NASA, and grew from $82 million in fiscal year 1980 to $352 million in fiscal year 1994 (see table 1-1). For FAA. these funds were appropriated to the agency's Research. Engineering and Development (RE&D) account. The term *RE&D* is used in FAA legislation, budget. and planning documents. In this report, the Office of Technology Assessment (OTA) uses *RE&D* only when referring to specific FAA accounts, programs, or organizations that use the term in their designations. OTA uses *R&D* to refer generally to scientific and technological research and development conducted at FAA or elsewhere. This distinction is important, since some FAA R&D is conducted outside the RE&D program.

Major increases for FAA R&D were provided under the Airport and Airway Improvement Act of 1982,[2] which authorized funding for the National Airspace System Plan to modernize the ATC system. Additionally, substantial amounts of ATC R&D ($555 million in fiscal year 1993)[3] are supported with FAA's facilities and equipment (F&E) account.

The achievements of the federal aviation research and technology programs have received mixed reviews. While FAA has been criticized by some for not being sufficiently proactive in uncovering safety deficiencies, the agency has a successful record of developing technological, procedural, or operational solutions once a safety problem is clearly defined. On the other hand, FAA has had a history of troubles in introducing complex technologies into the operational system.

Previous OTA studies have pointed to deficiencies in FAA's research agenda, especially the lack of attention to human factors and other long-term issues.[4] Legislation enacted since 1988 addressed these and other concerns. The Aviation Safety Research Act of 1988[5] required FAA to spend at least 15 percent of its R&D budget on long-term issues, specified human factors as part of FAA research, and created an agency advisory committee for R&D. This FAA RE&D Advisory Committee has taken an active role in reviewing FAA's R&D plans and has increased the visibility of research at

[2] Public Law 97-248 (49 USC 2201).

[3] Office of Technology Assessment estimates, based on FAA budget data. See table 2-3 in ch. 2.

[4] U.S. Congress, Office of Technology Assessment, *Safe Skies for Tomorrow: Aviation Safety in a Competitive Environment*, OTA-SET-381 (Washington, DC: U.S. Government Printing Office, July 1988); and U.S. Congress, Office of Technology Assessment, *Technology Against Terrorism: Structuring Security*, OTA-ISC-511 (Washington, DC: U.S. Government Printing Office, January 1992).

[5] Public Law 100-591, Nov. 5, 1988.

BOX 1-1: The Clinton Administration Proposal for a U.S. Air Traffic Services Corporation

In May 1994, the Clinton Administration proposed shifting U.S. air traffic control responsibillities from the Federal Aviation Administration to a wholly owned government corporation that would be a financially and operationally Independent organization within the Department of Transportation (DOT),[1] Concluding that "ATC is the kind of service best delivered by a businesslike entity, " the Executive Oversight Committee established by the Secretary of Transportation to study ATC restructuring options recommended that a U S Air Traffic Services (USATS) Corporation be created to operate, maintain, and modernize the ATC system. The USATS proposal is generally consistent with the recommendations of the National Performance Review and the Airline Commission,[2] and draws on examples of ATC corporations In other countries[3] as well as U.S. government corporations In other fields.[4]

The USATS would be a not-for-profit corporation funded by user fees and debt financing, with general aviation and public users permanently exempted from the user charges. The corporation would be governed by an 11-member board of directors, composed of a chief executive officer, the Secretary of Transportation, the Secretary of Defense, and eight Individuals from the aviation community, appointed by the President and confirmed by the Senate. Additionally, the Secretary of Transportation would have direct power to disapprove the level of user fees and borrowing. However, national security policy for air traffic services, Including joint civil-military use of the airspace system, would stay unchanged,

The USATS would be responsible for the day-to-day operations and long-term development of the U S ATC system, but would be subject to FAA safety oversight (see figure). FAA would retain responsibilities for safety regulation and certification, safety and environmental research, and airport development programs, as well as continue its current relationships with Congress, DOT, the Department of Defense, and other federal entities. Approximately two-thirds of FAA's budget supports ATC, FAA funding could be reduced by more than $6 billion once a USATS was in place,[5]

There are a number of issues yet to be resolved for the USATS proposal. The USATS study points to federal budget and procurement constraints as the primary causes of slow ATC modernization, and concludes that a corporation freed from these restrictions could accelerate ATC system modernization [6] However, the General Accounting Office (GAO) analyses do not support this concluslon,[7] GAO points to other technical and managerial factors, such as FAA's underestimating the complexity of system development, as the key causes of implementation delays, Furthermore, GAO states that " . among the financing issues raised by the [USATS] proposal, revenue and expenditure assumptions deserve a closer look, and close scrutiny of how safety will be ensured is warranted. "[8]

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[1] U S Department of Transportation, *Air Traffic Control Corporation Study,* Report of the Executive Oversight Committee to the Secretary of Transportation (Washington DC May 1994), p 5

[2] National Performance Review, *From Red Tape to Results Creating a Government That Works Better & Costs* Less (Washington DC Off Ice of the Vice President, September 1993), and National Commission To Ensure a Strong Competitive Airline Industry *Change, Challenge, and Competition A Report to the President and Congress* (Washington DC U S Government Printing Office, August 1993)

[3] United Kingdom, New Zealand Australia, and Germany U S Department of Transportation, Op cit footnote 1, P 141

[4] Examples Include St Lawrence Seaway Development Corporation, Amtrak, and the U S Postal Service Ibid p 147

[5] For fiscal year 1993, $6 3 billion of FAAs $91 billion total funding was allocated to ATC U S Department of Transportation. *Air Traffic Control Analysis of Illustrative Corporate Financial Scenarios* technical report prepared by the Corporation Assessment Task Force for the Executive Oversight Committee (Washington, DC May 1994) p 10

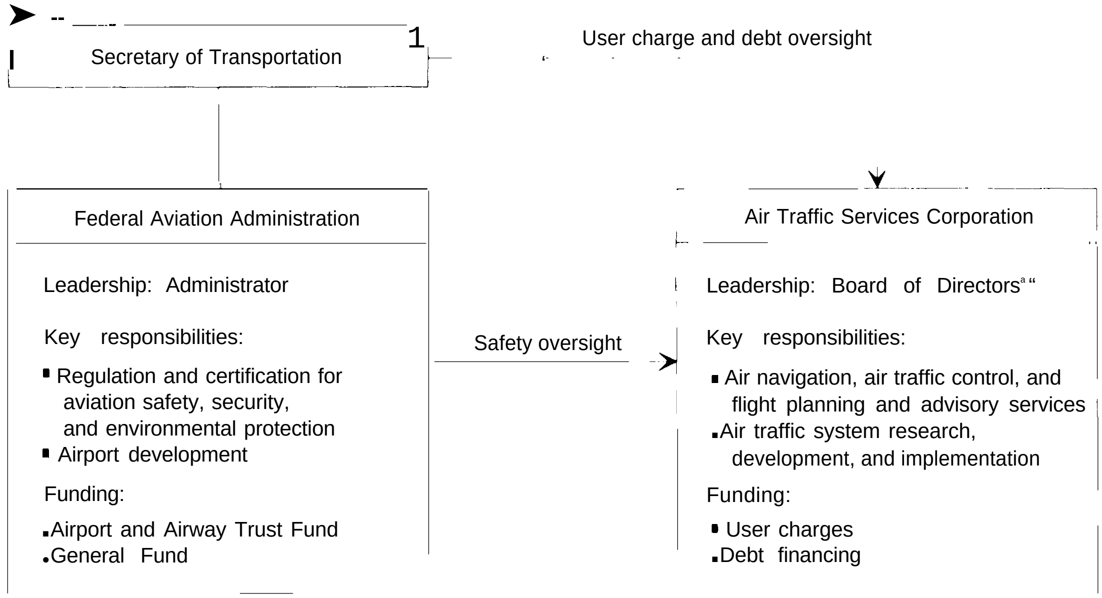
[6] U S Department of Transportation op cit , footnote 1, P 9

[7] U S Congress General Accounting Off Ice, Air Traffic Control Observations on Proposed Corporation, testimony at hearings before the Senate Committee on Appropriations, Subcommittee on Transportation and Related Agencies GAOT-RCED-94-21O, May 12, 1994, p 1

[8] Ibid p 2

BOX 1-1: The Clinton Administration Proposal for a U.S. Air Traffic Services Corporation (Cont'd.)

Federal Framework for Aviation With a USATS Corporation



[a]The 11 members of the board, who are appointed by the President, wou Id include a chief executive officer the Secretary of Transportation, the Secretary of Defense, and eight individuals from the aviation community

SOURCE Office of Technology Assessment, 1994, based on the U S Department of Transportation, *Air Traffic Control Corporation Study. Report of the Executive Oversight Committee to the Secretary of Transportation* (Washington, DC May 1994)

TABLE 1-1: FAA and NASA Aviation R&D Budgets in Four Categories

	FY 1992		FY 1993 (real-year dollars in millions)		FY 1994a	
Aviation category	**FAA[b]**	NASA	FAA[b]	NASA	FAA[b]	NASA
Air traffic system	1013	185	1031	31-9	1172	506
Safety	647	15.4	71 8	193	733	222
Environrnent[c]	4.0	170	4 8	193	54	470
Security	319	0 0	359	0 0	359	0 0
Subtotal	2019	509	2156	705	2318	1198
Total	**252.8**		**286.1**		**351.6**	

[a]Budget request
[b]FAA figures are fo, the agency's Research, Engineering and Development program, except management and InnOvatlve/Cooperative research line items that are not Included Additionally, R&D funded out of FAA's facilities and equipment account is not included
[c]NASA high-speed commercial transport environmental R&D not included ($76 4 million in FY 1992 $1058 million in FY 1993 $1346 million in FY 1 994)

SOURCE Office of Technology Assessment, 1994, based on NASA and FAA da?a

TABLE 1-2: Summary of Aviation Research and Development Issues

Issue	Potential improvements
Airspace efficiency	*Increased capacity and less delay without diminished safety by:* • Enhancing communications, navigation, and surveillance technologies and procedures to permit closer spacing between aircraft and increased aircraft arrival and departure rates at airports • Augmenting airport surface traffic management capabilities, especially in low-visibility conditions Improving the reliability and accuracy of weather forecasts
Safety	*Fewer and less severe accidents by:* • Improving the reliability of engines, avionics, and other aircraft systems • Enhancing aircraft crew and controller awareness of aircraft situation in all conditions. • Reducing personnel fatigue and stress • Reducing fire threat, • Enabling better crew communication and coordination, • Enhancing structural airworthiness and crashworthiness.
Security	*Threat deterrence and mitigation by:* • Enhancing explosives and weapons detection capabilities. • Increasing aircraft resilience to explosions, • Improving passenger and cargo screening methods and airport security systems, • Ensuring secure air traffic control system design and operation,
Environment	*Less environmental impact from aviation by:* • Reducing aircraft noise emissions in order to lower or maintain community noise levels as operations increase, • Minimizing engine emissions and increased fuel efficiency, • Improving management of existing deicing and firefighting compounds and Introducing new, more environmentally benign materials, • Improving aircraft cabin air quality

SOURCE Office of Technology Assessment, 1994

the agency. Aviation security and aging aircraft issues were addressed in subsequent legislation.[6]

Reiterating that a safe, efficient, and environmentally sound air transportation system is crucial to the national economy and the future of the aviation industry, Congress asked OTA to take a comprehensive look at the federal research and technology efforts that underpin this system. The effects of FAA's technology and regulatory activities on airline economics and international competitiveness were special concerns.

