Improving Aircraft Safety

Committee on FAA Airworthiness Certification Procedures, National Research Council

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Improving Aircraft Safety

FAA Certification of Commercial Passenger Aircraft

Committee on FAA Airworthiness Certification Procedures
Assembly of Engineering
National Research Council

NATIONAL ACADEMY OF SCIENCES
WASHINGTON, D.C. 1980

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

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

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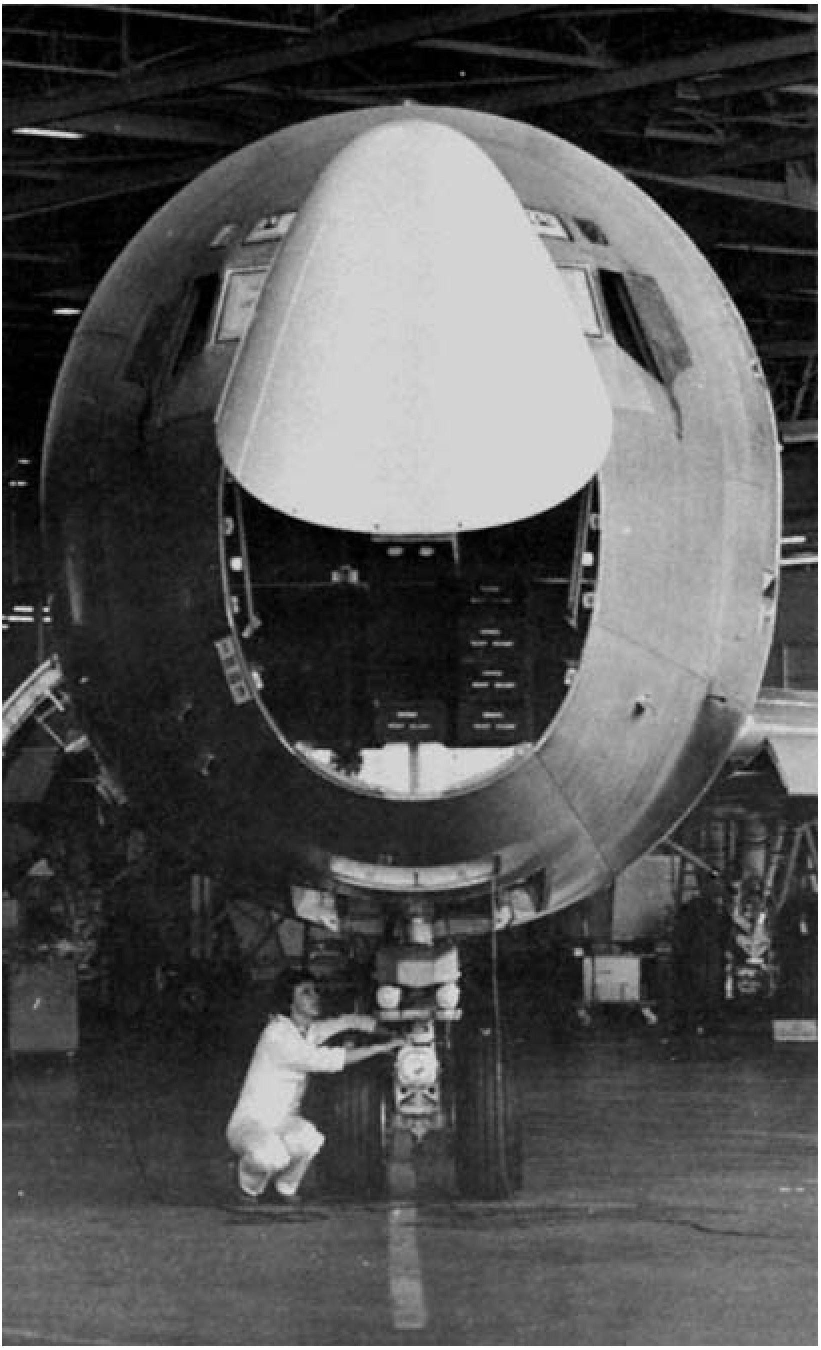


NATIONAL RESEARCH COUNCIL
OFFICE OF THE CHAIRMAN
2101 CONSTITUTION AVENUE WASHINGTON, D.C. 20418

June 24, 1980

The Honorable Neil Goldschmidt
Secretary of Transportation
Washington, D.C.

Dear Mr. Secretary:

I have the honor to transmit the report entitled Improving Aircraft Safety: FAA Certification of Commercial Passenger Aircraft, prepared by the Committee on FAA Airworthiness Certification Procedures of the National Research Council's Assembly of Engineering and supported by Contract DTOS59-80-C-00028 with the Department.

The report deals with one example of a genre of problems new to our age, i.e., the ability of government to minimize the risk to the public from a large, complex, sophisticated technological enterprise that contributes great public benefit attended by a very low probability of a major accident-in this case, the policies and procedures of the FAA for assuring the airworthiness of jet transport aircraft.

Early in its report, the committee makes the following observation: "Aircraft safety demands a 'forgiving' design that is tolerant of failure, careful production that is of the highest quality, and excellent maintenance that gives painstaking attention to detail throughout the life of the airplane. The rare fatal accident that involves airframe or equipment is almost without exception the result of a failure of at least two, and occasionally all three, of these factors." How to establish a reliable system of scientific and technological vigilance that polices without a garrison, that establishes technical standards while respecting creativity, innovations, and competition, that protects human life and the environment at costs that do not bar public enjoyment of the benefits is the challenge to FAA as it is to several other regulatory agencies.

The committee's task was complicated by the finding of significant deficiencies in a system that, nevertheless, has operated with a good safety record. Indeed, it may not be overstatement to suggest that, had we been evaluating the regulation of a different technology, aircraft safety could appropriately have been employed as a standard of excellence for comparison. How, then, can we impress a sense of urgency on recommendations for improving a good system, yet avoid alarming needlessly both passengers and purchasers of airplanes? One conclusion is evident: the technical sophistication of the responsible organization must not merely stand pat; it must keep pace with the advancing state of the art, or risk falling dangerously behind and, hence, insufficient to its task. Concern for the latter eventuality is a major message of this report.

The past safety record of the domestic airlines, (35 deaths per million landings in 1979), and the worldwide acceptance of U.S.-built airplanes, confirm that our nation's system for assurance of airworthiness has operated quite well. The committee finds, however, that this system can and should be better still, and warns against the perils of a complacency that it has detected. Noting that the past safety record is not necessarily a good predictor of future success, the committee calls into question the increasing technical domination of the agency by the industry it regulates and urges the FAA, as soon as possible, to centralize and upgrade the technical proficiency of its staff into a corps of rule-making and design certification engineers, and also to upgrade the skills and techniques of its force of production and maintenance inspectors.

The committee's view of its findings as well as its recommendations will, perhaps, best be appreciated as a struggle toward an ideal. The barriers to attainment are, however, generic to government, particularly to regulatory agencies, rather than unique to the FAA, e.g., the conditions and rewards of government service as compared to those in the private sector. To achieve the recommended staffing quality and pattern and to maintain high morale and a sense of creative accomplishment in a well-established regulatory agency will require a substantial effort to those ends. But, only thus can the FAA be expected to maintain an appropriate relationship to the regulated industry, to assure a future safety record at least as good as that of the last decade, and thus to warrant some measure of shielding from the winds of political change.

It should be appreciated that this report presents a limited approach to the entire scope of considerations relative to the FAA. By agreement, for example, aircraft engines, aircraft of foreign manufacture, and the consequences of the dual responsibility of the agency—to promote civil aviation as well as to assure its safety—were all outside the scope of this study and may warrant equivalent attention in the near future.

Allow me to take this opportunity to convey the great appreciation of our institution to George Low for his incisive leadership of this difficult and sensitive task, to the entire committee for their diligence, zeal, high competence, and spirited public service, and to our staff for their valiant efforts to assure that the committee would complete its assignment on schedule yet in good conscience that all aspects of the airworthiness system relevant to their limited charge had been adequately appraised.

Mr. Secretary, the National Research Council is pleased to make this report available to the Department of Transportation, the Federal Aviation Administration, the Congress, and to all Americans who share pride in and concern for aviation, a distinctively American enterprise.

Sincerely yours,

Philip Handler
Chairman, National Research Council
President, National Academy of Sciences

NATIONAL RESEARCH COUNCIL
ASSEMBLY OF ENGINEERING
2101 Constitution Avenue Washington, D.C. 20418

202/389-6677
COMMITTEE ON FAA AIRWORTHINESS
CERTIFICATION PROCEDURES

June 24, 1980

Dr. Philip Handler
Chairman
National Research Council
Washington, D.C.

Dear Dr. Handler:

It is my privilege to submit for transmittal to the Secretary of Transportation the report of the Committee on FAA Airworthiness Certification Procedures.

Our assignment, at the request of the Secretary, was to undertake a six-month assessment of the adequacy of the Federal Aviation Administration's policies and procedures for certifying the airworthiness of commercial transport aircraft. Airworthiness is the aspect of air safety related to the design, manufacture, and maintenance of airplanes and does not embrace such other key safety matters as airlines and flight crew operations or air traffic control, which are also within the province of the FAA.

Public and official concern following the fatal accident of an American Airlines' DC-10 at Chicago's O'Hare Airport on May 25, 1979, surely precipitated the Secretary's call for our study. But it should be stressed that our charge was to review the overall certification activity of the agency and not at all to review either the details of that or any other specific accident or the several reports of groups that examined in great detail the causes and circumstances of the Chicago crash.

Our study involved questions about the efficacy of the nation's system for assuring both the traveling public and domestic and foreign purchasers that Americanbuilt aircraft continue to warrant their worldwide reputation for safety, durability, and reliability. Since many of the committee's recommendations address what we find to be shortcomings in FAA practices and capabilities, it is important to remind the reader that this report is intended to help make a very good system even better. Indeed, the nation's commercial air travel system is the standard of the world for safety, dependability, and comfort.

Throughout our deliberations, each member of the committee has been impressed by the scope and complexity of the activities under its review, the importance of a safe aviation system to our nation's economy and life style, and the enormous burden of responsibility placed on the FAA to regulate the aviation industry in the public interest.

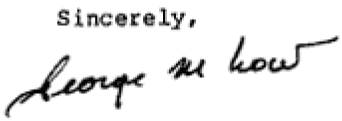
The elements comprising airworthiness are strongly interdependent, and our recommendations reflect this interdependence. Good people are needed, and they require workable regulations and current information, continued education and motivation, effective organization and leadership. Only when all of these are in place can the FAA be most effective. Therefore, we hope that the Secretary of Transportation and the Administrator of the FAA will implement our recommendations together as a package and not select one area over another for change.

The issues addressed in our study are related to other aspects of air transportation safety that remained outside the scope of our examination or that we could not examine in the time available. Both Secretary Neil Goldschmidt and Deputy Secretary William J. Beckham invited us to identify additional issues worthy of more extensive and detailed examination. As it happens, a number of issues at the periphery of our review did arise with sufficient repetitiveness to suggest that they may indeed warrant closer scrutiny—namely:

- While our study was limited to what some have called the safest component of the aviation triad, the airplane itself, the other two elements—the national aviation system (airports, airways, and air traffic control) and airline flight operations (flight crews, dispatchers, and meteorological services)—may need to be subjected to similar examination.

- Aircraft engines, which were specifically excluded from the committee's charter, are certificated in a manner similar to aircraft. The recommendations of our report should be evaluated for their applicability to engines.
- Deregulation has led to an increase in the number of airports where many airlines operate, placing an added burden on FAA inspectors. Another effect of deregulation is that commuter airlines are carrying more passengers at additional locations. The general implications of airline deregulation for safety need to be examined. In addition, the emerging problems of commuter airlines and their implications for FAA policies and procedures require study.
- In connection with the certification of commercial transport aircraft, our committee did not have time to conduct a detailed examination of three critical matters: the potential problems of an aging airplane fleet, the adequacy of the FAA's surveillance of subcontractors and suppliers, and the FAA certification of aircraft produced outside the United States and used by American carriers. None of these has been assessed adequately; each would benefit from careful and objective study.

As a personal note, may I say that this study could not have been undertaken and completed by volunteers within six months without a well-balanced and hardworking committee of experts and a highly skilled and dedicated staff. I am grateful that you have provided me with both.



"George M. Low
Chairman

COMMITTEE ON FAA AIRWORTHINESS CERTIFICATION PROCEDURES

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BERNARD C. DOYLE, Former Chief, Investigations Division, National Transportation Safety Board, Bethesda, Maryland

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DAVID C. HAZEN, Professor of Aeronautical Engineering, Princeton University, Princeton, New Jersey

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JAMES W. MAR, Hunsaker Professor of Aerospace Education, Massachusetts Institute of Technology, Cambridge, Massachusetts

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MAYNARD L. PENNELL, Former Vice President, Product Development, The Boeing Company, Seattle, Washington

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ROBERT G. LOEWY, Consultant

LAUREEN DALY, Secretary

BARBARA DARR, Secretary

DELPHINE D. GLAZE, Secretary

FRANCES SHAW, Project Assistant

Preface

In December 1979 the National Research Council was requested by the Secretary of Transportation, Neil Goldschmidt, to establish a "blue-ribbon" committee to assess the procedures and practices used by the Federal Aviation Administration (FAA) to assure the safety of commercial passenger aircraft. In making the request, the secretary asked that the study be completed no later than June 30, 1980. For its part, the Research Council accepted the commission, knowing full well that a six-month timetable to examine the complicated issues connected with FAA operations would require a knowledgeable committee working to a navigable course.

The members of the committee were selected consistent with the Research Council's policy of providing expert competence and balanced viewpoints. The chairman, who is now president of Rensselaer Polytechnic Institute, was manager of the Apollo spacecraft program and, later, deputy administrator of the National Aeronautics and Space Administration. Other members of the committee include three academic authorities in aeronautical engineering; three former aircraft and airline executives with experience in the design, manufacture, and maintenance of commercial airplanes; two members who were professional airline captains; an attorney in private practice who specializes in aviation law and regulations; a transportation economist; and two former government officials—one from the FAA, the other from the National Transportation Safety Board. The latter is also an engineer and attorney.

Of the three elements that determine safety in commercial passenger aviation—the flight crew, the control of traffic, and the quality, or airworthiness, of the machine itself—the committee was charged to focus its attention on the airplane. Its study examined the ways in which the FAA-approves the design, fabrication, and production of each new aircraft, as well as the maintenance and continuing airworthiness of each airplane. Concentrating on the large passenger aircraft used by the major commercial airlines, the committee's charter excluded from its study the certification of engines, airplanes operated by commuter airlines, businesses, and individuals, as well as aircraft under 12,500 pounds. These are regulated by separate, though similar, procedures. Although the committee learned about the airworthiness approval procedures in Great Britain and France, it restricted its concerns to understanding the important differences from the FAA process.

The committee began its work with three days of public meetings in Washington, D.C., where it heard from the Department of Transportation and the FAA, from industry representatives, and from various aviation interest groups. The participants are listed in Appendix A. It visited production facilities and met with representatives of the three major U.S. manufacturers—Boeing, McDonnell Douglas, and Lockheed. It spent a day in Seattle with staff members of the FAA's Northwest Regional Office and a day in Los Angeles with representatives of the FAA Western Regional Office. Of the 12 regional offices, these two are responsible for certificating the design and production of large transport aircraft built in the United States. The maintenance facilities, programs, and interactions with the FAA of Air Florida, United Airlines, and USAir were the subject of visits by members of the committee to the three airlines and with their corresponding FAA inspectors. In addition, committee members received briefings from the National Transportation Safety Board (NTSB), from the National Aeronautics and Space Administration (NASA), from the staff of the Government Activities and Transportation Subcommittee of the Committee on Government Operations, U.S. House of Representatives, and from representatives of the aviation authorities of the governments of Great Britain and France.

Failures play a role in examining any system and determining its weaknesses. In the case of aviation, failures can result in fatal accidents. The committee reviewed a number of accidents and incidents that involved malfunctions of aircraft. Some are used in the report as examples. Each is referred to usually by title, accompanied by commentary as necessary. For those readers who want to know more about two significant accidents caused by the condition of the aircraft, materials drawn from the official reports are provided in Appendix B.

The term "airworthiness," as defined by the FAA in briefings for the committee, refers to the safety and physical integrity of an aircraft, including its component parts and subsystems, its performance capabilities, and its handling characteristics. The practice of awarding actual certificates for design, production, and airworthiness has resulted in reference to the system as "certification," and to aircraft as having been "certificated." Because both terms are widely used in practice and in the regulations, they appear throughout this report to describe the FAA's process of assuring the safety of aircraft.

Other terms or acronyms used by those familiar with aviation but not known generally are defined when first introduced and also listed in the Glossary. A bibliography, listing reports and other information made available to the committee is also provided.

Throughout the study, the committee received unstinting cooperation from people in government and industry. In more than one instance, officials and staffs gave up weekends to meet with members of the committee. In particular, FAA staff members replied to committee inquiries with documents and briefings on frequent occasions. We are indebted not only to those who took the time to meet with us and make formal presentations, but also to those who helped prepare such material and provided answers to questions, very often on short notice.

Although this report was reviewed by individuals representing the National Academy of Sciences' Report Review Committee and the National Research Council's Assembly of Engineering, none of whom took part in the study, the findings and recommendations are those of the committee.

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Introduction and Summary of Recommendations

In creating the Federal Aviation Administration (FAA) 22 years ago, the U.S. Congress directed the agency to assure "the highest degree of safety" in flight.[1] With respect to airworthiness, i.e., the physical integrity of the airplane, the FAA carries out its mandate in a number of ways:

- It establishes, at its headquarters office, technical design standards and regulations through its rule-making powers.
- It assures, in its regional offices, that each new type of aircraft (e.g., the Boeing 747, the McDonnell Douglas DC-10, or the Lockheed L-1011) is designed and manufactured in accordance with the rules and standards set forth in the established Federal Aviation Regulations (FARs), and is subject to a process that ultimately awards the manufacturer a design Type Certificate and a Production Certificate.
- It establishes, also in the regional offices, a system for reviewing the fabrication of airplanes and for issuing an Airworthiness Certificate for each one.
- It employs a system of inspections and surveillance, at district offices within the regions, of the flight operations and maintenance procedures of the airlines to make sure that each aircraft adheres to FAA standards of continuing airworthiness.

In addition, the FAA-approves repair and overhaul stations, and licenses some mechanics who work on the equipment or who inspect the work of others. During the course of production and maintenance, it reviews and approves the processes and procedures of the manufacturer and airline. If violations are found at any stage, the FAA has the authority to enforce its regulations through warnings, fines, or revocation of licenses and certificates.

The FAA is organized into 12 regions reporting to its Washington headquarters. Its total employment is 57,490, with the largest segment of the staff assigned to air traffic control. The airworthiness function, which is the subject of this report, employs approximately 3,000 people.[2]

Large jet transport aircraft are produced in the United States by three companies, Boeing, Douglas, and Lockheed,[3] and operated in passenger service by some 30 U.S. air carriers. In addition, aircraft produced by two European concerns (British Aircraft Corporation and Airbus Industry) and one Japanese company (Nihon) are also operated by U.S. carriers. Aircraft types range from the smaller twin-engine B-737 and DC-9 to the three-and four-engine wide bodies, the L-1011, DC-10, and B-747.

The United States can be proud of its air transportation system, with an industry at the forefront of technology and innovation that employs more than half a million people, and a favorable trade balance from aircraft exports that approached $10 billion in 1979.[4] A passenger airliner takes off or lands somewhere in the United States on the average of every three seconds, around the clock, every day of the year. In 1979, 318 million passengers flew a total of 256 billion miles—some 1 million times the distance to the moon. The number of passengers carried by domestic airlines has risen 75 percent in the past decade.

Out of a total of 301 million passengers, 350 people died in U.S. commercial aviation accidents last year, with a passenger fatality rate of 0.115 per 100 million passenger-miles flown; this compares to 16 deaths in 1978 and 460 in 1974, the worst year in the past decade (0.005 and 0.197 passenger fatalities per 100 million passenger-miles respectively).[5] Since the introduction of jet-powered commercial flight in 1958, U.S. air carriers have been involved in 216 accidents resulting in fatalities. Only 16 of these were attributed primarily to failures of a jet aircraft or its equipment (see Appendix C), according to data from the National Transportation Safety Board, which is responsible for investigating and assigning "probable cause" to airplane accidents.[6] The balance was attributed to the categories of human error in flight and the air traffic control system.

Indeed, it is these three elements that contribute to the safety of aviation: (i) the airplane itself—how it is designed, built, and maintained; (ii) the national aviation system—the airports, airways, and the control of air traffic; and (iii) the airline flight operations that deal with the control of the aircraft. Although these elements are interrelated—how the airplane is flown depends on the handling qualities of the aircraft and on the instrumentation available to the pilot—they can be and often are addressed separately.

