Chapter 8
Aircraft Technologies

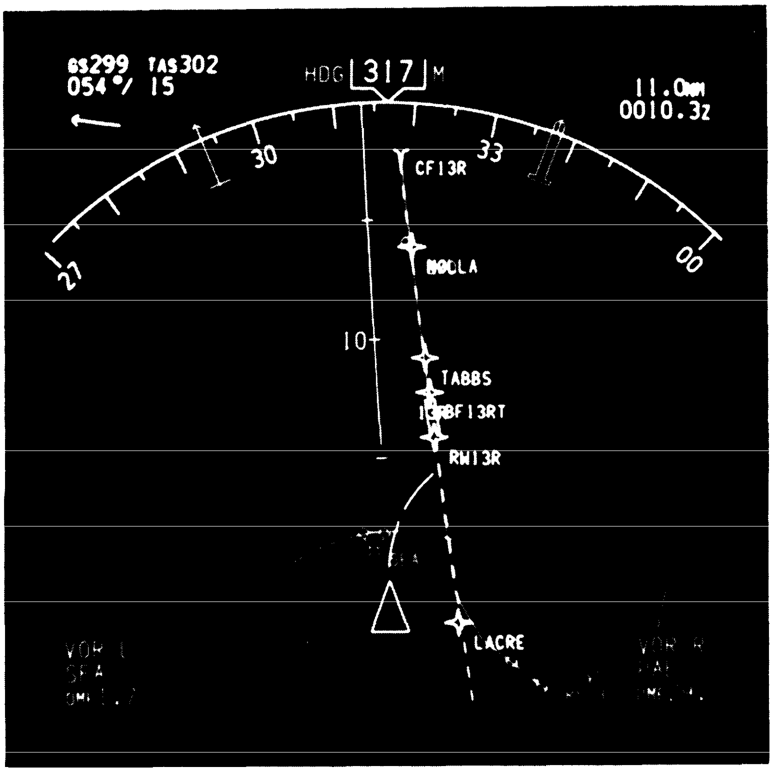

Photo credit: Boeing Commercial Airplane Co.

Horizontal situation display for the cockpit

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Technological advances have generated new types of sophisticated and complex commercial aircraft. Functions once performed by pilots using information provided by electromechanical displays are now performed automatically, with information for the pilot presented on electronic displays. New fly-by-wire concepts sever the mechanical connection between pilot and the aircraft wing and tail. Dozens of electronic devices monitor and control aircraft components, and newer types of aircraft provide pilots or automated control devices such as computers and actuators with enormous quantities of information. Simultaneously, at the other extreme, many airlines are operating older types of aircraft, finding the high cost of new equipment prohibitive. Thus, the commercial aviation industry uses a variety of aircraft technologies of various ages and levels of sophistication—all regulated by the Federal Government to assure the safety of the flying public.

This chapter examines the Federal *Aviation* Administration (FAA) rulemaking and enforcement activities for new aircraft technologies, including standardization across FAA directorates, technical expertise and personnel levels, and inspector training. Because the future will bring new cockpit and engine technologies and advanced materials, high-speed aircraft, and vertical and short takeoff and landing aircraft, the implications of such technologies for safety and regulatory activities are also reviewed.

REGULATION OF AIRCRAFT TECHNOLOGIES

FAA rulemaking in areas of technology is often controversial; parts of industry have, on occasion, claimed that FAA has forced the development of technology by proposing or suggesting a rule, often at the urging of Congress or the National Transportation Safety Board. However, the point at which a new technology is ready for implementation is quite subjective. For instance, anti-misting kerosene fuel was given a widely publicized crash test in 1984 with direct inference that a rule requiring its use was forthcoming. The test did not go as planned, at least in part, because the aircraft, controlled from the ground, hit the target for the controlled crash at an angle. An engine was damaged and exploded, igniting escaping fuel and creating an inferno. Temperatures within the cabin, however, remained within the survivable range. The failed crash test reinforced other evidence that, despite previous successes with smaller scale tests, anti-misting kerosene was still a developmental substance, and further research was needed. Another example is flammability standards for cabin materials. An FAA rule requires that cabin materials in transport category airplanes meet test criteria based on heat release as a measure of flammability, with two steps to incorporation—August 1988 and August 1990.[1] Some industry sources have argued that materials meeting the criteria did not exist, at least at the time of the rulemaking;[2] in any case, meeting the criteria will surely be costly to airlines and manufacturers. Concerns have also arisen about the applicability of the required test criteria, since they do not explicitly include smoke; FAA's position is that heat release alone is an adequate criterion because of a correlation between heat release and smoke.

Congress plays a role in regulating aircraft technologies through its oversight of FAA and hearings are often used to focus attention on regulatory issues that are important to Congress. Congress can also pass laws that force technology requirements. One example is the recent legislation, discussed in chapter 7, requiring collision avoidance equipment in commercial aircraft and expanding Mode C transponder requirements for general aviation (GA). Congress also urged rapid completion of regulations requiring the Ground Proximity Warning System

[1] 51 *Federal Register* 26206 (July 21, 1987).
[2] 51 *Federal Register 26166* (July 21, 1987).

