Federal Research and Technology for Aviation

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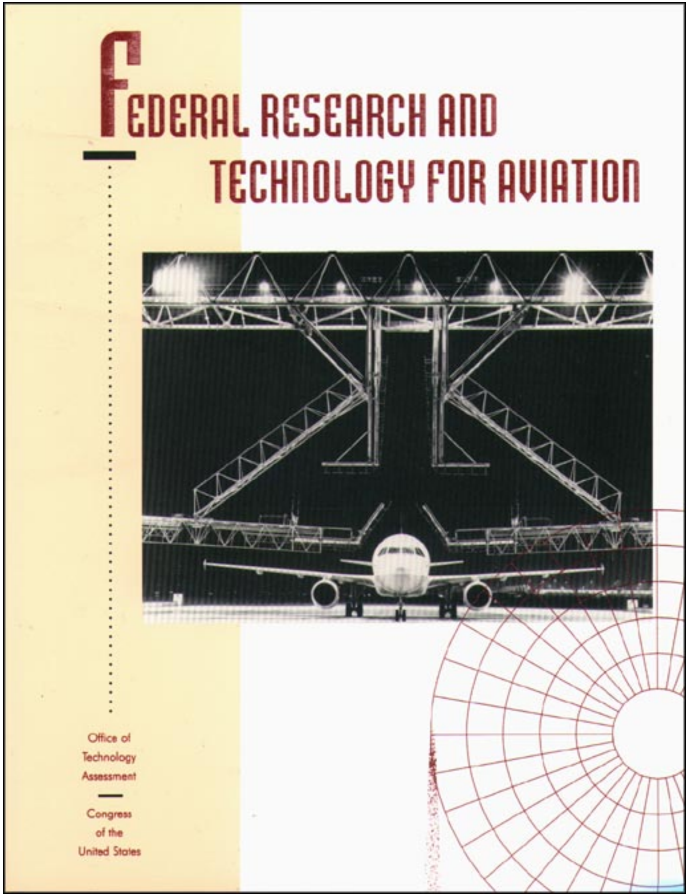

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Foreword

Within the United States, only the federal government has the resources to support large-scale, applied research and development programs for aviation safety and infrastructure. 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. The House Committee on Science, Space, and Technology and its Subcommittee on Competitiveness and Technology (now the Subcommittee on Technology, Environment and Aviation) asked the Office of Technology Assessment to take a comprehensive look at the federal R&D that underpins the Federal Aviation Administration's technology and regulatory development programs. Long-term research efforts and airline economics were special concerns. The study was also endorsed by the House Subcommittee on Aviation of the Committee on Public Works and Transportation, and the House Subcommittee on Government Activities and Transportation of the Committee on Government Operations.

This report focuses on research and technology policy issues for aviation operations: safety, security, environmental protection, and the air traffic system. Achievements in science and technology have helped make the U.S. air transportation system the safest and most efficient in the world, but the system could be improved further. However, operational success in the complex aviation system depends on more than technological advances. If technological solutions are to be more timely and useful, federal aviation R&D programs will need more effective approaches to priority setting and analysis, and more active participation by operational” experts. This is crucial for the air traffic system, where technology decisions have not always meshed with operational requirements. In this report, OTA identifies various initiatives that Congress and federal agencies could consider in setting the national aviation R&D agenda, restructuring the management process for air traffic system R&D, and clarifying FAA's role in long-term research and in international standards development for an increasingly global aviation system.

OTA appreciates the invaluable advice and assistance of the many people who contributed to this project, including the advisory panel, contractors, and reviewers.

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Note: OTA appreciates and is grateful for the valuable assistance and thoughtful critiques provided by the advisory panel members. The panel does not, however, necessarily approve, disapprove, or endorse this report. OTA assumes fuIl responsibility for the report and the accuracy of its contents.

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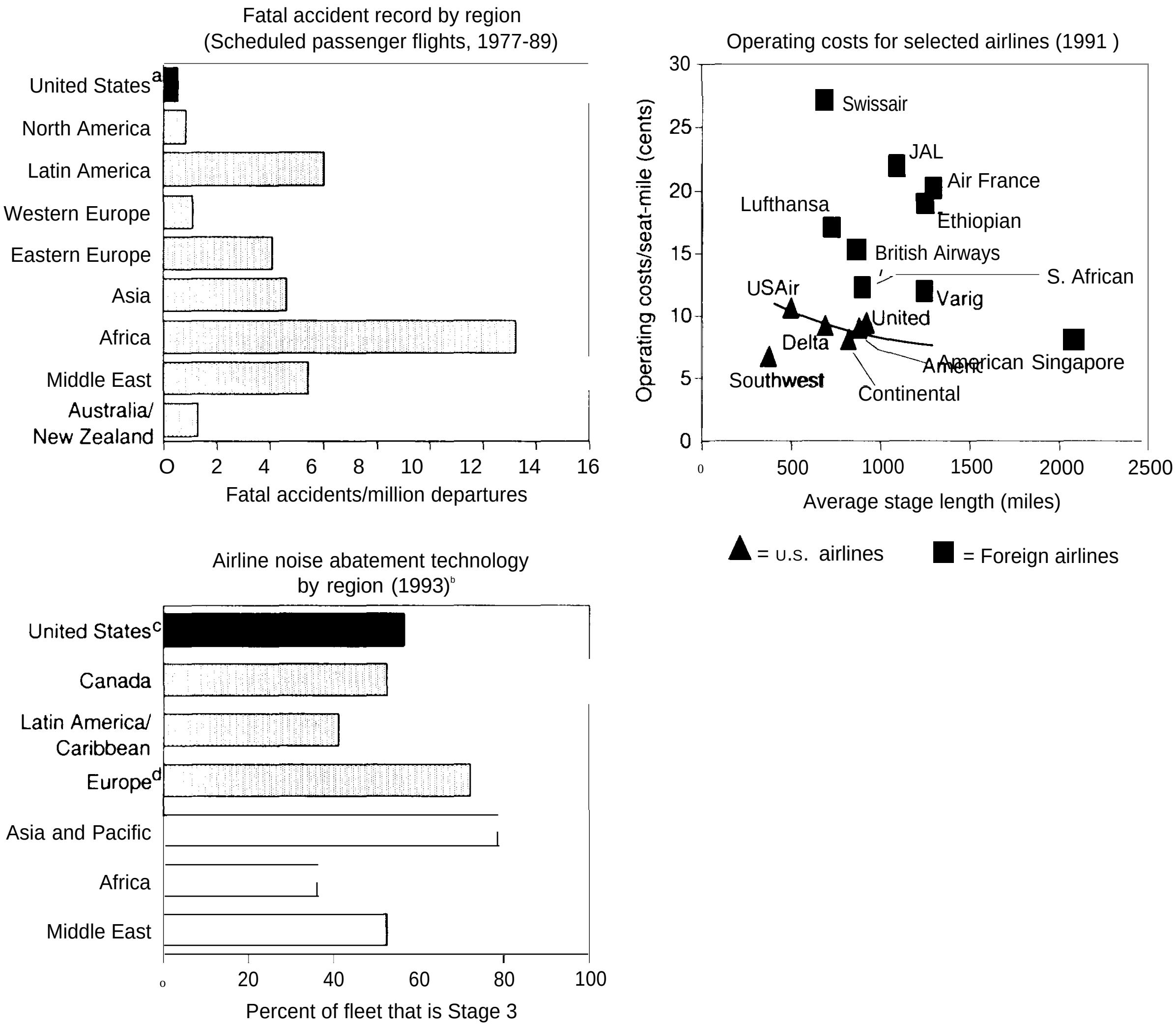
Summary and Policy Conclusions 1

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:

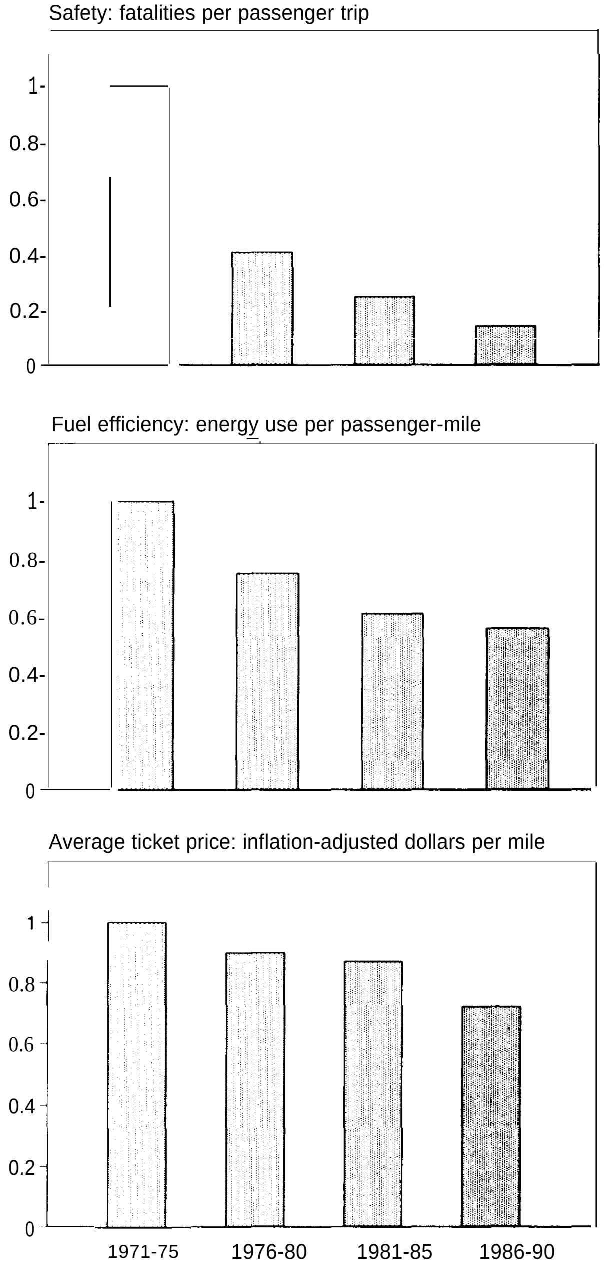
(2) The promotion, encouragement, and development of civil aeronautics;

(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 Office 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

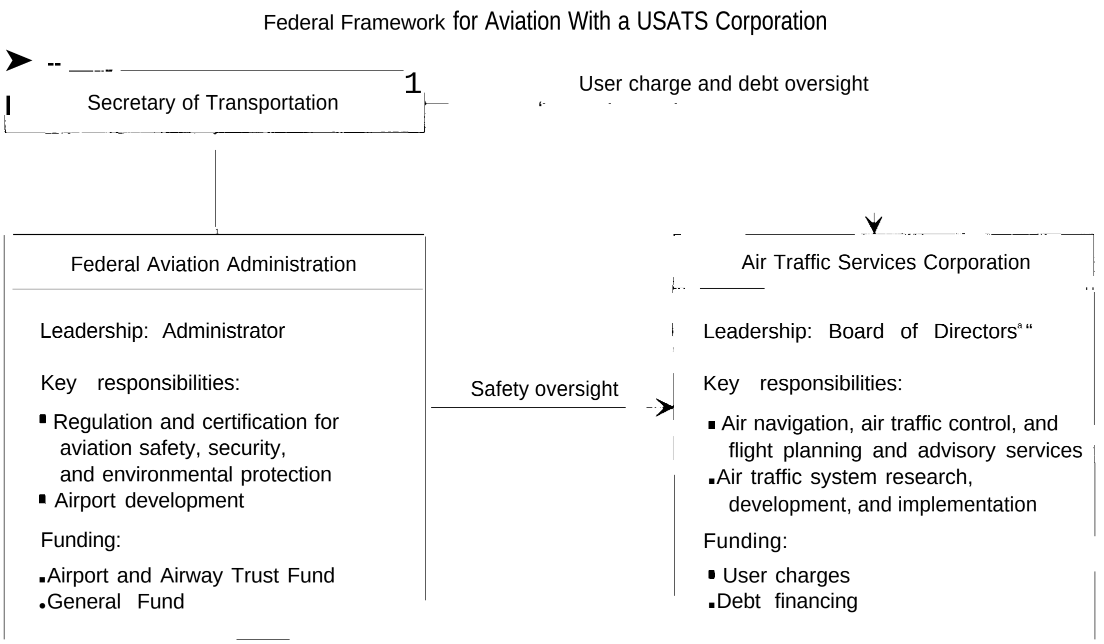
[5] For fiscal year 1993, $6 3 billion of FAAs $91 billion total funding was allocated to ATC U S Department of Transportation. *Air Traffic Control Analysis of Illustrative Corporate Financial Scenarios* technical report prepared by the Corporation Assessment Task Force for the Executive Oversight Committee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



[a]The 11 members of the board, who are appointed by the President, would 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		FY 1994a	
			(real-year dollars in millions)			
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
Environment[c]	4.0	170	4 8	193	5 4	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 for the agency's Research, Engineering and Development program, except management and Innovative/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 1994)

SOURCE Office of Technology Assessment, 1994, based on NASA and FAA data

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 1992, 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)

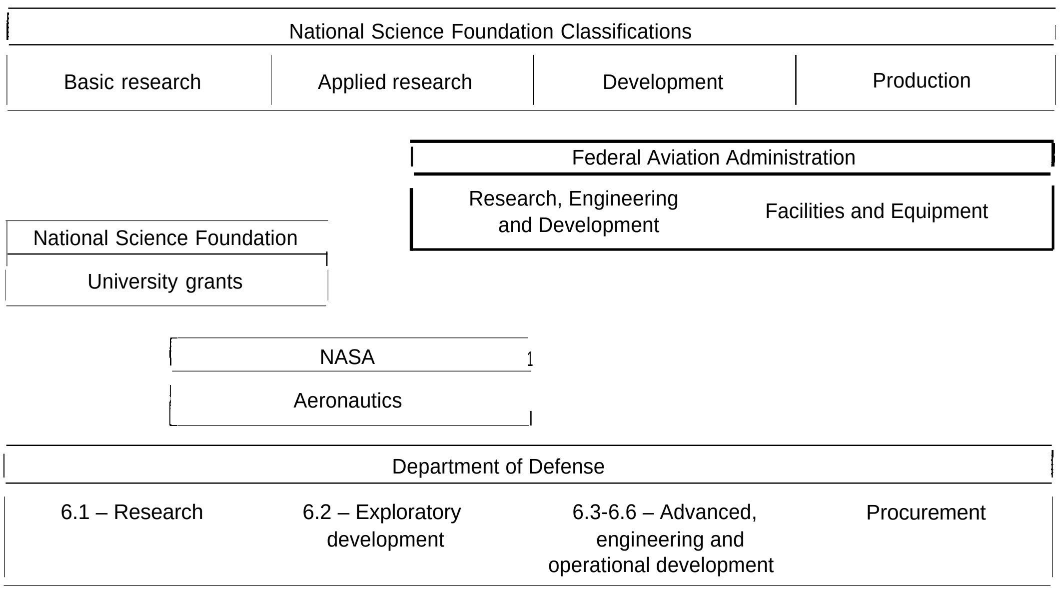
The National Aeronautics and Space Administration (NASA) conducts applied research to support its own space and aeronautics program goals, as well as other federal R&D needs. The programs that the Federal Aviation Administration calls Research, Engineering and Development (RE&D) generally correspond 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 mission-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

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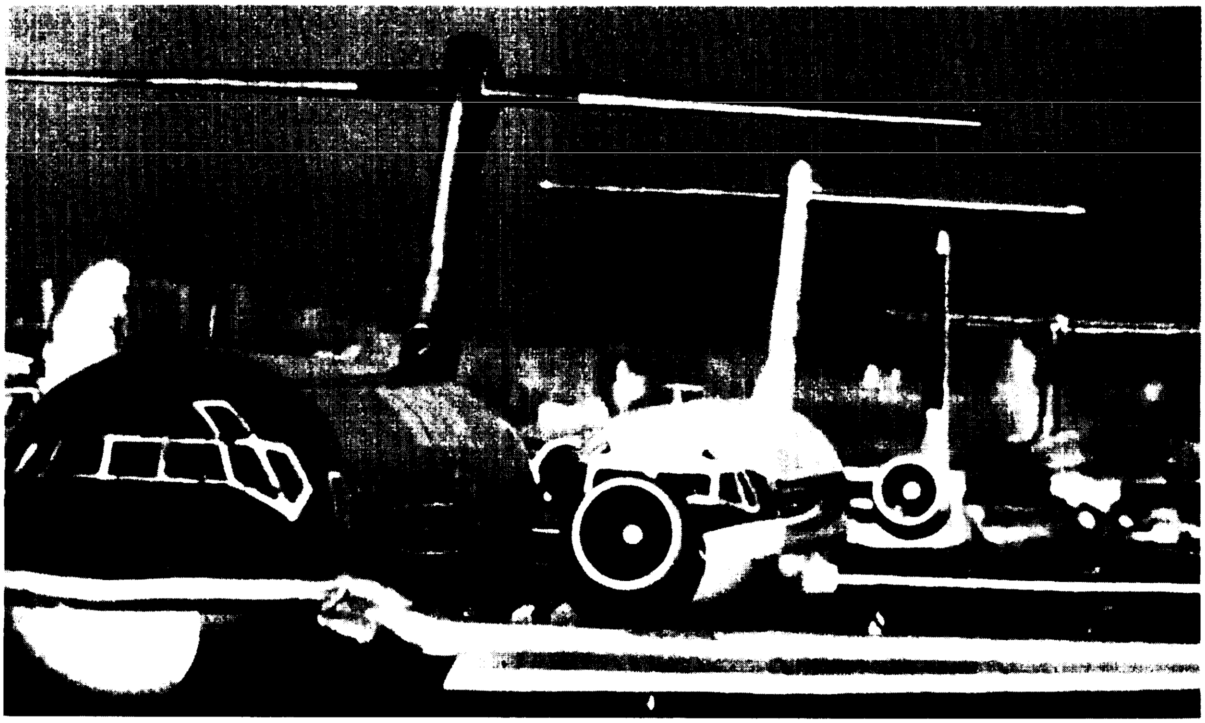

Small Improvements in airspace system capacity can mean large savings in time and money, protection, and the air traffic system. These findings arc presented in four categories: 1) technical standards for international aviation, 2) ATC modernization in the United States, 3) research for aviation safety 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 line-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 communication, 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 will 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 line-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

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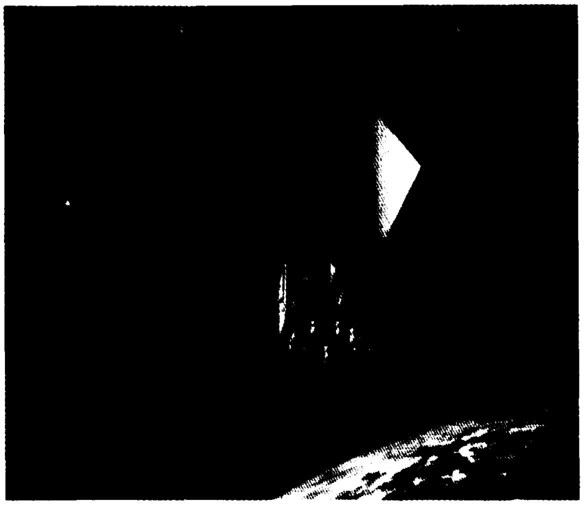

Satellite systems and digital communications will likely form the backbone of air traffic communications, navigation, and surveillance systems in the near future

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

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[21] In January 1979, when services began, there were approximately 500.000 contacts made per month using voice radio. Message exchange using datal ink 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. Theta+ 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

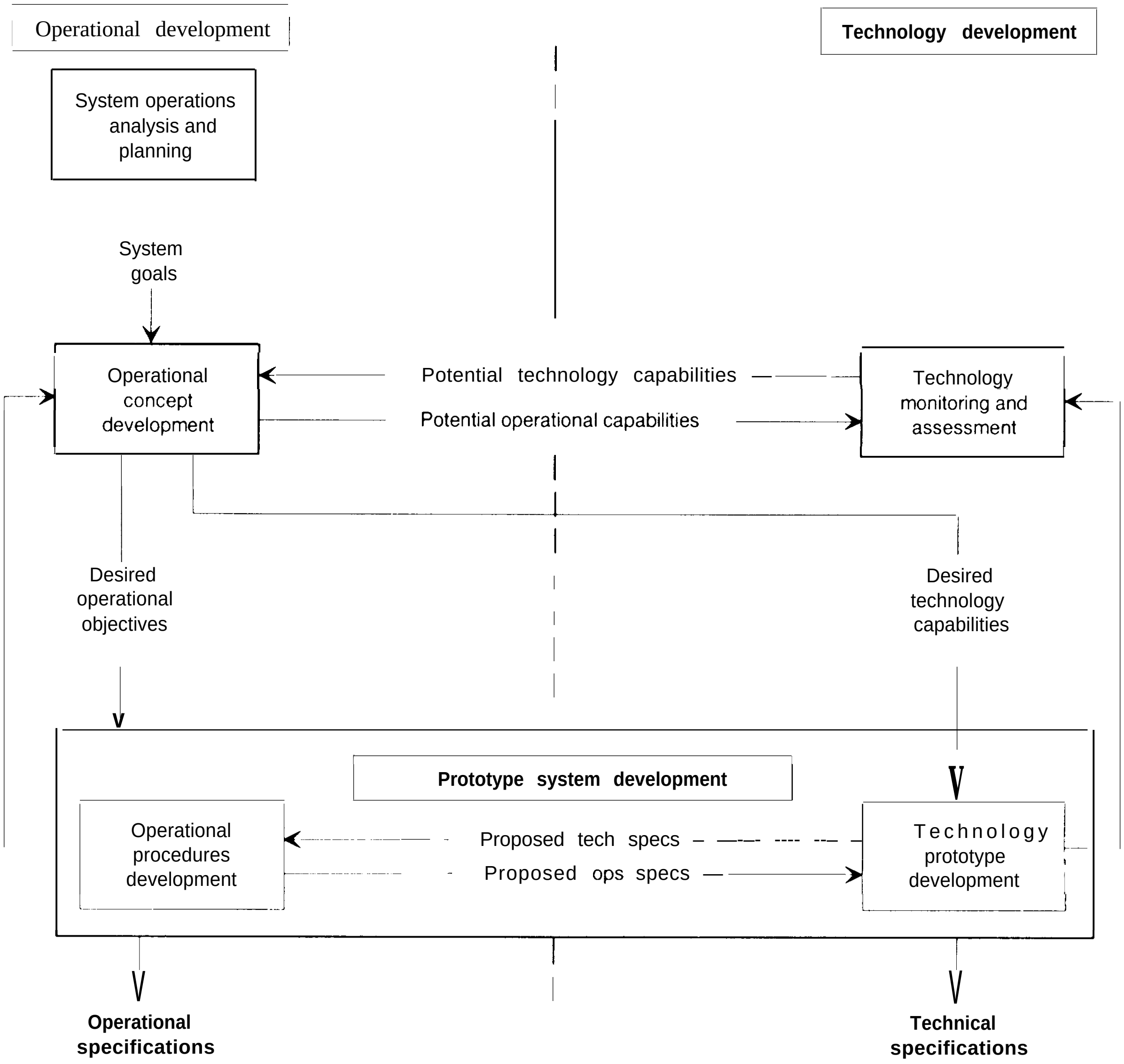
24 National Performance Review, *From Red Tape to Results: Creating a Government That Works Better & Costs Less* (Washington, DC: Office of the Vice President, September 1993); U.S. Department of Transportation, *Air Traffic Control Corporation Study: Report of the Executive Oversight Committee to the 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 in ch. 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

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[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).

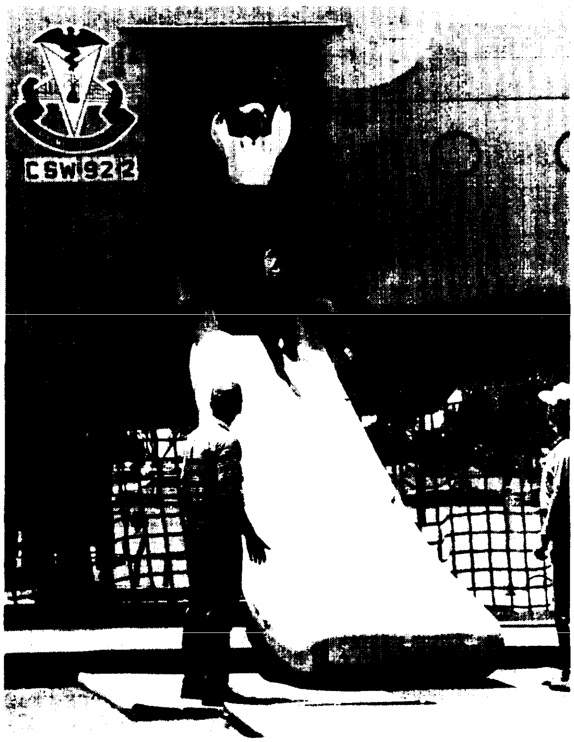
standard routes.[30] Airlines and the public accept this extra risk for the benefit of flying to those airports and for relatively less noise on the ground.

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

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 199 1), 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 (o 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. I *4, 1993.*

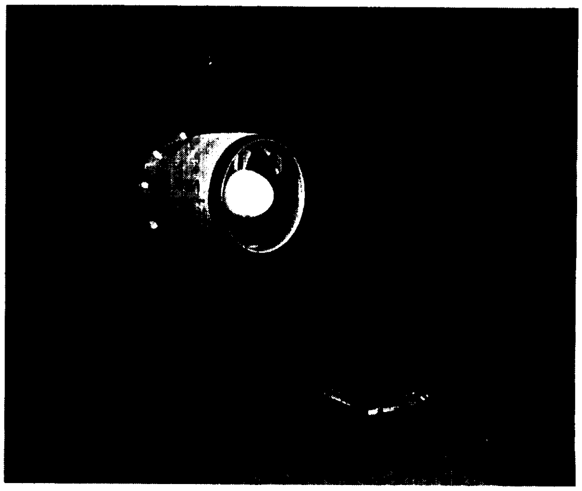
this type of weather research, despite the potential safety and operating cost savings associated with real-t i me forecasts of adverse or hazardous weather.

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

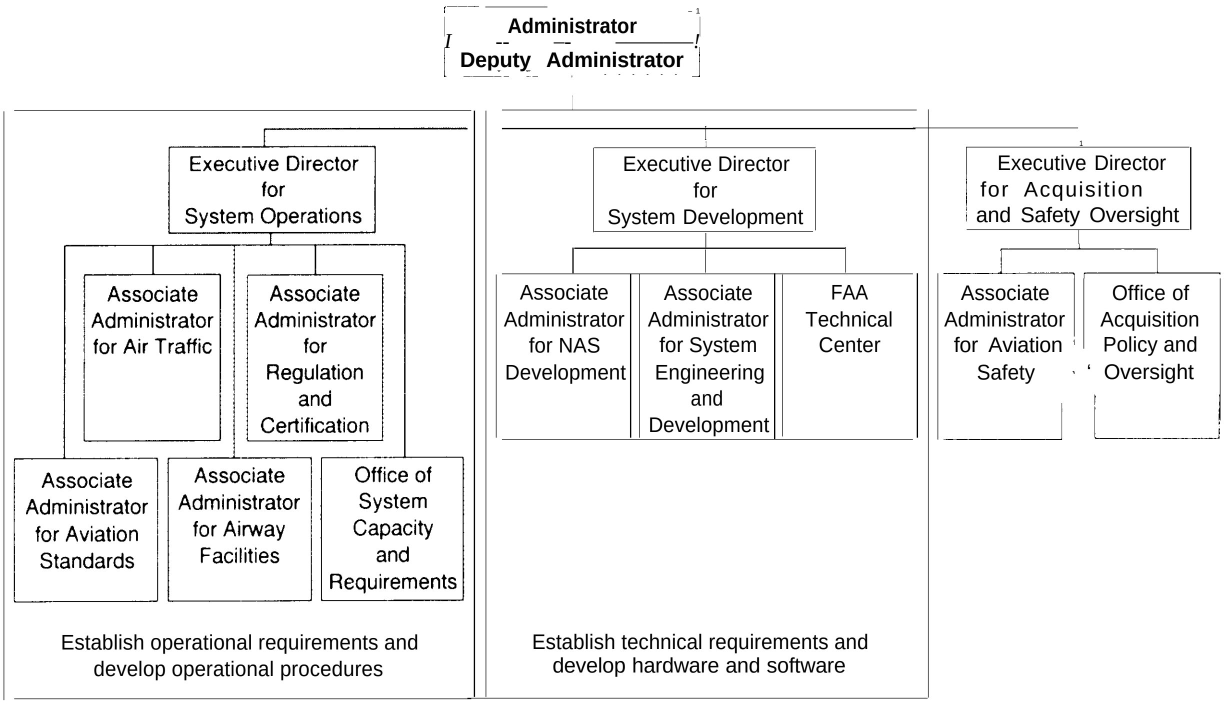
and procedures generated primarily within FAA. Congress may wish to ensure that guidance for future ATC system development and acquisition explicitly addresses operational procedures as well as equipment.

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.

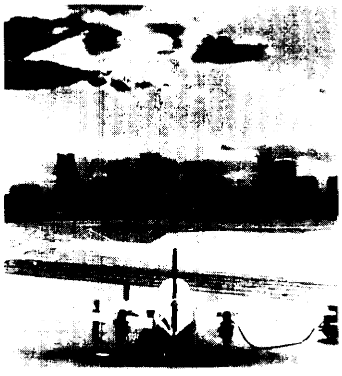
More effective approaches to priority-setting and analysis need to be developed, and the means must be found to ensure that all parties who will be part of solving a problem are considered in formulating the solution. This is especially important for air traffic system development, where technology decisions 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.

Institutional and Management Issues for Civil Aviation Research and Technology 2

The federal government is involved in most aspects of a typical aircraft flight in the United States. The aircraft design, its flight and maintenance crew, and the public airport it operates out of must all be certified by the Federal Aviation Administration (FAA), under the U.S. Department of Transportation (DOT). On the infrastructure side, most of the pavement, lights, and navigation devices at the airport are financed with federal funds, and air traffic control (ATC) and airspace systems through which the aircraft flies are owned and operated by FAA.

The tremendous size of the air transportation system and its importance to the U.S. economy, the federal responsibility for ATC, and the lack of commercial market or profit potential for certain safety, environmental, and air traffic management research have propelled the federal government into the role of major provider of aviation research and development (R&D). Within the United States, only the federal government has the resources to support large-scale, applied R&D programs for aviation safety and infrastructure. This chapter describes the present organizational framework for aviation R&D and discusses management and technology issues of concern to Congress.



ORGANIZATIONAL FRAMEWORK

Federal involvement in aviation began shortly after the inception of powered flight. At the end of World War I, Congress created the National Advisory Committee for Aeronautics (NACA) as an advisory group for aviation research, thus intertwining the federal government's interest in aviation for military and civil purposes from early on.

Many organizations hold prominent roles in U.S. civil aviation, especially in the areas of policy, regulation, and research and technology. This section looks at the roles of FAA, the National Aeronautics and Space Administration (NASA), and other organizations in providing the technical underpinnings for civil aviation.

Federal Aviation Administration

FAA promotes safety and fosters air commerce in three key areas—safety regulation, infrastructure development, and ATC system operation—and in the research and technology development to support them. FAA's regulatory authority covers virtually every aspect of aviation, from airports and airways to aircraft and the people who work in and around them. The agency is responsible for the nation's ATC system, a complex amalgam of people and equipment that must run 24 hours a day, every day of the year, in numerous locations across the United States and its territories.

Aviation R&D important to FAA is primarily mission-oriented; its key purpose is problem solving rather than other policy purposes such as technical leadership, competitiveness, educating scientists, or national security. Much of the fundamental research and core technology development for aviation is conducted outside of FAA.

FAA's legislative mandate for R&D is found in sections 312 and 316 of the Federal Aviation Act of 1958.[1] The act directs the Administrator to make long-range plans for developing airspace and landing areas, airways, radar installations, and other systems. It empowers the Administrator to develop improvements for aircraft and engines; to develop systems, procedures, and facilities for safe and efficient navigation and ATC; and to protect against terrorism. Although the language is broad, it supports R&D related to ATC.[2]

FEDERAL AVIATION ADMINISTRATION

The Federal Aviation Agency was created in 1958

Congress passed the Aviation Safety Research Act of 1988[3]". . . to add additional topics (structures, fire safety, human factors, and ATC computer simulation) to those on which FAA performs research."[4] Under the 1988 act, FAA must each year prepare an Aviation Research Plan. The act further required the FAA Civil Aeromedical Institute (CAMI) to conduct medical research, established an FAA Research Advisory Committee, and increased authorized funds.

The 1988 act also supported an expanded research program by directing FAA to create more "visibility and structure" in its research. Another aim of the legislation was for FAA to develop expertise in each of the new research areas and to have a closer working relationship between FAA R&D staff and the portions of the agency that implement the results, Congress designated 15 percent of the FAA research, engineering, and development budget for long-term research and also

[1] Public Law 85-726, Aug. 23, 1958.

[2] U.S. Congress, House of Representatives, *Aviation Safety Research Act of 1988, To Accompany H.R. 4686*, H. Rpt. 100-894 (Washington. DC: U.S. Government Printing Office, 1988), pp. 5-6.

[3] Public Law 100-591, Nov. 3, 1988.

[4] House of Representatives, op. cit., footnote 2, p. 5.

emphasized closer coordination with NASA's research program.[5]

Some of FAA's R&D is conducted in-house, primarily at the Technical Center in New Jersey and at CAMI in Oklahoma City. (Organizations within FAA that fund or conduct scientific or technological R&D are highlighted in figure 2- 1.) FAA also does cooperative research with NASA, the Department of Defense (DOD), the Department of Commerce, and other federal agencies.

National Aeronautics and Space Administration

Although it is sometimes difficult to draw a precise line between NASA activities that support military aviation and those supporting the civil side, commercial aircraft manufacturing is one of the few industries for which the U.S. government routinely funds R&D. The traditional rationale for this support is that it compensates for the tendency of the manufacturers to do less than the "socially optimal" levels of research.[6] NASA is the key agency conducting aeronautical research, and has the third largest federal research budget, although most of that is for space-related activities. NASA aeronautical research and technology activities support both military and civil aviation.

Following a June 1993 reorganization, NASA has two offices as its focal points for aviation: the Office of Advanced Concepts and Technologies and the Office of Aeronautics. NASA's aeronautics research is almost all basic and applied. Although the Associate Administrator makes most decisions about the direction of the research, the process is relatively open. with ample opportunity for those outside NASA to comment.

In the early 1990s, NASA's aeronautics program had six key areas:

- subsonic transport, for technology directed toward U.S. commercial transport aircraft:
- high-speed transportation, to resolve critical environmental issues and lay the foundation for economical, supersonic air transportation:
- high-performance aircraft, oriented toward military applications;
- hypersonic and trans-atmospheric flight research;
- critical disciplines, with emphasis on basic sciences: and
- critical national facilities, to modernize and refurbish the NASA wind tunnels and other research facilities.[7]

The NASA laboratories use about 50 percent of the aeronautics R&D funds, another 30 percent goes to contracts with industry, and the remainder is designated for university research.[8] Each NASA lab maintains unique facilities and areas of staff expertise. The Ames Research Center, at Moffett Field. California, has special capabilities in computational fluid dynamics and computer applications, along with facilities for aerodynamic testing and flight simulations. NASA is recognized as a world leader in human factors research, and Ames is the key research center in this effort. NASA Ames also conducts research in areas such as ATC, flight dynamics, and guidance and digital controls.

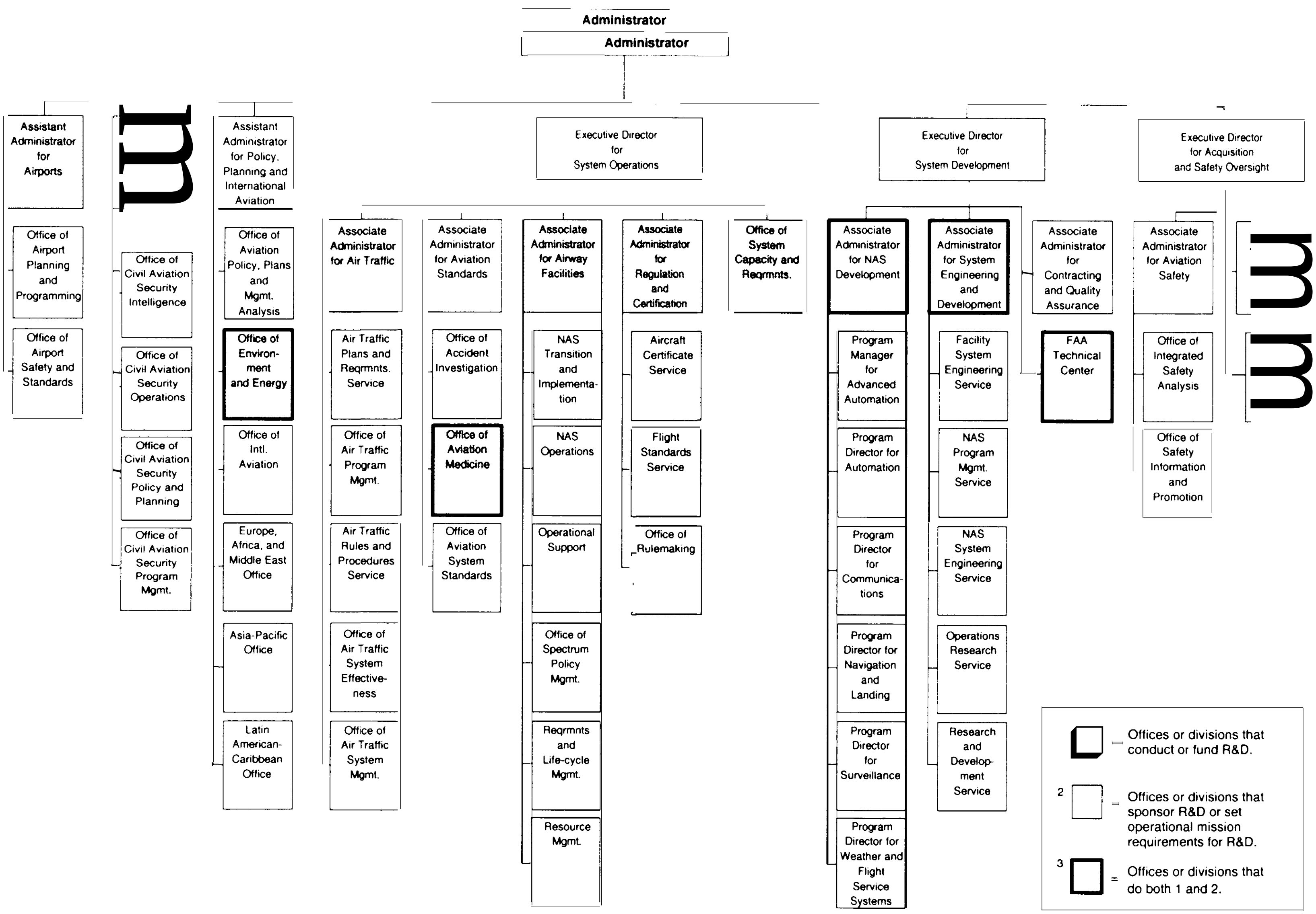
Among the other NASA centers, the Dryden Flight Research Facility at Edwards Air Force Base, California, focuses on aeronautical research and flight testing. while the Lewis Research Cen-

[5] I bid,. pp. 15. 18

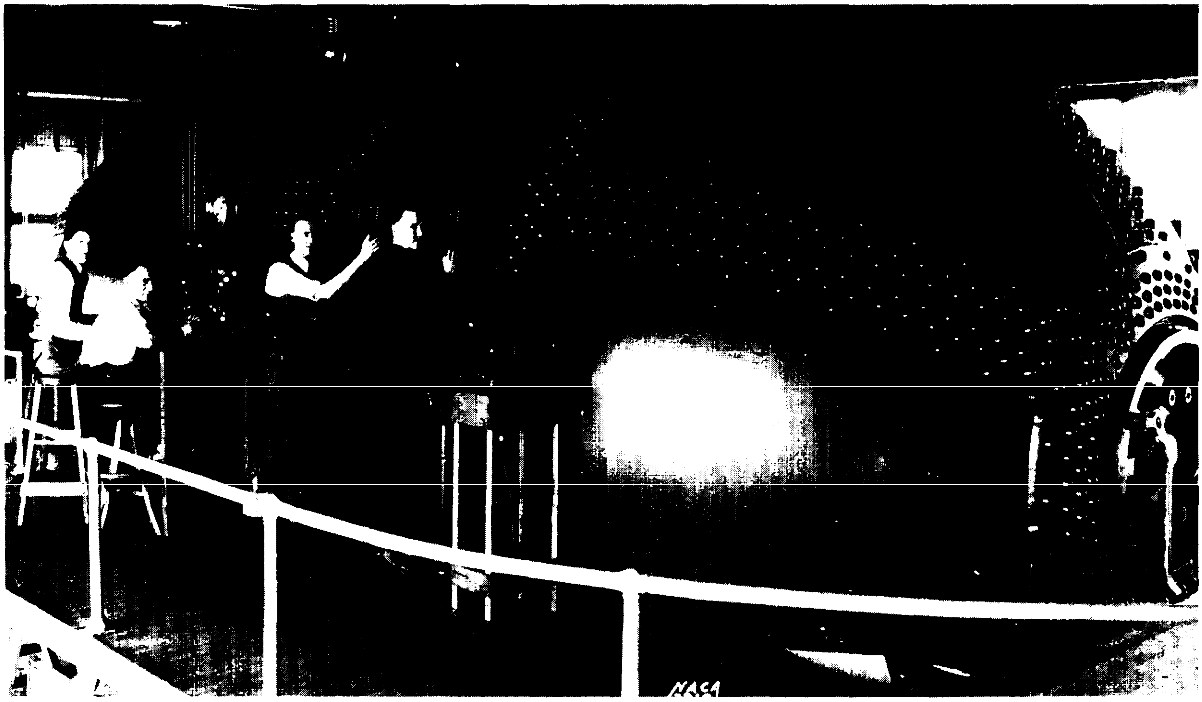
[6] In the case of aircraft manufacturers, the amount of money required to support some of the necessary research is so great that it is highly unlikely that an individual manufacturer would ever capture a return on its investment. U.S. Congress, Office of Technology Assessment, *Competing Economies America, Europe, and the Pacific Rim*, OTA-ITE-498 (Washington, DC. U.S. Government Printing Office. October 199 I), p. 344.

[7] National Aeronautics and Space Administration, *Aeronautics and Space Report of the President: Fiscal Year 1991 Activities* (Washington, DC: 1992), p. 47.

[8] U.S. Congress, Office of Technology Assessment, *Federally Funded Research: Decisions for a Decade*, OTA-SET-490 (Washington, DC: U.S. Government Printing Office, May 1991), pp. 126-127.



NOTE: Due to space limitations, FAA regional offices and administrative support sections have been omitted from ~s figure.
SOURCE: Office of Technology Assessment, 1994, based on Federal Aviation Administration information.



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

The National Advisory Committee for Aeronautics conducted aeronautics research for civil and military applications, as NASA does now

ter in Cleveland is a center for propulsion research. Finally, Langley Research Center, in Hampton, Virginia, has expertise in areas such as fundamental aerodynamics and fluid mechanics. computer science, unsteady aerodynamics, human factors, and aeroelasticity. Additional work at this NASA lab involves structures and material, flight control, windshear technologies, noise reduction, and simulations of advanced systems.

NASA labs conduct R&D of importance to FAA. Ames and Langley have worked with FAA on cockpit resource management, fatigue, information transfer. and ATC human-factors studies. Ames is the lead research facility for development of the Center-TRACON Automation System (CTAS, part of FAA's Terminal ATC Automation-or TATCA—system), which projects where aircraft are likely to go on final approach and creates an arrival plan for the controllers. Langley is the center for development of airborne windshear technology, which provides early warnings of hazardous windshear that may cross an aircraft's flight path.

State Authorities and Airport Operators

New air navigation technologies. environmental policies, and intermodal demands affect more than FAA research and technology decisions. Private companies, states, airport authorities, and other nonfederal organizations are now planning and installing air navigation and communication systems that could supplement, enhance, or replace existing or proposed federal ATC infrastructure (see box 2-1 for one example). Additionally, some airports are investigating and implementing technologies to address environmental and other challenges without FAA guidance or support.[9]

[9] OTA survey of airport operators and state aviation authorities, conducted by Jeanne Olivier, Port Authority of New York and New Jersey, on detail to OTA, January-April 1993.

BOX 2-1: Virginia's Initiative for Pilot Weather Information Technology

In the absence of timely federal support, states themselves often fund and oversee aviation research and development projects. In 1993, Virginia funded an engineering effort to take advantage of new technology to improve weather service for general aviation and business pilots using Virginia airports While applying a new technology, the Virginia effort also relies heavily on the existing aviation weather communication Infrastructure.

Weather is a critical factor in flight operations. Of both air carrier and general aviation accidents between 1983 and 1987, 25 percent were due, at least in part, to weather conditions.[1] The Federal Aviation Administration provides weather briefings to pilots through its Flight Service Stations and its computerized Direct User Access Terminal Service as part of the National Airspace Data Interchange Network (NADIN) This information, Including wind speed and direction, precipitation, barometric pressure, and cloud height, comes from manned weather stations and Automated Weather Observation Systems (AWOS) located at airports across the country. It is accessible on the ground for preflight planning as well as en route for in-flight adjustments to flight plans,

Pilots find it particularly useful to have advance information on the weather conditions at the specific airport where they will be taking off or Ianding so that they may make adjustments to avoid hazardous weather patterns. For this reason, in addition to the weather stations at major commercial airports, FAA has installed automated weather observation stations at 170 air taxi and commuter airports and at general aviation airports that are considered important to the national air system. (FAA is in the process of installing 30 additional sites) Still, many small airports do not have onsite weather observation systems Pilots using these airports must rely on weather reports from neighboring airports or other observation stations for their flight judgments Due to the variability of weather, this reformation is less reliable than onsite reports To improve the weather service for their customers, some sponsors of small airports have independently installed AWOS at their airports after FAA declined to do so Ninety percent of the cost of Independent AWOS may come from Airport Improvement Program grants, for those airports that qualify FAA maintains only AWOS that it installs; the airport sponsor must maintain those systems that it installs Independently

[1] National Transportation Safety Board, "Annual Review of Aircraft Accident Data U S Air Carrier Operations, Calendar Year 1988,"Apr 8, 1991, p 31 and National Transportation Safety Board, "Annual Review of Aircraft Accident Data U S General Aviation, Calendar Year 1988, " Mar 27, 1991, p 20

Airport operators note that federal aviation R&D focuses more on aircraft, ATC technology, and large airports, thus neglecting the interests of smaller airports. For example, noise reduction and capacity expansion research primarily benefits large airports, not general aviation airports, for which these issues are rarely problems. Large and small airports stand together in their position that there are not enough funds applied to airport research, but some state and local agencies have sought their own answers to pressing research and technology issues.

States generally do not have much money for research, although a number do fund and oversee testing and evaluation. For example, California funds several aviation research projects at the Air Transportation Research Center of the Institute of Transportation Studies (part of University of California, Berkeley). These include airport landside analysis for off-airport terminals, and the ap-

BOX 2-1: Virginia's Initiative for Pilot Weather Information Technology (Cont'd.)

Until Virginia's recent initiative few nonfederal AWOS have been linked to FAA's NADIN system due to financial and technological barriers [2] A pilot could get the information only by contacting the airport directly by phone or through a very-high-frequency radio broadcast accessible only in close proximity to the airport This access constraint limited the use of the data to local departure and landing approach aids and excluded pilots' use en route to these airports Those federal AWOS installations linked to NADIN are connected by telecommunication land lines at a monthly cost to FAA of $800 per AWOS [3] This high cost deterred FAA from assuming the expense for linkage of Independent AWOS to NADIN and similarly discouraged state aviation authorities from financing the connection

Working with a private contractor, the Virginia Department of Aviation has supported the development of a satellite-based linkage of AWOS to FAA's NADIN system, which obviates the need for expensive land line connections Virginia's contractor will use efficient communication bands of satellite technology to transmit weather data from 23 AWOS in Virginia to a collection point in Minnesota From this point the Information will be entered into NADIN for dissemination to FAA Flight Service Stations and the Direct User Access Terminal Service, FAA 604 service (venue for private vendors), and the National Weather Service Pilots nationwide will have access to weather Information for many of Virginia's general aviation airports and will be able to radio a flight service station en route to find out the weather at the airport where they will be landing, or any number of airports along their flight path The five-year cost for this system, including equipment, maintenance, and operation, is expected to be about $400,000 Officials of the Virginia Department of Aviation project that this will be one-third the cost of providing the same Information via land telephone lines

FAA is now looking into the Innovative work of Virginia in satellite linkage of AWOS and NADIN because of the dramatic operational cost advantages for its own AWOS data dissemination Other state aviation authorities have also expressed interest in providing this service

[2] The stale of Minnesota provides land line linkage of some AWOS in that state to NADIN Due to the favorable cost of the satellite linkage demonstrated by Virginia Minnesota will soon convert these land line connections to satellite linkage

[3] Ken Krous Federal Aviation Administration personal communication Apr 7 1993

plication of artificial intelligence to airport ground transportation systems.[10] occasionally, locally funded or state-funded projects[11] address a problem that the local agency has had trouble drawing to FAA's attention; they may also aim to counter FAA standards that do not consider the unique physical constraints of certain airports.

For example, LaGuardia (New York) Airport's two runways each have one end that extends over water, and the other end of one runway terminates at a dike adjacent to Flushing Bay. Faced with an FAA requirement to extend the emergency overrun areas of runways to a length of 1,000 feet—and resistance from nearby communities to do

[10] Ibid.

[11] What monies airports have for R&D usually come from state or airport revenues, not federal funds. (See box 2-1 again.)

this [12] *—the Port Authority of New York and New Jersey conducted independent research on passive in-ground arrestors that could safely stop an aircraft in a relatively short distance during an emergency. [13] If the in-ground arrestors are validated and become available, the Port Authority would likely put the arrestors at all four runway ends; the installation and maintenance would be much less costly than further extending overrun areas. [14]

Some states have universities with transportation research centers that conduct aviation research. These centers receive both state and federal funding and provide a useful supplement to the states' resources. An FAA initiative for pooling research resources with state agencies may become another way to expand available resources and to focus on projects important to state authorities.

For example, the "Minnesota Partnership" is an FAA experiment in cooperation on 10 research projects. Among these projects is an FAA study of pavement under cold region conditions using a Minnesota Department of Transportation test facility consisting of a 3-mile strip of instrumented pavement. However, there are usually administrative impediments to FAA's contracting out work to states. Principal among these impediments is the rigid federal procurement system for contract services. [15]

Airport operators often claim to have unmet research needs, but few can specify what these are. However, state aviation officials, industry analysts, and FAA managers concerned with airports maintain that this inability to articulate specifics does not belie the need; what may be necessary first is a mechanism for identifying research requirements. At issue, too, is the fact that airport managers claim to be restricted in their ability to share research conducted by consultants, even though the results might prove useful to other airports, obviating additional expense. States and airport authorities seldom share information about work that might benefit others. Of the several states conducting pavement research, for example, most are unaware of the projects of their counterparts. [16]

Public-Private Partnerships

The potentially increasing role of commercial communications in the air traffic system infrastructure makes public-private partnerships an attractive option for speeding technology development and implementation. Federal law permits and encourages agency participation in cooperative R&D agreements. [17] FAA has recently teamed with private industry to develop and test some commercial technologies for ATC functions. Examples include ATC pre-departure clearance delivery via the commercial ARINC Communications and Reporting System (ACARS) datalink and automatic dependent surveillance of oceanic flights by United Airlines through INMARSAT communciation links. Participants at an Office of Technology Assessment (OTA) workshop observed that such partnerships are most successful when the major customer for the technology is the

12 The Port Authority required approval from several city and state agencies in New York, along with FAA and the Army Corps of Engineers, to make changes to the runways. Perceiving that any extension of the landing and takeoff surfaces would lead to the use of larger planes and higher levels of activity at the airport, many communities actively opposed increasing the length of the overrun area. Steven Smolenski, Manager, Airport Facilities Division, LaGuardia Airport, Port Authority of New York and New Jersey, personal communication, July 20, 1994.

13 The testing program evolved into a cooperative effort with FAA to further study foam-based arrestors at the FAA Technical Center.

14 Smolenski, op. cit., footnote 12.

15 Patricia Haynes, Federal Aviation Administration, persona] communication, Mar. 16, 1993.

16 OTA survey of airport operators and state aviation authorities, op. cit., footnote 9.

17 From 1980 t. 1989, Congress passed several major laws that directed federal agencies and the labs 10 transfer technologies to State and local governments and the private sector. See Office of Technology Assessment, *Defense Conversion: Redirecting R&D, OTA*- ITE-552 (Washington, DC: U.S. Government Printing Office, May 1993), p. 86.

private sector, not the federal government (and where both need the technology at the same time).[18]

In 1992, FAA announced support for a cost-shared, public-private partnership with the airline community. Its objective was to enable FAA to enter into a cooperative agreement with an industry consortium to develop, test, and build the first Aeronautical Telecommunications Network (ATN)[19] components, taking advantage of "good commercial contracting practices."[20] FAA's contributions would include contract resources, test facilities and aircraft, expedited avionics certification, and accelerated procedures and standards development.

By the summer of 1993, nine airlines had formally indicated their willingness to conduct the work and had tentatively elected to have the consortium assume a full corporate identity.[21] The Mitre Corporation will likely continue to have a significant role in supporting the efforts of the ATN Consortium;[22] DOD intends to participate in the project.[23] Remaining issues include speeding the certification of commercial off-the-shelf software and operational system software.

One development that has boosted government-industry cooperation is the increased use of cooperative research and development agreements (CRADAs). Designed to promote technology transfer, they allow federal labs and private companies to share R&D projects; the Clinton Administration would like to see the national labs devote up to 20 percent of their budgets to these partnerships. While facing resistance from some government scientists who, up until now, have considered commercialization of technology a low priority, managers at the national labs realize that the labs' very existence may depend on how useful they can be to the private sector. The Air Force has therefore participated in CRADAs that could ultimately benefit commercial aviation.

Like DOD, FAA is using CRADAs as a means to work more closely with industry. As of July 1993, FAA had 50 CRADAs in place, although with eight completed and 31 still in the administrative process, only 11 could be considered active. Almost one-half (22) of the total were in the area of aircraft and airport safety; security and air traffic control split another 20 CRADAs between them.[24]

International Civil Aviation Organization

The International Civil Aviation Organization (ICAO), founded in 1944 and now part of the United Nations, had 182 signatory nations as of November 1993. These nations have agreed to adopt minimum standards regarding aircraft, ATC, pilot qualifications, and other areas of civil

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[18] Remarks at OTA workshop, February 1993

[19] In 1990 the Mitre Corporation began a voluntary government-industry program known as the Aeronautical Telecommunications Network (ATN) Project, to build an initial version of ATN components. ATN is intended to support user-transparent data transfer between aircraft and ground systems using any combination of datalink media. Also participating in the ATN Project were FAA, vendors (IBM, Honeywell, Rockwell-Collins, and Teledyne), and air-ground communication network service providers, including ARINC, the Communications Satellite Corporation (COMSAT), and the International Society of Aeronautical Telecommunications (SITA). Due primarily to resource constraints, the project is no longer active and will be subsumed by the ATN Consortium. See Lillian Z. Ryals, The Mitre Corporation "Development and Implementation of the Aeronautical Telecommunication Network (ATN), briefing for OTA, Mar. 13, 1992.

[20] John Fearnsides, General Manager and Senior Vice President, The Mitre Corporation, personal communication, Apr. 21, 1994.

[21] Hal Ludwig, FAA Liaison to the ATN Consortium, persona] Communication, Aug. 5, 1993.

[22] Ibid.

[23] Frank Colson, Executive Director, DOD Policy Board on Federal Aviation, personal communication, June 29, 1994.

[24] U.S. Department of Transportation, Federal Aviation Administration, *Report to Congress: Survey of Research, Engineering, and Development Research Facilities* (Washington, DC: July 1993), p. B-1.

aviation. The standards provide member nations with a baseline level of safety in international aviation operations.[25]

ICAO's authority on such topics as communication and navigation standards and air travel over the high seas is essentially absolute. For their respective territories, implementation is up to individual countries, which reserve the right to differ from ICAO standards. While the United States generally has no difficulty with compliance, other nations sometimes do.

ICAO has certain limitations. It lacks inspection capability and conducts no enforcement activities. Its standards tend to be the lowest common denominator, the result of many members trying to reach consensus. Although there has been some success, such as the significant progress made in determining the direction of air navigation development, ICAO can be slow to act. For example, despite pressure from industry groups eager to use the Global Positioning System (GPS) of satellite navigation, ICAO is powerless to establish an agency to oversee implementation of satellite communications, navigation, and surveillance systems.[26]

ICAO's ineffectiveness can have adverse effects on U.S. interests. For example, ICAO has worked since 1981 to establish guidelines for the use of the Traffic Alert and Collision Avoidance System (TCAS). So little progress has been made, however, that the panel chairman compared himself to "a rat on a treadmill," and speculated whether some ICAO members used the organization as a shield to avoid making decisions.[27] Meanwhile, the three companies that manufacture TCAS equipment—all of them American—wait for the impasse on this $350-million market to break.[28] However, one expert believes that ICAO's ineffectiveness stems from poor leadership by the United States in ICAO forums.[29]

Although FAA, through the Department of Transportation, attends ICAO meetings, all official U.S. positions are cleared through the Interagency Group on International Aviation (IGIA), which includes the U.S. Departments of Transportation, Commerce, Defense, Labor, and State, as well as NASA, the National Transportation Safety Board (NTSB), and the Federal Communications Commission (FCC). IGIA must also be informed when FAA negotiates or amends bilateral airworthiness agreements.[30]

Bilateral airworthiness agreements exist in part because FAA does not regard all ICAO airworthiness standards to be adequate and therefore holds some imports of aeronautical products to higher standards. U.S. bilateral agreements predate ICAO; the first was negotiated with Canada in 1929. The United States and selected countries negotiate these agreements, which may facilitate export of aviation items or may obligate the parties to treat each other's civil aeronautical products as equally airworthy, provided they have been certified through acceptable methods by the home country's aviation authorities.[31] (Table 2-1 lists the countries with which the United States had bilateral airworthiness agreements in place in 1993.)