Even though the airworthiness of the machine itself, the subject of this study, accounts for a relatively small portion of all aircraft fatalities, it is evident that even a single fatal accident of, say, a wide-body transport carrying hundreds of passengers is a matter for great concern and soul-searching. In the aftermath of the American Airlines' DC-10 accident over Chicago on May 25, 1979,* in-depth accident and engineering investigations were performed by the safety board and the FAA, and hearings were held by various Congressional committees. The accident lent added urgency, for instance, to an ongoing study by the U.S. House of Representatives' Government Activities and Transportation Subcommittee of the Committee on Government Operations, the May 7, 1980 report of which addresses many of the same matters considered here.

Aircraft safety demands a "forgiving" design that is tolerant of failure, careful production that is of the highest quality, and excellent maintenance that gives painstaking attention to detail throughout the life of the airplane. The rare fatal accident that involves

* When incidents or accidents are used as examples, they are referred to in the text as necessary. Further information on two accidents is found in excerpts from the official reports in Appendix B.

airframe or equipment is almost without exception the result of a failure of at least two, and occasionally all three, of these factors. For example, in the 1977 accident of a Dan-Air, Boeing 707 aircraft in Lusaka, Zambia,* a redundant or backup structural element in the horizontal stabilizer failed to carry the load after the primary element failed. This was clearly a design fault. Yet if more thorough inspection techniques had been used, or if knowledge of fatigue problems had been more widely shared, fatigue cracks would have been found before they grew to critical size.

Individual failures of a significant nature are relatively rare and combinations of failures that lead to serious accidents are unlikely. Yet with the vast number of flight operations that take place over the period of a year, even the unlikely event can occasionally occur.

The achievement of our air transportation safety record has its basis in the development, over the past half century, of necessary strengths on the part of both the federal government and the air transport industry. Even so, as described in the body of the report, and summarized below, the committee finds that the technical competence and up-to-date knowledge required of people in the FAA have fallen behind those in industry. As aircraft become more sophisticated, complex, costly, and numerous, and as the generation of government engineers and inspectors, who gained broad knowledge and experience as the industry was developing, begins to retire the FAA staff face fewer challenges and reduced expectations, a situation characteristic of a second generation regulatory agency.

Many of the committee's specific conclusions and recommendations for improving the airworthiness system flow from this central finding. Is the excellent safety record a good predictor of the continued safety of large transport aircraft in the future? Not necessarily. However, we hope that the recommendations that follow, many of which concern the need for personnel and organizational improvement, will help to make it so.

A report such as this, with many recommendations, necessarily emphasizes shortcomings and opportunities for improvement. We urge the reader to bear in mind,

* See Appendix B.

therefore, that we have discovered nothing in the course of this study that would lead us to conclude that the confidence gained in the airworthiness of our nation's transport aircraft is unwarranted. In this respect, the safety record speaks for itself. But, as reassuring as this record should be to passengers and purchasers of such aircraft alike, we do not counsel complacency for the decisionmakers who are responsible for continued flight safety. The airworthiness system can and should be improved.

TYPE CERTIFICATION AND RULE MAKING

The processes by which the FAA seeks to assure the inherent safety or airworthiness of aircraft are type certification and rule making. Type certification involves assuring that the manufacturer's new design for a particular type of aircraft complies with the statute and all applicable rules and standards. Rule making consists of establishing the regulations and technical standards that must be met by manufacturers and airlines in the course of designing, producing, operating, and maintaining the aircraft.

The FAA's engineering staff needs to be strong in order to deal effectively with its counterparts in industry. The organizational and technical qualities that are desirable in rule-making personnel are similar to those required for making the critical governmental judgments in applying the rules and standards to the certification process for a new type of design. Although there are many motivated and dedicated members of the FAA's airworthiness engineering staff, the regional structure of the agency, and other factors have contributed to a lesser technical competence in the FAA, especially in the offices where type certification is performed, than in the aircraft industry. Consequently, the level of technical oversight is becoming superficial. Moreover, this structure accounts, at least in part, for fragmenting the work of engineering specialists among many different functions, for inconsistent interpretations of regulations, from one regional office to another, and for a lack of communication among regional office and headquarters personnel on matters of common interest and experience. It also contributes to the agency's evident difficulty in attracting a sufficiently capable cadre of highly qualified engineering experts and specialists—a difficulty, the committee recognizes, that is neither unique in the federal government to the FAA nor easily remedied.

In the committee's view, however, the availability of outstandingly qualified airworthiness specialists is the sine qua non of the FAA's airworthiness activities. Specialists of high calibre are not likely to be attracted to the current organization. A centralized engineering organization is thus needed, led initially by a cadre of 20 to 30 senior experts, and charged ultimately with the following tasks: (i) the accomplishment of rule making in relation to airworthiness matters, including the interpretation of existing regulations and the identification of related research needs; (ii) the responsibility for the key governmental decisions affecting the design philosophy and criteria involved in the type certification of new aircraft and supplemental type certification, thus assuming the functions of the Type Certification Boards but not replacing the regional offices' project teams that work, on a day-to-day basis, with the applicants and their "designees"; and (iii) other related tasks calling for combining specialized and expert technical knowledge and seasoned judgment. *The committee therefore recommends that the FAA establish a central engineering organization, staffed with technical personnel of the highest competence, responsible for type certification and participation in rule making*. [pp. 20-29]*

FAA engineers cannot review each of the thousands of drawings, calculations, reports, and tests involved in the type certification process; yet the agency must be certain that each design for a new airplane meets all of the regulatory requirements. The present system thus depends not only on the quality of the FAA staff but also on the assistance rendered by aircraft company employees called Designated Engineering Representatives (DERs) who review the design and design process to make sure, on behalf of the FAA, that all aspects of the regulations are complied with. The "designees" are senior engineers

* Page numbers refer to the place in the report where the recommendation is discussed.

employed by the manufacturers who possess detailed knowledge of the design, based on a daily involvement that is not practical or for FAA personnel to achieve.

Accordingly, the advantages of the designee system as an extension of the limited FAA staff are apparent. Yet the system is often criticized. The possible disadvantage is the appearance, if not the existence, of a lack of independent objectivity—i.e., a form of conflict of interest for the designee who is in the position of serving two masters, the aircraft manufacturing firm that pays him, and the FAA to which he is expected to report problems. The committee finds, however, that potentials for conflict are checked in the following ways: (i) engineers are ethically motivated to maintain their reputation for technical integrity and professionalism; (ii) recognizing the stake of the manufacturer in assuring a safe, serviceable, and reliable airplane, the company's designees perform traditional engineering review tasks for the FAA that would, by and large, be performed for the company as well; (iii) the designees perform their work under the supervision of the FAA staff; and (iv) the FAA reserves to its own staff the most critical design decisions and approvals.

As the system is presently organized, therefore, the committee concludes that the designee system for augmenting the capability of the FAA to review and certify the type design is not only appropriate but indispensable. *The committee, therefore, recommends that the FAA continue to use Designated Engineering Representatives to perform the functions now delegated to them.* [pp. 29-31]

Of greater concern, however, is the identification of what appears to be a trend toward placing more and more reliance on the manufacturer in the course of type certification. Toward the end of the certification procedure, for instance, the designees submit large amounts of reports and calculations to their FAA counterparts for approval. While the requirement to make such submissions has value in assuring airworthiness in most cases the FAA staff performs only a cursory review of the substance of this great volume of documentation. Further, the process invites a review that focuses, however superficially, on the details, often at the expense of closely examining overall design concepts.

The introduction of a more thorough and different kind of review than is now performed by the Type Certification Board is needed. Such a review should be con ducted at key certification milestones or checkpoints, and by more knowledgeable, experienced, and specialized FAA staff of the kind recommended for the centralized engineering group. Special emphasis should be placed on the review, early in the process, of fundamental design concepts. Recognizing that this objective cannot be accomplished immediately, the committee concludes that, over time, the introduction of such upgraded milestone reviews would lend the high degree of technical quality in the FAA design review that is now lacking. *The committee thus recommends that the FAA adopt a longer range objective to improve the type certification process through a series of milestone reviews of the design data to examine fundamental concepts and to assure compliance with the full intent of safety regulations as well as with their specific details*. [pp. 31-33]

While the principal guarantors of safe flight are, of necessity, the builders and the operators of the airplanes, the airworthiness system of checks and balances depends on the establishment and updating of the governing safety standards for design, production, and maintenance. The committee finds that the FAA's rule-making activity is primarily reactive to the needs of safety as determined from accidents. What is lacking most is initiative—a systematic means for anticipating needs, for identifying and ranking priorities, and for assuring the necessary technical base, where absent, for rule making. Updating of rules to eliminate obsolescent ones is also needed. *The committee recommends that the FAA take more initiative in identifying the need for new rules and in establishing objectives, priorities, plans, and schedules for rule making and that it sponsor annual rule-making review conferences to support this activity*. [pp. 33-40]

As it studied the record of aircraft accidents, as well as present design philosophies, the committee came to recognize a serious shortcoming in the current regulations and in how they are applied. The problem has to do with the interpretation of the regulations that permits a manufacturer to demonstrate in the design of an aircraft that certain failures simply cannot occur and that, once demonstrated, the consequences to other structure and systems of such an "impossible" failure need not be taken into account.

This practice, however, fails to take into account an important consideration: structures designed not to fail when subjected to conditions within the design environment sometimes do fail, usually as a result of hazardous conditions outside the design environment. Examples of such hazardous conditions might include maintenance-induced damage, hard impact by ground servicing equipment, cargo-induced damage, or perhaps even faulty quality control during manufacturing. The simple fact is that during the long life of many fleets of aircraft, with millions of operations, one cannot guarantee that such damage will not occur.

In the committee's judgment aircraft design principles should take into account the potential of structural damage caused by conditions outside the design environment, and should seek to prevent catastrophic effects resulting from such damage. Of course, this theory cannot apply to the consequences of the kind of damage that by itself prevents the airplane from continuing to fly, such as a wing torn off in a midair collision. Specifically, *the committee recommends that the FAA develop a rule requiring assurance that an aircraft is designed to continue to fly after structural failure, unless that failure itself prevents the aircraft from flying*. [pp. 40-44]

In the course of certificating the design of a new aircraft, certain kinds of rule-making decisions (e.g., Special Conditions, exemptions, and the retroactive application of recent amendments to the regulations) are often made without benefit of public knowledge and comment that are a part of normal rule making. Often, such decisions involve questions of cabin safety, crew complement, cockpit design, and landing and takeoff limitations—matters of concern to the crew and public as well as the FAA and the affected applicant. In order to provide a legitimate measure of openness in this decision-making process, consistent with the need to preserve the confidentiality of proprietary information, *the committee recommends that the FAA publish, as a notice in the* Federal Register, *the availability of the FAA-approved preliminary regulatory and certification bases for new aircraft type design, with subsequent publication of changes thereto, to permit timely review and comment by the public and response from the FAA*. [pp. 44-46]

PRODUCTION AND MAINTENANCE

While standards and design are necessary to establish the concept of a safe new airplane, it is in the production and continuing maintenance phases, which involve the labors of thousands of individuals with scores of differing skills, that the opportunities are greatest not only for assuring that aircraft are built and maintained to established safety standards, but also for introducing (as well as avoiding) faults that could have later consequences.

The means for assuring the adequacy of the production system involve various levels of company and FAA quality control surveillance. FAA inspectors review and approve the company's manufacturing procedures and quality control systems, with the aid of company-employed Designated Manufacturing Inspection Representatives (DMIRs). From time to time, the agency also conducts detailed audits by quality assurance teams.

While the procedures work quite well and are generally well conceived, lapses in production have occurred and warn against complacency. Accordingly, *the committee recommends that the FAA increase its emphasis on quality assurance in all phases of the production process by increasing the frequency of Quality Assurance Systems Analysis and Review team visits to all Production Certificate holders, and by expanding the responsibilities of FAA inspectors and quality assurance teams to include the observation of actual hardware*. [pp. 50-53]

Once a new aircraft leaves the manufacturer's plant for service with a carrier, the airline accepts responsibility for maintaining it. At the same time, the day-to-day FAA activity also shifts from the manufacturing review staff of the regional office to air-carrier inspectors in the respective district offices, located near the principal airports of the country.

The committee found wide differences in the practices of the FAA maintenance and avionics inspectors, especially with respect to the extent of direct observation of the aircraft, the level of their maintenance inspection activity, and their assertiveness. While the regulations make them responsible for approving the carriers' maintenance programs, and changes thereto, the committee sees the system as allowing, and even encouraging, them to view this responsibility as a passive one. Furthermore, the committee finds that the detailed quality control audit teams formerly employed to augment the inspectors' ability to monitor the airlines' maintenance programs have been reduced to more infrequent visits.

Because of the importance of maintenance to the continued airworthiness of the carriers' aircraft, *the committee recommends that the FAA increase its surveillance of airline maintenance operations, making use of a team approach for frequent and unannounced inspections, and encouraging its air carrier inspectors to give higher priority to strategically selected on-site visits and hardware observations, both randomly during all shifts, and for specific maintenance proced ures that they deem especially critical or important*. [pp. 53-58]

With the exception of the flight crew, no group has a greater effect on aircraft safety than the maintenance workers at the airlines. It stands to reason that the skill levels of mechanics and inspectors should be of high quality and appropriate to the type and complexity of the particular aircraft on which they are working.

Development over the past 30 years of the technologically sophisticated modern jet transport with increasingly complex components has led to rapid changes in the level of skills and knowledge required to maintain aircraft. The committee considers the current FAA surveillance and certification procedures for licensing mechanics and approving their training to be outdated and of limited effectiveness. There is no stringent standard comparable, for instance, to that for flight crews, for establishing the initial experience level or periodic upgrading requirement of the skills of mechanics who repair or service aircraft. Further, mechanics working on advanced avionics are not required to have special credentials. Considering these factors, *the committee recommends that the FAA review and update the licensing and training certification requirements for airline maintenance personnel and consider designating avionics as a separate area for licensing* . [pp. 58-60]

FAA personnel must interact with their opposite numbers in the companies and airlines in a reviewing and approving (i.e., regulatory) mode, yet they must possess independence and objectivity. There is concern that too close and prolonged an association with the same company's personnel poses the possibility that the requisite characteristics of independence and objectivity will be eroded. Reassignment to other companies could provide the advantage of fresh perspectives and new learning experiences. Accordingly, *the committee recommends that the FAA adopt a system for reassigning its personnel on a periodic basis to deal with different manufacturers and carriers*. [pp. 60-61]

While the designer participates directly in the preparation of the initial maintenance program, once the carrier begins to make modifications to it, the FAA does not require that the manufacturer holding the Type Certificate be consulted before changes are made. Further, the FAA office responsible for approving such changes is not necessarily the same one that originally certificated the aircraft.

It is possible, then, that some changes in the maintenance program, or modifications of the aircraft, will degrade the safety of the airplane in subtle ways that only the aircraft designer is likely to recognize. Procedures for removing and reattaching major components may have such significance, as may different aircraft jacking or towing conditions, or changes in liquids and gases used for servicing, purging or cleaning. In some cases, the manufacturer will have more detailed knowledge than the carrier of the inherent strength of the aircraft structure and its major components or their susceptibility to damage. A requirement that the FAA seek and obtain formal review by the manufacturer of any proposed significant modification, or variation in maintenance procedures, before the agency approves it, should increase the likelihood of early warnings of any dangers.

With such considerations in mind, *the committee recommends that the FAA assure that the manufacturer (type certificate holder) have continuing knowledge of an operator's maintenance procedures by obtaining the manufacturer's formal review prior to authorizing any significant deviation from the approved maintenance program. Similarly, it recommends that the FAA assure that the manufacturer be made aware of an operator's application for a Supplemental Type Certificate by obtaining the manufacturer's formal review prior to authorizing any significant deviation from the approved design*. [pp. 61-64]

Procedures for reporting safety-related incidents and service difficulties, and the information and indication of trends that such reports provide, should be among the principal tools of all airworthiness personnel within the FAA and the industry. The present procedures are inadequate. While the FAA now recognizes this fact and has begun a five-year effort to develop a modern, comprehensive information-gathering and data-processing system, the committee views the pace of development as too leisurely. Hence, *the committee recommends that the FAA accelerate its development of an effective information-gathering and data system. This system should include access to the appropriate elements of the manufacturers' and carriers' records*. [pp. 64-68]

Information systems are no better than the information fed into them. The committee found excessive confusion in the current procedures for reporting occurrences involving structural damage to the aircraft. The confusion extends to the matter of what to report, whether to report it at all, when to report, and to whom the report must go. The maintenance-induced damage to the aft pylon bulkhead on two DC-10 aircraft of Continental Airlines prior to the American Airlines Chicago accident, which was not required to be reported, illustrates this dilemma. To reduce this important source of confusion, *the committee recommends that the FAA require that any damage to the primary structure of an aircraft, regardless of how the damage was caused, be reported* . [pp. 68-70]

LEADERSHIP AND ADVICE

Because the FAA regulates an industry that works at the frontiers of technology, it must be a leader in its field. It needs to be able to develop and apply new standards for rapidly changing technology. To ensure that the agency provides such technical leadership, the administration requires access to the advice of the foremost aviation specialists in the nation. Accordingly, *the committee recommends that the administrator appoint a senior advisory committee of experts from government, industry, and universities to advise on the adequacy of technical programs and on the direction of future developments* . [pp. 73-74]

As an agency of the U.S. Department of Transportation, the FAA operates under the oversight of the Secretary of Transportation. Given the fact that the

FAA regulates a single, relatively cohesive industry, where the similarities of training and perspective of industry and agency people far outweigh their differences, the secretary needs an objective group of policy advisors to review the FAA periodically and to address issues related to his oversight responsibility. *The committee recommends, therefore, that the Secretary of Transportation appoint an independent aviation safety policy board, reporting to him and responsible for advice on major safety and policy issues; for counsel on oversight of the FAA; and for recommendations of candidates for the positions of administrator and deputy administrator*. [pp. 74-76]

The rapid turnover of senior FAA officials in recent years has resulted in several new approaches to longstanding problems with each change in administration. Particularly in organizations concerned with safety regulation and high technology, of which the FAA is both, there is a decided value in continuity for programs and policies to be tested for effectiveness. Beyond continuity, the administrator and deputy administrator need to possess high technical, professional, and administrative competence. Accordingly, *the committee recommends that the President select the administrator and deputy administrator from a slate of candidates recommended by the proposed aviation safety policy board or a similar group of experts and that strong consideration be given to reappointment when appropriate*. [p. 76]

In the final analysis, no matter how proficient the FAA is, the safety of an aircraft depends on the people who design, produce, and maintain the machine—the aircraft manufacturers and air carriers. In any endeavor involving human beings, mistakes can be and often are made. The only known way to minimize them is through a system of checks and double checks.

There are already many checks and balances present in the industry's work to design, build, and maintain airplanes. But some companies lack a separate internal safety organization, akin to an internal audit staff, to assure management on a continuing basis that the proper processes and procedures are in place, that personnel are fully trained and qualified, that adequate controls exist, and that the product is indeed as good as it is stated to be.

The committee, therefore, recommends that each industrial firm involved in the design, production, or maintenance of commercial transport aircraft consider having an internal aircraft safety organization to provide additional assurance of airworthiness to company management . [pp. 76-77]

CONCLUDING REMARKS

Although this study was conducted under a severe time limitation of six months, the committee has completed a rather detailed examination of the process of certificating the design, production, and maintenance of large commercial transport aircraft. The results of this examination, including many specific findings, are centered in its recommendations. While each of these is considered important, the committee considers that the following conclusions warrant special attention:

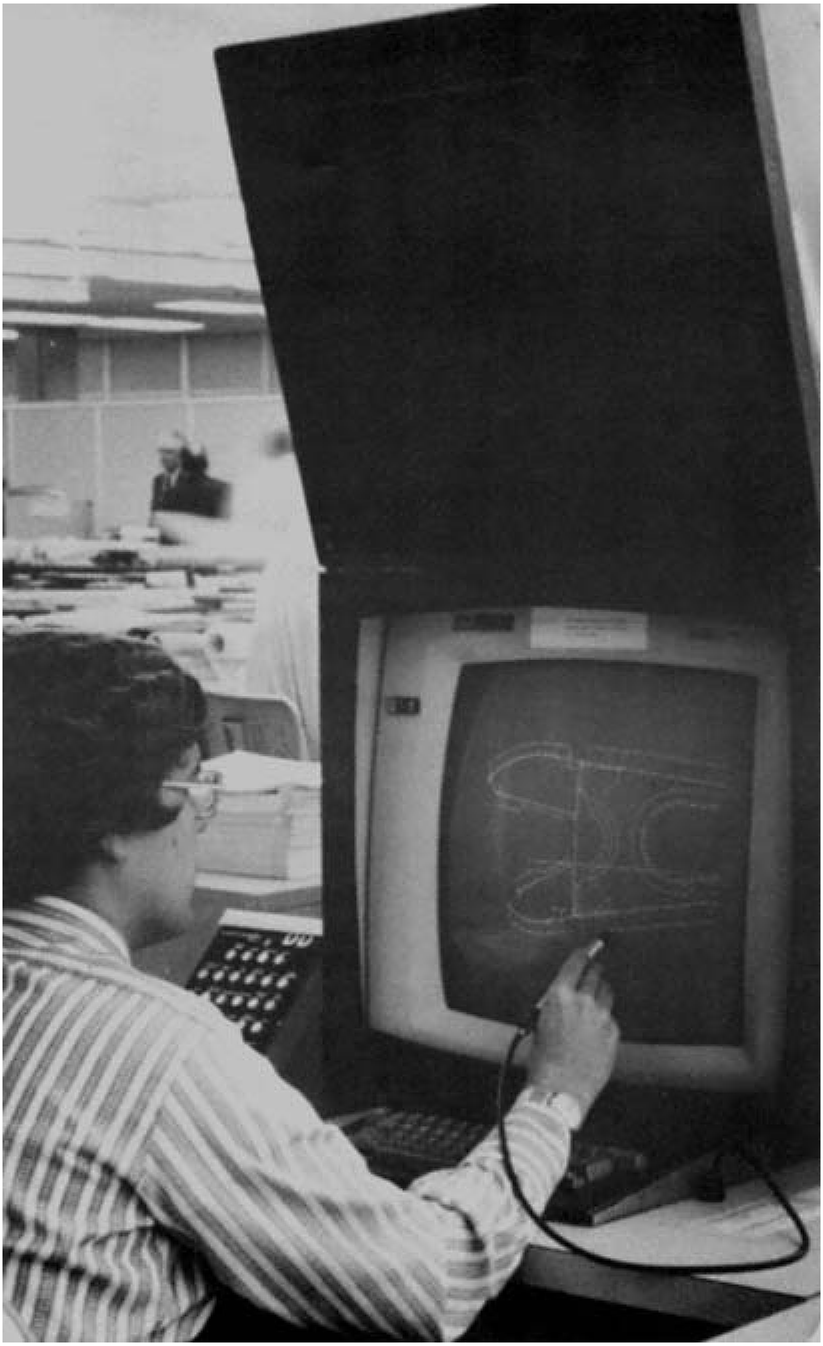
- The FAA needs highly competent, dynamic leadership, with terms of sufficient duration to provide stability and continuity.
- The FAA needs an improved technical staff of greater competence, which can be attracted only if significant organizational changes are made.
- The FAA needs a committee, reporting to the administrator, to provide advice on the application of new technologies to the work of the FAA. The Department of Transportation needs a board reporting to the Secretary of Transportation to provide advice on FAA policy matters and to recommend candidates for the positions of administrator and deputy administrator.

