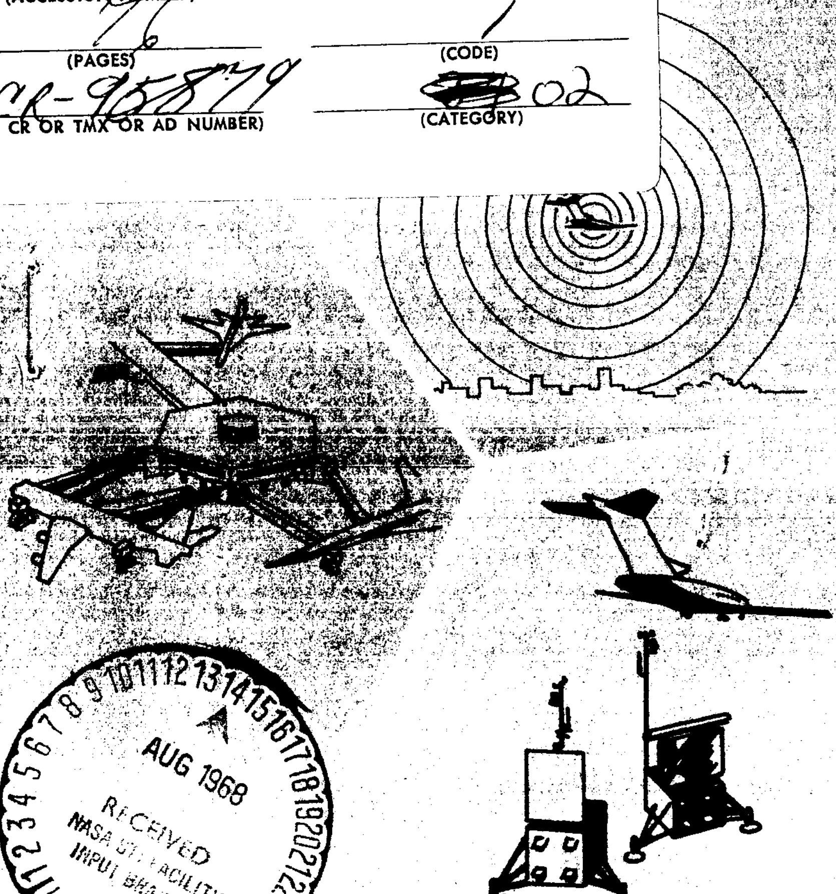
Civil Aviation Research and Development

An Assessment of Federal Government Involvement



AERONAUTICS AND SPACE ENGINEERING BOARD
NATIONAL ACADEMY OF ENGINEERING

CIVIL AVIATION RESEARCH AND DEVELOPMENT

An Assessment of Federal Government Involvement

SUMMARY REPORT
AERONAUTICS AND SPACE ENGINEERING BOARD
NATIONAL ACADEMY OF ENGINEERING
Washington, D. C.
August 1968

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Introduction

The National Academy of Engineering established the Aeronautics and Space Engineering Board (ASEB) in May 1967 to advise the National Aeronautics and Space Administration and other agencies of government. In consultation with officials of NASA, the Department of Transportation, the Federal Aviation Administration, the President's Science Adviser, certain interested committees of Congress, and the National Aeronautics and Space Council, as well as other government and private groups, the Board selected as its first topic of study "An Assessment of Federal Government Involvement in Civil Aviation Research and Development." This report summarizes the results of the study.

The Board has concluded that in a favorable economic climate civil aviation can continue to flourish; in fact it can accelerate its beneficial growth if a carefully conceived program of planning and research and development aimed specifically at the civil air transport system is carried out.

After considering the multiplicity of factors affecting the growth of civil aviation, the Board concluded that the three most critical factors are (1) airport and support facilities, (2) noise, and (3) air traffic control. These are highlighted in Section I entitled "Principal Factors Affecting the Future Growth of Civil Aviation."