This study focuses on research and technology policy issues for aviation operations: safety, security, environmental protection, and the air traffic system (see table 1-2). Other aviation technology policy issues, such as manufacturing competitiveness, national security, and training and education, are beyond the scope of this study.

Background

Aviation draws the persistent attention of policymakers, and few enterprises in the United States are subject to greater federal involvement. With the creation of the National Advisory Committee for Aeronautics in 1915, aeronautical research became the first segment of civil aviation to be addressed by federal policy. Through the following decades, the federal government has continued to

[6] Public Law 101-604, Nov. 16, 1990; and Public Law 101-508, Sec. 9208, Nov. 5, 1990.

be a major supporter of aeronautical and related aviation research and technology development. Federal responsibilities for aviation technology have steadily expanded to encompass safety and environmental regulation, infrastructure development, and ATC operations (see box 1-2). Each new generation of technology and operating procedures has brought performance advances to air transportation.

U.S. aviation industries have historically generated high-quality, well-paying jobs and produced technologically and economically superior equipment and services (see table 1-3). However, in recent years, aviation in the United States and Europe has suffered financially. No domestic carrier—with the notable exception of Southwest Airlines—was unscathed by the economic recession of the early 1990s. U.S. airlines lost $12.8 billion from 1990 to 1993,[7] three airlines ceased operations,[8] and three others filed for Chapter 11 bankruptcy (see chapter 5). That recession caused heavier than usual reductions in high-yield business travel, possibly indicating a systemic change in the demand for such travel.

The cost of implementing additional technical requirements was relatively minor while the aviation industry-and its productivity—grew rapidly, But times have changed. Benefits from future technical initiatives in aviation safety, security, and environment will likely be both small and relatively costly since the performance of the existing system is quite good.[9] U.S. aviation industries are likely to grow more slowly than in previous decades, and the challenge now is to increase the economic performance of the system while maintaining—and improving when feasible—its high level of safety, security, and environmental performance.

Air traffic infrastructure issues are somewhat different in that failure to improve system performance can have a severe economic penalty. The U.S. ATC system, while safer and more efficient than any other in the world, still uses equipment and procedures that fall far short of what are technologically possible. While upgrades to the current ATC system will not come cheaply, small advances in system capacity and efficiency can mean large savings in time and money to aircraft operators and the traveling public. For example, OTA calculates that a 1-percent reduction in flight time due to more efficient flight paths would yield U.S. airline industry savings of approximately $250 million a year in lower direct operating costs.

Therefore, FAA's regulatory and operational responsibilities may be more important to industry growth now than in the early days of aviation. Safety remains the top priority at FAA. Any lapse in maintaining safety could prove economically disastrous to aviation operators, not to mention the potential human cost. This is an especially important concern for the rapidly growing commuter airline segment of the industry, as highlighted by the convening of a National Transportation Safety Board (NTSB) special board of inquiry on commuter airline safety in June 1994.

But FAA's mandate is also to foster air commerce. While trade, finance, and other economic policies outside the scope of FAA's authority are generally more critical to aviation economics, FAA technical regulations and air traffic system management have substantial economic consequences. Without diminishing the agency's safety mission, FAA's capability for bolstering aircraft operating economics for all segments of the aviation community needs to be encouraged and strengthened.

FINDINGS

OTA findings on federal aviation research and technology development focus on aviation operational issues—safety, security, environmental

[7] Of the airlines' net].ss in] 992, approximately $2 billion was due t. accounting adjustments related [o retiree benefits (see ch. 5).

[8] Eastern Air Lines, pan Am World Airways, and Midway Airlines.

[9] The largest safety and environmental problems in aviation operations pale in comparison to difficulties in other sectors of modern society.

BOX 1-2: What Is Aviation Research and Development?

What Is “Research and Development”?

The meaning of research and development (R&D) varies throughout government and Industry. Using National Science Foundation (NSF) nomenclature, the objective of basic research is to better understand fundamental concepts and observations without specific applications in mind. Applied research seeks to gain such knowledge or understanding to determine how to meet a defined need. Exploring or solving problems in a specific context is therefore targeted, or applied, research. Development, in turn, is the systematic use of research results, directed toward the production of materials, devices, systems, or methods. Feasibility demonstration IS another component of development, as is engineering (see figure)

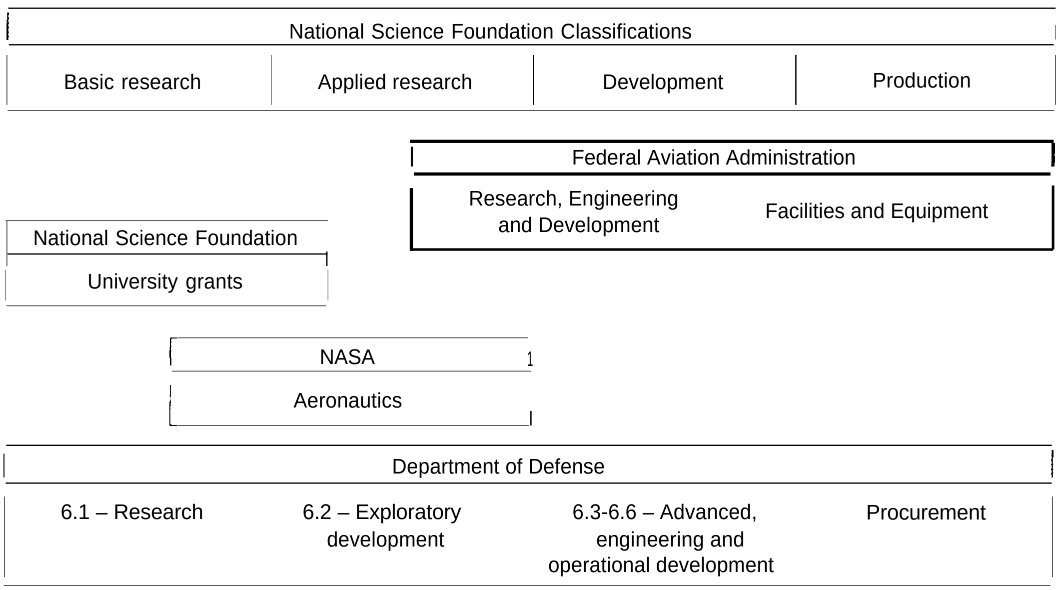
The National Aeronautics and Space Administration (NASA) conducts applied research to support its own space and aeronautics program goals, as well as other federal R&D needs. The programs that the Federal Aviation Administration calls Research, Engineering and Development (RE&D) generally correspond to what NSF would call development, focused on integrating new or upgraded technologies into an operational framework

What Is Aviation R&D?

Aviation R&D encompasses the science and technology of air transportation and systems of aircraft operations Two broad categories of aviation R&D correspond to FAA’s key missions: regulatory (safety, security, and environment) and operational (air traffic control). Aeronautics, a fundamental field underlying aviation, addresses the design and performance of individual aircraft—aerodynamics, structures, propulsion, and control systems

NASA conducts both aeronautical and aviation R&D; FAA’s R&D focuses on aviation, where it provides and uses research results FAA’s responsibility for technology development differs for its regulatory and operational missions FAA advances its R&D corresponding to safety, security, and environmental regulatory inltiatives to the feasibility demonstration or pre-production stage For the ATC system, however, FAA’s role continues through procurement and implementation.

Federal Research and Technology Programs and Terminology



SOURCE Off Ice of Technology Assessment, 1994

BOX 1-2: What Is Aviation Research and Development? (Cont'd.)

Long-Term Research and Technology Issues Differ for Each of FAA's Missions

Long-term research (from the Aviation Safety Research Act of 1988) ". means a research project which IS Identified as a discrete project in the aviation research plan required by section 31 2(d)(1) of the Federal Aviation Act of 1958 and which IS unlikely to result in a final rulemaking action within 5 years, or in initial installation of operational equipment within 10 years, after the date of the commencement of such project ' Research IS not defined in the act

Long-term research issues for aviation safety, security, and environment are primarily scientific or analytic—seeking better understanding of the '(problem " (See the table below, which lists particular areas of aviation R&D and the responsible federal organizations) The long-term needs for FAA's other mlsslon-developing and operating the National Airspace System—are primarily planning and system engineering. Long-term research on new air traffic system concepts and functions IS essential,

Federal Aviation R&D Responsibilities

R&D mission area	R&D conducted within FAA	R&D conducted within other agencies or organizations
Safety		
Human factors	Some[a]	NASA, DOD
Aeromedical	Yes	NASA, DOD
Aircraft safety (e g materials, fire, aging aircraft cabin safety, catastrophic failure prevention)	Yes[b]	NASA, NIST, DOD, DOE labs, industry
Weather	No[c]	NOAA, NSF (NCAR)
Environment	No[d]	NASA, NSF, DOE, EPA, industry
Security		
Explosives detection and mitigation	Yes	DOD, DOE labs, FBI, DOE, ICAO, Industry
Aviation security (e g , detectors, sensors, profiling)	Yes	DNA, DOD, DOE labs, CIA, FBI, industry
Airports and air traffic control	Some[e]	Industry, NASA, DOD labs
Environment		
Environment	Some[f]	Industry, NASA, DOD
Weather	No[g]	Industry NASA, NCAR, NOAA, DOD

[a] FAA conducts some human factors research at the Technical Center and funds more extensive research at NASA
[b] FAA conducts fire safety research at CAM I and the Technical Center, FAA funds NASA and Industry materials research and has funded NIST fire research
[c] No in house research conducted FAA funds aviation weather research at NCAR and has joint programs with NOAA
[d] FAA funds noise reduction research by NASA
[e] Limited in-house development effort, FAA sponsors work by the Mitre Corp Lincoln Labs, and industry
[f] FAA develops noise impact and ground-level emissions dispersion models
[g] FAA funds next generation weather radar (N EXRAD) system development with NOAA and DOD, and NASA sensor development

KEY CAMI FAA Civil Aeromedical Institute, Oklahoma City, CIA=Central Intelligence Agency, DNA = Defense Nuclear Agency, DOD= Department of Defense, DOE= Department of Energy, EPA= Environmental Protection Agency FAA= Federal Aviation Administration; FBI=Federal Bureau of Investigation, ICAO=International Civil Aviation Organization, NASA= National Aeronautics and Space Administration; NCAR=National Center for Atmospheric Research NIST=National Institute of Standards and Technology, NOAA= National Oceanographic and Atmospheric Administration; NSF =National Science Foundation

SOURCE Off Ice of Technology Assessment 1994

TABLE 1-3: Selected Economic Indicators for U.S. Civil Aviation Industries in 1992

Industry	Revenue ($ billions)	U.S. balance of payments ($ billions)	Employment (thousands)
Civil aircraft manufacturing[a]	$307	$19.5	133,4
Air traffic control equipment manufacturing	15	0.4	44
Airline service	77.9	6.4[c]	5404

