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.

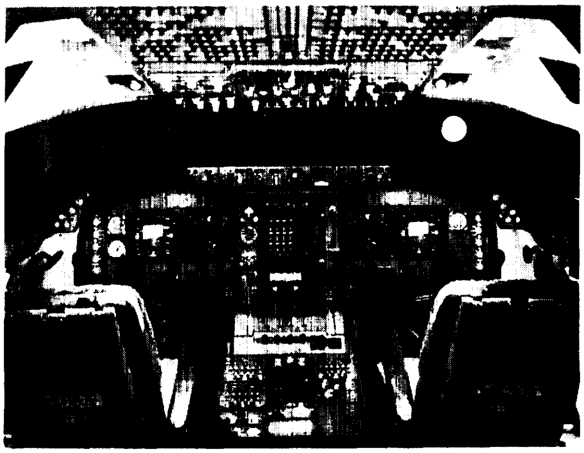
7 Mark Hofmann, FAA Chief Scientific and Technical Advisor for Human Factors, personal communication, Apr. 15, 1994.

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.[10] 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. 877-885.

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

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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$1Oblllonto$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

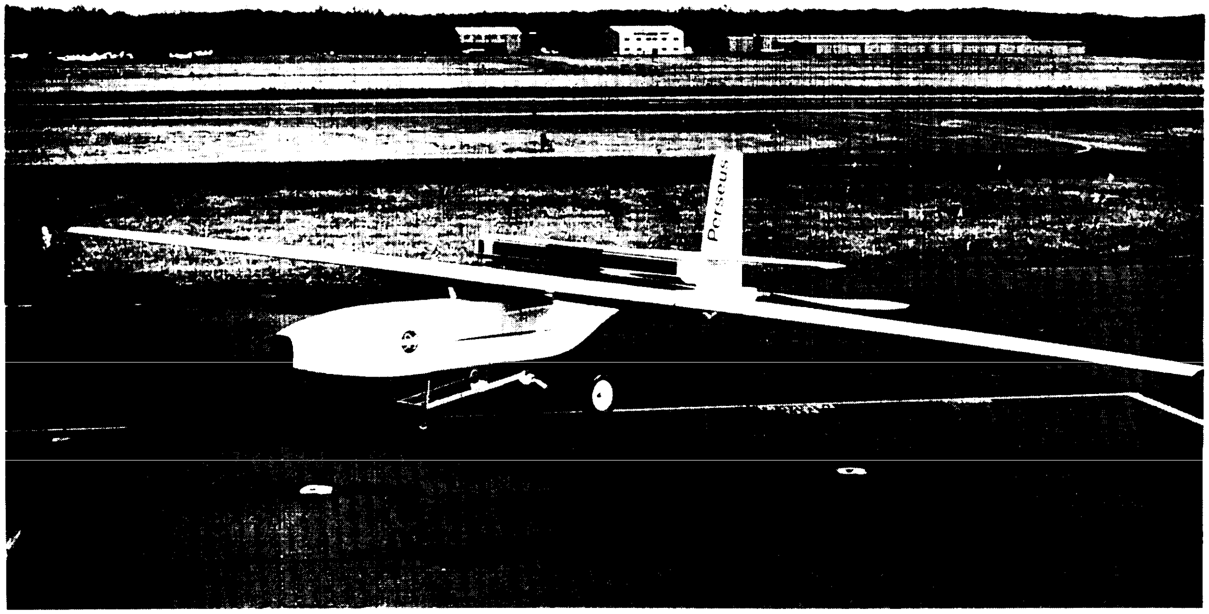
[5] National Aeronautics and Space Administration, "Atmospheric Effects of Aviation/Subsonic Assessment Modeling Data Analysis and Measurements in Support of the Advanced Subsonic Technology Program " research announcement NRA 94- OA-01, Oct 15 1993

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.

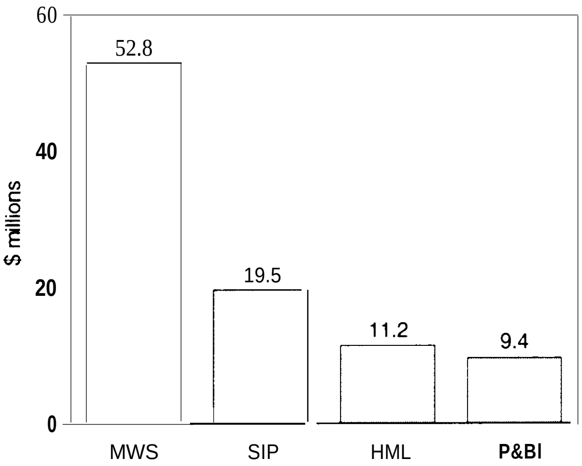
formation, cloud formation and dissipation, and mixing and transport inside and through the tropopause.[25]

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.