The most important recommendation of the Board pertains to knitting together more tightly the civil aviation research and development activities of the Department of Transportation, its major operating unit, the Federal Aviation Administration, and the National Aeronautics and Space Administration, and especially to dividing their responsibilities according to capability. The DOT should provide the leadership in conducting systems studies to identify, analyze, and rank civil aviation goals as well as the research and development needed to attain these goals; NASA should be responsible for research and development in all the areas of importance to civil aeronautics; the FAA should, in addition to operating the airways network, be responsible for the systems testing of the resulting operational concepts and hardware.

The Board has also made many detailed technical recommendations concerning research and development needs in Section II. These pertain to most of the important facets of civil aviation–including systems, flight vehicles, aircraft operations, air traffic control, airports, and noise. Although many technical recommendations are made, no priority ordering is attempted beyond the conclusion that the three most critical areas are airport and support facilities, noise, and air traffic control. A recommended first step beyond this study is to examine the priorities to be assigned to each research and development objective in terms of its relative contribution to the effectiveness of the civil air transportation system.

The Board membership is listed in Appendix I. It wants to express appreciation and indebtedness to a large number of individuals beyond its membership with whom it conferred. These are also listed in Appendix I. The Board is indebted to the American Institute of Aeronautics and Astronautics, the American Society of Civil Engineers, the American Society of Mechanical Engineers, the Institute of Electrical and Electronic Engineers, and the Society of Automotive Engineers for conducting special studies, making available special reports, and identifying members for participation in an advisory capacity. The cooperation of these societies served to broaden the advisory base.

The Board assigned detailed work to six ad hoc committees, each of which had supervisors appointed from the Board membership, as follows:

1. Flight Vehicles and Airbreathing Propulsion
   (Mr. Edward Wells, Mr. Perry Pratt)

2. Aircraft Operations
   (Mr. Willis Hawkins)

3. Air Traffic Control
   (Dr. Allen Puckett, Dr. George Solomon, Dr. Bernard Oliver)

4. Airport and Support Facilities
   (Mr. John Kyle, Jr.)

5. Economics of Civil Aviation
(Mr. Carlos Wood)

6. Noise
(Dr. Leo Beranek)

The membership of each committee was made up of knowledgeable men from different parts of the aviation community, whose valuable contributions are sincerely appreciated by the Board. The membership of these committees is listed in Appendix I.

One Board member, Dr. Raymond L. Bisplinghoff, chaired a drafting committee composed of the ASEB supervisors, which, together with the secretariat staff, Robert J. Burger and John R. Fowler, was responsible for preparing this report. Secretarial assistance was provided by Mrs. Violet McCarthy and Mrs. Michelle Struve.

I. Principal Factors Affecting the Future Growth of Civil Aviation

It became increasingly clear during the course of the Board's study that future flight vehicles for civil air transportation will be influenced not only by the advancements made possible by aeronautical technology but also by the extent to which they are assimilated by and compatible with the total transportation system and the population it serves. In the past, aviation research and development has been concerned primarily with improving the flight vehicle. But the flight vehicle is only one segment of the total air transportation system. In setting research and development objectives it is necessary to seek goals that improve the productivity of the total system - not just the flight vehicle. This implies that civil aviation research and development should be directed toward the most critical problems of the total system.

The growth rate of civil aviation will be the result of an equilibration of those forces that will tend to drive it to higher levels (such as increasing public demand for transportation facilities and a favorable economic climate) and those forces that will tend to impede its growth (such as technical limitations or social restrictions). A question frequently asked is whether the historic upward trend in the growth of civil aviation can be expected to continue through another decade in spite of these potential restrictions. The Board strongly believes that in a favorable economic climate this upward trend can be maintained and even accelerated if a carefully conceived program of planning, research, and development aimed specifically at the civil air transportation system is initiated.

Transportation is one of the major elements in any society. The history of civilization and the history of transportation have always been closely intertwined, since transportation assists in social developments, and society in turn demands better transportation. Starting within the last half century and accelerating greatly within the last 25 years, air transportation of all types has become a major element in world affairs as an expression of national policy, corporate business policy, and individual personal policy.