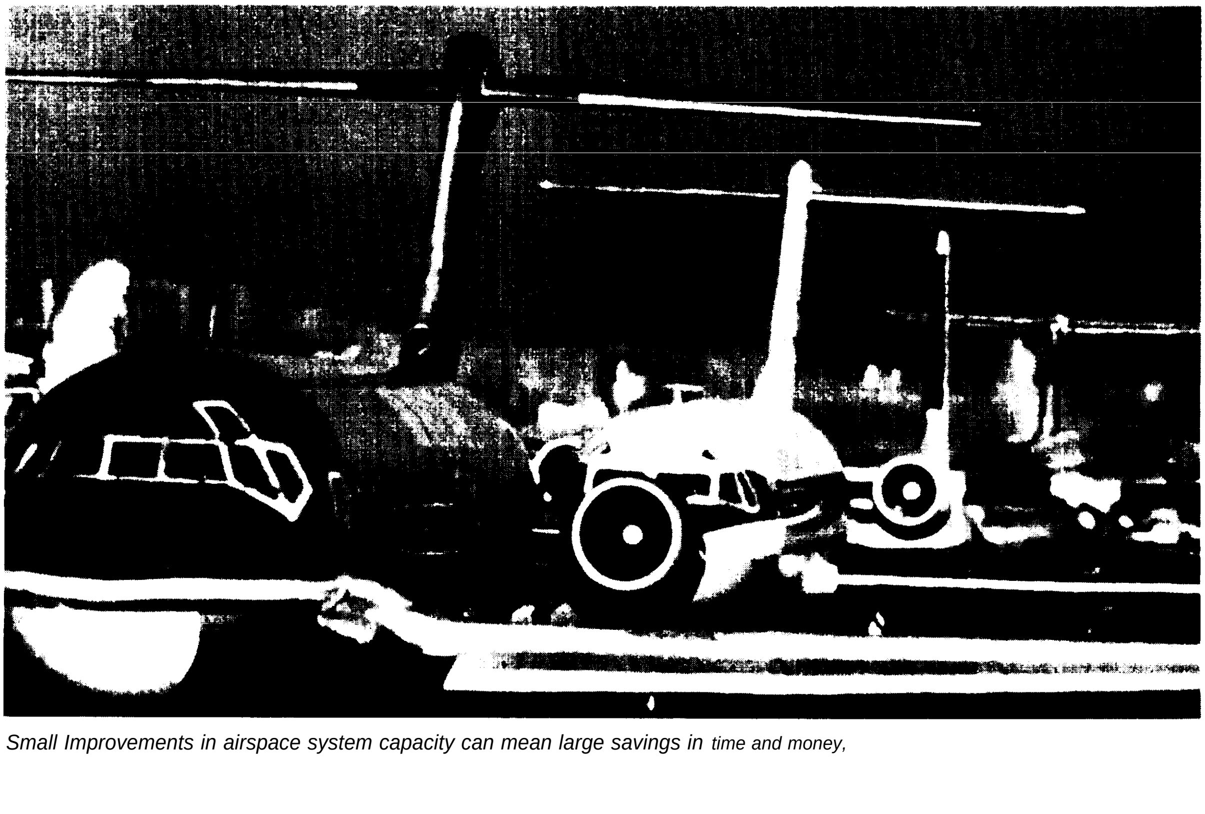
[a]Revenue, market share, and balance of payments calculations based on the value of civil transports, rotorcraft, and general aviation aircraft delivered by U S manufacturers in 1992 Excludes figures for separate engines and parts and production by foreign license

[b]All figures based on OTA survey of U S air traffic control equipment manufacturers, 1993

[c]Balance of payments for international air service represents the difference between airfares paid to U S carriers by international visitors traveling to the United States and fares paid to foreign carriers by Americans traveling abroad

SOURCES Off Ice of Technology Assessment, 1994, based on data compiled from Aerospace Industries Association of America, *Aerospace Industry Review*; Air Transport Association of America, *ATC Market Report,* Bell Helicopter Textron, Boeing, Bureau of Economic Analysis, General Aviation Manufacturers Association, *Interavia Aerospace World,* International Civil Aviation Organization; Office of Management and Budget, U S Travel and Tourism Administration; and World Jet Airplane Inventory

FEDERAL AVIATION ADMINISTRATION



Small Improvements in airspace system capacity can mean large savings in time and money, protection, and the air traffic system. These findings arc presented in four categories: 1) technical standards for international aviation, 2) ATC modernization in the United States, 3) research for aviation safety and environmental protection, and 4) interagency coordination on aviation R&D.

I Technical Standards for International Aviation

Commercial jets have made much of the world accessible within one day of travel. Now aviation industries, institutions, and technologies themselves arc becoming global in scale. This will have profound implications for U.S. regulatory, infrastructure, and other transportation policies. Many of the world's airlines are expanding—via strategic alliances, marketing agreements, or route acquisitions-in an attempt to offer passengers the most extensive route systems. Commercial aircraft manufacturers increasingly rely on international cooperation to help spread development costs for new-generation jets and to gain footholds in foreign markets. Developments in satellite CNS technology make "seamless" global ATC possible for every nation.

FINDING 1: *The future of U.S. aviation is global, International safety and environmental regulations and ATC standards and operational procedures are becoming increasingly important to U. S aviation industry economics.*

The International Civil Aviation Organization (ICAO) sets standards for international aviation-for safety, environment, and infrastructure (ATC and airports). However, ICAO safety standards are the lowest common denominator, and are far below those acceptable to industrialized countries. Many nations have their own civil aviation administrations (CA AS) to promulgate safety regulations, which meet or exceed ICAO standards and recommended practices. Other countries follow the standards of a major nation, usually the United States.

International differences in commercial aircraft and airline regulations impose a cost burden on U.S. industries. Aircraft manufacturers estimate they could save between $800 million and $1 billion between 1992 and 2002 if international differences in airworthiness standards and their interpretations and duplicate certification tests were eliminated. 10 These additional costs are passed to the airlines. Further, FAA estimates that international differences in operating regulations are more costly than disparities in airworthiness rules, and the economic burden falls mostly on the airlines.[11]

Complete harmonization of U. S., Canadian, and European Joint Aviation Authorities (JAA) airworthiness regulations is achievable in the next few years. However, agreement will be more difficult on common airline operational regulations. Foreign airlines flying into the United States do not have to meet the same standards FAA imposes on U.S. carriers, although most adhere to comparable standards. With FAA's input, JAA is attempting to harmonize its members' aircraft operating and maintenance regulations, which will likely provide for levels of safety consistent with U.S. rules and requirements. One expert believes that the harmonization efforts between FAA and JAA will provide the basis for real international standards.[12]

However, with regard to operating regulations, European nations tend to favor detailed technical requirements, while the United States prefers performance standards. As a result, it is unlikely that FAA and JAA operating regulations will be harmonized completely in the foreseeable future.

But it is the air traffic system that is in greatest need of a more efficient international process for

[10] U.S. Congress, General Accounting Office, *Aircraft Certification: Limited Progress on Developing International Design Standards*, GAO/RCED-92-179 (Washington, DC: August 1992), p. 20.

[11] Anthony Broderick, FAA Associate Administrator for Regulation and Certification, comment at OTA workshop, June 9, 1992.

[12] John O'Brien, Air Line Pilots Association, personal communication, June 26, 1994.

developing and implementing standards. Global standards are critical to ensure interoperability and stringent performance, integrity, and system availability requirements essential to air traffic systems. During the past decade, ICAO has studied technical options for future air traffic management and control systems, and has recommended that satellites become the core infrastructure for CNS systems (see box 1-3). Neither the U.S. Global Positioning System (GPS) nor any other satellite system can become operational for international air navigation until sufficiently detailed performance specifications are approved by ICAO. In part due to its large, diverse membership, however, ICAO has a poor record of efficiently planning and developing system standards even in the absence of any political controversy.

OTA concludes that institutional relationships for harmonizing international technical standards for aviation must be strengthened. Global agreement is crucial to aviation industry planning and technology decisions, and swift international consensus on system specifications and operational implementation of satellite systems is essential. **A more effective process for developing and implementing international ATC infrastructure standards is strongly needed.**

In late 1993, the ICAO Air Navigation Commission (ANC) appointed a panel of technical experts to develop performance capability envelopes for different global navigation satellite system (GNSS) applications and relate them to required navigation performance criteria.[13] However, some international aviation experts believe that technical standards for GNSS are a long way off, especially at ICAO's current pace.[14]

FAA could play an important role in accelerating this process. The United States is well positioned to lead in international technical standards for aviation. FAA is considered the technical leader among many of the world's aviation agencies, although other countries and regional blocs are pushing for preeminence. Among government agencies worldwide, FAA is now the strongest supporter of datalink and satellite-based CNS. FAA could be an effective advocate for U.S. aviation standards and procedures by sponsoring seminars and providing technical assistance.

In addition, increased involvement of senior U.S. officials at ICAO and other international aviation sessions may be necessary. Raising the visibility of international standards, regulations, and infrastructure in U.S. aviation policy decisions in other federal agencies may also be necessary.

FINDING 2: New air traffic *technologies, such as navigation satellites and digital communication networks, can provide enhanced capabilities and economic benefits to the operators of aircraft and ATC systems. Full implementation of these technologies will require new institutional frameworks here and abroad.*

New CNS infrastructure, combined with traffic management computers and advanced airborne sensors, should maintain or improve safety while increasing controller productivity, permitting closer spacing between aircraft and more efficient routes, and enabling flights to continue at maximum traffic rates in all but the most severe

[13] These criteria form the basis for proposed standards that must be validated and approved by ANC.

[14] Peter Ingleton, Technical Director, International Air Transport Association (IATA), and David Fischer, IATA representative to ICAO FANS committee, personal communications, Sept. 3, 1993.

BOX 1-3: The International Future Air Navigation System

In 1983, the International Civil Aviation Organization (ICAO) established a special committee on the Future Air Navigation System (FANS), and charged it with examining the existing air navigation systems and developing recommendations for the coordinated, evolutionary development of air navigation into the next century [1] The FANS committee completed its task in 1988, and attributed the system's limitations to three factors

- limits Imposed by Ilne-of-sight systems and by variable propagation characteristics of high-frequency and other communications systems in use,
- the difficulty of Installing communications, navigation, and surveillance networks in a consistent manner in large areas of the world and
- limitations of voice communicatlon, and the lack of digital air-ground data Interchange systems to support modern automated procedures [2]

The goals of the FANS concept are to 1) increase air transport capacity, 2) increase capacity for enhanced air traffic control automation and general air-to-ground data transmission needs, 3) Improve systems Integration, and 4) Improve organizational coordination.[3] ICAO views satellite systems, along with datalink capabilities as essential to achieving these objectives The FANS concept also relies on Required Navigation Performance Capability (RNPC), a performance-driven standard for new technology RNPC relieves operators of the burden of Installing specific avionics to meet requirements, rather, a performance standard (e g , 100 meters accuracy for the Global Positioning System—GPS) is effected

In September 1991, the 10th Air Navigation Committee of ICAO voted to adopt the recommendations of the FANS committee for a global aeronautical telecommunications network (ATN). The committee articulated the goal of a seamless, interoperable global data communicahons Infrastructure [4] ATN is intended to Integrate data communications among aircraft, ATC centers, and air earner facilities by enabling data to be transmitted by any of three paths Mode-S transponder, airline VHF, or satellite link The network and onboard avionics wiIl select the optimum path

Under the topic of communications, the committee recommended the introduction of a global satellite system for voice and digital communication between aircraft and the ground, and the launch of two types of datalink (VHF and Mode-S) in non-oceanic areas For navigation, the committee recommended the Implementation of the global navigation satellite system (GNSS) and the eventual phaseout of existing Ilne-of-sight radionavigation systems currently in use. The committee made three recommendations regarding surveillance make primary radar optional and rely on secondary surveillance radar, including Mode-S, in busy airspace, Introduce satellite-based automatic dependent surveillance for less busy airspace, and Implement some form of airborne collisIon avoidance As a technology-based group, the FANS committee did not address operational procedures to be derived from the new capabilities. Rather this was left to subsequent discussion by ICAO and member nations [5]