European Aviation Organizations

Despite the growing influence of the European Union (EU) and the European Free Trade Association (EFTA), European aviation organizations remain primarily advisory. But as European unity

[25] George A. Berman, *Regulatory Cooperation With Counterpart Agencies Abroad: The FAA's Aircraft Certification Experience* (Washington, DC: Administrative Conference of the United States, 1992), p. 82.

[26] "IATA Fails To Persuade ICAO To Set Up Special Agency for GPS," *Aviation Daily*, vol. 312, No. 64, June 30, 1993, p. 503.

[27] Lisa Burgess, "TCAS Rules: The Devil Is in the Details," *Commercial Aviation News, vol. 1, No. 33,* Sept. 13, 1993, p. 4.

[28] Ibid.

[29] Robert Simpson, Massachusetts Institute of Technology, personal communication, June 23, 1994.

[30] Berman, op. cit., footnote 25, pp. 119-120.

[31] Ibid., pp. 87-88.

TABLE 2-1: Countries With Which the United States Has Bilateral Airworthiness Agreements

Joint Aviation Authority member countries	Non-Joint Aviation Authority countries
Austria	Argentina
Belgium	Austria
Denmark	Brazil
Finland	Canada
France	China
Germany	Czech Republic
Italy	Indonesia
Net her lands	Israel
Norway	Japan
Spain	New Zealand
Sweden	Poland
Switzerland	Romania
United Kingdom	Singapore
	Slovakia
	South Africa

SOURCE Federal Aviation Adrrlnis'ration 1993

moves from concept to reality, a number of aviation organizations have taken on more prominent roles. (For membership of these groups and those discussed below, see figure 2-2,) The EU, for example, has a number of programs underway to determine specifications for common ATC equipment and facilities.

The Joint Airworthiness Authorities (JAA), established in 1970, is not a formal political body, although it could become the basis for a pan-European civil aviation authority. While largely driven by the demands of the EU and, to a lesser extent, EFTA, the organization does attempt to set common aviation standards for European nations. Like ICAO, however. JAA has no enforcement authority. J AA member nations jointly certificate air-craft. but the ICAO treaty and national laws require that national authorities remain responsible for actual certification in their own countries.[32]

One of the stated goals of JAA is to have Joint Airworthiness Regulations (JARs) that are similar to the FAA's Federal Aviation Regulations, although sometimes this involves JAA trying to persuade FAA to change. JAA and FAA hold joint policy meetings on a regular basis and working group sessions as needed.[33] JARs developed thus far cover certification of aircraft design and production; pending JARs will deal with maintenance, repair, and overhaul activities.

The European Civil Aviation Conference (ECAC), which has 31 member countries, was founded in 1955 to review the development of European air policies and promote coordination. Like the other international organizations, ECAC is a consultative body; political power rests with transport ministers of member nations. ECAC's ability to speak through the Ministers of Transport gives it some of the effectiveness that other groups seem to lack. It now also represents nations beyond Western Europe.

Eurocontrol, an air traffic management organization founded in 1960, aims to provide air traffic services for 15 European nations (see figure 2-2 again). Eurocontrol faces the massive task of harmonizing and integrating 31 different European ATC systems, most of which are incompatible with each other. This task is complicated by sovereignty issues.

With ECAC member nations likely to spend more than $3 billion on new ATC equipment by the end of the century, it is possible that some new systems could meet Eurocontrol specifications, or at least help speed the integration process. For Eurocontrol, this would be a strong and long overdue step. However, Eurocontrol's objectives cannot be met until there is continuous radar coverage across Europe.[34] There are areas of Europe where aircraft separations from 5 to 20 nautical miles are currently applied due to varying radar coverage.

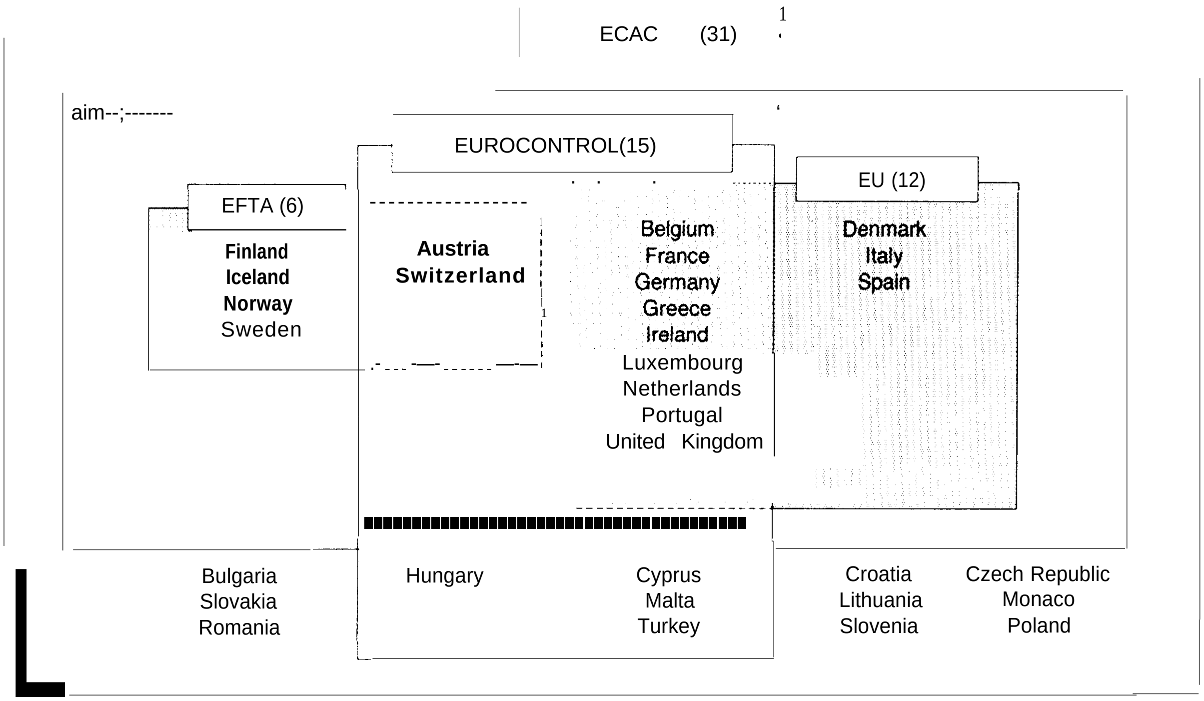
Eurocontrol undertook a study of the ATC systems of the 23 nations that were ECAC members

[32] Ibid, pp. 100102. In October 1993, FAA and JAA conducted the first simultaneous U.S. and European certification of a jet transport, the Airbus A330. "News Breaks," *Aviation Week & Space Technology*, vol. 139, No. 17, Oct. 25, 1993. p.17.

[33] Berman, op. cit., footnote 25, p. I 07.

[34] Chris Yates, "Eurocontrol Comes of Age," *June's Airport Review*, vol. 4, No. 3, April 1992, p. 42.

FIGURE 2-2: Membership of Selected European Organizations With Responsibility for Aviation



KEY ECAC = European Civil Aviation Conference JAA = Joint Aviation Authorities; EU = European Union, EFTA= European Free Trade Association, EUROCONTROL = European Organization for the Safety of Air Navigation

SOURCE Federal Aviation Administration and *Interavia Aerospace World, 1993*

in 1988, as part of the European Air Traffic Control Harmonisation and Integration Programme (EATCHIP). The goal of EATCHIP is to make the different national systems work together so well as to be virtually transparent to pilots.[35] Its focus is primarily on en route airspace. The United States and Canada have observer status for EATCHIP and the Airport./Air Traffic Systems Interface. Another Eurocontrol project, the ATC Radar Tracker and Server program, has the goal of harmonizing data from multiple radar systems.

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. Such programs should reflect one or more of these benefits, as cooperation con-

[35] Brooks Tigner, "Two Plans, One Goal: Align Europe's ATC," *Commercial Aviation News*, July 12-18, 1993, p. 10.

ducted for its own sake is seldom enough to justify the time and resources involved. And some agencies can benefit from access to the expertise of the in-house staff of other federal entities and also to the private sector research firms that work with those entities.[36]

Congressional actions affect the interests of cooperative research. When Congress passed the Aviation Safety Act of 1988 and the Catastrophic Failure Prevention Research Program,[37] both recognized that FAA's level of in-house expertise might be less than optimal, and so encouraged work with NASA, DOD, and other sources by providing enabling authority. By contrast, when Congress directs money for specific projects to specific institutions, problems may result from the recipient's lack of understanding of aviation needs. For example, one Federally Funded Research and Development Corporation (FFRDC) directed to address aviation security problems applied nuclear plant security systems without fully accounting for the dynamic needs of airports.[38]

Interagency Coordination at FAA Today

Coordination among federal agencies occurs at two levels: the agency program level and the researcher level. Agency advisory committees often promote agency-level coordination; coordination at the researcher level occurs through meetings and other activities.[39] And, as one FAA manager pointed out, when scientists learn of a project in their area, they often contact the funding source on their own. As he put it: "Resources draw others to the doorstep. others who want a piece of the funding and the action and who try to get involved."[40] The number of FAA interagency agreements for R&D grew rapidly in the late 1980s (see figure 2-3).

In 1991, the FAA Research. Engineering, and Development (RE&D) Committee advised that innovative and cooperative research be emphasized throughout the entire FAA RE&D Plan. A 1992 General Accounting Office report also recommended cooperative programs, with special emphasis on NASA and DOD in-house capabilities as a cost-effective alternative to private contractors and FFRDCs.[41]

Some of FAA's long-term research needs, such as human factors. are common to many other federal agencies. FAA conducts little basic or fundamental scientific research; its efforts are mostly systems development and engineering. However, there are substantial federal research efforts under way in areas important to aviation operations. For example, defense programs have been the source of many fundamental technologies for civil aviation—radar, computers, datalink, and satellite-based navigation, to name a few. Moreover, for aviation environmental and security issues, FAA must depend on other agencies research and data to characterize and assess risks.

Two examples of cooperative R&D efforts for aviation are aging aircraft and weather research. In the National Aging Aircraft Research Program, FAA's long-term goal of developing a corrosion-control management plan for aircraft is being met with the help of other government agencies, industry, and academia. One organization involved in this program is the Center for Aviation Systems Reliability, a consortium of institutions based at Iowa State University, which is charged with studying several aspects of corrosion control and re-

[36] Gellman Research Associates, "Cooperation and Coordination in Federal Aviation Research," OTA contractor report. Dec. 30, 1992, pp. 1-2.

[37] Public Law 101-508, section 9208, Nov. 5, 1990.

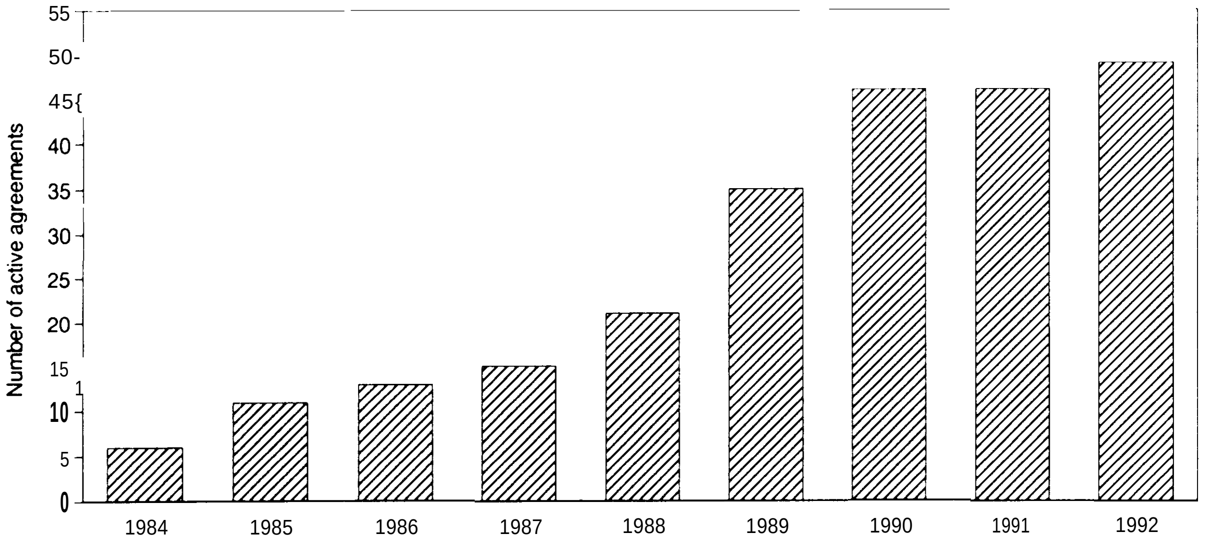
[38] Gellman Research Associates, op. cit., footnote 36. pp. 30-31.

[39] Office of Technology Assessment, op. cit., footnote 8, p. 117.

[40] Ken Byram, Research and Development Service, Federal Aviation Administration, personal communication, Apr. 9, 1992.

[41] However, both NASA and DOD rely heavily on contracts for R&D. Gellman Research Associates, op. cit., footnote 36, pp. 5-6.

FIGURE 2-3: Active FAA R&D Interagency Agreements, 1984-92



SOURCE Off Ice of Technology Assessment, 1994, based on Federal Aviation Administration data

lated human factors for maintenance and inspection. Another aging aircraft consortium is centered at DOE's Sandia National Laboratory; participants include the DOD's Naval Air Warfare Center, Air Force Flight Dynamics Laboratory and Wright Laboratory, NASA, the United Kingdom and Netherlands Civil Aviation Authorities, and various industry groups.[42]

Similarly, weather research involves multiple agencies. While the Terminal Doppler Weather Radar project is a well-run cooperative program, communication in the Automated Weather Observing System program has been spotty at best.[43] The differing needs of the participants in weather research may result in a fuzzy focus and difficulty in establishing common ground. Sometimes, too, the large number of participants-up to 13 in some cases—makes coordination an issue in itself.

FAA and NASA

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 in 1958, it was not until 1990 that FAA and NASA Administrators took personal and administrative actions to bolster the ties between the two agencies. The agencies now coordinate aviation research programs and planning through a joint committee, and have established six Memoranda of Understanding (MOU) in areas of mutual interest—ATC-cockpit integration, human factors, severe weather, airworthiness, environmental issues, and "program support."[44]

FAA has field offices at NASA's Ames and Langley Research Centers to monitor joint programs and to provide FAA with a close look at NASA's aeronautics work. This cooperation al-

[42] 1 bid., pp. 15-19.

[43] 1 bid., pp. 23-24.

[44] U.S. Department of Transportation, Federal Aviation Administration, *The Federal Aviation Administration Plan for Research, Engineering and Development—1994: Final Draft* (Washington, DC: September 1993), p. A-3.

lows a thorough understanding of mutual interests, reduces duplication of effort, and helps conserve scarce resources.[45] Typically, FAA identifies its needs and NASA determines the feasibility of providing the necessary support. Field office projects have dealt with such areas as simulation capabilities, human factors, windshear, microwave landing systems, and GPS.[46]

FAA and NASA also have a Joint University Program for air transportation research, in which university research supports national airspace system activities. FAA and NASA Langley Research Center sponsor annual grants to the Massachusetts Institute of Technology, Ohio State University, and Princeton University to work on topics suggested by the two agencies and related to their long-term needs.[47]

Joint FAA/NASA research and development activities typically occur under MOUs, Memoranda of Agreement (MOA), and Interagency Agreements for the Transfer of Funds (IAA/TOF). An MOU defines a broad area of interest between two or more federal agencies. These are usually arranged at high levels, with approval of both Administrators. NASA supplies most of the research personnel and facility support and contributes about $40 million beyond what is explicitly counted in interagency fund transfers.[48] Within MOUs, MOAs specify actual R&D activities to be undertaken and the resources to be committed by both agencies. MOAs are in effect for five years[49] and can be planned at lower managerial levels within the two agencies. Finally, the IAA/TOF is the budget transfer to NASA; it functions like a contract.[50]

Some tension exists between FAA and NASA regarding the financing of cooperative programs. FAA's contributions are explicit, for they require a transfer of funds. NASA, however, provides facilities and other institutional capabilities that are not delineated by a specified dollar amount. As a result of this technically unacknowledged contribution, NASA might be somewhat less enthusiastic than desired in pursuing cooperative ventures with FAA. More accurate accounting procedures that consider NASA's true costs might encourage NASA to pursue additional cooperative ventures.[51]

A potential handicap for FAA/NASA joint research is budget review. Different divisions of the Office of Management and Budget review the FAA and NASA budgets, leading to possible difficulties in pushing through joint projects. Similarly, separate congressional committees approve funding for FAA and NASA. This, too, can impede joint research. Similar situations exist for joint aviation research with DOD.

FAA and Defense Laboratories

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 of direct relevance to FAA. For example, the effect of high-intensity radiation on aircraft electronics is a certification issue for FAA, and is an area where DOD has expertise and research and test capabilities. R&D conducted for DOD's diverse aircraft inventory, such as the use of composite materials for aircraft primary structures, has applications in

[45] Ibid.

[46] Gellman Research Associates, op. cit., footnote 36, p. 28.

[47] Federal Aviation Administration, Op. cit., footnote 44, p. A-2.

[48] Gellman Research Associates, op. cit., footnote 36, p. 30.

[49] Extensions are possible.

[50] Gellman Research Associates, op. cit., footnote 36, p. 25.

[51] Ibid., p. 29.

civil aviation. Although some basic technologies can be applied in both civilian and military projects, most high-performance systems produced to meet military needs are not relevant to civilian aviation.

Military R&D has had a positive effect on the U.S. commercial aviation industry. There have been a few cases of entire systems developed for the military becoming integral to commercial application, reducing R&D costs. Military development programs often assume the risks of proving advanced technologies, and this has helped the U.S. commercial aircraft industry to achieve its current prominence. However, the increasing divergence in the interests of military and civil aviation applications means that such advantages will occur less frequently.[52] Meanwhile, civilian applications of new technologies are of growing importance to the military, because some commercial products can be five or more years ahead of military development.[53] The current DOD industrial base policy calls for more DOD reliance on the civil sector, especially in areas of rapidly changing technology and a large civilian demand base, such as avionics and communications.[54]

FAA has had long-term cooperative programs with two DOD laboratories under the Army Corps of Engineers: the Cold Regions Research and Engineering Laboratory (CRREL) in Hanover, New Hampshire; and the Construction Engineering Research Laboratory (CERL) in Urbana, Illinois. CRREL, as its name indicates, concentrates on the cold weather-related problems such as stresses on pavement and metals, as well as ice-related problems. CERL emphasizes environmentally benign construction quality and energy efficiency. Included among its programs are projects on nondestructive testing, corrosion prevention, materials, and information systems.[55]

Unlike NASA, the DOE and DOD national labs thus far do not have funds of their own to put toward FAA research projects.[56] While NASA can provide additional facilities and staff to an FAA project, the DOD and DOE labs can contribute only what FAA is willing to pay for. From the perspective of FAA and airspace users, limited FAA research dollars for cooperative programs might be stretched the most through joint efforts with NASA.[57] However, a broad, multiagency view should not be ignored. The DOD/Air Force facilities have extensive backgrounds in military aviation R&D. Whether this can be applied effectively to civil aviation R&D is open to question, but it bears investigation. FAA had agreements with 36 government labs (including NASA's) as of July 1993. The total dollar commitment exceeded $56 million, the largest single agreement being over $16 million with DOD's Lincoln Labs for ATC research (see table 2-2).

Barriers to Coordination

Although OTA has found that many cooperative activities are taking place, there are some funding and bureaucratic constraints that may prevent successful coordination. These constraints include administrative requirements and conflicting agency roles and responsibilities, as well as the

52 Office of Technology Assessment, op. cit., footnote 6, p. 345.

53 U.S. Congress, Office of Technology Assessment, *The Defense Technology Base: Introduction and Overview—A Special Report*, OTA-ISC-374 (Washington, DC: U.S. Government Printing Office, March 1988), p. 42.

54 Colson, op. cit., footnote 23.

55 U.S. Congress, Office of Technology Assessment, *Delivering the Goods: Public Works Technologies, Management, and Financing*, OTA-SET-477 (Washington, DC: U.S. Government Printing Office, April 1991), p. 215.

56 This could change as the roles and operating modes of the national labs will likely adapt to accommodate the R&D needs of America post-Cold War. Office of Technology Assessment, op. cit., footnote 17, p. 39.

57 Gellman Research Associates, op. cit., footnote 36, p. 26. There is also the difficult-to-quantify benefit of NASA's greater experience with FAA R&D projects.

TABLE 2-2: Federal Aviation Administration Research Agreements With Other Federal Facilities

	Number of federal facilities with FAA agreements				
FAA research area	DOD	NASA	DOE	Other[a]	Total by research area
Aviation security	7	0	3	1	11
Aircraft safety	8	2	2	0	12
Air traffic control	2	2	1	5	10
Airports	3	0	0	0	3
Total by facility	20	4	6	6	36
FAA funding commitment ($ millions)	$250	$74	$84	$156	$563

a Primarily weather research

NOTE Dollar totals may be different than sums due to rounding

KEY DOD - Department of Defense DOE = Department of Energy NASA = National Aeronautics and Space Administration

SOURCE Off Ice of Technology Assessment 1994 based on Federal Aviation Administration Report to Congress (pursuant to Public Law 102-388) July 1993 p 3 and app C

budget approval process and funding issues discussed earlier.

During the course of this study, OTA heard from many members of the aviation community familiar with civilian aviation R&D who generally gave NASA high marks for interagency communication, including its various efforts with FAA. Some have noted, however. that while the FAA/NASA Coordinating Committee and other mechanisms might be the right methods for ensuring interagency coordination, they are not working as well as they should.

One former government manager felt that while coordination was good at the staff level, it was generally inadequate for policy and planning. He blamed this on what he saw as a fundamental incompatibility between FAA and NASA: NASA prefers to look at the development of new aeronautical technologies, while FAA gives more attention to the actual implementation of systems using new or existing technologies.

Better interagency coordination and cooperation for aviation R&D is more than a NASA/FAA issue. While DOD helped FAA and NASA develop the National Plan for Aviation Human Factors, and FAA and NASA human factors programs are coordinated and linked to the National Plan, there is no formal agreement between FAA and DOD. However, closer involvement by DOD could be beneficial to civil aviation. FAA has established cooperative agreements with DOD laboratories. For example, Wright Laboratory is performing aircraft-hardening R&D in support of FAA's security program.

Furthermore, current FAA cooperative agreements do not adequately allow for basic research and independent R&D. A small pool of unallocated funds might help foster creativity and innovation within broader R&D objectives, although such funds are the most vulnerable to budget cuts.[58] An attempt to address this need is found in FAA's Innovation Development and Engineering Applications program, which ".. . will provide the FAA with a formal structure to ensure that novel ideas for innovative RE&D projects .,. will be evaluated and, if feasible, sponsored. "[59]

[58] Ibid., p. 31.

[59] Federal Aviation Administration, op. cit., footnote 44, p. A-7

Another issue is related to the overlap between some agency roles and responsibilities. For example, the Environmental Protection Agency (EPA) and FAA have shared responsibility for establishing aircraft noise standards, although aircraft noise is currently under FAA's domain.[60] But EPA has sole authority over other environmental issues that increasingly affect aviation and the air transportation industry, and explicit guidance for cooperation between the two agencies on these issues has not been provided.

The current basis for regulating upper atmospheric (i.e., stratospheric) pollution by aircraft is in international treaty, and EPA has authority to regulate materials and activities that contribute to the depletion of the ozone layer.[61] These include halons, used extensively in aviation for fire suppression. In addition, EPA sets standards for polluted stormwater runoff, engine emissions, and other sources of ground-level environmental problems. FAA, on the other hand, is charged with developing guidance for airport operators for facilities design and maintenance practices, imposing engine certification and aircraft equipment requirements, and regulating aircraft operations. This division of regulatory responsibility leaves open the possibility of ambiguity and even conflict over aviation environmental issues. Furthermore, neither agency conducts much related research. NASA conducts the lion's share of aviation environmental R&D, although the majority of this is focused on global atmospheric questions.

Finally, there is the possibility of competition between NASA and the national labs for FAA R&D funds. This may become acute as the national labs strive to demonstrate their versatility by moving beyond defense projects.[62]

TECHNOLOGY DEVELOPMENT AND IMPLEMENTATION FOR ATC

The following section focuses on ATC system development difficulties, an area where institutional and management issues are crucial. (ATC technologies are addressed in more detail in chapter 4.)

FAA-managed ATC projects often move slowly—to go from concept to operation can take 15 years or longer. As a result, Congress hears perennial calls to boost FAA R&D spending and make the agency more independent of federal personnel and procurement rules. Most recently, the Clinton Administration's "National Performance Review" and "Air Traffic Control Corporation Study," as well as the National Commission To Ensure a Strong and Competitive Airline Industry (known as the Airline Commission) have pro-

FEDERAL AVIATION ADMINISTRATION

For ATC, operational procedures and technologies have always been closely linked

60 FAA's statutory authority on noise issues is discussed in chapter 3.

61 See section 604 of the Clean Air Act Amendments of 1990, Public Law No. *101-549.*

62 Gellman Research *Associates,* op. cit., footnote 36, p. 32.

posed reorganizing FAA in order to improve ATC operations, finances, and modernization efforts.[63]

The combination of extreme safety requirements, continuous operations, large scale, and complexity make the ATC system unlike any other technological system (see box 2-2 and chapter 4, box 4-3). ATC technology 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. However, that is not what has been done.

While more technology R&D and easier procurement could help, major improvements will require fundamental changes in the system development process at FAA. Operational and procedural issues for ATC, not basic technologies, most often have been the critical hurdles to timely system implementation. ATC technologies frequently reach an advanced stage of development before those who are to install or use them discover that what was developed is not what was needed.

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. Unless this happens, improvements to safety. efficiency, and airspace capacity will continue to be prolonged.

Problems in System Development and Acquisition

Examples of FAA's slow implementation of aviation technology abound and are often mentioned in analyses of U.S. civil aviation. Most prominent is the National Airspace System plan, a multibillion dollar program to update FAA's ATC technology, whose elements have drastically fallen behind schedule. Similar situations prevail for software, weather, and radar systems, and other products that FAA must acquire and activate. Frustration with the habitual delays extends to all corners; even the most enthusiastic air traffic controller interviewed for this report lamented that for once he would like to use equipment that was state-of-the-art instead of two or three generations behind.

At the core of this problem is that FAA has set technical requirements for systems without adequately studying and developing operational procedures the systems are to support. 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 (AAS) before fundamental operational issues

[63] 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).

The Airline Commission recommendations are unclear as to the ultimate status of FAA. The Airline Commission calls for FAA to be established as an independent government corporation (on page 8) but also recommends that only ATC and related functions be placed in the corporation (page 9). According to the commission chairman, this inconsistent language stemmed from the inability of the commission to reach consensus. See also H. Jasper, "What Could Be Better Than an Air Traffic Control Corporation?" *ATC, Incorporated: The Corporatization of Air Traffic Control*, Les Blattner et al. (eds.) (New York, NY: McGraw Hill, June 1994).

BOX 2-2: U.S. Air Traffic Control System Overview

The federally operated ATC system, established principally for flight safety and efficiency, coordinates and directs all flights to and from U.S. airports, and comprises one of the most complex transportation systems in the world.[1] The routes and airspace that Iink airports are defined electronically and procedurally, not by physical structures, Assisted by ground- and cockpit-based navigation systems, pilots fly along paths prescribed by air traffic rules and instructions While modern electronics make such a complex system possible, its ultimate success depends primarily on human capabilities—monitoring, decisionmaking, and communicating

For air traffic control (ATC) purposes, the airspace above the United States and its territories IS partitioned according to airport Iocations and the amount of traffic into three broad categories terminal, en route, and oceanic airspace Terminal airspace surrounds airports and is characterized by aircraft changing speed, direction, and altitude as they maneuver after taking off or before landing The airways connecting airports make up the en route airspace, while oceanic airspace begins over International waters, with much of it lying beyond sight of land

The ATC system provides three basic services navigation aid, flight planning and advisory information, and traffic control Ground-based, line-of-sight radio navigation facilities define airways and approach paths to airports Satellite-based radio navigation will Iikely become the primary air navigation system in the next decade or so.

FAA, in conjunction with the National Oceanic and Atmospheric Administration, provides weather and other flight planning and advisory information to pilots, and publishes aeronautical charts and related documents Timely and accurate weather information is critical to all aspects of flight planning and operations, including whether the flight must be conducted under instrument flight rules (IFR) or visual flight rules (VFR) The IFR/VFR distinction governs the structure of the airspace and the corresponding pilot qualifications and the aircraft equipment required to operate in it.

The key aspect of traffic control is separation assurance, where ground controllers use surveillance radars to track aircraft and to detect and resolve conflicts. Controllers in the field and at the FM's System Command Center* also use flight plans, weather data, and airport and facility status reformation to anticipate potential flight conflicts Takeoffs are metered and flights are rerouted to avoid hazardous situations and to reduce congestion and delay.

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[1] Information in this box is drawn from U S Congress, Off Ice of Technology Assessment, *Delivering the Goods Public Works Technologies, Management and Finance*, *OTA-SET-477* (Washington, DC U S Government Printing Office, April 1991), p 118 and U S Congress, Off Ice of Technology Assessment, *Airport and Air Traffic Control System*, OTA-STI-175 (Washington, DC U S Government Printing Office, January 1982), pp 28-68

[2] Formerly called the Central Flow Control Facility

were resolved, including how controllers would use the new equipment and how present ATC facilities would be consolidated.[64] Underestimating the technical complexity of the systems has led to promises of overly optimistic delivery dates.[65] Ineffective management procedures and a rigid procurement process also contribute to these delays.[66]

Failure of FAA System Operations and System Development Directorates (see figure 2-1 again for FAA organizational chart) to emphasize and clearly establish operational requirements has resulted in some FAA R&D programs being driven by "technology push" rather than "operational needs." For ATC, the primary objective of new technologies is to allow a significant improvement in both the cost of providing air traffic services and the efficiency of aircraft operations .67 A suggested iterative process for the engineering of ATC systems entails (see also figure 2-4):

- creating a set of operational concepts, based on using new technologies for communications, navigation, and surveillance (CNS), that allow the subsequent creation of detailed, safe, and efficient operational procedures acceptable to pilots, controllers, and other airspace users and operators; and
- using the defined procedures to generate both operational specifications for new air traffic management procedures and the technical specifications for supporting CNS equipment.[68]

Some Examples

The usual practice has been for FAA to develop technical specifications and proceed directly into a development contract for prototype systems. System needs and required modifications become apparent as procurement becomes imminent and years of development activities have taken place.[69] Examples of where this approach was used include FAA's Wake Vortex Advisory System (WVAS), Microwave Landing System (MLS), and Precision Runway Monitor programs.

The WVAS program was under development for several years before controllers and pilots began to ask pointed questions about how the system was expected to operate. WVAS was to advise controllers whenever local meteorological conditions were such that an aircraft's trailing vortices would persist and pose a hazard to a following aircraft on final approach. Tested in 1979 and 1980 at Chicago's O'Hare International Airport, the project was deemed ". . . a technical success but an operational failure. "[70] It became clear that vortex monitoring needed greater coverage, and that a complementary system for local area meteorological measurements and forecasting was needed. In this instance, the operational requirements

[64] At an estimated cost of $5,9 billion, A AS was intended to be the heart of FAA'\ ATC modernization effort. It was designed to replace the ex i sting computer systems, including workstations. used by controllers at FAA facilities, and to increase controllers productiv ity through new software functions. AAS has had major cost and schedule problems since its start in 1988. See U.S. Congress, General Accounting Office, "Ad~ anced Automation System: Imp] ications of Problems and Recent Changes," GAO/T-RCED-94- 188, unpublished document. Apr. 13, 1994; and U. S. Congress, General Accounting Office, *Air Traffic Control: Status of FAA's Modernization Program, GAO'* 'RCED-94-167FS *(Washington*, DC: Apr. 15, 1994). In June 1994, FAA was in the process of modifying, including canceling some parts, of AAS.

[65] National Research Council, Transportation Research Board, *Winds of Change: Domestic Air Transport Since Deregulation* (Washington, DC: 1991), pp. 257-258.

[66] James L. Crook, Vice President for Operations, Air Traffic Control Association, Inc., persona] communication, June 30, 1994.

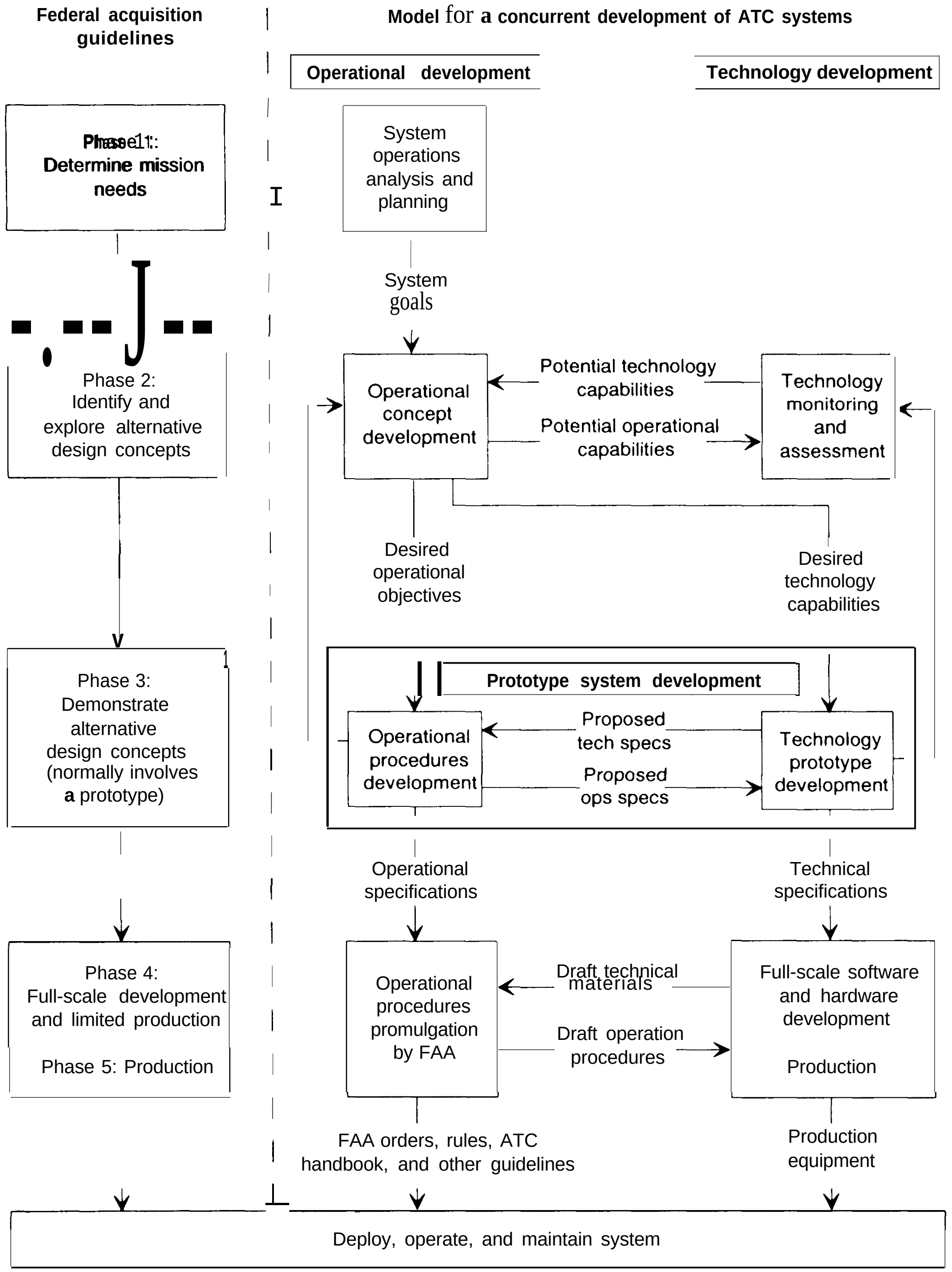
[67] Robert W. Simpson, "Using ATC Operational Requirements To Guide FAA R&D and procurement Activities, " OTA contractor report, June 1993, p. 2.

[68] Ibid.

[69] 1 bid., p. 3.

70 [)]Robert Machol, FAA Chief Scientist, personal communication, Aug. 30, 1993

FIGURE 2-4: Federal Acquisition Guidelines Compared With a Model for Concurrent Development of ATC Systems



[a]From Office of Management and Budget Circular A-109

SOURCE Office of Technology Assessment, 1994 were not studied, so technical requirements were inadequate.[71] Related R&D started again in the late 1980s, and by 1993 NASA had become the lead agency of a much larger effort designated Wake Vortex Systems Research, which is part of the NASA Terminal Area Productivity Program.

Operational procedures and specifications should be regularly revisited over the life of a program as the environment changes. In the 1960s, deficiencies in the existing instrument landing system (ILS) and the U.S. airlines' goal of all-weather automatic landings prompted the development of MLS; the airlines renounced the goal in the 1970s as not economically feasible. No studies of the continuing need for MLS were launched. Similarly, ILS has since been upgraded but no new operational need studies for MLS were initiated until the early 1990s.

By 2008, FAA had planned to acquire 1,280 MLS units at an estimated cost of $2.6 billion.[72] FAA canceled the MLS program in favor of using GPS-based systems to meet some (and possibly all) future instrument approach needs.[73] Curved final approaches using MLS (or GPS) have been promoted as a means of providing better approach and landing capacity at major airports in instrument flight rules conditions. To date, no detailed study of the operational procedures required for certificating curved approaches has been made.[74] The issues of obstacle clearance, missed approach paths, safe approach speeds, maximum bank angles, and maximum allowable windspeeds have yet to be considered for curved approaches.

The Precision Runway Monitor program is another example of an inverted development process. FAA did not begin conducting dynamic simulations involving real pilots and controllers until the two prototype technology development projects were completed. The results of these simulations have raised serious questions about test and evaluation criteria for PRM, and whether emergency procedures are adequate for all airports that could use the system.[75]

The agency's own RE&D Advisory Committee pointed out some of these problems in 1991:

> The nature of system enhancements and the advent of new technology now make it possible to manage FAA research and development as a process of innovation, which stresses prudent overlap in concept formulation, development and implementation, rather than a purely sequential process that begins with invention and postpones subsequent programmatic decisions until total demonstration of each facet of the concept and technology. . . . [A]n important part of developing new technologies is concurrently developing certification standards, protocols, operating procedures and the like. These processes are critical in bringing new technologies on line.[76]

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[71] Simpson, op. cit., footnote 67, p. 3.

[72] U.S. Congress, General Accounting Office, *Air Traffic Control: Status of FAA's Modernization Program,* GAO/RCED-93-121FS (Washington, DC: April 1993), p. 45.

[73] "FAA Cancels MLS in Favor of GPS," *Aviation Week & Space Technology,* June 13, 1994, p. 33; and "Europe Still Plans To Implement MLS," *Aviation Daily,* June 14, 1994, p. 419.

[74] Simpson, op. cit., footnote 67, pp. 3-4.

[75] The key issue is when an aircraft approaching one of the parallel runways deviates off-course (or "blunders") toward the approach path of the other runway. In this situation, the "nonblundering" aircraft would have to be redirected laterally away from the conflicting aircraft, but some airports do not have sufficient obstacle clearances to the sides of approach paths to permit this maneuver. Typical "missed approach" procedures for single or widely spaced runways usually require an aircraft to immediately begin a climb. However, this is not possible in this "blunder scenario," since it could be unclear which aircraft is above the other (aircraft altimeter measurement errors could be larger than the actual altitude difference between the two aircraft).

[76] 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. 32-33.

I Current Federal Policy for System Development and Acquisition

Critics point to a slow, cumbersome FAA procurement process as the cause of slippage and cost escalation of ATC milestones. While some institutional reforms may help improve the ATC system, few specifics have been given on how a new ATC entity, such as a U.S. Air Traffic Services Corporation. or changes in procurement rules would resolve ATC operational planning and development problems discussed above or otherwise significantly speed up the acquisition of complex, safety-critical systems.

The U.S. General Accounting Office has studied this issue and concluded that for FAA, government procurement policies and regulations are not the key snag. The central problem for the past decade, according to GAO, is that FAA did not follow federal acquisition guidelines for project development—specifically, OMB Circular A- 109 for planning and management oversight (see figure *2-4,* again), and OMB Circular A- 11 for budget oversight.

OTA spoke with companies handling FAA contracts for new ATC systems, and common among these manufacturers was frustration with the agency for constantly changing criteria, adding "bells and whistles" (or, more accurately and most often, software) that were never mentioned at the time of contract bidding.

The Federal Acquisition/ OMB Circular A 109 Process

In 1986, in testimony before Congress, GAO stated that it". ., would expect a major system acquisition program with significant technical, operational, and economic risks to require strict adherence to the phasing and extended competition principles fundamental to Office of Management and Budget Circular A- 109."[77] Unlike the four-phase process called out in A- 109, FAA's existing procurement strategy incorporated only one decision point before committing to a combined development, test, and production phase. Neither FAA nor the contractors planned to validate the contractors' models of the Advanced Automation System to ensure the proposed systems performed as required before the production commitment was made.

None of the 11 major system projects contained within AAS was subjected to the sequential A- 109 process; instead, FAA submitted all for DOT's acquisition approval at either of the final two phases of the process called out in A-109, that is, full-scale development and full production (see figure *2-4,* again).[78] Between 1983 and 1991, the average delay for first-site implementation of these projects grew to five years.[79] Modernization costs continue to escalate.

FAA did not follow the A-109 process for other major programs. In February 1983, FAA submitted the MLS program for production approval, bypassing the first three key decision points in A- 109.[80] As with other FAA projects that circumvented the Office of Management and Budget (OMB) process, the MLS project met schedule delays and cost overruns.[81] Even though the $353-million Terminal Doppler Weather Radar program was ahead of schedule, FAA committed to production before operationally testing the deliverable design. The prototype software that had been tested was not the same—nor was the com-

[77] Carl R. Palmer, Associate Director, Information Management and Technology Division, U.S. General Accounting Office, testimony at hearings before the House Committee on Appropriations. Subcommittee on Transportation, Aviation, and Material\, Apr. 16, 1986, p. 7.

[78] U.S. Congress, General Accounting Office, *Aviation Acquisition: Improved Process Needs To Be Followed,* GAO RCED-87-8 (Washington, DC: U.S. Government Printing Office, March 1987), p. 20.

[79] U.S. Congress, General Accounting Office, *Air Traffic Control: Status of FAA's Modernization Program,* GAO 'RCED-92-136BR (Washington, DC: U.S. Government Printing Office, April 1992), pp. 26-27.

[80] General Accounting Office, op. cit., footnote 78, p. 26.

[81] These problems were with the program for Category 1 systems. The development programs for more precise Category 2 and 3 systems were on schedule when terminated in favor of GPS. Crook, op. cit., footnote 66.

puter system—as what would ultimately go into the field.[82]

But there have been positive changes at FAA. An FAA directive issued in March 1993[83] revises FAA procurement guidelines to require mission need statements and key decision points, closely following the A-109 process.[84] Moreover, FAA cites more adherence to the A-109 process in the early 1990s, even before this guidance was issued. Today, mission needs are reviewed by its acquisition review committee before the first decision point. FAA's Office of Acquisition Policy and Oversight staff provide guidance to programs developing mission need statements, and have "inserted some discipline into the process" of approving program justifications.[85]

FAA already has seen success with the approach. For example, acquisition of a new voice switch for control towers "hit all the key decision points" and met both schedule and budget goals.[86] However, FAA's latest acquisition policy still does not emphasize operational procedure development. Furthermore, FAA has yet to fully make the cultural transition to a more demanding acquisition policy. The requirement for more quantitative justification for new programs and an exacting compliance atmosphere have generated some controversy; some program offices have not warmed to the stricter process .87

The Budget Process

OMB Circular A- 11 provides guidelines for federal agencies in preparing annual budgets. For R&D, A-1 1 calls for the following budget categories: basic research, applied research, and development. For major system development and acquisition, the budget criteria in A-11 parallel the acquisition phases in A-109. As GAO put it in a recent report, "[h]owever, FAA has repeatedly ignored these criteria by budgeting development activities in its F&E account."[88] DOD organizes its R&D closer to OMB criteria than FAA. For example, DOD R&D categories 6.1 (basic research) through 6.5 (management and support) roughly correspond to A-109 milestones.[89]

Development work done under two budget accounts

FAA's budget criteria require facilities and equipment (F&E) funding for programs beginning at full-scale development, then limited and full production. Projects that require R&D are first budgeted in the RE&D appropriation account. According to GAO, however, some RE&D projects, such as Terminal Air Traffic Control Automation, receive both RE&D and F&E funds.[90] FAA routinely budgets substantial amounts of R&D work into its F&E account. For example, much of FAA support for weather R&D comes out of F&E

82U.S. *Congress, Genera]* Accounting Office, *Aviation Acquisition: Further Changes Needed in FAA's Management and Budgeting Practices,* GAO/RCED-91-*159* (Washington, DC: July 1991), p. 6.

83U.S. Department of Transportation, Federal Aviation Administation, "Acquisition Policy Handbook," Order 1810. I F, Mar. 19, 1993.

84 David Morrissey, Director, FAA Office of Acquisition Policy and Oversight, persona] communication, May 17, 1993.

85David Morrissey, Director, FAA office of Acquisition Policy and Oversight, personal *Communication,* Apr. 15, 1994.

86Ibid.

87Ibid.

88General Accounting Office, op. cit., footnote 82, P. 2.

891 bid., p. 26.

90U.S. Congress, General Accounting Office, "FAA Reauthorization: Opportunity Exists To Address Safety, Capacity, and Efficiency Issue," GAO/T-RCED-93-75, Sept. 28, 1993.

funds. In a recent Office of Science and Technology Policy overview of U.S. weather research programs,[91] all weather-related R&D funding by FAA came from the F&E account.[92]

Including development and engineering tasks under F&E contracts accounts for the impression of delay in procurement, if the F&E account is viewed primarily for production. The reason for this budgeting oddity has to do with authorization levels for the RE&D account; if the development work in F&E were moved under RE&D, the latter account would exceed its authorization.[93]

This budget confusion has led some in the aviation community to conclude that FAA under-invests in technology R&D, and that this is a key source of ATC system modernization problems. It is true that the fraction of FAA's total budget designated as RE&D is small, especially when compared with R&D investments at other federal agencies and high-tech industries (see figure **2-5).** However, FAA funds about five times as much air traffic control R&D in its F&E account than in its RE&D program. Consequently, FAA R&D for air traffic control, including the R&D spending outside of the RE&D account, was 10.5 percent of FAA's total annual budget for ATC in 1993 (see table 2-3). This level of R&D investment compares favorably with figures for high-tech industries such as telecommunications and computer software. Insufficient funding for research and technology development is not a major source of FAA's ATC modernization difficulties.

Limitations of current procurement rules

Although the implementation delays caused by the federal procurement rules should not be overemphasized, they do slow the purchase of what should be readily available equipment. These laws ". . . place heavy reliance on competition. They give losing bidders multiple opportunities to protest, thereby delaying decisions for long periods."[94] This often prevents FAA from simply returning to a proven supplier, requiring instead a virtual repetition of the process for the initial procurement. "Procurement officers' emphasis on awarding a contract to the lowest bidder, despite significant quality advantages with other bidders, is one example of how procurement and program objectives often clash."[95]

Others have expressed similar views, that the competitive procurement system causes delays and added expense, although the resulting time lag seems to be roughly one year at most.[96] "An FAA study identified 250 government documents that levied requirements on acquisition officials, 140 of which were FAA generated . . . and included 4,500 citations that were identified as 'required activities. FAA has reduced these to 1,400 action steps."[97]

Purchase of off-the-shelf equipment, such as personal computers and radar display screens, would be most affected by any move to exempt FAA from federal procurement rules. By contrast, procurement of the large ATC systems unique to FAA is likely to be affected much less by such an

[91] Office of Science and Technology Policy, Federal Coordinating Council for Sciences, Engineering, and Technology, Committee on Earth and Environmental Sciences, Subcommittee on Atmospheric Research, "Predicting Our Weather: A Strategic Plan for the U.S. Weather Research Program," July 1992.

[92] Ibid., p. 33. The $18.4 million listed under DOT for fiscal year 199 I is all from FAA's F&E budget. Greg Geisler, Office of Budget, Federal Aviation Administration, personal communication, June 22, 1994.

[93] General Accounting Office, op. cit.. footnote 82, p. 8.

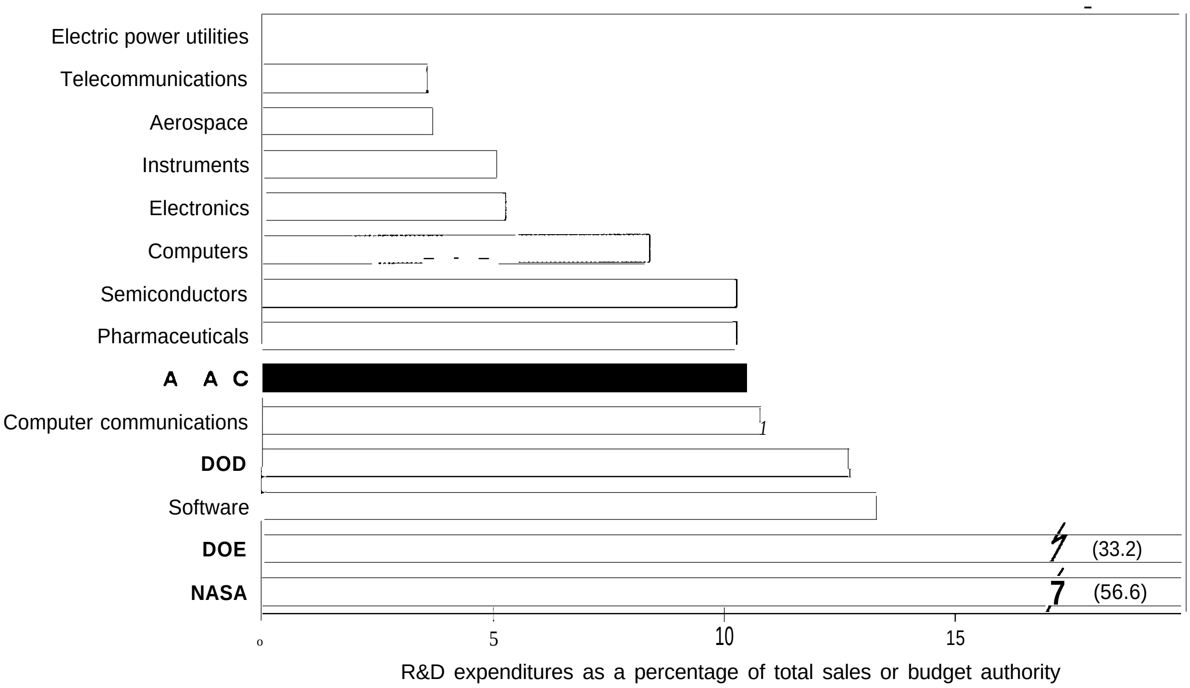
[94] National Research Council Transportation Research Board, *Winds of Change: Domestic Air Transport Since Deregulation* (Washington, DC: 1991), p. 329.

[95] 1 bid., p. 330.

[96] John Turner, FAA Associate Administrator for National Airspace System Development, personal communication, Oct. 21. 1992; and Crook, op. cit., footnote 66.

[97] The National Commission To Ensure a Strong Competitive Airline Industry, op. cit., footnote 63, p.10.

FIGURE 2-5: Research and Development Spending: Comparison of Selected Industries and Federal Agencies



[a] See table 2 3 for ATC R&D budget data

NOTES Values for individual federal agencies are for fiscal year 1993, values for Industries are for 1990

KEY FAA ATC Federal Aviation Administration air traffic control-related R&D spending as a percent of total FAA spending on ATC DOD Department of Defense DOE = Department of Energy, NASA = National Aeronautics and Space Administration

SOURCE Off Ice of Technology Assessment, 1994 based on Aerospace Industries Association: "R&D Statistics, " *Business Week/ Quality* 1991, p 214 Department of Energy Energy Information Administration, *Financial Statistics of Major Investor-owned Utilities 1991* Office of Management and Budget

exemption, although relief from the multiple reviews and challenges by losing bidders would have some impact. According to the Transporta-(ion Research Board:

> . . . no matter how much better the FAA plans its procurements, there are statutory impediments prescribing policies and practices, which give rise to many of the difficulties. Prominent among these are insistence on advertising and competition, even if only one or a few bidders are qualified: emphasis on choosing the lowest bidder when others may offer superior quality and value; prohibitions on working with contractors during the specification of follow-on procurements; and complex, time-consuming procedural requirements, including those affording allegedly aggrieved, unsuccessful bidders the right to multiple and protracted appeals.[98]

The Federal Acquisition Streamlining Act of 1994 would make it easier for federal agencies to purchase off-the-shelf products and technologies.

[98] Transportation Research Board, op. cit., footnote 94, pp. 336-337.

TABLE 2-3: Federal Spending on Civil ATC Research, Development, and Engineering

Accounts and calculations	FY 1993 actual ($ millions)	FY 1994 request ($ millions)
FAA:		
RE&D account		
(1) ATC portion	$ 988	$ 1126
F&E account		
(2) EDT&E	555.2	5492
(3) DT&E	160	106
(4) Non-ATC procurement	596	1272
(5) Total	2,4650	2,524.0
Operations account		
(6) ATC programs	3,480.9	3,522.9
(7) Overhead (ATC portion)[a]	4236	4157
(8) **Total ATC-related R&D spending= (l)+(2)+(3)**	**6700**	**6724**
(9) **Total FAA spending on ATC = (l)+(5)-(4)+(6)+(7)**	**6,4087**	**6,4480**
FAA ATC-related R&D spending as a percentage of total FAA spending on ATC = (8)/(9)	10.5%	10.4%
NASA:		
ATC portion of aeronautics R&D	319	50.6
Total ***NASA and FAA ATC-related R&D spending:***	***701.9***	***723.0***

[a] Off Ice of Technology Assessment estimate Overhead spending was prorated according to the ratio of ATC programs to non-ATC programs in the operations account

KEY DT&E = development test, and evaluation, EDT&E = engineering, development, test, and evaluation; F&E = facilities and equipment; RE&D = research, engineering, and development

SOURCES Off Ice of Technology Assessment, 1994, based on Budget of the United States Government, Fiscal Year 1994, Federal Aviation Administrtion budget documents, National Aeronautics and Space Administration

While this legislation is aimed largely at DOD, if enacted it will apply to other federal agencies, including FAA.[99]

I The System Development Process at FAA

In many cases, complying with A-109 (or FAA's own acquisition policy, which expands on A- 109) could have helped FAA identify, and possibly resolve, operational and procedural problems before committing to expensive technology development. However, while OMB guidelines provide a foundation for proper system development oversight, they cannot alone ensure fast and successful ATC system development and implementation. What is also needed is a change in ATC system development philosophy that places a much stronger emphasis on operational concept and procedure development.

Previous studies have concluded that stable leadership is needed at FAA to improve the system development and acquisition process.[100] The

[99] The legislation was in the conference committee as this report went to publication.

[100] Some examples include *Aviation* Safety Commission, *Volume 1: Final Report and Recommendations* (Washington, DC: April 1988); U.S. Congress, Office of Technology Assessment, *Safe Skies for Tomorrow: Aviation Safety in a Competitive Environment, OTA-SET-38 I* (Washington, DC: U.S. Government Printing Office, July 1988); and Transportation Research Board, op. cit., footnote 66.

average tenure of FAA Administrators (around two and one-half years during the past two decades) is far shorter than the development cycle of most ATC systems. And presently, no one below the Administrator has the authority to effectively bridge the operational and technological divisions of FAA. This means that ATC system development programs have had neither the mandate nor the leadership to ensure that operational and technological goals are continually coordinated and validated.

Technology development is the dominant culture in FAA system development programs. Technological improvements, rather than operational advances, become the focus of many projects. Furthermore, FAA technology development projects sometimes take on a life of their own. For example, the primary justification for MLS was changed or superseded by other technologies [101] at least three times in the project's history—yet the project stayed alive for three decades. Scrutiny by operational experts can threaten such projects and is rarely sought by technologists until absolutely necessary. Controllers and pilots are the ultimate users of the system and want to prevent new safety flaws from being introduced—implementation delays do not hurt that goal. Whether pilots and controllers are consulted early or late, their assessments have major impacts on new systems (see box 2-3 for one example).

Good acquisition policies alone are no panacea for FAA. One reason is that ATC system development issues are as much cultural as they are managerial. Air traffic controllers, equipment technicians, pilots, engineers, administrators, 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.[102] One former Administrator believes that the most critical challenge is to get the "Air Traffic. Flight Standards. and R&D parts of FAA to work as a team. It has never happened." [103]

Moreover, these cultural differences may send 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, but rarely is there agreement on what levels of safety and efficiency are acceptable or how they can be measured. However, current U.S. ATC is remarkably safe as measured by accident risk, and no safety crisis exists. Unresolved concerns about new risks slow the ATC development process. The tradeoff is that once the new ATC system safety concerns are satisfactorily addressed, the actual safety increase realized will likely be too small to measure, but the increase in efficiency could be substantial—worth billions of dollars per year. [104] Consequent-1y, it is important to tackle safety concerns as early and openly as possible to minimize the costs of delayed operating efficiency benefits.

The View From Inside

OTA talked to mid- and low-level FAA managers about the agency culture for research and system

[101] New capabilities that could serve some MLS missions include better ILS performance, potential for curved approaches using onboard flight management systems, and highly accurate satellite navigation.

[102] The problem has not been confined to the ATC arena. In the late1980s, coordination was weak between FAA's aviation security regulation section and the agency'~ security R&D branch at the Technical Center. For more information, see U.S. Congress, Office of Technology Assessment, *Technology Against Term-i\ m: Structuring Security*, OTA-1 SC -511 (Washing ton, DC: U.S. Government Printing Offi cc, January 1992).