While civil aviation is only a part of the transportation system, it is by far the most dynamic. Civil aviation provides some 1.2 percent of the total dollar contribution to the United States gross national product. However, the impact of civil aviation on the United States economy and on its people is far greater than its share of the gross national product would indicate. From 1939 to 1966, the air-carrier share of consumer outlay in dollars for domestic intercity travel increased from about 6 percent to about 72 percent, with the combined share for bus, rail, and other commercial carriers accounting for the remainder. If one accepts the FAA projections of civil aviation growth, the air share of the domestic commercial travel market in terms of passenger miles will have increased from about 10 percent to nearly 80 percent in the 30 years from 1947 to 1977.

The FAA assumed in making this forecast that the major factors behind growth rates achieved in fiscal years 1964, 1965, and 1966 will, over the next ten years, continue to exert a positive influence on traffic volume. These factors are, for example, increasing gross national product, high disposable income, virtually full employment, improved service, and decreasing average fares. The forecast for growth of commercial air travel takes into account not only the increasing number of people flying, but the increasing frequency these people travel on the average. The percentage of people in the United States who had used air travel at least once in their life rose from 30 percent to 45 percent between 1961 and 1966. Each air traveler had flown an average of 1.07 times a year in 1961 and 1.28 times a year in 1966. By 1975 it is expected that with a continuing healthy economic climate, these figures will be 66 percent and 1.44 times a year, respectively. Figure 1 shows the past trends and estimates for the future use of the various modes of commercial transportation.

The short-haul portion (less than 500 miles) of commercial aviation already accounts for more than 50 percent of the total number of passengers traveling by air. The air travel market has great potential within this range of travel distances. Corporate and private aviation are already filling a service gap created because scheduled airlines serve only 523 points, although there are some 10,000 airports in

ESTIMATED PROJECTION OF DOMESTIC
INTERCITY TRAVEL BY PUBLIC CARRIER

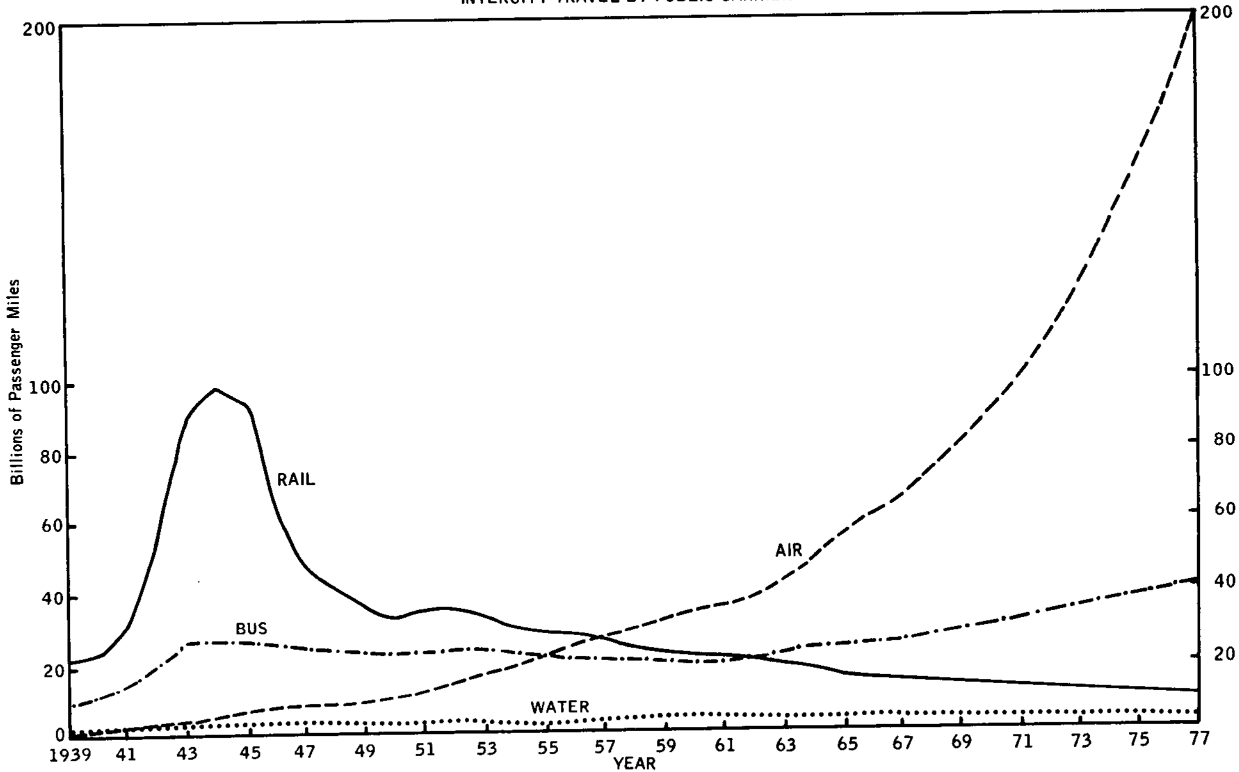

Figure 1

Source:

Air - Transportation Association of America (TAA) to 1967. FAA estimate, 1968 to 1977.

Bus - TAA to 1967. National Association of Bus Owners, 1968 to 1977.

Train - TAA to 1967. (Estimated for 1967 through 1977 based on trend established during 1962-1967. Assumes no changes in present legislation.)

Water - TAA to 1967. (1967 to 1977, projection of the 1967 level) the United States. The general aviation fleet is projected to grow from about 104,000 aircraft in 1967 to 180,000 aircraft by 1977. Air cargo is expected to expand by a factor of five over the next ten years.

United States civil aviation is a strong competitor in world markets. The commercial aircraft industry during the last five years has been exporting from 35 percent to 40 percent of its total annual production. United States industry during that same period exported only about 4 percent of its total production. Commercial aircraft exports increased from around \$400 million in 1963 to over \$1 billion in 1967, and the Aerospace Industries Association has predicted that by 1970 the comparable export figure will approach \$1.5 billion. Corresponding United States export figures are \$23.06 billion, \$31.15 billion, and an estimated \$35 billion. Thus, not only does the commercial aircraft industry export a far greater percentage of its total production than does United States industry as a whole, but its share of the total export market is increasing.

The Board is convinced that the pressures tending to drive the demand for civil air transportation toward a larger share of the total transportation system are real and will continue. It remains, then, to identify and solve those critical problems that might otherwise limit this potential.

Although the later sections of this report point up in some detail the major research and development areas that will affect the growth of civil aviation, the members of the Board believe that three of these areas are of such critical importance that they should receive special attention. These are listed in order of importance:

1. Airport and Support Facilities
2. Noise
3. Air Traffic Control

Any of these can exert strong inhibiting influences on the growth of civil air transportation unless satisfactory solutions can be found to problems that are now developing.

The Board also recognizes that these three areas are closely coupled in that they all relate to the ability of our air transportation system to accept and dispatch aircraft at key terminal points with safety and efficiency as well as with acceptance by the surrounding community. This interrelationship serves to emphasize the viewpoint of the Board that an essential requirement for the future will be to identify and rank research and development goals through systems studies of the total civil air transportation system.

Airport and Support Facilities

A little over a decade ago, the nation's growth outstripped the capability of its highway system to support its vehicle transportation requirements. As a result, the Interstate Highway System was initiated.

Today, the nation's airports are in similar need of attention, and unless comprehensive action is taken, the growth of civil air transportation will be severely curtailed. Many airports are experiencing peak-hour saturation; terminal facilities have become strained; and airport access to the community is becoming increasingly difficult.

At least two major obstacles hinder the required development of an adequate national airport system: financing and planning. The question of methods for acquiring and allocating funds for airport development is obviously outside the scope of this study. The Board is convinced, however, that before any effective action can be taken to solve the airport problem, it is essential to have sound and complete plans at both the national and regional levels that will assess capabilities, estimate demands, and identify steps necessary to meet requirements.

Although relatively modest research and development efforts have been directed toward airports in the past, the Board believes that substantial returns can accrue from research and development funds spent in this area. For example, to achieve maximum use of individual airports and airport systems, additional studies are needed which take account simultaneously of aircraft spacing in approach and departure patterns, lateral separation of runways, various aircraft categories, physical characteristics of runway approach and departure zones, and associated electronic equipment. A large potential exists for improvement of the nation's aviation system by focusing on the runway itself in a wide variety of areas from surface texture to improved lighting systems. The continuous maintenance of airport design and operation standards is essential to ensure that airport layout and passenger and cargo handling procedures keep pace with the expanding demands of air travel. This updating bears a direct relationship to the state of the art in the aeronautical sciences. For example, the progressive nature of flight vehicle development in the VTOL and STOL configurations requires a compatible development of ground facility standards and specifications.