These three conclusions deal with people and organizational matters. An entirely different kind of conclusion concerns the philosophy of aircraft design:

- Aircraft can be designed to be more tolerant of failure, and should be able to land safely even after some severe structural damage.

There is a final thought that concerns the attitudes of all those engaged in aviation and in the welfare of the flying public.

The airworthiness standards in the Federal Aviation Regulations are a set of minimum standards arising from experience with aircraft operation and accidents. The regulations cannot cover everything that might have an important bearing on safety. What is prescribed is based largely on past failures and readily predictable future ones and therefore is not all that is necessary to ensure safety. Indeed, the Federal Aviation Act states first that the administrator must find that the aircraft is of proper design, construction, and performance for safe operation and then that the aircraft also meets the minimum standards. In practice, this requirement of judgment means that to improve the present system will call for an exceptional capacity to imagine unlikely problems, and thus to anticipate the need for further rules and practices, before the unpredictable accident strikes. This idea is the basis for the admonition that pervades most of the committee's recommendations to the FAA. It must take more initiative in every aspect of its work and, to do so, it must improve the expertise and quality of the technical staff and advisors upon whose judgment it relies.



Type Certification and Rule Making

As stated in the introduction, the processes by which the FAA seeks to assure the inherent safety or airworthiness of aircraft are type certification and rule making. Type certification, handled primarily in an FAA regional office, involves assuring that the manufacturer's new design for a particular type of aircraft complies with the statute and all applicable rules and standards. Rule making, conducted at the agency's headquarters in Washington, D.C., involves establishing the regulations and technical standards that must be met by the manufacturers and airlines in the course of designing, producing, operating, and maintaining the aircraft.

Within each regional office, the group that reviews and approves each new aircraft design is the Type Certification Board. Usually chaired by the director of the office's engineering and manufacturing section, the "Type Board" is composed of the senior managers for various technical specialties. The board functions as a management or steering group for all certification projects within the region and acts as a reviewer and arbiter of major technical issues. It provides a point for appeal by the applicants and serves as an overall advisory group to its chairman, who issues the Type Certificate. The day-to-day interactions with the applicant are handled by an assigned project manager, supported by staff members of a project engineering team.

A typical certification project for a new type of airplane involves a process of interaction and iteration between the FAA regional office and the manufacturer over a number of years. It begins when the FAA receives an application from the manufacturer for type and production certificates. The process is characterized by a progression of design and testing activities conducted by the applicant and reviews for compliance by the FAA project team, punctuated by a small number of meetings —perhaps four to six—of the Type Board at critical decision-making points. Once the FAA project team has familiarized itself with the application, the board holds a preliminary meeting, attended by the FAA team and its applicant counterparts, to make an initial evaluation and to identify the pertinent design certification criteria, including the regulations, standards, and criteria that the applicant must meet, and the means by which the applicant must demonstrate compliance.

An interim meeting is held two to three years after the initial meeting to review the general progress and to settle any additional requirements. In the meantime, the applicant may undertake steps that rely on informal, interim decisions concerning Special Conditions that may be imposed. It does this because manufacturers are committed far in advance to aircraft delivery dates. Not to do so would run the risk of delaying the project to await the final approval.

The penultimate milestone is a preflight meeting of the Type Board at which, in addition to reviewing the overall progress of the project and identifying items that remain to be resolved, the board issues a Type Inspection Authorization. This document authorizes the FAA pilots to begin test flights to determine if the work has been accomplished. At the final meeting, in confirmation that all requirements have been met, the Type Certificate is issued.

FAA PERSONNEL AND ORGANIZATION

Rule making and type certification call for engineers and scientists—airworthiness professionals—of high technical competence. The organizational and technical qualities that are desirable for rule-making personnel are similar to those required for making the critical governmental judgments in applying the rules and standards to the certification process for a new type design.

The assurance of acceptable airworthiness rules and standards must proceed from a knowledgeable FAA staff of sufficient capability and depth to provide leadership and, when necessary, to challenge the industry. Similarly, the type certification system presumes a high level of quality on the part of the government certification staff in assessing the work of the manufacturer in designing a new aircraft. While much smaller in numbers than the manufacturer's staff, the FAA staff must be capable of holding the company to appropriate standards of design and proof, of going beyond the letter of the standard to provide interpretation and to ask the right questions, and, with the aid of company-employed Designated Engineering Representatives, of painstakingly checking the company's work to assure compliance.

The attributes of technical expertise, assertive judgment and independent initiative within the FAA are critical to its success. Although there are many motivated and dedicated members of the FAA's airworthiness engineering staffs, based on its discussions with FAA and industry engineers involved in certification and other processes, the committee found a greater technical competence and state of the art currency on the part of personnel in the aircraft industry than in the FAA.

In particular, the committee found that this situation existed with respect to type certification. While this difference cannot reasonably be expected to be otherwise at the detailed design level, in order for the FAA to be effective in making significant judgments, there is a need for more qualified, critical, and analytical oversight by the senior FAA staff than is presently exercised.

The present quality of aircraft designs is satisfactory largely because of the proficiency of the companies and the designee system. Although FAA staff members have raised apt and constructive questions, their contribution stems largely from the process itself. Systematic education and briefing by company engineers of the FAA staff provide a useful checklist against which the applicant can gain increased assurance that it has not overlooked important matters. While this role is by no means a trivial contribution to the design and ultimate airworthiness of the aircraft, it is not a sufficient one.

At one time, the FAA staff included senior recognized experts and authoritative sources in the field of aeronautics. One of the earliest books on aircraft flutter, for instance, was written by FAA employees Scanlan and Rosenbaum.[7] The agency's ability to perform its airworthiness mission credibly, and to command the respect of the aviation community, depends on its regaining such recognizable expertise.

The present situation with regard to the quality of FAA personnel can be traced in part to the current organizational structure which, as described below, does not foster an environment that attracts the best people. It is also a function of the history of the aviation industry. When aviation was a newer field of endeavor, opportunities were greater and challenges broader. As aircraft become more complex, those who oversee them become specialists in particular areas. Many government engineers and inspectors grew with the industry and developed seasoned judgment from involvement in a variety of new designs and a rapidly growing enterprise. As these people now begin to retire and are succeeded by another generation, the newer FAA staff expect to enjoy fewer fundamental challenges and opportunities for innovation than were experienced by their predecessors. Although aviation continues to present many challenges, this problem is endemic to the FAA's present age and that of many other established regulatory agencies.

A factor contributing to the lack of initiative by FAA staff, both engineers and inspectors, is their expressed concern that if they attempt to go beyond the precise letter of the regulation in overseeing the industry they will not be supported by their supervisors or by the Washington headquarters staff. Yet in making judgments about the safety of aircraft, some interpretation is necessary.

The current FAA organizational structure, which allocates type certification activities for the various categories of aircraft among several regional offices, results in a superficial level of technical oversight. The structure accounts, in part at least, for fragmenting the work of engineering specialists among many different functions, inconsistent interpretations of regulations from one regional office to another, and a lack of communication among personnel in the regional and headquarters offices on matters of common interest and experience. It also contributes to the agency's evident difficulty in attracting a sufficiently capable corps of engineering experts and specialists.

In the Western and Northwest Regional Offices, where certification of new domestic transport aircraft is concentrated, the work assignments of the engineering staffs are not limited to the certification of new aircraft types. The amount of time devoted to other functions varies according to specialties and the phase of design and test work in which the transport manufacturer is engaged. The two regions reported that their personnel devote, on the average, 60 to 75 percent of their time to such "other" related activities as the certification of modifications to existing jet transports, to business jets, and, perhaps primarily, to the review of service difficulty reports, service bulletins, and other kinds of in service surveillance and remedial action. The regional engineers are also occupied by a variety of administrative tasks. Accordingly, they are stretched beyond their capacities of both expertise and time by bulges in the workload caused by new type certification, supplemental type certification, or special assignments.

Problems due in part to the regional structure are demonstrated also by inconsistencies in the application of standards between the Western and Northwest Regional Offices. For example, while one region proposes to apply to one manufacturer, retroactively, the amendment to the rules relating to "accelerate-stop distances," (the minimum allowable runway lengths for an airplane to accelerate and stop safely, depending on its gross weight, speed, prevailing weather and runway conditions) the other office chose not to do so with other manufacturers during approximately the same period.*

An example of inadequate exchange of knowledge between regions is the fact that nine months after the Chicago accident, as this committee was informed, the engineering staff of the Northwest Regional Office had

* According to FAA personnel, Boeing, in the Northwest Region, is resisting the accelerate-stop rule because it claims that the 757 therefore will be at some competitive disadvantage when compared to the DC-9-80. Douglas, in the Western Region, is resisting the same rule because it claims that the DC-9-80 will be at a competitive disadvantage to the 737.

received no formal briefings on the relevant technical issues by representatives of the companies, by the Western Region's type certification team for the DC-10, or by the investigators of the accident.

The committee observed an especially important problem of the FAA's attenuated organizational structure: the pool of engineering talent is so shallow that many senior positions have remained vacant for several months. The Western Regional Office, whose airworthiness jurisdiction extends to Douglas, Lockheed, and a number of airlines, which is in the process of certificating the DC-9-80 and has just finished the certification of the L-1011-500, provides the most dramatic example. The office has operated for nearly a year with many vacant positions, including those of regional director, deputy director, and chief engineer. If on board, the chief engineer would serve as chairman of the regional Type Certification Board.

In addition to organizational structure, the committee identified a number of other factors that may contribute to the FAA's present inadequate level of technical currency and competence:

- Inadequate and ambiguous direction, supervision, and support of staff, resulting in confusion about priorities, reluctance to assert governmental prerogatives, and low morale.
- Cumbersome Civil Service and personnel regulations and artificial career barriers that have, for instance, blocked adequate advancement and recognition of nonsupervisory technical specialists.
- Difficulties in attracting and hiring new graduate and experienced engineers, particularly in the Los Angeles region where living costs are unusually high.
- Lack of a stimulating atmosphere and peer association, which is essential for a thriving technical organization.
- Lack of resources and incentives for continuing education of technical personnel as well as a systemwide failure to provide adequate opportunities for essential training in new areas of aviation technology.
- Competition in the allocating of new positions from operational components of the agency, such as air traffic control.

While the functions of rule making and type certification are similar and call for equivalent expertise and judgment, they are not congruent with the function of day-to-day reviews to assure compliance with established standards. Rule making and type certification require personnel of high technical competence, able to address the right questions about new technological features, including those for which guidelines have yet to be established. No less vital, but decidedly different, are the technical audit and surveillance functions which require personnel generally familiar with the state of the art and with production and maintenance techniques and procedures, rather than with evolving technologies.

The administrator has recognized and taken steps recently to deal with some of these concerns. In October 1979 he announced the intention to recruit a number of "national resource specialists" in such technical disciplines as aeroelasticity, advanced materials, special manufacturing processes, and airline maintenance techniques.[8] In April 1980, he advised our committee that he was exploring the merits of selecting either the Western or Northwest Regional Office as a "lead region" to coordinate type certification activities for transport aircraft. The "lead region" concept is already being employed for such other aspects of FAA certification responsibility as engines and helicopters.

The committee's recommendation goes even further. In the committee's view, the availability of outstandingly qualified airworthiness specialists is the sine qua non of the FAA's airworthiness activities, and specialists of high calibre are not being attracted to the current organization. *The committee, therefore, recommends that the FAA establish a central engineering organization, staffed with technical personnel of the highest competence, responsible for type certification and participation in rule making*.

Located in an appropriate environment, possibly adjacent to a government center of aeronautical research and under the leadership of a recognized authority in aeronautical engineering, the proposed central engineering organization would be charged, ultimately, with the following tasks: (i) the accomplishment of rule making in relation to airworthiness matters, including the interpretation of existing regulations and the identification of related research needs; (ii) the responsibility for the key governmental decisions affecting design philosophy and criteria involved in the type certification of new aircraft and Supplemental Type Certificates, thus assuming the functions of the Type Certification Boards but not replacing the regional offices' project teams that work, on a day-to-day basis, with the applicants and the designees; and (iii) other related matters calling for combining specialized and expert technical knowledge with experienced judgment.

Members of the centralized organization would thus be available as needed to all FAA offices throughout the country, and would have the advantages of the mutual reinforcement and common experiences gained from working on many of the same types of problems as they arise from rule making and certification activities. By regular and frequent participation in design reviews and similar functions, the team members would be continuously informed about new technologies and other innovations. They would be required to maintain a high level of technical skill. By continuous interaction with several companies and associations, these airworthiness specialists would be able to function as an inter-industry forum. While taking care to safeguard proprietary information, the specialists could work as a team to transfer from one type certification experience to another the safety principles learned.

Once it is fully organized, the central organization should comprise one-half to three-quarters of the FAA's present complement of 318 aerospace engineers and 50 flight test pilots, and take responsibility for most of the airworthiness engineering functions related to rule making and aircraft design. A comparatively small number of engineers would remain in the regional offices for day-to-day operations, to provide sign-offs and spot-checks of the work of the type certificate applicants, and to continue to oversee the remaining important regional activities involving the certification and surveillance of production, maintenance, continuing airworthiness, and responses to service difficulties. These functions are best served from regional offices close to the production and maintenance facilities. The functions and location of the present staff would be changed under the proposed plan, though no significant increase in the number of positions is expected.

This reorganization cannot be accomplished all at once. Initially, a cadre of 20 to 30 specialists should be put in place to undertake the rule-making functions and to assume the more limited responsibilities of the Type Certification Boards. A five-to-seven-year transition period would probably be required to reach the ultimate goals of the proposed reorganization.

An improved and centralized engineering organization is, in the committee's judgment, a prerequisite to upgrading the quality of the FAA staff. The agency needs to devise a means for attracting more experienced specialists than it presently has—a difficulty the committee recognizes is neither unique to the FAA nor easily remedied in any government agency. Even working within the constraints of the Civil Service System, however, the FAA should be able to find the relatively small number of experienced specialists required in private industry, other federal agencies, and universities. Certainly, the FAA would have to pursue a vigorous recruiting campaign to attract the engineers and scientists best suited to the central engineering organization; and the challenges and rewards of such an organization would have to be made sufficiently attractive to induce experienced professionals to make career changes to become airworthiness professionals for the FAA.

The possibility of building and nurturing a technical organization of high competence and esprit de corps by centralizing technical functions has ample precedent in government. The early National Advisory Committee for Aeronautics (NACA) and the Department of Defense's weapons systems programs (e.g., the nuclear-powered submarine, the SAGE network, and the ballistic missile program) all stimulated the enthusiasm of the engineering and scientific communities and attracted highly qualified experts into government service to manage and implement the efforts. Less visible examples of continuing activities that also attract highly motivated and capable people include the Air Force's Materials Laboratory, its Arnold Engineering Development Center, and NASA's numerous specialized programs in aerodynamics, materials and structures, avionics, propulsion, aircraft operating problems, and flight tests carried out at a number of facilities throughout the country.

These programs confirm the committee's judgment that some of the United States' best engineering talent can and should be attracted into the FAA's airworthiness organization. To do that, the organization needs:

- Recognition that aviation safety provides an important and challenging assignment.
- Outstanding professional leadership that will attract good engineers seeking positions under experts in their respective fields.
- Substantive responsibility and influence over project elements.
- Association with colleagues of high qualifications to provide a stimulating internal atmosphere.
- Opportunities for career advancement that reward merit and expertise as well as supervisory responsibilities.
- A stimulating environment that provides opportunities for associations with nearby universities and research establishments.
- Opportunities for further study and professional growth.

With regard to the last point, it is important to note that, while individuals with a science or technology orientation need to be exposed frequently to the state of the art and emerging technological possibilities, it is not necessary or desirable for the FAA itself to manage such recurrent educational programs. There are many people outside the FAA who can teach new technologies as well as those who want to learn about them. It is presumed that such programs could be arranged to meet the needs of the FAA and of others at the same time.

Organized and structured continuing education is not the only means by which the technological currency of FAA personnel can be maintained. For example, the FAA might consider a rotation or exchange program for its personnel to spend perhaps a year or more attached to other organizations, either public or private, in the United States or abroad, at such places as NASA, Air Force laboratories, research establishments, manufacturers, and universities.

An indispensable part of such a program is a sufficiency of travel and other funds to support it. To skimp on the resources devoted to building and maintaining a requisite level of FAA staff competence places the system's efficient operation in jeopardy over the long run and threatens the agency's mandate to provide "the highest degree of safety" in flight.

The collection of the FAA's engineering talent into a single, coordinated unit should resolve many of the problems of the current regional office structure, including too close alliance with any one manufacturer, and should result in a well-trained and technically qualified staff that can provide improved interaction with the manufacturers and their Designated Engineering Representatives (DER). It should also eliminate many inconsistencies in interpretation and application of regulations.

It is the committee's view that this revised organizational structure for airworthiness engineering, coupled with a recommendation to improve the type certification process (described later in the report) will result in a significant improvement in the quality of airworthiness certification and the overall effectiveness of the FAA.

DESIGNATED ENGINEERING REPRESENTATIVES

About 370 FAA engineers are occupied with the certification of aircraft of all types. Half of these are in the two regions with responsibility for Boeing, Douglas, and Lockheed. The FAA regional project engineering and flight test team certificating a new transport consists of 20 to 30 professionals, most of whom also perform other duties.

By contrast with the number of FAA engineers, Boeing estimates it will concentrate about 4,000 engineers on its new 767 transport at the peak of its design effort. As a measure of the volume of work to be performed and reviewed, Lockheed has reckoned that, in the course of certificating a new wide-body aircraft, it would submit approximately 300,000 engineering drawings and changes, 2,000 engineering reports, and 200 vendor reports. In addition, it would subject the airplane to about 80 major ground tests and 1,600 flight test hours. Throughout this period, it would send some 1,500 letters to the FAA. [9]

FAA engineers cannot review each of the thousands of drawings, calculations, reports, and tests; yet the agency must be certain that the design for a new airplane meets all the regulatory requirements. The certification process thus depends not only on a review of high quality by the FAA but also on the assistance rendered by employees of the aircraft manufacturers—the Designated Engineering Representatives, who review the design and design process to make sure, on behalf of the agency, that all aspects of the regulations are complied with.

These "designees" hold key technical positions and are usually selected from the ranks of the firm's more senior engineers, typically having 15 to 20 years' experience. Many hold supervisory positions as well. In general, they possess detailed knowledge of the design based on day-to-day involvement. It is not practical for FAA personnel to acquire the same familiarity with details of the drawings, analyses, and tests. Although, the committee was told, career path advancement is not affected by the designee role, the peer respect earned by virtue of the individual's appointment evidently contributes to what the committee observed as a high degree of dedication and motivation in the individual performance of designees. Indeed, among those interviewed, the committee detected that the job of a designee is a sought-after assignment.