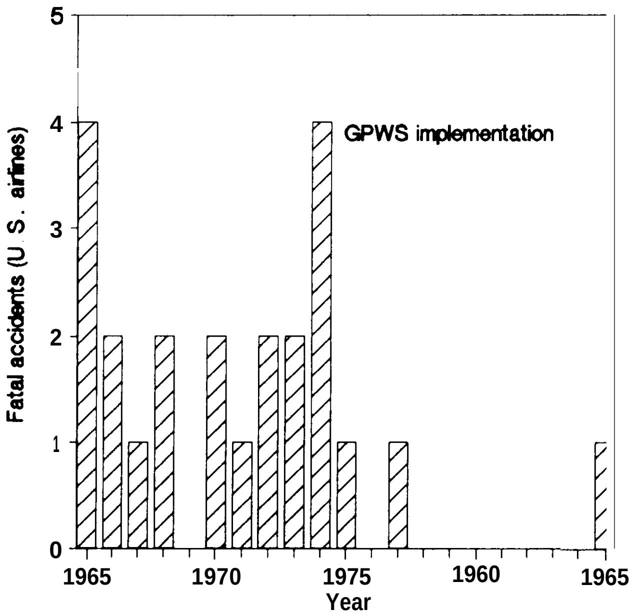
(GPWS). Although GPWS suffered from false-alarm problems early on, it has demonstrably improved safety for approach and descent phases of flight (see figure 8-1).

Airworthiness

Government responsibilities for equipment airworthiness include development and administration of safety standards for aircraft, engines, propellers, and appliances such as avionics. Certification of aircraft is at three levels: type, production, and original. Type certification is FAA approval of the design of an aircraft, production certification is approval of the quality control system for production, and the original certification process is the granting of approvals of the first and subsequent aircraft off the assembly line.[1] In cases where the FAA Administrator finds that airworthiness regulations do not contain adequate or appropriate safety standards for an aircraft, aircraft engine, or propellor because of a novel or unusual design feature, he may prescribe special conditions for the product to allow its certification.[4] FAA is also responsible for noise and emission level certification of aircraft.

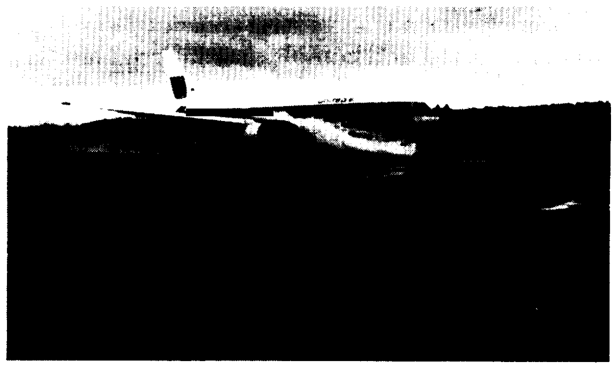
[1]U.S. Department of Transportation, Federal Aviation Administration, "Aircraft Certification Safety Regulatory Program Description," briefing document, n.d.

Figure 8-1.—Controlled Flight Into Terrain: Descent and Approach Phases of Flight



KEY: GPWS = Ground Proximity Warning System.

SOURCE Office of Technology Assessment, adapted from L.G. Lautman and P.L. Gallimore, "Controlling the Crew Caused Accident," Boeing Commercial Aircraft Co., May 1987



Prior to their use, commercial aircraft undergo extensive testing, such as this water spray test of the Boeing 767-200.

FAA rarely has the personnel or the specific technical expertise to certify an aircraft type without assistance from the manufacturer. FAA relies heavily on Designated Engineering Representatives (DERs), who are experienced engineers employed and paid by the manufacturer, but supervised by FAA, to help in the certification process. DERs provide opportunity for conflicts of interest, although the professionalism of the DERs and supervision by FAA mitigate against this.[5] Their experience in working with FAA regulations often makes DERs prized personnel for manufacturers.[6]

However, to ensure that certification requirements are adequately applied, FAA requires technical expertise on its staff to provide oversight for DERs. The largest pool of such expertise is in the ranks of engineers at the manufacturers, and FAA has had difficulty in attracting highly qualified and experienced engineers to work in certification in recent

[4]14 CFR 21,16 (Jan. 1, 1987).

[5]National Research Council, *Improving Aircraft Safety: FAA Certification of Commercial Passenger Aircraft* (Washington, DC: National Academy of Sciences, 1980), pp. 29-31.

[6]William Ashworth, office manager, Seattle Aircraft Certification Office, Federal Aviation Administration, personal communication, Aug. 4, 1987.

years. Some contend that this is due to the pay scale for engineers at FAA which has not kept up with industry, and because of limited career development opportunities at FAA.[7] The pay scale for certification engineers applies to engineers at the National Aeronautics and Space Administration (NASA), the Department of Defense (DoD), and other Federal organizations, as well. FAA maintains that broader systems knowledge is required of its certification engineers than of engineers at the other organizations and that FAA certification engineers could be on a higher pay scale.[8] FAA employs about 10 National Resource Specialists, who are experts in particular areas, at a higher salary level.

FAA's control over type certification is shared by four of its regional offices, a decentralized organization that lends itself to internal FAA disagreements over regulatory actions. An example is the Boeing request to screen off two of the 10 exit doors on 747s, discussed in chapter 3.

The FAA Associate Administrator for Aviation Standards has recognized that the certification program is not standardized across directorates, is unable to keep up with technical developments because of a shortage of expertise, and has human relations problems and training limitations for certification personnel. Project SMART is now under way to develop a master plan to address these problems and upgrade the aircraft certification regulatory program. So far, a job task analysis and management analysis for certification have been started. The knowledge gained from Project SMART has already begun to benefit the national training program, job design and restructuring, and other areas through its recommendations for improvement. Project SMART has not yet received project funding, but is supported by miscellaneous funds from other projects.[9]