GNSS as defined by ICAO, is a worldwide position and time-determination system that includes one or more satellite constellations, end-user equipment, and a system Integrity monitoring function The U S GPS will be one element for GNSS in the United States at least Other proposed supplemental or stand-alone elements of GNSS Include Inmarsat satellites, Russia's GLONASS, other government-sponsored satellite systems, and various low-Earth-orbit satellite systems for mobile communications

[1] *Future Air Navigation System,* September 1991, p 1 published by members and observers of the FANS committee

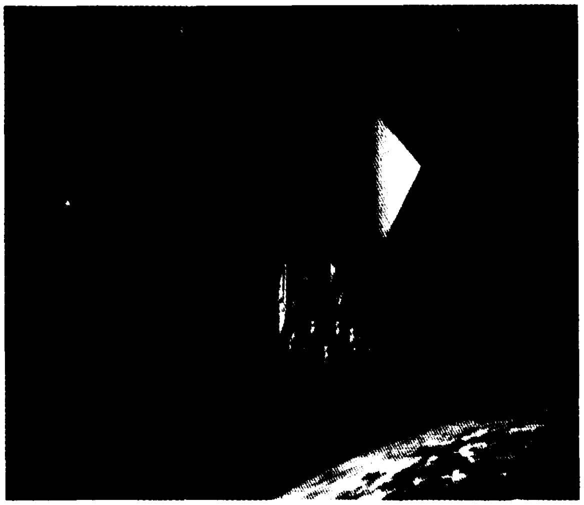
[2] Oliver Sutton "FANS To Rescue 21st Century Air Traffic" *Interavia Aerospace Review*, December 1989, pp 1171-1174

[3] Don Fuqua. "Meeting the Needs of ATM " *AIA Newsletter* May 1992, p 3

[4] Lillian Zarrelli Ryals The Mitre Corp "A New Public/Private Investment Model for the Aeronautical Telecommunications Network (ATN) n d p 2

[5] Robert W Simpson Using ATC Operational Requirements To Guide FAA R&D and Procurement Activities OTA contractor report June 1993 p 3

FEDERAL AVIATION ADMINISTRATION



Satellite systems and digital communications will likely form the backbone of air traffic communications, navigation, and surveillance systems in the near future

weather conditions.[15] If satellite navigation and communications technologies along with an advanced traffic management system were fully implemented, U.S. airlines could save $3.5 billion per year.[16]

Satellite navigation and digital networks make possible fundamental changes in how and where ATC services are provided, and raise difficult policy questions regarding infrastructure sovereignty and security. With these networks, top-notch air traffic services-equal to or better than the capabilities of the current U.S. domestic airspace system-could become practical anywhere in the world.[17] It is not financially or politically feasible for a single CAA to independently develop, build, and operate all of the elements comprising such a future ATC system. Thus, nations would have to work together more effectively than at present to implement such a system on a global basis.

Today, however, air navigation and traffic control is the responsibility of each nation under its agreement with ICAO. National governments finance, own, and oversee virtually all of the facilities and equipment necessary to control traffic in their airspace.[18] Globe-spanning systems will ultimately make these national systems obsolete. Although geographic or airspace sovereignty will not be altered if satellite systems become the basis for air navigation, many-or possibly all-could lose direct control of at least part of their domestic air traffic infrastructure.[19] Furthermore, components of these systems, such as satellite platforms and communications networks, may be privately owned and serve nonaviation applications as well. Consequently, serious issues regarding safety certification, liability, system integration, and overall management of aviation CNS infrastructure need to be addressed by all nations.

In the United States, aircraft operators, airports, and other transportation organizations are already using non-FAA communications and information systems to support flight operations. Private datalinks run by Aeronautical Radio, Inc.[20] provide some enhanced air traffic safety and commercial services, such as real-time monitoring of air-

[15] There are limits t. how much more capacity and efficiency can be squeezed out of the airspace system with new ATC technologies. FAA and others estimate that all feasible ATC technological advances combined would be able to meet at most 10 to 15 percent of projected shortfall in peak-hour capacity in the next 25 years. If the demand materializes as forecasted, more runways and demand management techniques will be necessary to minimize system delays. (See figure 3-9 in ch. 3.)

[16] Air Transport Association, "AirTraffic Management in the Future Air Navigation System," unpublished white paper, June 16, 1994. The International Air Transport Association estimates that the world's airlines would save at least $5 billion per year.

[17] Much of the world's airspace is characterized presently by poor navigation and communications services, relative to what is standard across the United States. For example, even parts of Western Europe lack radar coverage of overland commercial airways.

[18] Aircraft must have Complemental instrumentation and equipment installed in order to use the airspace infrastructure, Some nations have private or public corporations to operate their ATC systems.

[19] A satellite-based navigation system requires centralized control. Consequently, most nations that could use the system would have no direct authority over day-to-day operating decisions for the system.

[20] Aeronautical Radio, Inc. is owned by airlines and provides telecommunications services fOr diem.

craft engines and other equipment to improve maintenance, relay of en route flight status (for readying airport gates), and ground-to-air weather information.[21] FAA has approved the U.S. military's satellite-based GPS for some air navigation applications in the United States. Presently, these systems supplement, but do not replace, essential services and infrastructure provided by FAA.

There is a strong need now for swift international consensus on global navigation system specifications if GPS or other satellite systems are to provide international service in the next five to 10 years. Global agreement is crucial to aviation industry planning and technology decisions. GPS can provide the earliest operational capability for the GNSS concept proposed by ICAO (see box 1-3 again). The full constellation of GPS satellites became operationally ready in December 1993. As long as supplemental navigation aids are available, FAA now permits GPS use for domestic and oceanic en route flight navigation and for nonprecision approaches. FAA's goal is that the international community develop systems that are compatible with GPS, whether or not it chooses to rely on GPS for GNSS services in the future.[22]

Although most international aviation agencies would welcome the potential savings and enhanced capabilities from GNSS, some have expressed concern that initially, at least, the system would remain under U.S. military control. They worry that the system could be denied or degraded at any time for U.S. security reasons.[23] Other concerns include the potential for intentional or inadvertent jamming of GPS signals. The technical hurdles that remain for new navigation and communications systems to become operational seem surmountable. **Resolving the more difficult institutional issues of system ownership, operation, and control must become a national aviation priority if satellite CNS systems are to deliver significantly improved air traffic management worldwide and help reduce costs to aircraft operators.**

ATC Modernization in the United States

The U.S. ATC system represents both the success and failure of FAA. More than a million people fly in the United States every day and our airspace system is safer, far more efficient, and technologically superior to any other in the world. However, current ATC procedures do not support flight management capabilities of new aircraft, and ATC technologies lag behind comparable telecommunications, computing, and information systems used in other fields.

FINDING 3: *ATC system development and implementation are chronically delayed, in large part due to shortcomings in analyzing and establishing operational requirements.*

FAA-managed ATC projects often move slowly—to go from concept to operation can take 15 years or longer. Consequently, Congress hears perennial calls to boost FAA R&D spending and make ATC more independent of federal personnel and procurement rules. Budget autonomy and procurement reform are two cornerstones of FAA reorganization proposals in the Clinton Administration's "National Performance Review" (NPR) and "Air Traffic Control Corporation Study," as well as in the recommendations of the National

[21] In January 1979, when services began, there were approximately 500.000 contacts made per month using voice radio. Message exchange using datalink has grown to nearly 8 million messages per month while voice contacts have fallen to 25,000 per month. John Sullivan, Vice President of Quality Control, Aeronautical Radio, Inc., personal communication, Nov. 25, 1993.

[22] Mike Shaw, Satellite System Manager, FAA Satellite CNS Program, personal communication, Dec. 9, 1993.

[23] The Secretaries of Defense and Transportation requested the formation of a task force to discuss issues of system management, operation, and long-term sustainment. The task force released a report on its activities and recommendations in December 1993. See Joint DOD/DOT Task Force, "The Global Positioning System: Management and Operation of a Dual Use System," A Report to the Secretaries of Defense and Transportation, unpublished document, December 1993.

Commission To Ensure a Strong and Competitive Airline Industry.[24] However, those issues are peripheral to the ATC modernization problem.

With regard to spending levels, FAA R&D for ATC (including R&D spending outside of the RE&D account) is 10.4 percent of FAA's total annual budget for ATC.[25] This level of R&D investment compares favorably with figures for high-tech industries such as telecommunications and software production. Regarding procurement reform, changes in federal rules would do little to resolve ATC operational planning and development problems or otherwise speed up significantly the acquisition of complex, safety-critical systems. While the competitive procurement system causes delays and added expense, the resulting time lag seems to be roughly one year at most.[26] The General Accounting Office has studied this issue and concluded that government procurement policies and regulations are not the key impediment to ATC system development by FAA.[27] **OTA's analyses indicate that, while increased spending and easier procurement with respect to technology R&D could help speed ATC modernization, major improvements to the air traffic system will require fundamental changes in the overall development process at FAA.**

The combination of high safety standards, continuous operations, large scale, and complexity make the ATC system unlike any other technological system. Within this system, technology opportunities, rather than operational analyses, have driven specific ATC programs. Operational and procedural issues such as human factors, not basic technologies, most often have been the key hurdles to timely system implementation.

Time and again, ATC technologies reach the advanced stage of development before those who are to install or use them discover that what was developed is not what was needed. In many cases, operational problems have remained undetected until after a prototype ATC system has been completed and procurement is imminent or under way. For example, FAA committed to the development and production of the Advanced Automation System before fundamental operational issues were resolved, including how controllers would use the new equipment and how existing ATC facilities would be consolidated.