[103] John McLucas, personal communication, June 29, 1994.

[104] For example, world airlines could potentially save as much as $5 billion a year in fuel and delay costs by using satellite navigation according to Assad Kotaite, ICAO Council President. Lisa Burgess, "ICAO Urged To Help Nations Implement FANS," *Commercial Aviation News*, July 12-18, 1993, p. 8.

BOX 2-3: Difficulties With Intra-Agency Teams—Case Study on the Multiple Parallel Approach Program

In 1988, the Federal Aviation Administration's Air Traffic Service asked the Research and Development Service to help determine if multiple simultaneous parallel instrument approaches (to three- and four-runway configurations, referred to as triples and quads) were feasible using existing radar and monitoring equipment, Managers from the air traffic division created the Multiple Parallel Approach Program (MPAP) to conduct these studies, and formed a Technical Working Group (TWG) from representatives of interested FAA offices to design and evaluate the necessary simulations.

During its first few years, members described TWG as a successful group in which all participants understood and addressed not only their own needs, but those of the other members as well. [1] In the opinion of one participant, the mutual understanding was so strong that the team came to consensus about 99 percent of the time,[2] According to another TWG member, " [a]t FAA, much of what works occurs when the key players enter early and are included for the duration of the process, "

TWG met several times to develop test criteria before beginning simulations. Among the criteria agreed on in July 1989 were aircraft airspeeds of 150 to 180 nautical miles per hour and flight path "blunders'" of up to 30 degrees as the deviation the controllers and pilots in the test must successfully overcome. [3]

Competing Technologies

Evaluations began in 1990 with human-in-the-loop simulations of the radar and display indicators[4] currently in use at U.S. airports. This equipment passed tests of triples spaced at 5,000 feet apart. But with a 4,300-foot separation,[5] this combination failed the test, largely because of the poor resolution provided by the displays,[6]

TWG then brought in the Final Monitor Aid (FMA), a 20- by 20-inch, high-resolution color display with new features. The FMA had been developed as part of the Precision Runway Monitor (PRM) radar system but was separable, which allowed TWG to pair it with the Mode-S monopulse radar system.[7] The Mode-S/FMA combination passed the tests of triples at 4,300 feet, With the faster PRM radar, the FMA would likely perform even better.[8] FM documents from 1990 through mid-1 992, along with Off Ice of Technology Assessment interviews, indicated across-the-board acceptance-even enthusiasm—for the FMA,

The Turning Point

In summer 1992, a controversy began brewing concerning runway separations at the Denver International Airport (DIA), then under construction. FM had assured Denver officials that the airport would have independent triple Instrument flight rules capability on opening day, [9] and at first glance, the

(continued)

[1] Interviews with various FAA personnel

[2] Interview with manager in the Off Ice of System Capacity

[3] A "blunder" is when an aircraft established on its final approach path to a runway deviates frOm its intended course

[4] These are the ASR-9 radar and the ARTS IIIA/Data Entry and Display Subsystem (DEDS)

[5] Independent instrument flight rules approaches to dual parallel runways separated by at least 4,300 feet have been authorized without incident since 1974 The closest spacing in actual operation is at Atlanta Hartsfield International Airport, where the runway centerlines are separated by a little over 4,400 feet Notably, however, before setting this standard, FAA had not run simulations for parallel runways closer than 5,000 feet

[6] FAA Contract Report, Comparison of Controller Performance Using the Final Monitor Aid and the ARTS/DEDS Display Systems, " Air Traffic Control Simulation Contract No DTFA03-89-C-OO023, Sept 29, 1992, pp I-6--4-8

[7] The Mode-S system has the same one milliradian radar accuracy at PRM, but a slower update rate (4 8 seconds for Mode-S; 10 seconds for PRM)

[8] The PRM radar was only tested for 3,000- and 3,400-foot runway separations in the MPAP simulations However, controllers Indicated that the faster update rate significantly improved their performance CTA, Inc , "Test Report, Phases V b 1 & V b 2 Evaluation of Dual and Triple Simultaneous Parallel ILS Approaches Spaced 3,000 Feet Apart Using the Precision Runway Monitor System With a Simulated 10 Second Radar Update Rate, " Engineeing Research Psychology Services Contract No DTFA03-89-C-OO023, CDRL Item 002, June 16, 1992, p x

[9] City and County of Denver, ' FAA Affirms Triple Simultaneous Landings at DIA, " press release, Feb 26, 1993

BOX 2-3: Difficulties With Intra-Agency Teams—Case Study on the Multiple Parallel Approach Program (Cont'd.)

test results discussed above supported this claim The first three DIA parallel runways built are separated by 5,280 feet and 7,600 feet—greater than the 5,000 feet previously tested However, FAA had not adequately considered the effects of thinner air at higher altitudes in its tests on triples—without changing other aerodynamic parameters, an aircraft files faster as the air becomes thinner Consequently, for the same level of safety, parallel runways would need to be farther apart at Denver elevations than at sea level sites because of greater aircraft speeds,

Several members of TWG recommended testing to see if there might be a problem with DIA's runway configuration, and if so, whether there might be a technology solution. Despite strong sentiment by some FAA offices against running new simulations, TWG received senior management approval and conducted tests of high-alhtude runway configurations

The first simulation scenario strongly resembled DIA, though it was not explicitly designated Conducted in September 1992 and using previous test criteria, current radar and displays (ASR-9/DEDS combination) proved Inadequate in these simulations It was at this point that TWG became fractious, and research objectivity fell by the wayside Personnel from Air Traffic Service and FAA's Northwest Mountain Region (NWM) protested that the test criteria, which they had accepted in previous simulations, were the reason for the equipment's failure to pass the tests They Insisted that blunders did not happen and that the aircraft approach speeds were too high Project participants from FAA's regulatory and standards divisions and the Air Line Pilots Association held that the agreed-on criteria were necessary to the tests. Also, the original project manager from the Off Ice of System Capacity was replaced by someone from the Research and Development Service

At a TWG meeting a month later, the new project manager announced that these simulation data would not be used in the TWG analyses Instead, new simulations would be conducted, called the DIA simulations, which would replace the current controller displays with an upgrade, the Full Dlgital Automated Radar Terminal System Display System (FDADS) At the Insistence of NWM, and over the protests of others, TWG recommended that the simulation airspeeds be changed [10] The meeting minutes show that in the future only the TWG chairperson, not Individual members, would speak for the team when discussing the simulations[11]

The DIA simulations took place in November 1992 Even though the upgraded displays were supposed to provide better Information, the results of the first two days of testing appeared similar to those of the previous simulations. After much discussion. the FMA displays were used for the remainder of the simulation and were successful When the working group met again in January 1993, the MPAP manager stated that the data from the September 1992 simulations would remain archived and that there would be no mention of the aborted test of the upgraded display (FDADS) in the DIA report [12] However, all data were published in that report

(continued)

10 These airspeeds are different than those used in any simulation we have observed thus far The twm-engine piston aircraft normally fly at 120 knots, the turboprop at 150 knots, and the turbojets at 180 knots until the final approach fix Raising the speed of piston and turboprop aircraft and lowering the speeds of turbojets to the point where both types of aircraft are operating outside of their normal flight envelopes is not a realistic solution to reducing the potential blunder situations Air Line Pilots Association, letter to the Federal Aviation Administration, Dec 17, 1992

11 Multiple Parallel Approach Program (MPAP) Technical Work Group (TWG) Meeting Minutes, ' Washington, DC Oct 6-8 1992

12 There was no consensus among TWG memberson these decisions Further ' [t]his directive is apparently coming from a higher authority than the program manager No FAA person will name that authority ' National Air Traffic Controllers Association Internal memorandum Mar 22 1993

BOX 2-3: Difficulties With Intra-Agency Teams—Case Study on the Multiple Parallel Approach Program (Cont'd.)

Based on measurement of controller performance, the FMA performed 13,5 times better than FDADS, [13] and it appears to be no more costly.[14] Yet some factions within the Federal Aviation Administration tried hard to make FDADS pass, although it is unclear why. However, FAA ultimately decided that FMAs will be used at DIA.

Conclusions

Fundamental data from the field are essential Everyone agrees that testing against blunders can be helpful in developing and validating new air traffic system technologies and procedures. As stated by FAA's Chief Scientist "[i]f the system is shown to be safe even with extreme assumptions such as the 30-degree blunder, then the most reluctant doubters are easily convinced. But when such a model shows the system to be unsafe, we have learned nothing, and should not assume that it is really unsafe.'" [15]

At issue, then, is how often blunders actually happen and what criteria should be used in certifying new systems for actual operation. Although the 30-degree blunder criterion has been used by FAA since 1974, it was not until the status quo was challenged that individuals at FAA began to state that blunders are so rare that they should not be part of the tests. However, FAA has lacked the empirical data to support changing this criterion.

According to Flight Standards, "[t]he remaining issue is what should we be protecting against? .,, Deviations are rare events, but when one does occur, does the FAA have the capability to detect/recognize the deviation, alert the controller, and have the controller resolve the conflict?"[16] Over the years, FAA has Invested a great deal of resources and research into the development of PRM, FMA, new controller positions, and new safety procedures for simultaneous parallel approaches. All these efforts have been for the purpose of detecting and resolving the unlikely event of an aircraft deviating off the approach path, But better system data are needed. As the Director of Flight Standards stated, "[t]o date, no formal FAA data collection effort has been in place to capture the events of aircraft deviations and the degree of deviations systemwide.[17]

Intra-agency teams are valuable, but are difficult to manage under the current FAA organizational structure. There is an Inherent tension between system evaluation and implementation. Yet, many of the same groups—pilots, controllers, technologists—must have effective roles from start to finish in both the evaluation process and in system development and implementation, Close coordination among these groups is needed to establish the underlying operational objectives, criteria, and procedures essential to make both the evaluation and implementation processes more timely and effective. It is Important to note that top managers from FAA's different organizations participated in the MPAP discussions, the crosscutting team approach of TWG was quite successful at identifying potential problems early and figuring out ways to evaluate them.

(continued)

13"[T]he acceptable rate for the FMA is about 135 times larger than the acceptable rate for the FDADS, thus indicating that the use of the FMA will result in an operation with far less risk than the FDADS " Federal Aviation Administration,"FDADS Simulation at Denver, " draft Internal memorandum, n d

14 Federal Aviation Administration Mission Needs Statement, "High-Resolution Display Requirements for Final Monitor Aid, MNS Number 225, section 11 (d), Feb 9, 1994

15 Robert Machol, FAA Chief Scientist, internal memorandum, Jan 4,1993

16 Thomas C Accardi, Director, Flight Standards Sef'vice, FAA Internal memorandum, Apr 7, 1993

17 Ibid

BOX 2-3: Difficulties With Intra-Agency Teams—Case Study on the Multiple Parallel Approach Program (Cont'd.)

However, such crosscutting teams face a dilemma Involving the power of each member A strong voice for each is essential, but too much Influence on the decision process leads to problems, According to the National Air Traffic Controllers Association and others, in the past FAA has had working groups do retests, with the aim of validating favored technologies or procedures.[18] One option to address this problem is that when a team is created, the boundaries of authority and the levels of required management review must be clearly identified, This did not happen for TWG. Another option is to place evaluation teams such as TWG under the authority of a high-level, Independent arbiter who understands operational development issues as well as technology concerns Currently, FAA has the organizational structure to Independently evaluate major system acquisitions, but not the operational procedures and criteria the systems are to support.

18 Representatives of National Air Traffic Controllers Association, personal communication, Aug 11.1993

development.[105] While much positive was discovered, also unearthed were signs of a few pitched battles within the Systems Operations Directorate.[106] These conflicts placed the Air Traffic and System Capacity divisions on one side, and the Regulation and Certification division on the other. And the regulatory division did not always win. Some Air Traffic personnel have been quoted as saying that their job was not to improve safety but to increase capacity—as though the two were mutually exclusive.[107]

During its investigations, OTA found that FAA's upper management was attempting to change the culture of the agency by creating a research orientation and encouraging employees to think long term. The managers interviewed were aware of this effort and applauded it, though not all predicted success. Many felt FAA had a number of significant internal problems to address in order to reach its goal of well-coordinated research, technology development, and implementation. They emphasized the disparate relationships the offices within the System Operations Directorate have with those in the System Development Directorate.

FAA now emphasizes continual review of R&D projects by managers from the System Operations Directorate, which in turn requires good relationships between the Directorates and their respective divisions and offices. With all the talk of improved communications, however, the System Engineering and Development division (called the "R&D division" below) still seems to have a different relationship with each System Operations division. This may be only logical in light of the diverse natures of these divisions, it may be a function of an agency in transition, or it may be a remnant from the past. It is here that differences in agency culture remain an unresolved issue.

105 OTA staff spoke t. more than 30 low- and mid-level managers in order to get the perspective of those charged with actual implementation of upper management's plans.

106 In this report, sections of FAA managed by Executive Directors are referred to as *directorates* and those managed by Associate Administrators or Assistant Administrators as *divisions*. *These* terms are not used by or have different meanings within FAA.

107 The case history concerning parallel runways at Denver, presented in box 2-3, also involved animosity among participants. Those wanting to keep the more stringent test criteria claimed to be doing so in the name of safety, while those seeking new criteria cited the need for increased capacity and tended to come from ATC-related divisions of FAA.

One often-cited problem from the recent past was lack of communication between R&D personnel and the operating divisions, resulting in unwanted or unusable R&D. Therefore, when seeking solutions to this problem, FAA management first turned to improving relationships between R&D and the operating divisions. In some cases, "improving relationships" meant increasing the flow of current communications; in other cases, the managers involved started virtually from scratch.

More than one operating division manager has accused the R&D division of politicizing its priority-setting process to favor some operating divisions at the expense of others. Conversely, other division managers believe they have an advantage in their rapport with key individuals in the R&D division, but they also worry about what would happen to their projects if these persons were to leave. Maintaining continuity over long-term projects is a common concern.

Some parts of the System Operations Directorate, such as the Flight Standards Service, have specific branches to deal with the R&D division. Not every operating group at FAA is large enough to afford such units; indeed, the technical programs section within Flight Standards has more branches than some entire offices or services elsewhere in the agency. Furthermore, where some offices within the System Operation Directorate have a history of cooperation with the R&D division, others have a background of far less cordial relationships.

Within the offices under the Assistant Administrator for Airports (which is separate from the Directorates mentioned above), there have been discussions of a periodic review of R&D projects. There remains some concern within this group that the improved relationships with the R&D division are based on having "nice guys in charge;" they would like to see any new procedures fornalized so that success in accomplishing their R&D goals is less dependent on having a good rapport with a particular individual. A Flight Standards manager maintained that R&D programs go most smoothly when the R&D program manager seeks the help and input of the operating divisions, and the operating divisions have and take advantage of opportunities to outline their needs. The air traffic division uses quality action teams [108] to review the processes used to determine R&D (and other) projects, thus ensuring that Air Traffic's policies and technology needs are taken into account in the R&D decisionmaking process.

Another office that depends on the R&D division, the Office of Environment and Energy (under the Associate Administrator for Policy, Planning, and International Aviation), also has had improved cooperation with the R&D division. They have seen a major change in how the R&D division involves Environment and Energy people in the process. Although the planning and coordination process for R&D takes longer, Environment and Energy has found that it works better. They submit proposals and justifications for the following five years, which are then reviewed at several levels. The office is pleased with this procedure. According to one manager: "[t]he decisionmaking process is now on the table instead of in the back room."

Many FAA R&D projects involve or interest more than one operating office or division. For such projects, good communications require that multiple groups cooperate with one another. While the accusation has been made in the past that the different divisions had tunnel vision, not seeing past their own concerns, there is increased emphasis on ensuring that each relevant division be represented in the R&D decisionmaking process.

One R&D division manager likes to see the operating divisions making a strong commitment to

[108] These are part of total quality management (TQM) implementation. TQM is a concept that encourages team-building, increased communication, employee input, and continuing review as away of meeting a defined mission. A number of companies and government agencies now rely on TQM.

their projects. His feeling is that this has not always been the case. but that participation has improved and is now more active. He recalled that in the past, operations managers were sometimes passive and behaved "like judges of something other people were doing," rather than as integral members of a system development (earn. He prefers the increased number of R&D projects he is seeing in which the operations representatives "are more like team players. "

Positive Steps

In many ways. FAA is in transition. FAA has recognized some of the operational development problems discussed earlier 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.

As mentioned above, acquiring user input is an essential step in identifying operational requirements. For the development of the new 777 aircraft, Boeing has 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 satellite communications and surveillance. The teams have worked closely with representatives of the various FAA organizations, as well as with other parts of the aviation communit y. to improve the process for developing performance standards and requirements. [109]

The Satellite Operational Implementation Team (SOIT) was established to help speed the introduction of satellite navigation functions into the U.S. air traffic system. Sponsored by FAA's Flight Standards Service. SOIT serves as the single focal point for the review and approval of all operational implementation requirements: the team includes representatives of all the functional entities involved in implementing satellite technology. Industry. academia, and other advisory groups are also involved in certain SOIT activities, at the invitation of FAA. But by law, FAA must exclude industry from those sessions that involve rulemaking. [110] However, some industry representatives consider these prohibitions to be excessive—industry is now excluded from all meetings of the navigation portion of SOIT. [111]

SOIT provides guidance and direction to program offices responsible for research, development, operation, and acquisition of satellite navigation technologies. For example, SOIT consulted with the R&D division to develop the mission needs statement for GPS (i.e., for the first key decision point in the A 109 process) prior to the program's budgeting. In addition, SO IT is authorized to task member organizations to support agreed-O_n activities. [112] In 1993, FAA separately chartered a Communications/Surveillance Operational Implementation Team (C/SOIT) from a working group formerly based within SOIT. C/SOIT is focusing on the early operational implementation of satellite communications, surface movement surveillance systems, and datalink technologies.

CONCLUSIONS

Aviation research and technology development are performed by various public and private institutions in the United States and across the globe. The U.S. federal government is the major provider of R&D for aviation safety, security, environmental protection. and the airspace system. Such research is vital to FAA's regulatory and operating missions, and FAA is both a customer and supplier of R&D products in these areas.

FAA depends on other agencies for most basic research such as human factors and environmental science. To the extent that such research is

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

[110] Jim Crowling, Chairman, FAA Satellite Operational Implementation Team, personal communication, July 13, 1994.

[111] Edwin Thomas, United Air Lines, personal communication, July 14, 1994.

[112] From the Satellite Operational Implementation Team charter, June 7, 1993.

BOX 2-4: Possible Steps for More Effective ATC System Development

- **Involve suitably experienced operational personnel in the planning and prototype development process. Effective system development requires a balance of operational and technical views, and neither should dominate,** The planning, analyses, and experience of operating organizations, at the Federal Aviation Administration and across the aviation community, are critical to properly matching technological options to safety and operational initiatives "Too little, too late" has usually described the Involvement of operational experts in air traffic control (ATC) development
- Conduct operational **analyses and develop operational procedures for new system concepts early enough to affect the technology development process. Proposed operational procedures must be developed in sufficient detail that controllers, pilots, and other groups can understand and draw conclusions on the safety and operational implications Moreover, the operational and technical components of each ATC system must be developed concurrently, and must include frequent feedback from the aviation community (see figure 2-4),**
- **Use dynamic ATC simulations as "operational development" as well as "technology development" tools. Dynamic ATC simulation resources, capable of including real controllers and pilots, are essential to rapidly develop and test new ATC system concepts and procedures Operational** issues such as human-machine Interface and airspace configurations can be studied before the technology is fully mature Proposed operational procedures and technological concepts can be criticized constructively with dynamic simulations, provided that both operational and technical experts are closely involved in the process When used in the past, dynamic simulations have focused primarily on validating and fine-tuning technological concepts

SOURCE Off Ice of Technology Assessment, 1994

conducted within federal programs, coordination and cooperation for aviation R&D among federal agencies have improved in recent years, although it could be stronger still.

For its part, FAA's foremost responsibility for interagency research and technology is to identify the long-term operational needs and objectives for the aviation system. **It is especially important for FAA to confer with federal agencies conducting research to ensure that the specific needs of civil aviation, especially as they relate to U.S. policy in international standards-setting, are addressed within other research programs. 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; the agency alone has the breadth of expertise and connections across the aviation community to provide this service.

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 air traffic control, are useful to other agencies. For example, DOD plans to install the same air traffic equipment as FAA in its domestic control facilities. Additionally, FAA research facilities for aviation securit y, 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.

However, it is the system development programs at FAA that need the most improvement. ATC system development and implementation are chronically delayed, in large part due to shortcomings in analyzing and establishing operational requirements, Reform is most needed in ATC system development management rather than procurement rules. **If longstanding ATC modernization problems** are to be resolved, research and development of operational requirements and procedures must be strengthened and made into an integral part of FAA's ATC system development process. Box 2-4 presents three critical steps that could be part of an improved ATC system development process,

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, however, OTA heard little 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, and then failed. to have overcome system development and acquisition hurdles a number of times during the past decade. As long as technology development remains the dominant culture in FAA system development programs, however, implementation problems will persist.

Data and Analysis for Aviation R&D 3

"I find it very difficult to make a choice between an aggressive R&D program on aging aircraft, non-destructive testing, terrorism, runway incursions, [or] collision avoidance. I don 't know how one says that one is more important than the other We try to do them all. We try to do them all with what we have to work with."[1]

Resources for aviation research and development (R&D) are limited. Deciding how to allocate these resources among competing areas of interest and obligation is made even more difficult by the lack of assurance that the R&D effort will yield a usable product. Furthermore, tension exists between committing resources to immediate problem solving and longer term problem identification efforts, whether for continuing challenges or emerging issues. There is growing emphasis on understanding the economic effects of technology implementation (through regulatory or infrastructure decisions), given a financially strapped aviation industry that in the best of times only produces razor-thin profit margins. But not all problems or potential solutions can be quantified easily in terms of financial impact, and standard cost-benefit analyses are of limited use in planning R&D.

Criteria for selecting federal research projects include scientific merit (i.e., does it complement or deepen existing knowledge), program or mission relevance, technology-base expansion, balance between large and small, and enhancement of human re-

[1] Joseph Del Balzo, Executive Director for System Development, Federal Aviation Administration, testimony at hearings before the House Committee on Space, Science, and Technology, Subcommittee on Transportation, Aviation, and Materials, Mar. 6, 1990.

sources and education.[2] For civil aviation, many of these criteria are less important than solving pressing operational problems, primarily through targeted R&D efforts. Selecting options for applied R&D resources suggests different criteria: size of problem, feasibility and net cost of solutions, and level of understanding of the problem. Where the last is low, gauging size is difficult, in turn affecting one's ability to develop potential solutions and estimate their benefits; more data and R&D are needed (e.g., on human performance, complex systems, or new materials).

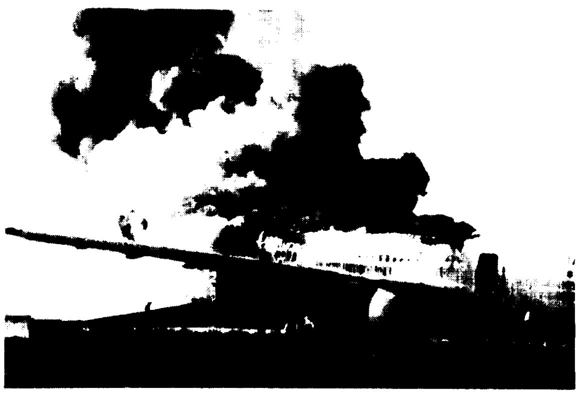
Table 3-1 summarizes the performance objectives for R&D, along with technology options and their limitations, in four areas. This chapter outlines the historical benefits of aviation R&D and provides a framework for analyzing the potential payoff of R&D efforts across as well as within the Federal Aviation Administration (FAA) missions. It also discusses the usefulness of cost-benefit calculations for setting R&D priorities and delineates further data or analyses needs—information to support both continued problem-solving activities and improved problem prediction efforts.

HISTORICAL PAYOFFS OF AVIATION R&D

In examining the potential payoffs of R&D, the Office of Technology Assessment (OTA) first looked to how well-known problems have been addressed or resolved in the past. The key concerns of the aviation community in the 1970s included mid-air collisions, noise and fuel efficiency, and hijacking. By the early 1980s, new issues emerged—safety oversight, traffic improvements, and aircraft bombings—and noise abatement continued to be a concern.

I Safety

Major accident data for Part 121 carriers reveal that safety has improved dramatically over the lifetime of the industry (figure 3-1).[3] The reduced accident rates for Parts 121 and 135 operations, shown in figure 3-2, resulted from repeated introduction of safety technologies and procedures, many based on federal R&D conducted through the years. For fire safety in particular, the federal government spent nearly a decade devising appropriate test scenarios, evaluating safety improvements provided by fire retardant materials, developing test methodologies for materials selection, and initiating rulemaking.[4] In the public's eyes, however, more remains to be done with cabin safety, which requires further study of the basic mechanisms of fire development. Also, because cabin interior materials technology is state-of-the art and because additional fire sources exist (e.g., jet fuel, cargo and luggage, and carry-on items), FAA is looking toward other means of fire



New technologies have helped to improve *aircraft tire safefy and reduce tire-re/ated fatalities, however postcrash, fuel-fed fires remain a threat*

[2] See discussion of prioritization in science in U.S. Congress, Office of Technology Assessment, *Federally Funded Research: Decisions for a Decade, OTA-SET-490* (Washington, DC: U.S. Government Printing Office, May 1991).

[3] A major accident involves fatalities and or substantial aircraft damage. Parts 121 and 135 refer to the major commercial carriers and commuter airlines, respectively.

4 See U.S. Congress, Office of Technology Awes\ merit, "Aircraft Evacuation Testing: Research and Technology Issues," Background Paper, OTA-SET-BP- 121, September 1993.

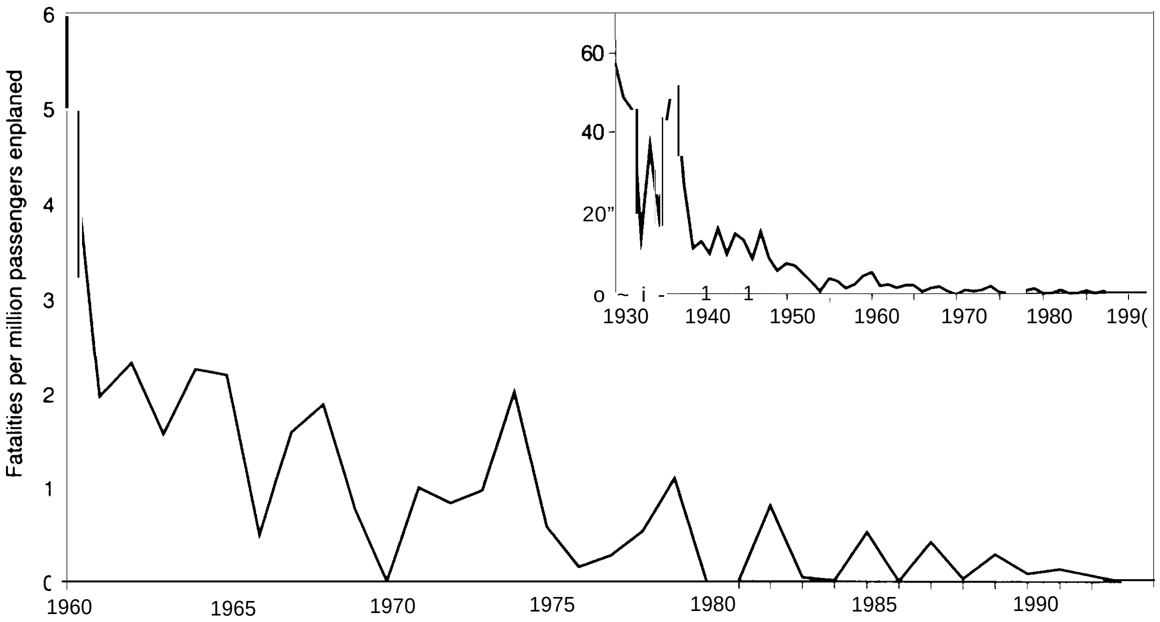
[redacted]

Issue	Potential improvements	Technology options	Limitations
Airspace and airport efficiency	Closer spacing between aircraft and increased aircraft arrival and departure rates at airports without increased risk of collision Augmented airport surface traffic management capabilities, especially in low-visibilty conditions	Enhanced communications, navigation, and surveillance technologies and procedures, including the global navigation satellite system, advanced traffic management tools, wake vortex detection	Technologies are site-speclflc, and for many, complex procedures must be revised or adapted for their use While use of new ATC and weather technologies can reduce airline operating costs and infrastructure expenditures, this technology wiIl meet but a small percentage of projected demand in coming decades Demand management options discounted by industry
	Oceanic separations equivalent to those in domestic airspace	Satellite-based communications, navigation, and surveillance systems, automatic dependent surveillance via datalink	Procedures subject to lengthy validation and International agreement process Initial benefits to airlines small until fleet-wide implementation IS accomplished Ground-based monitoring equipment required before automatic dependent surveillance can begin
	Improved reliability and accuracy of weather forecasts	Advanced weather detection and analysis systems, cockpit display of aviation weather products (e g , Icing at given altitudes or jet stream location)	Human/machine interface must be considered, and Increased amount of information must not overwhelm pilot or controller
	Minimal runway downtime	Enhanced pavement construction and maintenance techniques	Pavement design and evaluation methods require Improvement
	Reduced apron and gate occupancy times	High-speed tugs, advanced docking technologies, automated gate assignment techniques, integrated passenger, baggage, crew, and vehicle information systems	Divisions between airport and airline authority Onerous retrofit costs for communication systems, and terminal and airside access facilities
Safety	Enhanced pilot and controller awareness of aircraft situation in all conditions Reduced personnel fatigue and stress Improved crew communication and coordination improved reliabilty of engines, avionics, and other aircraft systems Reduced fire threat Enhanced structural airworthiness and crashworthiness	Enhanced training methods and facilties Advanced inspection tools and techniques New materials Predictive hazardous weather sensors and severe storm forecasting	Dimmishing returns—fewer lives to be saved even with exhaustive effort Overall risk may be increased by adopting new technologies or procedures
Security	Minimized risk of explosives and other weapons being brought onboard aircraft Enhanced aircraft resilience to explosions Reduced threat to ATC and airports Optimized costs of screening technologies and airport security service costs	Passenger profiling, explosives detection systems, other weapons detectors, aircraft and ATC system hardening human factors analysis	No single technology exists for preventing all acts of terrorism or mayhem Threat cannot be quantified Screening methods are costly and time consuming, and access control and hardening techniques costly
Environment	Minimum community noise exposure maintamed as operations increase Minimized engine emissions and increased fuel efficiency Reduced environmental impact of deicing and fire fighting compounds Improved cabin environment	Additional noise cancel lation and community noise abatement methods, low-emissions combustors, reclamation of glycol-based fluids and replacement with non-glycol deicers, halon conservation and halon-system replacement	Except for improved fuel performance, any economic benefits accrue to society rather than to airlines Scientific understanding lacking in some areas, problem not quantified

KEY ATC = air traffic control

SOURCE Off Ice of Technology Assessment, 1994

FIGURE 3-1: Passenger Fatality Rates for Scheduled U.S. Air Carriers



NOTE Security-related fatalities and suicides are not Included

SOURCE Off Ice of Technology Assessment, 1994, based on Civil Aeronautics Board, Federal Aviation Administration, and National Transportation Safety Board data

suppression to extend survivable conditions within a cabin threatened by in-flight or postcrash fuel fires. (See cabin safety section in chapter 4.)

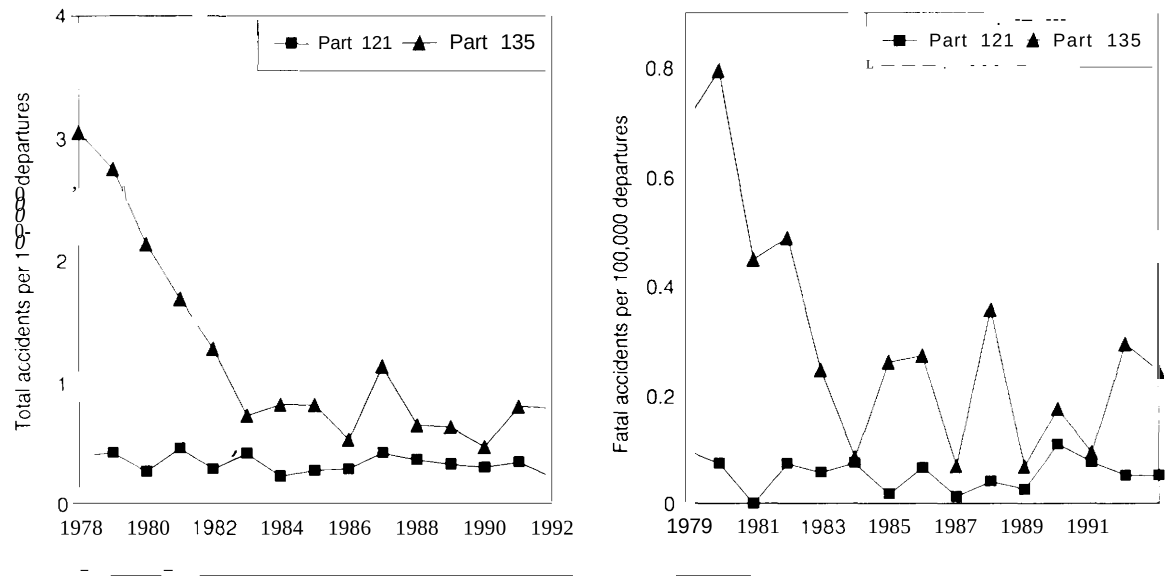
In some cases, a relatively low-technology solution is appropriate once the nature of a problem is known. During the period 1975 to 1985, windshear was a factor in accidents resulting in 50 percent of U.S. accident fatalities. After the phenomenon was widely recognized and better understood, FAA and industry were able to quickly put together a new training program for pilots to increase their awareness of the problem and provide them with better response capability. Although there have been close calls for commercial transports since then, no windshear-related passenger fatalities occurred in the United States after 1985, when the training aid was disseminated.[5]

Environment

The National Aeronautics and Space Administration (NASA) research during the 1960s and 1970s greatly aided fuel conservation efforts by developing highly efficient engines. In 1975, NASA's Aircraft Energy Efficiency (ACEE) program identified turboprops, along with laminar flow, active controls, and composite structures, as areas for

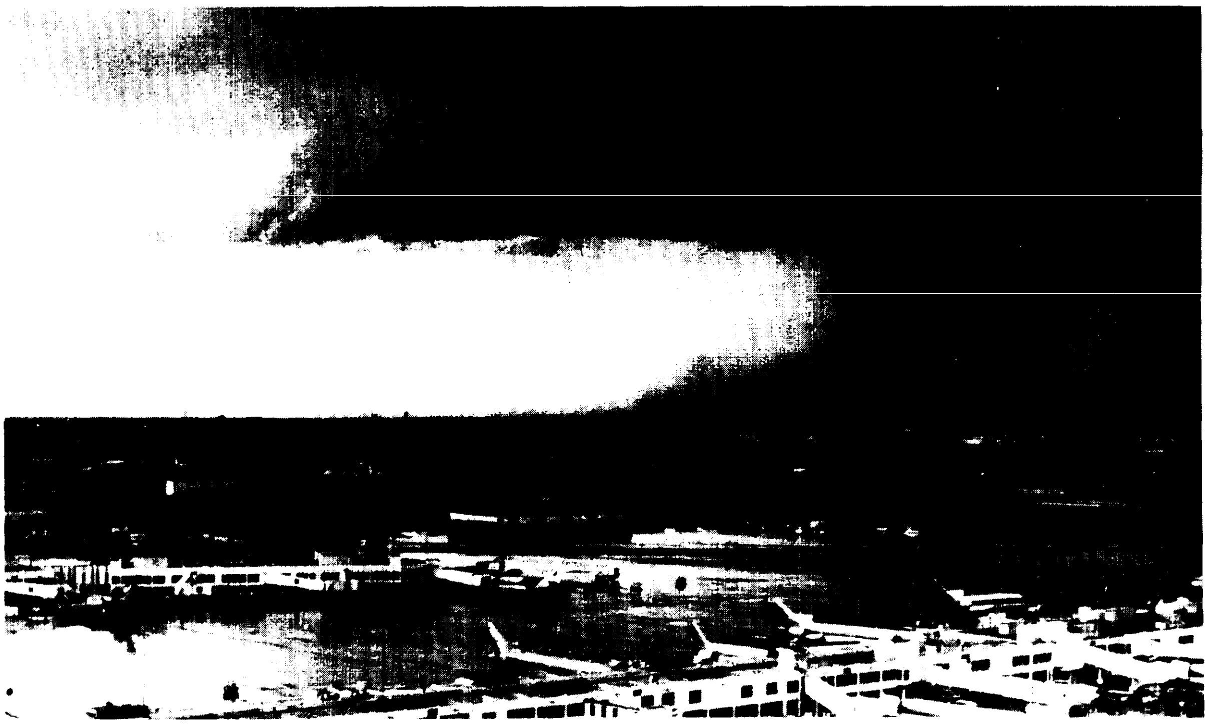
5 AS the understanding of windshear factors and phenomena has increased, new sensors allowing earlier warning of the hazard have become possible (see technology section inch. 4). Windshear may have been a causal factor in the July 1994 USAir crash in Charlotte, NC; determination of the probable cause of the accident will take many months.

FIGURE 3-2: Accident Rates for Scheduled Part 121 and Part 135 Carriers, 1978-92



NOTE Part 121 of the Federal Aviation Regulations is typically associated with the major airlines and Part 135 with commuter aircraft with fewer than 30 seats

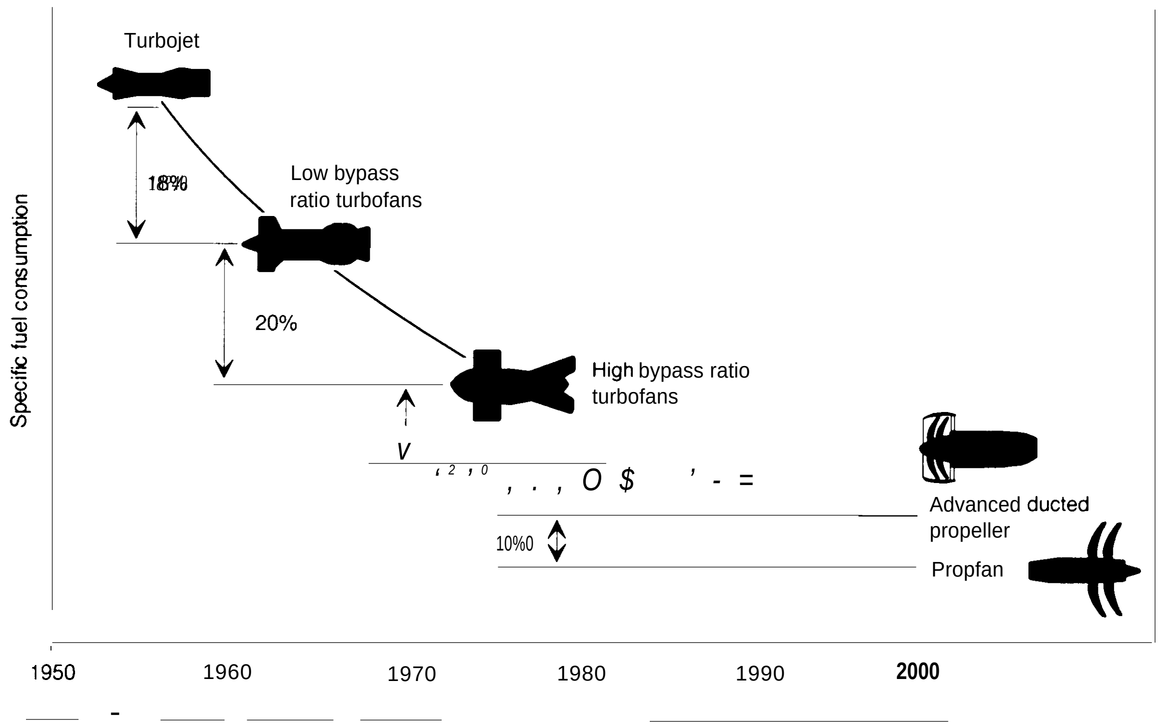
SOURCE Off Ice of Technology Assessment based on 1989 and 1993 National Transportation Safety Board data



NATIONAL CENTER FOR ATMOSPHERIC RESEARCH/NATIONAL SCIENCE FOUNDATION

Visible wlndshear indicators observed near Denver Stapleton Airport

FIGURE 3-3: Fuel Efficiency Trend in Aircraft Engine Design



SOURCE Off Ice of Technology Assessment, 1994, based on 1993 Pratt &Whitney information

major advances in fuel efficiency.[6] The ACEE program included the Engine Component Improvement (ECI) and Energy Efficient Engine (E^3) projects. ECI was designed to develop components to reduce fuel consumption for three engine designs in use at the time. E^3 consisted of long-term research for new engine development; demonstration engines achieved a fuel consumption reduction of 18 percent and an improvement indirect operating costs of 5 to 10 percent, exceeding the project's original goals.[7] The results are illustrated in figure 3-3.

NASA's clean, quiet engine programs also permitted engine manufacturers to reduce emissions of combustion products and noise in response to federal regulatory initiatives. In 1968, Congress authorized FAA to regulate aircraft noise emissions.[8] Under that statutory authority, FAA adopted Part 36 of the Federal Aviation Regulations (FAR) in 1969, prohibiting the further es-

6 John S. Langford 111, The *NASA Experience* in *Aeronautical R&D: Three Case Studies With Analysis*, IDA Report R-319 (Alexandria, VA: Institute for Defense Analyses, March 1989), p. 112.

7 George Eberstadt, "Government Support of the Large Commercial Aircraft Industries of Japan, Europe, and the United States," OTA contractor report, May 1991, pp. 75-76.

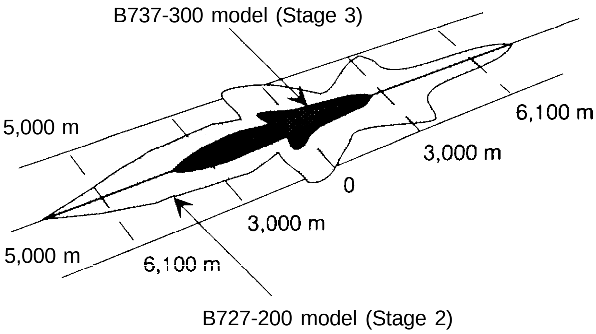
8 Public Law 90-411, 82 Stat. 395 (1968).

calation of aircraft noise levels in subsonic civil turbojet and transport category airplanes and prescribing noise measurement, evaluation, and level requirements for new aircraft types.[9] In 1977, FAA amended Part 36 to provide for three stages of aircraft noise levels. [10]

Through the Aviation Noise and Capacity Act of 1990, Congress directed the elimination of Stage 2 operations by the end of the century. [11] In September 1991, FAA promulgated a final rule amending FAR Part 91 to require the phased transition to all Stage 3 commercial aircraft operations by December31, 1999. The Stage 3 technology provides improvements of as much as 25 decibels over first-generation Stage 1 aircraft models, or over 80-percent reduction in perceived loudness. [13] Figure 3-4 shows one result of a drop in noise output normalized to thrust (i.e., the relative footprints of Boeing 727 and 737 aircraft).

The Environmental Protection Agency (EPA) data indicate the quantity of air pollutant emissions has remained fairly constant over more than two decades despite continued growth in operations (see figure 3-5). However, FAA estimates that hydrocarbon (HC) and carbon monoxide (CO) emissions have dropped 65 to 70 percent since 1984, when emission standards were introduced. [14] This reduction more than offsets increases in total fuel consumption. The disparity in estimates may stem from differences in the agencies' databases and changes in analytic methodologies (see section on Environmental Assessment).

FIGURE 3-4: Relative Noise Footprints for B727 and B737 Aircraft



SOURCE Office of Technology Assessment, 1994 based on William Green et al *Modern Commercial Aircraft* (New York NY Portland House 1987)

EPA regulates only HC emissions: the International Civil Aviation Organization (ICAO) has standards for CO and oxides of nitrogen (NO_x) as well as HC. [15] In the past. emissions from highly efficient engines have easily met the international minimums. Beginning in 1996, however, new engine designs must meet the 20-percent reduced NO_x standard; by 2000, all newly manufactured engines must meet the more stringent standard. [16] In addition, some locations in the United States

[9] Part 36 noise limitations, based on gross weight, are measured at three specific points: under the takeoff path, on the sideline from the extended center] ine of the runway, and under the approach path. At each of these points, the effective perceived noise level takes into account loudness, discrete tones, and noise event duration. FAA developed the standards in concert with the Environmental Protection Agency.

[10] 42 *Federal Register* 12360 (Mar. 3, 1977). Stage I is the noisiest; Stage 3 is the quietest to date.

[11] 45 *Federal Register* 79302 (Nov. 28, 1980).

[12] 56 *Federal Register* 48627 (Sept. 25, 1991). Some exemptions are possible until 2004.

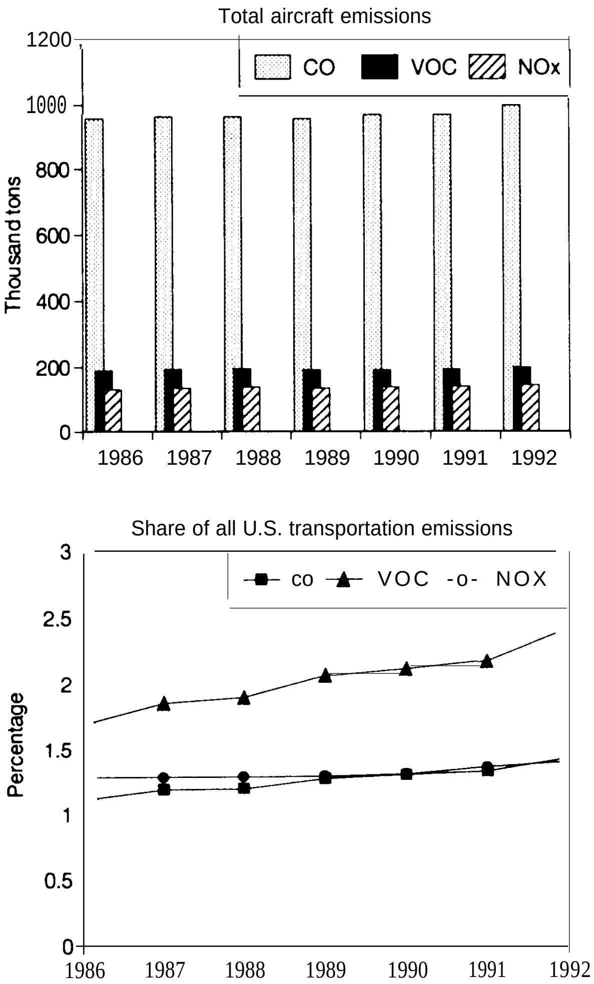
[13] U.S. Department of Transportation, Federal Aviation Administration, "Alternatives Available To Accelerate Commercial Aircraft Fleet Modernization," Report of the Federal Aviation Administration to the Senate and House Appropriations Committees Pursuant (o House Report 99-256 on the Department of Transportation and Related Agencies Appropriation Bill for FY 1986, Apr. 11, 1986, p. 13.

[14] NO_x emissions have remained nearly constant. Nicholas Krull, FAA Office of Environment and Energy, personal communication, Apr. 28, I 994.

[15] Jim Bryson, EPA Office of Mobile Sources, personal communication, Apr. 7, 1994.

[16] Adopted in March 1993. Ibid.

FIGURE 3-5: U.S. Aircraft CO, VOC, and NO_x Emissions, 1988-92



NOTE In the mid-1980s, changes occurred in the methodology for estimating emissions.

KEY: CO= carbon monoxide, VOC = volatile organic compounds (e g , hydrocarbons); NO_x = oxides of nitrogen.

SOURCE Office of Technology Assessment, 1994, based on U S Environmental Protection Agency, *National Air Pollutant Emission Trends, 1990-1992* (Research Triangle Park, NC October 1993)

may require total airport "bubble" emissions to stabilize or even be reduced.[17] Much of this can be accomplished through modifications to ground-assist equipment, reduced taxi/idle time, or the use of high-speed towing equipment, but reduced aircraft engine emissions may also be necessary eventually.[18]

Security

As federal intervention (i.e., increased vigilance and the implementation of improved weapons detection technologies) reduced the hijacking threat, terrorists moved their attention to bombing high-capacity aircraft. The nature of the security problem is such that R&D may yield tools to reduce risk of given types, but a new threat is likely to crop up elsewhere. Defining a security threat as one would the risk of engine failure is not possible—it constantly changes as political winds shift and deterrence efforts force terrorists or criminals to think up new ways of doing harm.

As a result, the federal aviation security R&D effort is evolving toward an integrated system of threat detection and mitigation methods. The scope of the FAA's program has changed dramatically in the 1990s, expanding beyond a concentration in weapons and explosives detection technology test and evaluation to a broader R&D effort-one that includes human factors, hardening aircraft to sabotage, and security system integration.

Capacity and Air Traffic Management

Despite increases in scheduled airline traffic (see figure 3-6), FAA-measured delays[19] on flights through the busiest airports decreased over 40 percent between 1988 and 1992.[20] With the current reporting system, however, FAA is unable to estimate the total amount of delay experienced by airlines and other users of the air traffic control

17 *Bubble* refers to a specific portion of the atmosphere surrounding one or more airports.

18 Bryson, op. Cit., footnote 15.

19 Based on 1993 data from the FAA Office of Air Traffic System Management, NAS Analysis Program, OTA calculated that the number of operations delayed per thousand operations dropped 44 percent.

20 Total operations at airports with FAA-operated air traffic control towers have remained steady in the late 1980s and early 1990s, in large part due to declining general aviation operations.

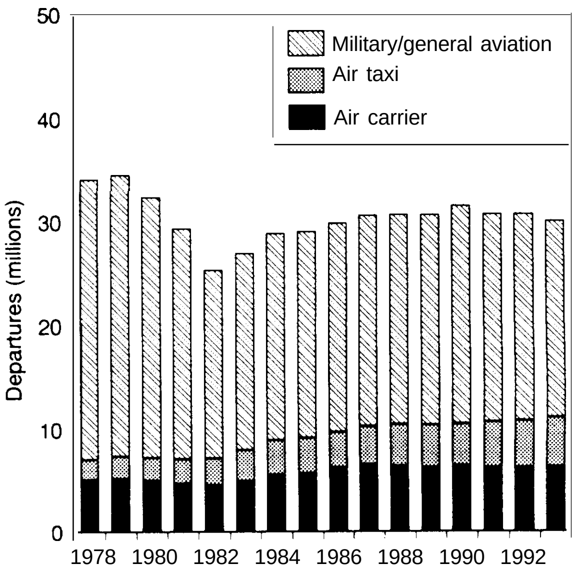
(ATC) system, nor can the agency precisely determine the cause of the delays.[21] Changes in airline scheduling practices in response to the Department of Transportation (DOT) publication of delay data further undermine trend analysis.[22] In short, what is known about delay is limited, and this lack of information affects both the planning and operation of the ATC system.

In addition, the area in which managing and fielding the results of aviation R&D has been most troublesome is capacity and delay. The focus of this R&D effort has been on tools to increase the efficiency of the ATC system in the face of increasing constraints on airport construction or expansion. Despite the availability of innovative technologies, new ATC systems implementation has been stymied from lengthy development cycles and reluctance on the part of controllers to accept some new products (see discussion of implementation issues in chapter 2).

As a result, the process of controlling (i.e., maintaining separation between) aircraft has changed little in decades, perpetuating costly inefficiencies. With the current ground-based surveillance system, aircraft fly from ATC sector to sector at select altitudes; route optimization for fuel consumption and minimum time is rarely facilitated. Over the oceans, beyond the range of radar surveillance, separations between aircraft are even greater and user-preferred routing nearly impossible to obtain.

The flight management capabilities of new aircraft greatly surpass those of ground infrastructure, which cannot support their use.[23] Some ATC automation has been introduced to help maximize the arrival and departure rates at airports, but no data have been assembled to assess any changes in

FIGURE 3-6: U.S. Air Traffic Activity, FY 1978-93



NOTE Departures calculated from operations at airports with FAA-operated control towers

SOURCE Off Ice of Technology Assessment, 1994, based on datafrom the FAA Off Ice of Aviation Policy, Plans, and Management Analysis

performance.[24] Airspace and airfield capacity remains open to enhancement through new management methods and supporting technologies. Essential to the latter's development are models of the National Airspace System (NAS) and its major elements (see later section on Delay and Air Traffic Analysis). In addition, reliable, timely weather data are required, along with effective means of disseminating this and other information. Many of the advances proposed for the ATC system hinge on this capability.

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[21] FAA delay data reflect only delays of 15 minutes or more in any flight segment (i.e., takeoff, en route, or arrival) experienced by aircraft under FAA control. This reporting method precludes identification of all delays in system (see data and analysis section).

[22] John J. Fearnsides, General Manager and Senior Vice President, The Mitre Corp., personal communication, Apr. 19, 1994.

[23] For example the automated flight management systems onboard aircraft permit "four-dimensional" flight planning, but this advanced programming of aircraft position at a given time does not mesh with FAA's arrival queuing methods.

[24] See U.S. Congress, General Accounting Office, *Air Traffic Control: Justifications for Capital Investments Need Strengthening GAO/* RCED-93-55 (Washington, DC: U.S. Government Printing Office, January 1993), pp. 9-1 I.

TABLE 3-2: Major U.S. Aviation Database

Safety				
Accidents	Accident Investigation database	NTSB accident database	Manufacturers	
Incidents	Near mid-air collisions	Pilot deviations	Operational errors	Runway incursions
Inspection	Service Difficulty Reporting System (SDRS)	Safety Performance Analysis System (SPAS)	Program Tracking and Reporting Subsystem (PTRS)	
Other	NASA Aviation Safety Reporting System	System Indicators Program	RSPA database	DOD Air Carrier Analysis System
Capacity and air traffic management				
Delay	Air Traffic Operations Management System (ATOMS)[a]	DOT Airline Service Quality Performance (ASQP)	Consolidated Operations and Delay Analysis System (CODAS)	
Capacity mode/s	SIMMOD (trademark name for airport and airspace simulation model)	National Airspace System Performance Analysis Capability (NASPAC)		
Pavement wear	National Airport Pavement Registration and Demonstration Program			
Environment				
Noise	**National** Noise Impact Model (NANIM)	Integrated Noise Model (INM)		
Emissions/air quality	Aircraft Engine Emissions Database (FAEED)	FAA/USAF Emissions and Dispersion Model (EDM)	EPA emissions inventories	

[a] ATOMS stores flight and delay data retrieved from the Operational Performance System Network (OPSNET)

KEY NTSB = National Transportation Safety Board, RSPA = DOT's Research and Special Programs Administration; USAF = U S Air Force

NOTE All databases or sources belong to FAA unless otherwise noted

SOURCE Off Ice of Technology Assessment, 1994

WEIGHING CURRENT ISSUES

This section relies on operational federal aviation databases, summarized in table 3-2, to illustrate what is known about the areas of greatest risk, least efficiency, or highest cost for the air transportation system. A more detailed discussion of the databases and analytical tools follows later in this chapter.

Safety and Security

The aggregate accident data show safety has improved dramatically since the introduction of commercial airlines (see figure 3-1, again). However, there are varying levels of safety (i.e., numbers of accidents and fatalities) for air carrier and general aviation operations (see table 3-3). For example, while the general aviation fatal accident rate declined almost 25 percent between 1982 and 1992, the rate and total number of fatalities remain high compared with the other aviation categories. Part 121 aircraft, while having the fewest accidents, on average experience the second largest number of fatalities. Aircraft operations data reveal that large commercial jets carry about 94 percent of all passengers and account for about 99 percent of passenger-miles.[25] Reducing the risk Of

25 Data for scheduled Part 121 earners. U.S. Department of Transportation, Federal Aviation Administration, *FAA Statistical Handbook of Aviation* (Washington, DC: 1991), p. 5-15.

TABLE 3-3: U.S. Aviation Accidents and Fatalities by Industry Segment, 1978-93[a]

	Major airlines	Commuter	Air taxi	General aviation[b]
Total accidents	**387**	**428**	**2,026**	**45,320**
Fatal accidents	69	108	497	8,329
Total fatalities	1,948	558	1,199	16,048

~ 1993 data preliminary
b) US .*registered* civil aircraft not operated under 14 CFR 121 or 14 CFR 135

SOURCE Off Ice of Technology Assessment, based on January 1989 and January 1994 National Transportation Safety Board data

fatalities aboard large air transports therefore minimizes the safety threat for the greatest share of the traveling public.

Relative to other transportation modes, however. aviation is an extremely safe industry. In 1992, highway-related deaths accounted for 94 percent of all transportation fatalities. Aviation fatalities numbered 1,103, or less than 3 percent of the total. General aviation and airlines experienced 874 and 33 fatalities, respectively.[26]

A small number of air carrier accidents are not survivable due to the extreme forces of impact.[27] Fatality rates in the remainder can potentially be reduced through implementation of advanced fire safety and crashworthiness technologies. Thus, a two-pronged safety effort is required: 1) preventing or reducing the chance an accident will occur in the first place, and 2) mitigating the effects. In order to derive possible solutions through operational and/or technology solutions, the primary and contributing causes of the accidents must be identified. The National Transportation Safety Board (NTSB) has primary responsibility for this ongoing effort.

Overall, the federal R&D programs directed at air transportation problems have had mixed success—the best results were obtained in areas where the problem was well characterized and the objectives clearly defined. Successful safety examples include reductions in the fire-related death rate among cabin occupants, mid-air collisions, and controlled flight into terrain. In addition, noise, engine emissions, and fuel consumption were reduced at the same time engines became more powerful and reliable.

OTA reviewed NTSB Part 121 accident briefs for the years 1985 through 1992 and found that human error (i.e., by pilots and other personnel) was an initiating factor in nearly 60 percent of total accidents.[28] Aircraft or component failure was the second-most frequent initiating factor; hazardous weather and other miscellaneous factors precipitated the remainder of the accidents evaluated (see table 3-4). A review of NTSB broad cause/factor assignments for all Part 121 accidents from 1975 through 1989 showed that rates for accidents related to aircraft malfunction or failure were nearly constant during this period: OTA noted several of

[26] National Transportation Safety Board, "Transportation Deaths Drop 4.9 Percent in 1992," SB 93-16, press release, July 1, 1993. Also see U.S. Congress, General Accounting Office, "Transportation Safety: Opportunities for Enhancing Safety Across Modes," testimony at hearings before the House Committee on Public Works and Transportation, Subcommittee on investigation and Oversight, Feb. 10, 1994.