Both Parts 121 and 135 prescribe minimum airplane instrument and equipment requirements,[10] and the regulations contain the specification and installation requirements for instruments and equipment. The major categories of instruments and equipment specified in the regulations are: flight and navigational equipment; engine instruments; emergency equipment; seats, safety belts, and shoulder harnesses; public address and crewmember interphone systems; special instruments for operations at night and under instrument flight rules or over-the-top conditions; oxygen and other protective breathing equipment; radio equipment; weather detection equipment; flight and cockpit voice recorders; and ground proximity warning devices. Carriers operating under Parts 121 and 135 are prohibited from using airplanes unless certain instruments or pieces of equipment, contained in a minimum equipment list for the aircraft type, are operable. However, there are numerous differences between the Part 121 and Part 135 instrument and equipment regulations. While many of these inconsistencies exist because of differing design and performance capabilities of large and small airplanes, certain pieces of equipment required for Part 121 operations have been intentionally excluded from Part 135, primarily for economic reasons that predate deregulation. These inconsistencies have caused concern since deregulation for several fundamental reasons. First, for some routes, Part 135 operations have replaced Part 121 operations. Second, the intent of Congress was to not allow any diminution of safety because of deregulation. Third, code-sharing arrangements have produced cases where passengers are not aware that they will be flying with a Part 135 operator when they buy a ticket from a major carrier. Regulatory initiatives are under way to address flight and cockpit voice recorders, ground proximity warning devices, and crew interphone systems for Part 135 operations.[11]

Equipment Certification Process

Aircraft engines and propellers are subject to the same certification process as aircraft. Appliances, such as avionics, are certified through the development of Technical Standard Orders. The technical

[7] Ibid.

[8] Dennis H. Piotrowski, program manager, Office of Airworthiness, Federal Aviation Administration, personal communication, Sept. 29, 1987.

[9] Ibid.

[10] 14 CFR 121, Subpart K and 14 CFR 135, Subpart C (Jan. 1, 1987).

[11] Examples of other differences include: 1) regulations for protective breathing equipment for flight crewmembers in pressurized aircraft, required under Part 121, are not included in Part 135; and 2) although airborne weather radar equipment is required for large transport category airplanes (20 seats or more) under Parts 121 and 135, multiengined aircraft with 10 seats or more are required to have airborne thunderstorm detection equipment only.

basis for appliance certification is often the work of standards organizations such as the Radio Technical Commission for Aeronautics (RTCA) and the Society of Automotive Engineers (SAE). RTCA covers communications systems, while SAE covers a wide variety of systems such as landing gear, oxygen equipment, aircraft instruments, and many others. RTCA and SAE form committees of industry and government representatives to examine standards for aircraft appliances, and produce documents which represent the consensus of the group. FAA is under no legal obligation to use these documents, but frequently utilizes them because of the technical knowledge they embody and because they are the products of agreement between many disparate groups.[12]

Maintenance regulations for operations under Part 121 and for operations using aircraft with 10 or more passenger seats under Part 135 are similar; separate maintenance requirements for Part 135 operations using aircraft with 9 seats or fewer are described below.[13] Certificate holders, who are primarily responsible for the airworthiness of their aircraft, are required to establish maintenance organizations and programs, or arrange to have some or all of the work performed by qualified outside entities.[14]

The operations specifications for each carrier describe the maintenance and inspection requirements that must be met. Typically, these activities include: routine aircraft inspections, tests, and servicing performed at prescribed intervals; scheduled maintenance tasks, such as replacement of life-limited items and nondestructive testing; unscheduled maintenance activities generated by inspections, flight crew reports, or other analyses; specific engine, propeller, and appliance repair and overhaul tasks; and major structural inspections and airframe overhauls. Required inspection items, work elements that could endanger the safe operation of an aircraft if improperly done, are also specified. All maintenance activities must be conducted in accordance with performance standards specified in 14 CFR 43, and records must be kept of all work performed on an aircraft.

Parts 121 and 135 regulations require that maintenance organizations be adequate to perform all work and required inspections; and that inspection and maintenance functions are kept separate below the administrative control level. Mechanics and repairmen employed by certificated carriers must meet minimum certification requirements contained in 14 CFR 65. In addition, carriers are required to prepare detailed manuals for employees prescribing methods, standards, and procedures for all maintenance. Some airlines use the job cards of the aircraft manufacturer's maintenance manual without modification for their own program; this saves the airline the cost of having to develop its own system.[15] Airlines may not perform major repairs on airplanes unless so authorized by FAA, *6 but there are ambiguities in the definition of "major repair."[17] Airlines are required to establish training programs to inform maintenance and inspection personnel about procedures, techniques, and new equipment and to develop an internal audit system to ensure quality control.

Although work limits have not been prescribed for maintenance personnel under Part 121, existing regulations require that they be relieved from duty for at least 24 consecutive hours during any 7 consecutive days or an equivalent period within any calendar month. A similar provision has not been included in the Part 135 regulations.[18]

Maintenance requirements for Part 135 operations using aircraft with nine seats or fewer are less extensive.[19] These operators are permitted to follow the maintenance requirements in 14 CFR 91 for GA aircraft, unless FAA determines that a more rigorous program is necessary. In these instances, oper-

[12] William G. Osmun, The *Authority of Agreement: A History of RTCA* (Washington, DC: Radio Technical Commission for Aeronautics, 1985).

[13] 14 CFR 121, Subpart L and 14 CFR 135, Subpart J (Jan. 1, 1987).

[14] A carrier authorized by the Federal Aviation Administration to perform all maintenance and inspection activities required under Part 121 or 135 on its own aircraft or for other carriers or operators does so under a Continuous Airworthiness Maintenance Program. See U.S. Department of Transportation, Federal Aviation Administration, "Continuous Airworthiness Maintenance Programs," Advisory Circular 120-16C, Aug. 8, 1980.

[15] David Sayre, supervisor, Maintenance and Ground Systems, Boeing Commercial Airplane Co., personal communication, Aug. 3, 1987.

[16] 14 CFR ch. 1 SFAR-36 (Jan. 1, 1987), pp. 288-290.

[17] William C. Keil, USAir and Melvin C. Beard, Federal Aviation Administration, in U.S. Congress, Office of Technology Assessment, "Transcript of Proceedings—OTA Workshop on Technology in Commercial Aviation Safety," unpublished typescript, July 1, 1987, pp. 227-229.