Designees are usually nominated by the applicant (i.e., aircraft manufacturer) but are appointed by the FAA regional director only after he is satisfied with their personal and professional qualifications and experience. Once appointed, they are delegated by the FAA administrator, through the regional office, to represent the FAA in helping to determine that the aircraft design complies with the relevant requirements of the regulations. In this capacity, designees are bound by the "same requirements, instructions, procedures, and interpretations as FAA employees."[10]

The use of designees has been successful in the past primarily because each of the three segments of the air transportation system—government, manufacturer, and airline—seeks to achieve a high degree of safety. While designees perform much work for the FAA, the agency reserves to itself the approval of such necessary and prudent elements in the certification process as:

- The regulatory basis.
- The analytical criteria to be used.
- The major design philosophy affecting safety.
- All fault-type safety analyses.
- All test proposals.
- The witnessing of all major tests.
- All major flight testing.

- All in service safety problems.
- The aircraft flight manual.

The advantages of the designee system are apparent. It enables the FAA to have a substantially increased number of highly qualified technical people reviewing and checking thousands of pages of data to determine whether or not all the pertinent regulations and procedures have been satisfied. The possible disadvantage of the system, one that has been often asserted by some members of the public and representatives of interest groups other than the companies and the FAA itself, is the appearance, if not the existence, of a lack of independent objectivity—i.e., a conflict of interest for the designee, who is in the position of serving two masters.

The committee finds, however, that potentials for conflict are checked by: (i) the ethical motivation of engineers to maintain a reputation for technical integrity and professionalism; (ii) the fact that, recognizing the stake of the manufacturer in assuring a safe, serviceable, and reliable product, the company's designees are senior engineers who perform traditional engineering review tasks for the FAA that would, by and large, be performed on behalf of the company; (iii) the organizational structure by which the designees perform their work under the supervision of the FAA staff; and (iv) the arrangement that the FAA reserves to its own staff the most critical design decisions and approvals.

As the system is presently organized, therefore, the committee concludes that the designee system for augmenting the capability of the FAA to review and certificate the type design is not only appropriate but indispensable. *The committee, therefore, recommends that the FAA continue to use Designated Engineering Representatives to perform the functions now delegated to them.*

A NEW PROCESS FOR TYPE CERTIFICATION

The success of the certification can be attested by the record of U.S.-designed aircraft in the world market. However, the committee finds that, as the design of airplanes grows more complex, the FAA is placing greater reliance on the manufacturer. Near the end of the certification procedure, for instance, the designees submit stacks of reports and calculations to the FAA staff for approval. While the requirement of making such submissions has value in assuring airworthiness, in most cases the FAA staff performs only a cursory review of the substance of this overwhelming volume of documents. Further, the process invites a review that focuses, however superficially, on the details, often at the expense of closely examining overall design concepts.

This is the case, in large part, because the FAA lacks the qualified experts to provide the proper leadership for the type certification process—a finding that led the committee to recommend establishment of a central engineering organization. We find that the FAA involvement in type certification, both at the project team and Type Board levels, lacks initiative, focuses on details, and gives insufficient attention to fundamental concepts at early stages. While appropriate questions are asked, and satisfactorily answered, to assure that the rules have been met, questions seldom address the appropriateness of the rule or whether a new rule would be a better approach. This situation appears to be the case more in the design stage than in the flight test stage, where FAA and company capabilities are more evenly matched. In essence, the granting of a Type Certificate indicates that the letter, but not necessarily the spirit, of the regulation has been met.

What is needed are more thoroughgoing reviews of type certification made at key design milestones or checkpoints by more knowledgeable, experienced, and specialized experts of the kind recommended for the centralized engineering group. Ultimately, such reviews would replace the reviews currently held by the present Type Certification Board. Recognizing that this objective cannot be accomplished immediately, the committee suggests a gradual replacement of day-to-day engagement with meetings of the central engineering organization at important stages to address significant matters and fundamental questions. In time, the establishment of such milestone reviews would provide the high degree of technical quality to the FAA design review that is now lacking. *The committee thus recommends that the FAA adopt a longer-range objective to improve the type certification process through a series of milestone reviews of the design data to examine fundamental concepts and to assure compliance with the full intent of safety regulations as well as with their specific details.*

In a technological environment, the determination of design and engineering adequacy and product safety cannot be legislated in minute detail. Establishing criteria for such matters would be the responsibility of the proposed central team in the course of developing reviews for oversight to replace those now practiced by the Type Board, project team, and designees.

For instance, the design and creation of a structural component such as a wing includes the following steps that are critical to airworthiness: (i) determination of the loads; (ii) creation of the structure to carry the loads; (iii) analyses to demonstrate adequate margins of safety for all conceivable modes of failure; and (iv) confirmation by structural tests. It should be possible for a team of experts to schedule reviews so as to provide guidance on airworthiness issues at critical periods in the design process, to ask penetrating questions, to examine a small sample of data, and to be satisfied, as a consequence of placing primary emphasis on design concepts, that the aircraft will be airworthy. These results could be achieved without acquiring a detailed knowledge of all drawings and analyses. We expect, therefore, that the instituting of upgraded milestone reviews, with the proper team of experts from the central engineering organization, will encourage greater initiative by the FAA and provide a higher degree of technical quality to its interaction with the manufacturer.

THE NEED FOR TIMELY RULE MAKING

The airworthiness system depends not only on the safety consciousness of aircraft manufacturers and air carriers but on the premise that the standards embodied in the Federal Aviation Regulations for design, production, maintenance, and operation will be set and kept as up-to-date as they reasonably can be through the rule-making process. Primarily through its headquarters staff, the FAA manages its rule-making steps in the following ways:

- Proposals for possible rules are reviewed initially by the staffs of the offices of airworthiness, aviation safety, and flight operations, under the associate administrator for Aviation

Standards, and ranked for priority attention by the office directors. Within the FAA, ideas for new rules may come from the rule-making staff, from members of the airworthiness staffs in the regional offices, from the aircraft and airline industries, and from organizations representing specialized personnel such as pilots, flight attendants, mechanics, and inspectors. Ideas also originate in a variety of formal and informal meetings and colloquia, including airworthiness conferences attended by domestic and overseas industry and government representatives. Rules also may be proposed by the Congress and by other federal agencies such as the Environmental Protection Agency and the National Transportation Safety Board. This board, an independent federal agency whose charge includes investigating and determining the probable cause of civil aircraft accidents, also may make recommendations for changes in the regulations as a result of its findings.

- When a matter is considered serious enough to justify a new or revised rule, headquarters project teams, typically comprising engineers from the rule-making and airworthiness offices and a regulatory attorney, are asked to develop the safety, technical, and economic justifications and to draft the proposed rule. Other members of the project staff include economists and environmentalists when these considerations are called for.
- Once drafted and approved for rule making by the administrator, the proposed rule is published in the Federal Register as a Notice of Proposed Rule Making (NPRM).* The notice sets forth a stated period, ranging from 30 to 180 days, during which all interested parties may submit written comments. In cases where public interest runs high, the FAA may elect to hold open hearings.[11]

* In very complex matters, or where the appropriate solution is not yet clear, the preliminary device of publishing an Advance Notice of Proposed Rule Making (ANPRM) is employed.

- After the designated period for comments has expired, all communications on the subject, to and from the outside, cease. At this stage, the FAA deliberates and decides, in light of the comments and its own technical judgment, whether or not to issue the rule, what form it will take, and what time period is needed before it takes effect.
- Finally, the administrator approves the rule by publishing it in the Federal Register, together with a preamble describing how the public comments were handled. The adopted rule is then incorporated into the regulations. Subject to President Carter's Executive Order No. 12044,[12] all "significant" rules, which means those involving high cost or stirring public controversy, must carry the approval of the Secretary of Transportation as well. Once the rule is final, an affected party not satisfied with the outcome may seek recourse in the courts.

It is not uncommon that investigation of a potential rule will reveal that further research is necessary before an appropriate standard can be defined. An example of such a problem is the rule concerning post-impact aircraft fire.

In the early 1970s, it became apparent that the latest jet aircraft, in particular the large wide-body airplanes, were absorbing the forces of crash impacts much more effectively than their predecessors. Aircraft occupants were surviving crashes in greater numbers, only to be exposed, on occasion, to fires. Beginning in 1973, the FAA, the National Aeronautics and Space Administration, the National Bureau of Standards, and many parts of the aviation industry substantially increased their research on aircraft fire. During the next three or four years, the FAA initiated three separate rule-making actions: (i) a proposed modification to the existing flammability rules for cabin interior fire-resistant materials; (ii) a Notice of Proposed Rule Making, calling for materials with reduced smoke output; and (iii) an Advance Notice of Proposed Rule Making, calling for materials with lower toxicity properties.

Soon afterward, research and development revealed the inadequate understanding of fire dynamics and the lack of standardized testing techniques for measuring flammability, smoke, and toxicity. Indeed, virtually no systematic, large-scale testing had been done in these areas, and it became clear that experiments carried out in laboratories bore little resemblance to full-scale fires in airplanes. The three pending rule-making actions thus had little or no basis. Accordingly, in 1977, the FAA withdrew the proposed rules to await a better understanding of fires in aircraft.

The several fire research efforts are still under way. The FAA, NASA, and the aviation industry are presently conducting large-scale tests of assembled components to determine their fire resistance levels in order to form the basis for new standards. Meanwhile, industry has, in some cases, taken advantage of the technology developed thus far by applying incremental improvements to certain cabin interior components—e.g., fire-resistant polyimide foam insulation around air-conditioning ducts, redesign of lavatory structures to contain fires, and new phenolic-resin-based cabin sidewall panels that exhibit markedly increased resistance to fire penetration.

The fact that the FAA has initiated rule-making actions without an adequate data base is an example of the agency's emphasis on the process of rule making rather than on the substance of regulatory needs. The FAA rule-making process is mainly reactive, either to the needs of safety as determined from accidents, or to new technologies as identified by manufacturers. In some instances, even this responsive mode has been lagging. A case in point involves two proposals discussed and agreed to by the FAA and the industry at a 1974 Airworthiness Conference,[13] concerning the use of continuous-gust criteria for strength and structural deformation design, and the need for a safety analysis of the probability of fuselage openings. Although the hole-size criteria have been applied by the FAA through Airworthiness Directives and Type Certification negotiation, and continuous-gust criteria have been used by industry, largely on a voluntary basis, the FAA has not yet incorporated into the Federal Aviation Regulations the detailed rules requiring these practices—some six years after they were first proposed.

Of equal importance to its ability to respond to rule-making imperatives of a new design or an accident is the FAA's need to be capable of understanding how new technology could give rise to the requirement for new rules as well. This is important in order to assure that the FAA is prepared to scrutinize competently the safety implications of new design approaches, to avoid or reduce the regulatory drag on innovation and the introduction of new technology, and to promote advances in safety in areas where the industry is not leading. Examples of emerging technologies where FAA expertise lags behind industry include advanced composite structures, avionics, active control systems, and the impact of new aerodynamic shapes. New standards, and the research and development to support them, in areas such as survivability and human factors, are examples of areas on which manufacturers place less priority, compared to airworthiness, reliability, and productivity. The FAA thus should be expected to exhibit a greater amount of guidance and leadership in the former areas.

In order to issue and maintain clear and technically current standards, the FAA must have an excellent rule-making process, one that keeps pace with advances in technology and meets the needs of those who interpret and apply the standards. The attributes of such a process are: (i) a scientific and technical knowledge base for proposed standards; (ii) a systematic approach to identifying the need for new rules or the modification of existing ones, coupled with set priorities and schedules; (iii) a capability to react to unforeseen emergencies (arising from an accident, for example) by reordering established priorities; and (iv) efficiency in the processes of scanning the technical horizon, soliciting recommendations from affected parties, drafting and inviting comments on proposed regulations, and preparing the final, adopted rule.

Of the above attributes, the committee finds that only the administrative processes of rule making are being actively pursued by the FAA today. Indeed, the agency has recently taken steps to improve the efficiency of its administrative rule-making. In the spring of 1979, it developed a rule-making project team system that holds promise for improving the scheduling and accountability of the rule-making staff. The FAA's rule-making actions also seem to work promptly in reacting to the external stimulus of a fatal accident. In other respects, however, the committee finds too much caution and passivity.

What is lacking is initiative—a systematic means for determining where new rules are needed, the ranking of priorities, and the development of the necessary technical bases, where absent, for rule making. In light of these findings, *the committee recommends that the FAA take more initiative in identifying the need for new rules and in establishing objectives, priorities, plans, and schedules for rule making and that it sponsor annual rule-making review conferences to support this activity*.

To provide the means for problem identification, the FAA should reinstate annual government-industry airworthiness reviews. Such reviews were convened by the Civil Aeronautics Board before rule-making functions were transferred to the FAA in 1959, and were eminently successful. Under that system, for example, the rules necessary for certificating the initial fleet of jet aircraft were developed in a timely manner, enabling the United States to assume quickly a leading position in commercial jet aviation.

The FAA attempted to revive this activity in 1974 with its all-embracing Airworthiness Review, the first in a planned biennial series. However, the bulk and comprehensive nature of the review, and the failure to limit its agenda, swamped the capability of the FAA to deal with the many recommendations. As a result, many of the recommendations still await action. Examples include: the desirability of requiring revalidation of, or life limits on, Type Certificates;[14] changes in accelerate and stop distances;[15] concern over regulations dealing with failure analysis and numerical probabilities;[16] and such "key design elements" as "compartment fire protection, emergency exits, seats and shoulder harnesses".[17]

Discussions with former FAA officials, and with industry personnel who participated in past reviews, have convinced the committee that this process is a good one, provided that the review is well organized, the agenda is planned in advance, and the FAA follows through in a businesslike way. The same procedures should be used for identifying the need for new standards, for discussing their significance, and for determining the state of the art necessary to write the rule.

The process for planning and setting priorities, once the need for a new or updated rule has been identified, should be managed and carried out by the FAA staff. Probably it was at this stage that the 1974 Airworthiness Review failed. From discussions at the review, from additional industry and public comments, and from its own knowledge, FAA management and technical staff should be able to determine a priority ranking for its rule-making activity.

From such a ranking, it should be an easy matter to develop a plan and schedule for rule making—in effect, a calendar—in considerable detail for the following year, and in lesser detail for the succeeding five years. The calendar should take into account the available resources, the need to obtain or develop the underlying technology base, and the administrative process of writing, reviewing, and publishing the rule itself. The calendar should also leave sufficient room, on a planned basis, for reactive rule making—the requirement to react quickly to a failure, an accident, or an unanticipated technological need.

Generally, by the time a technology is advanced to the point where it can be considered for incorporation into an aircraft, the research and development necessary to complete a rule should be capable of being scheduled. In other words, the research generally is not of such an advanced nature that its outcome is completely unknown or its impact unforeseeable.

The research and development in support of FAA rule-making activity can be carried out for the most part by other government agencies (e.g., NASA and the Air Force), by universities, and by private industry. The committee has reviewed the existing relationship between the FAA and NASA, and has found that, while the mechanisms for coordination have been established, they are not being used effectively.

Given NASA's statutory responsibility for aeronautical research,[18] , the FAA should request that agency to strengthen those research programs that lay the basis for future rule making. A formal interagency agreement between NASA and FAA could be established through which FAA submits requirements to NASA in accordance with FAA developed priorities and plans. NASA could perform the necessary research and development on a predetermined time scale. Such formal agreements should not take the place of the many ongoing technical meetings and discussions, but rather should reflect the outcome of these discussions in a way that the FAA can incorporate in its planning process.

NASA is not the only possible source for research to meet the FAA's rule-making needs. The Air Force, for example, has done a great deal of research directly applicable to airworthiness matters. If other public or private resources can assist the FAA with its research needs, the FAA should enlist their aid.

The recommended central engineering organization would play a significant role in this and all other aspects of the rule-making process. If this organization were to be located in proximity to an existing research center, the coordination required for technology development might be greatly facilitated.

The administrative process for rule making, as recently modified by the FAA with its project team concept, appears to be improving—although it is still too early to tell just how much. As an additional task, the FAA should develop a systematic approach to updating the entire body of Federal Aviation Regulations. While scheduled rule making and annual conferences can be expected to address new standards reflecting advancements in knowledge and new design practices, the systematic updating of the regulations should result in revising or deleting rules and criteria that have become obsolete. Even if a small fraction of the regulations—perhaps 10 percent—were redone each year, such action would fulfill within a decade the need that has been evident for at least the same period. This task being never finished, the FAA should perpetuate both the annual review and updating of the regulations.

FLIGHT AFTER FAILURE—A SPECIFIC RULE

While the purpose of this study has been to evaluate the procedures by which the FAA and industry together assure airworthiness, the committee has been mindful throughout its deliberations of the fact that the acid test of a process lies in the substance it produces, not in its organizational elegance. The substance of rule-making and type certification procedures is thus properly measured by the technical adequacy of the adopted standards or regulations and the quality of the judgments and decisions reached in applying the standards to the design of a new aircraft.

It is in the nature of every complex technological system that all possible risks—even mechanical ones—cannot be anticipated and prevented by the design. Most safety standards have evolved from the experience of previous errors and accidents. Airplanes built in accordance with current standards are therefore designed essentially to avoid the kinds of problems that have occurred in the past and to tolerate operational abuses deemed likely to occur. The high safety performance of the modern jet transport provides assurance that the current standards, which address the risks we now recognize, are sound.

The designer seeks to anticipate and defend against likely malfunctions and hazards that could defeat the component being designed. However, many of the fatal accidents that have occurred with airplanes manufactured by companies visited by the committee have involved rare and improbable combinations of mishaps, aspects of which were outside the "design environment" of the components in question, such as maintenance-induced damage, undefined weather hazards, and damage sustained outside the operating regimes. To comply with current FAA requirements, the designer of a new aircraft may establish that structural components that are critical to safety comply with the rules by either of two kinds of analyses. One involves the concept of "safe-life," which means that a structural component or assembly must be designed to retain its strength and integrity throughout its useful life. Landing gears, propeller blades, and engine fan blades are examples of safe-life parts.

Whenever appropriate, structures may also be designed to satisfy the concept of "fail-safe." Here, safety is assured through the provision of redundancy. This means that the designer must show, through a variety of analyses of possible failure modes, that if the fail-safe part is crippled, another redundant or backup part is available to do its job sufficiently, at least to permit a safe landing. For instance, a typical fuselage panel is designed with doubler strips that stop cracks from progressing while the additional members of the panel pick up the loads until the cracks can be detected and repaired, usually at the next scheduled maintenance.

FAA procedures do not normally require the designer to take into account, by analyses, the hazard to one component from the failure of some other component that was designed to meet safe-life or fail-safe standards. This has not been required because to do so would appear to involve a contradiction of the definition of these two structural design bases: why take into account a failure that cannot occur?

These procedures, however, fail to take into account an important consideration: structures designed not to fail when subjected to conditions within the design environment sometimes do fail, usually as a result of hazardous conditions outside the design environment. Examples of such hazardous conditions might include maintenance-induced damage, hard impact by ground servicing equipment, cargo-induced damage, or perhaps even faulty quality control during manufacturing. The simple fact is that during the long life of many fleets of aircraft, with millions of operations, one cannot guarantee that such damage will not occur.

When one goes beyond matters of structure design to consider similar design approaches to aircraft systems, the problems can be compounded. Critical control systems, for instance, are designed so that the probability of failing can be demonstrated to be "extremely remote." The convention normally applied to this definition is a calculation showing that the probability of failure is one-in-one-billion (10^{-9}) flights. However, critical control systems also have failed from causes outside the system design environment. The failure of a safe-life or fail-safe structure that surrounds such systems is currently not required to be considered within the system's design environment. Thus it is not taken into account when analysing possible modes of systems failure.

The accident in Chicago* involved presumably inconceivable combinations of events: the one-in-a-billion failure of critical control systems caused by the improbable failure of a fail-safe component. That failure, in turn, resulted from maintenance-induced damage not considered within the design environment of either the structural or systems components.

In the committee's judgment aircraft design principles should take into account the potential of structural damage caused by conditions outside the design

* See Appendix B.

environment, and should seek to prevent catastrophic effects resulting from such damage. Specifically, *the committee recommends that the FAA develop a rule requiring assurance that an aircraft is designed to continue to fly after structural failure, unless that failure itself prevents the aircraft from flying*.

There are obviously some kinds of failure—a wing torn off in a mid-air collision—that, by themselves, prevent the aircraft from continuing to fly. In the Chicago accident, however, a primary failure led to a series of secondary failures of flight control systems which, by making it impossible for the pilot to recover, were the actual cause of the accident. It is this kind of situation that justifies the need to go one step beyond the design assurances now required.

The recommendation would require that formal design consideration be given systematically and routinely to the consequences of the possible failure of critical structure and systems, even though these can be shown by analysis to meet design standards presumed to preclude failure. Structural elements or systems that could be rendered critical to continuing flight, because of the initial failure of a primary structure, must be designed to avoid or minimize being crippled or damaged by such initial failures.

While the principle underlying this proposed rule has not been generally applied, there are examples of its application to specific cases, developed in response to accidents that have occurred. One is the decompression venting of wide-body aircraft. The designer takes into account unanticipated structural damage resulting, for instance, from the inadvertent opening of a cargo door or from a mid-air collision, which could cause floor failure, and a secondary problem, such as the possible interference with control cables. A second example is the requirement that design consideration be given to the trajectories of disintegrating engine parts, even though such parts are designed to safe-life criteria.