[27] Gellman Research Associates, Inc., "Benefit Estimates of the FAA's Aircraft Safety Research Program: 1992-2001 ," prepared for the Federal Aviation Administration, July 10, 1992. Gellman figures for years 1964 to 1988 showed that 12 of 624 accidents (2 percent) were non-survivable.

[28] For this review, OTA identified the two most significant sequential causal events for each accident. Initiating causal factor is not the same as first occurrence; e.g., a passenger's refusal to obey seat belt signs after the likelihood of severe turbulence was announced-not the presence of weather-related turbulence—would be the initiating factor should he or she be injured in a subsequent bounce. Weather would be included in a tally of all causal factors.

TABLE 3-4: Part 121 Total Accidents, 1985-92

	Scheduled passenger	Scheduled cargo	Nonscheduled passenger	Nonscheduled cargo	Total	Total[a] (by percent)
Initiating causal factor						
Pilot	45	16	1	5	67	41%
ATC personnel	5	0	0	0	5	3
Other personnel	19	1	0	2	22	14
Weather	27	0	0	0	27	17
Aircraft/component	30	3	1	4	38	23
Miscellaneous[b]	4	0	0	0	4	3
All causal factors						
Pilot	52	16	1	8	77	47
ATC personnel	10	2	0	0	12	7
Other personnel	24	3	1	2	30	18
Weather	53	4	0	2	59	36
Aircraft/component	31	3	1	6	41	25
Miscellaneous	4	0	0	0	4	3
Total accidents	130	20	2	11	163	

a Sum of percentages of initiating causal factors do not total 100 percent due to rounding For all causal factors, numbers do not total 100 percent because most accidents revolve multiple causes

b Miscellaneous Comprised of two birdstrikes, one unauthorized evacuation, and runway collision with pedestrian

NOTE Part 121 refers to airline operations using aircraft having 30 or more seats or payload capacity greater than 7,500 pounds The category does not Include air taxis or general aviation, nor typically commuter airlines Accidents involving sabotage or non-operational events are not included

SOURCE Off Ice of Technology Assessment, 1994, based on National Transportation Safety Board data

these were linked to human error or poor management policies.[29] The data also showed a drop in weather-related causal rates (see figure 3-7).

Fire occurred in 37 of these accidents (28 percent). Of the four fires that occurred in flight, only one, an engine fire, was the initiating cause of the accident; none developed in the cabin. In 41 of the 130 accidents. weather-related or clear air turbulence was a factor: one fatal and 57 serious injuries to passengers and crew occurred but, typically, little or no aircraft damage.[30] In a dozen cases, serious injuries occurred during precautionary evacuations.

Over this same eight-year period, a total Of 33 fatal accidents occurred involving U.S. cargo and passenger carriers.[31] Table 3-5 shows the breakdown of initiating and all significant causal factors for the 31 accidents for which NTSB had provided accident briefs.

Despite the high number of fatalities (148) associated with two recent controlled flight into terrain (CFIT) accidents,[32] fatal accidents caused

[29] Examples of the latter include inadequate surveillance of operations by FAA and the failure of operators or companies to follow maintenance and inspection guidance.

[30] OTA found that human error, on the part of pilots, flight attendants, or passengers, was the initiating factor in almost 40 percent of the accidents involving turbulence. The one fatality, in 1990, stemmed from a combination of errors: the pilot flew through the overhang of a thunderstorm, contrary to company procedures; the flight attendants failed to enforce the seat belt instructions; and the passenger did not comply with the instructions.

[31] Included in this total are two accidents for which NTSB did not determine probable cause. Both accidents, involving controlled flight into terrain, occurred outside the United States; NTSB was not required to participate in the investigation. Not included were four security incidents that resulted in fatalities.

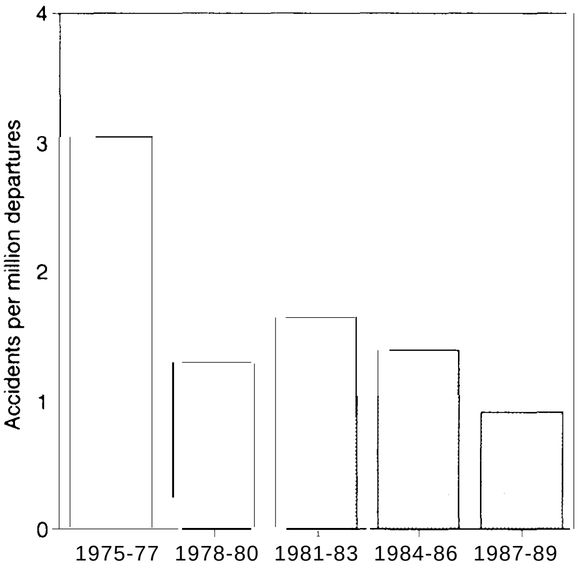
[32] Both accidents occurred in February 1989. The first, involving a charter passenger flight, took place in the Azores, Portugal. The second CFIT-related accident occurred in Kuala Lumpur, Malaysia, during a scheduled cargo flight.

by CFIT have decreased significantly since ground proximity warning systems were introduced onto large U.S. carriers in the mid-1970s. Based on this success, commuter aircraft are to be equipped by April 1994.[33] A recurring problem has been that some pilots, annoyed by prior false alarms, have turned off or ignored the system. Investigators suspect that this occurred in one of the most recent accidents.[34] Latest generation warning equipment presents far less of a false alarm problem, but proper pilot training is still required.

Loss of control related to aircraft malfunction or weather has been the primary factor in other accidents with high fatalities. Also, while runway incursions and collisions on the airport surface typically effect little damage or injury, the potential for catastrophic loss of life remains—recall the Tenerife collision and the 1991 accident at the Los Angeles International Airport involving an air transport and commuter aircraft. One of the most frightening images of aviation accidents is the mid-air collision. The last mid-air collision involving a large civil air transport over the United States occurred in 1986.[35]

The threat of an aircraft and its contents being quickly consumed by fire is equally horrifying. OTA estimates that approximately 13 percent of total fatalities in accidents involving U.S. commercial carriers during this period were due to fire.[36] This is down from earlier FAA estimates, using data from the 1960s through the 1970s, indicating that 15 to 20 percent of total fatalities was due to fire.[37] At about that same time, FAA estimated that 40 percent of fatal i ties in survivable accidents (e.g., where the fatalities from an accident in which no one could survive the forces of

FIGURE 3-7: Trend in Part 121 Accidents With Weather as a Factor, 1975-89



NOTE 1989 data were the last analyzed by the National Transportation Safety Board as of 1993

SOURCE Off Ice of Technology Assessment, 1994, based on National Transportation Safety Board data

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[33] 57 *Federal Register* 9951 (Mar. 20, 1992).

[34] Don Nelson Senior Engineer, Boeing Airplane Safety, personal Communication, Nov. 1, 1993. Worldwide, not all aircraft have been equipped with ground proximity warning systems. ICAO reports that 638 people were killed in 1992 in 26 CFIT accidents, which include two crashes of A irbus aircraft at Katmandu, Nepal. "Brief s," *Traffic World,* Jan. 4, 1993, p. 23.

[35] The accident involved the coll ision of an Aeromexico aircraft and a general aviation aircraft; the coll if ion took place over Cerritos, California. There have been several mid-air collisions involving commuter aircraft, but the last one involv ing a major scheduled U.S. carrienn U.S. airspace happened in 1978 over San Diego (Pacific Southwest Airlines). Wanda Glenn, National Transportation Safety Board, personal communication, July 29, 1994.

[36] The General Accounting Office cited 140 fire-related fatalities for the period 1985 through 199 1; in 1992, none of the 31 fatalities was caused by fire or its effects. Total fatalities for the period 1985 through 1992, excluding deaths due to criminal or terrorist acts, numbered 1,049. National Transportation Safety Board, press release, Jan. 15, 1993; and U.S. Congress, General Accounting Office, *Aviation Safety: Slow Progress in Making Aircraft Cabin Interiors Fireproof,* GAO,' RCED-93-37 (Washington. DC: U.S. Government Printing Office, January 1993), p. 11.

[37] Constantine Sarkos, Manager, Fire Safety Branch, FAA Technical Center, personal communication, May 11, 1994.

TABLE 3-5: Part 121 Fatal Accidents, 1985-92

	Scheduled passenger	Scheduled cargo	Nonscheduled passenger	Nonscheduled cargo	Total	Total[a] (by percent)
Initiating causal factor						
Pilot	10	5	1	3	19	61 %
ATC personnel	2	0	0	0	2	7
Other personnel	2	1	0	0	3	10
Weather	1	0	0	0	1	3
Aircraft/component	4	1	0	0	5	16
Miscellaneous[b]	1	0	0	0	1	3
All causal factors						
Pilot	11	5	1	3	20	65
ATC personnel	4	0	0	0	4	13
Other personnel	10	1	1	0	12	39
Weather	5	1	0	1	7	23
Aircraft/component	4	1	0	0	5	16
Miscellaneous	1	0	0	0	1	3
Total accidents	20	7	1	3	31	

a Sum of percentages of initiating causal factors may not total 100 percent due to rounding For all causal factors, numbers do not total 100 Percent because most accidents revolve multiple causes

b Miscellaneous comprised of runway collision with Pedestrian

NOTE Part 121 refers to airline operations using aircraft having 30 or more seats or payload capacity greater than 7,500 pounds. The category does not include air taxis or general aviation, nor typically commuter airlines Accidents involving sabotage or non-operational events are not Included

SOURCE Office of Technology Assessment, 1994, based on National Transportation Safety Board data

impact are excluded) were fire-related.[38] Neither FAA nor NTSB has more recently published data on this percentage.

In addition to the hazard of accidental injury, fatality, or damage to aircraft, the possibility of intentional harm requires FAA and the industry to preclude the introduction of weapons or explosives aboard aircraft.[39] Figure 3-8 shows the escalation in terrorist threat to aircraft since the 1950s. Although the hijacking threat diminished in the 1980s, high-capacity aircraft became a favorite target of terrorist bombs, expanding the death toll and galvanizing public attention to the problem of aviation security (see box 3-1). Worldwide, the number of persons killed by bombings in general between 1980 and 1989 was approximately 1 ,020.[40]

Three catastrophic acts of sabotage involving U.S. airlines have occurred since the early 1970s. The estimated cost of the 1988 Pan Am bombing ranges between $411 million and $520 million.[41] According to FAA, the estimated direct cost of another such incident is $600 million—$150 million for the wide-body aircraft and $450 million for passenger lives.[42]

As access control and screening measures become more stringent, the threat of large amounts of common explosives being placed aboard air-

38 Ibid.

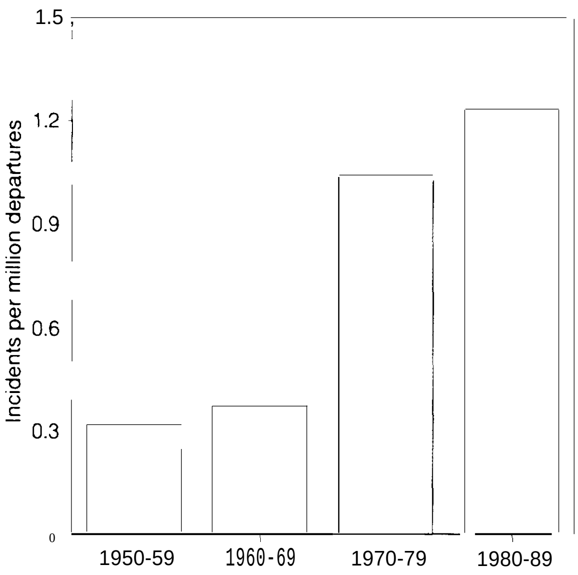
39 Hostage-taking, aircraft Piracy and hijacking, sabotage, and indiscriminate bombings and shootings are examples of the many risks.

40 Stefanie Stauffer, Manager, Strategic Intelligence Division, FAA Office of Aviation Security Intelligence, personal communication, May 29, 1994.

41 54 *Federal Register* 28987 (July 10, 1989).

42 see U.S. Department of Transportation, Federal Aviation Administration, *The 1993 Federal Aviation Administration Plan for Research, Engineering and Development* (Washington, DC: February 1994), p. 7-1.

FIGURE 3-8: International Aircraft Security Incidents



SOURCE Off Ice of Technology Assessment 1994 based on 1993 FAA data

BOX 3-1: Recent Significant Terrorist Incidents in Aviation

1982 Mid-air explosion on a Pan Am jet bound for Hawaii from Tokyo, killng a Japanese boy and injuring 15 other passengers

1985 Hijacking of TWA Flight 847 by Shi'ite terrorists, lasting 17 days, with the torture and klll-ing of a U S Navy diver

1986 Hijacking of Pan Am Flight 73 in Karachi, killing two U S citizens Bombing of TWA Flight 840 en route from Rome to Athens, killing four Americans

1988 Destruction of Pan Am Flight 103 over Lockerbie, Scotland, by an onboard explosive device, killing 271 people in the aircraft and on the ground

NOTE In 1987 a Catastrophic nonterrorist security incident occurred a recently dismissed Pacific Southwest Airlines (PSA) employee boarded a PSA flight and, en route shot the pilot and copilot The plane crashed as a result killing all 43 passengers and crew aboard

SOURCE U S Congress Off Ice of Technology Assessment *Technology Against Terror/sin Structuring Security* OTA-ISC-51 1 (Washington DC U S Government Printing Off Ice, January 1992) pp 24-25

craft or in airports is reduced. However, new types of explosives may be introduced that can more easily elude detection: in addition, another type of risk has arisen—more than 100 countries possess some version of shoulder-launched heat-seeking missiles.[43]

Comparing R&D Funding to Risk

Table 3-6 shows the categories of accident types or factors and the applicable FAA R&D program area, along with the percentage of fatal accidents, fatalities, and program funding. For the period 1985 to 1992, the two most prevalent factors in fatal airline accidents were human error and fire: security was third.

When fatalities are considered, however, another ranking emerges. While human error was again predominant, comparable percentages of fatalities were attributed to security incidents and factors FAA includes in its Flight Safety R&D program area (i.e., ground icing, encounters with hazardous weather, and CFIT). The smallest share of fatalities was related to structural failures.

As shown in table 3-6, the greatest share of FAA's safety-related Research, Engineering and Development (RE&D) budget in fiscal year 1994 (33 percent) is directed at security. Nearly 21 percent of the 1994 RE&D budget is directed at aging aircraft, although the risk of fatality is minimal compared with that associated with human error, which receives 25 percent. These figures indicate that funding does not correlate with such measures of the safety problem.

[43] Philip J Klass, "Hardened Containers Under Development," *Aviation Week & Space Technology*, Nov. 23, 1993, pp. 90-91. Also see Marvin B. Schaffer, "Concerns About Terrorists With Manportable SAMS," RAND P-7833, paper prepared for the Transport Aircraft Survivability Symposium and Exhibition Session on "New and/or Unique Threat Challenges," St. Louis, MO, Oct. 12-21, 1993.

TABLE 3-6: Comparison of Fatal Accidents and Related FAA Safety R&D Expenditures

Accident factor	Percent of fatal accidents	Percent of fatalities	FAA RE&D Program	Percent of total budget[b]
Security	11%	28%	Systems Security	33%
Human factors[c,d]	75	60	Human Factors and Aviation Medicine	25
Structural				
Aging aircraft	3	<1	Aging Aircraft	21
Other airframe failure or malfunction	6	<1	Crashworthiness/Structural Airworthiness	4
Subtotal	9	1		25
Engine or fuel system				
Propulsion and fuel system reliability	3	3	Propulsion and Fuel Systems	3
Catastrophic engine failure	3	10	Catastrophic Failure Prevention	3
Subtotal.	6	12		5
Flight safety hazards				
Icing, snow	11	5	Flight Safety/Atmospheric Hazards and Weather	5
Other weather	8	14		
Controlled flight into terrain	6	13		
Subtotal.	25	32		5
Fire[d,e] -			Aircraft Systems Fire Safety	5
In-flight fire	3	0		
On-ground fire	47	12		
Surface collisions	14	4	Airport Safety Technology	3

a percent of 36 fatal accidents and sabotage events for Part 121 aircraft from 1985 to 1992 (excludes 1990 collision with pedestrian on runwaY) Total fatalities were 1,146
b Total FAA safety/security R&D funds requested for fiscal year 1994 were $109 2 million
c Loss of control or use of Improper procedures—not including controlled flight Into terrain
d Some accidents counted twice
e National Transportation Safety Board, press release, Jan 15, 1993, and U S Congress, General Accounting Office, *Aviation Safety Slow Progress in Making Aircraft Cabin Interiors Fireproof*, GAO/RCED-93-37 (Washington, DC U S Government Printing Off Ice, January 1993)

NOTE Percentages may not add due to rounding

SOURCE Office of Technology Assessment, 1994, based on Boeing and National Transportation Safety Board data

However, safety and security R&D budget allocations cannot be decided based on U.S. fatality or fatal accident rates alone. Major accidents involving non-U.S. carriers help to focus FAA's attention, as does security intelligence. In addition, economic and other factors contribute to the potential escalation of some hazards.

In 1990, roughly 46 percent of the U.S. commercial air transport fleet was over 15 years old, and 26 percent was over 20 years old.[44] The number of aircraft with more than 20 years of service life is expected to double by 2000; given this, it is possible that the aging aircraft problem will become more significant. Similarly, although the number of deaths related to terrorism and criminal acts averages less than accidental fatalities, security threats could be expected to increase greatly in the absence of a visible, active deterrence effort (which includes R&D to derive methods to minimize the risk). Of course, another problematic task is deciding the level of investment for security program elements, for example, explosives detection, aircraft hardening, or passenger profiling.

44 National Aeronautics and Space Administration, Office of Aeronautics, "Advanced Subsonic Technology Program: Program Summary," February 1994, p. 8.

Besides the possibility of risk escalation, other factors to consider are:

- existing operational or technological options, even if economically unfavorable:
- secondary effects of possible solutions on other problems; and
- timing of realized benefits, improvements, and the longevity of solution.

Existing Options

Often, several options exist to address current problems, even though some may be uneconomical. Fatal icing-related airline accidents in 1982, 1987, and again in March 1992 spurred the development of new ground deicing procedures, including wider use of a longer lasting anti-icing fluid. However, rather than the lack of deicing technologies, pressure to keep to schedules and perhaps some pilot hubris were the primary factors in takeoff accidents; closer scrutiny of the aircraft's control surfaces and application (or reapplication) of existing deicing fluids was needed.

Options for reducing the risk of structural fatigue-related accidents include improved maintenance oversight, less time-consuming and more effective inspection technologies, and design changes. Enhanced scientific understanding of aging aircraft phenomena is a prerequisite. Other examples of accident prevention options include more thorough visual screening of passengers and baggage, and holding aircraft on the ground in bad weather. Each would exact huge costs.

Detecting and predicting hazardous weather are benefiting from steady, if relatively little, R&D attention and a recent confluence of improved communications and display technologies and advanced sensor and analysis tools. As a result, enhanced situation awareness for pilots and improved air traffic management capabilities are feasible; OTA notes this is one area where additional dollars might accelerate benefits across several missions (e.g.. the savings resulting from reduced delay, increased safety, and reduced flight times, fuel use, and engine emissions).[45] The capacity implications and weather R&D and paucity of long-term weather research are discussed further below.

On the other hand, steady attention to the role of human factors in causing accidents has not reduced its prevalence. Its constancy suggests there is no "silver bullet" solution to the multidimensional human factors problem in aviation. Another suggestion is that automation introduced to relieve workload has only shifted problems from one phase of activity to another. Quantitative evaluation methods are needed; therefore, further R&D on human performance issues in the aircraft, the control tower, and on the ground will be required.

Much of FAA accident mitigation R&D focuses on improving fire safety. Developing titanium hulls, for example. is a feasible but inordinatey expensive method of reducing the hazard of burn-through during postcrash fires. Despite the relatively few number of fatalities caused by fire in recent years, if further improving fire safety is desired, additional R&D will be required to devise ways of speeding safe evacuation from aircraft cabins or better detecting and suppressing fire development. For example, if ultra-fire-resistant materials alone are expected to *increase* cabin survivability times, then more research into the mechanisms of fire development is needed (see chapter 4). Changing passenger demographics suggest further fireproofing of the cabin and fuselage would be more beneficial than attempting to increase average evacuation rate. The mean time required for leaving one's seat, moving down an aisle, and exiting through emergency doors tends to be greater for older passengers; the continued aging of the flying public, along with increased flights by persons with disabilities, make it un-

[45] OTA also notes the possibility of technology spinoff for avoiding clear air turbulence and the seemingly intractable wake vortex-related problem of safely reducing separations between aircraft.

likely that overall evacuation times can be reduced without radical (and costly) changes to cabin configurations.[46]

Secondary Effects

Because considerable progress has already been made toward achieving an extremely safe aviation system, any technological or procedural "improvement" may also have unintended, negative side-effects. Examples include the overall effect on pilot workload from the introduction of automation in the cockpit and the wide variety of complex avionics with which mechanics must familiarize themselves.

"Risk/risk" analyses of technology or regulatory decisions are increasingly valuable for illuminating the interactive effects of changes to the system. The results are sometimes controversial, especially when they prevent a safety initiative. For example, FAA concluded in the late 1980s that using portable breathing equipment (PBE) in transport aircraft emergencies could result in more deaths, rather than fewer, and support for mandating passenger PBE onboard commercial aircraft diminished.[47]

Timing of Costs and Realized Benefits

Another factor to be weighed in selecting areas of applied R&D is the length of time required to realize benefits from development efforts (just as the impact of attempting to accelerate implementation of new designs or components must be considered in imposing regulatory requirements). For example, should new materials be developed to augment an aircraft hull's resistance to explosion or fire, the costs of retrofitting entire fleets preclude their immediate introduction. While effective near-term enhancement to cabin safety is possible with speedier installation of new seat designs and interior materials technology, the costs are substantial and, when compared with the economic value of lives saved, the effort is not cost-effective.[48]

Over the long term, though, there are many potential safety and security enhancements that could be attained for new generations of aircraft and the future air traffic management system. These include enhanced situation awareness, improved selection and training methods for airline and FAA personnel, aviation weather "nowcasts," fire-proofed cabins, and airframes hardened against explosives of minimal strengths (all described in the subsequent chapter on crosscutting research and innovative technologies).

Capacity and Traffic Management

FAA's delay data show that, while the number and cumulative amount of delays have decreased in previous years, congestion remains a problem at many major airports. Using 20,000 hours of annual aircraft delay as the indicator of congestion, FAA identified 23 airports as congested in 1991.[49] FAA data indicated that approximately one-third of delays resulted from peak demands that exceeded the capacity of ATC and runways.[50] Bad weather was a factor in approximately two-thirds

46 See Office of Technology Assessment, op. cit., footnote 4, ch. 2; and J.G. Blethrow et al., Civil Aeromedical Institute, *The Emergency Escape of Handicapped Air Travelers, FAA-AM-77- 11* (Washington, DC: Federal Aviation Administration, July 1977).

47 FAA found that, while devices such as smokehoods would reduce passenger incapacitation from toxic fumes during a fire, *donning the* hoods would lengthen the time it takes to evacuate the aircraft, the most critical factor in postcrash survivability. See E.A. Higgins, *Summary Report the History and Events Per* (Washington, DC: U.S. Department of Transportation, Federal Aviation Administration, June 1987); and Garnet A. McLean et al., *The Effects of Wearing Passenger Protective Breathing Equipment on Evacuation Time Through Type III and Type IV Emergency Aircraft Exits in Clear Air and Smoke,* Final Report, DOT/ FA.4 AM-89/ 12 (Washington, DC: U.S. Department of Transportation, November 1989).

48 See General Accounting Office, op. cit., footnote 36.

49 Frank Soloninka Office of System Capacity and Requirements, Federal Aviation Administration, personal communication, 'ay 19, 1993.

50 U S Department of Transportation, Federal Aviation Administration, *1993 Aviation System Capacity Plan*, DOT/ FAA/ASC-93-] (Washington, DC: 1993), p. I -15.

of reported delays—largely because corresponding instrument flight rules, although in effect less than 10 percent of the time, require greater separation between aircraft in controlled airspace. This contrasts greatly with the situation in Europe, where ATC and airports account for nearly two-thirds of delay and bad weather for much less than one-third.[51]

Other measures of capacity (i.e., airspace efficiency and flexibility) include traffic volume and rate and deviations from preferred routes, and the resulting extra fuel and maintenance penalty. In general, airlines desire routes optimized for distance and favorable winds in order to reduce crew time and maintenance costs and to minimize fuel consumption. The current ATC system rarely can accommodate user-preferred routes. In addition, there is a fuel bum penalty for flying extra distances around storms; more accurate weather data could be used to optimize paths.

For air carriers, the impact of insufficient airport or en route capacity is measured in additional operating costs, including extra fuel required by inefficient routing, and passenger time due to delays. According to the Air Transport Association, member airlines are losing $3.5 billion per year because of ATC system limitations.[52]

Because of political and economic factors, it is increasingly difficult to derive additional system capacity from new airport construction or expansion. New technology is expected to provide a small fraction of the capacity needed to meet projected demand in coming years (see figure 3-9); other alternatives will be essential to making up some of the shortfall.[53] However, measurable, near-term improvements are achievable.

Long spacings between alrcraft on approach and takeoff, designed to mitigate the hazard posed by wingtip vortices, exacerbate capacity constraints m the terminal area

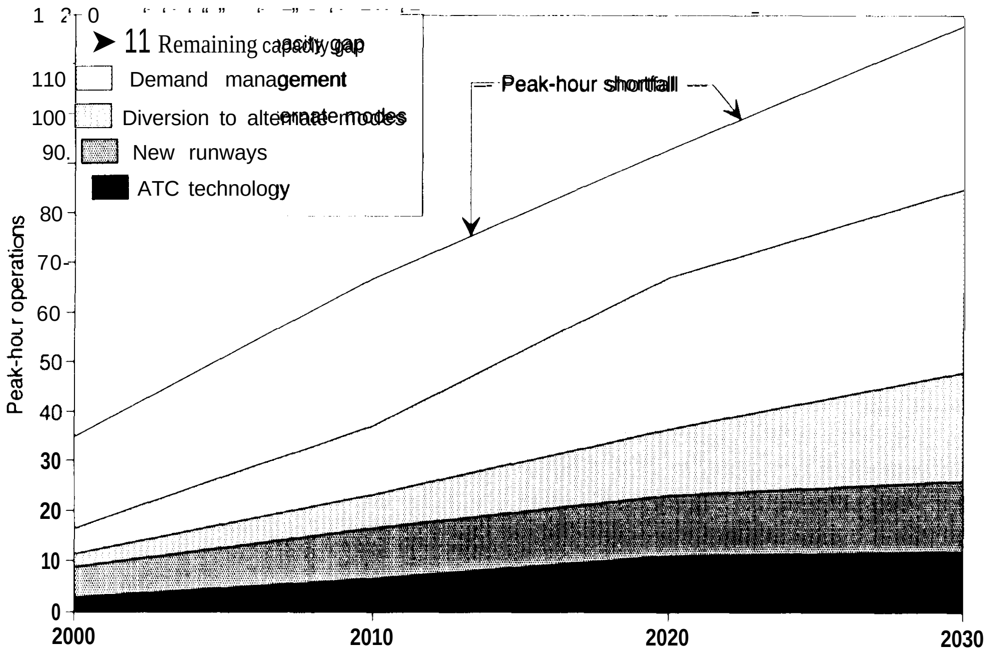
Innovative technology will permit reduced longitudinal separation standards and spacing between aircraft approaching multiple runways, key sources of additional capacity (see table 3-7). Models of the National Airspace System. including new simulation capabilities, help FAA to evaluate the interaction of new air traffic management procedures and their net effect on system performance. The performance of these systems depends greatly on aircraft and ATC capabilities, whose basic components are described in chapter 4. Also, the ability to better monitor weather along flight routes will help pilots trim miles, and reduce fuel consumption, during detours around bad weather. Based on NASA tests of cockpit weather

[51] David Henderson, Data Division, Association of European Airlines, personal communication, Mar. 15, 1994. The ATC delay stems in large part from the more prevalent use of instrument flight rules for governing European air traffic. Fearnsides, op. cit., footnote 22.

[52] Air Transport Association of America, "Air Traffic Management in the Future Air Navigation System," white paper, June 16, 1994, p. 1.

[53] At least 80 percent of future demand must be addressed by options that are difficult to execute, e.g., demand management and alternative modes of transportation.

FIGURE 3-9: Options To Meet Projected Shortfall in Peak-Hour Capacity Level 1 Airports



SOURCE Apogee Research, 1992

display systems, the estimated savings in a typical airline's operating costs would be $5.9 million annually.[54]

However, many weather-related delays result from not being able to predict the start and end of instrument meteorological conditions. To illustrate the problem, FAA uses the hypothetical example of morning fog at Chicago's O'Hare International Airport that halves the potential acceptance rate for arrival traffic. If the fog lifts an hour earlier than forecast, the pipeline of traffic will not be filled quickly enough to regain normal acceptance rates until that hour expires, even if the ground hold is removed immediately. The inadequate weather information thus results in a loss of 50 percent of capacity for an hour; furthermore, the loss has a ripple effect throughout the national system.[55] This points to the need for ceiling and visibility forecasting methods.

Environment

Relative to other transportation modes, aviation pollutant emissions are small. However, the industry's energy efficiency, measured in energy use per passenger-mile, is higher than that of other modes. For example, the respective energy inten-

[54] Charles H. S[can]]on, NASA Langley Research Center, quoted in "'NASA Says Cockpit Weather Display Cuts Fuel Bum, Aids Safety,'' *Air Line Pilot*, December 1993, p. 45.

[55] U.S. Department of Transportation, Federal Aviation Administration, *Aviation System Capacity Annual Report* (Washington, DC: October 1993), p. 18.

TABLE 3-7: Potential Airport Capacity Enhancements

Parameter	Capacity increase (percent)	Comments
Visual flight rules		
ATC system Improvements	18 to 22[a]	Depends on whether operations are arrivals-only mixed (e. g., 50/50), or departures-only
Interarrival time variability	17 to 18	Arrivals-only operations—assumes 50 percent reduction in interarrival time variability. Negligible capacity Increase for mixed operations
Interarrival separation	7	Arrivals-only operations
Departure separation	3 to 18	Function of share of departures
Runway occupancy time	0 to 9	Reductions m other parameters have little or no effect on mixed operations unless there are corresponding reductions in runway occupancy time (mean and variability),
Instrument flight rules		
System variabilities	13 to 16	May be technologically difficult to achieve reductions in interarrival time variability.
Longitudinal separations	4 to 6	
Multlple-independent approaches	31 to 100[b]	Function of runway configurations
Separations for multlple-dependent approaches	25	Reduction in diagonal separation requirements
Runway occupancy time	—	Insignificant limitation in Instrument flight rules

[a]Potential capacity Increases are nonadditive and assume approximately 50-percent reduction in variabilities
b Instrument flight rules base capacity is 75 to 90 percent of visual flight rules base capacity fOr the *same* runway configuration However use of converging and multiple parallel runways is restricted under Instrument flight rules, Imposing a significant capacity penalty at many airports

SOURCE The Mitre Corporation, 1987 and 1994 data

sities for Part 121 aircraft and automobiles in 1990 were 4,811 and 3,739 Btu per passenger-mile.[56] While commercial aviation's energy efficiency has improved (see figure 3-10), the drive for energy efficiency continues because a significant portion of airline operating costs relate to fuel use,[57] and increased fuel use resulting from more operations or longer flights generates more emissions of combustion byproducts.[58] For some general aviation aircraft, replacement—not reduced use—of leaded aviation gasolines is being sought: small aircraft are the largest single source of airborne lead particles.

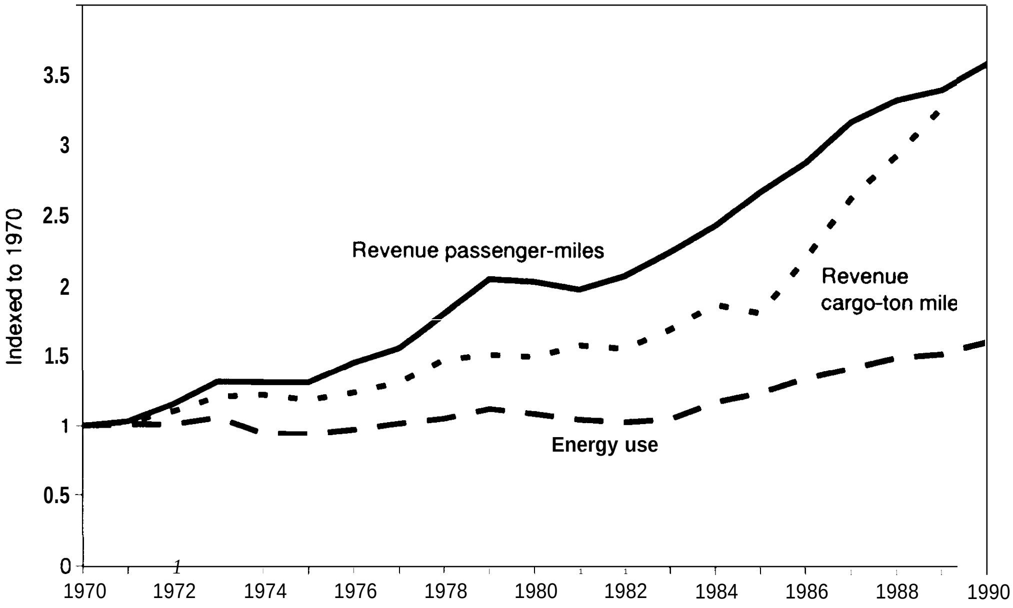
Reducing engine exhaust impacts, along with aircraft noise, requires further attention because: 1) U.S. and international communities will permit little or no backsliding even as the industry continues to grow; 2) there is a push for increased stringency; and 3) with existing technology, these improvements cannot be attained for the current

56 See Center for Transportation Analysis, Energy Division, *Transportation Energy Data Book: Edit/on 13*, ORNL-6743 (Oak Ridge, TN: Oak Ridge National Laboratory, March 1993), table 2.13, p. 2-24.

57 *According* to *Boeing,* for a typical aircraft, fuel expenses are roughly *50* percent of the cash direct operating costs (i.e., for fuel, flight crew, and maintenance), and 33 percent of all cash airplane-related operating costs. Calv in Watson, Boeing Commercial Airplane Group, personal communication, Aug. 17, 1994. Actual fuel costs depend heavily on world market price.

5X In the Prior decade, e.g., aviation's share of the total U.S. demand for petroleum rose to 10.2 frOm 8.2 percent and fuel consumption rose 41 percent to 414 million barrels. Frank A. Smith, *Transportation in America, 10th* Ed. (Waldorf, MD: Eno Transportation Foundation, Inc., October 1992), pp. 56-57.

FIGURE 3-10: Energy Use, Passenger-Miles, and Cargo-Miles for Certificated Route Air Carriers, 1970-90



SOURCE Office of Technology Assessment, 1994, based on 1993 Energy Information Administration data

fleet. In addition, the scientific understanding of potential problems with high-altitude subsonic aircraft emissions is limited. Before an extensive effort to design improved combustors and evaluate their performance in terms of safety and cost-effectiveness is undertaken, increased knowledge of the effects of engine emissions on the atmosphere is needed.[59]

Where only scanty or inexact measures of the environmental effects are available, the indirect economic costs of environmental degradation are difficult to assess.[60] However, the direct cost to industry of compliance with emissions, noise, or stormwater runoff regulations can be more easily quantified. The Albany (New York) Airport, for example, spent over $13 million for a recovery and treatment system to preclude runoff from contaminating the local drinking water supply.[61] Aircraft modifications necessary to meet Stage 3 noise abatement requirements could mean spending $1.5 million to $3 million per aircraft for hushkits or $10 million to $12 million per aircraft for re-engining.[62]

59 Some of the ground-level impact can be derived from information contained in EPA databases, but data from the up troposphere and stratosphere are missing.

60 For example, the cost to society of increasing airport noise by 1 decibel is relative to the ambient noise level in a given neighborhood. Furthermore, even when the amount of pollution or other impact can be quantified, there is little agreement on how to calculate the costs of such impacts.

61 "Airports Tackle Deicing concerns," *Aviation Week & Space Technology,* Jan. 11, 1993, p. 43.

62 Stanley W. Kandebo, "Hushkits Gain Favor in Poor Economy," *Aviation Week & Space Technology,* Nov. 23, 1992, p. 83.

Other examples of imposed costs are the impact of the mandated phase-out of leaded gasoline on general aviation fuel price and availability[63] and the pollution-reduction expenses incurred in areas of nonattainment with respect to air quality standards. Also, there are capacity constraints associated with noise, air-, and water-quality impacts. The aviation industry is capital-intensive with long development horizons. Because airports and aircraft have long lives, the timing and feasibility of environmental requirements are increasingly important.

In general, the impetus for environmental R&D typically comes less from concern over the impact on the environment (after all, it is often small compared with other sources) but from the potential effects environmental rulemaking has on air transportation. The major exceptions to this involve high-altitude atmospheric impacts from subsonic and supersonic civil aircraft.

The viability of a new generation of supersonic transports—the proposed high-speed civil transport (HSCT)—hinges on environmental compatibility (i.e., reducing any stratospheric ozone depletion caused by a large HSCT fleet to acceptable levels). This requires an extensive research effort in order to quantify the potential impact and evaluate possible control measures. NASA's work in this arena is described in chapter 4.

ISSUES IN SETTING PRIORITIES

There have been periodic attempts to revise FAA's R&D priorities and better define its capabilities. In recent years, Congress and the aviation community have urged greater emphasis on R&D that is directed at identifying or predicting problems and focusing on long-term issues. The General Accounting Office (GAO) has recommended that FAA develop a mechanism to track long-term or future-oriented research efforts; FAA is exploring ways to modify the RE&D information system and otherwise implement GAO's recommendation.[64]

Legislation enacted in 1988 and 1990[65] required FAA to expand its R&D focus specifically to include human factors, aging aircraft, catastrophic failure prevention, simulation, and security. Corresponding changes in program funding between 1988 and 1994 are shown in table 3-8. For fiscal year 1993, Congress appropriated $230 million to FAA for R&D. Roughly 45 percent of these funds went to projects related to system capacity, approximately 16 percent each to safety and security, and nearly 12 percent to human factors and aviation medicine.

TABLE 3-8: Effects of Aviation Safety Research Act on FAA R&D Spending ($ millions)

Mandated area	1988a	1991	1994[b]
Human factors and aviation medicine	$62	$17 2	273
Simulation modeling	0.8	9. 2[c]	11,8
Aircraft structured	1 7	176	26.8
Fire safety	3 5	4,3	5 7
Total	12.2	48.2	715

[a] Obligations
b Requested funding for fiscal year 1994
[c] Includes National Simulation Lab National Airspace System Performance Analysis Capability, simulation model and development and airspace system models
d Includes aging aircraft research

SOURCE Office of Technology Assessment, 1994, based on General Accounting Off Ice analysis of Federal Aviation Administration data

[63] Sections 220 and 226 of the Clean Air Act Amendments of 1990, Public Law 10 1-549, Nov. 15,1990, prohibit the manufacture or sale of new lead-burning engines after model year 1992 and the sale of leaded fuel for use in motor vehicles by 1996. Although general aviation aircraft were exempted from the former provision, general aviation advocates fear that the amendments will make it economically infeasible for fuel companies to continue to manufacture general aviation fuel in the interim. "Tough Times for the Little People," *Interavia Aerospace Review*, March 1991, pp. 3 I -32.

[64] Allen Li, Associate Director, Transportation Issues, Resources, Community, and Economic Development Division, U.S. General Accounting Office, testimony at hearings before the Senate Committee on Appropriations, Subcommittee on Transportation and Related Agencies, May 20,1 993, p. 7.

[65] Aviation Safely, Research Act of 1988, Public Law 100-591, Nov. 3, 1988; Catastrophic Failure prevention Act of 1990, Public Law 101-508, Nov. 5, 1990; and Aviation Security Improvement Act of 1990. Public Law 10 I -604, Nov. 18, 1990.

The 1988 Aviation Safety Research Act also mandated establishment of an advisory committee to assist FAA in evaluating its research effort. Comprised of experts drawn from all aspects of air transportation, the FAA Research, Engineering and Development Advisory Committee meets quarterly to discuss the status of individual R&D programs and their progress relative to agency objectives. Similarly, the 1990 Aviation Security Improvement Act directed the formation of the Aviation Security Research and Development Scientific Advisory Panel, constituted under the auspices of the committee.

In 1991, at the request of the FAA Administrator, the FAA RE&D Advisory Committee established a panel (often called the Augustine Panel)[66] to review FAA's plan for R&D. The panel found that "... no factor poses more severe potential limits of future air transportation than ... system capacity."[67] The panel also stated that the application of new technology will be a large part of the solution to the air traffic saturation problem and recommended that FAA be provided with additional financial and human resources to accomplish its objectives. Other recommendations included strengthening FAA's systems engineering methodology, expediting funding and use of the national simulation capability, and giving increased attention to the application of space-based communications, navigation, and traffic surveillance system elements. The review panel also suggested that FAA adopt a matrix-based approach for comparing and quantifying the estimated contributions of individual research projects to FAA goals.[68]

However, a 1992 GAO assessment of the FAA RE&D plan found that the RE&D program alone could not achieve all the goals set out in the plan.[69] GAO indicated that FAA could strengthen its plan by delineating staffing and resource requirements, and by incorporating the RE&D goals into the rest of the organization.

The Augustine Panel updated its recommendations in 1993, documenting the need for a concentrated effort in the FAA RE&D program to establish more specific goals to help the agency manage congestion problems (among other issues), and to present a coordinated program for consideration by the agency as a whole.[70]

In its 1992 assessment, GAO also recommended that FAA take this type of systems approach to its multifaceted mandate, citing a special relationship between developing specific ATC and security technologies and understanding how various technologies interact.[71] For example, an aircraft's ability to withstand a blast must be considered when developing requirements for explosives detection system designs. Understanding aircraft hardening limitations thus influences the operation of security screening systems.

I Cost-Benefit Analysis

To improve its methods of setting R&D priorities, FAA is also using cost-benefit analysis (CBA),

66 Named for its Chairman, Norman Augustine.

67 FAA Research, Engineering and Development Advisory Committee, R&D Plan Review Panel, *Review of the FAA Research, Engineering and Development Program* (Washington, DC: November 199 I), p. 1.

68 ibid., pp. 1, 31-32, 36-38.

69 U.S. Congress, General Accounting of ffice, *Aviation Research: FAA Could Enhance Its Program To Meet Current and Future Challenges,* GAO/RCED-92-180 (Washington, DC: U.S. Government Printing Office, June 1992), p. 2.

70 Feamsides, op. cit., footnote 22. See FAA Research, Engineering and Development Advisory Committee, R&D Plan Review panel, *U.S. Leadership in Air Traffic Services: An Update of the Earlier Review of the FAA Research, Engineering and Development Program* (Washington, DC: January 1993).

71 Genera] Accounting office, op. cit., footnote 69, p. 10.

which FAA successfully employed for the Capital Investment Plan (CIP) budgeting process.[72] (See box 3-2.) Paralleling the CIP effort, CBA for individual RE&D projects is used to support mission needs statements as part of a multiphase decision process similar to A- 109.[73] The projected benefits are based on the operational savings associated with the implementation of the systems and technologies that might be derived from the RE&D program.

According to a Volpe National Transportation Systems Center (VNTSC) assessment of ATC and capacity projects, the benefits to be realized from the RE&D program are: for FAA, increased controller and maintenance staff productivity and cost savings in operations; and for air carriers, reduced

BOX 3-2: Cost-Benefit Analysis at FAA

The Federal Aviation Administration's use of cost-benefit analysis (CBA) goes back at least to the 1970s Early examples include facility establishment criteria for control towers, airport surveillance radar, and Instrument landing systems The acquisition of major new systems, such as the upgraded third-generahon ATC system, was evaluated with CBA.[1] When FAA formulated the Capital Investment Plan (CIP) In 1981, CBA continued as an Integral part of the process More recently, it has been applied to elements of FAA's Research, Engineering and Development program

The Off Ice of Aviation Policy, Plans, and Management Analysis sets agency standards for CBA, performs regulatory analyses, and conducts CBA for terminal area facilities such as ATC towers and airport surveillance radar The Operations Research Service (AOR) performs analyses for facilities and equipment Investment projects contained in the CIP and for technological program-level decisions [2]

The Office of Management and Budget (OMB) requires major system acquisitions to have a CBA justificatlon Specifically, this analysis supports the mission needs statement, which is the first phase of the OMB A-109 "Major System Acquisition Process. " AOR's work has several other applications in addition to supporting mission needs statements One application has been to develop the CIP baseline, a summation of the estimated benefits for all projects in the CIP AOR's analyses have also improved FAA program offices' understanding of CIP benefits Under contract to FAA, Martin Marietta Information Systems Group performs much of the analysis and data collection required for this effort Martin Marietta also maintains the database of results for each of the CIP projects

(continued)

[1] Carlton Wine, Manager Information Systems, FAA Off Ice of Aviation Policy Plans and Management Analysis, personal communication June 17 1994

[2] Ibid

[72] FAA's Office of Operations Research staff informed OTA, during personal communications, that the results of the analyses performed for the CIP have been used by FAA project offices, the FAA budget office, and by the Office of Management and Budget.

[73] FAA's Office of Operations Research manages this program with primary analytical support from DOT'S Volpe National Transportation Systems Center (VNTSC). Although VNTSC is responsible for an overall evaluation of the RE&D program, the FAA Technical Center manages the work for the aircraft safety, airport technology', and system security programs. For example, one recent effort at the Technical Center compared the potential benefits from different areas of aircraft safety research (flight safety, aging aircraft. structural safety, and aircraft systems fire safety).

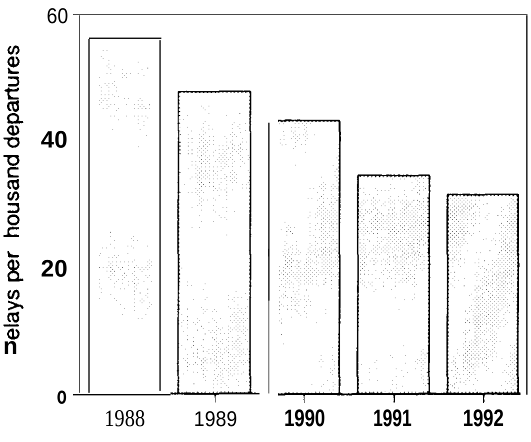
BOX 3-2: Cost-Benefit Analysis at FAA (Cont'd.)

Analytical Methodology

For the CIP, the two major categories of benefits are the cost savings for FAA and for aviation system users. FAA benefits Include personnel cost reduction resulting from increased air traffic controller productivity and reduced maintenance needs. AOR's analysis indicates that FAA will realize **additional operational savings in nonlabor areas such as leased communications costs, rents, and utilities. User benefits consist of systemwide delay reductions, availability of more efficient routings, and the reduced risk of accidents. The first two of these benefits are quantified by counting the savings derived from decreased aircraft direct operating costs and passenger travel time. In determining costs, only future expenditures are included. Sunk costs (those amounts that have already been spent) are excluded from the analysis.**

Reduction in Delays

The amount of time by which delays will be reduced is estimated by combining forecasts of the growth in air travel with forecasts of the length of delay per aircraft operation. However, FAA's long-term traffic forecast does not allow for the effect of airport congestion on traffic demand. Basing projections of flight delays on the difference between the unconstrained air traffic forecast and actual airport capacity, then, results in an overstatement of predicted delays. Air carrier operating practices would probably change if the cost of delays becomes prohibitive. For example, the use of larger aircraft might alleviate the peak-hour delays at the busiest airports.[3] In addition, community opposition to aircraft noise may reduce some of the forecast growth in aircraft operations. In fact, while FAA's airport delay forecasts have shown increasing congestion until recently, FAA's current data have shown reductions in delays (see figure). The estimate of the length of reduced delays forms the basis for 60 percent of total CIP benefits. Thus a significant portion of the CIP benefits projected by FAA are open to question.



Delays of 15 minutes or more at
55 major **airports in the United States.**

Passenger *Time Savings*

The value of passenger time savings represents the gain to travelers resulting from decreased time in the air and more reliable airline schedules. AOR's analysis uses a value recommended by FAA's Off Ice of Aviation Policy, Plans, and Management Analysis,[4] However, because of the range of reported results, an estimate of the value of travel time for air travel cannot be considered an exact value.[5] Thus, the CIP benefits attributed to passenger time savings, which represent more than one-half of total benefits, should be recognized as Imprecise.

(continued)

[3] U S Congress, Off Ice of Technology Assessment, New *Ways. Tiltrotor Aircraft and Magnetically Levitated Vehicles*, OTA-SET-507 (Washington DC. U S Government Printing Off Ice, October 1991), p. 45

[4] The amount used is $4050 per hour Based on a review of theoretical and empirical studies This value represents a weighted average for both business and nonbusiness travel and for the different types of air travel (e g , domestic air carrier, International air earner, commuter) In general, the value of travel time saved for business trips is the typical traveler's hourly earnings rate, for nonbusiness travel, II is 1 5 times the wage rate

[5] U S Department of Transportation, Federal Aviation Administration, *Economic Values for Evaluation of Federal Aviation Administration Investment* and Regulatory Programs (Washington, DC October 1989), pp 1-12

BOX 3-2: Cost-Benefit Analysis at FAA (Cont'd.)

Timing of Benefits

Benefits realized before the current date are categorized as "actual, " "Accruing" benefits occur over the CIP planning horizon—to be realized as a result of projects that have been Implemented before the current date—and are considered future benefits. Only future benefits figure into a project's cost-benefit ratio.

Several changes have been made in the methodology used to calculate the CIP benefits since analyses were first done for the National Airspace System Plan in 1981 Prior to 1986, benefits to aviation system users were not part of the analysis, The planning horizon for counting benefits was expanded from the year 2000 to include a project's entire life cycle, a timeframe from 1991 to 2025,

FAA's economic analysis of the 1991 CIP yielded a present value of $55.1 billion in future benefits,[6] $16,2 billion in future costs, and a benefit to cost ratio of 347 (See table 1 for relative shares of the benefits by category for both FAA and aviation system users.) However, if delays are not as bad as predicted and benefits to passengers are only 20 percent of the total benefits, for example, this cost-benefit ratio could be less than 1.

An alternate method of describing the benefits realized by users is to break them down by how they are calculated: 57 percent of total CIP benefits are passenger time savings and 24 percent are due to aircraft direct operating cost savings The six CIP projects that make the largest contribution to total benefits are listed in table 2.

TABLE 1: FAA Estimates of Future Capital Investment Plan Benefits

Category	Percent of future benefits[a]
FAA	
Air traffic controller productivity gains	5 3%
Maintenance personnel savings	2 7
Nonlabor-related operational savings	4 4
Total for FAA	12.4
Users	
Reduced delays	607
Increased availability of more efficient routes	20.7
Avionics cost savings	2 6
Reduced risk of accidents	3.6
Total for users	*87.6*
Total	**100.0**

[a] In 1991 dollars, the estimated value of *undiscounted* future benefits between 1992 and 2025 is $2579 billion Total projected discounted benefits of FAA's 1991 Capital Investment Plan are $551 billion

SOURCE Office of Technology Assessment, based on 1992 Federal Aviation Administration data

TABLE 2: 1991 Capital Investment Plan Projects With Largest Estimated Future Benefits

Project name	Percentage of total CIP benefits[a] User	FAA
Advanced Automation Program[b]	**32,2%**	*3.7%o*
Global Positioning System Monitors	18,8	0.5
Microwave Landing System	10.4	**0.2**
Central Weather Processor	7,1	**0 0**
Terminal ATC Automation	5.6	**0.0**
Traffic Management System	2,2	1.9
Total for top six projects	**76.3**	**6.4**

[a] In 1991 dollars, the estimated value of *undiscounted* future benefits between 1992 and 2025 is $2133 for the top six projects and $2579 billion total The total projected discounted benefits of FAAs 1991 Capital Investment Plan are $551 billion Totals may not add due to rounding

b Includes 10 separate projects For a description of these projects see U S Department of Transportation, Federal Aviation Administration, *Capita/ Investment Plan* (Washington, DC December 1990)

SOURCE Off Ice of Technology Assessment based on 1992 Federal Aviation Administration data

[6] The values in this section are in 1991 dollars

[7] Federal Aviation Administration, "An Economic Analysis of the 1991 Capital Investment Plan " unpublished document, May 1992

delay and increased safety.[74] In 1991 dollars, the estimated benefits for a subset of the RE&D program are $31.3 billion.[75] Table 3-9 presents the relative shares of these benefits broken down by category and by how the benefit was quantified.

TABLE 3-9: Relative Shares of Projected Benefits for Selected FAA RE&D Plan Projects

Benefit grouping	Percent of benefits
By benefit category	
Improved system capacity and reduced delays	91 .4%
Cost savings, Improved efficiency of operations, and Improved safety and security	8.6
Total	**100.0**
By how benefit was quantified	
Passenger time savings	470
Reduced aircraft operating costs	43.8
Increased controller productivity and other savings	9.3
Total-	**100.0**

NOTE Projected benefits are the operational benefits for the systems and technologies that might be derived from the RE&D program, and are associated with the Implementation of a subset of the projects included in the 1991 RE&D plan Benefits are calculated for the period 1992 through 2105 Total projected discounted benefits (in 1991 dollars) for this subset of RE&D plan projects are $31 3 billion

SOURCE Volpe National Transportation Systems Center, 1992

Limitations to Cost-Benefit Analysis for R&D

FAA faces some obstacles in adapting CBA for analyzing its R&D priorities. For example, it is not entirely appropriate to attribute the benefits from a future operating system in the field to a particular RE&D program. Because the benefits of the program are realized far in the future (perhaps 15 to 30 years), it is difficult to predict whether the RE&D program will result in new systems that can be implemented as part of the National Airspace System. The nature of R&D is such that only a fraction of the research undertaken results in the development of beneficial technologies. Those new technologies will only yield benefits if they can be successfully integrated and operated within the NAS. Recently, FAA has taken steps to define clearly the linkage between RE&D initiatives and broader agency objectives .76 Also, with assistance from the federal Center for Advanced Aviation System Development, FAA's Research and Development Service is attempting to develop ways to measure achievement of its R&D goals.[77]

Another limitation of R&D cost-benefit analysis is that data are often not sufficiently robust to allow reliable calculations of potential benefits. Projected benefits occur in the distant future and depend on a multiple-step process: successful research resulting in new technologies; fielding of new technologies; and, finally, benefits being realized from operation of the new system. In the case of capacity-related projects, delay forecasts are problematic—lending uncertainty to the baseline costs and projected net benefits to be derived from airspace capacity and efficiency enhancements. Better delay data and improved models of airspace and air traffic could reduce some of the uncertainty (see Delay and Air Traffic Analysis section below).

A third difficulty is reliably calculating the costs of conducting RE&D projects and implementing the resulting technologies. In particular, given the uncertainty of projecting 15 to 30 years into the future the costs of implementing and operating systems that do not currently exist, estimates of these costs would be subject to error.[78]

74 Volpe National Transportation Systems Center, "Benefits Evaluation of the FAA's Research, Engineering & Development Program," project memorandum, Jan. 14, 1992.

75 Ibid.

76 See Federal Aviation Administration, op. cit., footnote 42, pp. 1-7—1-13.

77 Tony Dundzila and Sam Bowden, The Mitre Corp., Center for Advanced Aviation System Development, "Baseline Measures for Goals in the R,E&D Plan," draft working paper, November 1993.

78 VNTSC, in its 1992 assessment, did not include the costs of individual programs needed to yield benefits.

According to FAA, the purpose of CBA is to allow the comparison of net benefits from disparate sorts of projects.[79] OTA finds, however, that CBA has not matured (o the point that it is effective for comparing R&D projects in different missions. When probable risk cannot be determined, as in security, the difficulties in estimating benefits and costs of R&D programs are compounded. This undermines direct comparison of investment benefits, e.g., between security and capacity or safety projects. Furthermore, within a program area, while a dollar value can be assigned to minimizing safety hazards or economic penalt ies (e.g., those asso-ciated with glycol disposal or recycling costs), not all benefits of improvements sought through R&D can be quantified. Examples include the value of "peace and quiet" and fewer emissions.

It is also doubtful that CBA can be effective in gauging the value of risk assessment efforts or more basic research, for example, long-term weather research. Improved understanding of weather phenomena through mesoscale meteorology research is integral to: defining usable airspace through understanding the behavior of thunderstorms and related hazardous weather phenomena: identifying regions of clear air turbulence and icing; predicting short-term changes in ceiling and visibility at airports; and understanding the meteorological elements that sustain wake vortex turbulence.[80] Yet FAA's RE&D budget contains no funding for this type of research,[81] and its weather R&D effort is focused primarily on new tools for processing and displaying increasing amounts of weather information generated by a modernized weather service.[82]

Neither the magnitude of a problem nor potential savings can be the sole determinant of the level of support required to devise solutions for any of the mission areas. In some cases, the technology base (including personnel and facilities) already exists upon which new or enhanced options can be constructed (e.g., cockpit weather displays). Other questions or difficulties (e.g., atmospheric science for environmental protection or weather forecasting) require more extensive effort before sufficient data can be gathered and assessed and options presented. Assessing the myriad human performance issues requires that measurement methods be developed and validated.

A broad portfolio of aviation R&D is therefore necessary, with research and technology needs derived from user input, analysis of performance trends, expert review, and breakthroughs in related areas of study. Many R&D investment planning decisions must still transcend the CBA methodology described above. For example, a more appropriate quantitative method for setting capacity-related research priorities may be a "needs" analysis that allows decisionmakers to focus on the operational systems required for the NAS in the future rather than the potential operational benefits that will result from the successful development of projects currently in the RE&D plan.