Better systems engineering could help, and FAA has strengthened its systems engineering capabilities in recent years. However, aviation systems engineering must be more than making technologies work together. It must get people, organizations, procedures, and technologies to work together. If longstanding ATC modernization problems are to be resolved, research, development, and engineering of operational requirements and procedures must be strengthened and made into an integral part of FAA's ATC system development process. Three key steps are needed: 1) involve suitably experienced operational personnel closely in the planning and prototype development process; 2) conduct operational analyses and develop operational procedures for new system concepts early enough to affect the technology development process; and 3) use real-time, dynamic ATC simulations as "operational

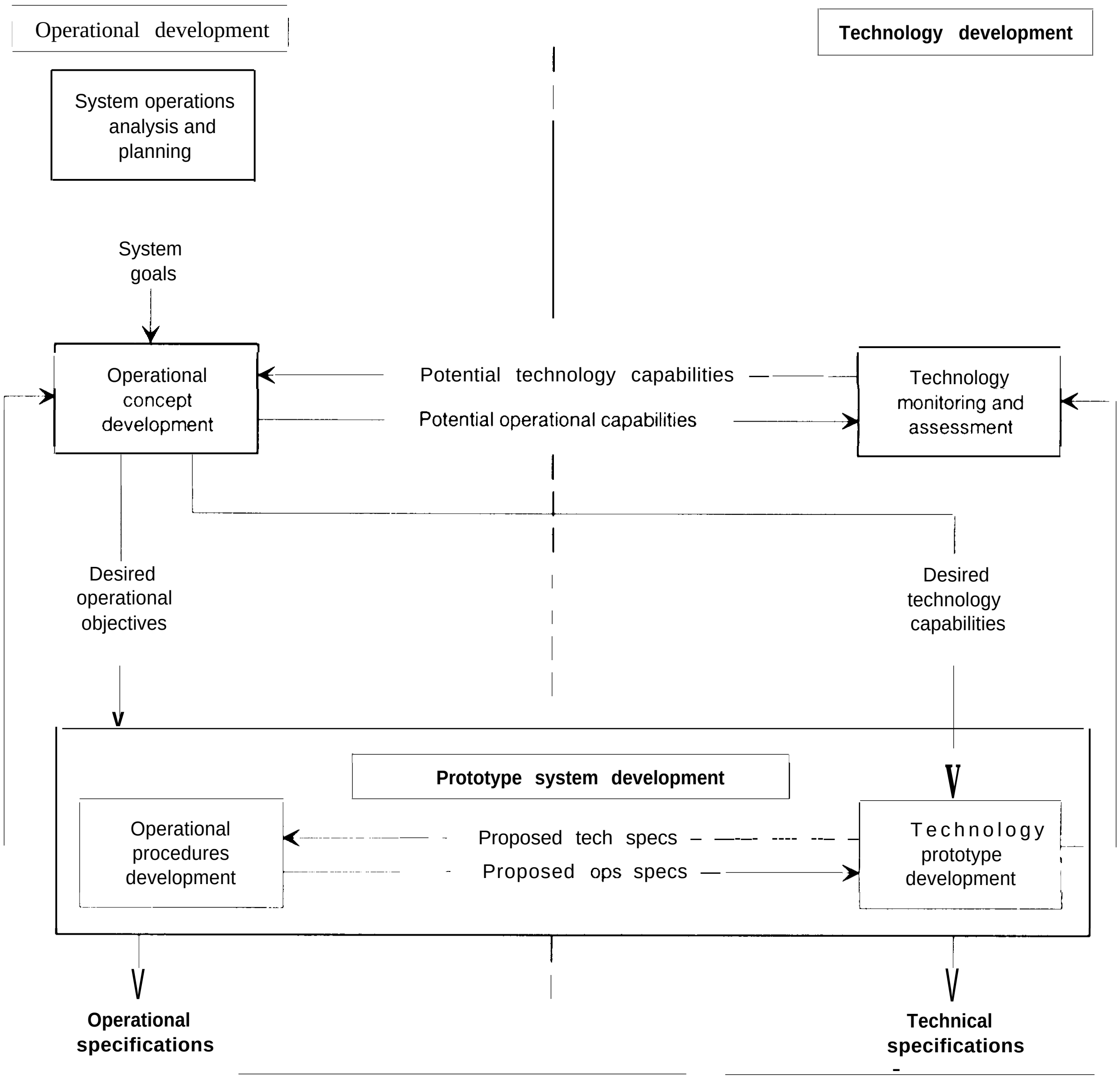
[24] National Performance Review, *From Red Tape to Results: Creating a Government That Works Better & Costs Less* (Washington, DC: Office of the Vice President, September 1993); U.S. Department of Transportation, *Air Traffic Control Corporation Study: Report of the Executive Oversight Committee to the Secretary of Transportation* (Washington, DC: May 1994); and National Commission To Ensure a Strong Competitive Airline Industry, *Change, Challenge, and Competition: A Report to the President and Congress* (Washington, DC: U.S. Government Printing Office, August 1993).

[25] See table 2-3 inch. 2.

[26] John Turner, FAA Associate Administrator for National Airspace System Development, personal communication, Oct. 21, 1992; and James L. Crook, Vice President for Operations, Air Traffic Control Association, Inc., personal communication, June 30, 1994.

[27] U.S. Congress, General Accounting Office, "Air Traffic Control: Observations on Proposed Corporation," testimony at hearings before the Senate Committee on Appropriations, Subcommittee on Transportation and Related Agencies, May 12, 1994.

FIGURE 1-3: A Model for Concurrent Development of ATC Systems



a For Federal Aviation Administration orders and regulations ATC handbook and other guidance
b For hardware and software

SOURCE Office of Technology Assessment 1994

development" as well as "technology development" tools. Figure 1-3 presents one model for in*tegrated* operation] and technological development of ATC systems.

FINDING 4: *FM has taken steps to incorporate operational expertise into its ATC technology development efforts* However, the agency *lacks institutional incentives to ensure consistent operational guidance for ATC system development and implementation*

In many ways, FAA is in transition. FAA has recognized some of the operational development problems mentioned above and is making efforts to resolve them. Almost all agency operating units report improved relations with FAA's R&D division, and the general feeling is that technology R&D is more targeted than in the past to the needs of the operating units.

Acquiring user input is an essential step in identifying operational requirements. For the development of the new 777 aircraft, Boeing used this approach and met with success. Likewise, FAA increasingly welcomes industry into its fold. In 1991, FAA established operational implementation teams for satellite navigation and for communications and surveillance. Sponsored by the Flight Standards and Air Traffic Control organizations within FAA, the teams work closely with industry and representatives of the various FAA organizations to improve the process for developing performance standards and requirements.[28]

ATC system development issues are as much cultural as they are managerial. Air traffic controllers, equipment technicians, pilots, engineers, and managers are vital to ATC system development and operation. Each group has strengths and shortcomings, and communication across these cultural gaps can be difficult. Inadequate coordination between the operational sections and the technology developers is a longstanding problem at FAA.[29] Moreover, these cultural differences may lead to conflicting messages to policymakers—each group may have a different priority or perspective on ATC problems. Safety and efficiency are the primary purposes for ATC operations, but rarely is there agreement on what levels of safety and efficiency are acceptable or how they can be measured. However, the current U.S. ATC system is remarkably safe as measured by accident risk, and no safety crisis exists. Unresolved concerns about new risks slow the ATC development process. Moreover, operational efficiency gains and development costs suffer to a much greater extent than safety by delays in implementation.

FAA does incorporate operational expertise into parts of its ATC technology development efforts, but it is unlikely that, on its own, FAA can take all the steps necessary to resolve internal management and cultural impediments to improving the ATC system development process. In the course of its research, OTA heard 1ittle confidence expressed in FAA's ability to plan for and introduce new ATC systems effectively without some change in institutional structures and incentives. FAA has claimed to have overcome system development and acquisition hurdles a number of times during the past decade, but has failed to do so. **As long as technology development remains the dominant culture in FAA system development programs, however, implementation problems will persist.**

I Research for Aviation Safety and Environmental Protection

Safety requirements, environmental protection, and economics are closely intertwined for aviation. FAA and the aviation community have endeavored to make safety preeminent; the U.S. safety record attests to their success. But there are tradeoffs. For example, special flight paths designed by airports to reduce the impact of aircraft noise on nearby communities proliferated in the 1980s. Pilots and airline management considered some of these noise abatement procedures to be less safe (but not necessarily unsafe) than more

[28] Jim Crowling, Chairman, FAA Satellite Operational Implementation Team, personal Communication, June 14, 1993.

[29] The problem has not been confined t. the ATC world. In the late 1980s, coordination was weak between FAA's aviation security regulation section and the agency's security R&D branch at the Technical Center. For more information, see U.S. Congress, Office Of Technology Assessment, *Technology Against Terrorism: Structuring Security*, OTA-ISC-5 11 (Washington, DC: U.S. Government Printing Office, January 1992).

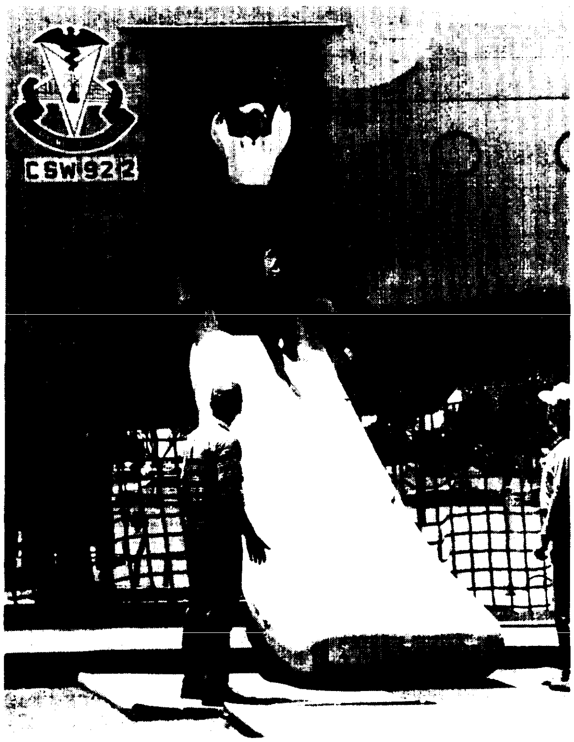
standard routes.[30] Airlines and the public accept this extra risk for the benefit of flying to those airports and for relatively less noise on the ground.

Critics and champions of the present aviation system agree that it is possible to make the system safer still and continue to reduce the environmental impact. However. disagreement is intense on the value and economic consequences of possible technological and procedural options and what new problems will emerge in the future. Federal safety, environmental, and infrastructure decisions are important factors in the financial health of the aviation industry. Less costly choices are desirable, and supporting the search for them is an appropriate role for federal aviation R&D programs.

FINDING 5: *Federal R&D efforts for aviation often lack explicit priorities and objectives, better data collection and analyses of the aviation system could help guide federal R&D Investment decisions.*

Federal budget limitations and the potential, at best, for only incremental improvements in certain areas of aviation call for clearer statements of aviation problems and priorities. Although FAA, other agencies, and industry collect and use a wide range of data on the safety, operations, and environmental effects of the aviation system, little has been done to set priorities and measurable objectives for R&D in those aviation fields. FAA uses the available databases primarily to support its day-to-day decisions on operations and regulation, but the data have not been systematically used to direct R&D.

Although data quality and analytic resources differ for aviation safety, environment, and operations, many of the problems that R&D could address are measurable. For example, aviation accidents are investigated in extraordinary detail by



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Aircraft evacuation is one area of aviation safety research

federal, industry, and labor professionals; this information provides benchmarks of overall safety and specific safety problems, and can suggest the potential value and effectiveness of technological and other prescriptions.

Ultimately, an assessment of R&D objectives and priorities must consider not only the size of any problem and value of possible solutions stemming from R&D, but also the probability and cost of achieving the solution and the potential for new or growing problems. In addition, the system consequences of introducing new technologies must be understood. **The early and continuing advice of operational experts is imperative to setting priorities and objectives for federal aviation**

[30] At one time the John Wayne Airport in Orange County, California, required that pilots "power down" their aircraft upon reaching 500 feet altitude in order to reduce takeoff noise. The Air Line Pilots Association (ALPA) considered the Orange County procedures to be a "big safety problem, because [the pilot is] too close to the ground to react should there be a mishap." Capt. Dick Deeds, ALPA, personal communication, Sept. 7.1993, FAA conducted a study of the marginal benefits of different departure profiles and in 1991 recommended that airports use either of two standard noise abatement procedure. Both procedures have a minimum thrust reduction altitude of 800 feet above field elevation. See FAA Advisory Circular 91-53a.

R&D and ensuring that new technological systems bring the greatest safety, environmental, and airspace benefits.