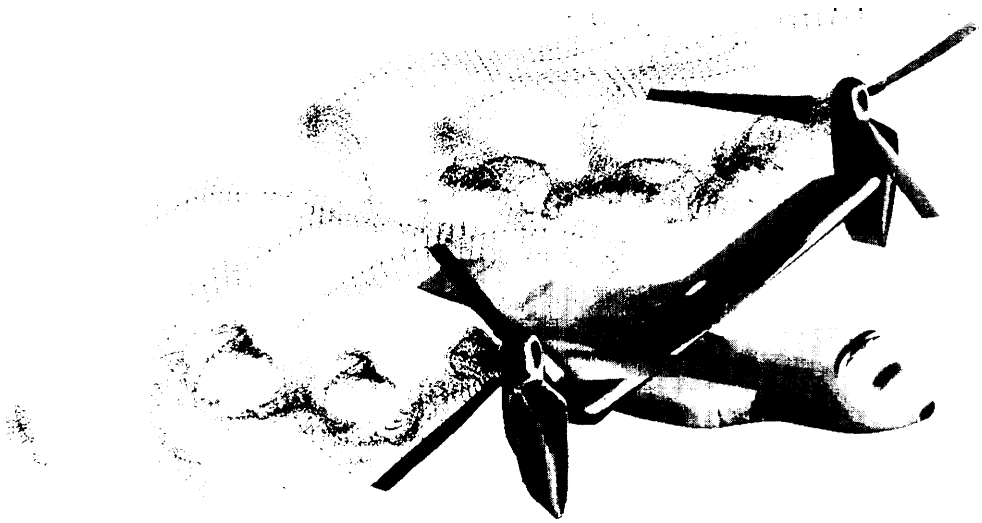
The U.S. Weather Research Program no longer benefits from the visible, high-level coordination effort it had under the FCCSET Committee on Earth and Environmental Sciences, Subcommittee on Atmospheric Research. Under the new National Science and Technology Council committee structure, there is no entity 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 Technology 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 world-wide 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 longitudinal 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:

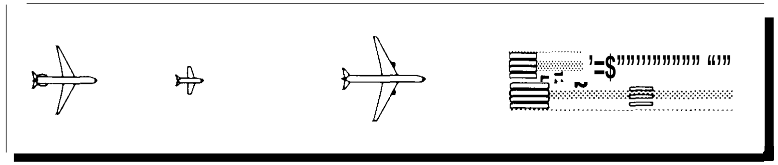
- *Phase 1:* GPS is permitted as a supplemental navigation system. (Ground-based navigation aids must be available as backup.)
- *Phase* **2:** GPS is permitted as the primary guidance system. (Ground-based navigation aids

[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

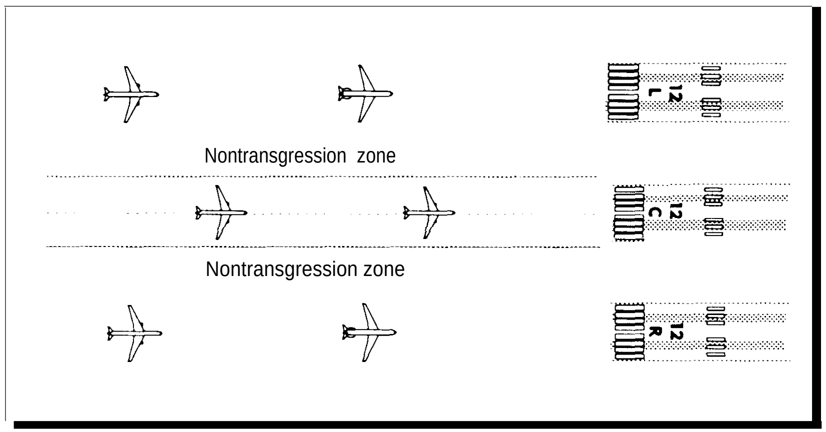
Objectives:
- **More** operations per runway
- More operating runways per airport
- Minimized delay
- No diminished safety

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.)[50]

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 it pow\ 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 wiII 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 wiII 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 wiII 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 1994[4]

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 1996[6] 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

[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 repot-t. Feb. 28, 1993, p. 2.