Noise

The growth of civil aviation brought about by the introduction of jet aircraft has been accompanied by a worldwide concern for the noise they produce. Table 1 illustrates the way in which these noise levels were raised with the successive introduction of new generations of transport aircraft.

Table 1

Comparison of Maximum Perceived Noise Levels Measured During Takeoff and Approach For Various Transport Aircraft

Aircraft	Year[a]	Typical Maximum Gross Weight, pounds	Noise Levels, PNdB	
			Takeoff[b]	Approach[c]
Douglas DC-3	1936	27,000	98	96
Douglas DC-6B	1951	100,000	106	105
Boeing 707-120	1959	250,000	129	117 (50° flaps)
Boeing 707-320B	1963	330,000	130	121 (40° flaps)

a. Year of introduction into widespread airline service.
b. As measured under the flight path at 15,000 ft from start of takeoff roll with the aircraft at maximum gross weight and with no power cutback for noise abatement purposes. Sea level and standard day conditions are assumed to exist. A power cutback to a 3-deg climb angle for the Boeing 707-120 results in a 6-PNdB (perceived noise decibels) reduction and for the Boeing 707-320B in a 1-PNdB reduction.
c. As measured under a 3-deg glide-angle approach path, 1 mile from touchdown with normal approach flight conditions.

It is likely that the introduction of some of the new generations of transport aircraft might produce even higher noise levels in neighborhoods under flight paths or to the sides of runways. These noise levels most certainly will be accompanied by increasing frequencies of operation, which will result in longer duration of high noise levels in neighborhoods adjacent to airports.

The noise problems associated with civil aviation are receiving increasing attention from airframe and engine manufacturers, airport operators, government agencies, and the public. The complex relationships developed between the air transport industry and the communities surrounding airports as a result of aircraft noise will become a major obstacle to the growth of aviation if noise exposure and its effects on operations cannot be resolved.

It is clear that any solution to the noise problem must include the development of quieter aircraft; the establishment of federal noise criteria and of noise standards for aircraft; the development of consistent land-use practices in areas surrounding airports; and the development of low- and moderate-cost building air-conditioning and soundproofing techniques to reduce noise inside houses already in such areas. These problems are evidenced by the difficult situations now existing at many major commercial jet airports, and they could become even more pronounced around V/STOL terminals and under V/STOL flight corridors unless new solutions are found.

In addition to engine noise, the advent of supersonic commercial air transportation will increase noise problems caused by sonic booms. At the present time, prospects are not readily apparent for significant reductions in the intensities of sonic booms. The possibility that research and development may produce unconventional supersonic aircraft configurations having significantly reduced sonic-boom signatures cannot be disallowed, but the future must be viewed in terms of small reductions obtained through better understanding of theory, design refinements of aircraft, and improvements in propulsive efficiency and operating procedures.

The Board considers that several basic issues need to be resolved in approaching a solution to the noise problem:

1. Adequate noise exposure criteria in the form of Noise and Number Index (NNI, British), Composite Noise Rating (CNR) replaced by Noise Exposure Forecast (NEF, U.S.), and $\overline{Q}$ (German) have been available for several years to indicate the general level to which aircraft noise needs to be reduced to be acceptable to airport neighbors. Noise exposures in areas near international hub airports are so far above these criteria that it is obvious that all means of alleviating the noise problem should be employed. The absence of adequate government-established noise criteria for aircraft certification and operation and of government regulation of land uses has produced confusion in the air transport industry. Thus, insufficient political and economic incentives have been offered to manufacturers and operators of aircraft and to airport managers to use existing technology and to develop new technology and operating

procedures for achieving lower aircraft noise exposures and developing proper land use in the vicinities of airports.