In 1991, the FAA RE&D Advisory Committee called for the agency to establish a comprehensive approach for evaluating research and development programs.[31] FAA has since investigated at least two methods for quantifying the contributions of individual research programs.[32] However, FAA has yet to publicly measure or rank aviation research objectives or R&D programs.[33]

FINDING 6: *Better information and analyses may now be more important than new technologies for continued long-term gains in aviation safety*

Unquestionably, a diverse technology base is essential for future aviation safety gains. FAA, NASA, and DOD are investigating numerous aircraft technologies that promise new levels of safety performance-cabin water spray, fire-resistant materials, explosive-resistant aircraft systems, and advanced sensors, to name a few. Most of these technologies are still too expensive to install in their current forms.

Historically, once an aviation problem became known and understood, actions could be taken to greatly reduce the risk-often before (or without) a technological response. For example, the meteorological conditions associated with low-level windshear were not widely recognized until the early 1980s. The U.S. accident rate from windshear plummeted after a nationwide pilot training and education effort was implemented. This occurred well before new windshear warning devices were installed on many aircraft.

The biggest safety problems today and the greatest risks in the future will likely come from areas where we lack fundamental knowledge rather than technological expertise. Human performance is the leading example of a field where basic and applied research is the key to better safety. Human error is implicated in two-thirds of aviation accidents; there are currently no clear technological or operational options, regardless of cost, that would go very far to address this problem, since we do not yet know enough about human cognitive processes.

Based on aviation accident trends, there is little reason to believe that any of the previously encountered safety problems will significantly escalate in the future. However, there are scenarios where new, substantial threats could emerge. Research and risk assessments to identify and quantify such problems are essential to any long-term aviation research program. However, risk analyses are not yet a prominent part of FAA's RE&D efforts.

In addition, there are new technologies on the forefront for gathering, processing, and relaying weather data, but critical information needs remain and long-term, fundamental science is required to address them. Basic research in mesoscale meteorology, for example, is essential to understanding the development and behavior of many atmospheric phenomena that preclude efficient use of the airspace. In recent years, little or none of FAA's R&D budget has been allocated for

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31 FAA Research, Engineering and Development Advisory Committee, R&D Plan Review Panel, *Review of the FAA Research, Engineering and Development Program* (Washington, DC: November 1991), pp. 31-32.

32 Cost-benefit analysis has become an integral part of FAA's regulatory decisions and the agency's budget process for the Capital Investment Plan for ATC equipment projects. However, cost-benefit analysis does not appear to be an appropriate tool for setting priorities among individual research projects. Among the difficulties with R&D cost-benefit analyses are estimating the probability of "success" as well as the costs of the necessary production and implementation following R&D that would be required to generate benefits. Furthermore, the data are often insufficient to reliably calculate potential benefits.

33 The Mitre Corporation is developing baseline levels and metrics to measure progress of the entire RE&D program for FAA's Research and Development Service. Some of Mitre's measures were used to assess the RE&D goals listed in chapter one of the *1993 Federal Aviation Administration Plan for Research, Engineering and Development.* Tony Dundzila, Member of Technical Staff, Mitre Corp., personal communication, Dec. 14, 1993.

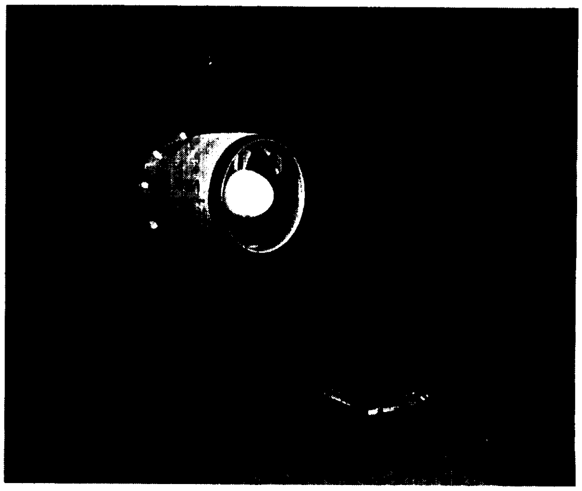
this type of weather research, despite the potential safety and operating cost savings associated with real-t i me forecasts of adverse or hazardous weather.

FINDING 7: *Environmental research for subsonic aviation is fragmented, and there is no clear federal policy guidance or support,*

Environmental challenges are expected to be a key constraint on aviation industry growth during the next decade.[34] As with safety issues, effective response to environmental problems requires adequate data and analytic capability to understand the extent of problems and optimize mitigation options. For aviation environmental policy, unlike aviation security and safety, no one federal agency has the leadership role.

FAA has responsibility y for setting aircraft noise standards and for assisting communities in assessing and abating airport noise. NASA has been the lead agency for aviation noise research. Despite decades of noise R&D to enable quieter aircraft to meet stringent noise limits and decreased national impact, continued growth in operations will undercut the progress made to date. Finding ways to further reduce noise remains a high priority for the industry, public, and FAA. With FAA and industry support, NASA has incorporated challenging noise reduction goals into its newly launched Advanced Subsonic Technology initiative.[35]

But aircraft noise is no longer the sole environmental liability, and many issues today threaten to constrain operations and increase costs. The unified regulatory-R&D approach enjoyed by the noise effort, in which FAA works closely with NASA to plan R&D and shape technical requirements, has rarely been applied to other environmental issues such as air quality. The Environmental Protection Agency (EPA) has broad



NASA LEWIS RESEARCH CENTER

Research and technology development are essential in meeting environmental challenges Microphones mounted on the side of a NASA wind tunnel measure fan noise from an advanced ducted propeller engine

regulatory authority over many environmental issues but has devoted few of its analytic or research resources to aviation-specific problems.[36] Without its own regulatory authority in these areas and no explicit mandate to support environmental research beyond noise, FAA has difficult y in formulating a comprehensive aviation environmental research agenda or sponsoring such research.

When addressing broad issues such as climate change or air and water quality, a comprehensive understanding of aviation's impact on the environment, particularly relative to other sources of pollution, is needed. Furthermore, FAA requires such an assessment in order to evaluate the costs and benefits of control measures and to draft technical and operational requirements. OTA finds such data are not always readily available, and the lack of an explicit mandate to address non-noise related issues, combined with FAA's small environmental R&D budget limit the agency ability to move quickly on emerging issues. There are

[34] National Research Council. Transportation Research Board, *Future Aviation Activities Eighth International workshop,* Transportation Research Circular Number 425 (Washington, DC: May 1994), p. 57.

[35] NASA defined a 10-decibel reduction relative to 1992 technology by the end of the century. The reductions are anticipated from changes to engines, airframes, and operational procedures.

[36] To estimate total civil aircraft emissions, in fact, EPA relies on FAA estimates of aircraft operations and emission indices.

few staff to devote to environmental issues other than noise, and FAA must rely on NASA and other federal agencies to perform scientific work and technology development.

While FAA and EPA share some aviation emissions data and analyses, the record of coordination and cooperation is spotty in other areas. For example, EPA's proposal to include airport deicing operations in the national water pollutant discharge permitting process,[37] which is required of many other "industrial" activities, left airport operators scrambling to find and use acceptable deicing materials in the face of more stringent reporting and disposal regulations. According to an FAA official, the agency was not advised of the proposed rule change and did not learn of it until the comment period had nearly expired.[38] A more recent issue relates to stringent air pollutant emissions standards EPA has proposed for some regions in California, and their potential economic impact on aviation operations.[39] Airlines are concerned that extensive improvements in engine technology are required to meet the proposed standards. According to FAA, the two agencies intend to designate points of contact for cooperative discussion.[40]

Another problem relates to the effects of subsonic emissions on the atmosphere, especially at higher altitudes. Little attention was paid to their potential role in climate change, in part because conventional aircraft contribute so little to the pollutant budget relative to other transportation sources and because EPA's purview over emissions in the lower atmosphere does not extend up to aircraft cruise altitudes.[41] In December 1991, however, the ICAO Committee on Aviation Environmental Policy heard calls for increasing the stringency of emission standards beyond what current aircraft engines can meet. European research organizations quickly established supporting R&D programs. But reliance on European efforts to improve understanding of the impact of current air traffic on the atmosphere and to develop low-nitrogen oxides emission combustors leaves the United States ill-placed to dispute or validate proposed international rules on engine emissions or aircraft operations. Nearly two years later than European agencies, NASA incorporated the issue into the Advanced Subsonic Technology program and provided $25 million in fiscal year 1994 for studying subsonic aircraft impacts and developing next-generation combustors.

As with aviation noise, the United States has the expertise to address the other aviation environmental issues. However, a comprehensive R&D agenda has not been established and no mechanism yet exists for ensuring and integrating input from the appropriate agencies. The lack of an integrated U.S. approach to defining environmental risks from aviation and the commensurate level of regulatory and R&D attention are hampering a timely, effective response to environmental challenges that confront the industry. This piecemeal approach may undermine U.S. leadership in setting aviation environmental standards and result in environmental policy decisions that inadequately consider the aviation safety and performance implications of new technology or operating mandates. At a minimum, the sharing of existing data and impact assessments among federal agencies is needed, along with cooperative evaluation of emerging issues.

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[37] This program is known as National Pollutant Discharge Elimination System (NPDES). In 1990, EPA included airport runoff in the category of industrial operations affected by the NPDES program. 55 *Federal Register 48066* (Nov. 16, 1990).

[38] George Legarreta, FAA Office of Airport Safety and Standards, personal communication, Nov. 2, 1993.

[39] See 59 *Federal Register 23264-23605* (May 5, 1994).

[40] Louise Maillet, Director, FAA Office of Environment and Energy, cited in Paul Page, "Airlines preparing To Fight 'Draconian Proposed California Emissions Rules," *Transport World,* June 27, 1994, p. 46.

[41] EPA's duty t. protect the public health and welfare has been focused on impacts in the mixing layer, the portion of the atmosphere nearest the ground.

I Interagency Coordination on Aviation R&D

The budget deficit and defense conversion are among the factors that have led to increased congressional interest in cooperation among federal agencies conducting aviation R&D. The primary advantages of interagency R&D programs include economies of scale, elimination of redundant efforts, and more rapid technology development and deployment,

FINDING 8: *Coordination and cooperation for aviation research and technology programs among federal agencies have improved in recent years, but these efforts could be stronger still,*

Recognizing that FAA's level of in-house R&D capabilities cannot address all aviation research challenges, Congress included provisions to encourage work with NASA, DOD, and other agencies in the Aviation Safety Research Act of 1988 and the Catastrophic Failure Prevention Research Program. FAA has increased the number and dollar amount of interagency R&D efforts since this legislation was enacted.

Long-term research integral to FAA's missions, such as human factors, is also important to many other federal agencies. Substantial federal research efforts are under way in areas significant to aviation operations. For example, defense programs have been the source of many fundamental technologies for civil aviation, such as radar, computers, datalinks. and satellite-based navigation. Moreover, for aviation environment and security, FAA must depend on other agencies' research to characterize and assess risks.

Among its R&D relationships with other federal agencies, FAA's ties are strongest to NASA. Although NASA and FAA have worked together since their inception, it was not until 1990 that the FAA and NASA Administrators took personal and administrative actions to bolster the ties between their agencies. The agencies now coordinate aviation research programs and planning through a joint committee and have established Memoranda of Understanding (MOU) in more than a dozen science and technology areas. NASA supplies most of the research personnel and facilit y support, and contributes about $40 million beyond what is explicitly counted in interagency fund transfers. FAA has small field offices at NASA's Ames and Langley research centers to help coordinate these efforts.