PREDICTING FUTURE PROBLEMS

The phrase "tombstone technology" is used. often disparagingly, to describe safety measures developed after an accident or series of accidents has occurred. But pursuing a focused development program before an accident occurs is risky and may divert precious funds from areas where prob-

[79] Carlton R. Wine, Manager In formation Systems, FAA Office of Aviation Policy, Plans, and Management Analysis, personal communication, June 17, 1994.

[80] Arthur A. Shrantz, Associate Director, Research Applications Program, National Center for' Atmospheric Research, personal communication, Apr. 6, 1994.

[81] Of FAA's $250 million fiscal year 1994 request for RE&D funding, $1.9 million is included for weather R&D; all of this is devoted to the integrated airborne windshear research program, a primarily technology-oriented effort.

[82] See discussion of FAA's Aviation Weather Development program in ch. 4.

lems may crop up sooner. For example, even if FAA or other agencies had supported more extensive materials science R&D in the late 1970s or early 1980s, it is not known whether the aging aircraft problem could have been averted before the Aloha accident occurred, nor is it clear that the expenditures in time and money (and opportunity costs) would have been fitting in light of the few fatalities to date.

In addition to aging aircraft and terrorist threats, other risks arise from an evolving industry, including highly complex software, the susceptibility of new avionics and digital systems to electromagnetic fields, increased use of composite materials, changes in aviation fuels and engine designs, and replacement of halons in fire extinguishing systems.[83] Other new issues relate to demographics, aviation's role in global climate change, and operation of the proposed very large commercial transports.

Based on FAA estimates that approximately 80 percent of its safety R&D has near-term applications, OTA calculates that less than 5 percent of the safety effort is longer term, generic knowledge gathering.[84] However, one future catastrophic accident that arises from anew mode of failure could cause as much damage and loss of life as many of the problems known to date. Predicting potential catastrophic problems requires a combination of improved data collection and analysis and generic research in order to confidently identify performance trends and derive a basic understanding of the elements (e.g., materials behavior and cognitive skills) that could contribute to such an accident.

Rather than focusing nearly all resources on specific problems, greater emphasis on operations research or analysis and risk assessment may be appropriate. The object of this activity is to examine elements of the aviation system for sensitivity to changes in technology or procedures, for example, the impact of deregulation and resultant shift to hub-and-spoke operations on capacity and safety.

Furthermore, this capability could be useful in better defining, prior to establishing requirements, the objectives of any technology development program. Key parts of this approach are integrated databases and assessment tools to support timely analysis of the state of the airspace system, and validated, appropriately scaled models for estimating traffic, environmental impact, and weather.

Additional cooperation with other federal agencies to leverage R&D dollars could be helpful. For example, the Department of Defense (DOD) national laboratories have an extensive background in aviation R&D and much of their work applies to FAA missions.[85] In 1993, in response to congressional direction, FAA performed a survey of external laboratory capabilities and identified 128 facilities whose work could benefit FAA; working agreements had already been established with 36 of these, but FAA found the capabilities of some of the remaining labs were too narrow in scope or had less than substantial relevance.[86] FAA plans to conduct further assessments of the advantages of fuller participation with certain DOD laboratories.

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83 U.S. Department of Transportation, Federal Aviation Administration, *1993 Federal Aviation Administration Plan for Research, Engineering and Development*, Report of the Federal Aviation Administration to the U.S. Congress pursuant to Section 4 of the Aviation Safety Research Act, Public Law 100-591 (Washington, DC: February 1994), p. 6-1.

84 The remainder is directed at long-term technology development programs.

85 Gellman Research Associates, "Cooperation and Coordination in Federal Aviation Research," OTA contractor report, Dec. 30, 1992, p. 39.

86 U.S. Department of Transportation, Fe&-a] Aviation Administration, *Survey of Research, Engineering, and Development Research Facilities*, Report of the Federal Aviation Administration pursuant to House Report 102-639 on the DOT Appropriations Act for FY 1993, Public Law 102-388 (Washington, DC: July 1993), p. 4.

Congress, in the 1990 Catastrophic Failure Prevention Act, also enabled FAA to provide grants to universities for exploring long-term R&D questions. In May 1992, the first recipient was selected; by July 1993, 58 grants totaling in excess of $32 million had been awarded.[87] Research areas include ATC automation. artificial intelligence, human factors. simulation, airport planning and design, aviation security, and aviation safety.[88]

FEDERAL AVIATION DATA AND ASSESSMENT RESOURCES

There are a variety of federal resources and efforts to gather information for determining the state of the aviation system (e.g., number of delays, operations, passengers), assessing or predicting potential problems (e.g., accident risk or security threat, environmental impact, capacity shortfall), and identifying technology and operational improvements to the system. In addition, performance data and analyses arc useful for developing R&D program goals and gauging the progress of those problem-solving efforts. While the current data-gathering effort sheds light on the issues confronting the industry, some key information is lacking.

This section describes the primary resources for each of the key mission areas and identifies further data and assessment tools needed to improve both the understanding of operational issues and R&D decisionmaking.

I Capacity-Related Data and Analysis

Information needs for airspace capacity assessment and air traffic management include:

- sources and characteristic lengths of delays, in order to support operational decisions and forecasts of activity and delay:
- improved short-term predictions of weather, which are essential to more efficient use of airspace as well as flight safety; and
- performance characteristics and longevity of critical infrastructure, for example, runways and other airport surfaces.

Delay and Air Traffic Data

The two primary delay reporting systems in use today are maintained by DOT and by FAA's Office of Air Traffic System Management.

DOT's Airline Service Quality Performance (ASQP) system stores data submitted by major airlines with service at the nation's top 100 airports. Actual departure time, flight duration, and arrival time are recorded and compared with the equivalent data published in the *Official Airline Guide* and listed in the computerized reservation system. Under the NAS Analysis Program, FAA collects data from 55 major airports and all 20 air route traffic control centers within the continental United States to track the number and length of delays (of 15 minutes or more) at airports or within ATC sectors. Each night, controllers relay delay information noted on flight strips[89] via the Operational Performance System Network (OPSNET) computer to FAA headquarters, where the data are compiled for the next day's status briefings. OPSNET also supports the compilation of statistics for a biennial report to Congress on NAS performance.[90]

OPSNET and related databases have some drawbacks. Chief among them are that the quality and completeness of controller reports vary with

[87] Ibid., p. 4.

[88] Gellman Research Associates, op. cit., footnote 85, p. 11

[89] Marked with flight data, these paper strips serve as memory aids for controllers and as the backup system for automated surveillance and traffic display systems.

[90] Pat Beam, Manager, NAS Analysis Program, Federal Aviation Administration, personal communication, Aug. 6, 1993.

workload; and only delays of a minimum magnitude are reported, distorting the estimate of average and overall delay.[91] Unlike ASQP, OPSNET does not reflect airline-related delays, because the system records delay from the point an aircraft enters the takeoff queue. ASQP, OPSNET, and other sources of airline delay data are outlined in **box 3-3.**

Models and Analytical Tools

Today, capacity analysis uses a full spectrum of models in three key areas—policy analysis, detailed design, and operations support—to assess activities on different scales in order to determine where the bottlenecks are and under what condi(ions. The object is to revise operations and procedures as needed and to predict air traffic manage-

BOX 3-3: Sources for Airline Delay Data

ACARS	*Aeronautica/Radio, Inc. (ARINC) Communications and Reporting System* provides data (i.e., when the cabin is pressurized and the aircraft leaves the gate, wheels fold into wells, wheels lowered, and aircraft stopped at arrival gate and cabin depressurized) to track flights for the approximately 3,500 ACARS-equipped aircraft
ARTS	*Automated Radar Terminal System* provides runway use data, instrument flight rules (IFR) and visual flight rules airport operations data, and airline, flight number, and aircraft Information,
ASQP	*Airline Service Quality Performance* provides comparison of actual versus scheduled flight times for airlines with 1 percent or more of enplanements
ATA	*Air Transport Association* provides a monthly report to the Federal Aviation Administration on delays by phase of flight, derived from ACARS messages,
CATER	*Collection & Analysis of Termlnal Records (managed by Aviation Data Systems) gives* flight strip and airport configuration data, along with winds/celllng data for the few airports served by CATER, Does not provide flight plan data
CODAS	*Consolidated Operations and Delay Analysis System* uses ETMS (see below) data (indicatlng when centers takeup and give away flights to approximate takeoff and touchdown times) to supplement ASQP Information, the goal is monthly reporting of statistical delay data, Does not reflect causes of delay.
ETMS	*Enhanced Traffic Management System* utilizes host computers for providing flight plan versus actual flight data, but does not reflect ground Information. Includes only IFR flights.
OPSNET	*Operational Performance System Network* includes delays of 15 minutes or more *in* departure and arrival queues and en route. Includes general aviation, air taxi, and military flights, but cause of delay identified only when workload permits, (OPSNET is a subsystem of FAA's Air Traffic Operations Management System—ATOMS)

SOURCE Federal Aviation Administration, Off Ice of Aviation Policy, Plans, and Management Analysis, 1993

[91] These problems go back to the early 1980s. In addition, all databases measure delay against the *Official Airline Guide* times, which may have resulted in overestimates and underestimates of delay at different airports due to differences in typical taxing and queuing times and the inflation of schedules to improve on-time performance. See U.S. Congress, Office of Technology Assessment, *Airport System Development*, OTA-STI-23 *1* (Washington, DC: U.S. Government Printing Office, 1984), p. 50.

ment and infrastructure environments of the future.[92]

Operational models

FAA's Air Traffic Control Systems Command Center, responsible for daily traffic control planning, uses both real-time. interactive analyses and offline analyses after the fact (see table 3-10). To enable controllers in centers to similarly respond to changing traffic conditions, computer-based decision aids with electronic databases are being developed.

Design models

Anal yses of ATC system configurate ion and the environmental impact of changes to the system rely on detailed models of air traffic, which also support airspace and airport design. SIMMOD[93] is the best known of these and is used to simulate how airplanes interact in different regions, including detailed airport operations.[94] The Sector Design analysis tool, in trial use at three sites, is intended to allow ATC to redesign sectors to increase capacity and balance workload. FAA also is using the Graphical Airspace Design Environment (GRADE) computer graphics tool. Incorporating radar data, airspace geometries, and geographical information, GRADE analyzes and displays the effects of airspace modifications and changes in flight procedures.[95] FAA is seeking to adapt this visualization tool, with the support of its vendor, to permit concurrent analysis of noise impacts.[96]

TABLE 3-10: FAA Models for Traffic Flow Management and Capacity Analysis

Model	Purpose	Description
NASSIM	Strategy evaluation	'Detailed National Airspace System-wide traffic prediction and simulation
FLOWSIM	Strategy evaluation	Daily flow simulation for fast-time national major airport traffic.
SMARTFLO	Strategy generation	Planning for quick-response flow advisories using expert systems,
OPTIFLOW	Strategy generation	Optimized flow planning for dynamic national traffic flow simulation.
Planned arrival and departure system (PADS)	Strategy generation	Real-time development of optimal arrival and departure scheduling plans
High-alt\tude route system (HARS)	Strategy generation	Enables optimized, fuel-efficient jet routes
Daily decision analysis system (DDAS)	Information and analysis support	Automation tools to allow quick analysis of airline schedule change Impacts.

SOURCE Off Ice of Technology Assessment, 1994, based on the 1993 FAA Research, Engineering and Development Plan.

[92] Policy analysis models tire characterized by their approximate, macroscopic nature; detailed design or planning models are highly accurate and use simulations extensively; operations support models tend to be very fast, accurate, and microscopic, but those used for offline, post analyses need not be real-time. See Amadeo Odan i, Massachusetts Institute of Technology, *Transportation Modeling Needs: Airports and Airspace* (Cambridge, MA: U. S, Department of Transportation, Volpe National Transportation Systems Center, July 1991). p. 8; and Saul I. Gass, University of Maryland, "Evaluation of Air Traffic Modeling Tools: Validation and Review of Results and Documentation," paper prepared for the Federal Aviation Administration, Oct. 16, 1992, p. 91,

[93] A trademark name for an airport and airspace simulation model.

[94] SIMMOD is a stochastic model; multiple simulation runs must be performed to lend results any statistical significance. The model now can be directed to perform iterations until a specified confidence level is achiev cd.

[95] Federal Aviation Administration, op. cit., footnote 50, p. 5-19.

[96] GRADE is a privately owned, proprietary tool. As of August 1994, contract negotiations are under way to merge the tool with FAA's Integrated Noise Model (see section on environmental assessment); the combined function is expected by the end of fiscal year 1995. FAA also hopes to further Integrate several of its capacity models into the revised tool. which could serve as the parent program for rapid analysis and visualization of interrelated changes in traffic, noise impact, and airspace design. "In this case, a picture's worth a billion w orals." Richard Nell, Manager, Airspace Design Division, FAA Office of System Capacity and Requirements, personal communication, Aug. 4, 1994.

FAA's National Airspace System Performance Analysis Capability (NASPAC), which is ". . . essentially the first effort to develop a system-wide model of airport and ATC activities,"[97] has had several applications.[98] A second network model used to evaluate the national system is AIRNET. Intended for policy analysis, AIRNET has the advantage of being much faster, but does not have the same level of detail and does not reflect changes in airspace configuration.[99]

Model limitations and data requirements

A basic requirement for all models is that they correctly interact.[100] For example, the results of analyzing a problem situation using a network model must be consistent with results from a regional or airport model. However, the data reporting shortcomings limit FAA's ability to accurately model the airspace/airport operations. For example, the various data gathering systems have used different definitions of delay.[101] **An unambiguous definition of delay, in the context of flight routes and airport configurations, accepted by both airlines and FAA is needed.** Comprehensive analysis of the potential benefits of technology and procedure changes to the airspace system hinges on this capability. Furthermore, the National Simulation Capability[102] under development requires a baseline against which future performance of the National Airspace System can be evaluated.

Three divisions within FAA are exploring ways to consolidate data systems and enhance analytical capabilities. The Office of Operations Research (A OR) is developing CONDAT, a central memory bank for its suite of operational analysis tools (see table 3-10 again); CONDAT will permit AOR models to share data and analysis results.

In response to a congressional request for ATC performance assessment, FAA's Office of Air Traffic System Management conducted a study of NAS data for one day's activities to better understand issues affecting en route sector throughput. The initial study recommended an extended collection of operational data, including ground activity data from airlines, to support further analyses of NAS performance, trends, and throughput.[103]

FAA's Air Traffic System Management Office went on to establish a national flights database required for the broader assessment and a system for further automating and integrating delay information reports and improving ATC performance analysis. The project's objectives included a reusable product, one based on government and commercial off-the-shelf systems, and adaptability. With assistance from the Department of Energy's Oak Ridge National Laboratory, the Center for Naval Analysis, and Martin Marietta's Energy Systems, Inc., FAA developed the methodology to gather and integrate data from airlines and FAA's ATC facilities in order to represent an air-

[97] Odani, op. cit., footnote 92, p. 63.

[98] Although undergoing further development, NASPAC has been used for several years at the Center for Advanced Aviation System Development and the FAA Technical Center, and was used to assess the nationwide and local impacts of the proposed Denver International Airport. It has been adapted for analysis of European airspace issues. Fearnsides, op. cit., footnote 22.

[99] Alan Breitler and Carl ton Wine, FAA Office of Policy, Plans and Management Analysis, Planning Analysis Division, personal communication, Jan. 26, 1993.

[100] Gass, Op. cit., footnote 92. p. 118.

[101] Odani, Op. cit., footnote 92, P. 75.

[102] The National Simulation Capability is comprised of: a simulation system at FAA's Technical Center; several laboratories engaged in National Airspace System R&D; and the Integration and Interaction Laboratory, a proof-of-concept demonstrator developed by the Mitre Corporation. The system is intended to integrate various RE&D program elements across the NAS environment, permitting early requirements validation, problem identification, solutions development, and system capability demonstration. U.S. Department of Transportation, Federal Aviation Administration, *Airport Technology Program Plan* (Atlantic City, NJ: Federal Aviation Administration Technical Center, November 1991), p. 2-66.

[103] Lee Berry et al., Oak Ridge National Laboratory, *An Analysis of the National Airspace Capacity*, report prepared for the Federal Aviation Administration. Office of Air Traffic Management, K/DSRD-1098 (Oak Ridge, TN: Martin Marietta Energy Systems, Inc., Sept. 29, 1992). p. 7.

craft flight from gate to gate and calculate delays within any flight leg.[104] As yet, however, it cannot develop "what if' scenarios on a national scale.

The Office of Aviation Policy, Plans, and Management Analysis is developing the Consolidated Operations and Delay Analysis System (CODAS), which combines host computers, ASQP, and the National Oceanographic and Atmospheric Administration (NOAA) weather information (when available) and calculates delay by phase of flight for instrument flight rules operations from all airports. The intended product is a reliable statistical database from which definitions for delays can be standardized (e.g., average delay between city pairs for specific airports/runway configurations).[105] According to FAA, the flights represented by CODAS account for roughly 95 percent of system delays.[106]

Rather than daily assessments of traffic conditions (e.g., for central flow control), CODAS will support non-real-time analyses and projections of delays in future scenarios. Retrieval of key information for CODAS, i.e., runway configuration data, has yet to be finalized; a "patch" on Automated Radar Terminal System computers is the likely mechanism for automated collection of this data.[107] In addition, there is a rule in progress for airlines to report, via the ARINC Communications and Reporting System, the exact times on takeoff and touchdown.

Weather Data

In the past, an insufficiently dense weather observation network made it impossible to resolve weather phenomena on space and time scales necessary for aviation operations.[108] Next-generation weather radar (NEXRAD) and the Automated Surface Observing System (ASOS) are two elements of a broad weather service modernization program being conducted jointly by FAA, NOAA, and DOD to meet this data need. NEXRAD utilizes Doppler radar technology to provide improved estimates of precipitation amounts, detect the transition between rain and snow, track storm movement and intensity, and allow for earlier detection of the precursors of thunderstorm development and other important weather phenomena. ASOS provides the basic ground-level data required for severe weather forecasting and for support of aviation operations.[109]

Satellite-based observation platforms (e.g., the Geostationary Operational Environmental Satellite) provide images of clouds and precise atmospheric soundings, additional data that are required for accurate and timely warnings of severe weather. By 1995, daily weather observations using these and other measurement systems are expected to increase 30-fold relative to 1985 levels, significantly enhancing the understanding of the state of the atmosphere.[110] The ability to process these data and present results in useful formats to the aviation community rests on advances in computing, communications, and display technologies (see chapter 4).

Runway Pavement Performance Data

Pavement requires regular maintenance in order to seal cracks and repair damage, and major rehabilitation is usually required every 15 to 20 years to correct the effects of age and exposure. Pavement

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1134 The system reflects activity over the entire NAS for selected periods in late 1991 and early 1992.

105 Alan Brietler, FAA Office of Aviation Policy, Plans, and Management Analysis, presentation to the Transportation Research Board, Jan. 12, 1994.

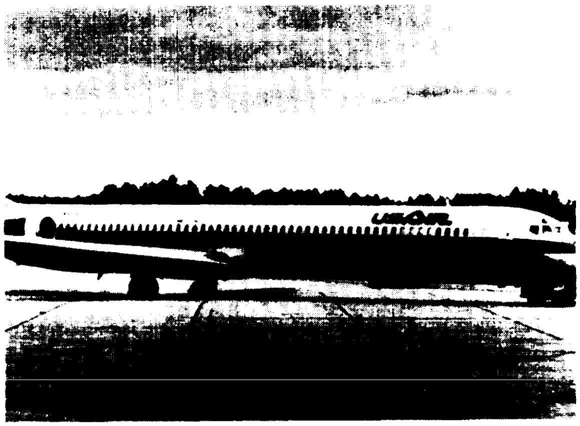
106 Brietler and Wine, op. cit., footnote 99.

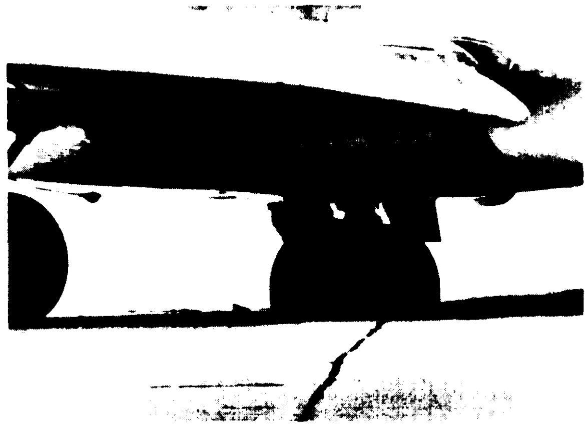
107 Ibid.

108 U S Department of Transportation, Federal Aviation Administration, A *Weather Vision To Support Improved Capacity, Efficiency, and Safety of the Air Space System in the Twenty-first Century* (Washington, DC: April 1992), p. 4.

109 National Research Council, Commission on Engineering and Technical Systems, Committee on National Weather Service Modernization, *Toward u New National Weather Service*, Second Report (Washington, DC: National Academy Press, March 1992), p. 33.

110 Federal Aviation Administration, op. cit., footnote 108, p. 4.





FEDERAL AVIATION ADMINISTRATION

Gradual wear and loss of serviceability are the most common airport pavement issues, although catastrophic pavement failure can occur

wear is a factor of aircraft axle weight distribution (determined by the type and weight of aircraft), moisture (usually from rainfall or melting snow), temperature, fuel spillage, and construction and maintenance,[111] Neglected pavement can lead to foreign objects on the airport surface, which can damage propellers, turbines, and landing gear.

The advent of new landing gear and tire configurations, faster landing speeds (e.g., those associated with the proposed HSCT), and potential ultra-high-capacity aircraft with weights exceeding 1.3 million pounds require that new design methodology for runway pavements be developed. [112] FAA is planning a long-term data collection effort for assessing pavement performance. The National Airport Pavement Registration and Demonstration Program will use sensors imbedded in the new Denver International Airport runways to provide data for validating pavement design theory. Modeled after the Strategic Highway Research Program, it will annually identify new airport construction to determine pavement life-cycle costs and other performance factors. [113]

Safety Factors

Fatality and accident rates are the primary measure of safety. Safety factors are derived from events or procedures related to passenger fatalities.114 NTSB maintains the largest collection of accident data and, with assistance from FAA and aircraft manufacturers, determines probable cause. Boeing and McDonnell Douglas also have extensive accident databases and analytic staffs.

In addition to accident-incident data and causal factors, there are secondary and tertiary factors with which changes in safety can be measured or forecasted. These include airline operating, maintenance, and personnel practices and federal ATC management practices. Also, regulatory and corporate policies influence these practices.

While studies of aggregate accident data are useful in identifying and understanding existing

I 11 The spread of the weight over the gears and tires is more important than total weight; e.g., a 727 can cause more pavement wear than a heavier aircraft that distributes its weight over a greater number of tires.

112 Current airport pavement design methods evolved from highway design theory developed in the 1920s and applied to aviation in the 1940s and 1950s, Further design standards were established between 1968 and 1970 through research on two- and four-wheel landing gear, as used on narrow-body aircraft (200,000 to 400,000 pounds). The design theory was successfully extended for 747s, but the pavement loading characteristics of newer heavy aircraft, such as the B-777 and the proposed MD-12, are not well understood, nor have they been tested.

113 Federal Aviation Administration, op. cit., footnote 83, p. 5-4.

114 See 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), p. 69.

problems, the infrequency and variability of major accidents limit FAA's ability to measure aviation safety and estimate short-term changes in risk. Supplementing the accident data is a host of federal safety data resources, including operational databases managed by the FAA Associate Administrators for Aviation Standards, Air Traffic, Regulation and Certification, and Aviation Safety; and specialized data systems kept by NTSB, DOT's Research and Special Programs Administration, and DOD's Air Mobility Command.[115]

Key difficulties in using federal aviation databases identified in the past include consistency and availability y of data, accessibility and compatibility of various data systems, and an emphasis on administrative purposes in the design and use of databases that makes analysis difficult.[116] These issues and problems with inaccurate, incomplete safety and inspection data have prompted FAA to improve its data collection and assessment capabilities.

Safety Data and Indicators

In 1988, FAA established the Safety Indicators program to improve its forward-looking ability to measure and manage aviation safety. Program objectives included both developing and monitoring key safety indicators, and developing a computer analysis tool. The latter, designated an automated decision support system, was intended to obtain information from existing safety databases for sophisticated analysis and presentational But, FAA's progress was limited: according to GAO, the lack of effective user involvement and unclear management commitment helped to delay development of five categories of safety indicators and the analysis tool.[118]

In 1992, the Associate Administrator for Aviation Safety (ASF) established a high-level task force to reexamine the indicators effort.[119] After soliciting input from technical staff that use the various FAA databases. ASF revised the program to reflect trends in accidents and incidents, measures of efficiency and compliance with FAA regulations, and inspector activity.[120] In addition, the new Systems Indicators program includes data on the general operating environment to illustrate potential demands on the aviation system (e.g., gross domestic product, enplanement forecasts, and numbers of certificated airports and airmen).[121] FAA has produced quarterly reports on systems indicators since 1993 for in-house consumption; an annual report to an external audience is in the works.[122]

In recent years. FAA also has begun to integrate its safety databases. The first to be integrated were

[115] Another important source of safety data is the Aviation Safety Reporting System (ASRS), administered by NASA, funded mainly by FAA. and maintained with NASA guidance by the Battelle Memorial Institute. Pilots. controllers, and others submit voluntary and confidential accounts of safety-related incidents to the system. This and other safety databases are described in more detail in OTA's 1988 report, *Safe Skies for Tomorrow*. See ibid., p. 85.

[116] Ibid., p. 77,

[117] U.S. Congress General Accounting Office, *Aviation Safety: Progress on FAA Safety Indicators Program Slow and Challenges Remain*, GAO IMTEC-92-57 (Washington, DC: August 1992), pp. 2-3.

[118] The categories are air traffic, flight operations, aircraft certification, airports, and security. I bid., p. 6.

[119] Steve Cohen, Safety Information and indicators Division, Office of the Associate Administrator for Aviation Safety, personal communication, May 6. 1994. See U.S. Department of Transportation, Federal Aviation Administration. "FAA System indicators Program Report," July 15, 1992.

[120] Cohen, op. cit., footnote 119.

[121] Associate Administrator for Aviation Safety, Office of Safety Information and Promotion, *Aviation System Indicators*, vol. 2, No. 1 (Washington, DC: Federal Aviation Administration, February 1994), p. 3-1.

[122] Cohen, op. cit., footnote 119.

incident databases directly managed by ASF.[123] Currently, **ASF** has ready access to NTSB accident databases and FAA's Accident Investigation Data System, along with earlier systems. As a result, FAA can quickly gather information from a variety of sources on a particular category of operations and prepare material for analysis by users inside or outside FAA.[124] Additionally, FAA is working toward integrat on of some administrative safety databases.

Inspection and Maintenance Data

Also useful for pointing out potential safety problems are data gathered by FAA's airworthiness and operations inspectors, and provided by the airlines and aircraft manufacturers. FAA's Flight Standards Service, under the Associate Administrator for Regulation and Certification, has attempted to improve the collection of these data and target personnel more effectively.[125] These efforts have had mixed success. A familiar contributing factor to the difficulties in upgrading the databases is FAA's failure to fully flesh out the requirements for the new databases and tools in advance of their development (see Problems in System Development and Acquisition in chapter 2).

According to GAO, inadequate oversight by regional and district office managers of safety inspection policies and omissions and errors in the entry of inspection data contributed to shortcomings in a previous automated program for tracking air carrier inspections, the Work Program Management Subsystem (WPMS).[126] The incomplete nature of the required inspections and reporting affected the data's consistency and limited the program's utility in safety analysis. In fiscal year 1990, FAA replaced the WPMS with the Program Tracking and Reporting Subsystem.[127]

In March 1990, FAA announced the launch of two new initiatives intended to improve air safety, the self-audit program and the voluntary disclosure program.[128] As they were originally designed, FAA could use data from both programs to target inspections and make for efficient use of inspector time. According to GAO, FAA did not clearly articulate basic implementation issues, provide convincing arguments on the merits of the programs, or adequately train its inspectors in the programs' benefits and execution; the result has been limited airline participation in the programs.[129]

In 1991, GAO found that the Service Difficulty Reporting System database, intended to allow

123 These four are Operational Error, Pilot Deviation, Vehicle, and Pedestrian, from which the Runway Incursion database is compiled. Charles Huettner, Deputy Associate Administrator for Aviation Safety, Federal Aviation Administration, personal communication, July 22, 1993.

124 Robert Matthews, Special Assistant to FAA Associate Administrator for Aviation Safety, personal communication, May 10, 1994.

125 According t. GAO, there has been a shortage of fully trained inspectors for assessing compliance with both Operations and airworthiness requirements. U.S. Congress, General Accounting Office, *Aviation Training: FAA Aviation Safety Inspectors Are Not Receiving Needed Training*, GAO/RCED-89-168 (Washington, DC: U.S. Government Printing Office, September 1989), pp. I -2.

126 U.S. Congress, General Accounting Office, *Aviation Safety: Inspection Management System Lucks Adequate Oversight*, GAO/RCED-90-36 (Washington, DC: U.S. Government Printing Office, November 1989), pp. 4-6.

127 John Lapin[e, FAA Aircraft Safety program, personal communication, Apr. 19, 1994.

128 Under the se] f-audit Program, airlines are to: develop clearly defined safety evaluation organizations and ensure their independence; report evaluation results directly to [he president or other top managers to ensure their involvement in resolving safety problems; conduct continuing, indepth analyses of such problems; and develop written audit schedules, corrective action plans, and complete records. The voluntary disclosure program was drafted to encourage airlines to report safety violations by extending amnesty for any fines or penalties if the airlines take corrective actions approved by FAA. U.S. Congress, General Accounting Office, *Aviation Safety: Progress Limited With Self-Audit and Safety Violation Reporting Programs*, GAO/RCED-92-85 (Washington, DC: U.S. Government Printing Office, March 1992), p. 3.

129 Ibid., pp. 2-3, 8.

identification of trends in serious aircraft malfunctions, was also plagued with inconsistent, incomplete, and outdated data.[130] Since then, FAA has enabled airlines to enter data directly into the system and accelerated dissemination of the data by providing FAA's Flight Standards Service district offices with direct access to the database. FAA staff also attribute some improvements to the additional field experience many airworthiness inspectors now have when hired.[131]

Other FAA initiatives have had more success at the outset. With funding from the aging aircraft program, the Flight Standards Service established a research effort in 1990 to assist in monitoring the performance of FAA certificate holders (e.g., air operators. air agencies, and aircraft types). Like the original safety indicator program described above, the Safety Performance Analysis System (SPAS) initiative includes the development of an analytical tool, complete with performance indicators and supporting data.[132] However, there are key differences. SPAS metrics are more specific and are intended to help direct the agency's inspector workforce toward areas determined from statistical analysis of a wide array of performance data.[133] In effect, SPAS is an analytic engine that sits atop the Flight Standards Service's databases and monitors financial, maintenance, and operational trends. Data are updated every 24 hours and, using algorithms developed for FAA by the Volpe National Transportation Systems Center, SPAS generates statistical indicators for analysis of anomalies within 1ike groups of aircraft or operators.

Phase 1 of SPAS addresses large airlines and regional commuters, which correspond to roughly 90 percent of the flying public. By 1994, the first phase of SPAS has been established at 17 sites for test and evaluation; a production model is expected, on schedule and under budget, in January 1995. FAA staff attributed the success of the program to learning from prior mistakes in developing analytic tools; and, more importantly, relying on an expert panel to establish system requirements and developing the system with early and frequent input from the project's primary users, FAA inspectors.[134]

Security Data

For security, relying on past threats as indicators of problems allows FAA to attempt to prevent similar incidents, but leaves the agency one or two steps behind in identifying new concerns. In turn, this makes the task of devising effective methods of countering a threat more onerous. Thus, FAA needs a constant flow of intelligence data. To support the intelligence requirements of the aviation security program, the Aviation Security Improvement Act of 1990 created new high-level security positions within DOT and FAA.[135] Figure 3-11 shows the positions and duties of these personnel and their relationship to one another.

The second key area of data needs relates to how deterrence technologies perform. Once a security technology is in the field, operational problems may and do arise. FAA regularly sends staff to the field to evaluate FAA- or airport-installed

[130] U.S. Congress, General Accounting Office, *Aviation Safety: Changes Needed in FAA's Service Difficulty Reporting Program*, GAO/RCED-91-24 (Washington, DC: U.S. Government Printing Office, March 1991).

[131] Harlan Hillers, FAA Office of Flight Standards, Regulatory Support Division, personal communication, May 6, 1994

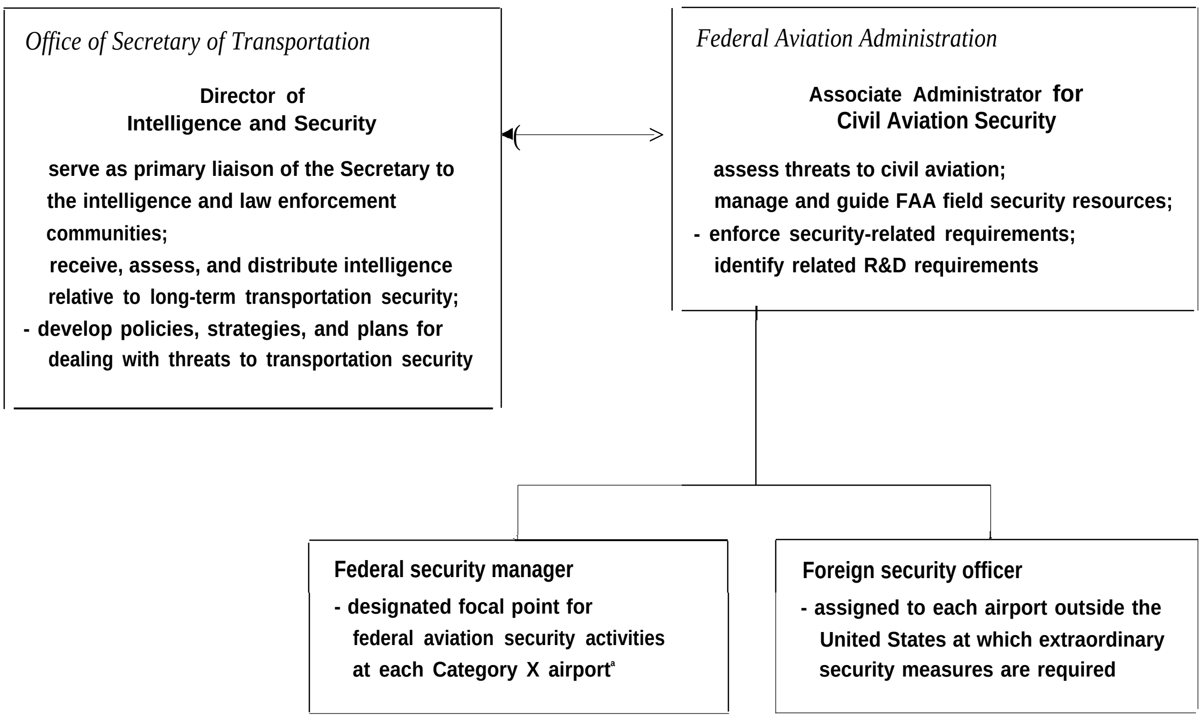
[132] Lapointe, op. cit., footnote 127.

[133] FAA inspectors, approximately 2,000 of them, are sent out to survey aircraft operations and maintenance activities. They log their observations and reports on the Performance Tracking and Recording System. Other data of interest are drawn from service difficulty reports, incident reports, and DOT financial information. Because only the largest carriers are represented in the latter data, FAA is looking to glean financial data on the other operators to support analysis of that risk factor, Frederick Leonelli, Manager, Aircraft Maintenance Division, FAA Flight Standards Service, personal communication, Apr. 29, 1994.

[134] Ibid.

[135] Public Law 101-604, Nov. 18, 1990. See U.S. Department of Transportation, Federal Aviation Administration, *Aviation Security Research and Development Plan* (Atlantic City, NJ: Federal Aviation Administration Technical Center, March 1992). p. 5.

FIGURE 3-11: Aviation Security Positions Created by the Aviation Security Improvement Act of 1990



[a] Category x airports (19) typically have a large number of passenger enplanements per year, along with departing international flights

SOURCE Office of Technology Assessment, 1994, based on FAA Aviation Security Research and Development Plan, March 1992

equipment and procedures. According to GAO, however, the Civil Aviation Security Information System (CASIS) that FAA uses to record the results of its inspections has several drawbacks. For example, GAO found that CASIS does not inelude information on the severity of a deficiency or how it relates to airport security as a whole. Nor can CASIS be used to determine whether unsatisfactory conditions reflect individuals' carelessness or the existence of systemic problems.[136] A more robust analytical approach would assist in evaluating security system strengths to further shape R&D plans and implementation methodologies.

Environmental Assessment

As concern over environmental degradation has grown in the United States and elsewhere, aviation's role has come under increased scrutiny. Ground-level emissions from aircraft and airport sources contribute to local air pollution (e.g., ozone formation). Aircraft emissions at higher altitudes are circulated and dispersed over much larger areas; although not unimportant or insignif-

136 U.S. General Accounting Office, *Aviation Security: Additional Actions Needed To Meet Domestic and International Challenges*, GAO/RCED-94-38 (Washington, DC: U.S. Government Printing OftIce, January 1994), pp. 42-45.

icant, they do not directly affect the immediate area of the release. It is difficult to quantify these emissions and determine their effects.[137]

Federal responsibility for aviation environmental issues is divided between EPA and FAA. The burden of collecting data for assessing environmental impact of aircraft and airport operations typically falls onto FAA's shoulders. For example, EPA's listing of all transportation emission sources uses data from FAA aircraft engine emission inventories. The listing, however, reflects only ground-level operations; the levels of engine emissions at cruise altitudes remain unknown. Neither agency maintains databases of other impacts on the environment (e.g., local air pollution, airports' use of deicing materials and their effects on water quality, and other substances that affect air or water quality).

Aircraft Noise Assessment and Modeling

No real-time monitoring of noise effects takes place on a national scale. Instead, FAA uses models to estimate the impact of aircraft noise on communities. The two most commonly used are the Integrated Noise Model (INM) and the National Noise Impact Model (NANIM).[138]

The Transportation Research Board (TRB) has suggested that these models could be enhanced considerably by combining the sound level estimates with population distribution and land use information.[139] Further improvements include incorporating the effects of local topography and meteorology on sound propagation, and verifying whether or not the models are valid at distances from the airport where climb-to-cruise noise may be the dominant noise source.

The Community Noise sub-element of NASA's Advanced Subsonic Technology (AST) Noise Reduction program is incorporating population density into noise impact models.[140] For FAA, DOT's Volpe National Transportation Systems Center is evaluating whether topography effects on sound propagation should be considered for the agency's models. In December 1993, FAA released a new version of INM that addresses nonstandard atmospheric conditions for prediction of takeoff-related noise. A second enhancement, expected to be released in January 1995, will include basic topography and demographic data (from geographical information systems) to refine calculations of community noise exposures.[141]

VNTSC has also developed software additions to INM to support analysis of noise impact of operations in transitional airspace (i.e., up to 18,000 feet altitude). This would support analyses of proposed flight plan modifications like those made for the Expanded East Coast Plan.[142] In addition, impact modeling efforts will be expanded to integrate aircraft noise certification and airport planning requirements (Federal Aviation Regulations Parts 36 and 150), along with flight operations data to enable air transportation system noise impact prediction.

Noise metric

In 1992, the Federal Interagency Committee on Noise (FICON) reaffirmed the adequacy of the current noise metric, the average sound level des-

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137 Bryson, op. cit., footnote 15.

138 The INM enables FAA t. predict the distribution of areas adjacent to an airport that experience noise exceeding the levels recommended by EPA for residential neighborhoods. The Air Force uses a similar model called NOISEMAP for assessment of the impact of military operations. NANIM estimates the total U.S. population exposure.

139 Transportation Research Board, "Environmental Research Needs in Transportation," Transportation Research Circular Number 389, March 1992, p. 30.

140 Terrence J. Hertz, Manager, Advanced Subsonic Technology, Office of Aeronautics, National Aeronautics and Space Administration, personal communication, Apr. 26, 1994.

141 Thomas Connor, FAA Office of Environment and Energy, personal communications, Oct. 18, 1993 and July 26, 1994.

142 In the late 1980s, FAA began implementation of its Expanded East Coast Plan in order to reduce air traffic delays at the New York City area airports. The changes to the distribution of traffic resulted in many complaints about aircraft-related noise.

ignated as DNL, as the principal means for describing long-term noise exposure for civil (and military) aircraft operations.[143] However, FICON also recommended that the federal government increase R&D on: the "masking" effects of various types of nonaircraft noise when compared with aircraft noise; and including ambient noise in the current assessment methodology.[144] Furthermore, the introduction of engines with higher bypass ratios has shifted the dominant frequency in aircraft noise—a new metric may be required to reflect corresponding changes in perceived noise impact.[145]

TRB also recommended evaluation of supplementary noise metrics, because the existing DNL metric may not be sufficient in other situations. Three areas in which community response (i.e., expression of annoyance) to aircraft noise exceeds that expected using the DNL metric are:

- near small and mid-sized airports where the average impact of single aircraft overflights within a given DNL contour is much greater than the corresponding impact near a large airport,
- at points distant from airports where new air traffic patterns have introduced recognizable aircraft noise into regions that rarely experienced such noise events previously, and
- near airports where there has been a discontinuous increase in air traffic or a dramatic change in air traffic patterns.[146]

Air Quality and Global Climate Change

Aviation can affect the atmosphere on both local and global scales. For example, aircraft and airport-related operations have an impact on the attainment of regional ozone standards, air toxics levels, and smog.[147] Estimating the total quantity of pollutants and their impact on local air quality requires knowledge of specific pollutant emissions and their behavior in the atmosphere. In addition, subsonic aircraft engine emissions are suspected to contribute to global climate change (e.g., through nitrogen oxide and water vapor emissions at high altitudes).

In the United States, EPA calculates average emission factors for various types of aircraft and, using FAA-supplied operations data (i.e., the number of takeoffs and landings), estimates nationwide aircraft emissions.[148] Data on key pollutant emissions from other transportation sources are gathered from a variety of federal, state, and regional sources, and assembled for inclusion in EPA's annual national emission estimates document.

In most areas, the data indicate that air transportation-related contributions are small or insignificant when compared with other sources. However, because the methodologies for estimating emissions and assessing their air quality impacts have changed over the last decade, comparison of trends for source categories is suspect.[149] Addi-

143 Federal Interagency Committee on Noise, *Federal Agency Review of Selected Airport Noise Analysis Issues* (Washington, DC: August 1992), p. 3-1.

144 Ibid., p. 3-11,

145 Higher frequency noise generated by ultra-high-bypass engine fan blades can cause more annoyance or discomfort.

146 Transportation Research Board, op. cit., footnote 139, p. 29.

147 Alfred W. Lindsey, Director, EPA office of Environmental Engineering and Technology Demonstration, persona] communication, Apr. 18, 1994. Related activities include transportation to and from the airport, fueling, maintenance, and other surface operations.

148 Estimates do not reflect activities above 3,000 feet. U.S. Environmental Protection Agency, *National Air Pollutant Emission Trends, 1900-1992*, *EPA-454' R-93-032* (Washington, DC: October 1993), p. 5-4.

149 See ibid., ch. 5.

tionall y, EPA estimates of aircraft contributions to pollutant emissions may suffer from use of dated information. The agency‘s comprehensive catalog of emission indices, designated AP-42, includes aircraft data from 1980.[150] While new EPA guidance material [151] now reflects FAA’s existing data, the AP-42 information pertaining to aircraft predates almost all of FAA’s data and the promulgation of hydrocarbon standards in 1984. [152]

The capability of analyzing local impacts is improving. In 1993, FAA and the U.S. Air Force jointly issued an updated Emissions and Dispersion Modeling System to assess air quality around airports. FAA also established and released the Aircraft Engine Emissions Database for use in calculating the emissions impacts of specific aircraft/ engine combinations. [153] Over the long term, FAA and EPA may need to address emissions of air tox - ics from aircraft in addition to the nontoxic pollutants already included in the databases. 54

An understanding of aviation’s historical global air pollution impact is lacking, thus additional data gathering and atmospheric modeling efforts to support assessment of upper atmospheric issues are required. A major unknown is the emission factors of engines at cruise altitude. ’55 In June 1992, in preparation for the third meeting of the ICAO Committee on Aviation Environmental Protection, an emissions inventory subgroup initiated a study of global pollution from aircraft emissions.

GERMAN AEROSPACE RESEARCH ESTABLISHMENT (DLR)

Condensation trails (contrails) left in well-traveled flight corridors over central Europe Contra//s and related clouds may have an effect on the Earth's surface temperature and climate, under certain atmospheric conditions, they can persist for many hours

Because the sizable modeling effort in place for NASA’s supersonic research program did not address subsonic aircraft effects on the upper troposphere, in April 1993 NASA established a Atmospheric Effects of Aviation Project. In addition to the continuing Atmospheric Effects of Stratospheric Aircraft element of the High-Speed Research Program, the new effort includes a subsonic assessment focused on defining the issues related to quantifying the impact of current and fu-

150 U.S. Environmental Protection *Agency, Compilation of Air Pollutant Emission Factors, Volume II: Mobile Source.$,* AP-42 (Ann Arbor, MI: 1985). Aircraft data from 1980.

151 U.S. Environmental Protection Agency. “Procedures for Emission Inventory Preparation.” Emissions From Aircraft, Chapter 5: draft, Nov. 1, 1991.

152 A planned revision of AP-42 is on hold. Krull, op. cit., footnote 14.

153 National Aeronautics and Space Administration, *Aeronautics and Space Report of the President: Fiscal Year 1992 Activities* (Washington, DC: 1993), p. 45.

154 Lindsey, op. cit., footnote 147.

155 Jack Durham, Director, EPA Office of Environmental Processes and Effects Research, personal communication, Apr. 18, 1994.

ture subsonic fleet emissions in both the upper troposphere and stratosphere.[156]

CONCLUSIONS

Despite significant advances in safety, airspace and airport capacity, and environmental protection, U.S. air transportation system problems remain. There are few, if any, easy solutions to human error and hazardous weather, costly delays from congestion and poor weather, and public displeasure and concern over aviation environmental impacts. Furthermore, defining the problems themselves is often an arduous task.

Consequently, the data collection and analysis requirements for aviation are daunting; for example, not only must the causes of accidents or delays be determined, but also the efficacy of R&D programs established to mitigate them. While new tools and methods of assessment are being developed to aid in this process, quantitative measures of performance or success are still lacking in some areas. Another limitation is that many R&D projects depend on broader FAA or federal activities for success. For example, the goal of introducing satellite-based nonprecision approaches into most U.S. airports by 1996[157] is one that can be attained only with a cooperative effort by FAA's R&D, safety, ATC, and airport divisions, along with airline operators and avionics manufacturers. Estimating the time and expense required to complete such an effort is problematic, making it difficult to compare the anticipated benefits of this type of R&D program with others. However, FAA is making progress in this endeavor and in its efforts to improve related databases and models.

Perhaps an even more difficult task for the agency has been establishing a more forward-looking analysis capability. OTA finds that a greater emphasis on assessing emerging risks—likely to arise in areas where we lack fundamental knowledge—is still needed. New security risks are examples, along with human performance in an increasingly complex system. FAA has upgraded its databases and developed new analytical tools for illustrating trends and assessing multiple safety, security, and environmental factors. With careful attention to the input and results, FAA will be better prepared to identify emerging problems. In addition to ongoing analysis of system activities and trends, long-term research is essential to continued gains in safety and security and mitigating the environmental impacts of aviation.

As the agency with responsibility for regulating many facets of the industry and operating the extensive ATC system, FAA is constantly faced with many challenges—all of them seeming to demand immediate attention and concerted effort. However, FAA's resources, like those of the federal government as a whole, are limited. Not all problems can be addressed at the same time or to the degree desired by the public, other members of the aviation community, or the government itself. FAA and its partners in aviation R&D must learn where their resources can be applied most effectively and conduct data collection and analysis to support priority efforts.

[156] National Aeronautics and Space Administration, Office of Aeronautics, "Atmospheric Effects of Aviation Project Flyer," March 1994, p. 7.

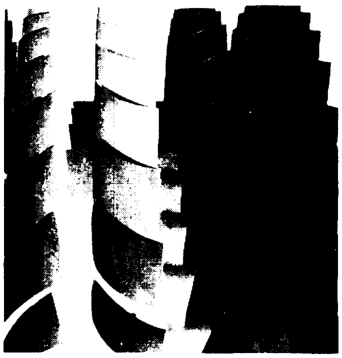
[157] Federal Aviation Administration, op. cit., footnote 42, p. 1-13.

Research and Technology Issues 4

In December 1903, the Wright brothers conducted the first controlled, powered flight of an airplane near Kitty Hawk, North Carolina. This event heralded a new age of adventure and service, and decades of aviation research and development (R&D) have since fostered the growth of an extensive industry. An example of the degree of change witnessed in aviation is that a Boeing 747 aircraft fuselage could contain not only the Wright brothers' plane but *its entire fright path.* More important than the dramatic growth in aircraft size is that federal research and technology efforts have helped to make aircraft operation safer, more economical, and quieter.

Innovations in technology also have provided for effective and efficient methods of managing air traffic in congested airspace and on crowded airport surfaces; reliable, rapid means of communication over vast distances; advanced warning of hazardous weather; improved air- and crashworthiness; reduced security threats; and enhanced training methods for personnel throughout the industry. However, a broad array of basic science, risk assessment, technology development, and test and evaluation efforts is needed to improve existing technologies and add new functions to the air transportation system, strengthen analytic capabilities in order to identify and clarify emerging issues, and develop technology or procedural options to unresolved problems.

As both the regulatory agency for civil aviation and the operator of the nation's air traffic control system, the Federal Aviation



[1] Roger E. Bilstein, *Orders of Magnitude: A History of the NACA and NASA, 19/5-1990,* NASA SP-4406 (Washington, DC: National Aeronautic and Space Administration, 1 989), p. 2.

Administration (FAA) has a central role in defining aviation R&D priorities. FAA supports R&D in three areas: capacity and airspace efficiency, safety and security, and aviation environment protection. The National Aeronautics and Space Administration (NASA) and the Department of Defense (DOD), however, are the primary contributors to the research and technology base from which solutions to many aviation problems are drawn.

This chapter describes areas of long-term research that cut across FAA's operational, regulatory, and infrastructure development missions, and likely will help fill knowledge gaps and support aviation technology development in the future. It also discusses innovative technologies and technology development efforts currently under way to improve the performance of the civil aviation system.

CROSSCUTTING RESEARCH ISSUES

To lay the groundwork for meeting existing and future technical challenges, long-term R&D in several areas is essential. In addition, R&D is required for a clearer understanding of the impact of aviation on the world around it. Five areas of study—human factors, atmospheric science, computing methods, software, and materials—have benefits that cut across FAA's missions.

Human Factors

In 1981, the President's Task Force on Aircraft Crew Complement identified the need for FAA work in a number of research areas related to human factors.[2] FAA released its first human factors research plan in 1985. Believing a new, comprehensive effort in identifying and addressing human factors in aviation was still needed, Congress identified human factors as a critical research area in the Aviation Safety Research Act of 1988.[3] In response, FAA established a Human Factors office under the Executive Director of Regulatory Standards and Compliance and a Human Factors Coordinating Committee, chaired by the Chief Scientific and Technical Advisor for Human Factors.

In April 1991, FAA issued the National Plan for Aviation Human Factors.[5] The plan's fourfold purpose is to:

- identify the technical efforts necessary to address the most operationally significant human performance issues in aviation and acquire the necessary resources to fund these efforts,
- efficiently allocate resources by coordinating various government laboratory programs,
- communicate research needs to academic and industrial "centers of excellence," and
- facilitate the transfer of human factors knowledge to government and industry.[6]

Since its initial publication, the National Plan has focused increasing attention on human factors within FAA; effected increased coordination among NASA, DOD, and FAA research elements; and spawned a number of actions directed toward the application of research products.[7]

NASA contributes extensively to human factors research for civil aviation. NASA Langley Research Center and NASA Ames Research Center, historically responsible for the bulk of this work, investigate physical aspects and psycholog-

2 The president's Task Force on Aircraft Crew Complement, "Report of the President's Task Force on Crew Complement," unpublished manuscript, July 2, 1981, pp. 8-12.

3 Public Law 100-591", Nov. 5, 1988.

4 The directorate has since been abolished; the Human Factors program now falls under the authority of the Executive Director for System Development.

5 U.S. Department of Transportation, Federa] Aviation Administration, *National Plan for Aviation Human Factors* (Washington, DC: April 1991).

6 Ibid., vol. 1, p. 1.

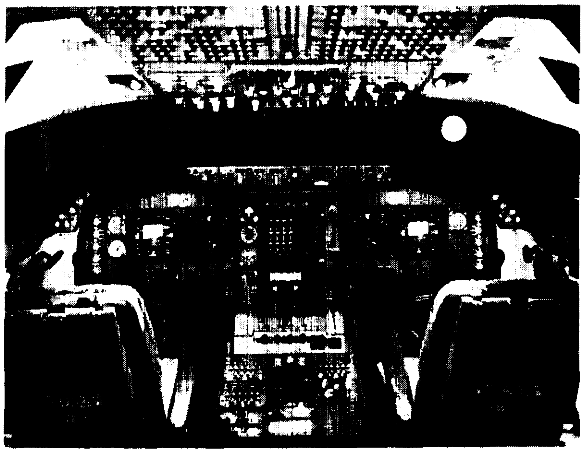
7 Mark Hofmann, FAA Chief Scientific and Technical Advisor for Human Factors, personal communication, Apr. 15, 1994.

ical elements, respectively.[8] NASA and FAA coordination is achieved through the FAA/NASA Executive Coordinating Committee and guided by a Memorandum of Understanding (MOU) for all areas of collaborative research. In addition, FAA has established a new human factors laboratory at the Technical Center.

Human factors R&D comprises a large part of DOD's broad effort in Human Systems Interface (HSI), which addresses the full spectrum of military systems including aviation and ground-control systems. Funding for HSI, one of DOD's Key Technologies, was approximately $170 million and $131 million in fiscal years 1993 and 1994, respectively.[9] An interagency agreement with DOD similar to the FAA/NASA MOU is still under development—DOD laboratory reorganization and the lack of a focal point representing all services contributed to the delay in formalizing a cooperative agency link. *[0] However, FAA has established Memoranda of Understanding and Agreement for joint efforts with individual service laboratories. Focal points have now been established in the Office of the Secretary of Defense and each of the three services, supporting formalization of coordination and joint program planning.[11]

Automation

The first objective of FAA's human factors plan relates to 'human-centered" automation and the design of advanced systems that capitalize on the relative strengths of humans and computer-based technologies.[12] Much is being done in this area. but much remains to be done. For example, using its Human Engineering Methods Laboratory. NASA Langley researchers study the behavioral and psychophysiological response of flight deck crew to assess mental workload demands and measure their response and awareness in individual performance states. The Ames Research Center is developing human performance models for the design, analysis. integration, and prototyping of human-machine systems. Applications include aging aircraft inspection, cockpit display. and electronic checklists. Other intelligent cockpit aids under evaluation include route replanning, windshear advising, task-tailored flight information management, and fault monitoring.[13] Studies of countermeasures to pilot fatigue, effectiveness of electronic checklists and decision aids in reducing errors, and the suitability of data and graphical


BOFING COMMERCIAL AIRCRAFT GROUP

Advanced cockpits, like that designed for the Boeing 747-400 feature electronic, flat panel dlsplays and offer higher /eve/s of aufomation

[8] 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, 1988), p. 129.

[9] Maris Vikmanis, Office of the Secretary of Defense (focal point for HSI), personal communication, Apr. 18.1994. In comparison, fiscal year 1994 funding for human factors R&D at FAA and NASA was $27.3 million and roughly $59 million. respectively.

[10] Hofmann, op. Cit., footnote 7.

[11] Vikmanis, op. cit., footnote 9.

[12] Federal Aviation Administration. op. cit., footnote 5, vol. I, p. 5.

[13] Paul C. Schutte, National Aeronautics and Space Administration, "Real-Time Fault Monitoring for Aircraft Applications Using Quantitative Simulation and Expert Systems," *Proceedings of the 7th AIAA Computers in Aerospace Conference, Monterey, California, October 3-5, 1989* (Washington, DC American Institute of Aeronautics and Astronautics, 1989). pp. 87(1-885.

displays for pilots and controllers are also under way.

Of key interest is the impact of automation in the terminal area air traffic control (ATC) environment. The compatibility of aircraft flight management system and ATC capabilities is also of concern. FAA and NASA have established cooperative projects in their respective Terminal Air Traffic Control Automation (TATCA) and Center-TRACON Automation System (CTAS) programs (see discussion of air traffic management in technology section below). Also, FAA has continuing efforts with researchers in academia and elsewhere examining automation in aircraft and facilities maintenance. In addition, efforts are being made to assess the organizational and procedural impacts that can result when tasks change as a function of automation.[14]

Training and Selection

FAA is looking at devising new training methods for controllers and aviators, both to increase the effectiveness of current programs and to support the needs of a future, highly automated airspace system. Future training methods will likely incorporate factors such as psychology, engineering, human physiology, medicine, sociology, and anthropometry.[15] Important areas of application for crew resource management (CRM)[16] instruction include commuter airline, air traffic, and maintenance settings; in addition, CRM should be considered for pilots' initial as well as aircraft-type transition training.[17] For the selection process, personality characteristics of prospective controllers have emerged as another issue to consider. A major research need for training and selection is to develop a means of accurately measuring the human behavior element in performance.