[18] 14 CFR 121.377 (Jan. 1, 1987).

[19] 14 CFR 135.411 (Jan. 1, 1987).

ations specifications are amended to require a program that contains: instructions and procedures for aircraft inspections, specifying parts and sections of airframes, engines, propellers, rotors, and appliances; schedules for performance of aircraft inspections in terms of time in service, calendar time, or number of system operations; and instructions and procedures for recording discrepancies found during inspections, corrections, or maintenance deferrals.

Principal Maintenance Inspectors (PMIs), who inspect airlines' maintenance operations, are stationed at FAA field offices. PMIs also participate with factory maintenance specialists assigned to the aircraft manufacturer in an FAA review board to develop minimum maintenance requirements for aircraft types. Questions have been raised over the adequacy of FAA surveillance of airline operations and the capabilities of inspectors to monitor maintenance programs and approve waivers or deviations from operating specifications. For further discussion of the adequacy of the number of FAA inspectors and FAA training programs for inspectors, see chapters 3 and 5.

An aircraft or part manufacturer may send airlines a service bulletin recommending a change in a configuration or an inspection or maintenance procedure to be carried out by the maintenance department. More urgent service bulletins, called alert service bulletins, usually evolve into Airworthiness Directives (ADs) issued by FAA, which require changes that must be made to retain aircraft certification. Sometimes extensive negotiation is required between an airline and FAA to ensure that an airline receives credit for promptly responding to a service bulletin, prior to the issuing of the AD.[20] In other cases, however, FAA and a manufacturer have utilized the efforts of an operator, incorporating the procedures into a service bulletin and AD.[21]

Simulators for Pilot and Mechanic Training

Simulators are currently used for initial, transition, and upgrade training, recurrent training, and proficiency checking of pilots. The efficiency, speed, safety, and low cost of simulator training compared to training in aircraft makes it attractive to airlines, as they order new aircraft and new aircraft types and recruit and train pilots. Simulators become more important from a safety standpoint as airlines must hire less experienced pilots, because simulators can provide experience in dealing with many safety-critical situations in a short time.

In addition to the full-motion, full-visual training simulators provide, a substantial amount of training is done in fixed-base cockpit training devices with no simulated scenes outside the cockpit. Personal computers (PCs) with graphics and touch-screen capabilities are also used extensively for air-craft systems and avionics training, typically one system at a time. The fixed-based cockpit training de-vices and PC-based training aids save precious time in the expensive full-motion simulators.

In general, a full-motion, full-vision simulator with a complete mock-up of the cockpit and avionics costs on the order of $10 million, regardless of aircraft type. Because of this high cost, airlines that buy simulators usually intend to sell simulation services to others, except for large airlines that have many aircraft of the same type.[22] Some airlines also send pilots to aircraft manufacturers for simulator training.

Photo credit: The Singer Co.

The exterior of a full-motion pilot training simulator

[20] William C. Keil, staff director, Engineering and Quality Assurance, USAir, Inc., personal communication, Oct. 14, 1987.

[21] David Letterer, Air Transport Association of America, letter to OTA, Jan. i, 1988.

[22] Mark Lambert, "Simulator Makers Face New Market Conditions," *Interavia*, vol. 42, January 1987, pp. 75-76.

Part 121 operators use full-motion simulators extensively, but Part 135 operators generally do not, because of the prohibitively high cost of the simulators. Federal regulations spell out requirements for Part 121 operators on simulator capabilities and what they can be used for, but are not specific on simulator use by Part 135 operators.[23] However, FAA recently released advisory circulars which delineate Part 135 requirements for advanced training devices (ATDs, which are essentially simulators without motion or visual simulation), and state where ATDs may be used instead of flight in an actual aircraft for training and testing.[24] The regional airlines have been arguing for use of ATDs since 1984.[25]

Simulators for aircraft maintenance personnel are used to provide systems overviews and demonstrations, and for practice at equipment analysis, fault reporting, and diagnosis. Computer-aided training using microprocessors is also used at certain stages of training.[26]

[23] 14 CFR, Ch. 1, Part 121, Appendix H (Jan. 1, 1987).
[24] U.S. Department of Transportation, Federal Aviation Administration, "Advanced Training Devices (Airplane Only) Evaluation and Qualification," Advisory Circular No. 120-45, May 11, 1987.

[25] Richard L. Collie, Technical Services, Regional Airline Association, personal' communication, Aug. 17, 1987.
[26] R. O. Jollie, "Digital Avionics Training," *Boeing Airliner,* April-June 1987, p. 21.

THE FUTURE OF COMMERCIAL AIRCRAFT TECHNOLOGY

The future will bring changes in commercial aviation technology, including further development and use of electronic systems for sensing the environment and control of the aircraft, new aircraft engine types, use of composite materials in aircraft construction, and new types of aircraft such as tilt-rotor and supersonic/hypersonic aircraft. Most of the changes will not be motivated primarily by concern for safety, but by the desire for efficiency and speed of travel. Significant changes are also likely in the air traffic control (ATC) system, bringing more automation, automatic decisionmaking, and methods of dealing with limited airport capacity. The changing state of technology and the airspace system require continuous safety oversight by government and industry, so that efficiency and speed are not gained at the expense of safety. Advanced technologies will present significant challenges to the government in terms of certification and flight safety. In particular, as automated systems take over more tasks, including decisionmaking, that are now performed by humans, the interaction between humans and advanced equipment will need special attention.

Cockpit Technologies

The current trends in cockpit technology are toward more automation and advanced displays for pilots, driven primarily by the push for two-pilot cockpits to save airlines the cost of a third crewmember. More information is available to pilots from new sources, and new systems can provide quick, automatic reaction within safe aircraft performance limits to events such as windshear encounters. Moreover, new technologies offer increased equipment reliability, trouble-shooting capability, and reduced weight, compared with older technologies. For all these reasons, the trends will continue into the foreseeable future.