The committee believes, moreover, that, with the acceptance of this recommendation, the FAA should examine currently certificated type designs to determine if they substantially and reasonably comply with the rule that would result from this recommendation. In cases where they do not, it should consider issuing appropriate Airworthiness Directives to accomplish changes that can reasonably be made or to permit exemptions for any special circumstances that may exist.

THE ISSUE OF PUBLIC ACCESS

The special issue just cited is one example of a rule-related problem that is often first identified in the course of type certification decisions. Other rule-making issues also arise during the certification process in the regional office. Several of these, including cockpit design, the interpretation of cabin safety, and the methods for determining crew complement, affect in a direct way other parties as well as the manufacturers and airlines with which the regional offices customarily deal. Some could later affect other manufacturers, such as the proposed retroactive imposition of an amendment to the regulations dealing with accelerate-stop distances.

The committee has heard many proposals for "openness" in the certification process, especially with respect to the issues raised in this study. We find that much of the debate on the subject of openness involves a confusion between the right of the public to be heard in setting new standards (which is a formal rule-making function in which the public clearly has the right to participate) and the desire of the public to appear before, or even become voting members of, the Type Certification Board. The board is a decision-making body only of FAA employees, in whose ultimate decisions the public should not participate. FAA practices may inadvertently have added to the confusion in that certain rule-making decisions—Special Conditions, exemptions, or the retroactive application of amendments to the regulations—are usually made in the course of type certification without providing the normal period for notice and comment characteristic of formal rule making.

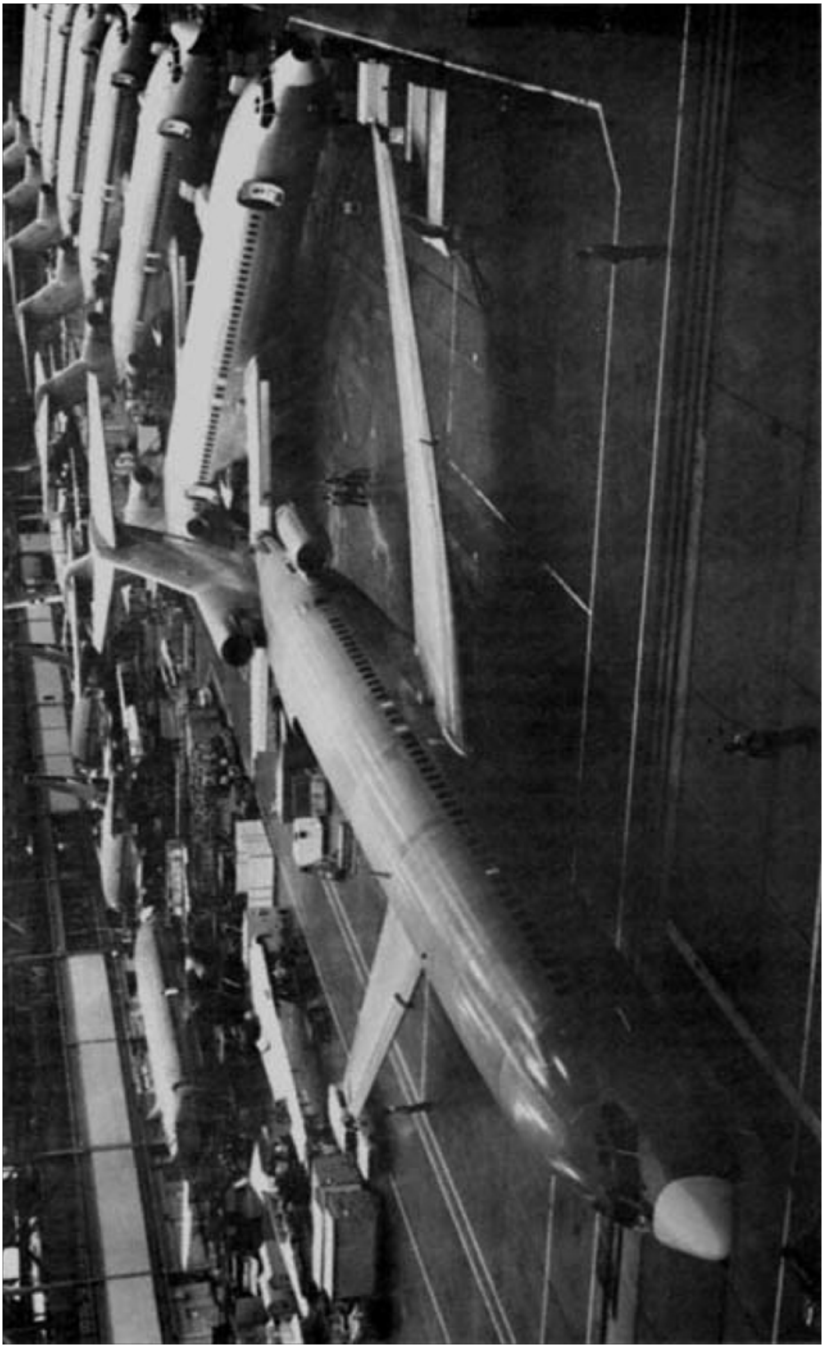
The committee recognizes that, in the course of reaching formal decisions in these respects, there is a vital element of negotiation that is best accomplished by the parties most concerned—i.e., the FAA and the applicant manufacturer. Moreover, there are instances in which proprietary information is justifiably held in confidence. Even so, the committee recognizes the right of the public to be heard in rule-making decisions, especially in the case of parties who are both knowledgeable and interested in the consequences of such decisions. Therefore, *the committee recommends that the FAA publish, as a notice in the* Federal Register, *the availability of the FAA-approved preliminary regulatory and certification bases for new aircraft type design, with subsequent publication of changes thereto, to permit timely review and comment by the public and response from the FAA*.

In making this recommendation, we seek to accommodate two equally important objectives: (i) consistent with the Administrative Procedures Act, the public should be given notice of rule-making decisions that are being contemplated, and the FAA should receive and take into account all pertinent information or recommendations prior to making its final decision; and (ii) consistent with the statute, any manufacturer may apply to the FAA and hold confidential any information provided to the FAA that would adversely affect the company's interest, as long as the information "is not required in the interest of the public."[19]

In practice, we are recommending that the regional offices, through their respective Type Certification Boards, increase the observance of rule-making formalities with respect to their special rule-making decisions—just as they now do in issuing Airworthiness Directives when time permits in nonemergency cases. The committee envisions the situation where, subsequent to providing notice concerning the regulatory and certification bases, the Type Certification Board would invite all interested parties to make formal submissions for review at one of its early meetings. Thereafter, within a reasonable specified period of, say, 30 to 60 days, the board, on behalf of the FAA, would be required to make a formal, written, and public response to the issues raised, addressing their merits and providing available supporting data.*

* The relationship of the public to the activities of the Type Certification Board is also being reviewed in the Congress. At least one bill relating to the matter, S. 11433 (95th Congress, 1st Session), is being considered in the Senate Committee on Commerce, Science, and Transportation. A companion bill, H.R. 4679, also has been introduced in the House of Representatives.

The procedure contemplated should in no way restrict the type board or design certification project engineers from also seeking additional technical advice and counsel from such appropriate sources as other government agencies and individual specialists and consultants, paid or volunteer, from industrial and academic settings.



Production and Maintenance

The manufacture of modern jet transport aircraft is an organizational tour-de-force. Components of the aircraft-wings, tail and landing gear assemblies, fuselage sections, doors and latches, avionic and radio equipment—arrive at the assembly plant from all over the world. In hangars the size of several football fields, work crews tow the airplanes through a dozen or more positions on the production line, until each finished airplane eases from the hangar ready for testing and approval for flights.

Once an airplane is in service, the airline performs myriad maintenance operations on it—daily checks, periodically scheduled maintenance, major overhauls, repairs of unexpected damage and replacement of failed components. The number of aircraft in daily service for each air carrier, the complexity of the airplane, the distances between centers of operations, and the variations in procedures and practices among airlines all figure into a maze of maintenance operations in which millions of actions are performed by thousands of individuals.

As a consequence, there are many opportunities for assuring that each aircraft is built and maintained to established safety standards. With careful workmanship, failures are preventable. By alert examination, errors are detectable. Carelessness and inattention, by contrast, often lead to mistakes and mishaps.

QUALITY ASSURANCE IN PRODUCTION

For each new type of aircraft, a manufacturer must obtain a Production Certificate from the FAA. Prior to awarding the certificate, a team of specialists from the FAA regional office, constituted as a Production Certification Board, reviews and evaluates the applicant's proposed manufacturing and quality control procedures. The review is intended to make sure that each aircraft produced conforms to the design specifications of the Type Certificate. Once the Production Certificate is awarded, government oversight of production is maintained by a system that couples direct FAA review by assigned inspectors with the work of delegated company-employed Designated Manufacturing Inspection Representatives (DMIRs).

The job of assuring that the aircraft meets the design specification rests with the manufacturer's quality control organization. It reviews all aspects of the production process, including the materials, parts, tools, and equipment; the methods of operations and the sequence in which these are performed; in-process and final inspections and tests; and the qualifications and training of all production personnel.

Inspections are performed by company employees who are required to verify by formal record that the product meets the established standards. The record signifies that the inspector stands behind the proper performance of the work. Articles are tagged or stamped with marks that identify the individual inspector and ensure that only inspected and accepted items are used in the finished product. For example, suitable "acceptance," "rework," or "rejection" stamps are placed on articles subjected to heat-treatment, welding, riveting, soldering, hardness tests, laboratory analysis, and other tests.

Responsibility for the continuous review and monitoring of the quality control system on a daily basis resides with the FAA Principal Inspector assigned to the facility. The inspector supervises the work of and is assisted by a staff of FAA inspectors and the Designated Manufacturing Inspection Representatives. The designees certify on behalf of the FAA that aircraft are consistent with the approved design and specifications. FAA inspectors provide surveillance of the entire production and quality control system. They also participate in FAA enforcement actions, a function specifically excluded from the designee's authority.

Designees are company employees with many years' experience in manufacturing or special processes and in inspection, all gained with the same firm, generally. They are nominated by the company and approved by the FAA in a manner analogous to the appointment for design review of the Designated Engineering Representatives.

Their responsibilities include: (i) the witnessing and verification of tests; (ii) issuance of Airworthiness Certificates (a certificate that the individual aircraft meets the design specifications of the Type Certificate and has been flown, either by FAA or company test pilots on behalf of the FAA, and has been found in compliance with applicable standards) and export approvals; and (iii) performance of conformity inspections. In the last instance, they provide a second assurance that the product conforms to its design, not by repeating the work of the company inspector, but by performing an audit of what was done to the product. They also work on behalf of the FAA during type certification to determine whether or not prototype articles conform to design data. Designees accomplish the audit primarily by reviewing the paperwork and process documents. They also make spot checks of the inspections at selected points. Once an error is detected by a designee, he is charged with seeing that it is corrected, but not necessarily with reporting the error to the FAA.

The FAA inspector is charged with the broader responsibility of ensuring that the entire quality control system is carried out in accordance with the plan submitted to the FAA and approved by its Production Certification Board—a procedure called "Certificate Management." The FAA inspector's concern extends to the tools or equipment used, the sequence of operations, the training of the individual performing the work, and the steps taken by the company's quality control organization.

The processes that go into producing aircraft have increased in number and complexity over the years. At present, according to company representatives, quality control activities represent approximately 15 percent of the total cost of an aircraft. To verify that the multiple tasks are consistent with established procedures, even by reviewing the system on a spot check basis, is beyond the daily capabilities of the few FAA inspectors and manufacturing designees who work in production. For instance, early in 1980, the FAA indicated that there were only about 21 inspectors and 36 manufacturing designees working in the production facilities of the three major manufacturers. Most of the FAA staff had other assignments.

Accordingly, the routine surveillance of the manufacturers' production and quality assurance systems by FAA inspectors is augmented by special FAA teams who periodically perform a Quality Assurance Systems Analysis Review (QASAR) of the systems. Such in-depth audits involve, primarily, a detailed examination of documents and records. Little specific attention is given to hardware.

The committee found the relationship between the FAA principal inspectors and company designees to be one of mutual respect. In comparing the two groups, it concluded that the basic minimum requirements for training and inspection experience were similar. Accumulated experience levels are about the same, as are basic salary ranges, although the FAA offers a higher maximum salary to its most senior inspectors.[20]

Some differences exist among companies in how the designees are used. At two companies, they are assigned to the quality assurance organization, report to the FAA principal inspector, and perform inspections and approval actions only for the FAA. At the third company, the same functions are performed, although some functions in addition to their FAA tasks are required at the direction of their employer.

The FAA regional office staffs view the work of the designees as essential and of excellent quality. Similarly, each of the companies describes the designee function as necessary to demonstrating compliance with the regulations. The committee is satisfied that FAA manufacturing inspectors relate to their counterparts essentially on a peer basis. The committee also found that the team approach to auditing quality assurance is well conceived, but that the typical intervals between audit visits are too long, often as much as three years.

While the manufacturers' quality control systems and the quality of the FAA inspectors appear generally to be good, there have been nevertheless a number of lapses that raise warning flags. Examples are such production failures as the faulty cargo door latch that caused the Turkish Airlines DC-10 accident outside Paris[21] and the discovery in the course of an inspection, after the Chicago accident of loose, failed, and missing pylon spar web fasteners on another aircraft.[22] Materials used in aircraft production also may present quality problems. In the absence of extremely alert quality control personnel, flaws can enter the manufacturing cycle before they are identified.

In connection with the need for alertness, the committee observed that the FAA inspection personnel are tied to their offices too much. It would be more valuable if inspectors were to establish their presence on the production floor with greater frequency, observing first-hand the manufacturer's fabrication and inspection activities. While recognizing that it is not the FAA's function to inspect and approve specific hardware and operations, as the company inspectors must do, it is the committee's view that an understanding of and judgments about the total process are enhanced by greater familiarity with the hardware being produced, by observing the manufacturing and inspection operations, and by talking with the individuals performing the work.

Considering all of these matters, *the committee recommends that the FAA increase its emphasis on quality assurance in all phases of the production process by increasing the frequency of Quality Assurance Systems Analysis and Review team visits to all Production Certificate holders, and by expanding the responsibilities of FAA inspectors and quality assurance teams to include the observation of actual hardware*.

MAINTENANCE SURVEILLANCE

Once a new aircraft leaves the manufacturer's plant for use in service by a carrier, the responsibility for maintaining it in compliance with applicable FAA regulations devolves upon the airline. At the same time, the day-to-day FAA responsibility shifts from the manufacturing review staff of the regional office to air carrier inspectors in the respective district offices, located near the principal airports of the country.

Prior to operating a particular aircraft in revenue service, the individual air carrier has to develop and submit a maintenance program to its assigned FAA Principal Maintenance Inspector for approval. The program includes a combination of maintenance operations specifications and a manual of instructions for accomplishing maintenance and inspection, as well as a means for their administration. In practice, preparation of the initial maintenance program for a specific type of aircraft is begun early in the design stage. The FAA review is accomplished during the type and production certification period. An industry committee, called the Maintenance Steering Group (MSG), representing relevant airlines, other operators who expect to purchase the airplane, and the manufacturer, provides advice during its preparation. Once the manufacturer has presented the initial maintenance program and manual for approval to the FAA, the document is reviewed in the regional office by a Maintenance Review Board (MRB). The Board, an FAA committee of specialists, including engineers and representative maintenance and avionics inspectors, prepares a Maintenance Review Board Report to approve the maintenance program.

In the normal course of events, each carrier modifies the initial maintenance program, subject to review and approval by the FAA's assigned maintenance or avionics inspectors, in light of the carrier's particular maintenance practices and the experience gained from maintaining the aircraft in service. The maintenance program is also changed in response to Airworthiness Directives (FAA regulations prescribing mandatory inspection and/or repair), manufacturers' service bulletins, and relevant maintenance reports of other carriers.

The process of revising both the manufacturer's' maintenance manual and the program in actual use by the carriers is one of considerable magnitude. A major carrier visited by the committee includes in its maintenance manual all engineering and maintenance policies, procedures, specifications, and job instructions. Its manual has 200,000 pages, in which some 300,000 pages of revisions—some revised several times—were made during one year.[23]

It is likely that two airplanes produced one after the other on the same production line will be subject, after a period of use by different carriers, to quite different maintenance operations. The particular route and operation of each airline call for differences in the type and frequency of the work required. Even so, each carrier's program of maintenance bears the approval of the FAA.

The FAA's primary means for effecting the surveillance of the carriers' maintenance program is the assignment of Principal Maintenance (and Avionics) Inspectors and their staffs at locations adjacent to the carriers' principal maintenance bases. These officials are responsible for assuring that the carriers to which they are assigned maintain the airplanes in compliance with the regulations. They do so primarily by reviewing the airline's maintenance system and checking its maintenance job records. Depending upon the workload and inclination of the respective inspectors, they may review or spot-check actual work done or in progress.

This system of surveillance is supported by three backup activities: (i) FAA inspectors at other airport facilities along the carrier's route perform ramp checks to evaluate the apparent condition and routine servicing of the aircraft; (ii) audit-type inspections, called situation monitorings—analogous to the system of audits performed for manufacturing by quality assurance teams, though not so regular—are conducted in limited cases, especially where the regional office becomes aware of specific safety problems; and, (iii) a formal system for reporting and reviewing accidents, incidents, and service difficulties.

Boeing, Douglas, and Lockheed all have product support departments that play important roles in their respective operations. One has 1,440 product support personnel;[24] another has an even larger staff. These units monitor the use of their products and provide assistance to the owners, no matter how often the equipment changes hands, because, as they view it, the performance of one aircraft reflects on all others from a manufacturer. Typically, company representatives are assigned to an airline 30 days in advance of the delivery of a new type of aircraft. They assist the customer, on request, with engineering and maintenance advice, provide specialized training as the need arises, and, in general, become the carrier's instant point of contact with the manufacturer. The company representatives also gather and report home to their companies all data on component repair, routine operational data, and other matters of technical significance.

Manufacturers regularly issue service bulletins to their customers concerning recommendations related to product improvement or reliability. One kind, called an Alert Service Bulletin, which also is sent routinely by the manufacturer to its FAA regional office, concerns significant problems in which safety is considered an issue. While many airlines may make changes immediately in response to an Alert Service Bulletin, they are not legally required to do so unless the FAA incorporates the bulletin into an Airworthiness Directive (AD). Carriers also are not required to report the completion of work in response to service bulletins to either the FAA or the manufacturer.

Service bulletins may or may not be reviewed by the FAA maintenance inspector as part of the examination of the airline's maintenance documents. However, the project engineer in the regional office often considers the Alert Bulletins for possible issuance of a mandatory Airworthiness Directive.

The differences in maintenance organizations and practices lead the FAA, in turn, to varying local interpretations of the regulations by its air carrier inspectors. The lack of consistency from one office to another is an inevitable and reasonable consequence of the diversity of users' needs and not a shortcoming to be eliminated.

There are, however, wide differences in the practices of FAA inspectors, especially the frequency of their direct observation of the aircraft, the level of their maintenance inspection activity, and their general assertiveness. While the regulations make inspectors responsible for approving the maintenance program and any changes in it, the committee sees the system as allowing and even encouraging them to view their responsibility as a passive one. Because of the importance of maintenance to the safe operation of aircraft, the FAA needs to do all it can to encourage its inspectors to be more assertive, and to take full advantage of the opportunities to detect and correct conditions they consider to be unacceptable. As in the case of manufacturing inspectors, the committee found that, while FAA maintenance inspectors now acquire information principally by reviewing documents, it is important that the inspectors acquire first-hand familiarity with the carriers' extensive maintenance activities that go on around the clock.

One way of enabling inspectors to observe maintenance events is to provide them with better tools and knowledge about their work—e.g., access to carriers' service computers and to their own computer systems, more and better training about new aircraft, and annual conferences on matters of wide concern. Periodic telephone conferences linking inspectors to each other and to regional project engineers would provide greater understanding of the findings of other inspectors and the possible implications of those findings.

FAA inspectors also should be encouraged to observe more strategically, acting, for instance, on the natural "cues" that the system provides. Cues are to be found in Airworthiness Directives, individual aircraft maintenance records, manufacturers' service bulletins, government and industry trend analyses, and statistical data. The manufacturer's issuance of an Alert Service Bulletin, for instance, provides an opportunity for the FAA inspector to gain insights on how the carrier perceives a particular safety problem.

While there is a clear value to be gained by increasing the awareness of the maintenance and avionics inspectors to ongoing maintenance activities, as well as their knowledge of other operations, the total amount of activity and information generated will nonetheless exceed their day-to-day grasp and capabilities. Their reach could be extended by reinstituting the systematic deployment of the FAA's former Systemworthiness Aircraft Program (SWAP) maintenance auditing teams to supplement the work of the assigned inspectors. This program was "reoriented" recently to the less regular "situation monitoring" inspections,[25] which are conducted in response to known problem conditions.