FEDERAL AVIATION ADMINISTRATION

Advanced air traffic controller workstations have new features—including advanced high-resolution, color displays and the capability for greater automat/on of tasks and data reporting-that affect training requirements

Additional Issues

According to industry, FAA's plan is currently underfunded. In addition, the plan does not address certain elements of the aviation system. Except for a brief discussion of passenger education, the plan makes no reference to human factors related to the cabin environment. Also missing is aviation security human factors, and nowhere is the potential impact of changing demographics or issues specific to general aviation explicitly considered. According to FAA, the plan is being updated to address these issues and incorporate modifications precipitated by changes in technology, insights from implementation, and maturing relationships among plan participants.[8]

Atmospheric Science

Knowledge of both the effects of aviation on the environment and the effects of environmental phenomena on aircraft and the air transportation system is dependent on atmospheric science. Two

14 Hofmann, op. cit., footnote 7.

15 Gunter Endres, "Can New Training Curb Pilot Error?" *Interavia Aerospace Review*, July 1992, pp. 35-38.

16 Cockpit or crew resource management and Line Oriented Flight Training (LOFT) are training programs initiated by airlines to curb pilot error through focusing on communications, interpersonal relationships, and decisionmaking in the cockpit. Ibid., pp. 35-38.

17 Hofmann, op. cit., footnote 7.

18 Ibid.

key areas of supporting R&D applicable to aviation are global climate change and meteorology.

The federal atmospheric R&D effort has many participants, including NASA and DOD, the Department of Energy (DOE), the Environmental Protection Agency (EPA), the National Oceanographic and Atmospheric Administration (NOAA), FAA, the Department of the Interior (DOI), and the U.S. Department of Agriculture (USDA). The National Science Foundation (NSF) supports work at nongovernmental organizations (e.g., the National Center for Atmospheric Research—(NCAR) and universities as well.

Climate Change

A host of measurement technologies, computing and modeling methods, and graphics systems are required to determine the current state of the atmosphere and predict its response to numerous human activities. Complementary research is carried out by DOE. NASA, NOAA, NSF, EPA, DOI, and USDA under the banner of the U.S. Global Change Research Program (GCRP) to help develop sound national and international policies related to global environmental issues, particularly global climate change.[19] First developed and coordinated by the Federal Coordinating Council for Science, Engineering and Technology (FCCSET), GCRP is now managed by the President's National Science and Technology Council Committee on Environment and Natural Resources.[20]

For fiscal year 1994, NASA requested nearly $190 million for its high-speed commercial transport program. According to NASA, over one-half of this is devoted to the study of potential environmental effects and controls[21] (see box 4-1). Little or none of this effort directly relates to subsonic

BOX 4-1: High-Altitude Emissions

The aircraft Industry appears to be confident that high-speed Civil transports can be designed, and that these aircraft will be economically viable as long as they are also environmentally acceptable[1]

Nitrogen oxides (NO_x) and other aircraft engine exhaust gases emitted into the stratosphere contribute to catalytic ozone depletion Recent studies of NO_x effects have revived concerns that the Earth's upper atmosphere may be significantly affected by both conventional aircraft and proposed high-speed civil aircraft[2]

Such worries about the potential impact of supersonic transport (SST) NO_x emissions on the Earth's ozone layer led to the derailment of the U S SST program in the 1970s Only 13 Concordes comprise the current civil supersonic fleet Subject to today's more rigorous environmental standards, the viability of the proposed high-speed civil transport (HSCT) hinges on reducing its ozone-depleting potential to

(continued)

1 Donald J Wuebbles and Douglas E Kinnison "Sensitivity of Stratospheric Ozone to Present and Possible Future Aircraft Emissions," *Air Traffic and the Environment Background Tendencies and Potential Global Atmospheric Effects* U Schumann (ed) (Berlin, Germany Springer-Verlag, 1990), p 108

2 Robert A Egli "Nitrogen Oxide Emissions from Air Traffic," *CHIMIA*, vol 44 1990 P 370

19 Federal Coordinating Council for Science, Engineering and Technology, *Our Changing Planet: The FY 1993 U. S. Global Change Research Program,* A Report by the Committee on Earth and Environmental Sciences, A Supplement to the U.S. President's Fiscal Year 1993 Budget (Washington, DC: Office of Science and Technology Policy, n.d.), p. 3.

20 Donna Wieting, Executive Secretary, Committee on Environment and Natural Resources, National Science and Technology Council, personal communication, May 3, 1994.

21 However, approximately $80 million of this funding relates to providing advanced materials and engine components for the Propulsion system, and enhancing aerodynamic performance—activities that NASA will continue beyond the close of the environmental phase of the High-Speed Research Program.

BOX 4-1: High-Altitude Emissions (

Funding for Environmental Elements of HSRP, FY 1990-94($ millions)[a]

FY 90	FY 91	FY 92	FY 93	FY 94a
$245	$440	$764	$1058	$1346

[a] Requested.

SOURCE Office of Technology Assessment, based on National Aeronautics and Space Administration data, 1994

an acceptable level at the outset, because manufacturers are unlikely to proceed with extraordinarily costly development without assurance that the product will be accepted wholeheartedly [3]

But predicting the atmospheric effects of a large fleet (i e , 500 or more) of supersonic vehicles requires extensive computer modeling of the chemistry, physics, and dynamics of the stratosphere, along with reliable projections of emissions and an improved understanding of their behavior in engine exhaust and aircraft wakes. The current understanding of upper atmospheric chemistry and transport phenomena, hampered by the lack of data from these altitudes, cannot yet support a reliable impact assessment

Since 1990, the National Aeronautics and Space Administration (NASA) has funded the High Speed Research Program (HSRP), one element of that program, the Atmospheric Effects of Stratospheric Aircraft, is a six-year effort to assess the potential effects of proposed HSCTs on stratospheric ozone, atmospheric chemistry, and climate NASA, with Industry support, also is investigating mitigation technologies. HSRP funding requested for fiscal year 1994 was approximately $200 million. The table shows funding levels for the environmental portion of HSRP for its first few years Topics of study Include atmospheric Impact, propulsion emissions and noise reduction (including materials development critical to low-emission combustors and noise-reducing exhaust nozzles), aircraft noise reduction (including some boom), and environmental research aircraft and remote sensors [4]

Unfortunately despite growing interest in addressing the potential Impacts of subsonic aircraft, much of the HSCT work is not applicable because

- different regions with in the atmosphere are affected and data needs are dissimilar, and
- tropospheric and tropopausic interactions, including transfers across the boundary between upper and lower atmosphere, are considerably more complex than those of the relatively tranquil stratosphere, and thus more difficult to assess

Also more is known about ozone depletion (as a result of a continuing international collaborative effort) than the radiative forcing (global temperature) issues associated with conventional aircraft emissions

In support of the environmental element of the recently established Advanced Subsonic Technology program, NASA issued a research announcement in October 1993 soliciting proposals for work directed at understanding and predicting the atmospheric effects of subsonic aviation, in particular, those related to commercial aircraft at cruise altitudes [5] The primary areas of concern, because of their potential role in global warming, are the effects of emissions on atmospheric water content and on ozone concentrations in the upper troposphere and lower stratosphere Requested funding for fiscal year 1994 was $85 million

[3] Estimated development costs for a 250-seat Mach 2 transport are$1Obllllonto$15 billion, direct operating costs could be **40** to *50* percent higher than for current long-range subsonic aircraft Pierre Aparaco and Carole A Shifrin, "European Firms Team on Supersonic Studies *Aviation Week& Space Technology* Apr 11 1994 p 21

[4] Robert Anderson, NASA High Speed Research Division personal communication, Dec 17, 1993

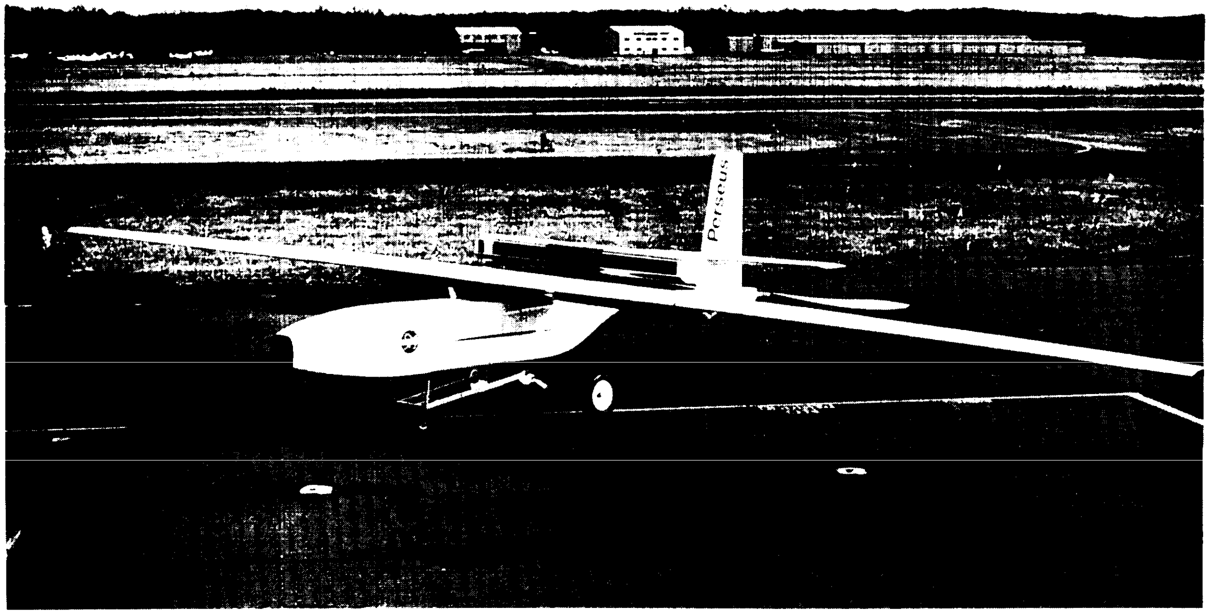
[5] National Aeronautics and Space Administration, "Atmospheric Effects of Aviation/Subsonic Assessment Modeling Data Analysis and Measurements in Support of the Advanced Subsonic Technology Program " research announcement NRA 94- OA-01, Oct 15 1993

aircraft, and expertise in emission control technologies far exceeds our understanding of the impacts of aircraft engine emissions on the atmosphere and global climate.

The task of measuring atmospheric constituents in the upper troposphere and modeling their behavior is daunting. Even the less complex chemistry and dynamics of the stratosphere are not well understood, despite years of observation and calculation. In short, the scientific community lacks definitive analyses of the behavior of upper tropospheric elements to either support or refute assumptions related to aircraft impacts.

At the December 1991 meeting of the International Civil Aviation Organization (ICAO) Committee on Aviation Environmental Protection, members discussed increasing the stringency of the existing nitrogen oxides (NO_x) standard and heard proposals for introducing limits on NO_x emissions at cruise altitudes.[22] Consideration of these limits will likely resume at the next meeting of the ICAO Committee on Aviation Environmental Protection, scheduled for late 1995 or 1996. Participants at a 1992 Office of Technology Assessment (OTA) workshop concurred that an estimated $100 million, spread over a five-year period, would be needed to support a comprehensive scientific assessment of subsonic aircraft's impact on the atmosphere.[23]

The highly developed general circulation model (GCM) is an important tool in predicting future climate changes, as is the parametrization of complex, small-scale physical phenomena.[24] Both depend on atmospheric measurements for further validation. Their capabilities also depend on high-performance computing technologies (see below). Major advances in GCMs are needed, especially those related to the representation of ozone



AURORA FLIGHT SCIENCES

The Perseus is an example of remotely piloted aircraft developed specifically for high-altitude atmospheric data collection

[22] In March 1993, ICAO members ratified the 20 percent more stringent NO_x standard for the landing and takeoff cycle.

[23] Michael Prather, "High Altitude Emissions Case Study," OTA contractor paper, February 1993, p. x.

[24] J.T. Houghton et al., (eds.), *Climate Change: The IPCC Scientific Assessment* (New York, NY: Cambridge University Press, 1990), p. xxv.

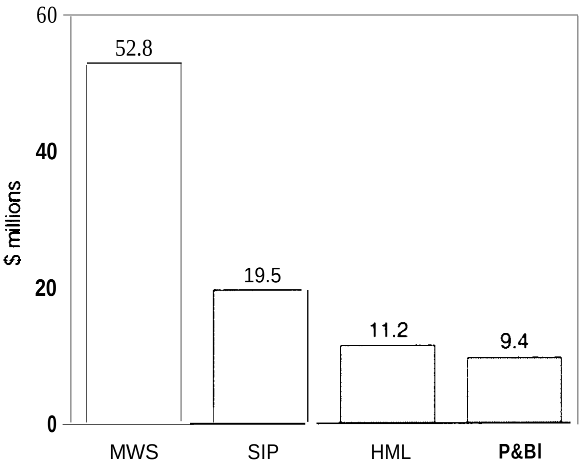
formation, cloud formation and dissipation, and mixing and transport inside and through the tropopause.[25]

Weather

Storm research has significant benefits for a r transportation. In addition to programs for the development of weather observation and data processing systems, a comprehensive federal effort is under way in more basic weather research. In the early 1990s, FCCSET steered this effort, designated as the U.S. Weather Research Program. The program's goals were to achieve by 2000 operational atmospheric prediction for North America based on mesoscale observations and model results, and to establish the scientific and technological basis for global atmospheric mesoscale prediction, in order to meet the weather information demands of the 21st century.[26] Figure 4-1 shows funding for the four major elements of the U.S. Weather Research Program budget for fiscal year 1992. The Department of Transportation (DOT) provided more than one-third of that fiscal year's mesoscale weather system budget; the $1 8.4-million funding came from the FAA's facilities and engineering budget, not the research, engineering, and development budget.

DOT/FAA support was directed at enhancing numerical modeling and numerical weather prediction techniques specific to aviation hazards and for short-term forecasts ("nowcasts"), sensors and software algorithms for the detection and measurement of meteorological phenomena hazardous to aviation, and other tools tailored for aviation meteorologists, air traffic controllers, and commercial and private pilots.[27] For example, R&D is under way at NCAR using dual-wavelength radar to estimate the rate and characteristics of precipitation to be able to more effectively combat icing on the ground. FAA continues to support algorithm development activities by NCAR and the National Weather Service Forecast Systems Laboratory; requested funding for fiscal year 1994 was $19.36 million.[28]

FIGURE 4-1: U.S. Mesoscale Weather Research Program Budget by Science Element, FY 1992



MWS = Mesoscale weather systems
SIP = Scale-interactive processes
HML = Hydro-meteorological linkages
P&BI = Physical and biogeochemical interactions

SOURCE Office of Technology Assessment, based on FAA National Science Foundation, and Federal Coordinating Council for Science, Engineering, and Technology, Committee for Earth and Environmental Sciences, 1992

25 Jack Durham, Dire' -(or, EPA Office of Environmental Processes and Research, personal communication, Apr. 18, 1994.

26 Mesoscale refers t. the intermediate scale of processes and events-smaller, localized phenomena—that interact with larger and smaller scale atmospheric processes to produce local and regional weather. Precipitation, for example, is inherently mesoscale in nature. Federal Coordinating Council for Science, Engineering and Technology, Committee on Earth and Environmental Sciences, Subcommittee on Atmospheric Research, *Predict/rig Our Weather: A Strategic Plan for the U.S. Weather Research Program* (Washington, DC: Office of Science and Technology Policy, July 1992), pp. 7,9.

27 Ibid., p. 32.

28 Greg Geisler, Analyst, FAA Office of the Budget, personal communication, June 22, 1994.

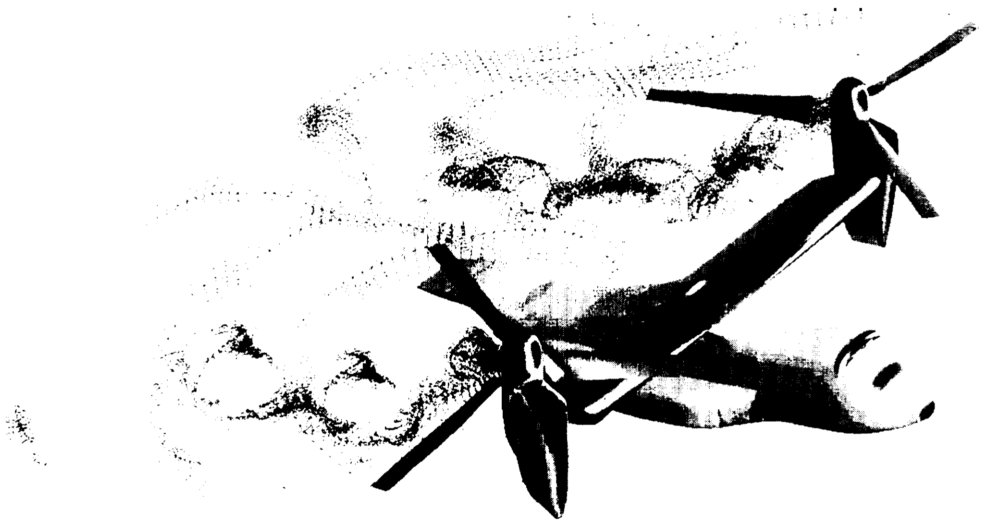
The U.S. Weather Research Program no longer benefits from the visible, high-level coordination effort it had under the FCCSET Committee on Earth and Environmental Sciences, Subcommittee on Atmospheric Research. Under the new National Science and Technology Council committee structure, there is no entity charged with reviewing the multiagency weather research effort, assessing strategies, or developing priorities and goals.[29]

The capabilities derived from fundamental weather science rely in turn on a host of new technologies to integrate and analyze the data, and present it in a useful, timely manner. These technologies, and the corresponding R&D projects, are described in a later section.

High-Performance Computing

Increasingly, advances in aeronautics are closely linked to high-speed computing capabilities. Along with supercomputers, mass data storage capabilities and advanced visualization techniques are essential to continuing improvements in computational fluid dynamics (CFD) and other numerical analysis methods used in the design of aircraft and support systems. Applications include three-dimensional fluid mechanics for combustion, high-lift/low-drag design, system noise prediction, and structural assessments. Modeling of the Earth's atmosphere and of the behavior of elements within that complex environment also depends heavily on computing capabilities, as does real-time simulation of ATC or security system operation.

NASA's Numerical Aerodynamic Simulation Program was created to ensure the United States' continuing leadership in CFD. The program's linking of supercomputers for CFD with high-performance workstations enables visualization of various physical phenomena—such as pressure fields, combustion, and turbulence-that have application in the design of aircraft and propulsion devices and modeling the atmosphere and weather systems.



NASA AMES RESEARCH CENTER

CFD visualization of tiltrotor *aircraft and complex flow phenomena behind rotors*

29 See National Science and Technolog y Council, Executive Secretariat Office, "The National Science and Technology Council FY95 Program Document," unpublished document, Mar. 17, 1994.

A combination of private sector development of hardware, university research in computer languages, and NASA development of application codes and communication technologies has been the driving force behind increases in computing capabilities for aeronautics. However, a major component of theory and tool validation efforts is facilities (see box 4-2).

BOX 4-2: National Aeronautics Facilities

Before advanced computational methods and "virtual" laboratories were a gleam in any researcher's eye, a wide array of facilities was constructed to assist in developing theories of flight and aircraft control Beginning with the first National Advisory Committee for Aeronautics (NACA) wind tunnel, these facilities have been Instrumental in evaluating the performance of scaled models in various flight regimes, gauging the effects of design changes on flow characteristics, allowing designers to optimize and integrate aircraft components; and making powerplants more resilient to debris, severe weather, and other hazards to engine Integrity

One of the first major advances in research facilities was the introduction of closed-circuit, pressurized wind tunnels in the early 1920s. This permitted investigators to vary the density of the air in the tunnel and to extrapolate results expressed in the nondimensional Reynolds number [1] The closed-clrcuit tunnel is one of many types, as summarized in the table

Types of Wind Tunnels

Type	Description
Closed circuit, continuous	Air circulates in a closed loop, permitting conditioning (e g., temperature, pressure, and volumetric flow).
Open circuit	Air is discharged into the atmosphere after passinng through test section
Induction	High-velocity streams of air rejected into tunnel just downstream of test section entrain air into tunnel and establish flow.
Intermittent or blow-down	Utilizes air supply from a storage tank.

SOURCE Office of Technology Assessment, based on H W Liepmann and A Roshko, *Elements of Gasdynamics (New* York, NY John Wiley & Sons, Inc , 1957)

In concert with instrumented full-scale flight tests, the body of validated aerodynamic data grew steadily; refinement of wing designs and engine nacelles, and deeper understanding of many aerodynamic phenomena followed.[2] In turn, this led to increases in aircraft fuel efficiency and reductions in noise,

Awareness of the wide disparity between theoretical and experimental aeronautics capabilities in Europe and in the United States at the outset of the first World War led to the creation of NACA and establishment of legislative support for U S. aeronautical research [3] Today, U.S progress in advancing the caliber of its wind tunnels again lags behind that of some European agencies,

(continued)

1 Expressed as Re, the Reynolds number is a nondimensional parameter representing the relative magnitude of viscosity effects m fluid (e g , air) flow By changing the pressure and velocity of air within a wind tunnel, investigators could simulate conditions on a larger scale of the model being tested

2 Roger Bilstein, *Orders of Magnitude A History of the NACA and NASA, 1915-1990*, NASA SP-4406 (Washington, DC National Aeronautics and Space Administration, 1989), pp 10-11

3 Ibid , pp 3-4

Advances in computing speed and data storage also have facilitated the development of computational structures technology (CST) a tool for computer-based mathematical representations and predictions of various aircraft subsystems' performance in response to inservice conditions.[30] CST tools enable treatment of couplings between structures, aerodynamics, propulsion, and controls in a realistic, reliable manner without resorting to compromising assumptions.[31] CST and the "pa-

BOX 4-2: National Aeronautics Facilities (Cont'd.)

The Boeing Commercial Aircraft Group tests about 12,000 hours per year in wind tunnels—for a couple of reasons, about 20 percent of this testing is performed outside the United States (e g , in France and Russia)[4] First, for the new aircraft designs, the ability to conduct tests at the highest Reynolds number available is necessary The National Aeronautics and Space Administration (NASA) Langley Research Center operates a suitable tunnel, but manufacturers find its "productivity" is so low as to be unusable for aircraft development tests[5] Second, there are no U S alternatives to the Langley tunnel or European facilities In addition, the manufacturers face difficulties in carrying out programs with less stringent facilities requirements Many of the NASA Ames Research Center tunnels regularly used by manufacturers are or will be shut down for refurbishment Some military-owned and -operated tunnels are Increasingly available, but scheduling testing periods in these facilities is risky, as commercial ventures can be displaced by high-prlorlty defense activities

NASA LANGLEY RESEARCH CENTER

The frost NACA wind tunnel was completed m 1920 at the Langley Research Center

NASA and Industry are working to develop the requirements and estimated costs for a new high-Reynolds number high-flow quality and productive tunnel complex A broad, multiagency study of national facilities needs has been completed and is being used as a basis for the NASA-industry study[6] Further advances in the nation's aerodynamic simulation capability depend in part on enhancements to aeronautical testing facilities

[4] Calvin Watson Boeing Commercial Airplane Group personal communication, May 5, 1994

5 That is the turnaround time for setting up a test and collecting data is lengthy

6 Calvin Watson Boeing Commercial Airplane Group personal communication Aug 3 1994 and also see National Facility Study Team *National Facilities Study Summary Report* working draft Feb 25, 1994

[30] Harry Armen et al., "CST Gives Aircraft Industry a Lift," *Aerospace America*, February 1993, p. 32.

[31] Ibid., p. 33.

perless" airplane concept used in the development of the new Boeing 777 aircraft also have potential for revised certification methods.[32]

Complex Software

The development of the Airbus A320 airplane initiated a new era of civil aviation characterized by increasing dependence on flight-crucial digital avionics. The fly-by-light technologies featured in new aircraft depend on complex control systems; this increases the possibility that design faults will persist and emerge in the final product, despite rigorous and systematic testing.[33] Complex software reliability and certification has emerged as a long-term research issue. Guaranteeing that millions of lines of software being developed for aircraft management systems (and ATC systems) are without critical faults may be impossible; FAA may need to determine the level of complexity that permits validation.

Software Verification and Validation

The 1985 Radio Technical Commission for Aeronautics (RTCA) document RTCA/DO-178A provides guidelines for aviation software certification. The document ". . . explicitly refuses to mandate quantitative terms or methods for evaluating software reliability."[34] RTCA emphasizes a disciplined approach to software design over quantitative methods for error analysis. But conventional testing and evaluation techniques cannot address the two major reliability factors, hardware component failures and software design errors.

NASA is investigating the software development process called out in the RTCA/DO-178A guidelines through its Guidance and Control Software experiment.[35] A joint NASA Langley Research Center and RTCA project, sponsored in part by FAA, the GCS experiment is designed to help characterize the software development process and understand failure behavior. Of particular significance is whether or not there are any critical faults[36] latent in the software after it has completed the DO- 178A process.[37]

Complex control systems incorporating new digital technologies are also subject to malfunction and damage from electromagnetic field (EMF) sources. In 1992 and 1993, airlines increasingly chose to restrict the use of certain electronics by passengers during takeoff and landing; portable radios and cellular phones have been prohibited altogether. Another area of concern is the increasing complexity of the national ATC system and its reliance on complex software systems, which may be subject to the same design and EMF hazards.

Materials

A multiyear, multiagency venture is under way to increase the effectiveness of the federal R&D program in materials science and technology.[38] Initially developed and coordinated by FCCSET, the program is now steered by the NSTC Committee

32 For example, extensive use of computer-aided design and manufacturing techniques for the 777 drastically revised the production process.

33 Bev Littlewood and Lorenzo Strigini, "The Risks of Software," *Scientific American*, November 1992, p. 62.

34 Ibid., p. 66.

35 Anita M. Shagnea, Research Triangle Park, and Kelly J. Hayhurst, NASA Langley Research Center, "An Evaluation of a DO- 178A Software Development Process," *IEEE*, April 1991, pp. 97-102.

36 A critical fault is defined as one that would prevent the safe flight and landing of the aircraft.

37 Shagnea and Hayhurst, op. cit., footnote 35, p. 101.

38 Federal Coordinating Council for Science, Engineering, and Technology, Committee on Industry and Technology, *Advanced Materials and Processing: The Federal Program in Materials Science and Technology,* A Report by the FCCSET Committee on Industry and Technology to Supplement the president-s Fiscal Year 1993 Budget (Washington, DC: Office of Science and Technology Policy, May 1992), p. 8.

on Civilian Industrial Technology. Materials of particular interest to the aviation community are advanced metals and polymer matrix composites for airframe structures and high-temperature polymeric, intermetallic, and ceramic matrix composites for subsonic and supersonic gas-turbine engines.[39] Validating the technical feasibility y of manufacturing these components and lowering the cost of engineered materials are challenges that require sustained effort to achieve.[40] Traditionally, these have not been FAA activities: rather, industry and NASA/DOD have taken on such tasks.

Materials science and technology does have a critical role in FAA's R&D programs. For example, airport pavement advances lag behind current aircraft technologies. Federal R&D addresses three areas for meeting new pavement requirements: pavement design and evaluation, new materials and construction methods, and repairs and maintenance techniques. FAA's primary goal is a common pavement design theory; there is growing concern that current procedures do not accurately predict the damage to pavements from existing and new aircraft.[41]

Aircraft

There is already substantial use of composite materials in new subsonic transports, and more is planned (e.g., for future 737 models and the proposed all-composite civil tiltrotor aircraft). Innovative structural concepts and improved fabrication processes will enable stronger and more cost-effective primary wing and fuselage structures.[42] This, and advanced engine technologies, will result in extended range and reduced noise and emissions. Other applications of advanced materials are liquid crystal displays, fire- and smoke-resistant cabin materials, aviation security technologies, and eventual replacements for ozone-depleting substances.

To reduce drag and improve fuel savings for future supersonic aircraft, NASA is investigating laminar flow wing designs and new composite materials for lighter airframes; advanced ceramic and other high-temperature materials for engine cores are also being studied. For example, ceramic-matrix composite materials may be used to reduce the weight and flow requirements of the exhaust and noise-suppression systems for the high-speed civil transport.[43] Rather than using an inherently quieter but complex widely variable engine cycle, a large and effective suppressor can be attached to a relatively simple engine.[44]

A key role for FAA is to evaluate the system implications of the use of these new materials, for example, increased susceptibility to lightning and other flight safety hazards. FAA has requested that the National Materials Advisory Board (NMAB) study the effects of new materials on the safety of future advanced civil aircraft. For the study, NMAB will identify new candidate materials and structures for advanced subsonic aircraft and suggest laboratory testing and inservice monitoring programs; NMAB will also recommend methods for FAA to enhance coordination with industry and other government laboratories.[45] In addition, FAA devotes roughly one-third of its aircraft

[39] Ibid., p. 32.

[40] For a discussion of the major materials technology drivers expected for the aircraft industries, see National Research Council, National Materials Advisory Board, *Materials Research Agenda for the Automotive and Aircraft Industries*, NMAB-468 (Washington. DC: National Academy Press, 1993).

[41] U.S. Department of Transportation, Federal Aviation Administration, *Airport Pavements: Solutions for Tomorrow's Aircraft* (Atlantic City, NJ: FAA Technical Center, April 1993), p. 9.

[42] Federal Coordinating Council for Science, Engineering and Technology, op. cit., footnote 38, p. 60.

[43] Terrence J. Hertz, Manager, Advanced Subsonic Technology, Office of Aeronautics, NASA, personal communication, Apr. 26, 1994.

[44] Bill Sweetman, "Why Composites Wait in the Wings," *Interavia Aerospace Review*, April 1992, p. 53.

[45] National Material, Advisory Board, National Research Council, *NMAB Newsletter*, 1994, p. 7.

crashworthiness/structural airworthiness program to long-term study of new aircraft issues ($1.4 million of $4.1 million requested for fiscal year 1994).

Airport Pavement

The existing classes of pavement are: 1) a flexible, asphaltic concrete layer followed by various layers of sub-base; and 2) a rigid, portland cement concrete layer followed by various layers of sub-base.[46] Current design methods for rigid and flexible pavements do not allow for valid comparison between these two types of pavement.

A layered-elastic pavement design theory is the most likely near-term candidate for permitting rapid analysis of both pavement types and combinations of types (i.e., a rigid or flexible pavement with a flexible overlay), as well as the use of different materials and compositions. FAA has initiated research on this theory and developed a preliminary computer-based design model. DOD Waterways Experimental Station (WES) of the Army Corps of Engineers is also exploring the use of layered-elastic theory for pavement design; FAA is coordinating with DOD to avoid duplication. WES has developed a computer model of the layered-elastic theory for use on a mainframe computer. The FAA Technical Center is doing sensitivity analyses and further developing this code for use on personal computers.[47]

Alternate pavement materials being investigated for their strengthening and life-lengthening properties include recycled rubber (for asphalt) and polymer fibers, grids, and sheets. Remaining research needs include defining future airport-aircraft compatibility issues, particularly those related to larger and heavier planes (i.e., 1 to 1.5 million pounds). Requested spending for airport pavement technology for fiscal year 1994 is approximately $4 million; FAA staff estimate that **$300,000** of this effort is devoted to long-term research.[48]

NEW FUNCTIONS AND TECHNOLOGY OPTIONS

Numerous technologies have been developed to improve the efficiency of aircraft and the ATC system, mitigate hazards to flight, and assist airlines and airport operators in complying with safety and environmental requirements. Nevertheless, expanding the technology base will aid in solving continuing problems. New aviation technologies include advanced sensors and measurement devices, new materials, satellite-based communications and positioning systems, and automated decisionmaking systems. Few, if any, radical changes are envisioned for the air transportation industry; instead, incremental improvements in capacity, safety, security, and environmental protection are anticipated from the implementation of these technologies.

Capacity

The primary components of the nation's ATC system are described in box 4-3. Enhancements to airspace and airport capacity are achievable largely through communications, navigation, and surveillance (CNS) improvements, and optimized air traffic management. Table 4-1 outlines the numerous technology options. In addition, improved weather technologies, enhanced landside and airside access, and alternative transportation technologies offer delay reductions and further increases in system capacity.

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46 Rigid pavements use a stiff upper layer that deforms only slightly, while flexible pavements use a flexible upper layer that distributes deformation throughout all of the pavement layers.

47 Satish Agrawal, Manager, Airport Technology Branch, FAA Technical Center, personal communication, Apr. 30, 1992.

48 John Rybka, FAA R&D Program Analysis Division, personal communication, Nov. 30, 1993.

BOX 4-3: Air Traffic Control System Components

The air traffic control system operates on four levels tower facilities, terminal radar approach control facilities (TRACONs), air route traffic control centers (ARTCCs), and one central flow control facility, the ATC System Command Center (ATCSCC), near Washington, DC Unlike other control facilities, CFC assesses airport capacities nationwide using weather information and meters the takeoff of aircraft to reduce delays at destination airports across the country

Air traffic controllers consider their fundamental responsibility to be maintaining safe separation between aircraft In addition to separation assurance and flow control, the ATC system provides weather and flight information, navigation aids and traffic management, and landing services [1] Controllers' tasks are made easier by numerous tools (e g , computers and display terminals) and, Increasingly, automation aids

Communications

Today, voice radio over the high frequency and very high frequency (VHF) radio bands remains the primary medium for communications between pilots and controllers There is limited use of air-ground digital datalink using the Aeronautical Radio, Inc (ARINC) administrative message system [2] The Federal Aviation Administration is pursuing the transmission of real-time ATC and weather Information using a mode-select (Mode-S) datalink, which would permit digital messages to be addressed to specific recipients

An aggressive federal-industry effort is under way to develop and implement two-way datalink, which will permit automatic dependent surveillance (ADS)—essentially the frequent, reliable reporting of aircraft position data obtained from onboard navigation equipment

Navigation and Guidance

Civil navigation needs spread across the continuum of oceanic, en route, terminal, and airport surface segments; they Include precision and nonprecision approaches and auto-landing [3] FAA is responsible for the development and Implementation of radionavigation systems to meet the needs of all civil and military aviation, except those unique to air warfare [4] Ground-based navigation equipment and airborne receivers currently provide pilots with the aircraft's position relative to an airspace corridor, airport, or runway [5] In the next century, satellite-based systems are anticipated to be the principal radio navigation aid used by aircraft in all segments of flight [6]

Global Navigation Satellite Systems (GNSS)

GNSS offers the aviation community major Improvements in navigation capability The U S Global Positioning System (GPS), developed by the military is available free-of-charge for civilian uses for 10 years, beginning in 1993 In June 1993, FAA approved use of basic satellite-based service for supple-

(continued,)

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1 U S Congress, Office of Technology Assistance, *Airport and Air Traffic Control System,* OTA-STI-175 *(Washington* DC U S Government Printing Office, January 1982), p 68

2 The system is designated the ARINC Communications and Reporting System (ACARS)

3 U S Department of Transportation, Federal Aviation Administration, *Airport Technology Program P/an* (Atlantic City, NJ Federal Aviation Administration Technical Center, November 1991), p 3-15

4 Ibid p 3-18

5 U S Congress Off Ice of Technology Assessment *Airport System Development* OTA-STI-231 (Washington, DC U S Government Printing Off Ice August 1984), p 62

6 U S Department of Transportation, Federal Aviation Adminstration, *Concepts and Description of the Future Air Traffic Management System for the United States* (Washington, DC April 1991), p 8

BOX 4-3: Air Traffic Control System Components (Cont'd.)

mental en route, terminal area, and nonprecision approach navigation. Research issues include worldwide Integrity, failure warning, and accuracy augmentation systems (e g , differential GPS)

Precision Approach and Landing Technologies

FAA requires Increased separation between aircraft and use of Instrument-aided approaches when visibilty is minimal [7] Under the current system (instrument landing system—ILS), all aircraft approaching an ILS-equipped runway must merge into a single fixed path that extends 5 to 7 miles from the runway threshold and descends at a fixed slope (3 degrees or less).8

ILS replacement is scheduled for 1998 under international agreement. In 1978, the International Civil Aviation Organization (ICAO) selected microwave landing systems (MLS), which overcome many of the disadvantages of ILS, as the successor to ILS. The projected installation costs for MLS receivers, delays and changes in FAA's MLS program, and the potential near-term, relatively Inexpensive application of satellite-based technology have undermined the appeal of MLS. In June 1994, the FAA Administrator announced the termination of the development program for MLS for the most restrictive categories of precision landings, Category 2 and Category 3.[9] Installation of MLS Category 1 systems at 22 U.S. airports will be completed as planned.

Surveillance

In domestic airspace, a combination of primary and secondary radar provides controllers with aircraft position data [10] (Air traffic controllers also use surveillance radar to monitor both weather developments in the terminal area and surface traffic movements.) An automated radar terminal serivce computer system (ARTS II or Ill) combines data from both systems for display

The present oceanic ATC system relies on pilots' hourly position reports, transmitted over human factors voice communications links. This procedural operation requires aircraft to follow rigid, fixed tracks with limited flexibilty often necessitating inefficient separations and routes In the future, datalink and satellite-based navigation systems will permit user-preferred routing.

Weather

Weather service is divided between the Departments of Commerce and Transportation The Federal Aviation Act of 1958 directed the National Weather Service (NWS) to provide reports, forecasts, and warnings required for the safe and efficient movement of air commerce; FAA became responsible for the dissemination of the weather information.[11] Over the years, FAA and NWS have established several joint programs, including the Next Generation Weather Radar (NEXRAD) Program Council. Several of the technological approaches to expanding airspace capacity hinge on providing improved weather Information to pilots, flight dispatchers, and controllers.

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7 F/@ classifies the weather conditions as Category 1, 2, and 3, in order of their severity The least stringent of the approaches, Category 1, establishes a 200-foot ceiling and l/z-mile visibility requirement

8 Off Ice of Technology Assessment, op cit , footnote 1 P 92

9 *CNS Outlook*, vol 2, No 6, June 151994 P 3

10 The Primary radar issues radio pulses and estimates an aircraft's distance Using reflected signals Secondary surveillance radar (SSR) uses beacons or transponders, aboard the aircraft to transmit coded identity, position, and altitude responses to ground-based interrogators The SSR ground equipment and onboard transponders are known collectively as the Air Traffic Control Radio Beacon System

11 Edwin S Harris Jr Associate Administrator for Development and Logistics, FAA, testimony at hearings before the House Committee on Science, Space, and Technology, Subcommittee on Transportation, Aviation, and Materials, Sept 30, 1987, p 59

TABLE 4-1: Technology Options for Enhancing the Performance of the National Airspace and Airport Systems

Enhancement area	Requirements	Enabling technologies
Reduced en route separation	**Frequent reliable communications, precise,** reliable onboard navigation	Datalink, satellite communications, navigation, and surveillance-global navigation satellite system
Increased aircraft arrival/ departure rate	Reduced Iongitudinal separation	Wake vortex detection and prediction
	Reduced arrival time variability	Automated sequencing, ATC/aircraft integration
	Reduced runway occupancy time	High-speed exits, advanced landing gear and brake design
	Multiple Independent approaches	Blunder protection precision runway monitoring
	Low-visibility landing	Precision approach aids synthetic vision
	Less delay due to weather uncertain ties	Improved weather detection and fore-casting
Low-visibility surface operations	Improved ground surveillance Enhanced situation awareness	Runway and taxiway status lighting automated detection systems
Minimal runway downtime	Reduced maintenance requirements night construction techniques	New pavement design and construction techniques, improved rubber removal technologies
Reduced airport surface congestion	Reduced gate occupancy time Reduced apron space required for servicing aircraft	Positive visual guidance aids for aircraft docking pneumatic and electrical systems housed underground or in passenger loading bridges

SOURCE Off Ice of Technology Assessment, 1994

Communications, *Navigation, and Surveillance*

The primary objectives of CNS R&D are reduced en route separation requirements and improved terminal area productivity y (see figure 4-2), but expanded communications capabilities will provide additional benefits (e.g., from commercial activities such as passenger entertainment and business communications). The major enabling technologies are:

- satellite CNS (removes line-of-sight constraints):
- digital data] ink (less congestion, more reliability, and faster transmission of messages); and
- precision approach and runway monitoring techniques (including enhanced vision).

Satellite CNS and digital datalink

Both satellite navigation and digital communications are key components of the future global airspace system envisioned by FAA and ICAO (see boxes 1-3 and 4-3). Global Positioning System (GPS) navigation under visual flight rules was approved June 9, 1993.[49] Also in 1993, **FAA** initiated a phased effort to integrate navigation via the GPS satellite network into instrument flight operations, as outlined below:

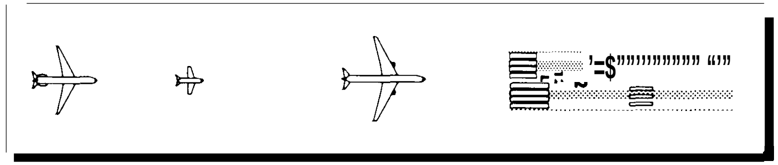
- *Phase 1:* GPS is permitted as a supplemental navigation system. (Ground-based navigation aids must be available as backup.)
- *Phase* **2:** GPS is permitted as the primary guidance system. (Ground-based navigation aids

[49] As a supplemental system. Robert Loh, Mitre Corp. detailee to FAA Satellite Program Office, personal communication, Sept. 3, 1993.

FIGURE 4-2: Terminal Area Productivity Objectives

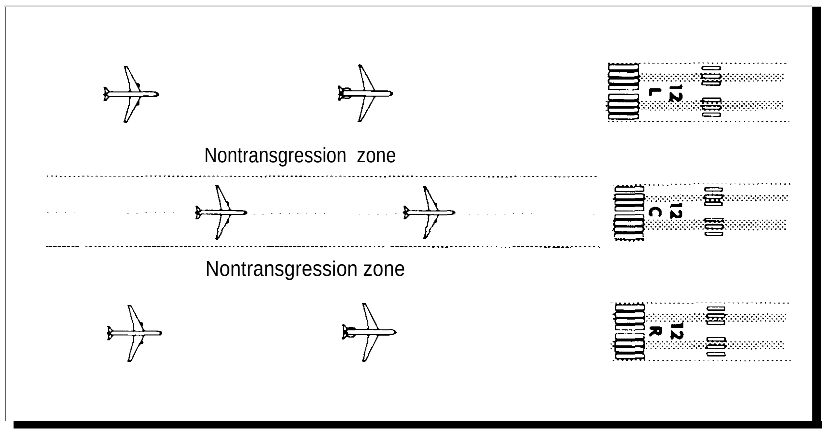
Objectives:
- **More** operations per runway
- More operating runways per airport
- Minimized delay
- No diminished safety

Examples:



Reduced longitudinal separation

Enabling methods and technologies:
- **Enhanced terminal area air** traffic management through upgraded information requirements, advanced traffic displays, and automation improvements
- Integrated aircraft and ATC systems through augmented flight facilities and systems sensitivity evaluation
- Reduced aircraft separation standards through wake vortex systems, ATC-compatible cockpit equipment, ready information for lateral spacing; and requirements development, integration, and assessment
- Enhanced low-visibility landing, runway turnoff, and taxi operations



Simultaneous independent approaches on multiple parallel runways

KEY ATC = air traffic control, CTAS = Center - TRACON (terminal radar approach control) Automation System, FMS = flight management system
SOURCE Office of Technology Assessment, based on National Aeronautics and Space Administration, 1994

are not required at destination or alternative airport.)[5o]

Each of the phases will be observed for the basic applications: oceanic; en route; and terminal area through nonprecision and precision approaches. Phase 1 of the instrument flight rules (IFR) application was enabled when initial operational capability was achieved (i.e., completion of the GPS satellite constellation, announced by DOD in December 1993). For phase 1, receiver autonomous integrity monitoring is required; the GPS Integrity Broadcast, part of the proposed Wide Area Augmentation System,[51] is expected to be the primary means of ensuring signal integrity for phase 2.[52]

While international aviation leaders are convinced of the potential savings satellite navigation will provide to airlines, some have expressed concern that the system remains under DOD control; they worry that the system will be turned off at an y time to preclude precision military attacks against U.S. troops and facilities. In response, 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.[53] In addition, an executive board representing civilian and military interests was established to ensure that civilian worldwide operations remain feasible.[54] Other concerns include the potential for intentional or inadvertent jamming of the GPS signals and "spoofing."[55]

FAA, in the meantime, is working to obtain international definition and endorsement of a global navigational satellite system (GNSS) that can be implemented over the long-term (GPS is perceived as a viable near-term vehicle for satellite navigation capability). Toward this end, required navigation performance criteria arc sought. that is, performance-based standards for supporting equipment. There is also talk of a civil ian-funded satellite network for navigation, and hope that the Global Orbiting Navigation Satellite System (GLONASS), initiated by the former Soviet Union, will become operational. Ultimately, GPS may or may not become part of a broader network of systems (including Inmarsat, GLONASS. and state-sponsored satellite systems) that compose GNSS: at the very least. the United States wishes to participate in the negotiations over the system's structure.[56]

A concurrent effort aimed at improving airspace efficiency via satellite CNS is under way to permit automatic dependent surveillance (ADS, see box 4-4). ADS promises significant fuel savings for flights in oceanic airspace: domestic ADS is not anticipated until the next century. Until then, integration of flight management systems and four-dimensional navigation systems with ground-based sequencing for user-preferred routing and increased fuel savings is the goal.

50 John J. Fearnsides, Senior Vice President and General Manager, The Mitre Crop,, personal communication. Apr. 20, 1994.

51 In June 1994 FAA announced the launch of a six-year program to develop the Wide Area Augmentation System (WAAS). Scheduled to become operational in 1997, WAAS will use a network of ground stations to enhance the integrity and availability of GPS signals for support of all phases of navigation. The system also has the potential for use in Category 1 precision approaches. This last capab i l ity, st i 11 under consideration by a joint DOD DOT task force, hinges on the dissemination of differential correction signals by satellite. "FAA launches WAAS Program," *CNS Outlook*, vol. 2, No. 6, June 15.1994. p. 1.

52 Ibid.

53 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.

54 Fearnsides, op. cit., footnote 50.

55 *Jamming* relates t. a signal made unavailable, a condition recognized by system users. *Spoofing* refers to the intentional issue of an erroneous signal, unknown to an aircraft. GPS signal format and size of the constellation make spoofing difficult, although i t pows the greater safety risk. Jamming, while more technically feasible, is a risk common to other navigation systems. Loh, op. cit., footnote 49.

56 Michael Shaw, Satellite System Manager, FAA Satellite CNS program, personal communication, Sept. 3, 1993.

BOX 4-4: Automatic Dependent Surveillance

Automatic dependent surveillance (ADS), which is not yet available, will implement satellite-based navigation and communications to provide real-time surveillance Information over the ocean and in low-density en route airspace. Current voice relay of position reports wiIl be replaced with two-way datalink, which is essential to full implementation of ADS Also needed are adequate ground-based systems to display aircraft positions to air traffic controllers

Using datalink, information generated by an aircraft's onboard navigation system can be automatically related via satellite to air traffic control centers and displayed in a manner similar to radar. Frequent and rapid transmission of accurate aircraft position data, along with quick receipt of ATC instructions, offers reduced separation and optimized flight routes, even over remote areas [1] In addition to position reports, ADS wiIl provide aircraft intention and operational data that support air traffic management and collision avoidance tools.[2]

U S airlines expect substantial savings of time and fuel over oceanic routes with Implementation of ADS methods Quickly obtaining clearance to climb to higher altitudes as fuel loads lighten or to change routing to achieve more favorable wind conditions are the key mechanisms for reducing fuel burn Today, track systems over the Pacific and North Atlantic Oceans are adjusted twice daily in response to forecasted winds More precise navigation capabilities (such as those possible with the global navigation satellite system) and ADS wiIl enable decreased Iongitudinal separation between aircraft, helping to reduce delays in congested flight tracks particularly over the North Atlantic.

With the Federal Aviation Administration, United Airlines has participated in position reporting trials over the Pacific Ocean since April 1992 and is already saving as much as $100,000 in fuel costs per year for the 747 aircraft Involved [3] Estimated savings are $2 million for 19944

Gwen a 1995 implementation date, United Airlines expects cumulative savings of $200 million in fuel and direct operating costs for the balance of the decade [5] The airlines are pressing the FAA Administrator to push for the 1995 start date However, FAA does not expect the supporting ground infrastructure to be in place until 19966 Part of the delay relates to FAA's Oceanic Display and Planning System (ODAPS), intended to provide controllers with accurate, continuous display of aircraft positions based on pilot reports; ODAPS has experienced a number of software problems In addition, there are institutional issues to overcome regarding provision of the ground-ground data communications link (i.e., between ATC facilities in different sovereign systems) and validated procedural changes.

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1 U S Department of Transportation, Federal Aviation Administration, *Concepts and Description of the Future Air Traffic Management System for the United States* (Washington, DC April 1991), p 9

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

3 "United Expects $300 Million in Saving From SATCOM," *Aviation Week & Space Technology*, Oct 12, 1992, P 40

4 Scott Stahr, Staff Representative, New Technology Engineering, United Airlines, personal communication, Aug 5, 1993

5 Ibid

6 Joseph Fee, Manager, FAA Oceanic System Office, personal communication, Sept 3, 1993

Message exchange using datalink offers near-term, systemwide improvements, including relieving overburdened ATC radio frequencies at many terminals.[57] Unlike conventional voice communications, datalink offers both textual (i.e.. directed at humans) and machine-to-machine formats.[58] A common digital system can support all basic functions that depend on radio-frequency propagation (e.g., communications, navigation. and surveillance).[59] In addition, groups of data having distinct priorities can be transferred rapidly on common channels. The primary links will likely be Mode-S, VHF (using commercial communications and reporting systems), and satellites. (See figure 4-3 on datalink connectivity.)

Precision approach and landing

To permit more closely spaced arrivals and departures under IFR conditions, precision navigation, enhanced vision, and improved surveillance capability are required. A favored but largely unproven alternative to microwave landing systems is to augment the accuracy of GPS technologies. FAA has a cooperative research agreement with NASA Ames Research Center for evaluating local differential GPS operational performance for precision approaches, and is coordinating with the ICAO R&D group for developing GNSS navigation (FANS IV).[60]

To date, FAA has approved one nonprecision approach using GPS as the primary navigation aid—at the Steamboat Springs (Colorado) airport, which began in 1994. FAA is planning to use the Houston airport as a test bed for studies of local differential GPS-based precision approaches into mountain airports. Continental Express is seeking supplemental type certification for special (i.e., single operator, not public) Category 1 approaches into Steamboat Springs and Aspen. FAA also is evaluating GPS-based Category 1 approaches in Juneau. Alaska, and likely will begin testing at the Dallas-Fort Worth Airport in late 1994.[61]

Surface guidance, surveillance, and control

Surface traffic procedures at U.S. airports have changed little in decades. Technologies of various complexity offer several potential benefits, including improved pilot-controller communication, reduced controller workload, less time and fuel spent on taxiways and runways, and less risk of runway accidents. Closer aircraft spacing will help to increase the average takeoff and landing rates.

In 1993, United Airlines and Aeronautical Radio, Inc. (ARINC) began conducting tests of differential GPS and a modified ARINC Communications and Addressing Reporting System (ACARS) datalink for real-time surface traffic surveillance at O'Hare International Airport.[62] Advancements in airport surface detection equipment (ASDE) will improve display resolution and weather penetration. Introduction of solid-state ASDE-3 at 31 domestic airports began in 1992. These and related technologies are described in table 4-2.

Lighting and signage changes offer equally welcome safety and productivity improvements. At smaller airports, however, the cost of some new technologies has prompted investigation of alternative means of achieving improved surface guidance. For example, the North Dakota Department of Aviation tested reflective signs for taxiways

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[57] Charles E. Knox and Charles H. Scanlon, *Flight Tests With a Data Link Used for Air Traffic Control Information Exchange*, NASA TP-3135 (Washington, DC: National Aeronautics and Space Administration, September 1991), p. 1.

[58] Andrew Pickens, AvCom, Inc., "Aeronautical Data Links: A Case Study," OTA contractor report, Feb. 28, 1993, p. 2.

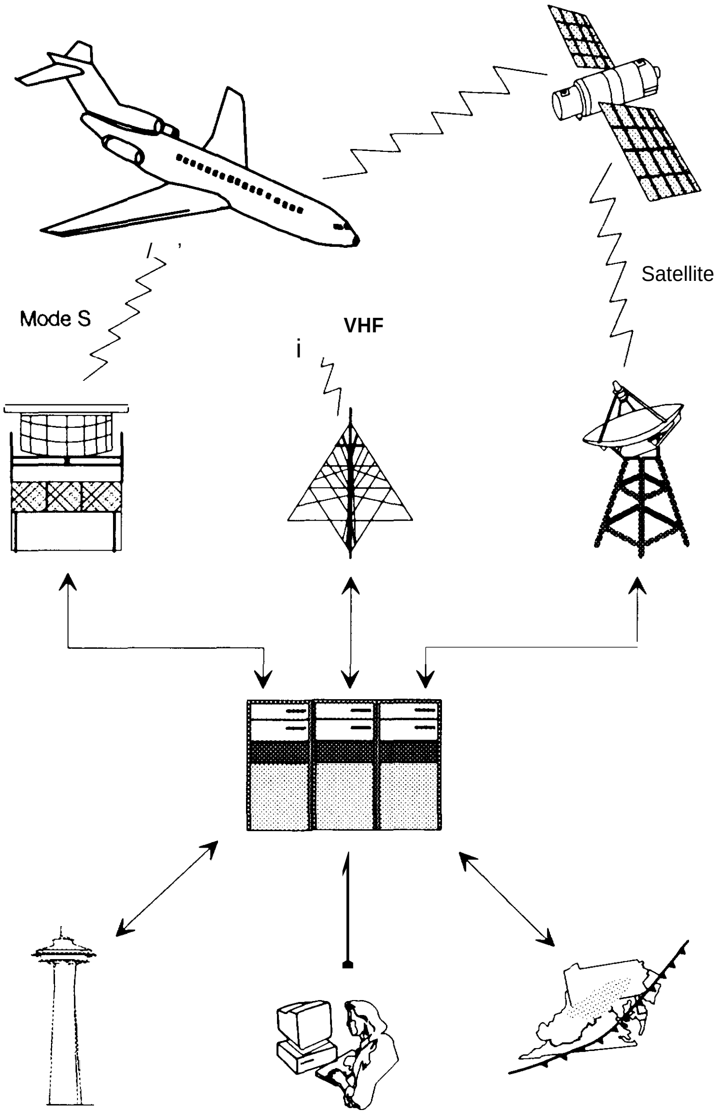
[59] Ibid., p. 3.

[60] U.S. Department of Transportation, Federal Aviation Administration, *Airport Technology Program Plan* (Atlantic City, NJ: Federal Aviation Administration Technical Center, November 1991), p. 3-16.

[61] Gerry Jensen, Airway Facilities Division, FAA Alaska region, personal communication, June 30, 1994; and Thomas Katri, Manager, Flight Procedures Branch, Flight Standards Division, FAA Southwest region, personal communication, July 1, 1994.

[62] "O'Hare Tests GPS, Data Link for Surface Traffic Control," *Aviation Week & Space Technology*, Feb. 1, 1993, p. 52.

FIGURE 4-3: Datalink Connectivity



SOURCE The Mitre Corp 1992

and runways to demonstrate an alternative to expensive FAA-mandated internally illuminated signs. At one airport in this project, the cost for purchase and installation of reflective signs was $1,250, compared with an estimated $17,500 for electrically illuminated signs required by FAA.[63] FAA subsequently placed a moratorium on the signage mandate, pending further analysis.[64]

63 Gary Ness, Director of North Dakota Aeronautics Commission, personal communication, Mar. 12, 1993.

64 See Jeanne M, Olivier, "Aviation Research and Technology Needs for Airport Operators and State Aviation Authorities," draft OTA background paper, July 1, 1993, pp. 14-15.

TABLE 4-2: Airport Surface Traffic Surveillance and Control Technologies

Technology	Purpose	Comments
Airport Surface Detection Equipment (ASDE-3)	Provide controllers with real-time, high-resolution display of ground traffic positions via radar and datalink.	ASDE-3 to be placed at 37 busiest domestic airports—first field site is Seattle-Tacoma International Airport (Sea-Tac) in 1994
Airport Movement Area Safety System (AMASS)	Alert controllers to potential runway incursions using automated radar terminal system and ASDE data and safety logic processing,	Operational demonstration at San Francisco International Airport completed, second demonstration planned for Boston
Airport Surface Traffic Automation (ASTA)	Phase 1 Using AMASS, alert controllers to runway Incursions and reforms pilots of runway status. Phase 2 Using Mode-S datalink of differential Global Positioning System position reports, will provide aircraft identification and location on surface situation display; also, automatic traffic planning and datalInk of taxi clearance Phase 3. Provide automatic cockpit alerts, automatic taxi guidance and surveillance, and transmission of route clearance data.	In March 1993, Lincoln Labs and FAA conducted an offline (out-of-tower) demonstration of ASTA-1 status lights at Boston Logan airport
Runway and taxway status lights (e g , stop bars and takeoff hold lights)	Stop bars warn pilots not to proceed on runway until it has been cleared. Takeoff hold lights Indicate that another aircraft or ground vehicle has entered runway	Stop bars tested at Sea-Tac and John F Kennedy International Airport, automated stop bar system initiated at Sea-Tac in 1994 Runway status lights, activated by information from ASDE-3 and AMASS, are being tested at Boston.
Smart lighting	Enable control of individual airfield lights or groups of lights (e g., for status lighting), control .signals are sent over existing power cables	In 1994, completed evaluation of smart lighting with stop bar system at FAA's Technical Center and demonstration at Detroit airport Complete system at Salt Lake City planned for 1995

SOURCE Off Ice of Technology Assessment, 1994

Air Traffic Management

The heart of FAA's efforts to both modernize the national airspace system and meet future air traffic management needs is the development and use of automation to reduce controller workload while making critical information more readily available to pilots. In the mid- 1980s, NASA Ames Research Center began to develop a system for the automated management and control of arrival traffic. NASA's Center-TRACON Automation System-consists of three types of integrated tools:

- Traffic Management Adviser (TMA) sequences and schedules arrival traffic to minimize delays.
- Descent adviser provides cruise speed and descent clearances to help aircraft meet TMA's schedules with minimum fuel consumption.
- Final approach spacing tool (FAST) assists TRACON controllers in spacing aircraft accurately on final approach.[65]

65 Heinz Erzberger, NASA Ames Research Center, "CTAS: Computer Intelligence for Air Traffic Control in the Terminal Area," unpublished document, October 1991, pp. 3-4.