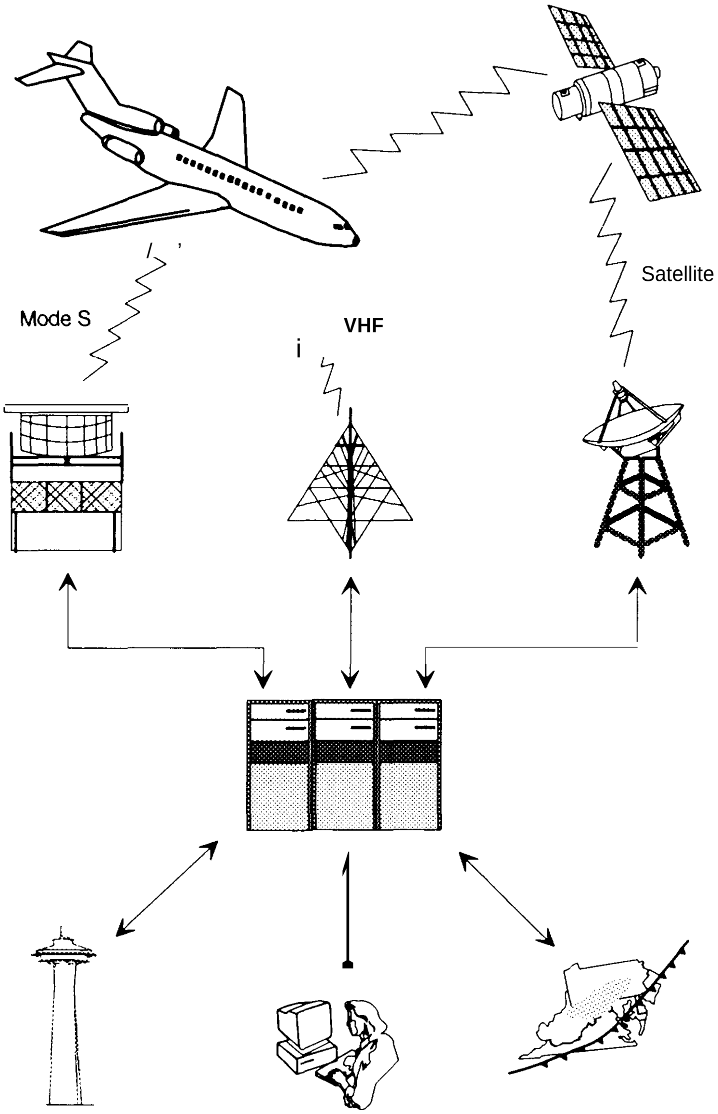
[59] Ibid.. p. 3.

[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, persona] 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, wiIl provide aircraft identification and Iocation 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]

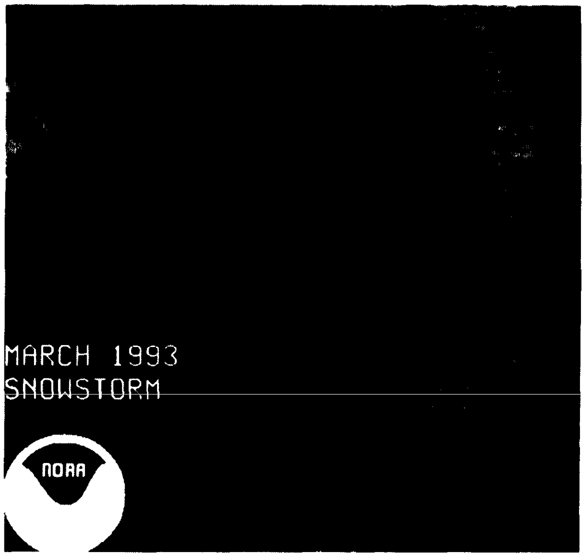
Automated en route air traffic control

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

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.

I 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]

EDERAL 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 m 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-

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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 WALLACF OTA

As for other aviation personnel, airport rescue and fireflghting (RFF) crew capabilities must be developed and exercised regularly An RFF vehicle is shown extlngulshing a fuel-fed fire during a tralning 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).

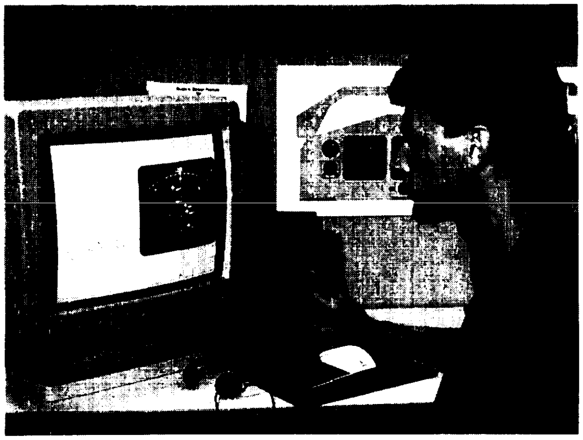
[97] The mandated implementation of state-of-the-art, heat-resistant materials (see 14 CFR 25.853) limits the utility of further materials R&D over the near term. Constantine Sarkos, Manager, Fire Safety Branch, FAA Technical Center, personal communication, Apr. 22. 1992.

[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-

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[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 BaltImore-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-

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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)

[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

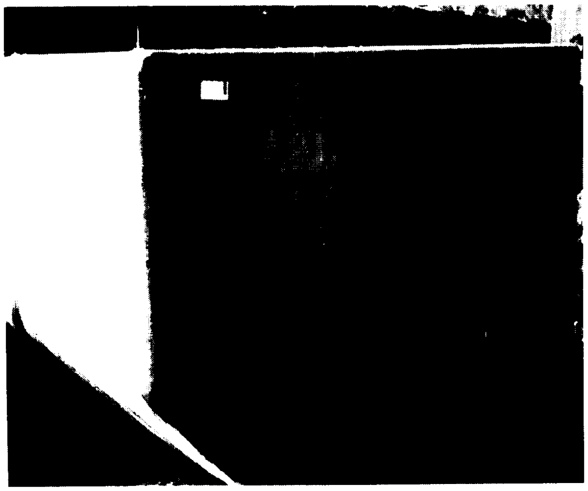
[7] Paul Polski Director FAA Aviation Security R&D Service personal communication Apr 28, 1994

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]

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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 1ike 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.