With proper preparation, members of the reinstituted teams could provide checks of the carriers' maintenance systems from broadly based experience. They could be specifically prepared to investigate individual areas of concern prompted by analyses of reported problems, and could be in a position to conduct spot reviews of aircraft hardware to assure that Airworthiness Directives are implemented and that other changes are made to safe-guard the condition of the aircraft. By not giving advance notification of an audit, the team could obtain a candid picture of the actual circumstances of the operator's maintenance program. Such team visits would have an additional advantage of assuring that the performance of the resident FAA inspection staff lives up to expectations.

Because of the importance of maintenance to the continued airworthiness of the carriers' aircraft, *the committee recommends that the FAA increase its surveillance of airline maintenance operations, making use of a team approach for frequent and unannounced inspections, and encouraging its air carrier inspectors to give higher priority to strategically selected on-site visits and hardware observation, both randomly during all shifts, and for specific maintenance procedures that they deem especially critical or important*.

LICENSING OF MAINTENANCE PERSONNEL

With the exception of the flight crew, no group has a greater effect on aircraft safety than the maintenance workers at the airlines. It stands to reason that the skill levels of mechanics and inspectors should be of high quality and appropriate to the type and complexity of the particular aircraft on which they are working.

The FAA certificates aircraft mechanics by awarding Airframe and Powerplant (A&P) licenses after an individual has passed written tests covering the construction and maintenance of aircraft appropriate to the rating sought.[26] The FAA requires that all maintenance work be signed off by an individual holding an appropriate license. Under the present arrangement, an individual obtains such ratings and remains perpetually licensed, irrespective of the extent or kind of subsequent work experience, training, or qualifications.

The development of increasingly complex, modern jet transport over the past 30 years has led to rapid changes in the level of skills and knowledge necessary to maintain aircraft in airworthy condition. When the concept of licensing or certificating U.S. airline maintenance personnel was originally developed in the late 1920's, the aircraft and the air transportation system were far simpler. That was a period in which materials and structures were less complex and reciprocating internal combustion engines and simple electric circuits were the most important items affecting airworthiness. The term "avionics," which combines modern aircraft electrical, electronic, navigation and communication systems, had not been coined. Today's maintenance staff is required to bring great competence to aircraft functions requiring avionics skills in operation and flight control systems, protection and warning systems, communication and navigation components, instrumentation and cockpit displays, and passenger support and safety equipment. Such maintenance functions require knowledge of complex equipment and circuits, and complex test equipment. However, mechanics dealing with avionics do not have special credentials under the present system.

By regulation, responsibility for the adequate training of maintenance personnel lies with the carrier. It must provide "a training program to ensure that each person who determines the adequacy of work done is fully informed about procedures and techniques and new equipment in use and is competent to perform his duties."[27] In the committee's judgment, the FAA's current licensing and training requirements for airline maintenance personnel are, unhappily, of limited effectiveness.

There is no stringent standard, comparable, for instance, to that for flight crews, for initially establishing or periodically upgrading the skills of mechanics who repair or service commercial aircraft. In 1977, the FAA proposed an amendment to the regulation cited above, observing that "no minimum standard exists today to ensure that airline maintenance personnel have adequate initial and recurrent training."[28] This is still the case. The change proposed in 1977 (but not yet adopted) addressed only the requirement of certification and training for supervisory personnel—i.e., the persons who determine the adequacy of work performed.[29] At present, there is no regulation that effectively prevents an airline from assigning persons with little relevant training and/or qualification to the performance of critical maintenance tasks, as long as someone who is certificated signs off the work. (The committee has made no evaluation to determine if such assignments are actually made in practice.)

Considering these factors, *the committee recommends that the FAA review and update the licensing and training certification requirements for airline maintenance personnel and consider designating avionics as a separate area for licensing*.

While the committee recognizes that specific decisions relating to license endorsements carry implications for labor-management relations, as well as for safety, the issue raised here goes to the heart of the FAA's responsibility for reviewing the adequacy of the carrier's maintenance training programs—a responsibility that the committee finds has not been fulfilled.

REASSIGNMENT OF PERSONNEL

The committee heard a variety of viewpoints on the desirability of establishing a system for the periodic reassignment of FAA airworthiness personnel. At present, there is no policy requiring such personnel to be reassigned from responsibility for one manufacturer or carrier to another within the regional offices or to move to an assignment in a different region. As a result, FAA personnel may and generally do remain assigned to the same carrier or manufacturer for many years.

At each stage of the process, FAA personnel are expected to interact with their opposite numbers in the companies and airlines in a reviewing and approving (i.e., regulatory) mode. To do so properly, they must possess the independence and objectivity for the required governmental checks and balances that are implicit in the nation's airworthiness process. The concern is that too close and prolonged an association with the same company's personnel poses the possibility that the requisite characteristics of independence and objectivity will be eroded. Moreover, through reassignment to other companies, FAA personnel would gain fresh perspectives and additional experiences.

While the issue calls for a subjective judgment, the committee is persuaded that the concern raised over the matter is warranted. Accordingly, *the committee recommends that the FAA adopt a system for reassigning its personnel on a periodic basis to deal with different manufacturers and carriers*.

This recommendation applies to design and production personnel as well as to maintenance personnel. It is not suggested that each member of every staff must be relocated periodically. A rule of reason, taking into account the many personal considerations involved, should be applied humanely. The important point is that the rotation and reassignment of personnel should become, over a period of time, an accepted way of life in the FAA, just as it is now in some fields and in some other parts of the federal government.

It is likely that many reassignments can be accomplished without geographical moves. If the recommendation for a central engineering organization is implemented, for instance, rule-making and type certification specialists would be centrally located and assigned to different companies at different times, without permanent moves. Furthermore, personnel assigned to the two principal manufacturers in the Western Region, as well as air carrier inspectors employed in district offices having responsibility for more than one operator, could easily be reassigned within their present locations.

THE MANUFACTURER'S CONTINUING ROLE

Product services departments of the major manufacturers have been previously described as fulfilling two functions: assistance to customers in the operation of the aircraft, and transmittal of service experience information back to the manufacturer. Data obtained from customer service representatives and from air carriers can be used to identify trends in the operation of the equipment that may lead to a change in design or to a new or modified inspection or maintenance procedure.

The stage at which the manufacturer makes the initial decisions about the design and maintenance plan for an aircraft is one at which only estimates and calculations can be made about the extreme conditions to which the aircraft may be subjected. At that point, there are many uncertainties. For instance, it is not possible to predict with accuracy how frequently a specific aircraft may encounter severe gusts or the particular types and combinations of malfunctions that may occur. While specific limits are used as design conditions, in flight operation is the ultimate test. Accordingly, it is largely through knowledge gained in operational experience that changes in maintenance procedures, and modifications to design, are made.

The manufacturer's experience in analyzing maintenance operations and manufacturing changes is not always sought, however, before maintenance programs or designs are modified. While the designer participates directly in the preparation of the initial maintenance program, once the carrier begins to alter it, the FAA does not require that the manufacturer holding the Type Certificate be consulted before changes are made. Further, the FAA personnel or offices responsible for approving such changes are not necessarily those who originally approved the maintenance procedures during the certification of the aircraft.

It is possible that some changes or modifications will degrade the safety of the airplane in subtle ways that only the aircraft designer is likely to discern. Aircraft safety may be eroded by unusual procedures for removing and reattaching major components, different aircraft jacking or towing conditions, or changes in liquids and gases used for servicing, purging, or cleaning. The modification of a fuselage to accommodate a larger cargo loading door could result in changes to load paths and the consequent overloading of another critical part of the fuselage structure. In some cases, the manufacturer will have more detailed knowledge than the carrier about the strength of structures and sensitivity to damage of the aircraft and its major components. A requirement for seeking formal review by the manufacturer, as well as the FAA, of a proposed significant modification or variation in maintenance procedure could improve the likelihood of early warnings of any dangers.

In some cases, particularly as an aircraft puts on many flight hours in operation and major component replacements are necessary, or as an airplane is modified, the air carriers purchase parts and assemblies from vendors other than the original manufacturer and either make their own alterations or have the work done at a Designated Alteration Station (DAS), a repair facility whose work procedures have been approved by a regional office of the FAA. In either case, the operator must have received a Supplemental Type Certificate (STC) from the FAA prior to making the change. The application for a certificate is handled by the regional office where the carrier or repair facility is located, which, in most instances, is not the same office that deals with the manufacturer.

Just as with variations to the maintenance program, changes can be introduced and even approved by a designee (subject to subsequent FAA-approval) in cases where the manufacturer-designer is best able to judge whether or not unacceptable degradation to safety margins might result. In this case, the designee could be a Consultant Designated Engineering Representative, and not an experienced employee of the original manufacturer. Because the committee did not examine the matter of consultant designees, it cannot extend its previous favorable recommendation to anyone other than designees employed by an aircraft maker.

With such considerations in mind, *the committee recommends that the FAA assure that the manufacturer (type certificate holder) have continuing knowledge of an operator's maintenance procedures by obtaining the manufacturer's formal review prior to authorizing any significant deviation from the approved maintenance program. Similarly, it recommends that the FAA assure that the manufacturer be made aware of an operator's application for a Supplemental Type Certificate by obtaining the manufacturer's formal review prior to authorizing any significant deviation from the approved design*.

The committee recognizes that this recommendation introduces the need to define "significant" in a way that will make it clear which items require a review by the manufacturer-designer. Such items should be confined strictly to those involving the continuing integrity and safety of the design. One way to accomplish this would be to require the Type Certificate holder to identify all structural and functional system items essential to safety by marking their location clearly on a diagram associated with the maintenance program.

In carrying out this recommendation, the FAA needs to take care that small and/or independent businesses do not unjustly lose contracts as a result of the manufacturer's review, or that innovative improvements to aircraft are not discouraged. The purpose of the recommendation is to assure that safety is maintained by seeking the guidance of those responsible for the original design, not to provide a power of approval or veto to the manufacturer or imply that only it or a major repair facility is capable of satisfactorily performing the work.

INFORMATION SYSTEM

The maintenance and operation activities of all air carriers produce vast numbers of reports and service data. Manufacturers, carriers, and the FAA collect, organize, and transmit much of the available data and information via their own systems. These systems, some of which interconnect and overlap, are intended to keep track of what is occurring with respect to the various aircraft, to permit analyses that help identify trends or predict future trouble spots, and, generally, to provide information and advice to carriers and manufacturers that can be used in future improvements and contributions to safety.

In addition to sharing the results of the FAA's formal reporting and disseminating mechanisms, manufacturers receive information from their customer service representatives stationed at the airlines as well as from the carriers directly. They scrutinize all such material to identify trends in the use of their equipment that may suggest the need for a change in the design, manufacture or recommended maintenance, or that may indicate significant operational occurrences. They communicate their findings to the carriers by a variety of means including regular newsletters and service bulletins.

Each carrier is required to have a system for the "continuing analysis and surveillance of the performance and effectiveness" of its maintenance program.[30] Specific records are to be maintained and monitored on failures and other significant events. The carriers collect data on maintenance and reliability characteristics from a number of internal information systems—e.g., unusual flight incident reports, flight log reports of malfunctions, aircraft maintenance information systems, daily operations reports, flight log monitoring systems pertaining to engine reports, monthly summaries of flight delays and cancellations, monthly premature removal reports, and shop cost records.

Many of the larger air carriers keep computerized maintenance records on each of their airplanes. Such records portray the aircraft's complete maintenance history—the date and nature of all work performed and the status of any deferred items, and the planned future maintenance schedule. They also can call special attention to any unanticipated failures. Some airlines conduct a daily telephone conference with their various repair stations across the country to receive and share information concerning current failures and service difficulties. A few carriers also make sampling inspection techniques a part of their maintenance programs to ensure the monitoring of the aging process in their equipment.

The airlines must submit daily Mechanical Reliability Reports (MRR) to their assigned FAA maintenance inspectors concerning the occurrence of 16 specified types of aircraft failure, malfunction, or defect. Thirteen of these involve events occurring in flight-defined as "the period from the moment the aircraft leaves the surface of the earth on takeoff until it touches down on landing,"[31] and widely interpreted to exclude from the reporting requirements any incident occurring while the plane is taxiing or otherwise on the ground, including during maintenance.

Carriers also are required to submit Mechanical Interruption Summaries (MIS), listing the causes of all mechanical difficulties that result in the delay or cancellation of a flight.[32] These are submitted approximately every 10 days and are reviewed for any unusual trends by the Principal Maintenance Inspector. All "major" alterations must be reported as well.*

FAA inspectors convert some of the information acquired to Service Difficulty Reports (SDRs) and forward these to the FAA Maintenance Analysis Center in Oklahoma City. The center incorporates them into its data bank together with all other reports it receives. The data are analyzed to help identify problems and trends in various categories of aircraft, components, and assemblies. The staff at the center examines the information

* The distinction between "major" and "minor" damage is discussed on pages 68-69.

and sends it on to the regional offices and to manufacturing inspectors.

The FAA also receives the National Transportation Safety Board's aircraft accident reports and the reports of special studies that the board conducts on recurrent problems or trends noted from its knowledge of accidents and incidents. Additionally, the FAA can request special computer runs of the Safety Board's accident data bank to identify problems and failure trends in aircraft.

The information-gathering mechanisms presently used by the FAA are a collection of individual systems that have come into being at different times in response to the identification of particular problems. In the past, the Congress and the General Accounting Office[33] have found that the FAA's data base and communications system are inadequate both in scope and practice for the modern aviation system. The individual systems have little or no common basis for cross-correlation of information. Consequently, information in these data systems is often not available in timely fashion, not able to be crossreferenced, and not presented in a format that can be easily used.

Recognizing this problem, the FAA has requested the Department of Transportation's Transportation Systems Center in Cambridge, Massachusetts, to develop a modern, comprehensive information and data-processing system. The committee was pleased to learn of this plan; however, we view the five years contemplated for its development, testing, and implementation to be excessive. Hence, *the committee recommends that the FAA accelerate its development of an effective information-gathering and data system. This system should include access to the appropriate elements of the manufacturers' and carriers' records*.

A properly employed information system is indispensable to providing clues to, and early warning of, potential accidents. Critical to the effectiveness of such a system are the following elements:

- Information should be gathered and processed quickly, and the system should be capable of highlighting those items having possible consequences for safety.
- Additional information, beyond what is now available, should be obtained, wherever possible. The FAA needs to devote more

attention to the safety information passing between and among the airlines and manufacturers that is now largely outside its purview. The manufacturers should draft service bulletins so as to provide the carriers with more complete descriptions of the events or consequences that the bulletins are intended to prevent. By the same token, the carriers should provide more details to the manufacturer identifying the circumstances that led carriers to request maintenance or alteration assistance.

- Analysis of the data should be made by wellqualified users.
- The users of the system must be disciplined to determine the cause of every incident, failure, or accident, to require that corrective action be taken, and to provide feedback to all concerned parties.

An example of a potentially effective information system is the experimental Aviation Safety Reporting System (ASRS), a project developed at the request of the FAA by NASA. The committee was impressed, from the briefing it received from NASA, that this project is already making a major contribution to safety, largely because of the painstaking and detailed analysis of the data that NASA is providing.

Since 1975, NASA has developed and operated the safety reporting system, which permits confidential reporting of safety problems and violations of procedures within the aviation system, including information on human error. Anyone is permitted to file a confidential report of observed or experienced safety problems but, to date, pilots and air traffic controllers have been the principal reporting sources. In all, more than 22,000 incidents have been reported. NASA has published quarterly reports containing both the statistical grouping of items and analyses of the more significant ones. In addition, special studies are conducted at the request of the FAA or other parties. An adequate statistical base now permits some trend studies to be undertaken.

Importantly, in the NASA system, no single report is regarded as trivial. Indeed, some seemingly trivial but recurring items have turned out to be far from trivial.

Examples of such problems, subsequently corrected, include ambiguous and hard-to-read approach chart information for high density major airports, and taxiway/runway near misses. The system also reveals altitude assignment violations and ambiguous or contradictory controller instructions.

Information of this kind—largely subjective and anecdotal—is valuable and not available in the data systems operated by the FAA. It should be included in the proposed new data system. Although mechanics and other ground personnel have not made use of the NASA system so far, and there are some distinguishing or identifying features in the data that would be submitted that would make the confidentiality of such sources difficult to preserve, the committee urges that the system be extended to the reporting of maintenance errors related to airworthiness concerns.

DAMAGE TO PRIMARY STRUCTURE

The efficacy of the FAA's information and data system depends in large part on its dependability for reporting damage to the aircraft structure and associated repairs. Under present regulations and guidelines, damage to aircraft structure is reported in different ways depending on: the consequence of the occurrence, where it occurred (flight or ground), what structure was involved, the repair involved, interpretations of degree of damage (e.g., significant or not significant), interpretations of the type of repair (e.g., major or minor), and, to a degree, a combination of these matters.

Depending on the descriptor, the requirements for reporting and approval vary widely, thus increasing the possibility that the FAA and the industry may fail to identify an unsafe condition. An example of the confusion existing in the present system involves the distinction between major and minor repairs. "Major" is generally understood to refer to primary structure, i.e., the principal load-carrying members, such as the main wing beams. FAA regulations, however, are ambiguous in distinguishing major and minor.

The regulations call for reporting the condition of the aircraft's structure. The procedure for preparing and submitting Alteration Reports and Repair Reports requires that: "Each certificate holder shall, promptly, upon its completion, prepare a report of each major alteration or major repair of an airframe, aircraft engine, propeller, or appliance of an aircraft operated by it."[34] Copies of reports concerning major alterations are to be submitted to the FAA representative, while copies of reports about major repairs are to be kept available for inspection by the same representative.[35]

In another part of the regulations, the terms "major repair" and "minor repair" are defined as follows:

> "Major repair means a repair:
> "1. That, if improperly done, might appreciably affect weight, balance, structural strength, performance, powerplant operation, flight characteristics, or other qualities affecting airworthiness; or
> "2. That is not done according to accepted practices or cannot be done by elementary operations.
> "Minor repair means a repair other than a major repair."[36]

In yet another place in the regulations, airframe major repairs are defined as those involving the "strengthening, reinforcing, splicing, and manufacturing of primary structural members or their replacement, when replacement is by fabrication such as riveting or welding."[37]

The application of these definitions requires considerable interpretation by many individuals of variable experience to determine whether or not to initiate a repair report and thus enter the condition into the FAA's information system. Such judgments, concerning whether a major repair is reportable, and if so to whom, include where the damage has occurred on the aircraft and, in the case of structural damage, whether the aircraft was in flight, or on the ground with engines operating.

It appears to the committee that some important occurrences of structural damages may not be—indeed are not likely to be—promptly and effectively reported and reviewed by the FAA. For instance, the damage to the aft pylon bulkhead, caused by a faulty maintenance procedure by Continental Airlines prior to the American

Airlines Chicago accident,* involved damage to a load-carrying structure, but apparently was not a candidate for reporting. According to the FAA Western Region, the existing reporting system does not call for reporting nonservice-related occurrences; therefore, the pylon damage did not have to be reported. Arguably, if it had been clear to Continental that such damage should have been reported, the subsequent American Airlines accident might have been prevented.

It is obvious that these confusing requirements for reporting accidents, incidents, occurrences, and repairs of structural damage or deterioration need to be revised to provide a clearer and more direct decision process concerning what, when, and where to report. Accordingly, *the committee recommends that the FAA require that any damage to the primary structure of an aircraft, regardless of how the damage was caused, be reported*.

This recommendation requires a commonly accepted definition of primary structures, which are the principal load-carrying members, as known by the designer. Identification of primary structures by maintenance personnel would be made easier by requiring the manufacturer to include sketches of the aircraft structural skeleton, which are normally produced during the aircraft design stage, in the maintenance manual. Primary structures should be clearly marked.

* See Appendix B.

Leadership and Advice

Although its members were familiar with one or more aspects of U.S. aviation before this study began, the committee became more and more impressed as the study progressed with the size, complexity, and importance of the task facing both the aviation industry and the FAA in minimizing the risks of accidents in flight. The committee is thus convinced that the FAA needs more than the specific adjustments and improvements in organization, personnel and methods recommended above. Certain changes in the structure of the agency at the highest level also need be to made-changes involving improvements in the quality of policy and technical advice available to the Secretary of Transportation and the Administrator of the FAA, and the provision of greater continuity in the leadership of the FAA.

A SENIOR TECHNICAL ADVISORY COMMITTEE

Because the FAA regulates an industry that works at the frontiers of technology, it needs to be a leader in its field. It needs to be able to develop and apply new standards for rapidly changing technology. To accomplish these goals, the administrator requires access to technical knowledge and advice of the highest order.

The administrator should turn for such advice to the foremost technology specialists available in the nation—individuals who, for the most part, are not likely to be available for full-time FAA service, including men and women from universities, industry, research institutions, and such other branches of the federal government as NASA, the Air Force, and the National Bureau of Standards. Accordingly, *the committee recommends that the administrator appoint a senior advisory committee of experts from government, industry, and universities to advise on the adequacy of technical programs and on the direction of future developments* .