Some areas of current research and development (R&D) include liquid crystal flat-panel displays, head-up displays, voice recognition systems, fly-by-wire and fly-by-light, and artificial intelligence (AI) applications. Liquid crystal displays offer the potential for high luminance and resolution using little power. Powered by lithium-cell batteries, such displays could be useful as standbys in case of engine or power system failure. However, the displays are very temperature sensitive and have a slow transition time, weaknesses that are subjects of current R&D.[27]

Fly-by-wire technology is included on the Concorde, the Boeing 757 with the Pratt and Whitney 2037 engine, and the Airbus 320. Fly-by-light tech-

[27] John T. Merrifield, "Transport Manufacturers Press for Automated Cockpits," *Aviation Week & Space Technology,* Mar. 10, 1986, p. 247.

nology may appear on the Boeing 7J7, if Boeing completes its development of that airplane. These technologies replace most of the mechanical links from the pilot's controls to the wings and tail by electrical wire or optical fibers. Fly-by-wire and fly-by-light save weight, reduce maintenance, and eliminate the variabilities of hydromechanical systems, thereby making airplanes easier to operate and reducing the rate of increase of aircraft operating costs. Furthermore, computers can analyze information about the behavior of the airplane and, through the fly-by-wire or fly-by-light mechanisms, physically prevent a dangerous maneuver. Currently, research is taking place in the areas of stick configuration, stick "feel," and how to handle cases where both pilots use the controls simultaneously.[28]

Most research on AI applications for the cockpit takes place in a military context. For example, the Defense Advanced Research Projects Agency sponsors the Pilot's Associate program to evaluate and demonstrate the utility of AI and expert systems techniques for military applications. Applications under examination include monitoring aircraft systems (i.e., the role of the flight engineer), mission planning and replanning, external situation assessment, and devising optimum strategies to deal with external threats.[29] NASA-Ames is also pursuing a program to optimize the guidance and control of aircraft (including ATC) using AI techniques. Although the program may have civil applications, its basic thrust is toward military aircraft.[30] Potentially, AI techniques could find application to civil aircraft in monitoring aircraft systems and dealing with complex weather information.

Advanced Materials for Aircraft

Many new types of advanced materials may be used in future aircraft. Composite materials are attractive because of their strength/stiffness properties and their lighter weight and corrosion resistance. Other advanced materials include aluminum alloys, advanced ceramics, special high-strength steels, titanium/aluminum alloys, and rigid-rod polymers, which consist of small rods of high-strength polymer embedded in a tough polymer matrix. Improved material coatings may also be used in stressful environments, such as for turbine engine blades.[31]

Processing and assembly techniques are also advancing in the areas of powder metallurgy, precision die casting and forging, lightweight metal web casting, superplastic forming, and diffusion bonding. Powder metallurgy uses highly-engineered powders at high pressure to form precision metal parts that do not require machining. Powder metallurgy permits use of superalloy developed for high temperature service and severe mechanical stressing with high surface stability. Use of cast metal web parts is currently limited by Federal regulations, which apply a safety margin to cast parts that increases their weight. Superplastic forming produces large changes in the shape of material under conditions of high temperature and low pressure. Diffusion bonding joins parts at high temperature and pressure without melting, because metal atoms diffuse across the solid surface.[32]

New types of materials will be used in propulsion systems and airframes of subsonic aircraft primarily to gain fuel efficiency. Composite materials are already used in some large commercial aircraft, including the Boeing 757 and 767 in ailerons, rudders, and certain landing gear doors, although not for any critical structures.[33] For supersonic aircraft, advanced materials will be used where the aircraft surface reaches high temperature and in propulsion systems for weight reduction and resistance to high temperatures.[34]

Research is under way to examine the implications of using advanced materials for crashworthiness;[35]

[28] John T. Merrifield, "NASA/Douglas Team Studies Fly-by-Wire Control Concepts," *Aviation Week & Space Technology*, Oct. 27, 1986, p. 38.

[29] *Aviation Week & Space Technology*, "DARPA's Pilot's Associate Program Provides Development Challenges," Feb. 17, 1986, p. 45.

[30] John T. Merrifield, "AI Research at Ames Focuses on Increased Crew Effectiveness," *Aviation Week & Space Technology*, June 2, 1986, p. 73.

[31] Morris A. Steinberg, "Materials for Aerospace," *Scientific American*, October 1986, pp. 67-72.

[32] Pierre Condom, "Forming Aircraft Structural Components: A Slow Revolution," *Interavia*, vol. 41, December 1986, pp. 1429-1430.

[33] U.S. Congress, Office of Technology Assessment, *New Structural Materials Technologies: Opportunities for the Use of Advanced Ceramics and Composites-A Technical Memorandum* (Springfield, VA: National Technical Information Service, September 1986).

[34] Steinberg, op. cit., footnote 31.

[35] Edward H Phillips, "NASA, Army Testing Composite Airframe Crashworthiness," *Aviation Week & Space Technology*, Sept. 28, 1987, p. 61.

continuing this type of research is important to ensure that FAA has sufficient knowledge to regulate the materials for safe use and maintenance. Composite materials bring a set of unique properties, such as vulnerability to impact, where surface inspection cannot detect subsurface delamination, and new technologies for inspection will be needed. The proliferation of these new materials will require the certifying and inspecting agency to have considerable expertise in their properties at its disposal, and at present FAA has one National Resource Specialist in nonmetallic advanced materials and one in fracture mechanics and metallurgy.