The first major element of CTAS to be evaluated in the field is TMA. FAA selected the Denver Center as the field site; operational evaluations began in late 1992. Completion of the prototype TMA is expected in 1995.[66] A real-time simulation evaluation of FAST, continuing since November 1990, exposes FAA operational controllers to a variety of traffic conditions, including runway capacity-limited arrival rates under IFR conditions, overcapacity rates, closely spaced parallel runway operations, and multiple missed approaches.[67] FAST and descent adviser prototypes are scheduled to be available in 1996 and 1997, respectively.[68]

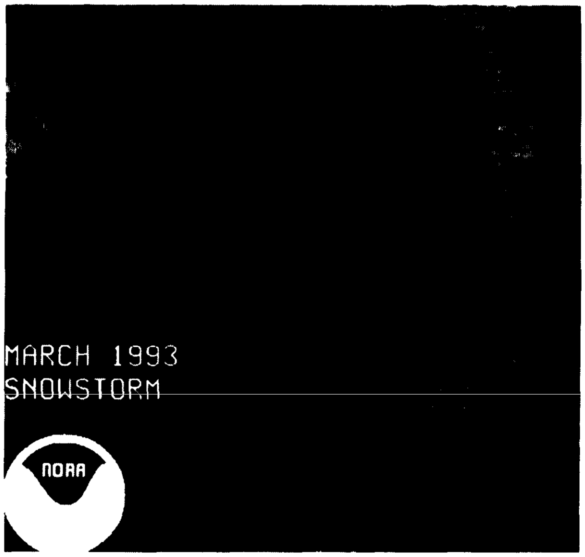
Automated en route air traffic control

Automated en route air traffic control (AERA) is designed to assist ATC personnel in predicting and resolving traffic conflicts (flow control and traffic management), and to permit more fuel-efficient, user-preferred flight paths. To be implemented in three phases, FAA plans to introduce AERA 1 in 1997. Full implementation is expected early in the next century.

Weather Technologies

Another key component of the system is the Advanced Weather Interactive Processing System and supporting communications systems, without which the rapid dissemination of weather data is less feasible.[69] Modernization depends on the integration of Next Generation Weather Radar (NEXRAD), Automated Surface Observing Systems, satellite systems, and supporting mesoscale atmospheric science. The intended result is a significant improvement in forecasting ability, which in turn will allow better assessment of potential weather-related delays across the nation.

To consolidate data from the enhanced observation systems described above into information that is immediately usable by nonmeteorologists (e.g., controllers, pilots, dispatchers, and airport operators), FAA is conducting an aviation weather development program.[70] This program supports three major capital investment plan initiatives, the Aviation Gridded Forecast System, the Aviation Weather Products Generator (AWPG), and the Integrated Terminal Weather System.



NASA AMES RESEARCH CENTER

Satellite observational systems help to reveal hazardous weather phenomena, such as the extensive snow system that disrupted traffic in the eastern United States in March 1993

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66 Barry Scott, FAA Liaison to NASA Ames Research Center, personal communication, Aug. 1, 1994.

67 Erzberger, op. cit., footnote 65, p. 11.

68 The prototype is the product of full operational testing and evaluation; once this phase has been completed for a CTAS element, it can be fielded at any FAA developmental site (e.g., Denver and Dallas). According to FAA, the prototypes will likely be fielded first at the Denver site. Ibid.

69 National Research Council Commission on Engineering and Technical Systems, Committee on National Weather Service Modernization, *Toward a New National Weather Service*, Second Report (Washington, DC: National Academy Press, March 1992), p. 35.

70 David A. Sankey, FAA Aviation Weather Development Program, "An Overview of FAA-Sponsored Aviation Weather Research and Development," unpublished document, n.d., p. 1.

TABLE 4-3: FAA Aviation Weather Development Program Elements

Element	Purpose	Comments
Aviation Gridded Forecast System **(AGFS)**	**Translate state-of-the-atmosphere data** into aviatilon impact variables to produce aviation weather forecasts	Receives meteorological data and forecasts from the National Weather Service (NWS) National Meterological Center
Aviation Weather Products Generator (AWPG)	Create high-resoluhon displays of hazardous conditions and other operationally significant weather	Assembles AGFS data for regional and national flight planning Information is transmitted to en route centers the central flow control facility, and flight service stations
Integrated Terminal Weather System (ITWS)	Generate four-dimensional estimates of current and predicted hazardous weather, datalink to pilots for cockpit display	Receives gridded observation and forecast data from NWS every five minutes and combines these with FAA terminal sensor data (i e from Terminal Doppler Weather Radar and Low-Level Wlndshear Alert systems)

SOURCE Off Ice of Technology Assessment, 1994

Being developed for FAA by NCAR, AWPG is intended to serve both the pre- and en route flight phases on national and regional scales. Products under investigation include icing characterization tools for use in the cockpit, predictive thunderstorm and gustfront forecasting, and turbulence identification. In 1993, FAA completed preliminary testing of AWPG prototypes at the Denver en route center, Denver automated flight service station, and FAA Technical Center. FAA is seeking to transfer further development of AWPG to the private sector and has established Cooperative Research and Development Agreements with commercial weather service providers. FAA facilities and equipment appropriations for fiscal years 1993 and 1994 were $26.1 million and $36.4 million, respectively, for AWPG.[71] Table 4-3 summarizes AWPG and other weather development program elements.

Safety

Through design certification, maintenance oversight, and the introduction of new safety technologies and procedures, FAA attempts to both reduce the likelihood of accidents and mitigate the effects. Objectives include improved collision avoidance, hazardous weather detection, airworthiness of aging and newer aircraft, and optimal selection and training of controllers, pilots, and other personnel. Several of the safety concerns and related technology developments are listed in table 4-4. Some of these issues are described more fully below.

Enhanced Situation *Awareness*

Negotiating through crowded skies, adverse weather. or atmospheric hazards. a pilot relies on many observational tools. Perhaps the most significant change in avionics since the introduction of glass cockpits will be ascribed to a more comprehensive situation awareness system intended to place the pilot in a visual flight rule-like situation at all times.[72] In 1992, Boeing and United Airlines jointly launched the Enhanced Situational Awareness System project, intended to include the following capabilities:

- collision avoidance and techniques for avoiding flight into terrain or obstacles:

[71] U.S. Congress, General Accounting Office, *Air Traffic Control: Status of FAA's Modernization Program*, GAO/RCED-94-167FS (Washington, DC: April 1994), p. 74.

[72] David Hughes, "Boeing, United Pursue Major Cockpit Advance," *Aviation Week & Space Technology*, Nov. 23, 1992, p. 89.

TABLE 4-4: Technology Options for Enhancing Aircraft and Airport Safety

Enhancement area	Limitations	Enabling technologies
Aircraft, component reliability	Lengthy, tiring inspections Harsh operating environments, Long service lives	Fail-soft[a] technologies, nondestructive Inspection/evaluation technologies, anticorrosion applications
Detection, prediction of hazardous weather	Measurement and forecasting Inadequacies, equipment obsolescence	Integrated ground-based sensors, predictive algorithms, airborne detection systems
Human performance	Fatigue, boredom, hubris, injury	Realistic simulators, enhanced human-machine Interfaces, crew coordination, protective equipment,
Fire suppression	Fuel flammability, inaccessibility of some inflight fires, distance to accident site	Onboard extinguishing systems, fire-retardant materials, airport rescue and fire fighting services (low-visibility operations, penetrating nozzles for cabin fires)
Impact survivability	Weight, bulk of materials	Impact-resistant designs (seats and fuselage), '(hardened" evacuation systems
Inflight collisions, runway collisions	Congestion, poor visibility, pilot error, air traffic control error, mechanical failure	Collision avoidance, ground-proximity warning, and enhanced situational awareness systems, surface control and guidance
Cabin air quality	Fuel efficiency goals and available bleed air from engines	Filters.

[a] *Fail-soft* refers to warning of degraded performance

SOURCE Off Ice of Technology Assessment, 1994

- takeoff and landing performance monitoring;
- improved weather radar, turbulence detection, and predictive windshear sensors;
- headup display; and
- enhanced vision for takeoff, approach, and landing.

These technologies have varying degrees of readiness. As of December 30, 1993, all of the Part 121 fleet is required to be equipped with the version of the airborne Traffic Alert and Collision Avoidance Advisory System (TCAS) that detects and displays range, bearing, and altitude of transponder-equipped aircraft within 4 nautical miles, alerts pilots to aircraft within approximately 40 seconds of closest approach, and advises pilots to climb or descend when intruding aircraft is equipped with altitude-encoding transponders.[73]

Pending certification by FAA, United Airlines plans to implement in 1994 predictive or "forward-looking" windshear detection systems on its A320 aircraft. This technology was the subject of a widely appreciated joint FAA/NASA research and development effort, considered to be ". . . independent verification that the [predictive] technology works and is certifiable."[74] Enhanced vision and other landing aids that allow operation in all but the worst weather would provide significant economic returns to the airlines, but difficult technology development and certification challenges lie ahead.

[73] 55 *Federal Register* 13247 (Apr. 9, 1990). By February 9, 1995, all Part 135 aircraft with 10 to 30 passenger-seats must be equipped with the version of TCAS that only provides pilots with traffic advisories. 54 *Federal Register 951* (Jan. 10, 1989).

[74] Jerry Aubrey, Lead Engineer, United Airlines New Technology Engineering group, personal communication, Aug. 5, 1993.

Icing anti Hazardous Atmospheric Conditions

Airlines combat the icing threat by applying (hot) deicing or anti-icing fluids to wings and critical surfaces exposed to freezing precipitation. Varying weather conditions, poor visibility, and gate and runway delays compound the problem of assessing the degree of icing hazard. The effectiveness of deicing and anti-icing techniques varies for different airplane types and precipitation conditions. Most ground deicing operations are done at the gate; few U.S. airports have incorporated runway deicing facilities. Should the pilot determine ice removal is warranted, significant time penalties can result from returning to gate, awaiting a second deicing, and re-queuing for takeoff. Because ice contamination was suspected as the primary cause of the March 1992 crash of USAir Flight 405, considerable public attention focused on FAA's ground deicing regulations. At the time of the accident, FAA rules prohibited takeoff if ice, snow, or frost was adhering to critical surfaces, but no procedures for determining these conditions were delineated.

Under regulations effective November 1, 1992. pilots retain the ultimate responsibility for verifying that the plane's wings are free of ice.[75] However, programs have been established for airline operators and pilots to increase their awareness of the hazard. In addition, specific procedures stipulating how and when to check for and remove ice during ground operations have been added to the regulations.[76] Holdover time, the estimated time before ice accretion begins after a surface has been treated with Type I or Type II fluids, now determines the window of opportunity for takeoff, inspection. and reapplication of fluids.

In 1992. FAA initiated efforts to assess the holdover time of deicing and anti-icing fluids, and conducted a survey of aircraft ice detectors for both inflight and onground applications. Results of this survey indicated that technology for inflight ice detectors was adequate, and in most cases appropriate inflight ice detectors were available from sensor manufacturers. However, FAA noted a void in available on ground aircraft surface ice detectors, and the need for development of new sensor capabilities.[77]

DERAL AVIATION ADMINISTRATION

Commercial transport aircraft undergoing wing deicing

The FAA Technical Center issued a Broad Agency Announcement in February 1993 to facilitate technological developments in this area. Several contracts with industry and grants with academia have been awarded; they will continue over several years. The new technologies typically use some form of video, laser, radar, or other broad coverage technology as opposed to spot sensors that cover only a local area of an aircraft.[78] In addition to R&D in atmospheric icing characterization and the detection of freezing precipitation, FAA is supporting the study of advanced wing and engine deicing concepts, methodologies for their certification, and computer modeling.

[75] 57 *Federal Register* 44942 (Sept. 29, 1992).

[76] U.S. Congress, General Accounting Office, *Aviation Safety: New Regulations for Deicing Aircraft Could Be Strengthened*, GAO/RCED-93-52 (Washington, DC: U.S. Government Printing Office, November 1992), p. 4.

[77] Charles O. Masters, FAA Aircraft Safety Program, personal communication, Apr. 19, 1994.

[78] Ibid.

The FAA/NASA Integrated Wind Shear Program, begun in 1986, focuses on detection, avoidance, and survival of severe windshear conditions, with a goal of at least 30 seconds warning. In 1990, NASA Langley conducted computer and pilot simulations of airplane recoveries from microbursts, evaluating both the recovery procedure and the point at which it was initiated. The latter proved most effective in simulation. Completed in 1993, NASA's research program included windshear phenomena characterization, forward-looking avoidance capability, and flight management system concepts that promote risk-reduction piloting.[79] FAA is in turn developing the related performance standards.[80] The fundamental requirement, according to NASA, for a forward-looking system is: 1) real-time remote sensing, and 2) the ability to reliably measure line-of-sight and vertical components of wind velocity and alert crew to an approaching windshear hazard.[81]

Several advanced technologies offer predictive, forward-looking windshear detection capabilities. These include passive infrared technology, Doppler radar, and light detection and ranging (LIDAR) devices.[82] Passive infrared systems monitor shifts in temperature to identify the cold cores of microbursts. Using microwaves, weather radar gauges windshear patterns by tracking water droplets. LIDAR detects air motion by tracking the movement of dry particles.[83] Other applications of passive infrared technology include detecting clear air turbulence, volcanic ash, wake vortices, and the location of the jet stream.[84] NASA has been testing all three systems aboard its Transport Systems Research Vehicle, a 737 outfitted with both conventional and research flight decks that enable investigation of innovations in cockpit display formats, contents, and in-aircraft operations.[85] These tools can be integrated with enhanced vision or situation awareness systems, along with severe weather displays being developed under the AWPG program.

Aging Aircraft

The key safety objectives for aircraft with long service histories are detecting and arresting any fatigue-initiated structural damage before multiple site damage occurs. Box 4-5 summarizes the primary technical issues. Ultrasonic scanning, eddy-current probing, and other existing inspection technologies require trained technicians and are very tedious. Wider use of some nondestructive evaluation (NDE) technologies has been constrained by equipment cost.[86] New technologies are being sought to improve the speed and reliability of aircraft inspection techniques.

FAA's aging aircraft program includes extramural exploratory research to determine the effects of corrosion on crack growth rates and an evaluation of boredom, fatigue, and tedium expe-

79 Rowland L. Bowles, "Reducing Windshear Risk Through Airborne Systems Technology," paper presented at the 17th Congress of the International Council of the Aeronautical Sciences, Stockholm, Sweden, Sept. 9-14, 1990, p. 1; and Hertz, op. cit., footnote 41.

80 Lester Reingold, "Waging War on Wind Shear," *Air Transport World,* March 1992, p. 70.

81 Russell Targ et al., "Coherent LIDAR Airborne Windshear Sensor: Performance Evaluation," *Applied Optics, vol. 30, No. 15,* May 20, 1991, pp. 2013-2026.

82 J.R. Wilson, "Danger Forecast for Pilots," *Interavia Aerospace Review,* May 1991, pp. 65-66.

83 Reingold, op. cit., footnote 80, p. 70.

84 Ibid.

85 NASA Langley Research Center, "Transport Systems Research Vehicle (TSRV) and TSRV Simulator," *Langley Aerospace Test Highlights,* NASA Technical Memorandum 104090, 1990, p. 92. As of July 1994, NASA has begun to equip a 757-200 model that is scheduled to replace the 737 in 1996. Interim projects are planned for both aircraft until the transition is complete. Hugh Bergeron, FAA Liaison to NASA Langley Research Center, personal communication, July 27, 1994.

86 Alan S. Brown, "Seeing Beneath the Surface With NDE," *Aerospace America, vol. 30,* May 1992, p. 28.

rienced by maintenance personnel during inspection and repair.[87] NASA conducts large-area inspections research and performs other aging aircraft R&D in cooperation with FAA. One of the nation's largest aviation-specific NDE R&D programs is managed by the NASA Langley Research Center.[88] In large part, NASA's structural analysis activities are aimed at predicting the remaining usable life of aircraft. The FAA-supported Center for Aviation Systems Reliability, a consortium of institutions based at Iowa State University's Institute for Physical Research and Technology, is developing analytical models for quantifying inspection effectiveness for various methods and equipment.[89]

NASA LANGLEY RESEARCH CENTER

A robotic rivet inspection tool under evaluation for use in aircraft maintenance

Cabin Safety

Like aging aircraft, an area of particular importance to Congress is cabin safety. FAA develops, tests, and evaluates numerous cabin safety technologies for transport airplanes, rotorcraft, and general aviation aircraft. The majority of the work takes place at the Technical Center and the Civil Aeromedical Institute. FAA also relies on NASA and the National Institute of Standards and Technology for contract or cooperative work in crashworthiness and fire safety, respectively.

Time and the thermo-toxic environment are the most critical survival factors in aircraft accidents involving fire.[90] Beginning in the 1980s, several improvements to the cabin interior have been developed to delay the onset and expansion of smoke and fire. Also, equipment changes have been imposed to help speed the exit rate from the aircraft (e.g., floor-path lighting and dual-lane slides). However, aircraft evacuation system performance is also highly dependent on its human elements; the preparedness and performance of flight attendants factor greatly into the success of an evacuation. Technologies taking on larger roles in training flight attendants include motion-based cabin simulators, full-scale cabin/cockpit evacuation trainers, cabin evacuation simulators, and actual aircraft.[91] Some operators also use computer-

87 U.S. Congress, General Accounting Office, *Aging Aircraft: FAA Needs Comprehensive Plan To Coordinate Government and Industry Actions,* GAO/RCED-90-75 (Washington, DC: U.S. Government Printing Office, December 1989), pp. 8-9.

88 Brown, op. cit., footnote 86, p. 29.

89 Gellman Research Associates, "Coordination and Cooperation in Federal Aviation Research." OTA contractor report, Dec. 30, 1992, p. 16, and ibid., p. 30.

90 Garnet A. McLean et al., "The Effects of Wearing Passenger Protective Breathing Equipment on Evacuation Times Through Type III and Type IV Emergency Aircraft Exits in Clear Air and Smoke," Final Report, DOT FAA AM-89 12, November 1989, p. 1.

91 National Transportation Safety Board, *Flight Attendant Training and Performance During Emergency Situations,* Special *Investigation* Report, NTSB SIR-9202 (Washington, DC: June 9, 1992), p. 18.

BOX 4-5: Primary Technical Issues Posed by Aging Aircraft

Mutiple site damage (MSD), caused by widespread cracking of the structure, leads to degradation of the aircraft's residual strength to an unsafe level

Corrosion is a time-dependent process that decreases the size of structural members and leads to higher stresses and lower structural margins Corrosion has undesirable synergism with the factors that lead to cracking

Fatigue damage, repeated application of pressure cycles during flight, is the primary cause for fatigue damage to the fuselage, whereas fatigue damage to wings is caused by ground-air-ground cycle forces and by pilot-induced maneuvers and turbulence

Nondestructive evacuation (NDE) is Inspection technology central to early detection of corrosion and fatigue-related damage. No single NDE method successfully identifies all types of damage to all types of material.

Structural repairs, intended to restore static strength, may not fulfill damage-tolerance and fall-safe requirements

Terminating actions, in Federal Aviation Administration language, are the structural actions necessary to eliminate MSD Further testing and analysis is required before the design life of the terminating actions or the inspection Intervals for continued airworthiness can be established,

SOURCE National Research Council, Transportation Research Board, *Winds of Change Domestic Air Transport Since Deregulation,* Special Report 230 (Washington, DC 1991)

assisted instruction.[92] However, the training provided in mockups does not test the flight attendants' ability to manage passenger flow, which has become increasingly important as seat density has increased.[93] Computer-based simulations of emergency evacuation could be useful for displaying the predicted effects of different commands and situations on passenger behavior and egress.[94] FAA is developing a new cabin safety program, with increased funding for evacuation R&D. Scheduled to formally begin in fiscal year 1996, the program, in cooperation with British investigators, will study competitive behavior of passengers and the impact of flight attendants on the evacuation process.[95]

Because demographics indicate the average mobility of passengers will decrease in the future, efforts toward extending survivable conditions (beyond the extra time provided by materials improvements) within the aircraft may be more fruitful than attempting to further speed evacuation rates. Two such concepts are cabin water spray systems and passenger protective breathing equipment (smokehoods). Although they are lightweight, simple to use, and mitigate the effects of toxic gases and smoke, smokehoods require time to be donned, possibly delaying passenger evacuation during the period when conditions permit the fastest egress. FAA concluded that this

[92] Ibid., p. 19.

[93] Nora Marshall, Senior Accident Investigator, National Transportation Safety Board, personal communication, Nov. 16, 1992.

[94] See U.S. Congress, Office of Technology Assessment, "Aircraft Evacuation Testing: Research and Technology Issues," background paper, September 1993, pp. 37-41.

[95] Constantine Sarkos, Manager, FAA Fire Safety Branch, personal communication, May 11, 1994.

factor reduces their potential to save lives and may even result in more deaths.[96]

Water spray, because it works independently of fire origin, has more potential to delay flashover—the eruption of flames throughout the cabin—under a variety of fire scenarios.[97] The benefits of cabin water spray include cooler cabin temperatures, suppressed ignition of cabin materials, delay of flashover, absorption of combustion gases, and washout of smoke particles. The possibility of inadvertent system discharge during flight and the weight/cost and reduced visibility are key drawbacks that preclude near-term implementation. The concept demonstrated effectiveness in full-scale U.K. and U.S. test beds suggests further R&D, with the aim of improving the cost-benefit ratio, is warranted.

GREG WALLACE OTA

As for other aviation personnel, airport rescue and firefighting (RFF) crew capabilities must be developed and exercised regularly An RFF vehicle is shown extinguishing a fuel-fed fire during a training exercise at New York S La Guardia Airport

Human Factors

Essential ingredients to safe operation of the aircraft and airspace systems are:

- training for individual technical skills, judgment, and crew communication; and
- technology that supports reliable, timely air-ground communication and improved situation awareness (e.g., aircraft positions, atmospheric hazards, and system faults or failures).

The broadest area of technology application to improve safety is human factors. Employing systems with advanced sensor technologies, communication capabilities, and increased computer involvement are central to a safe (and competitive) air transportation system. However, the end user of these systems and the ultimate responsible agent for safety is still the human. Therefore, FAA and the aviation industry are well aware that the design, introduction, and safe use of these systems must address the human factor.

Existing training tools, such as crew resource management,[98] have been greatly aided by new data and performance assessment methods,[99] as well as by FAA guidelines.[100] High-fidelity simulation and computer-aided instruction have improved the training capabilities of FAA and airlines alike. NASA and FAA have simulation capabilities ranging from low-cost, part-task simulators to full-mission simulators. The high-end aircraft simulators contain full-motion systems and high-resolution visual generators, as reflected

[96] Louise Speitel and Richard G. Hill, "Study of Benefits of Passenger Protective Breathing Equipment From Analysis of Past Accidents," Final Report, DOT FAA' CT-88 03 (Atlantic City, NJ: FAA Technical Center, March 1988).

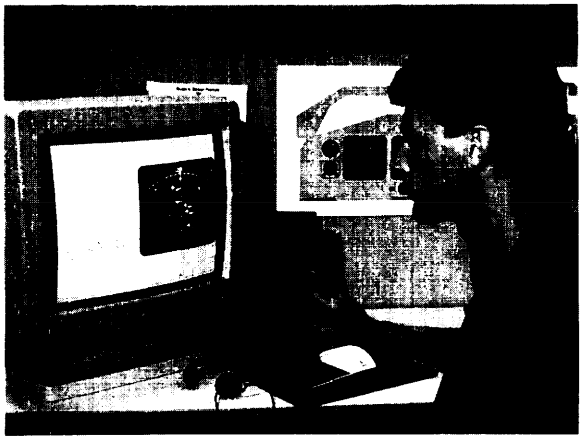
[97] The mandated implementation of state-of-the-art, heat-resistant materials (see 14 CFR 25.853) limits the utility of further materials R&D over the near term. Constantine Sarkos, Manager, Fire Safety Branch, FAA Technical Center, personal communication, Apr. 22. 1992.

[98] See footnote 16.

[99] Earl Wiener et al., *Cockpit Resource Management* (San Diego, CA: Academic Press, 1993); and U.S. Department of Transportation, Federal Aviation Administration, Volpe National Transportation Systems Center, '"Crew Resource Management: An introductory Handbook," DOT-VNTSC-FAA-92 -8, unpublished document, August 1992.

[100] U.S. Department of Transportation, Federal Aviation Administration. "Crew Resource Management Training,"' Advisory Circular 120.51A, Feb. 10, 1993.

NORTHWEST AIRLINES



Desk-top computers are increasingly used in pilot training.

FEDERAL AVIATION ADMINISTRATION

Ever-changing security threats spur advances in technologies and methods for screening aircraft passengers, carry-on luggage, and cargo

in the 747-400 glass cockpit simulator.[101] Beginning-to-end, human-in-the-loop system simulations, complete with air traffic, are possible to establish human factors design and procedure guidance.[102]

In general, the increasing complexity of ATC, aircraft, and security technologies requires an improved understanding of the human-machine interface in aviation. Any technological aid for improving traffic control or aircraft performance must not add to controller or pilot workload or stress, design-induced errors, or loss of situation awareness. Otherwise, these human factors will be compounded and overall safety diminished.

Security

The civil aviation security program is structured around detecting, deterring, or mitigating the terrorist threat, one defined in terms of small quantities of explosives and personal weapons. FAA's R&D effort is directed at both technology development (i.e., developing a suite of security technologies, procedures, and certification methods) and program integration and implementation.[103]

Its major elements are projects in explosives and weapons detection, aircraft hardening, airport security and perimeter control, and the integration of security systems, including the human elements (see table 4-5). This section discusses the complementary efforts in explosives detection and aircraft hardening, and the expanding field of aviation security human factors.

Explosives and Weapons Detection

Small, concealed explosive devices pose the most severe threat because they are difficult to detect and can cause tremendous destruction and loss of life.[104] While technically feasible, the detection of all weapons is complicated by many factors, including the range of weapons available, the inverse relationship between detection threshold and false alarm rates, and the large number of pas-

101 The 747-400 simulator has been operational since October 1993. Hertz, op. cit., footnote 43.

102 Hofmann, op. cit., footnote 7.

103 The technology development component is likened to placing a number of devices on a shelf, ready for use by FAA, industry, or even other governments. Paul Polski, Director, FAA Aviation Security Research and Development Service, personal communication, Apr. 28, 1994.

104 National Materials Advisory Board, Commission on Engineering & Technical Systems, National Research Council, *Detection of Explosives for Commercial Aviation Security* (Washington, DC: National Academy Press, 1993), p. 1.

TABLE 4-5: Technology Options for Enhancing Aviation Security

Enhancement area	Requirements	Enabling technologies
Explosives detection	High throughput, low false alarm rate Less operator fatigue, boredom High confidence for small quantities	X-ray, nuclear radiation, and electromagnetic energy detector computerized tomography Trace detectors, canines Passenger/baggage matching Passive and active passenger screening
Other weapons detection	High throughput, low false alarm rate Less operator fatigue, boredom Recognize new materials	Inductive metal detectors Reflectometry, millimeter wave holography Passive and active passenger screening
Blast mitigation	Low weight Durability Mimmized retrofit costs Compatibility with aging aircraft requirements	Hardened luggage containers Venting Cargo liners Powerplant control methods
Access control	Compatibility with multitude of airport configurations, services Efficiency of movement	Entry control Perimeter surveillance Baltlmore-Washington International Airport demonstration project
ATC system security	Reliability, accessibility	Complex software verification and validation, telecommunications hardening

SOURCE Off Ice of Technology Assessment, 1994

sengers and baggage that must be inspected or screened.[105]

The FAA Technical Center is aggressively working the explosives detection facets of its security program. The R&D program focuses on two new basic explosives detection system technologies, bulk detection and trace detection. Bulk detectors use nuclear radiation, x-ray techniques, or electromagnetic energy to identify explosives based on analysis of their elemental or structural composition. The limitations of existing concepts include size, shielding requirements, throughput, and false alarm rate.

Trace detection technologies rely on identifying the presence of explosives by detecting actual vapor or residual particle contaminants through sampling the ambient air around the passenger or baggage, collecting and separating the chemical compounds of interest, and analyzing the samples for traces of explosives.[106] Current technical challenges include quickly and reliably obtaining an appropriate sample.

FAA plans to begin certification testing of explosive detection system in August 1994 using a protocol developed by the National Research Council.[107] Airport implementation is pending the results of this testing and FAA regulation.

Testing protocols for trace detectors are still being developed the first to be completed will apply to carry-on electronic devices. According to FAA, protocols for other carry-on items and for passengers are not expected until mid- 1995. For checked

[105] Ibid.

[106] U.S. Department of Transportation, Federal Aviation Administration, *Aviation Security Research and Development Plan* (Atlantic City, NJ: FAA Technical Center, March 1992), p. 53.

[107] David Hughes, "FAA Prepares Testing Procedures for Explosive Detection Systems," *Aviation Week & Space Technology*, June 7, 1993, p. 122.

baggage, bulk detectors will likely be the primary screening method; trace detection may be used as a secondary, confirming device.[108]

No single detector exists or will likely exist in the near future that can provide practical, reliable detection of explosives of the types and quantities of concern to the aviation community.[109] A National Research Council committee, asked to review issues surrounding the implementation of the Aviation Security Improvement Act of 1990, concluded that FAA faces a systems engineering challenge of combining detection devices and procedures in a cost-effective manner. The committee recommended that FAA develop simulation tools for analyzing detection device requirements within various operating environments and make these accessible to the aviation community.[110] In its own review of the security program, OTA found that the throughput of security checkpoints can be improved by the incorporation of effective profiling techniques, which allow the elimination of large numbers of passengers from further screening.[111]

Aircraft Hardening

FAA is also seeking ways of making aircraft less vulnerable to explosions should screening mechanisms fail. Baggage container hardening has become a key aspect of FAA's security program, and one intended to yield near-term improvements in survivability. (Box 4-6 describes the aircraft hardening program.)

Human Factors

A more recent concentration in the security R&D program is human factors.[112] FAA is focusing on three areas, the advanced screener checkpoint, domestic passenger profiling, and human systems integration. Guidelines and standards that are based on empirical data do not yet exist for the detection of explosives and weapons, personnel training, selection, and certification. FAA's Screener Proficiency Evaluation and Reporting System (SPEARS) effort is designed to gather this data, model and optimize screener performance, and prepare guidelines and performance criteria.

Work in progress in support of SPEARS includes:

- in-house laboratory and field assessment of the effectiveness of computer-based training and evaluation systems for x-ray screeners; and
- extramural work to define the abilities and traits of the "optimal x-ray screener"; the data are intended for validation of commercial, off-the-shelf tests for screener selection.[113]

Projects are also under way in developing and testing domestic passenger profiling systems, including both passive and active methods.[114] FAA feasibility studies of automated versions are scheduled to begin in late summer 1994.

Additionally, in 1993, FAA began testing and evaluation of an enhanced airport security system, using the Baltimore-Washington International Airport as the test bed for integration of EDS, ac-

108 Paul Jankowski, Systems Development, FAA Aviation Security Research and Development Service, personal Communication, Apr. 28, 1994.

109 U.S. Congress, Office of *Technology Assessment, Technology Against Terrorism: Structuring Security, OTA-ISC-511* (Washington, *DC:* U.S. Government Printing Office, January 1992), p. 57.

110 National Materials Advisory Board, op. cit., footnote 104, p. 5.

111 Office of Technology Assessment, op. cit., footnote 109, P. 71.

112 For its security program, FAA considers human factors to include all security system events, activities, and phenomena that significantly influence operational human behavior and performance (e.g., selection and training, performance assessment and certification, job design and workload management, motivation, human-equipment interface, perception, behavioral lapses, and health. Paul A. Polski, "International Aviation Security Research and Development, ''Journal *of Testing and Evaluation, vol. 22, No. 3,* May 1994, p. 273.

113 "Aviation Security Human Factors," FAA fact sheet, n.d.

114 passive methods include the collection of data from passports and tickets (e.g., flight origin, age, and nationality). Active profiling entails questioning of the passenger.

BOX 4-6: Aircraft Hardening

In 1988, the Federal Aviation Administration's security research and development program focused on weapons detection The 1990 Aviation Security Improvement Act prompted modification and expansion of the program Between 1989 and 1991, overall funding rose approximately 210 percent, most of it devoted to explosives detection [1]

In 1992, the FAA RE&D Advisory Committee Security Subcommittee recommended that funding for the aircraft hardening portion of FAA's security effort be Increased " [the c]ontainer program has the potential to provide significant near-term payoffs and should receive special emphasis and funding to ensure its earliest possible deployment "2 In 1993, the newly established hardening program budget was $449 million, the request for fiscal year 1994 was $78 million

Key Aspects of Hardening Program

FAA's program IS concerned not only with structural sabotage from onboard explosive devices, but also with **spurious** electromagnetic security signals that can sabotage or Interfere with the flight controls of an aircraft [3] In addition, it recognizes the relatively new threat posed by surface-to-air missiles

The hardening program IS cooperative-FAA makes use of the talents at the Air Force's Wright Laboratory, the Navy's China Lake facilities, and the assistance of the National Institute of Aerospace Studies and Services (NIASS) The latter IS an organization that coordinates Industry research and the sharing of data, much of it proprietary [4] Since fiscal year 1993, Wright Laboratory has been conducting a modeling effort focused on narrow-body aircraft explosions [5] The effort has been augmented with FM monies in fiscal year 1994

For validating blast vulnerability analytical methods and testing potential hardening techniques, NIASS has proposed use of an "iron bird" test bed, a reusable steel fixture representative of the forward fuselage of a wide-body aircraft [6] FM expects the test bed to be completed in 19967

In a joint International program, FM is concentrating on wide-body U.S. aircraft French and British Investigators are studying the hardening of Airbus and narrow-body U S aircraft, respectively [8]

(continued)

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[1] U S Congress, General Accounting Office, *Aviation Research Information on Funding, Staffing, and Timing of FAA's Research Projects, GAOIRCED-92-1O8FS* (Washington DC U S Government Printing Off Ice, February 1992) p 20

2 Report of the FAA RE&D Advisory Committee Aviation Security Research and Development Subcommittee Scientific Advisory Panel, June 1992 p 11

3 Paul A Polski "International Aviation Security Research and Development " *Journal of Testing and Evaluation*, vol 22, No 3, May 1994 p 271

[4] N IASS consists of three teams representing the three U S airframe manufacturers a Memorandum of Understanding delineates their respective responsibilities Rokaya Al-Ayat, Aircraft Hardening Research and Technology Program A Case Study OTA contractor report August 1992 p 15

[5] Major Stephen R Whitehouse U S Air Force, Wright Laboratory Program Manager Commercial Aircraft Hardening Program personal communication Mar 11 1993

6 John Amatetti Vice President Operations, National Institute for Aerospace Studies and Services, personal communication Feb 8 1993

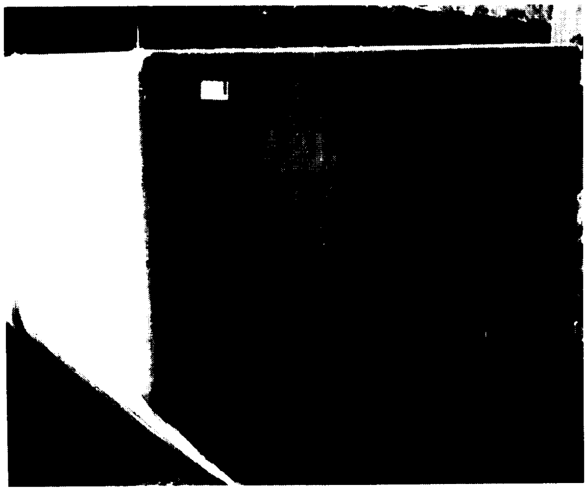
[7] Paul Polski Director FAA Aviation Security R&D Service personal communication Apr 28, 1994

8 Polski op cit footnote 3, p 2 7 1

BOX 4-6: Aircraft Hardening (Cont'd.)

A near-term concept is the hardened baggage container, to be used aboard wide-body passenger aircraft Alternative hardening techniques (also required because containers are not useful for narrow-body and cargo aircraft) Include blast channeling and blankets, energy and fragment absorbing panels, and blow-out panels and venting [9]

In the coming years, several technologies may be used to harden aircraft and their contents Attention to their Initial cost, weight, and durability is needed, but these are not the only issues for U S airlines For example, redesigning the layout of hydraulic systems to make them more resistant to damage, intentional or accidental, presents a problem to easy maintenance of an aircraft. [10] Because of the expense of retrofitting the U S commercial fleet, many aircraft hardening elements will be Implemented only in future aircraft designs



FEDERAL AVIATION ADMINISTRATION

To help prevent catastrophic aircraft damage from small explosives, FAA is investigating hardened cargo container designs Shown is a prototype container constructed of a high-strength, lightweight composite material

Of key importance is the promise aircraft hardening holds for reducing explosives detection requirements.[11] This is particularly advantageous in an environment where the threat is continually changing and system security hinges on intelligence data With explosives detection system targeted at higher explosive mass, expense and the false alarm rate fall and throughput increases FAA is putting together an explosive modeling advisory group to delineate the type of data required and how the data will be used and validated. [12]

Also, hardening may benefit from aging aircraft and catastrophic failure prevention R&D projects that augment the scientific understanding of aircraft materials In addition, safety efforts such as propulsion-only control and the reconfiguration of hydraulic lines enhances the ability to withstand explosions However, to date, there has been little exchange of Information between commercial or military aging aircraft programs and the security program [13]

9 Al-Ayat op cit footnote 4, p 20

10 Polski, op cit footnote 7

11 To cause the same degree of damage to a hardened aircraft requires larger amounts of explosive, Increasing weight and detectability Polski, op cit , footnote 3 p 269

12 Polski, op cit footnote 7

13 An important consideration is the characteristics of the *aging* U S fleet and the extent to which aircraft hardening recommendations are compatible with requirements mandated by the aging aircraft program Al-Ayat, op cit footnote 4, p 30

cess control and intrusion detection devices, security procedures, and other technologies.[115] The airport's Enhanced Security Demonstration project is supported by an interagency agreement with DOE's Sandia National Laboratory, a cooperative R&D agreement with the Maryland Aviation Administration, and a Small Business Administration program contract.

Environment

R&D can assist in improving the environmental acceptability of aviation operations while allowing for further growth in the air transportation industry. For years, federal programs in aircraft noise abatement, engine emissions control, and fuel conservation have been under way, conducted primarily at NASA with help from airframe and engine manufacturers (see discussion in chapter 3), FAA and EPA, along with the U.S. Air Force, also contribute. Environmentally benign deicing and anti-icing materials and recycling/replacement of halon are examples of relatively new objectives of the federal aviation environmental protection effort. Other potential technology applications are listed in table 4-6.

Noise

The federal noise-related R&D program is comprehensive and multifaceted. NASA leads the most extensive effort, directed at reducing aircraft noise that propagates to the ground from a variety of aircraft types—piston-powered, propeller-driven general aviation, business jets. commuters, rotorcraft and the civil tiltrotor, as well as commercial transports. FAA participates in program planning and provides a small amount of funding to NASA ($1.3 million in fiscal year 1994). A complementary effort focuses on minimizing the engine noise transmitted to cockpit and cabin. Improvements in engine technology. airframe design and integration with powerplants, and composites constitute the means for reducing aircraft noise.

TABLE 4-6: Technology Options for Improving Aviation Environmental Protection

Enhancement area	Requirements	Enabling technologies
Aircraft noise	Reduce cockpit and cabin noise, and engine and airframe noise propagated toward ground	Active and passive cancellation devices Engine/airframe integration high-lift/low-drag operations
Airport noise	Reduce community annoyance	Abatement procedures Soundproofing Land use planning
Engine emissions at cruise, water vapor/contrails	Minimize climate Impacts	Combustor improvements, alternate flight procedures
Groundwater contamination, discharge into bays and lakes	Reduce toxicity, oxygen demand, and fertilization	Alternate substances, recovery of glycol
Halons and other stratospheric ozone depleting substances	Minimize use and develop replacements	Recovery, recycling
Airport surface traffic, air pollution	Reduce impact on local air quality.	Electric ground vehicles, reduced idling and taxing times, electric-powered aircraft power unit, supertugs, airpacks[a] Unleaded aviation gasoline Low-emission jet engines

[a] Airpacks are conditioned air supplies used while on the ground

SOURCE Off Ice of Technology Assessment, 1994

[115] "Enhanced Airport Security System: Baltimore-Washing[on International Airport," FAA fact sheet, n.d.

Noise reduction technology

In 1991, the Aircraft Noise Abatement Working Group, chartered by the FAA Research, Engineering and Development Advisory Committee to review past and present aircraft noise abatement technology, identified R&D areas that can ". . . significantly mitigate the [subsonic] aircraft noise problem to offer the promise of improving airport capacity enhancement while maintaining environmental capability."[116] In turn, NASA proposed new subsonic noise reduction research in five areas: engine noise reduction, nacelle aeroacoustics, engine/airframe integration, interior noise, and community noise.[117] The Advanced Subsonic Technology program, a multiyear NASA program initiated in fiscal year 1994, includes these projects.

Higher bypass ratios and swept, lower speed fan blades will be investigated for minimizing engine noise, along with an integrated approach for the installation of engines and wing/high-lift systems. Placing adaptive liners in engine nacelles is another option for damping sound before it is radiated from the nacelle to the ground. NASA also is investigating new active cancellation technologies for reducing noise in aircraft cockpits and cabins, and is looking to extend some of these techniques to reduce engine noise within the nacelle that would otherwise propagate toward the ground.[118]

NASA researchers have demonstrated the active cancellation of interior noise in a one-third scale model commuter aircraft by changing the vibration behavior of the structure.[119] Because of the potential problems this approach poses for manufacturing and aircraft certification, NASA is trying this method on the internal fuselage trim panel.

For engines, one technique relies on microphones, loudspeakers, and electronic processing to generate sound waves at the appropriate time and place that cancel the fan noise propagating through the nacelle before it radiates to the ground. 20 Static tests with aJT15D engine demonstrated 10 to 20 decibel reductions in fan noise. NASA is also looking at ways of actively canceling engine noise at its source (e.g., minimizing the interaction between fan blade wakes and stators). In general, NASA active cancellation R&D goals are to extend the methods to engine source noise, broader frequencies, and wider distribution over the aircraft; of key importance is achieving lower lifetime operating costs for noise reduction systems.

Another objective is high-lift, low-drag airframes that will allow the same payload to be lifted with less power, further reducing engine noise. Research into integrated wing technology for efficient high-lift with minimized wake vortices will contribute to efforts to enable shorter takeoff distances, reduced power requirements, slower approach speeds, steeper climb-out profiles, and optimal flight path control.[121]

Engine Emissions Control

Today's aircraft engines are highly efficient and emit extremely low amounts of "pollutants."

116 Aircraft Noise Abatement Working Group, "Progress in Aircraft Noise Abatement and Recommendations for Future Technology Development," unpublished document, November 1991, p. 1.

117 Hertz, op. cit., footnote 43.

118 NASA Langley Research Center, "Research and Technology," NASA Technical Memorandum 4243, 1990, pp. 54-55.

119 This is accomplished by applying voltage t. thin composite material attached to the skin Or frame of the fuselage. William Wilshire, Advanced Subsonic Technology, Office of Aeronautics, National Aeronautics and Space Administration, personal communication, Apr. 26, 1994.

120 That is, actuators cause pressure waves that rarefy, or disperse, air molecules at the same instant compression waves reach that spot; the result is noise cancellation. Will i am Wilshire, Advanced Subsonic Technology, Office of Aeronautics, National Aeronautics and Space Administration, personal communication, May 5, 1994.

121 Robert Rosen, Deputy Association Administrator for Aeronautics, Exploration and Technology, National Aeronautics and Space Administration, testimony at hearings before the House Committee on Science, Space and Technology, Sept. 27, 1990, p. 3.

Most aircraft can easily attain the NO_x reductions of 20 percent recommended by ICAO, for the landing and takeoff cycle. While the technology base exists for further NO_x reductions of 30 to 50 percent, reduction technology has yet to be developed for extremely high-pressure, high-temperature advanced engines being considered for next-generation transports. In its Advanced Subsonic Technology program, NASA has included R&D on emissions control technologies for current and new-generation subsonic aircraft engines.[122]

FAA's Office of Environment and Energy has established cooperative research efforts with EPA and the U.S. Air Force in emissions and dispersion modeling work and in reduced NO_x combustor design for the high-speed civil transport with NASA.

In June 1992, in support of the next (third) meeting of the ICAO Committee on Aviation Environmental Protection (CAEP), an emissions inventory subgroup initiated study of global pollution from aircraft emissions. FAA and NASA are seeking to establish an emissions abatement technology program like the joint venture directed at aircraft noise.[123] The near-term goal is assessment of control technology to support cost analyses of stringency (emissions restrictions) proposals in time for CAEP/3, tentatively scheduled for 1995 or 1996.

One option for attempting to reduce high-altitude emissions until concepts capable of minimizing emissions at both cruise and landing and takeoff operating conditions are developed and validated is changes in flight procedures (e.g., attempting to fly above or below the tropopause or seasonal route changes). However, the technical feasibility of this approach is suspect, again because the relative impacts of different flight patterns are unknown, strategic control of traffic beyond radar range has not been attained, and significant economic penalties are likely.

Deicing and Anti-icing Methods

Less hazardous alternatives to glycol-based fluids include solid and liquid forms of sodium and potassium acetate and sodium formate.[124] The costs (and availability) of the alternatives vary; all are uniformly more expensive. While effective on airport surfaces, the solid compounds are not feasible for aircraft deicing and anti-icing.[125]

NASA Ames researchers, with support from the U.S. Air Force, are developing a direct substitute for glycol-based aircraft deicing and anti-icing fluids that is intended to be "environmentally friendly" and cost competitive.[126] Analysis of existing fluids is being performed to confirm the properties necessary for the new compound. Subsequent test phases will evaluate whether fluid properties conform with industry standards and the fluids' performance under actual weather and airport conditions.[127] However, for airlines to initiate its use, the NASA/Air Force compound must also be less toxic and/or harmful to aquatic life while being equally effective in removing or preventing ice buildup.

If proven to be a successful substitute, it is expected that the new compound will be used first on

[122] NASA Lewis Research Center is the lead agency for this effort.

[123] Thomas Connor, FAA Office of Environment and Energy, personal communication, Oct. 18, 1993.

[124] Liquid urea, once commonly used, has its own environmental drawbacks and can no longer be applied at many airports to clear runways and taxiways.

[125] In addition, there is mounting evidence that high electrical conductivity associated with such salt compounds poses problems to aircraft and runway lighting. Leonard Haslim, Program Manager, NASA Ames Research Center, personal communication, May 2, 1994.

[126] Leonard Haslim, Program Manager, NASA Ames Research Center, personal communication, Feb. 1, 1993.

[127] Ibid.

runways and other airport surfaces; a lengthy certification process will likely delay use with aircraft. Three of the largest U.S. airlines have offered nonrevenue aircraft for testing.[128]

CONCLUSIONS

Each element of the air transportation system benefits from a multilayered federal aviation R&D effort. Many technologies intended to permit continued advances in aviation already are being designed, tested, and evaluated; they offer new functions and higher levels of automation and, at the same time, promise greater reliability.

However, further progress in some areas awaits better information: quantitative data on the performance of key elements of the aviation system, in particular, the human element; knowledge of how the atmosphere behaves and of the impact of aviation operations on the environment; and analysis of new materials and design methods. The areas of crosscutting science and applied research described in this chapter will offer insights into both emerging and longstanding problems, along with methods for gathering and assessing critical data.

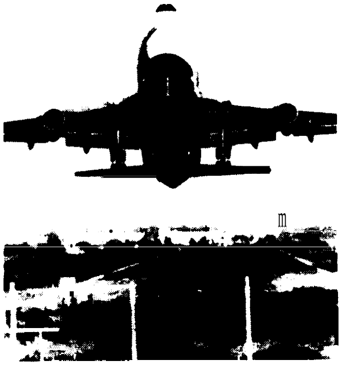
Of vital importance in realizing the benefits of these research and technology development efforts is effective communication and coordination among participating agencies and the user community. For the technology programs in particular, the system implications of their use must be addressed in order to achieve the full measure of their potential without undue delay, cost, or risk.

The introduction of ultra-high-capacity aircraft, for example, will require extensive infrastructure changes; the proposed fleet of new supersonic transports prompts thorough analysis of potential atmospheric impacts; and new satellite-based communications and navigation technologies necessitate changes to air traffic management policies and institutions. In addition, for all sizes of airport and aircraft operations, further attention is needed to the affordability of advanced technologies intended to provide higher levels of efficiency, safety, and security, and to better mitigate environmental impacts. Finally, any modification to the aviation system imposes the requirement to consider the human factors of that change.

[128] Ibid.

Economic Issues for Aviation Operations 5

By many measures, U.S. aviation industries are world leaders, and each industry contributes positively to the U.S. international balance of payments and has significant world market shares (see table 5-1). However, industry finances, employment, and international competition have become crucial issues for the future of U.S. aviation. Congress must now, and in the coming decade, struggle with difficult and often conflicting trade, finance, and other economic policies important to the long-term fiscal health and competitiveness of U.S. aviation. U.S. regulatory and infrastructure decisions, and the research programs that underpin them, will likely have growing implications for U.S. industry economics and competitiveness.



THE U.S. AIRLINE INDUSTRY

The nation's largest carriers increasingly rely on global markets to sustain growth in revenue. In an attempt to offer passengers the most extensive route system, many of the world's carriers have been expanding since the late 1980s—via strategic alliances, marketing agreements, or route acquisitions. The expansion of low-cost, short-haul domestic service offered by startup as well as existing carriers is prompting some of the largest U.S. carriers to concentrate on serving international and long-haul routes and/or to restructure their operations in order to compete with the low-cost carriers.

State of the Industry

International markets have become more and more important to U.S. airlines. Growth in international passenger service by U.S. airlines outpaced both the rise in gross domestic product and the rapid

TABLE 5-1: Selected Economic Indicators for U.S. Civil Aviation Industries, 1992

Industry	Revenue ($ billions)	U.S. market share (% of world revenue)	U.S. balance of payments ($ billions)	Employment (thousands)
Civil aircraft manufacturing				
Civil transports	***$288***	***79%***	***$204***	1103
Rotorcraft	**0.3**[b]	**46**[c]	**-01**	**2.1**[d]
General aviation	1.8	***60e***	***-0.8***	***213***
Air traffic control equipment[f]	1.5	40	0.4	4 4
Airline service	779	37	6.4[g]	5404
Air traffic control servlce[h]				
FM air traffic control	N A[i]	*46*[j]	NA	319

a Revenue, market share, and balance of payments calculations based on the value of delivered products for 1992 Does not Include figures for separate engines and parts
b Excludes production by foreign licensees
c Excludes production of piston-powered rotorcraft
d Employment calculated by multiplying the total number of employees for each of the three major U S turbine rotorcraft manufacturers by their respective civil to total revenue ratios
e Department of Commerce estimate based on industry data
f All figures based on OTA survey of U S ATC equipment manufacturers
9 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 earners by Americans traveling abroad.
h ATC service is not a commercial industry m the United States It is shown here for comparative purposes
i The cost of developing and operating the U S ATC system was approximately $6 billion, based on OTA analysis of the 1992 FAA budget for ATC operations, facilities and equipment, and research, engineering, and development
j In 1992, FAA handled about 46 percent of all commercial aircraft departures in the world, based on FAA and Boeing data

KEY NA = not applicable

SOURCES 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 Analysts, Federal Aviation Administration; General Aviation Manufacturers Association, *Interavia Aerospace World*; International Civil Aviation Organization; Off Ice of Management and Budget, Off Ice of Technology Assessment, U.S Travel and Tourism Administration; and World Jet Airplane Inventory

expansion of U.S. domestic traffic in the decade following deregulation (1979 to 1989).[1] Although domestic airline traffic increases have slowed markedly since 1988, the growth in international markets continues to climb (see figure 5-1).[2]

Most recent forecasts of the industry's performance indicate that total U.S. air traffic will continue to grow through 2010, albeit at lower levels than in the past. Federal Aviation Administration (FAA) forecasts indicate that passenger traffic will increase at a 3.5-percent annual pace in domestic markets and a 6.6-percent annual rate on international routes during the 12 years from 1993 to 2004.[3] If this forecast holds, international travel will account for one-third of U.S. airline passenger-miles by 2004.[4]

1 International air travel markets remain regulated. During this period, average annual growth rates were gross domestic product 2.5 percent, domestic traffic 4.6 percent, and international traffic 6.8 percent.

2 In 1991, however, international traffic suffered a 2 percent drop in growth due to the U.S. economic recession and the persian Gulf War. The average annual growth rate for international traffic carried by U.S. airlines since 1987 is 10.3 percent.

3 U.S. Department of Transportation, Federal Aviation Administration, *FAA Aviation Forecasts, Fiscal Years 1993-2004* (Washington, DC: February 1993), pp. III-38 -111-40.

4 Ibid., p. 1X- 12.

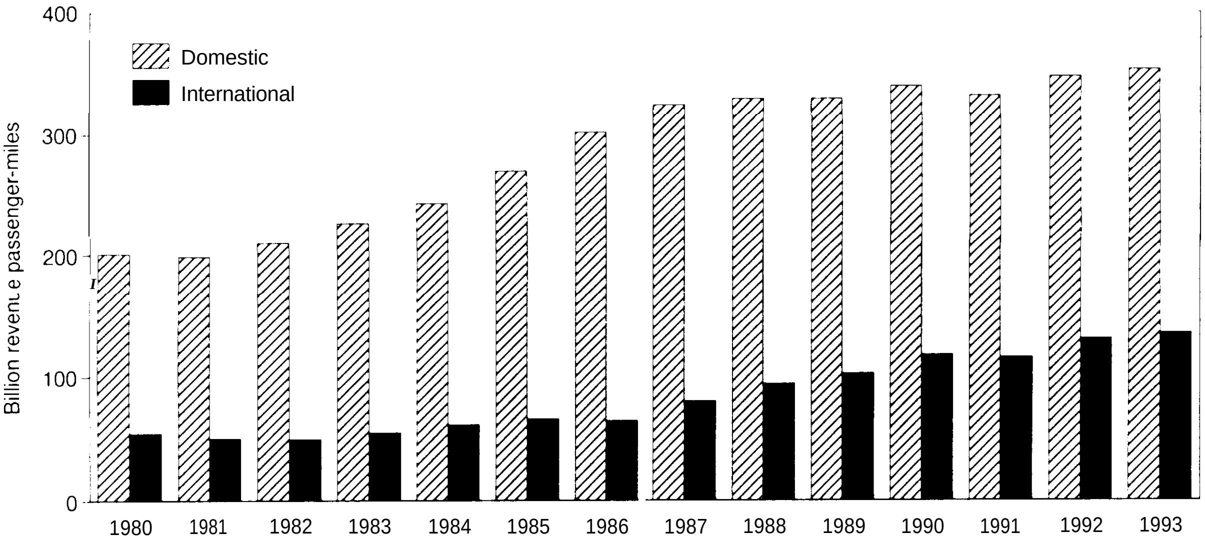
IN FLIGHT PHONE CORP

Advances in telecommunications technology especially satellite and digital communications, permit airlines to offer new in-flight passenger services

Carrier Fleet Forecast

The total U.S. air carrier fleet is projected to increase from a 1992 inventory of 4,206 large jets to more than 5,700 such aircraft in 2004.[5] At the same time, expectations are that the distribution of the fleet by aircraft type will change significantly during this period. The category that is forecast to experience the largest growth in terms of number of aircraft is two-engine narrow-body aircraft, growing from 52 percent of the fleet to 67 percent.[6] Two-engine wide-body aircraft are projected to have the fastest annual growth rate, with flect size more than doubling during this period.[7] Due to the Aviation Safety and Capacity Expansion Act of 1990,[8] Stage 2 aircraft (comprising 41 percent of the U.S. fleet in 1992)[9] will be virtually eliminated by the year 2000.

FIGURE 5-1: U.S. Scheduled Airline Traffic



SOURCE Office of Technology Assessment 1994 Data compiled from the Air Transport Association of America

[5] Ibid., p. IX- 17.

[6] Examples of two-engine narrow-body aircraft include the B-737, B-757, MD-80, and A320. Ibid., p. III-41.

[7] Examples of two-engine wide-body aircraft include the B-767 and the A300. I bid.. p. IX 17

[8] Public Law 101-508.

[9] Federal Aviation Administration, op.cit., footnote 3, pp. 111-40-111-43.

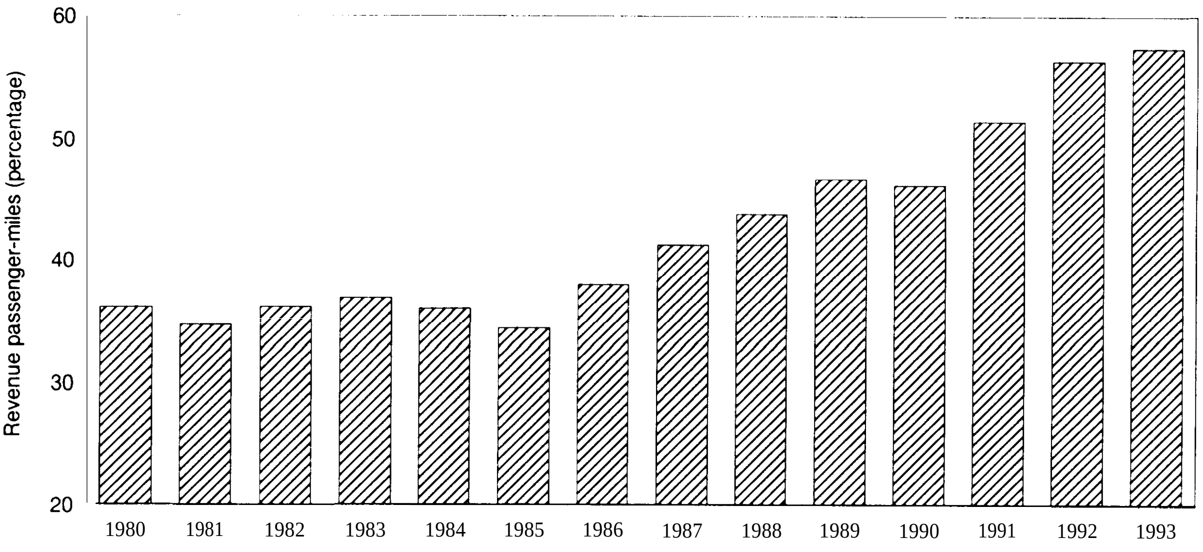
The change in the distribution of the world's airline fleet mirrors that of the U.S. fleet. The two categories that are forecast to grow the fastest in terms of number of aircraft are those with between 171 and 240 seats, which are expected to increase from 13 percent of the 1992 fleet to 19 percent of the 2010 fleet, and aircraft with more than 350 seats, which are forecast to increase from 9 to 19 percent of the world fleet. [10]

Airline Competition

Opinions vary about the number of domestic U.S. airlines that will exist in the 21st century and the extent to which they will continue to compete. The passage of the Airline Deregulation Act of 1978 resulted in huge growth in the number of competing airlines, followed by consolidation of the entire industry. The industry reached a peak of 123 carriers, including cargo and charter airlines, in February 1984.1] By the end of 1991, however, there were only 58 U.S. carriers. [12] From 1985 to 1987, there were 12 mergers involving major or national carriers. This and the large number of airline bankruptcies resulted in fewer firms controlling more of the industry's traffic than in the period preceding deregulation. The market share in terms of traffic (by revenue passenger-miles) of American Airlines, United Airlines, and Delta Air Lines increased from 34 percent in 1985 to 57 percent in 1993 (see figure 5-2).