Other high technology agencies have consistently benefited from the advice of such committees. Examples are the Scientific Advisory Board of the U.S. Air Force, the committee structure of the former National Advisory Committee for Aeronautics (NACA), and the NASA committees. To be successful, a technical advisory committee must have outstanding people in their respective fields as members; be structured to give advice not only to the highest level of management but also to the lower working levels of the organization; have an effective secretariat to provide administrative support; and be provided with feedback on the application of its recommendations.

In February 1977, President Carter urged all agencies to review advisory committees and to reduce their number. He expected that committees not created expressly by statute should be abolished except those (i) for which there is a compelling need; (ii) that will have truly balanced membership; and (iii) that conduct their business as openly as possible consistent with the law and with their mandate. Moreover, the President urged a continuing effort to assure that no new advisory committees be established unless they were essential to meet the agency's responsibilities.[38] Considering the FAA's, and the public's, crucial dependency—in terms of safety and costs—upon the quality of technical judgments that must be made by the agency, the committee finds that this recommendation falls well within the President's strictures.

AVIATION SAFETY POLICY BOARD

The Federal Aviation Act of 1958 charges the Secretary of Transportation, and through him the FAA, to promote safety in air commerce, and to promote, encourage, and develop civil aeronautics.[39] As an agency of the department, therefore, the FAA is overseen by the secretary. Given the fact that the FAA regulates the safety practices of a single, relatively cohesive industry, where the similarities of training and perspective of the industry and agency personnel far outweigh the differences, the committee concludes that the entire air safety system would benefit from a broadly based and objective group of advisors to the secretary that would periodically review the FAA activities, provide him with thoughtfully considered judgments on questions of FAA policy, and respond to requests in aid of his oversight responsibility.

The secretary has no such source of continuing advice at present. Moreover, when there are vacancies in the positions of administrator and deputy administrator, such a policy advisory board would be an ideal source of nominations to the secretary and to the President. *The committee recommends, therefore, that the Secretary of Transportation appoint an independent aviation safety policy board, reporting to him and responsible for advice on major safety and policy issues; for counsel on oversight of the FAA, and for recommendations of candidates for the positions of administrator and deputy administrator*.

Unlike the previous recommendation, which would provide a technical advisory committee to the FAA administrator for addressing important technological issues affecting the agency's operating decisions, rule making or research strategies, and the like, we envision that the proposed aviation safety policy board would review the FAA from a more detached vantage point and address the kinds of overarching policy issues which are of concern to the secretary. Such issues might include, for example, whether the FAA has struck the appropriate balance between allocating resources for air traffic control versus airworthiness, or between its dual roles of promoting safety and encouraging civil aeronautics, or between aggressive inspection and monitoring techniques and dramatic enforcement and punishment practices.

The committee envisions that the board would have approximately nine members, appointed for staggered, six-year terms. In searching for such members, the secretary should seek out individuals who are eminent in public affairs, aviation, and related fields, including research management. They should represent, as a group, a balance of interests and be selected solely on the basis of distinguished contributions to their fields of activity.

SELECTION OF THE ADMINISTRATOR AND DEPUTY ADMINISTRATOR

The job of administrator of the FAA is a presidential appointment, subject to change at least with each new administration. In practice, the changes have come even more frequently. In the past 10 years, there have been five different heads of the agency. This pattern of rapid turnover has meant that policies, procedures, and organizational approaches initiated by one administrator have not taken hold before new changes were imposed by another administrator. In organizations involving safety regulation and high technology—the FAA encompasses both—there is a decided value in continuity to provide time for programs and policies to be tested for effectiveness.

Beyond continuity, the administrator and deputy administrator of this kind of agency need to possess high technical, professional, and administrative competence. It is therefore important to have a selection process for these posts that acknowledges the importance of such credentials and provides for possible reappointment even when the presidential administration changes. Provision has been made for continuity and selection procedures in other government agencies whose role involves technology and public welfare.

Accordingly, *the committee recommends that the President select the administrator and deputy administrator from a slate of candidates recommended by the proposed aviation safety policy board or a similar group of experts and that strong consideration be given to reappointment when appropriate*.

INDUSTRY RESPONSIBILITY

In the final analysis, no matter how proficient the FAA, the safety of an aircraft depends on the people who design, produce, operate, and maintain the machine—the aircraft manufacturers and air carriers.

In any endeavor involving human beings, mistakes can and do occur. The only known way to minimize them is through a system of checks and double checks. Thus, design calculations are always reviewed by a second engineer, and mechanics' operations are checked by an inspector. In some cases separate organizations are employed to perform this function: in most businesses an audit staff independently and directly assures management of fiscal propriety; in the nation's space program, after the Apollo fire, a separate team was employed to review all aspects of the program, from bottom to top. We have addressed this need on the part of the FAA by recommending the establishment of two kinds of advisory groups.

There are already many checks and balances present in the aircraft and airline industries' work as well. But some companies lack a separate internal aircraft safety organization, akin to an internal audit staff, to assure their management on a continuing basis that the proper processes and procedures are in place, that personnel are fully trained and qualified, that adequate controls exist, and that the product is indeed as good as it is believed to be.

The committee therefore recommends that each industrial firm involved in the design, production, or maintenance of commercial transport aircraft consider having an internal aircraft safety organization to provide additional assurance of airworthiness to company management.

The committee hesitates to propose any set pattern for such an organization, because organizational structure is a function of the management style of each company; nor does the committee wish to propose mandating the use of a special safety organization, because experience has shown that such a body will be effective only if the company's chief executive wants it and will make use of it.

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Appendices

Appendix A

Presentations at Public Meetings Committee on FAA Airworthiness Certification Procedures January 21-23, 1980 (in order of appearance)

William J. Beckham, Deputy Secretary, Department of Transportation

Langhorne Bond, Administrator, Federal Aviation Administration

M. Craig Beard, Director of Airworthiness, Federal Aviation Administration

Warren A. Stauffer, Director of Engineering, Technical Staff, and

Marty Krupitsky, Airworthiness Engineering Manager, Lockheed-California Company

Richard Taylor, Vice President—Special Assistant to the President, Boeing Commercial Airplane Company

Richard Tabery, Senior Vice President, Maintenance Operations, United Airlines

Cornish F. Hitchcock, Associate Director, Aviation Consumer Action Project

King McCulloch, Chairman, Permanent FAA Committee, International Association of Machinists and Aerospace Workers

Jack Howell, Executive Central Air Safety Chairman, Airline Pilots Association

Delfina Mott, Director of Safety, and

Mya Shelton, Aircraft Technical Committee, Association of Flight Attendants

David Stempler, Chairman, Government Affairs Committee, Airline Passengers Association

Clifton von Kann, Senior Vice President, Operations and Airports, Air Transport Association

Appendix B

Excerpts from Official Accident Reports

This section contains excerpts from official reports of two accidents involving jet transport aircraft that illustrate deficiencies in design, manufacturing, maintenance, or service. They are: Dan-Air Services, Ltd., Boeing 707-321C, G-BEBP near Lusaka, Zambia, May 14, 1977 (Aircraft Accident Report 9/78, Department of Trade, Accidents Investigation Branch, London); and American Airlines, Inc., McDonnell-Douglas DC-10-10, N 110AA, Chicago O'Hare International Airport, Illinois, May 25, 1979 (NTSB AAR-79-17)

Dan-Air Services, Ltd., Boeing 707-321 C, May 14, 1977

The aircraft was engaged on a nonscheduled international cargo flight, on behalf of International Aviation Services for Zambian Airlines, from London Heathrow to Lusaka International Airport, with intermediate stops at Athens and Nairobi, where there was a crew change. The flight from London to Nairobi was without incident and only minor aircraft unserviceabilities were recorded en route.

The aircraft took off from Nairobi for Lusaka at 7:17 a.m. with a fresh crew on board comprising a commander, copilot, two flight engineers (one under training), and a loadmaster. In addition, there was one passenger on board, a ground service engineer whose duty was to supervise ground handling during transit stops.

The flight proceeded normally and apparently without incident at cruise altitude. At 9:07 a.m., the copilot contacted Lusaka Approach on radio and the aircraft was cleared to descend. At 9:23 a.m. the copilot reported that the aircraft was leveling at 11,000 feet, 37 nautical miles from Lusaka. The aircraft was then cleared by Lusaka Approach to a lower altitude following behind another aircraft also bound for Lusaka International Airport.

The copilot reported that the airfield was in sight. Lusaka then cleared the aircraft to descend to an altitude of 6,000 feet (2,221 feet above touchdown elevation). A minute later, the copilot reported that the aircraft was turning downwind with the preceding aircraft in sight ahead. The Lusaka approach controller then gave the aircraft a clearance to make a visual approach to runway 10 and to report leaving 6,000 feet. At 9:32 a.m. the copilot contacted the tower controller and reported that the aircraft was turning on base leg with an aircraft in sight on the runway. The tower controller then cleared the aircraft to land. The copilot replied "Roger"; this was the last transmission received from the aircraft.

A readout of the Cockpit Voice Recorder (CVR) indicated that 50 degree flap was selected at 9:32 a.m. and that the landing checks were completed by 9:33 a.m. Six seconds later, a loud "break-up" noise was recorded. The record terminated five seconds after the fact.

Eyewitnesses on the ground observed that the aircraft had established what appeared to be a normal approach to runway 10 at Lusaka International Airport. They saw a large portion of aircraft structure separate in flight. The aircraft then pitched rapidly nose down and dived vertically into the ground from a height of about 800 feet and caught fire.

The accident was observed from the airfield: the fire and rescue services responded rapidly and were quickly at the scene of the accident. When the fire was under control, it became apparent that the degree of damage to the cockpit structure was such that no one could have survived the impact forces. In fact, all six occupants were killed. There were no casualties to persons on the ground.

The complete right-hand horizontal stabilizer and elevator assembly was found some 200 yards back along the flight path, indicative of having become detached in flight prior to the final nose down pitch maneuver.

Aircraft #G-BEBP was the first aircraft off the 707-300C series convertible passenger/freighter production line. Since manufacture, it had been operated in the passenger-carrying role registered as N765PA. After it was withdrawn from service in March 1976, it was put into storage in Florida. In June 1976, the aircraft was flown to the United Kingdom where it went through a modification and overhaul program at the Dan-Air engineering facility prior to the issue of a U.S. Export Certificate of Airworthiness which was the basis for the issue of a U.K. Certificate of Airworthiness in the Transport category (passenger) on October 14, 1976.

During service on the U.S. register, the aircraft had been maintained in accordance with an FAA-approved schedule and, subsequent to its transfer onto the British register, it had been maintained to a U.K. CAA-approved schedule. The records indicate that the aircraft had not been involved in any incidents which might have affected the aircraft's structure. It has been established that both the horizontal stabilizers on the aircraft at the time of the accident were those fitted at the time of manufacture. Both left and right horizontal stabilizers were removed and reinstalled by Dan-Air to provide access to the stabilizer center section and for minor refurbishment.

Consideration was given to reports that the aircraft pitch trim was unusual in its response on the previous flight. No evidence was found that could be related to these reports, which referred to an unusually sensitive stabilizer trim brake. Such behavior could only be related to the stabilizer structural failure had there been stabilizer torsional deflections large enough to affect significantly the aircraft's flight characteristics. It is considered that such gross torsional deflections would have produced total failure at that time and the reported behavior is not therefore considered relevant to the accident.

Examination of the detached stabilizer revealed evidence of a fatigue failure of the top chord of the rear spar. The rear spar center chord, and lower chord, and the front spar root attachments had failed in overload because the stabilizer had bent downwards. There was evidence of a preexisting fracture of the rear spar upper web between the top chord (adjacent to the fracture), and the center chord, and in certain sections of the closure rib and associated structure.

The aircraft struck the ground with 50-degree tailing edge flap and leading edge flaps fully extended, with the landing gear down. Engine power could not be accurately assessed in the field but the damage to each unit indicated a low to moderate power setting. It was later established that the spoilers were retracted at impact.

The stabilizer trim screw jack and associated cable drum were recovered from adjacent, but separate, areas of wreckage. Both units were found to be set at positions consistent with a stabilizer setting of 6-1/4 units aircraft nose up.

It was not possible to establish rudder and aileron trim settings although the cockpit rudder trim indicator was found at an approximately neutral setting. However, the impact attitude tended to rule out any significant directional or roll trim problems.

All structures which became separated in the air, together with the left horizontal stabilizer, stabilizer center section, stabilizer jack screw and trim drum, and the power level console were transported to the United Kingdom for more detailed investigation.

The detailed investigation of the wreckage was confined primarily to the stabilizer and rear fuselage structure to establish (i) the reason for and age of the fatigue failure and (ii) why the fail-safe structure in the rear spar had failed to carry the flight loads once the top chord had fractured as a result of fatigue.

In order to check the accuracy of existing stabilizer flight-load data, which had been based on wind tunnel tests and on extrapolation of flight data obtained from earlier models of the 707 aircraft, the Boeing company conducted a flight test program on a suitably instrumented 707-300 series aircraft during which horizontal stabilizer flight loads were recorded throughout the normal flight envelope. In general, the load values obtained approximated quite closely the predicted values. The maximum (normal operational) horizontal stabilizer down loads were experienced with the aircraft in the landing configuration with 50 degree wing flap extended and the landing gear down. In the normal landing configuration, the flight tests indicated that the horizontal stabilizer bending moment during a simulation of the Lusaka approach was 75 percent of the value which caused the static test specimen to fail. Analysis shows that application of up elevator could increase this figure to about 120 percent of the test failure load.

It was found that, during a normal landing roll, with spoilers deployed and using reverse thrust, the horizontal stabilizers were subjected to oscillating loads which peaked at a value of 80 percent of the maximum load on a typical flight. These oscillating loads, which were found to be caused by speed-brake deployment, were not accounted for during the initial fatigue analysis and explain the higher than expected crack growth rate on G-BEBP.

Both the U.S. and U.K. regulations contain safe fatigue life or fail-safe design options. The Boeing 707 was designed to comply with the requirements of the fail-safe option. Neither the U.S. nor the British airworthiness regulations specifically required fatigue testing. In both cases, the manufacturer was permitted to demonstrate compliance "by analysis and/or tests." Also, for the safe fatigue life case, it was acceptable that the service history of aircraft of similar design, taking into account differences in operating conditions and procedures, be used as a basis for fatigue life assessment.

A review of the 707 fleet worldwide in June 1977 showed that 521 aircraft were then operating fitted with the 300 series horizontal stabilizer. A survey of post-accident inspections of these aircraft revealed that 38 of these aircraft (i.e., 7 percent of the fleet) were found to have horizontal stabilizer rear spar cracks of varying sizes. Four of these required spar replacement.

The original Boeing 707-300 series stabilizer differed from the 100 series design by having increased span and a redesigned rear spar of three chord construction. The rear spar was redesigned because the fail-safe capability of the original structure with a top chord failure would not have been adequate to cope with the increased loads acting on the larger stabilizer. It was during the initial 300 series design phase that the assessment of fatigue sensitivity and fail-safe capability was made for the purposes of certification.

Fatigue tests on the earlier 100 series stabilizers had produced a crack in the top chord of the rear spar after a period representing some 240,000 flight cycles. The crack was caused by loads which were being fed into the chord by the trailing edge structure at a point where there was a change in chord geometry. There were no indications of problems arising out of loads from the torsion box. The new 300 series spar chords were continuous extrusions with integral terminal fittings and had no abrupt changes in section. It was therefore reasonable to conclude that, because of the similarity of the 100 and 300 series structures in the undamaged state, these spar chords would have an improved fatigue life over the original 100 series chords. The manufacturer appears to have taken this view and considered the rear spar safe in terms of fatigue in a normal service environment. However, the design was certificated on the basis that it was fail-safe, not as a result of fatigue tests.

During the initial flight test program, a lack of stabilizer torsional stiffness became apparent. This shortcoming was cured by stiffening the top and bottom inner torsion box skins which, in the case of the top-skin, was achieved by a change in material from light alloy to stainless steel. This modification was made after the basic stress analysis work had been carried out. Because the stabilizer was certificated on static strength fail-safe capability, restressing was limited to that necessary to ensure that the static strength was not reduced by the modification.

It was known that the greater stiffness of the stainless steel skin would result in higher skin loadings, and hence higher fastener loads in the steel "hi-shear" fasteners toward the root end of the rear spar top chord. These higher fastener loads would also increase the bearing stress in the chord forward flange. However, given the existing chord flange design, there was little that could be done to improve this situation because the use of larger diameter fasteners to reduce the bearing stresses would have reduced the edge margin to an unacceptable level. (Boeing's current 1978 fatigue design practice is to use larger edge margins than were used on the 300 series.) However, it was considered that the design was adequate in this area, given the general acceptance at that time of its fail-safe capability. It was not realized that the skin modification, while improving the static strength, would significantly reduce the fatigue strength. This was the first of a chain of events which culminated in the accident to G-BEBP.

It is considered that the design employed is evidence of a responsible approach on the part of the manufacturer in attempting to cover, with additional margins of safety, the failure case which they considered to be the most critical, or the most likely to occur. However, the apparent lack of attention given to potential top chord failure cases outboard of the terminal fittings strongly suggests that the earlier work on the 100 series design influenced thinking on the 300 series design.

While it might be considered reasonable to view the 707-100 and 300 series horizontal stabilizer structures as being broadly similar, this line of thought is only appropriate when the structures are completely undamaged. Subsequent to a top chord failure, the 300 series stabilizer structure behaves in a fundamentally different manner to that of the 100 series stabilizer.

The failure to appreciate the influence which the top chord and upper web inboard of the fracture have on the local stress distribution was the principal factor in bringing about the final spar failure which resulted in the accident to G-BEBP.

The U.K. Accident Investigation Branch summarized its findings as follows:

- The aircraft had been maintained to an approved maintenance schedule and its documentation was in order.
- The crew were properly licensed and adequately experienced to carry out the flight.
- Pitch control was lost following the in flight separation of the right-hand stabilizer and elevator, which occurred shortly after the extension of 50-degree flap.
- The stabilizer variable incidence screw jack actuator fractured in the stabilizer separation sequence allowing the left-hand stabilizer to travel to the fully nose-up position under aerodynamic loads, thereby increasing the aircraft rate of pitch, nose down.
- The right-hand stabilizer rear spar top chord had failed prior to the accident flight as a result of long-term fatigue damage. The fatigue crack had existed for about 7,200 flights, of which approximately 6,750 flights were made when the aircraft was on the U.S. register.
- Following the failure of the stabilizer rear spar top chord, the structure could not sustain

the flight loads imposed upon it long enough to enable the failure to be detected by the then-existing inspection schedule. It cannot, therefore, be classified as fail-safe.

- Insufficient consideration had been given at the design and certification stages to the stress distribution in the horizontal stabilizer spar structure following a top chord failure in the region outboard of the closure rib.
- The replacement of the horizontal stabilizer light alloy top skin by stainless steel significantly altered the stiffness distribution of the structure, creating the high fastener loadings which led, ultimately, to the fatigue failure in the rear spar top chord in G-BEBP.
- Neither the inspections detailed in the approved maintenance schedule nor those recommended by the manufacturer were adequate to detect partial cracks in the horizontal stabilizer rear spar top chord, but would probably have been adequate for the detection of a completely fractured top chord.
- The inspections required by the Dan-Air U.K. CAA-approved maintenance schedule in respect of the stabilizer rear spar top chord were less specific than those recommended by the manufacturer.
- No fatigue tests were carried out on the 707-300 series horizontal stabilizer structure prior to U.S. or U.K. certification. Neither at the time of certification nor at the time of writing were such repeated load tests required by either U.S. or U.K. legislation for structures declared to be fail-safe.
- A post-accident survey of the 707-300 fleet, worldwide, revealed a total of 38 aircraft with fatigue cracks present in the stabilizer rear spar top chord. Of this number, four stabilizers required chord replacement.
- Post-accident flight tests revealed that deployment of speed brakes during the landing roll produced a horizontal stabilizer load condition spectrum which was significantly different to that used in the original design.

- Cause:

  The accident was caused by a loss of pitch control following the in flight separation of the right-hand horizontal stabilizer and elevator as a result of a combination of metal fatigue and inadequate fail-safe design in the rear spar structure. Shortcomings in design assessment, certification, and inspection procedures were contributory factors.

American Airlines, Inc., McDonnell-Douglas DC-10-10 May 25, 1979

About 3:04 p.m., CDT, May 25, 1979, American Airlines, Inc.'s, Flight 191, a McDonnell-Douglas DC-10-10 aircraft, crashed into an open field just short of a trailer park about 4,600 feet northwest of the departure end of runway 32R at Chicago O'Hare International Airport, Illinois.

Flight 191 was taking off from runway 32R. The weather was clear and the visibility was 15 miles. During the takeoff rotation, the left engine and pylon assembly and about three feet of the leading edge of the left wing separated from the aircraft and fell to the runway. Flight 191 continued to climb to about 325 feet above the ground and then began to roll to the left until the wings were past the vertical position. During the roll, the aircraft's nose pitched down below the horizon.

Flight 191 crashed into the open field and the wreckage scattered into an adjacent trailer park. The aircraft was destroyed in the crash and subsequent fire. All two hundred and seventy-one persons on board were killed; two persons on the ground were killed; and two others were injured. An old aircraft hangar, several automobiles, and a mobile home were destroyed.