New Aircraft Engine Types

Turbofans are the engines used in most commercial jet aircraft today. While improvements in materials and computer modeling design techniques will allow more efficient turbofans to be built, ultra-high bypass (UHB) engines are likely to surpass turbofans by sometime in the 1990s. Current UHB engines are limited to speeds under Mach 0.80 and therefore require further development for long-range applications. (The Boeing 747, for example, currently flies at speeds of Mach 0.84 to 0.85 where Mach 1 is the speed of sound—about 660 mph at cruise altitudes.) Advanced, high-speed propellers in UHB engines improve the fuel efficiency of the propulsion system by as much as 25 percent compared to current turbofans, potentially cutting by as much as 10 percent the direct operating costs of airlines.[36]

UHB engines raise safety concerns in areas such as bird strike and icing effects, while their external propellers pose potential safety hazards because of the possibility of penetrating fuselage, flight controls, or critical components in case of a malfunction. This problem is partially mitigated by the relatively light weight of the small blades—one manufacturer has developed UHB engine blades weighing only about 10 pounds each. Other safety-related aircraft design features may include separate routing of connections to the aircraft's tail structure and locating the cabin's aft pressure bulkhead forward of the blades' plane of rotation to prevent rapid decompression in the event of blade penetration.[37]

The more distant future may bring new types of engines for use in supersonic and hypersonic aircraft. (Hypersonic refers to speeds five or more times the speed of sound in air.) The turboramjet engine is being studied for hypersonic application. This type of engine would operate as a turbofan for speeds up to Mach 3.5 and as a ramjet at higher speeds. Problems with the turboramjet engine include noise and the need to use endothermic fuels which can absorb thermal energy from the surface of the aircraft produced by aerodynamic heating.[38] For speeds above Mach 6, the supersonic combustion ramjet (scramjet) is being investigated by NASA and others.[39]

Advanced high-speed aircraft include supersonic and hypersonic aircraft. Past experience with high-speed aircraft includes the Concorde and Supersonic Transport (SST) programs. The Concorde was developed by the British and French during the 1960s and 1970s. During the development cycle, sales estimates for Concorde ranged between 100 and 500, but only 16 Concordes were actually built, at a loss of over $3 billion. Although the Concorde was an economic failure, some technology was transferred to other aircraft projects, particularly the French Mirage fighter airplane.[40]

The SST program was undertaken in the United States in 1963 and terminated in 1971, after a total expenditure of about $1 billion. Sales estimates during the program were originally from 25 to 125, and swelled to over 800 at one point, but no aircraft were built. The basic reasons for termination concerned the noise and alleged health consequences of the SST, the social implications of a taxpayer-funded project to benefit only a few well-off people, and technical difficulties: cost estimates by 1971 had grown considerably beyond the original estimates.[41]

[36] *Aviation Week & Space Technology,* "Ultra-High Bypass Engines Will Enter Commercial Service by Late 1990s," Mar. 9, 1987, p. 189.

[37] *Aviation Week & Space Technology,* "No. 2 UDF Engine Prototype Will Fly on MD-80 by June," Apr. 13, 1987, p. 58.

[38] Paul Proctor, "Advanced Fuel Systems Crucial to High-Speed Transport Progress," *Aviation Week& Space Technology,* Feb. 9, 1987, p. 45.

[39] Raymond S. Colladay, associate administrator, Office of Aeronautics and Space Technology, National Aeronautics and Space Administration, testimony before U.S. Congress, House Committee on Science and Technology, Subcommittee on Transportation, Aviation and Materials, July 24, 1985.

[40] U S, Congress, Office of Technology Assessment, *Impact of Advanced Air Transport Technology: Part 1, Advanced High-Speed Aircraft* (Springfield, VA: National Technical Information Service, April 1980).

[41] Ibid.

Since the SST, there have been many advances in computers for wing design, and materials and propulsion systems, which have given impetus to further R&D in hypersonic aircraft, although primarily for military application. The National Aero-Space Plane (NASP) project is a joint DoD/NASA program to develop a research aircraft with hypersonic cruise and single-stage-to-orbit capabilities. NASP is currently in a conceptual stage, and speeds up to Mach 25 are projected, Applications that could be developed out of the NASP include strategic reconnaissance aircraft, a replacement for the space shuttle, and civil hypersonic transport aircraft.[42]

NASA has also sponsored studies to examine the viability of SST aircraft around the year 2000. The studies suggest that transports in the speed range of Mach 2 to Mach 6 may be commercially viable, but there appear to be diminishing productivity returns at Mach numbers greater than six.[43]

Technical problems with supersonic aircraft include takeoff noise and sonic boom, possible depletion of the ozone layer, and their very high specific fuel consumption at low speeds. They could not be kept cost-effective for very long in holding patterns at low speed because of high specific fuel consumption and because the value of supersonic travel would quickly dissipate. Capacity problems at many U.S. airports along the coasts are already severe, and may worsen, so airport delays may seriously reduce the advantages of supersonic travel. Also, noise is a major issue with many citizens who live near airports, and is likely to remain so. For all these reasons, the future of commercial supersonic transportation is very uncertain.

Vertical takeoff and landing (VTOL) and short takeoff and landing (STOL) aircraft offer the possibility for landing in and taking off from downtown areas of cities, if appropriate sites can be found at reasonable cost. Passengers on the V/STOL aircraft could be transported directly to their final destination, or to a remote airport for a flight on a subsonic or supersonic airliner. The helicopter is one example of a V/STOL aircraft, but its current speed and fuel efficiency limitations prevent economic use for routine passenger service. Efforts to improve on the basic helicopter design to provide high-speed V/STOL travel has resulted in two practical designs: the tilt-rotor and the X-wing. Both designs are in R&D for military applications with civilian certification criteria in mind.