The industry can be expected to remain competitive through the foreseeable future, assuming

FIGURE 5-2: Industry Market Share of American, Delta, and United—Domestic and International Service



NOTE Since 1987, American Airlines, United Airlines, and Delta Air Lines have been the leading carriers In 1980, United ranked first, American fourth, and Delta fifth

SOURCE Off Ice of Technoloqv Assessment, 1994 Data compiled from the Air Transport Association of America

[10] Boeing Commercial Airplane Group, 1993 *Current Market Outlook* (Seattle, WA: March 1993), p. 3.9.

[11] U.S. Department of Transportation, Federal Aviation Administration, *FAA Aviation Forecasts, Fiscal Years 1989-2000* (Washington, DC: March 1989), p. 53.

[12] U.S. Department of Transportation, Federal Aviation Administration, *FAA Aviation Forecasts, Fiscal Years 1992-2003* (Washington, DC: February 1992), p. 27.

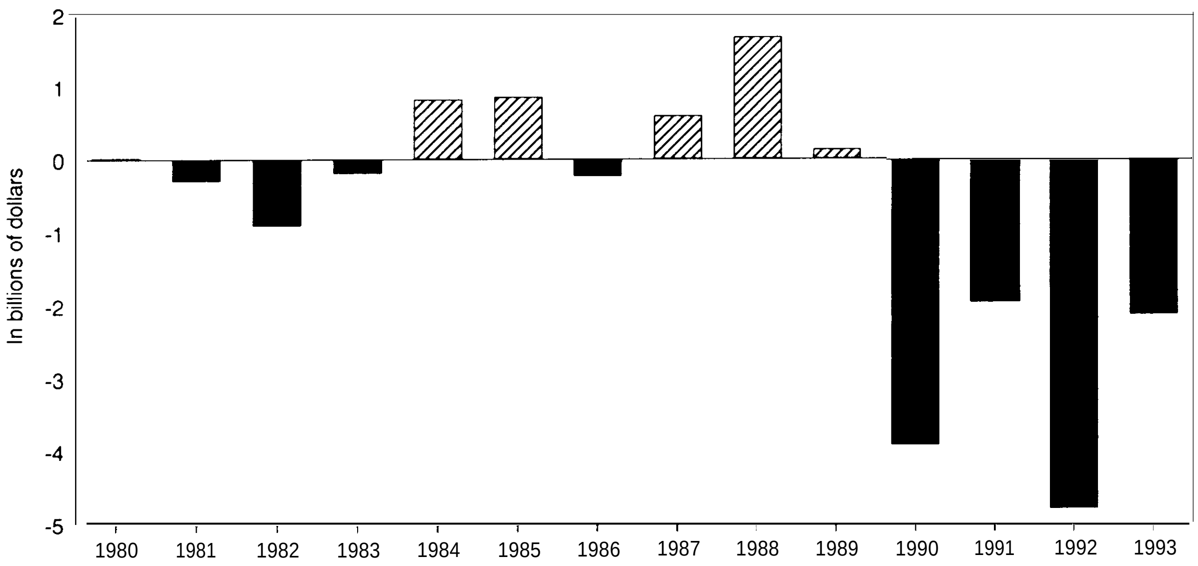
the current trend toward consolidation does not change dramatically. The Transportation Research Board concluded in 1991 that at least five major carriers would be necessary for a competitive industry.[13] Other economists believe that three to five major airlines with several regional airlines would provide a sufficient level of competition.[14]

The Financial Condition of the Industry

No carrier-with the notable exception of Southwest Airlines—was unscathed by the recession of the early 1990s. U.S. airlines lost $12.8 billion from 1990 to 1993,[15] three airlines ceased operations,[16] and three others filed for Chapter 11 bankruptcy[17] (see figure 5-3).

Following two years of profits (1987 and 1988), the industry experienced a downturn in profitability in the second half of 1989. The slow growth in both domestic and international air travel during 1990 and 1991—when the U.S. economy entered a recession—and the increase in jet fuel prices following the Iraqi invasion of Kuwait

FIGURE 5-3: Net Profit of U.S. Scheduled Airlines



NOTE Of the airlines net loss in 1990 and 1991 approximately $2 billion was recurred by Eastern Airlines and Pan Am World Airways Of the 1992 net loss approximately $2 billion was due to accounting adjustments related to retiree benefits

SOURCE Off Ice of Technology Assessment, 1994 Data compiled from the Air Transport Association of America

[13] National Research Council, Transportation Research Board, *Winds of Change: Domestic Air Transport Since Deregulation*, Special Report 230 (Washington, DC: 1991), p. 3. The Transportation Research Board did not explicitly define competition, beyond indicating that it meant competition in a domestic context. According to economic theory, the U.S. airline industry, to remain competitive, would require enough carriers such that no one carrier or coalition of carriers exercises a high degree of market control; i.e., no carrier could dictate fares in any of its markets without losing passengers to other airlines.

[14] Peter Passell, "Waiting Out the Airline Shakeout," *The New York Times*, May 22, 1992, p. D1.

[15] Of the airlines' 1992 net loss, approximately $2 billion was due to accounting adjustments related to retiree benefits

[16] Eastern Air Lines, Pan Am World Airways, and Midway Airlines.

[17] Continental Airlines, America West Airlines, and TWA.

SOUTHWEST AIRLINES

Southwest remained profitable in the ear/y 1990s, whale the rest 01 the U S airline industry lost over $ 12 billion

AT&T

Videoconferences may substitute for some growth in future business travel,

in August 1990 were the main factors behind the industry's losses during this period.[18] Following the start of the Persian Gulf War, discounted fares offered by U.S. airlines caused systemwide yields to fall, further contributing to the airlines' losses.[19] The economic recession caused heavier than usual reductions in high-yield business travel, possibly indicating a systemic change in the demand for such travel. Airline forecasters believe that increased use of facsimile machines and videoconferences replaced some business trips and may cut into future business travel .20

Due to cost and personnel reductions, higher prices absent the deep discounting of the summer of 1992, and a gradual increase in economic growth since 1992, U.S. airlines posted narrower losses in 1993 than in the previous year. In response to the industry's losses between 1990 and 1992, airlines engaged in a substantial effort to reduce costs by closing hubs and the feeder routes that serve them, negotiating significant wage and benefit concessions from their unions, and laying off employees.

Adding to the financial pressure on the largest airlines is the recent introduction of low-cost, point-to-point, jet service by new domestic carriers. In the 12-month period preceding July 1993, over a dozen passenger airlines began operations. As of 1993 the new startups had less than a 2-percent share of the domestic market, but some analysts forecast that they could reach an 8-percent share by the end of 1994.[21] Southwest Airlines, which has successfully provided this type of service in the southwestern United States since the 1970s, expanded its service to the east coast in 1993. The major airlines—with higher operating costs on the short-haul routes—have responded

[18] After growing by 5.9 percent in 1990, total traffic fell by 1.6 percent in 1991. Federal Aviation Administration, op. cit., footnote 3, p. Ix-13.

[19] Ibid., pp. 27-58.

[20] James Ott, "'Modest World Airline Traffic Growth Seen for '92, Bigger Hike Eyed for '93,'' *Aviation Week and Space Technology*, Mar. 16, 1992, p. 61.

[21] James S. Hirsch, "Takeoff Is Bumpy for Start-Up Airlines as They Try To Grab a Piece of the Sky," *The Wall Street Journal*, July 1, 1993, p. B].

by transferring money-losing routes to their regional affiliates, most of which are not part of the corporate entity, or by pulling out of markets. Several of the larger carriers-including United, Delta, and USAir—have plans to create low-cost airlines-within-an-airline to compete with the newer carriers on short-haul routes.[22] Continental Airlines introduced CALite, a low-price, quick turnaround service. in October 1993 to compete with Southwest.[23]

Employment

Despite the loss of three carriers and the filing for Chapter 11 bankruptcy by three others between 1990 and 1992, airline industry employment has remained fairly steady since peaking in 1990 at 546,00().[2X] Approximately one-half of the employment loss experienced in 1991—2 percent—was regained **in 1992.** In fact, 1991 was the only year in which employment and air traffic dropped since 1983. Thus, the loss of an individual airline will not—in and of itself—result in a decline in the overall number of jobs in the industry: for the most part, only a drop in the demand for air travel will significantly affect employ ment.[25] The impact of layoffs, however, should not be minimized; employees who are laid off may be forced to relocate to find other airline jobs—sometimes lower paying ones than they held previously.

Capital investment

In such an uncertain economic climate, only the industry's healthiest airlines can be assured of obtaining the necessary financing to expand their fleets and replace their older aircraft with those that meet Stage 3 noise requirements, the most de-


AIR TRANSPORT ASSOCIATION

Some new commerclal aircraft were stored m desert facilities as financially strapped airlines deferred orders in the ear/y 1990s

[22]In July 1994, UAL Corp.—United's parent company —agreed m sell a majority stake in the airline (55 percent of its equity) to its machinists and pilots unions in exchange for approximately $4.9 billion in wage and work-rule concessions over six years. This transaction opens the way for the air] ine to create a separate low fare, short-haul carrier. James Ott. "Vote Sets UAL on New Course," *Aviation* **Wick&** *Space Technology*, July 18, 1994. p. 20.

[23]Robert L. Rose and Susan Carey. "The Frugal Skies: Money -Losing Routes Prompt Big Carriers To Mull Radical Steps," *The Wall Street Journal,* Oct. 19, 1993. p. A 1.

[24]Air Transport Association, *,4 ir Transport 1992* (Washington, DC: June 1992)

[25]In a not unlikely scenario, the demand for air travel could decline during an economic recession. The resulting loss rn revenue could cause one or more carriers to go bankrupt and employees to be laid off. But in this set of circumstances, it is still the traffic loss—and not the carriers that ceased to operate-that caused employment to drop.

manding ones. To help control costs, airlines are retiring older planes and deferring new aircraft orders. Each of the nation's three largest carriers has cut back its capital spending plans: American by $8 billion between 1991 and 1995, United by $6.7 billion between 1992 and 1995, and Delta by $6 billion between 1992 and 1995.[26] As of June 1993, firm orders for the industry stood at 696 aircraft, requiring an estimated $39 billion.[27] Because of the difficulty in raising money through issues of stock, the top three airlines have increased their amount of long-term debt to finance recent property and equipment acquisitions.

International Developments

Due to fewer intra-Europe airline flight restrictions and the increasing share of passenger traffic expected to come from the Pacific Rim, many international airlines are forming (or considering) alliances large enough to compete on a global scale.[28] For example, in early 1993, the United States approved a $300-million investment by British Airways in USAir and allowed the two airlines to form a code-sharing alliance[29] that links USAir's domestic service to British Airways' international destinations.[30] This type of agreement—where two airlines offer seamless service through the sharing of aircraft and crews—is one type of strategic alliance.[31]

'The current limits set by federal law on foreign investment in U.S. airlines restrict ownership to 25 percent of an airline's voting stock and require decisionmaking control to remain in the hands of the airline's U.S. owners.[32] In 1991, the U.S. Department of Transportation (DOT) announced that it would interpret this law to allow a foreign investor to hold up to 49 percent of an airline's total stock (voting and nonvoting). In addition, DOT has proposed allowing foreign investments in as much as 49 percent of a U.S. airline voting stock. DOT sees this proposal as a way of giving financially troubled U.S. airlines access to needed capital.[33]

The 1992 agreement between Northwest Airlines and KLM Royal Dutch Airlines to operate as one airline (KLM has a 20-percent common stock investment in Northwest's parent company, Wings Holdings) through the joint scheduling of

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26 Anthony L. Velocci, Jr., "Big Three Cuts To Reduce Debt Downgrade Effects," *Aviation Week & Space Technology]',* Mar. 22, 1993, p. 38.

27 Richard Crum, Economic and Data Analyst, Air Transport Association of America, persona] communication, Nov. 5, 1993.

28 In June 1992, the European Community, now the European Union (EU), approved the third and final package of airline liberalization measures that went into effect on January 1, 1993, The agreement gives EU airlines freedom to set fares on intra-EU flights; establishes limited rights of cabotage in which EU airlines will be allowed to pick up passengers and freight in another EU country and continue to another point within that country with certain restrictions; and sets up common licensing criteria for any airline operating within EU territory, Carol A. Shifrin, "EC Ministers Approve Liberalization, But 'Safeguards' May Slow Competition," *Aviation Week & Space Technology,* June 29, 1992, pp. 21-22.

Because the European Union's third package of liberalization measures allowed national governments to retain significant control over their domestic aviation markets and to restrict competition within their markets at least until 1997, the EU cannot be considered an open air travel market as of 1993. For more information, see U.S. Congress, General Accounting Office, *International Aviation: Measures by European Community* Could *Limit U.S. Airlines' Ability To Compete Abroad,* GAO/RCED-93-64 (Washington, DC: April 1993), pp. 22-34.

29 A Code. sharing alliance is an agreement between two airlines to use the same code in computer reservation systems, allowing them to jointly serve the same route.

30 The $300-million investment is the first of three planned stages of investment by British Airways that would bring the total investment in USAir to S750 million after five years. Bruce Ingersoll. "U.S. Approves British Air Stake in USAir Group," *The Wall Street Journal,* Mar. 16, 1993, p. A3.

31 Gellman Research Associates, Inc., "Airline Strategic Alliances: Definition and a Case for Caution" *Transportation Advisor,* vol. 3, *No.* 1, January 1993, pp. 1-4.

32 See U.S. Congress, General Accounting Office, *Airline Competition: Impact of Changing Foreign Investment and Control Limits on U.S. Airline.\, GAO/* RCED-93-7 (Washington. DC: December 1992).

33 As of 1994, the current administration has under way a complete review of the United States' international aviation policy.

their flights as well as cooperating on pricing, purchasing, and marketing can also be termed a strategic alliance.[34] Other U.S. carriers have established alliances that are closer to marketing agreements—the offering of joint services, such as limited code-sharing, that does not involve the sharing of assets: United with Lufthansa German Airlines, Delta with both Swissair and Singapore Airlines, and Continental Airlines with SAS.[35]

The deal between British Airways and USAir could have several consequences for both U.S. and foreign airlines. It could encourage other foreign airlines to invest in U.S. airlines, which would provide the investing airline a direct link to U.S. passengers destined for Europe or Asia while possibly strengthening the balance sheet of the U.S. airline. The agreement could also encourage the liberalization of future bilateral aviation treaties involving the United States. The United States linked its approval of the investment by British Airways to the negotiation of a more liberal bilateral agreement with Britain. Because the agreement between British Airways and USAir provides British Airways with feeder traffic from USAir's routes, other U.S. carriers are demanding that the bilateral treat y currently under negotiation between the United States and Britain give them access to a greater number of British destinations. A new treaty containing such liberalized provisions could form the basis for other treaties the United States establishes under DOT's Open Skies policy, which is designed to remove many of the international market and capacity constraints contained in current bilateral.

Working against the possibility of the opening of future bilateral treaties is the threat from several foreign countries to renounce their current pacts and negotiate more restrictive agreements so that

GREGORY WALLACE OTA

British Airways has revested in USAir and the services of the two airlines are coordinated

their carriers will not have to compete to the same extent against the lower cost U.S. airlines. Both France and Japan are considering placing more restrictions on the number of routes and flights in their bilateral agreements with the United States; the issue of beyond rights—allowing U.S. carriers to pickup passengers in those countries and fly to other destinations—is particularly contentious.[36] However, the recently agreed to 1993 aviation treaty between the United States and Germany preserves the current liberal agreement in effect, gradually moves the two countries toward a full Open Skies regime—allowing unlimited flights free of government restrictions—in four years, and allows an increasing number of code-sharing opportunities between international carriers.[37]

Factors Affecting the International Success of the U.S. Airline Industry

As the share of air traffic originating in international markets increases, the ability of U.S. carriers to compete in the international arena becomes

[34] The United States granted tentative approval to this agreement in November 1992. Brett Pulley and Bruce Ingersoll, "U.S. Gives Tentative Clearance to KLM, Northwest To Start Integrating Service," *The Wall Street Journal, Nov. 17, 1992,* p. A3.

[35] Gellman Research Associates, *Inc.,* op. cit., footnote 31, pp. 1-4.

[36] Bruce Ingersoll, "Unclear for Takeoff, Big U.S. Airlines Fly Into Foreign Barriers Over Expansion Plans," *The Wall Street Journal,* May *14,* 1993, p. A1.

[37] Jeffrey Lenorovitz, "Lufthansa. United To Link Efforts," *Aviation Week & Space Technology,* Oct. 4, 1993, pp. 22-23.

more important to their economic growth. Heightened competition with foreign airlines has made operating under different safety and environmental regulations an issue for U.S. carriers. But while the absence of common regulations affects the balance of international competition, it is not an overriding concern. International trade policy, including bilateral aviation agreements and airport facilities and service issues[38] that influence the ability of carriers to access foreign markets, is the most significant factor affecting the international competitiveness of U.S. airlines, according to industry officials.[39] Table 5-2 presents U.S. airline views on how trade policy, international differences in operating regulations, FAA's air traffic system management, technology innovation, and other federal policies can affect the international competitiveness of U.S. carriers-both overseas and in the U.S. market.

The success of U.S. airlines in international markets can be measured by a number of different indicators: the market share of U.S. airlines versus foreign airlines in overseas markets, the U.S. international balance of payments for airline services, and a comparison of labor productivity between U.S. and foreign carriers. @Reliance on any single measure can result in an inaccurate assessment of an industry's competitiveness. For instance, the U.S. airline industry contributed positively to the U.S. international balance of payments over the five years from 1988 through 1992.[41] In 1992, according to the Bureau of Economic Analysis (BEA), the industry contributed a surplus of $6.4 billion out of a total balance for services of $61 billion (see table 5-3). BEA's count seems to overstate the balance for air service. It is more likely that the 1992 U.S. balance was between $2.5 billion and $3 billion.[42] However, this trend alone may not be proof that the U.S. airline industry is a stronger competitor in international markets than foreign airlines. One explanation for the change in the balance of payments for air service since 1985 is the effect the fall in the value of the dollar had on the attractiveness of travel to the United States in general and travel on U.S. airlines for international travelers. An examination of the different measures of competitiveness show that U.S. airlines are strongly positioned to compete in international markets (see table 5-4).

FAA Safety, Security and Environmental Regulations

The Federal Aviation Administration is responsible for regulating the operations of commercial aircraft, including: approving flight procedures, determining equipment requirements, and overseeing flight crew training.[43] Prior to the issuance of a new safety rule, FAA performs a cost-benefit analysis to determine if the estimated benefits of a regulation outweigh its estimated costs. Despite

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38These international access issues include landing and other user fees, terminal space, passenge and cargo handl ing, and customs and visa requirements. U.S. airline industry concerns are with the unfair or discriminatory practices in certain countries that favor national airlines over U.S. and other outside earners.

39OTA survey of seven senior representatives of U.S. airlines, spring 1993.

40A more comprehensive definition of *competitiveness* is contained in the 1985 report of the President Commission on Industrial Competitiveness: "Competitiveness is the degree to which a nation can, under free and fair market conditions, produce goods and services that meet the test of international markets while simultaneously maintaining or expanding the real incomes of its citizens."

41Balance of payments *for* international air service *represents* the di fference 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.

42Based on data from BEA and DOT, and OTA analysis. The National Research Council has raised questions concerning the accuracy of the passenger survey data on which BEA relies for its estimates of airfares paid by U.S. and foreign travelers. They have suggested that the survey data be checked for consistency with actual data on airfares. For more information, see National Research Council, Panel on Foreign Trade Statistics, Committee on National Statistics, *Behind the Numbers: U.S. Trade in the World Economy* (Washington, DC: National Academy Press, 1992), pp. 140- 146.

43For more information on FAA regulation of commercial aircraft, see U.S. *Congress,* Office of Technology *Assessment, Safe Sk/es for Tomorrow: Aviation Safety in a Competitive Environment, OTA-SET-381* (Washington, DC: U.S. Government Printing Office, July 1988), pp. 56-57.

TABLE 5-2: Industry Ranking of Factors Affecting the International Economics and Competitiveness of U.S. Airlines[a]

Factor	Description	Example
1. International trade policy		
Bilateral aviation agreement	Defines the markets and air service constraints in which an air carrier must operate	Routes, the number of carriers that may operate each route, the number of flights, and the method for gaining approval for fare changes
Airport facilities and service issues	Affect the ability of carriers to compete in foreign markets, such as airport access, ground handling, and ticket counter space	To provide access for foreign earners, DOT has expropriated slots from U S carriers at slot-controlled airports Foreign governments rarely help U S carriers obtain airport access
2. FAA operating regulations	Complying with FM rules, many of which do not apply to foreign carriers, can result in higher operating costs for U.S airlines	The modification of 14 proposed or existing rules could result in a 3 5-percent increase in enplanements on U S carriers annually [b c]
3. U.S. tax policy	Aviation ticket taxes, alternative minimum tax, lack of Investment tax credit	Returning user fees to the levels that existed prior to the Budget Reconciliation of 1990 could result in a 1 -percent Increase in enplanements annually [b]
4. Non-FAA regulations	Agriculture, environment, immigrahen, worker safety, and pension benefits	Fines for inadmissible passengers (INS), aircraft inspection fees (USDA), and passenger manifests (DOT, proposed).
5. Domestic airport and ATC infrastructure	A more efficient system would reduce airline operating costs on domestic legs and generate feed traffic for international flights	United Airlines has estimated it could save over $600 million per year in lower direct operating costs if an advanced air traffic management system were fully implemented [d]
6. Commercial technology	Not a major factor, since in most cases aircraft, communications, and cabin service technologies are available to any airline	Technologies that are more difficult to emulate, such as computer reservation systems and pricing management systems, confer a degree of competitive advantage for U S carriers

[a] These conclusions are based on a 1993 survey of senior representatives of U S airlines with International service: specifically five passenger airlines one cargo airline and an executive from the Air Transport Association

[b] The WEFA Group *The Potential Impact of Selected Airline Tax and Regulatory Changes on the U S Economy* *submitted to* the Air Transport Association of America, May 1992

[c] This aggregate result includes five non-FAA regulations

[d] Edwin A Thomas United Airlines personal communication, June 29 1994

KEY ATC = air traffic control, DOT = Department of Transportation FAA = Federal Aviation Administration; INS = Immigration and Naturalization Service; USDA = Department of Agriculture

SOURCE Off Ice of Technology Assessment, 1994

TABLE 5-3: U.S. Balance of Payments for Merchandise Trade and Services ($ billions)

Category	1987	1988	1989	1990	1991	1992	1993
Merchandise trade[a]	($1 596)	($127 O)	($1 152)	($109 o)	($74 1)	($96 1)	($1326)
Civilian aircraft, engines, and parts	98	133	170	217	249	25 1	214
Private services	128	197	329	390	525	60.2	591
International air service[b]	-- - (0.3)	1.2	– 24	4 8	5 8	6 4	5 1

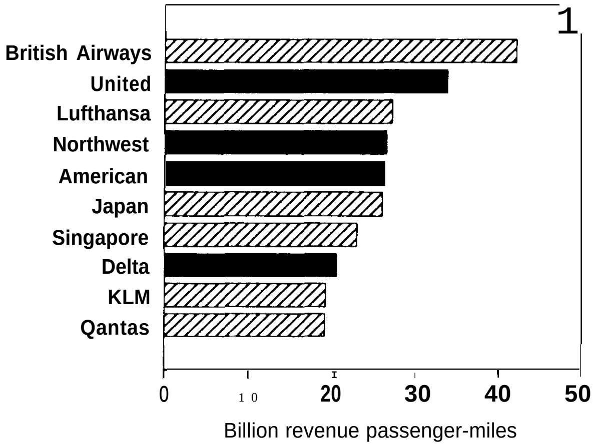
[a] Excludes military transfers

[b] 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

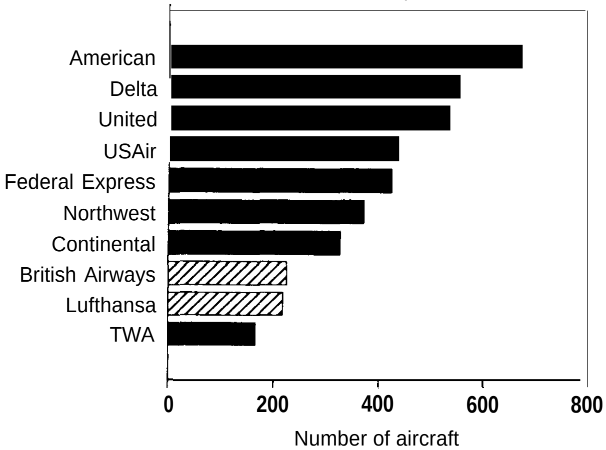
SOURCE U S Department of Commerce, Bureau of Economic Analysis Balance of Payments Division 1994

TABLE 5-4: U.S. Airline Industry's Position in International Markets

Top 10 airlines by International revenue passenger-miles, 1992



Fleet size, 1992



Market share-international passenger traffic

U S airlines are among the world's largest airlines in terms of scheduled passenger traffic carried On international routes, three U S airlines were ranked in the top five in 1992 When total traffic (domestic and international) is counted, U S airlines held four of the five top slots

The market share (in terms of passengers) of U S carriers for international travel to and from the United States remained above 51 percent from 1988 through 1991

Unit costs and productivity

U S carriers' operating costs are 30 to 50 percent lower than those of most European and Japanese carriers, according to a 1993 study [a] Another study concluded that overall productivity of the European airline industry was 28 percent lower than that of U S airlines in 1989 The relative productivity levels of the major personnel functions[b] varied from 46 percent lower for marketing (European versus U S airlines) to 11 percent lower for airport handling [c,d] (Labor productivity rates are one of the determinants of unit labor costs, i e , labor costs per available seat-mile)

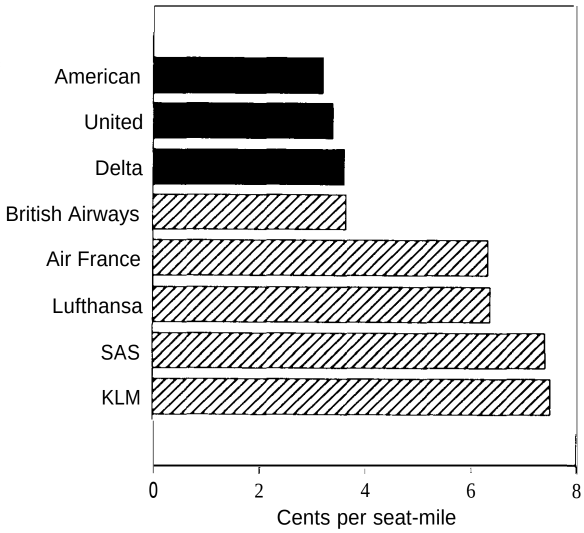
For most of the 1980s, international service has been more profitable for U S airlines than domestic service Since 1989, though, the annual operating profit margin[e] for domestic service has been better[f]

Fleet size-capacity

U S carriers have the world's six largest fleets Each of the three largest U S airlmes-American, Delta, and United—has a fleet more than twice the .size of British Airways'

U S carriers offer almost one-half of the total seating capacity available in the North Atlantic market In July 1993, four U S airlines were ranked among the top five international airlines by capacity share.

Unit labor costs for selected international carriers, 1990-91



[a] Mercer Management Consulting, Inc ,' Update on the Global Airline Industry, " unpublished report, Apr 27, 1993, p 21

[b] The six major functions were cockpit crew; cabin attendants; airport handling, maintenance and overhaul, ticketing, sales, and promotion; and other personnel

[c] McKinsey Global Institute *Service Sector Productivity* (Washington, DC October 1992), pp 2A-4 2A-8

[d] A host of variables considered to lie behind the U S advantage in unit labor costs, including deregulation of the market and the relative lack of protective work rules in the United States

[e] Operating *profit margin* is defined as operating profit (operating revenues minus operating expenses) as a percentage of operating revenues

[f] From 1990 to 1992, however, the operating profit margin for domestic service was negative

KEY BA = British Airways, JAL = Japan Air Lines, KLM = Royal Dutch Airlines; SAS = Scandinavian Airlines System

SOURCES Off Ice of Technology Assessment, 1994, based on data compiled from Global Aviation Associates, Ltd , International Air Transport Association, Air Transport Association of America, U S Travel and Tourism Administration, Volpe National Transportation Systems Center, and U S General Accounting Off Ice this analysis and other parts of the federal regulatory review process instituted during the 1980s to control the burden of regulations, new rules continue to generate opposition from those within industry who question their impact on costs.[44]

Historically, regulation was concerned with economic issues, such as entry into markets by individual firms, the prices they charged, and the selection of products or services offered. Starting in the 1960s, though, federal regulation broadened its scope to include social objectives. Social regulation was intended to improve consumer protection, workplace safety, and environmental quality and to eliminate discrimination.[45]

The justification used by government for both social and economic regulation is that it corrects market failures that occur when either adequate competition does not exist in an industry, or market forces are not sufficient to allocate social resources efficiently. A typical example of market failure is externalizing the cost of pollution, or not accounting for its effect on a community when pricing transportation equipment or the operation of stationary pollution sources.

Effect of operating regulations on airline economics in general

Compliance with a new regulation can affect a company in several ways. In the case of the airline industry, each carrier should be able to pass along part of the resulting cost increase to the consumer in the form of higher ticket prices. But. because higher ticket prices will cause aggregate passenger demand to fall, the resulting increase in revenue may not full y offset the increased cost of complying with a new regulation.[46] Thus profits are likely to drop. Any part of the cost increase not passed along would most likely result in lower profits as well.[47]

There is an extensive literature that attempts to describe the cost of federal government regulation. One study estimated the cost of regulation to businesses and individuals for consumer safety and health (of which FAA regulations are a subset), worker safety, and other nonenvironmental social regulation at $32 billion in 1990.48

Estimating the cost of implementing a given regulation is a difficult exercise. Cost estimates often rely on traffic forecasts, and these are subject to question. But in addition to the inherent uncertainties in forecasts of changes in airline industry operations, discrepancies between FAA's and industry's estimates arise due to differing economic assumptions as well as a certain amount of bias. The airline industry, unlike FAA, does not discount its estimates of future costs. 49 Also, industry factors projected inflation into their cost estimates. FAA, in accordance with guidance from the Office of Management and Budget, does not adjust for inflation. The result of these two differences alone is that for a typical regulatory forecast of costs over a 15-year time horizon, industry es-

[44] For more information on the FAA rulemaking process, see ibid., pp. 59-60.

[45] Congressional Quarterly, *Federal Regulatory Directory* (Washington, DC: 1990), pp. 1-7.

[46] The extent to which revenues rise after ticket prices increase depends on the price elasticity of demand for air transportation. Only in the unlikely case in which passenger demand is completely unresponsive to changes in price (i.e., price elasticity of demand equals zero) would airlines be able to fully recoup the cost of a new regulation through increased fares.

This analysis assumes that airlines will not be able to significantly cut their (flying) operating costs by decreasing capacity in response to the lower passenger demand. Including in the analysis any incremental drop in variable labor and passenger service costs associated with lower demand should not affect the conclusion. In the long run, airlines will have more flexibility to lower their operating costs by decreasing system-wide capacity,

[47] Over time, carriers may become more efficient as they adapt to new requirements. Thus, they maybe able to absorb some Of the regulatory cost increase without attempting to raise prices and/or suffer a loss in profits.

[48] Robert W. Hahn and Thomas D. Hopkins, "Regulation Deregulation: Looking Backward, Looking Forward." *The American Enterprise*, July 'August 1992, p. 72.

[49] Discounting is an accounting methodology that accounts for the time value of money so that expenditure that occur at different times can be compared.

timates will be approximately two times higher than FAA's.[50] Because of the political consequences of rulemakings, it is often in the best interest of the airline industry to bias its cost estimates on the high end. FAA is often forced to balance these high estimates against lower ones from other industry constituents. For instance, in estimating the purchase cost of equipment using newly developed technology, forecasts of costs from a potential manufacturer will likely be lower than those provided by the airlines.

Despite industry's claim that the burden of federal regulation is a significant cause of the airlines' current financial difficulties, virtually no analysis on this topic has been done in either the private sector, the federal government, or academia. The estimate of the cost of FAA-imposed technical regulations by the National Commission To Ensure a Strong Competitive Airline Industry (Airline Commission) was the first federal effort to quantify the regulatory burden in a formal manner.[51]

According to the Airline Commission, 16 major aviation safety and security rules have added $2 billion in total costs to airlines since 1984.[52] In addition, other regulatory actions by FAA have imposed costs on the airlines: between $1.5 billion and $4.5 billion for U.S. airlines to convert to an all Stage 3 fleet by the end of 1999 in response to the Aviation Safety and Capacity Expansion Act of 1990;[53] $900 million to comply with airworthiness directives from 1989 through 1992; and $200 million for heightened security during the Persian Gulf crisis.[54]

FAA regulations and international competitiveness

The regulatory burden on the U.S. airline industry only affects U.S. carriers' ability to compete internationally when it creates an "unlevel playing field"; that is, the same rules are not being followed by foreign carriers. Foreign carriers implement a large proportion of U.S. airline safety regulations voluntarily because of safety and economic considerations, although many of these safety regulations are not required of foreign carriers under international treat y or U.S. law.[55] Representatives of the International Air Transport Association stated that a comparison of the regulatory operating environment among countries will show that the similarities greatly outnumber the differences. Until recently, FAA rules were implemented by most foreign airlines as if they were the international standard. Differences in international regulations affect aircraft manufacturers as well. (See box 5-1.)

Nonetheless, according to American Airlines, rules requiring U.S. carriers to follow FAA security procedures at foreign airports cost the airline $50 million per year more than foreign carriers are spending at the same airports.[56] Besides the direct cost associated with these rules, industry representatives say they adversely affect marketing due to the earlier airport arrival times they require and

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50 Paul Larson, Manager, Regulation and Organizational Analysis Division, Office of Aviation Policy, Plans, and Management Analysis, Federal Aviation Administration, letter to OTA, Aug. 25, 1993.

51 National Commission T. 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), p. 10.

In 1993, an FAA contractor began an effort to create an automated database of costs and benefits of past regulations. Ward Keech, Manager. Aircraft Regulatory Analysis Branch, Office of Aviation Policy, Plans, and Management Analysis, Federal Aviation Administration, personal communication, Oct. 28, 1993.

52 This value represents a simple aggregation of FAA's original cost estimates for individual rules (in current year dollars).

53 Public Law 101-508.

54 Based on the Airline Commission report and FAA analysis.

55 14 CFR 129 is the federal safety regulation governing the operation within the United States of foreign air carriers authorized by DOT.

56 Robert W. Baker, Executive Vice President, Operations, American Airlines, comment at OTA advisory panel meeting, Sept. 15, 1992.

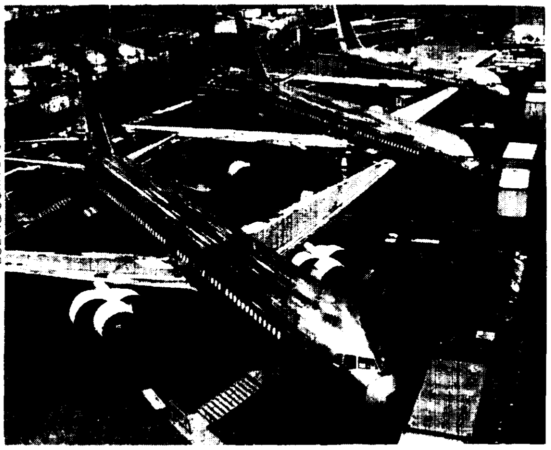
BOX 5-1: International Harmonization of Aircraft Certification Standards[1]

The Federal Aviation Adminstration has established minimum standards for the design and manufacture of commercial transport aircraft produced in or imported into the United States to certify them as safe In 1970 a number of European civil aviation authorities created the Joint Aviation Authorities (JAA) to develop common aircraft design regulations. By 1988, JAA had eliminated most of the differences among its members Although JAA is not a statutory authority, the European Union required its member countries, as of 1992, to adopt all of JAA's existing rules, includlng its certification code

Because a non-uniform system of certifying aircraft designs results in an increase in manufacturers' costs and an inefficient use of resources FAA and JAA initiated an effort in 1983 to harmonize (resolve) the differences in their standards, Interpretations, and procedures Over the following nine years, however, limited progress was made in eliminating unnecessary duplication on specific certification projects The General Accounting Off Ice (GAO) found that of the 267 differences in either wording or interpretation between the two sets of regulations that existed in 1980, 87 percent still remained in 1992[2] In response to aircraft manufacturers' criticism of their harmonization efforts, FAA and JAA began drafting a strategic plan in 1992 to eliminate regulatory differences within established time frames Additionally, the two groups also began working on a proposal for a cooperate and concurrent approach in which FAA and JAA specialists would work together during the certification process

Differences between FM's and JAA's code may continue to arise as the result of the longer timeline to Implement new rules in the United States, as well as from the possibility of changes being incorporated into a proposed FM rule during the rulemaking process Also, FAAs use of issue papers that contain new requirements for manufacturers could hinder the harmonization process if they appear late in the certification process and differ from JAA's requirements GAO found that FM used issue papers to impose additional requirements faster than the rulemaking process allows

BOEING COMMERCIAL AIRPLANE GROUP



U S manufacturers supply annually over half of the world market for large commerclal aircraft

Estimates vary regarding the additional costs borne by aircraft manufacturers as a result of inefficiency in the certification process The Aerospace Industries Association of America estimated that eliminating regulatory differences and duplication of activities would save U S aircraft manufacturers between $800 million and $1 billion between 1992 and 2002

One source of additional costs are design changes Imposed by either FAA or JAA late in the certificatlon process as a result of differences in the Interpretation of Identical regulations To meet more conservative interpretations of rules by JAA concerning. derivative aircraft and the segregation of electrical wiring, for example, Boeing created

(continued)

[1] This box is based on U S Congress General Accounting Off Ice *Aircraft Certification Limited Progress on Developing International Design Standards* GAO/RCED-92- 179 (Washington, DC August 1992)

[2] GAO relied on FAA's determination of the number of differences that existed in 1980

BOX 5-1: International Harmonization of Aircraft Certification Standards (Cont'd.)

a second design for the 747-400 and also agreed to retrofit aircraft it had already exported to Europe These design changes Increased Boeing's production costs by $60 million to $90 million for the estimated number of 747-400 aircraft they would sell to members of JAA

Another source of added costs are duplicate certification tests (Including flight tests and other analyses) that add little to the safety of the aircraft and waste resources of both the regulating organizations and the manufacturers Due to its past experience of conducting 90 foreign certification analyses to export 12 separate aircraft designs, Boeing has budgeted approximately $30 million for JAA certification of the new 777 aircraft after FAA completes its review.

These additional costs are often passed directly to airlines when they purchase new aircraft In addition, airlines must spend millions of dollars modifying aircraft to obtain foreign certifications [3]

3 Kenneth M Mead, Director, Transportation Issues, Resources, Community, and Economic Development Division, U S General Accounting Office, State of the Airline Industry Strategies for Addressing Financial and Competition Problems, " testimony at hearings before the House Committee on Appropriations, Subcommittee on Transportation and Related Agencies, Mar 10, 1993

the perception they create that U.S. airlines are more likely than foreign airlines to be targets of terrorism.[57] According to FAA's Associate Administrator for Regulation and Certification, international differences in operating regulations are more costly than disparities in airworthiness rules, and the economic burden falls mostly on the airlines.[58]

AIR TRAFFIC CONTROL EQUIPMENT MANUFACTURING

The need to replace obsolete equipment in Western Europe, along with likely economic growth in Eastern Europe and Asia, is expected to result in a fast-growing worldwide market in air traffic control (ATC) equipment.[59] Due to cutbacks in U.S. military spending, defense contractors have entered the marketplace. U.S. companies are well positioned to compete successfully for a portion of the ATC equipment market. Airport automation systems for baggage handling, security, and terminal management are a related and possibly faster growing market.[60]

During the next decade, the international market for ATC equipment is expected to expand faster than the markets for air travel and commercial aircraft combined. Foreign ATC sales are projected to grow at a 10 percent annual rate. Meanwhile, opportunities exist not only for ATC equipment manufacturers, but possibly for providers of air traffic communications, navigation, and surveillance services.[61]

57 Office of Technology Assessment, based on a survey of senior representatives of the U.S. airline industry, 1993.

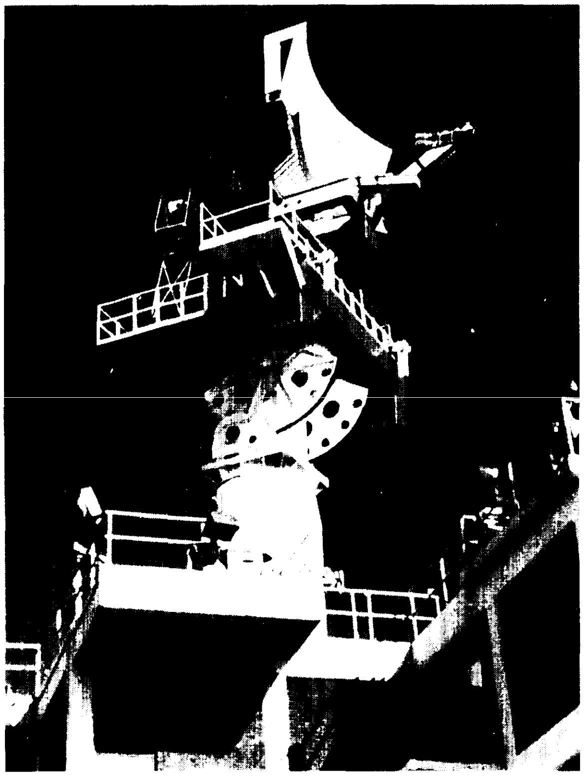
58 Anthony Broderick, FAA Associate Administrator for Regulation and Certification, comment at OTA workshop, June 9, 1992

59 For the purpose of this section, *air traffic control equipment* is defined as the various components of ground-based equipment (radars, sensors, computer hardware and soft ware, landing systems, and communications equipment) that enable an organization to provide commercial ATC services. This definition excludes onboard aircraft avionics.

60 David Hughes, "ATC, Airport Upgrades Poised for New Growth," *Aviation Week & Space Technology,* Apr. 5, 1993, pp. 40-43.

61 ATC service is a governmental function throughout the world, rather than a commercial industry; FAA is responsible for ATC services for the United States. One economist estimates that the United States provides ATC services for one-third to one-half less cost than for similar traffic levels and airspace coverage than European agencies. Richard Golaszewski, Gellman Research Associates, Inc., "Improving Air Traffic Control in Europe," *34th Air Traffic Control Association Fall Conference Proceedings,* Oct. 30- Nov. 2, 1989 (Arlington, VA: Air Traffic Control Association, 1989), pp. 508-515.

WESTINGHOUSE ELECTRIC CO



The Westinghouse ASR-9 airport surveillance radar developed for FAA is also sold to foreign countries

State of the Industry

While hard to estimate, the ATC equipment market—globally and nationally—is only about 1 or 2 percent of the size of the civil aircraft and equipment market. The federal government does not track trade and production data separately for the ATC equipment industry; ATC equipment is a small part of the Department of Commerce's Standard Industrial Code SIC 3812: search, detection. navigation, guidance. aeronautical, and nautical systems instruments and equipment. A study by the consulting firm DRI/McGraw-Hill calculated worldwide ATC sales by both U.S. and foreign companies as $6.3 billion in 1992. projected to grow at a 9-percent annual rate over the following decade.[62] Even those ATC manufacturing executives surveyed by OTA[63] who thought that DRI/McGraw-Hill's estimates were reasonable noted the uncertain availability of funds in Eastern Europe, the Commonwealth of Independent States, and China as a factor that could reduce the size of the market in the future. In addition, the DRI/McGraw-Hill estimate includes aircraft avionics; several respondents thought that the DRI/McGraw-Hill estimate overstated the true size of the worldwide ATC market by two to five times. Of the world market (including the United States). the consensus of the surveyed executives was that the U.S. share is close to 40 percent, or $2.7 billion if the DRI/McGraw-Hill estimate was correct.[64]

OTA's survey of seven firms in the civil ATC market can also be used to estimate the size of the U.S. ATC industry. Total employment was 4,400 in 1992 and revenue was approximately $1.2 billion for the seven firms. OTA estimates that revenue for the entire U.S. ATC industry in 1992 was between $1.2 billion and $1.9 billion-or slightly over one-half of the DRI/McGraw-Hill number.[65] Based on U.S. firms' foreign revenues, the United

[62] "Worldwide ATC Market Expected To Grow More Than 9% Annually," *ATC Market Report*, vol. 1, No. 12, Dec. 3, 1992, pp. 1-2.

[63] The following firms were surveyed: IBM Corp., Westinghouse Electric Corp., Hughes Aircraft Co., Paramax Systems Corp., Raytheon Co., Martin Marietta Corp., All ied Signal Co., Textron, Inc., Wilcox Electric, Inc., Hazeltine Corp.. and ITT Gilfillan.

[64] This estimate—that the U.S. worldwide market share is 40 percent—was originally provided by Ed Hazelwood, Editor, *ATC Market Report*.

[65] Since the primary customer for ATC equipment in the United States, FAA, does not purchase any foreign -made equipment, FAA outlays for ATC equipment can be used as a proxy for the domestic share of U.S. industry revenues. In 1992, FAA spent S 1.6 billion on ATC equipment and services. Herman Tharrington, Special Assistant to the FAA Associate Administrator for NAS Development, verified that FAA does no(purchase AT(' equipment from foreign-based manufacturers. It should be noted that some of FAA's ATC equipment contracts are with U.S. subsidiaries of foreign-owned corporations; i c., Wilcox Electric, Inc. and Cardion, Inc. The Department of Defense purchases ii small amount of ATC equipment less than $ I 00 million per year–for use in the National Airspace System and. occasionally, an airport authority will as well

States had a 1992 balance of trade surplus in ATC equipment of approximately $300 million to $475 million.[66]

Both the DRI/McGraw-Hill study and an independent forecast by Raytheon, an ATC equipment manufacturer with significant foreign sales, project the international market to grow at almost a 10-percent annual rate.[67] However, even if the foreign contracts awarded to U.S. firms grow at this rate, their profits may not increase as quickly, since foreign contracts often require firms to subcontract out a significant share of the work to local firms. Still, industry forecasts project that the world market for ATC equipment will grow faster than the markets for commercial aircraft and airline service. According to Boeing, the transport aircraft market, as measured by the value of annual deliveries, is not expected to grow from 1993 through 2005 while passenger travel will increase around 5 or 6 percent per year during this period.[68]

U.S. Trade Policy for ATC Equipment

To penetrate foreign markets, countries that produce ATC equipment require government attention to a greater extent than even commercial aircraft manufacturers. In virtually all cases, the ATC equipment is sold to national governments, while aircraft sales are made to airlines, which may or may not be government-owned.

In this context, home government subsidies enable foreign ATC manufacturers (some of which are state-owned) to outbid U.S. companies for equipment contracts-either through lower prices, loan guarantees, or other attractive financing, or by selling equipment as part of a foreign aid package. Unfortunately, the General Agreement on Tariffs and Trade (GAIT)-under which international ATC equipment sales are covered—does not effectively deal with government subsidies. Although GATT contains rules regarding subsidies, they do not directly address a multilateral trading situation (e.g., U.S. and European firms competing for a contract award from a developing country). If the playing field regarding subsidies could be leveled for multilateral trade through GATT-as it is for bilateral trade—U.S. firms would become stronger competitors in the global market.

The European Union is defining an ATC technology plan for Europe with a goal of ensuring that European industry does not fall behind the United States in this technology area. If Europe succeeds at consolidating its ATC system and equipment manufacturing industries, then U.S. suppliers will have fewer opportunities in Europe and greater competition in developing-country markets.[69] Moreover, Eurocontro1[70] claims not to be bound by aviation bilateral agreements and provides favored status to European companies bidding on its research and development contracts.[71]

CONCLUSIONS

The future of U.S. aviation is global. U.S. aviation manufacturers and service providers are strong international competitors. They are world leaders in

66OTA's survey indicated that 25 percent Of ATC manufacturers' revenue was from foreign customers. This figure was used to estimate the U.S. balance of trade in ATC manufacturing.

67The forecast by Raytheon did not state a specific time horizon. See David Hughes, "Raytheon Stresses ATC Oversew Market," *Aviation Week & Space Technology,* Mar. 1, 1993, p. 54. The surveyed executives were split as to whether DRI/McGraw-Hill's forecast growth for the entire world market, 9 percent annually, was accurate or too high.

68Boeing, *1993 Current Market Outlook* (Seattle, WA: 1993), p. 1.5.

69Gellman Research Associates, inc.. "Cooperation and Coordination in Federal Aviation Research," OTA contractor report, Aug. 27, 1992, p. 34.

70A supranational air traffic management organization in Western Europe (see ch. 2)

71 James L. Crook, Vice President for Operations, Air Traffic Control Association, Inc., personal Communication, June 30, 1994.

delivering high value and quality aircraft. ATC equipment, and airline and ATC services. However. further market opportunities exist, especially in the fast-growing ATC markets. The international market for ATC equipment is expected to grow at a higher rate than either the market for commercial aircraft or air travel during the next decade.

Safety, environmental. and ATC standards are becoming increasingly important to U.S. aviation industry economics. International differences in these regulations impose a cost burden on U.S. industries. While good progress is being made in harmonizing European and U.S. safety standards for aircraft design, it will take more than a decade to completely harmonize operating regulations.

Abbreviations | A

ACAS	airborne collision avoidance system
ACARS	ARINC Communications and Reporting System
ACEE	Aircraft Energy Efficiency program
ADP	advanced ducted propeller
ADS	automatic dependent surveillance
AEAP	Atmospheric Effects of Aviation Project
AERA	Automated En Route Air traffic control
AESA	Atmospheric Effects of Supersonic Aircraft program
AGFS	Aviation Gridded Forecast System
AIRNET	Airport Network Simulation Model
ALPA	Air Line Pilots Association
AMASS	Airport Movement Area Safety System
ANC	Air Navigation Commission
AOR	FAA Operations Research Service
APO	FAA Office of Aviation Policy, Plans, and Management Analysis
ARINC	Aeronautical Radio, Inc.
ARTCC	air route traffic control center
ARTS	Automated Radar Terminal System
ASDE	Airport Surface Detection Equipment
ASF	FAA Associate Administrator for Aviation Safety
ASOS	Automated Surface Observing System
ASQP	Airline Service Quality Performance
ASRS	Aviation Safety Reporting System
AST	Advanced Subsonic Technology
ASTA	Airport Surface Traffic Automation
ATA	Air Transport Association
ATC	air traffic control
ATCRBS	Air Traffic Control Radio Beacon System
ATCSCC	Air Traffic Control System Command Center
ATM	air traffic management
ATN	Aeronautical Telecommunications Network
ATOMS	Air Traffic Operations Management System
AWIPS	Advanced Weather Interactive Processing System
AWOS	Automated Weather Observing System
AWPG	Aviation Weather Products Generator
BEA	Bureau of Economic Analysis
BWI	Baltimore-Washington International Airport
CAA	Civil Aviation Administration
CAEP	ICAO Committee on Aviation Environmental Projection
CAMI	Civil Aeromedical Institute

CASIS	Civil Aviation Security Information System
CASR	Center for Aviation Systems Reliability
CATER	Collection & Analysis of Terminal Records
CBA	cost-benefit analysis
CD	compact disc
CERL	Construction Engineering Research Laboratory
CFD	computational fluid dynamics
CFIT	controlled flight into terrain
CIA	Central Intelligence Agency
CIP	Capital Investment Plan
CNS	communications, navigation, and surveillance
CO	carbon monoxide
CODAS	Consolidated Operations and Delay Analysis System
CONDAT	consolidated data system
CRADA	Cooperative Research and Development Agreement
CRM	crew resource management
CRREL	Cold Regions Research and Engineering Laboratory
CRS	computerized reservation system
C/SOIT	Communications/Surveillance Operational Implementation Team
CST	computational structures technology
CTAS	Center-TRACON Automation System
DA	descent advisor
DDAS	Daily Decision Analysis System
DNA	Defense Nuclear Agency
DNL	averaged day-night noise level; also, L_{dn}
DOD	Department of Defense
DOE	Department of Energy
DOI	Department of the Interior
DOT	Department of Transportation
DUATS	Direct User Access Terminal Service
E^3	Energy Efficient Engine program
EATCHIP	European Air Traffic Control Harmonisation and Integration Programme
ECAC	European Civil Aviation Conference
ECI	Engine Component Improvement program
EDMS	Emissions and Dispersion Modeling System
EDS	explosives detection system
EFTA	European Free Trade Association
EMF	electromagnetic field
EPA	Environmental Protection Agency
ESAS	Enhanced Situational Awareness System
ETMS	Enhanced Traffic Management System
EU	European Union (formerly European Community)
F&E	facilities and equipment
FAA	Federal Aviation Administration
FAEED	FAA Aircraft Engine Emissions Database
FANS	Future Air Navigation System
FAR	Federal Aviation Regulation
FAST	final approach spacing tool
FBI	Federal Bureau of Investigation
FCCSET	Federal Coordinating Council for Science, Engineering, and Technology
FDADS	Full Digital ARTS Display System
FFRDC	Federally Funded Research and Development Corporation
FICON	Federal Interagency Committee on Noise
FLOWSIM	airport traffic flow simulation model
FMS	flight management systems
GA	general aviation
GATT	General Agreement on Tariffs and Trade
GCM	general circulation model
GCRP	Global Change Research Program
GCS	Guidance and Control Software
GLONASS	Global Orbiting Navigational Satellite System
GNSS	global navigation satellite system
GOES	Geostationary Operational Environmental Satellite
GPS	Global Positioning System
GPWS	ground proximity warning system
GRADE	Graphical Airspace Design Environment

HARS	high-altitude route system
HC	hydrocarbon
HF	human factors
HF	high frequency
HSCT	high-speed civil transport
HSI	Human Systems Interface
HSRP	High-Speed Research Program
IAA/TOF	Interagency Agreements for the Transfer of Funds
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
IFR	instrument flight rules
IGIA	Interagency Group on International Aviation
ILS	instrument landing system
IMC	instrument meteorological conditions
INM	Integrated Noise Model
ITWS	Integrated Terminal Weather System
JAA	Joint Aviation Authorities
JAR	Joint Airworthiness Regulation
LIDAR	light detection and ranging
LOFT	Line Oriented Flight Training
LTO	landing and takeoff cycle
MLS	microwave landing system
MOA	Memorandum of Agreement
Mode-S	mode select
MOU	Memorandum of Understanding
MPAP	Multiple Parallel Approach Program
MSD	multiple site damage
NACA	National Advisory Committee for Aeronautics
NADIN	National Airspace Data Interchange Network
NANIM	National Noise Impact Model
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NASPAC	National Airspace System Performance Analysis Capability
NASSIM	NAS traffic simulation model
NATCA	National Air Traffic Controllers Association
NCAR	National Center for Atmospheric Research
NDE	nondestructive evaluation
NEXRAD	next-generation weather radar
NIASS	National Institute of Aerospace Studies and Services
NIST	National Institute of Standards and Technology
NMAB	National Materials Advisory Board
NOAA	National Oceanographic and Atmospheric Administration
NOx	nitrogen oxides
NPDES	National Pollutant Discharge Elimination System
NRC	National Research Council
NSF	National Science Foundation
NSTC	National Science and Technology Council
NTSB	National Transportation Safety Board
OAG	*Official Airline Guide*
ODAPS	Oceanic Display and Planning System
OMB	Office of Management and Budget
OPSNET	Operational Performance System Network
OPTIFLOW	optimized national traffic flow planning model
PADS	Planned Arrival and Departure System
PBE	portable breathing equipment
PRM	Precision Runway Monitor
PSA	Pacific Southwest Airlines
PTRS	Program Tracking and Reporting Subsystem
R&D	research and development
RAIM	receiver autonomous integrity monitoring
RE&D	research, engineering, and development
RF	radio frequency
RNPC	required navigation performance capability
RSPA	Research and Special Programs Administration
RTCA	Radio Technical Commission for Aeronautics
SDAT	sector design analysis tool
SDRS	Service Difficulty Reporting System

SIMMOD	trademark name for airport and airspace simulation model
SMARTFLO	expert system-based flow planning tool
SOIT	Satellite Operational Implementation Team
SPAS	Safety Performance Analysis System
SPEARS	Screener Proficiency Evaluation and Reporting System
SSR	secondary surveillance radar
SST	supersonic transport
TATCA	terminal ATC automation
TCAS	Traffic Alert and Collision Avoidance System
TDWR	terminal Doppler weather radar
TMA	Traffic Management Advisor
TRACON	terminal radar approach control
TSRV	Transport Systems Research Vehicle
USAF	U.S. Air Force
USATS	U.S. Air Traffic Services
USDA	U.S. Department of Agriculture
VFR	visual flight rules
VHF	very high frequency
VNTSC	Volpe National Transportation Systems Center
VOC	volatile organic compounds
WES	Waterways Experimental Station
WPMS	Work Program Management System
WVAS	Wake Vortex Advisory System

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