FAA has made efforts to involve the national laboratories in aviation R&D programs within their areas of expertise. Many of these facilities. especially the Air Force labs. have capabilities directly relevant to FAA's missions. R&D conducted for DOD's diverse aircraft inventory. such as the use of composite materials for aircraft primary structures, has applications in civil aviation.

POLICY CONCLUSIONS

Aviation safety and efficiency-the primary missions of FAA-depend strongly on advanced technologies and the people who use them. Many improvements in these areas stem from core technologies derived from federal research programs.

But "technology push" rather than "operational demand" has driven some aviation research and technology programs in the past. This bottomup model of developing technology linearly from the lab to the field will not be effective for improving aviation safety and air traffic operations significantly in the future. Operational success in the complex aviation system depends on more than practical technologies. Technology must be

FEDERAL AVIATION ADMINISTRATION

Effective research for aviation security depends on coordination and cooperation among federal agencies adaptable to system requirements, rather than the other way around. It must assist pilots, air traffic controllers, and security screeners instead of creating new, complex tasks. Superb technology is of little use if those responsible for installing and operating it do not see a need for it.

91 Research and Technology Priorities: Better Guidance Needed for and by FAA

FAA can contribute the most to aviation R&D by providing an important operational perspective—whether or not it conducts or funds the R&D. FAA is in a strong position to be the catalyst and clearinghouse for technological advances vital to aviation progress; it alone has the breadth of expertise and connections across the aviation community to provide this service.

FAA's Role in Setting the National Aviation R&D Agenda

If FAA is to have an effective voice in national research decisions, the agency must develop a detailed blueprint for future safety, environmental, and air traffic operational objectives. Aviation R&D should be closely linked to these objectives, and priorities developed to carry them out. More effective approaches to priority-setting and analysis are required, and a means must be found to guarantee that all parties who will be part of solving a problem—including those from other agencies conducting aviation research—are considered in devising the solution.

FAA has taken some steps in setting R&D objectives and assessing R&D programs, but still has a way to go. The agency's goals for its R&D efforts now are better linked to research or technology advances. However, the contribution of FAA RE&D programs will be difficult to measure since most of these goals are still broadly defined. For example, attaining FAA's RE&D goal to ". . . reduce accident and incident rates attributable to controller, flightcrew, and maintenance crew human error. . ."[42] will depend strongly on R&D, but will also require the efforts of FAA's regulation and certification divisions, the airlines, and aircraft manufacturers. To help ensure effective use of federal aviation R&D resources and emphasize the importance of FAA's needs, Congress could consider having FAA testify at NASA, DOD, and other agency authorization and appropriations hearings; NASA, DOD, and other agencies have testified at FAA-related hearings in the past.

The Role of Outside Advice in Setting FAA's R&D Agenda

Essential to the process of setting priorities for aviation is to incorporate, on a continuing basis, the advice of pilots, controllers, technicians, and industry experts. Congress may consider giving advisory committees that include these experts a stronger role in this process. Possibilities include revising the charter of the FAA RE&D Advisory Committee, combining FAA and NASA advisory committees, or creating an independent advisory committee similar to the former National Advisory Committee for Aeronautics (NACA).

Advisory committees are effective only to the extent the agency takes their advice into account when making decisions. Congress may wish to give FAA advisory committees more accountability, such as requiring that FAA formally respond to official recommendations by advisory committees.

While not a panacea, federal advisory committees have provided valuable operational perspectives, technical expertise, and political balance to aviation programs at FAA and NASA. The congressionally chartered FAA RE&D Advisory Committee has provided sound recommendations for strengthening FAA R&D endeavors and has helped FAA better focus its R&D plans while encouraging the agency to pursue new research and technology directions. But most aviation research plans to support FAA missions must be tied to reg-

[42] U.S. Department of Transportation, Federal Aviation Administration, *1993 FAA Plan for Research, Engineering and Development* (Washington, DC: February 1994), p. 1-8.

ulatory, infrastructure, and operating procedure goals. FAA needs guidance and assistance in planning and coordinating objectives across these areas. Although the RE&D Advisory Committee has provided such assistance at times (e.g., for satellite navigation implementation), the charter of this committee is too narrow to serve the larger purpose.

If Congress wishes to provide FAA with more comprehensive guidance, it could consider either broadening the charter and membership of the RE&D Advisory Committee or forming a new group that would consider regulatory, operational, infrastructure, and R&D issues in total. This "Aviation System" Advisory Committee would have primary advisory responsibility for FAA priority-setting, including R&D, This committee could help FAA look at the aviation system as a whole and determine what goals are most important. Only then can tradeoffs be made on the technological, procedural, and regulatory paths to take to meet those goals.

FAA has taken promising steps to improve communication and coordination for aviation—internally, with other government agencies, and with private industry. Noteworthy are FAA's recent efforts to institute better operational planning and to encourage public-private partnerships for technology development. An Aviation Systems Advisory Committee could be complementary to those efforts.

FAA will continue to need expert guidance on research methodology and management, and new developments in other fields, agencies, and industries. With an Aviation System Advisory Committee in place, the membership of an R&D Advisory Group (an Aviation System subcommittee or independent committee) could be composed primarily of individuals with expertise in the conduct or management of scientific research or technology development programs. They could focus on ensuring that FAA R&D plans and the conduct of R&D programs reflect the long-term needs and objectives of the aviation system and could help coordinate FAA in-house research with that of other federal, private, and international research programs.

Another option Congress may wish to consider is recreating a group similar to the former NACA. a prestigious group of individuals who would advise on aviation priorities across agencies and improve the visibility of aviation R&D in general. Many of the issues such a group would address—the U.S. aviation technology base, research and manufacturing competitiveness, and dual use technologies—go beyond the scope of this report. However, civil aviation safety, environmental protection, and air traffic operations as well as FAA research and technology programs could be a subset of such a group's charter.

I ATC System Development: Providing New Management for New Technologies

As discussed above, advisory groups can help research agencies set priorities and objectives. However, more than better advice is needed to improve ATC system development and implementation. **OTA finds that delays in ATC modernization usually stem from inadequately addressing operational issues throughout the stages of system planning and development at FAA. To** address this fundamental flaw in the ATC R&D process, new management methods and organizations are also needed.

Reform is most needed in ATC system development management and philosophy rather than in the procurement rules and funding for fully developed equipment. FAA acquisition policy[43] focuses on technology development and products. which is what the federal government purchases from contractors. Consequently. federal acquisition policy does not make the development process for operational requirements and procedures a clear priority. For ATC, operational products are not equipment or software, but are requirements

[43] OMB Circular A-109 and FAA Order 1810.1F for acquisition policy

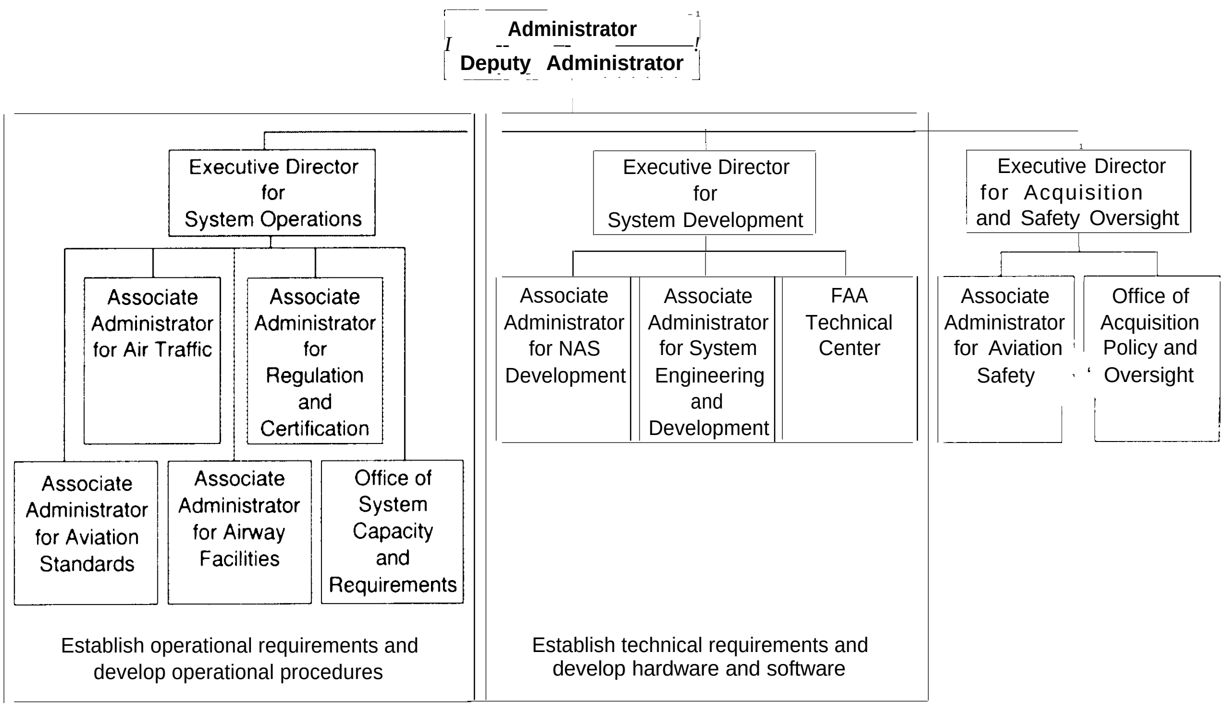
and procedures generated primarily within FAA. Congress may wish to ensure that guidance for future ATC system development and acquisition explicitly addresses operational procedures as well as equipment.

This does not necessarily require a major reorganization of FAA or a change in its institutional status. However, neither does it preclude such actions. **OTA concludes that key criteria necessary for more effective ATC system development include stable leadership within the organization, multidisciplinary development teams that cross organizational and public-private boundaries, and a commitment and understanding throughout the organization that ATC system development must be more operationally driven than technology driven.** The following section examines how these criteria could be applied within the present FAA organization and in a new institutional framework.

Improving ATC R&D Within the Present FAA Organization

In the current internal structure of FAA, two executive directors, and eight organizations under them,[44] have important technical responsibilities for ATC system development (see figure 1-4). Presently, however, no one below the Administrator has the authority or the mandate to effectively bridge the operational and technology directorates of FAA. Moreover, long-term system development requires long-term leadership, but the aver-

FIGURE 1-4: Operational and Technological Development for Air Traffic Systems in the FAA Organization



SOURCE Office of Technology Assessment 1994

[44] Air Traffic, Airway Facilities, Regulation and Certification, Aviation Standards, and System Capacity and Requirements within the Systems Operations Directorate; and System Engineering and Development, National Airspace System Development, and the Technical Center within the Systems Development Directorate.

age tenure of an FAA Administrator is far shorter than the development cycle of most ATC systems.

Within the present FAA framework, one option is for Congress to create a new, fixed-term position at the Deputy Administrator level with responsibilities for system development oversight and coordination within FAA.

The new position would be subordinate only to the FAA Administrator. This person would be provided with a clear mandate to integrate operational and technological development processes, would have the authority to form teams from across the agency, and would maintain a core staff (o administer teams. He or she would also have adequate resources to conduct operational analyses and procedure development, including dynamic ATC simulations, and have a voice in the system acquisition and procurement process. In essence, this person would be responsible for the actual direction of entire projects and would have sufficient status to make things work, Presumably such a position would be created in a way that would allow the hiring and transfer of people of excellent managerial and technical quality and ensure adequate tenure to get the job done.