The tilt-rotor aircraft is a winged aircraft with two large rotors on the wings that can tilt to either a helicopter position for takeoff (with a horizontal plane of rotation) or a fixed-wing position for cruising (with a vertical plane of rotation). DoD is funding development of the V-22 Osprey tilt-rotor aircraft for military application. Six European companies have begun preliminary studies of a tilt-rotor aircraft for civil applications called Eurofar. Tilt rotors have been flown before, and the main technological problem with commercial application is providing improved performance and reduced weight. Some projections indicate that a market for tilt-rotor service exists in the Northeast United States, and service could begin as soon as the 1990s provided that the proper infrastructure is in place to support the operations.[44]

The X-wing aircraft accomplishes vertical or short takeoff with helicopter blades, and uses the blades as an X-shaped wing when cruising. The blades must stop in order to cruise, and the conversion from takeoff to cruise configuration has not yet been mastered. The X-wing concept is under development by Sikorsky Aircraft, following R&D by NASA, the Army, and Sikorsky, and the first flight of a demonstrator could take place around 1990. If successful, the X-wing aircraft could achieve higher cruising speeds than the tilt-rotor.[45]

If used commercially, V/STOL aircraft would fly across the centers of cities, so safety and reliability considerations are especially important. Specifically,

[42] John D. Moteff, Congressional Research Service, The Library of Congress, "The National Aero-Space Plane Program: A Brief History," issue brief 88-146 SPR, Feb. 17, 1988.

[43] Louis J. Williams, National Aeronautics and Space Administration, "High-Speed Civil Transport Study Status Report," briefing document, n.d.; Boeing Commercial Airplane Co., "High-Speed Civil Transport Studies Phase II Oral Report," briefing document, Mar. 17, 1988; McDonnell Douglas, "High-Speed Civil Transport Studies NASA Contract NAS 1-18378 Phase II Summary Review," briefing document, Mar. 17, 1988.

[44] Hoyle, Tanner & Associates, Inc., "VTOL Intercity Feasibility Study," prepared for The Port Authority of New York and New Jersey, July 1987.

[45] *Aviation Week & Space Technology*, "NASA Rotor Systems Research Leads to X-Wing VTOL Aircraft Design," June 2, 1986, p. 22; and Steven Ashley, "X-Wing Aircraft," *Popular Science*, July 1987, p. 48.

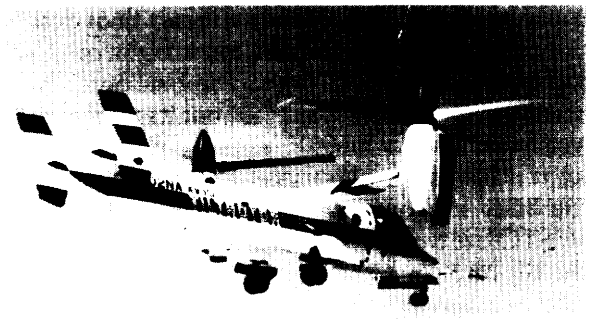


Photo credit: Federal Aviation Administration.

The XV-15 tilt rotor technology demonstration aircraft has been flying successfully since 1977.

transmission systems of tilt-rotor aircraft must be extremely reliable, since a transmission failure could cause a catastrophic desynchronization of the rotors, at least in the context of current design thinking. Public acceptance of new V/STOL concepts in terms of safety will be necessary for their success.[46]

Technologies and Training for Icing

Since 1975, four fatal Part 121 accidents have occurred in which aircraft icing during takeoff has been a major causal factor. Thus, improvements in detecting and removing aircraft ice prior to takeoff have a potentially great safety payoff.

With the exception of analyses and testing to ascertain flight characteristics of an aircraft during flight, all analyses and aircraft certification testing required by FAA are conducted with a clean aircraft flying in a clean environment. Thus, current certification procedures do not require tests for airworthiness of an aircraft with ice on its surface prior to takeoff.[47] FAA regulations do not require use of any de-icing technology before takeoff, but forbid takeoff when frost, snow, or ice is adhering to the wings, control surfaces, or propellers of the aircraft.[48] (Part 135 regulations also forbid takeoff when frost, snow, or ice adheres to a number of other surfaces.) In general, U.S. carriers rely on pilots to observe their own aircraft for signs of adhering ice. FAA has published advisory documents that provide guidance to airlines and pilots on the icing phenomenon, on technologies for ice removal, and on estimated safe holdover times for aircraft that have been de-iced.[49] Additional basic and recurrent training for pilots is a relatively low-cost method for helping prevent icing accidents. FAA is beginning efforts to enhance training programs for pilots through media such as video presentations.

For roughly 15 years, some European airlines have successfully used more viscous de-icing fluids than those used in the United States; these are called Association of European Airlines (AEA) type-II fluids. Longer-lasting than fluids used in the United States, they are fragile and must be handled carefully to avoid destroying their desirable characteristics. They stick readily to aircraft surfaces and may interfere with the aerodynamic characteristics of the aircraft. AEA type-11 fluid is, however, designed so that its viscosity breaks down with shear force, so that the movement of the aircraft tends to knock off the fluid. Because humidity/temperature trends in the United States differ from those in Europe, U.S. airlines might not be as successful as European airlines with type-11 fluids; U.S. operators would need time to learn to use type-II fluids effectively.[50]

Despite these limitations, Federal Express has recently begun using the type-11 fluids in its aircraft operations. FAA does not plan to develop more specific regulatory guidelines on de-icing technologies, and regulations requiring use of high-viscosity de-icing fluids would impose large costs on airlines and providers of de-icing service for new equipment, operational procedures, and training. FAA regulations might discourage development of more advanced types of de-icing fluid, which would not meet the requirements of the regulation, and other actions can be taken to address icing problems.

Most U.S. airlines de-ice aircraft from trucks at departure gates, after which the aircraft must taxi to the runway entrance and may be delayed waiting for other aircraft to take off. If ice forms on the aircraft during this time, the pilot must taxi back to the gate for de-icing again. At several foreign air-

[46] Marc Granger, "For or Against the Tilt-Rotor? Two Views of the Enrofar Project," *Interavia*, vol. 42, June 1987, pp. 649-650.