The National Transportation Safety Board determined that the probable cause of this accident was the asymmetrical stall and the ensuing roll of the aircraft because of the uncommanded retraction of the left-wing outboard leading edge slats and the loss of stall warning and slat disagreement indication systems resulting from the separation of the No. 1 engine and pylon assembly at a critical point during takeoff. The separation resulted from damage by improper maintenance procedures which led to failure of the pylon structure.

Contributing to the cause of the accident were the vulnerability of the design of the pylon attach points to maintenance damage; the vulnerability of the design of the leading edge slat system to the damage which produced asymmetry; deficiencies in Federal Aviation Administration surveillance and reporting systems which failed to detect and prevent the use of improper maintenance procedures; deficiencies in the practices and communications among the operators, the manufacturer, and the FAA which failed to determine and disseminate the particulars regarding previous maintenance damage incidents; and the intolerance of prescribed operational procedures to this unique emergency.

After the accident, the Federal Aviation Administration required a fleetwide inspection of the DC-10. During these inspections, discrepancies were found in the pylon assemblies. Among these discrepancies were variances in the clearances on the spherical bearing's fore and aft faces; variances in the clearance between the bottom of the aft wing clevis and the fasteners on the upper spar web; interferences between the bottom of the aft clevis and the upper spar web fasteners; pylons with either loose, failed, or missing spar web fasteners; and aft pylon bulkheads with upper flange fractures. The fractured flanges were found only on the DC-10-10 series aircraft.

During post-accident inspections, six DC-10s were found to have fractured upper flanges on the pylon aft bulkheads (four American Airlines DC-10s and two Continental Airlines DC-10s).

The failure modes on the Continental Airlines' aircraft that were examined by metallurgists were similar to those found on the American Airlines' DC-10s. Of the two Continental fractures discovered during the post-accident inspections, one crack was six inches long, and the other three inches long; neither crack showed any evidence of fatigue propagation.

The investigation also disclosed that two other Continental Airlines DC-10S had had fractures on their upper flanges. These two aircraft were damaged on December 19, 1978, and February 22, 1979. The damage was repaired and both aircraft were returned to service. In addition, a United Airlines' DC-10 was discovered to have a cracked upper spar web on its No. 3 pylon and 26 damaged fasteners.

The damaged pylon aft bulkheads of the four other American Airlines' DC-10s were also examined at the Safety Board's metallurgical laboratory. Each of these aft bulkheads contained visible cracks and obvious downward deformations along their upper flanges. The longest crack—about six inches—was the only one in which fatigue had propagated. The fatigue area was about 0.03 inch long at each end of the overstress fracture.

Of the nine DC-10's with fractured flanges, only the accident aircraft had shims installed on the upper surface of the flange.

The National Transportation Safety Board summarized its findings as follows:

1. The engine and pylon assembly separated either at or immediately after liftoff. The flight crew was committed to continue the takeoff.
2. The aft end of the pylon assembly began to separate in the forward flange of the aft bulkhead.
3. The structrual separation of the pylon was caused by a complete failure of the forward flange of the aft bulkhead after its residual strength had been critically reduced by the facture and subsequent service life.
4. The overload fracture and fatigue cracking on the pylon aft bulkhead's upper flange were the only preexisting damage on the bulkhead. The length of the overload fracture and fatigue cracking was about 13 inches. The fracture was caused by an upward movement of the aft end of the pylon which brought the upper flange and its fasteners into contact with the wing clevis.
5. The pylon to wing attach hardware was properly installed at all attachment points.
6. All electrical power to the No. 1 a.c. generator bus and No. 1 d.c. bus was lost after the pylon separated. The captain's flight director instrument, the stall warning system, and the slat disagreement warning light systems were rendered inoperative. Power to these buses was never restored.
7. The No. 1 hydraulic system was lost when the pylon separated. Hydraulic systems No. 2 and No. 3 operated at their full capability throughout the flight. Except for spoiler panels No. 2 and No. 4 on each wing, all flight controls were operating.

8. The hydraulic lines and followup cables of the drive actuator for the left wing's outboard leading edge slat were severed by the separation of the pylon and the left wing's outboard slats retracted during climbout. The retraction of the slats caused an asymmetric stall and subsequent loss of control of the aircraft.
9. The flight crew could not see the wings and engines from the cockpit. Because of the loss of slat disagreement light and the stall warning system, the flight crew would not have received an electronic warning of either the slat asymmetry or the stall. The loss of the warning systems created a situation which afforded the flight crew an inadequate opportunity to recognize and prevent the ensuing stall of the aircraft.
10. The flight crew flew the aircraft in accordance with the prescribed emergency procedure which called for the climbout to be flown at V_2 speed. V_2 speed was 6 KIAS below the stall speed for the left wing. The deceleration to V_2 speed caused the aircraft to stall. The start of the left roll was the only warning the pilot had of the onset of the stall.
11. The pylon was damaged during maintenance performed on the accident aircraft at American Airline's Maintenance Facility at Tulsa, Oklahoma, on March 29 and 30, 1979.
12. The design of the aft bulkhead made the flange vulnerable to damage when the pylon was being separated or attached.
13. American Airlines engineering personnel developed an ECO [Engineering Change Order] to remove and reinstall the pylon and engine as a single unit. The ECO directed that the combined engine and pylon assembly be supported, lowered, and raised by a forklift. American Airlines engineering personnel did not perform an adequate evaluation of either the capability of the forklift to provide the required precision for the task, or the degree of difficulty involved in placing the lift properly, or the consequences of placing the lift improperly. The ECO did not emphasize the precision required to place the forklift properly.
14. The FAA does not approve the carriers' maintenance procedures, and a carrier has the right to change its maintenance procedures without FAA-approval.
15. American Airlines personnel removed the aft bulkhead's bolt and bushing before removing the forward

bulkhead attach fittings. This permitted the forward bulkhead to act as a pivot. Any advertent or inadvertent loss of forklift support to the engine and pylon assembly would produce an upward movement at the aft bulkhead's upper flange and bring it into contact with the wing clevis.

16. American Airlines maintenance personnel did not report formally to their maintenance engineering staff either their deviation from the removal sequence contained in the ECO or the difficulties they had encountered in accomplishing the ECO's procedures.
17. American Airline's engineering personnel did not perform a thorough evaluation of all aspects of the maintenance procedures before they formulated the ECO. The engineering and supervisory personnel did not monitor the performance of the ECO to insure either that it was being accomplished properly or if their maintenance personnel were encountering unforeseen difficulties in performing the assigned tasks.
18. The nine situations in which damage was sustained and cracks were found on the upper flange were limited to those operations wherein the engine and pylon assembly was supported by a forklift.
19. On December 19, 1978, and February 22, 1979, Continental Airlines maintenance personnel damaged aft bulkhead upper flanges in a manner similar to the damage noted on the accident aircraft. The carrier classified the cause of the damage as maintenance error. Neither the air carrier nor the manufacturer interpreted the regulation to require that it further investigate or report the damages to the FAA.
20. The original certification's fatigue-damage assessment was in conformance with the existing requirements.
21. The design of the stall warning system lacked sufficient redundancy; there was only one stickshaker motor; and further, the design of the system did not provide for crossover information to the left and right stall warning computers from the applicable leding edge slat sensors on the opposite side of the aircraft.
22. The design of the leading edge slat system did not include positive mechanical locking devices to prevent movement of the slats by external loads following a failure of the primary controls. Certification was based upon acceptable flight characteristics with an asymmetrical leading edge slat condition.

23. At the time of the DC-10 certification, the structural separation of an engine pylon was not considered. Thus, multiple failures of other systems resulting from this single event was not considered.

Appendix C

Fatal Accidents Attributed Primarily to Airframe, Powerplant and Systems Failure on Jet Transport Aircraft

U.S. Scheduled Air Carriers, 1961-1979

Date	Location	Carrier	Number of Fatalities/ Total on Board	Type of Failure
7/11/61	Denver, CO	United DC-8	18/122	Hydraulic system degradation
3/1/62	Jamaica, NY	American B-707	95/95	Rudder control system malfunction
2/12/63	Miami, FL	Northwest B-720B	43/43	Turbulence, airframe failure in flight
12/8/63	Elkton, MD	Pan Am B-707	91/91	Lightning strike, fuel explosion in flight
2/25/64	New Orleans, LA	Eastern DC-8	68/68	Flight control system failure
11/23/64	Rome, Italy	TWA B-707	48/73	Reverse thrust warning light malfunction caused abort of takeoff, swerved, and struck runway repair vehicle
8/6/66	Falls City, NB	Braniff BAC 1-11	42/42	Turbulence, airframe failure in flight
6/23/67	Blossburg, PA	Mohawk BAC 1-11	34/34	Engine air bleed value malfunction caused fire in tail section, damaged flight control system
1/18/69	Los Angeles, CA	United B-727	38/38	Loss of electrical system to attitude instruments
1/26/69	Pomona, NJ	TWA B-707	5/5	Hydraulic pressure loss uncorrected by pilot
3/31/71	Ontario, CA	Western B-720	5/5	Rudder support material failure
12/29/72	Miami, FL	East L-1011	99/176	Landing gear warning light malfunction
11/3/73	Albuquerque, NM	National DC-10	1/128	Engine fan disintegration, damage to window
4/4/77	New Hope, GA	Southern DC-9	62/85	Turbulence/rain caused powerplant malfunction and subsequent forced no-power landing/crash
3/1/78	Los Angeles, CA	Continental DC-10	2/200	Tire failure caused landing gear failure and fuel spillage
5/25/79	Chicago, IL	American DC-10	271/271	Failure of engine pylon

Glossary

Accelerate-Stop Distance: The minimum allowable runway lengths for an airplane to accelerate and stop safely, depending on its gross weight, speed, prevailing weather, and runway conditions. If an emergency occurs after the accelerate-stop distance has been exceeded, usually the takeoff must be completed.

Accident (as opposed to incident, q.v.): An accident is an occurrence in which there is substantial damage to an aircraft and/or injury or death to a person or persons.

Advance Notice of Proposed Rule Making (ANPRM): A public notice announcing the intention of the FAA to establish a regulation or amendment on a particular subject, inviting comments on the adequacy of the data base. (See NPRM.)

Airframe: The major and essential parts of an aircraft structure.

Airframe and Powerplant License (A&P): A license granted to an individual who is at least 18 years of age and has demonstrated a command of the English language and competence through examination in specific maintenance tasks specified in Federal Aviation Regulations, Part 34.

Airmen: People such as mechanics, pilots, and parachute riggers, who work or operate aircraft or ancillary equipment. They are licensed by the FAA and are the subject of Part 65 and Part 91 of the FARs.

Airworthiness: The safety and physical integrity of an aircraft, including its component parts and subsystems, its performance capabilities, and its flight handling characteristics, when operated within its intended environment and within its quantified and declared limitations.

Airworthiness Certificate (AWC): A certificate, granted by the FAA, stating that an aircraft meets all specifications required by the Type Certificate, and has been flown and found to be in compliance with applicable airworthiness standards. When an airplane is transferred to a second or subsequent person, the AWC is transferred along with it to the new owner who is required to maintain the aircraft in a state of continuing airworthiness.

Airworthiness Directive (AD): An FAA regulation, usually issued in response to a safety situation, requiring mandatory action, e.g., inspection, repair, or modification within a specified period of time, depending on the urgency.

Telegraphic AD: An AD issued for immediate action, without public participation.

Immediate AD: An AD issued for prompt action, without public participation.

Alert Service Bulletin: A special Service Bulletin (q.v.) issued to all owners of a given aircraft by the manufacturer of that aircraft, containing safety directive information.

Applicant: As used in the text, a manufacturer, airline, or repair station that applies to the FAA for the appropriate certificate.

Avionics: That specialized branch of electronics pertaining to aircraft-installed electronic devices, primarily used for navigation and flight control functions.

Certificate (v.t.): As used in the text, the act of granting a certificate (q.v.) to an applicant (q.v.) signifying approval of aircraft design, production, or maintenance plans and procedures.

Certificate (n.): As used in the text, a document issued by the FAA to an applicant (q.v.), which serves as evidence that the applicant has complied with applicable statutes, rules, standards and procedures in design, manufacturing, maintenance, or operation of aircraft.

Certificate Holder: A manufacturer, operating airline, or maintenance or overhaul facility which has been examined by the FAA and found to meet the standards established by the Federal Aviation Regulations.

Certification Basis: A negotiated agreement between the Type Certification Board and the manufacturer on how compliance with various standards will be demonstrated.

Composite Materials: Structural materials, generally nonorganic and nonmetallic, that have high strength and low weight.

Continuing Airworthiness: The assurance that an aircraft with an airworthiness certificate is operated, maintained, and repaired in accordance with FAA-approved procedures.

Continuous Gust Criteria: An engineering basis for designing aircraft structure and flight control systems to sustain safely a broad spectrum of flight loads imposed by atmospheric gusts of various frequencies and intensities.

Crashworthiness: A term that has come to signify the ability of the aircraft structure to tolerate given crash loads and to provide occupant protection.

Design Basis: A negotiated agreement between the manufacturer and the FAA Type Certification Board on the specifications that the design of the aircraft must meet. (See Certification Basis.)

Designated Alteration Station (DAS): An FAA-approved facility that specializes in major overhaul and repair of aircraft.

Designated Engineering Representative (DER): Employees of the manufacturers, deputized by the FAA to review and verify certain elements of the design.

Designated Manufacturing Inspection Representative (DMIR): A company employee to whom the administrator delegates the functional determination of conformity of prototype articles to design data prior to type certification, and the final inspection and airworthiness certification or approval of type certificated aircraft and related products. The DMIRs are trained and supervised in their FAA duties by the responsible FAA Manufacturing Inspectors.

Exception: A waiver granted to permit noncompliance with a specific FAR requirement, negotiated as an agreement with the FAA.

Extremely Remote, Extremely Improbable: Terms applied to a measure of system reliability, equivalent to a 10^{-9} or one chance in a billion of failure.

Fail-safe: A design philosophy that assumes components of a system have a limited lifetime, and that provides safety assurance through alternative components which can function in the event of failure of the primary component.

Fatigue: The tendency of a material to break under repeated load.

Fatigue Crack: A crack appearing in a metallic element of an aircraft structure as a result of repeated loads caused by flight and ground forces and vibrations.

Federal Aviation Regulations (FARs): As used in the text, that part of the U.S. Code of Federal Regulations that includes the rules, regulations, and standards by which the FAA assures the safety and airworthiness of aircraft and their operations.

Fuselage: The long, main tubular body of an aircraft to which is attached the wing structure.

Hard Landing: A landing of an aircraft in which the vertical component of the speed at which ground contact is made is higher than the maximum normal operating value specified in the design. A hard landing must be followed by an inspection of the landing gear and support structure for possible damage before the aircraft is permitted to fly again.

Hole-size Criteria: An engineering basis for designing the pressurized fuselage of an aircraft to sustain a damage-caused hole of a specified size and continue to fly.

Horizontal Stabilizer: One of the primary elements of the tail assembly of an aircraft; the fixed horizontal airfoil that provides stability in flight.

Incident (as opposed to accident, q.v.): An event involving a malfunction of equipment or human error in which no significant damage or injuries occurred, but which, under other circumstances, could have been an accident, and which has significance to safety.

Inherent Airworthiness: The assurance that both the design of the aircraft and the manufacture and assembly of individual aeronautical products are in accordance with FAA-approved procedures. Approval of the design basis and of the manufacturing and quality control systems under which the product will be manufactured and inspected are thus preconditions to establishment of inherent airworthiness. (See Continuing Airworthiness.)

Inspect: As used in the text, the process by which company employees examine parts, equipment, processes, and procedures for conformity to applicable standards, certifying that the standards are met; or FAA inspectors assure that company maintenance and production systems are properly in place to assure compliance with applicable standards.

Maintenance Program: A set of procedures that assures continuing airworthiness and approval by the FAA. It is developed from the manufacturer's Maintenance Manual to suit the individual air carrier's particular system, facilities, and needs.

Maintenance Review Board (MRB): A Board of FAA regional specialists, convened to review the maintenance manual for a particular aircraft that has been developed by a maintenance manual steering group. This maintenance manual then becomes the basis for an air carrier's individually developed maintenance program.

Maintenance Steering Group (MSG): A committee of industry experts, convened to develop a maintenance manual for a given aircraft type, in order to assure the continuing airworthiness of each aircraft. The maintenance manual is proposed to the FAA MRB and, upon approval, forms the basis for the air carrier maintenance program for that type of aircraft.

Manufacturer's Maintenance Manual: See Maintenance Review Board and Maintenance Steering Group.

Mechanical Interruption Summaries (MIS): A summary report required of the air carrier by the FAA concerning interruptions to a flight for mechanical reasons or the number of engines removed prematurely because of malfunction, failure, or defect.

Mechanical Reliability Report (MRR): A report required of an airline for submission to the FAA of the occurrence or detection of each failure, malfunction, or defect concerning 16 specific items—including fires and fire-warning systems malfunctions; engine exhaust system-caused damage; aircraft component causing accumulation or circulation of smoke, vapor, or noxious fumes in the occupied part of the aircraft; engine shutdown; failure of propeller control; malfunctioning fuel dump system; inadvertent landing gear system operations; brake system component malfunction; aircraft structural damage requiring major repair; cracks, permanent deformation or corrosion of aircraft structures, malfunction of aircraft components or systems that results in taking emergency action.

National Aviation System (NAS): The system of airports, airways, and air traffic control, within which aircraft and airmen operate.

Notice of Proposed Rule Making (NPRM): An announcement in the Federal Register of intention to establish a rule or amendment to an existing rule, providing a description of the intended action, and arguments therefor and inviting public comment prior to final adoption.

Operator: As used in the text, an air carrier or operator of a transport aircraft.

Primary Structure: The part of the aircraft structure that carries and transmits all loads.

Principal Avionics Inspector (PAI): An FAA employee who provides continuing surveillance of an air carrier's avionics maintenance program and who works at the regional or district office level.

Principal Inspector (PI): An FAA employee, resident at the manufacturer's site, who monitors the quality control system, conducts inspections, and supervises the Designated Manufacturing Inspection Representative (q.v.).

Principal Maintenance Inspector (PMI): An FAA employee who provides continuing surveillance of an air carrier's maintenance program and who works at the regional or district office level.

Production Certificate: An approval of a manufacturer's facility granted by the FAA Production Certification Board, and an authorization for that manufacturer to proceed with the manufacture of aircraft which are faithful copies of the type certification specification.

Production Certification Board (PCB): A regional-level board of FAA specialists convened to examine a manufacturer's capability to produce aircraft as specified in the Type Certificate and to grant authority in the form of a Production Certificate.

Pylon: As used in the text, the main support structure attaching an engine to an airframe.

Quality Assurance System Analysis and Review (QASAR): A periodic review by a team of FAA specialists which consists of in-depth audits of companies' production, quality control, and inspection processes. Originally scheduled at 18-month intervals, QASAR intervals are now about three years.

Regional Office: An office of the FAA, located within one of 10 federal geographical regions of the United States, and two overseas areas (Pacific and Far East; Europe, Africa, and Middle East), through which the policies, practices, and regulatory oversight of the FAA are carried out.

Regulatory Basis: A determination, by the Type Certification Board, of which regulations will apply to a proposed aircraft design. (See Design Basis.)

Retrofit: As used in the text, the practice of installing a substitute component in an existing system for purposes of design change, or fault correction.

Rule making: One of the two main procedures (along with certification) by which the FAA assures inherent safety or airworthiness of aircraft. Rule making is a public, due process, establishing the baseline standards by which aircraft are designed, built, operated, and maintained.

Safe-life: A design philosophy that treats a structural component or assembly as designed to retain its strength and integrity throughout its useful life.

Service Bulletin: A bulletin issued by a manufacturer containing nonmandatory information and recommendations regarding product improvement and equipment reliability. (See Alert Service Bulletin.)

Service Difficulty Report (SDR): A report compiled by the Air Carrier District Office every 24 hours on the basis of the MRRs (q.v.) submitted by the air carriers. SDRs are sent to the Maintenance Analysis Center for computation, analysis, and dissemination.

Situation Monitoring Program: A program of audit-like inspections, conducted in limited cases, of maintenance programs, especially where the regional office becomes aware of specific safety problems.

Special Conditions: Special rules, applied in arriving at a design basis for the Type Certificate, that define compliance requirements not covered under the existing FARs.

Systemworthiness Analysis Program (SWAP): A program involving an FAA team of experts that inspects air carrier and general aviation maintenance programs and practices. Discontinued and replaced by Situation Monitoring Program (q.v.).

Type Certification: The process of issuing a Type Certificate to an aircraft design.

Type Certification Board (TCB): A board of FAA technical experts at the regional level that examines the manufacturer's proposal, negotiates the design basis, supervises the design evolution, and grants a Type Certificate upon satisfaction that the proposed design meets the FAA-approved specification.

Type Inspection Authorization (TIA): An authorization granted by the TCB, for FAA flight test crews to examine the aircraft in flight prior to issuing the Type Certificate.

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