OTA believes it is necessary that these functions be performed regardless of whether Congress considers establishing a fixed term for the FAA Administrator.[45] Many aviation issues and immediate crises other than system development vie for the Administrator attention: a fixed-term Administrator. like the Administrator in the present FAA. would need subordinate executives to manage and oversee ATC development.

In addition to or in lieu of the option above, Congress may also wish to consider changes in funding procedures to strengthen ATC system development. For example. ATC R&D is presently funded out of two FAA budget accounts (RE&D and Facilities and Equipment). Congress may wish to more closely delineate RE&D and F&E accounts to match the actual phase of system development, such as defined in the Office of Management and Budget's and FAA's acquisition guidelines. This could possibly entail raising RE&D authorization levels and reducing those in the F&E account, whether or not there is an overall change in FAA's authorized budget.

Improving ATC R&D Through Major Reorganization of FAA

To help speed ATC modernization in the United States, and for other objectives, various options to restructure FAA have been presented to Congress during the past decade.[46] These proposals generally involve making either FAA or some subset of the agency more independent of federal budget, personnel, and procurement constraints, and of bureaucratic controls. The latest alternative is the U.S. Air Traffic Services Corporation (USATS) proposed by the Clinton Administration in May 1994. **These options raise significant issues that require serious discussion but are outside the scope of this study.** Based on its analyses in this and past studies, however, OTA has identified certain ATC R&D issues that Congress may wish to consider in the context of possible FAA restructuring.

If Congress considers a major restructuring of the federal ATC system, it is important to ensure that any institutional changes directly address the problems in the system development process, and not only budget, procurement, and personnel issues. The criteria discussed earlier—stable leadership; ability to bridge cultural gaps among operational, technical, and management groups; and sufficient attention to operational issues in the development process—are critical to improving the

[45] This option has been proposed by a number of studies, including U.S. Congress, Office of Technology Assessment, *Safe Skies for Tomorrow: Aviation Safety in a Competitive Environment*, OTA-SET-381 (Washington, DC: U.S. Government Printing Office, July 1988); and Aviation Safety Commission, *Volume I: Final Report and Recommendations* (Washington, DC: April 1988).

[46] Other proposals presented in the literature include making FAA an independent agency or authority: combining FAA and NASA into an independent agency; converting 1;\,+\ into a government corporation; establishing the ATC portion of FAA as an independent agency, authority, or government corporation, in or outside of DOT, and privatizing all or part of FAA,

air traffic system. While most FAA reorganization proposals address the stable leadership issue, to date none has made explicit how the ATC R&D process would be improved.

For example, the USATS proposal does not contain specific measures to provide better coordination for ATC R&D among operational, regulatory, and technology organizations, as well as with the private sector, or for a stronger operational focus for system development. While the USATS would develop air traffic rules and procedures, which has the benefit of keeping operational and technological development in the same organization, those procedures would require the approval of the FAA Administrator to be implemented. It is unclear how the early and continuing advice of operational and safety experts, especially FAA certification staff, would be incorporated into this process. It will be important to address these issues if the USATS or other proposals reach the congressional agenda.

Improving ATC With New CNS Infrastructure and Institutions

Satellite-based communications, navigation, and surveillance technologies are becoming part of the ATC system in the United States. For the next decade or longer. the federal government will likely continue to own and operate all essential U.S. air traffic system infrastructure, However, economics and international politics dictate that this must eventually change. For example, advanced ATC over the oceans requires satellite systems, and it is unlikely that the U.S. government will or should be the sole entity to provide those satellites. Ultimately, nonfederal entities such as private companies or multinational organizations will own and operate some communications satellites, digital networks, and other key elements of the CNS infrastructure. Congress must ensure that whichever institution is responsible for U.S. ATC has the authority to address, on an international basis, the liability, ownership, and control issues that these systems raise.

Whether or not a USATS is created, **FAA priorities and responsibilities for system development, operation, and oversight will have to change if digital communications networks and satellite systems are to become the primary air navigation infrastructure for the United States.** FAA has the statutory authority to certify air navigation facilities for use by U.S. flyers, whether or not the federal government owns or operates those facilities.[47] FAA's ultimate responsibility for safety need not and most likely should not change. However, Congress may wish to authorize additional FAA staff and analytic resources to certify and regulate these facilities and the organizations that build and operate them. New operational and economic benefits must be balanced against possible reliability and security risks, and international and public-private cooperation and coordination for air traffic system development and operation will need to be strengthened substantially. If Congress becomes confident that FAA has the resources and capability to ensure the safety and economic benefits of such systems, it may wish to encourage FAA to pursue more private sector and international collaboration for CNS infrastructure development and implementation. Moreover, the agency's research and system development efforts may need to adjust, and possibly expand, to apply and integrate these new systems into the National Airspace System.

Furthermore, the United States must focus more on international issues for ATC system implementation. Congress could encourage the Department of Transportation and the State Department to take one or more steps to help speed international acceptance of satellite navigation standards and systems. One possibility is to bolster FAA's technical support for ICAO panels, especially by accelerating the development of de-

[47] 49 U. S.(-. 1426

tailed operational procedures for satellite-based CNS. Another possible step is to negotiate, outside of ICAO, bilateral or multilateral agreements for CNS standards compatible with the ICAO Future Air Navigation System concept. This could be accomplished much sooner than through ICAO negotiations and would result in earlier economic benefits and wider operational expertise to U.S. aircraft operators. Yet another approach is to develop and support internationally acceptable institutions to control and operate these systems. **It is important for Congress to determine what aviation leadership role it desires for the United States and to encourage international alliances that foster those interests.**

Long-Term Research: Providing FAA With a Clearer Mandate

To address fundamental research concerns for aviation safety, environment, and operations, Congress included provisions in the Aviation Safety Research Act of 1988 to make FAA R&D more "future-oriented." One intent of Congress was that long-term safety research at FAA generate better information.[48] As a result of this legislation, human factors first became an explicit FAA research field. In subsequent legislation, Congress mandated additional analytic research tasks for FAA, including assessing the risk of aging aircraft and catastrophic engine failures. In other areas. however. it appears that FAA research to identify and assess emerging problems has not increased, in part because the statutory definition of "long-term research"[49] in the Aviation Safety Act of 1988 does not distinguish between technology development and more fundamental research and analysis. OTA finds that less than 5 percent of FAA's safety R&D may be aimed at identifying or understanding future problems.

Congress may wish to encourage more fundamental research rather than technology development within FAA's long-term R&D programs. A greater emphasis on a process (possibly quantitative risk assessment) that identifies priority problems could be part of this effort.[50] Safety technology development resources become more valuable when they can be directed at the most important problems. What has been missing so far is a more unified effort across disciplines. Scientific, operational, and technology development data are all essential to this effort; such information is not now being combined systematically.

Interagency Coordination *and Cooperation*

Coordination and cooperation depend on personalities at all levels, and temporarily transferring NASA, DOD, and other personnel to FAA facilities could be effective ways of fostering cross-agency links. Congress may also wish to have FAA establish field offices at DOD labs similar to the ones at NASA research centers. For example, an FAA field office at Wright-Patterson Air Force Base could have access to both vehicle-related research at Wright Laboratory and human factors expertise at Armstrong Laboratory.

Although FAA has relatively little to offer as a supplier of scientific R&D in interagency programs, certain technological systems developed and engineered in FAA programs, such as those for explosives detection or ATC, are useful to other agencies. For example, DOD plans to install in its domestic control facilities the same air traffic

[48] A core of "long-term, generic research programs" was the intended goal of the 15-percent R&D funding requirement. U.S. Congress, House Committee on Science, Space, and Technology, "Aviation Safety Research Act of 1988," H. Rept. 100-894, Sept. 8, 1988, p. 18.

[49] In drafting the 1988 act the House Committee on Science, Space, and Technology' characterized a long-term research project as one *at unlikely to result in a final rulemaking action within five years or in initial installation of operational equipment within 10 years after the project has commenced. Ibid., p. 27.

[50] Previous high-level federal attention to FAA risk assessment has been directed, with limited success, at near. term products by the FAA regulatory and operating sections. In 1988, FAA established a safety indicators program to provide management with reliable, rapid displays of the state of aviation safety and supporting decisionmaking tools. Progress was slow in defining the indicators and developing the analytic tool; in the early 1990s, the project was wrapped and replaced with the system indicators program. Scc ch. 3.

systems as FAA. Additionally, FAA research facilities for aviation security, fire safety, and ATC simulation are national resources that could be useful to other agencies. While some interagency research projects are under way at the FAA Technical Center, FAA research programs and facilities have offered few research opportunities for NASA, DOD, and other researchers. **Congress could consider making interagency and cross-discipline research an explicit goal for certain FAA research facilities and technology programs.**

Congress might also wish to implement more thorough procedures to account for the true costs of an agency's cooperative research. Research conducted for other agencies, such as FAA, is sometimes implicitly subsidized. If these costs were fully recognized, the "host" agencies might be more willing to emphasize cooperative research.

Aviation Environmental Research

Environmental research is underway at many federal agencies, as well as in academia and industry. However, there has not been a comprehensive environmental research plan for aviation. To increase emphasis in this critical area, Congress might wish to designate explicit agency responsibilities for domestic and international aviation environmental issues and bolster aviation environment research resources.

Regulatory responsibility is a key forcing mechanism for environmental research. Congress may wish to consider reexamining and clarifying the current division of regulatory responsibilities in light of the expanding number and complexity of environmental issues confronting aviation. One option is to request that FAA prepare a "hot-list" of regulatory issues and outline the areas of data collection, analysis, and extramural research needed to address them.

Whether or not the current lines of authority are changed, Congress may wish to explore means of closer coordination between EPA and FAA in order to ensure continuous and open communication in areas critical to aviation operations. These could include joint reporting of air- and water-quality guidance activities related to airports, integrated databases on engine emissions, and participation in an interagency working committee or group on aviation environmental issues. The latter should include NASA and the defense agencies.

Furthermore, FAA needs greater in-house expertise and the capability to provide stronger technical support at international meetings. Currently, FAA lacks this expertise to deal with some atmospheric and water-quality issues associated with the existing aircraft fleet-issues that will become more challenging in the future. FAA, with its understanding of aviation operational issues, could play a larger role in setting federal environmental research goals. Should Congress choose to expand FAA's environmental role, however, it will need to consider that the agency lacks the resources to coordinate across many of the key fields and agencies. Congress might consider increasing funding for FAA environment programs to allow additional technical specialists in the areas of emissions and climate. This would mean an approximately 10-percent increase ($500,000) in the current FAA environmental R&D budget. Expanding FAA-NASA coordination of environmental R&D beyond the problem of aircraft noise could be one objective of this enhanced responsibility.

CONCLUSION

Research and technology development for aviation has served the United States well as the aviation community grew and commerce expanded. To continue to serve the national aviation needs well in the next decades, changes will be required.

More effective approaches to priority-setting and analysis need to be developed, and the means must be found to ensure that all parties who will be part of solving a problem are considered in formulating the solution. This is especially important for air traffic system development, where technology decisions have not always meshed with operational requirements.

Moreover, this country and much of the world are relying on post-World War II institutions for aviation that have not been able to transform themselves as needed to accommodate changes in technology, a global economy, and more modern forms of management. New technologies for air traffic system infrastructure will require new institutional relationships among national airspace authorities and also between public and private providers of aviation communications and navigation systems.