[47] U.S. Department of Transportation, Federal Aviation Administration, "Hazards Following Ground Deicing and Ground Operations in Conditions Conducive to Aircraft Icing," Advisory Circular 20-117, Dec. 17, 1982.

[48] See 14 CFR 121.629, 135.227, and 91.209 (Jan. 1, 1987).

[49] U.S. Department of Transportation, Federal Aviation Administration, op. cit, footnote 47.

[50] Richard Adams, national resource specialist for Aircraft Icing, Federal Aviation Administration, personal communication, Feb. 23, 1988.

ports, including Montreal, fixed-base facilities have been set up near the end of a runway to permit de-icing nearer to the time of intended takeoff. One U.S. airline has a fixed-base de-icing facility at Denver Stapleton Airport. Operation of fixed-base facilities in the United States could be limited by liability concerns–most large U.S. airlines do their own de-icing and so do not now have this problem. Such facilities, if their use were mandated, could also limit traffic flow at congested airports.

Another possibility is remote de-icing shortly before takeoff from trucks located near the entrances to runways, already a trend, although many airports are limited by insufficient apron space for de-icing trucks to travel and operate. Federal funds could be allocated from the Aviation Trust Fund to expand aprons near entrances to runways and remote de-icing sites to allow mobile de-icing equipment to move and operate.

Lights installed near the airport surface could help pilots see the surfaces of the aircraft better, and qualified ground personnel could examine surfaces not visible to the pilots. Another approach to reducing the icing hazard before takeoff is to use icing sensors on the aircraft surface. Sensors are available, but they pose problems, because they detect ice only at specific areas on the aircraft surface, and pilots may rely heavily on them without proper training.

Given the many possibilities for addressing the icing hazard, FAA could develop a plan for icing similar to the Integrated Wind Shear Program Plan. The best first step could be a training program for pilots and technicians, developed in cooperation with industry. Technological and infrastructure approaches to reducing the icing hazard could also be evaluated for their impact on safety, cost to government and industry, operational factors, and time to implement.

Crash and Fire Safety Technologies

Advances have been made in recent years in developing and implementing technologies to reduce risk to passengers in the event of a crash or in-flight fire. Some technologies, such as smoke hoods, are controversial because their use could have unintentional negative side effects for safety (e.g., putting on smoke hoods could slow passengers' egress from the cabin after a crash).[51] Thus, careful research by the Federal Government is needed to evaluate potential crash and fire safety technologies; this research is performed at FAA's Technical Center in Atlantic City, New Jersey.

Areas for further investigation include aircraft and aircraft engine structural integrity, improved fire- and smoke-resistant materials for aircraft interiors, improved smoke detection and fire containment systems (particularly for in-flight fires), automated systems to aid pilots in detecting and responding to in-flight fires, and advanced fuels with low flammability.

Although technology can improve crash and fire safety, regulations requiring these technologies will have economic and other effects on aircraft manufacturers, airlines, and passengers. For example, the FAA rule to require cabin materials in transport category aircraft that meet a test criterion based on heat release[52] will have significant impacts on design and construction of aircraft interiors. Cost-benefit analysis can shed light on difficult decisions regarding regulations for crash and fire safety technologies, but other types of judgment are necessary in balancing the many disparate considerations.

[51] Bron Rek, "Escape From Burning Cabins: Are Smoke Hoods the Answer?" *Interavia*, vol. 42, January 1987, pp. 37-38.
[52] 51 *Federal Register 26206* (July 21, 1987).

CONCLUSIONS AND POLICY OPTIONS

FAA has occasionally attempted to push industry to develop and/or implement new safety technologies. The point at which a new technology is ready for implementation is inevitably subject to a good deal of disagreement. At times, government requirements can act as a forcing mechanism on industry to develop or implement new technology that will lead to greater public safety.

As the aviation industry continues to undergo technological advances and changes, FAA needs adequate numbers of expert technical personnel and training capabilities for new staff not currently available to it, because funding resources are not sufficient to attract trained experts from industry. FAA programs such as Project SMART and National Resource Specialists are steps to address this issue. The future will bring new and increasingly sophisticated commercial aviation technologies, many of which will be introduced not for the sake of safety, but for the economic benefits they promise. However, many hold the potential for decreasing accident risk. OTA finds that, in the long term, FAA will need greater expertise on its staff in areas of new aviation technology to provide oversight comparable to today 's. Congress may wish to consider make ing additional funding available to bolster FAA's technical staff.

Part 135 regulations have weaker minimum im strument and equipment requirements than Part 121. This is significant because, since deregulation, Part 135 operations have replaced Part 121 operations over some routes, and code-sharing arrangements have created situations where passengers are not aware they will be flying on a Part 135 operation. One policy option is to eliminate the differences between Parts 121 and 135; however, the economic consequences for Part 135 operators could be serious. Another option is to attempt to identify specific hazards in Part 135 operations, and to rectify the most serious hazards through cost-effective measures as part of overall system safety management.

Aircraft icing before takeoff is an important weather hazard. Better training for pilots and technicians appears to be the most cost-effective near-term approach for reducing the icing hazard to aircraft before takeoff. For the longer term, greater use of advanced de-icing fluids and de-icing facilities located near the entrances to runways offer possible improvements, but the economic and operational consequences of using these technologies need to be weighed carefully. The Aviation Trust Fund could be tapped to support construction of wider aprons on runway ramps which would help facilitate use of de-icing vehicles near entrances to runways. Sensors for detection of ice on the aircraft is another approach, but has operational liabilities if pilots rely too heavily on them. FAA has begun to increase industry awareness of icing problems through bulletins and advisory circulars. An additional option is for FAA to work with industry to develop an integrated plan for training and other improvements in icing safety. FAA's integrated windshear plan, with its heavy participation from many industry groups, is a good model for this option.