2. Although substantial empirical knowledge and some scientific theories exist concerning the sources of aircraft noise and the technology for its partial control, the scientific basis for understanding the remaining primary noise-generating mechanisms is inadequate. Research now underway in this country generally is not aimed at the fundamental physical problems of jet noise generation and propagation, but instead is conducted primarily at the engineering level and consists largely of trial-and-error attempts to reduce noise. There is almost a total absence of basic research in physical acoustics that would further our understanding of jet noise, and there is a serious shortage of qualified research scientists to undertake such research programs.

3. The lack of an overall analysis of the civil air transportation system up to the present time has prevented a proper allocation of the responsibilities required to achieve lower noise exposures. In this regard, the Board noted a current industry-sponsored study of the system composed of aircraft, airlines, airports, and airport communities, which is aimed at determining the relationship between aircraft noise exposure, cost, and other factors involved in the aircraft noise problem. This type of study is a necessary first step to help resolve the problems now existent and about to be incurred with future commercial fixed-wing jet aircraft. However, the Board feels that there is an urgent need for a government-supported analysis of the total air transportation system, including the social and economic aspects, <u>before</u> these new types of aircraft as well as V/STOL aircraft begin extensive operations over major metropolitan areas.

4. Suitable low- and medium-cost air-conditioning equipment and building materials and techniques do not exist for controlling noise inside houses located in neighborhoods with high levels of aircraft noise exposure. Research and development programs are necessary to evolve products and to develop guides for architects and building contractors.

5. Current research on human reaction to aircraft noise should be continued and extended. With increased air traffic and introduction of new kinds of aircraft noise, it is of the greatest importance to have more accurate information about human response to different characteristics of

noise and to a total environment in which noise may be an important negative element.

Air Traffic Control

The air transportation growth recorded in the last four years, coupled with forecasts for future growth, indicates that air traffic will be increasing at a greater rate than the present or programmed traffic control system can handle. An increasing number of terminal areas are already experiencing unusually long delays in receiving and dispatching aircraft.

Federal Aviation Administration forecasts through 1977 show that the demands placed on the national airspace system by air carrier and general aviation are expected to increase sharply and that military flying will continue to decline. Total aircraft operations at airports with FAA traffic control service will rise from 41.2 million operations in fiscal year 1966 to an estimated 139.0 million operations in fiscal year 1977, an increase of approximately 337 percent.

Instrument operations at airports with FAA traffic control service, including those at FAA-operated military radar control facilities, totaled 11.0 million in fiscal year 1966, up from 7.4 million in fiscal year 1962, as shown in Table 2. The forecast calls for 26.0 million instrument operations by fiscal year 1977, more than double the 1966 level. During the forecast period, an increasing proportion of air carrier and general aviation operations will be flown under instrument flight rules (IFR).

The number of IFR aircraft handled, which is used to measure en route IFR activity and workload at FAA air route traffic control centers, is predicted to increase from 13.5 million in fiscal year 1966 to 30.3 million in fiscal year 1977. The projected expansion in air carrier traffic and the increasing tendency of the air carriers to fly IFR provide the basis for further strong growth, and air carrier aircraft handled have been predicted to increase from 7.4 million in fiscal year 1966 to 17.8 million in fiscal year 1977.

Historically, general aviation has accounted for a relatively small but rising proportion of en route IFR traffic. In fiscal year 1966 general aviation aircraft handled rose

Table 2

Instrument Operations at Airports
with FAA Traffic Control Service

Fiscal Year	Instrument Operations in Millions
1962	7.4
1963	7.8
1964	8.7
1965	9.6
1966	11.0
1967*	12.0
1968*	13.5
1969*	14.8
1970*	16.1
1971*	17.5
1972*	18.9
1973*	20.3
1977*	26.0

*Forecast.

Note: An instrument operation is defined as the handling by an FAA terminal traffic control facility on the arrival or departure at an airport of an aircraft on an IFR flight plan or the provision of IFR separation to other aircraft by an FAA terminal traffic control facility. Includes instrument operations at FAA-operated military radar approach control facilities.

to 1.7 million, representing 13 percent of the total, up 35 percent from fiscal year 1965 and approximately double the fiscal year 1962 volume. The continuing growth and upgrading of the general aviation fleet, particularly as turbine-powered and other more fully instrumented aircraft enter into service, should result in a further rise in IFR flying by general aviation. The forecast is for approximately 9.0 million general aviation IFR aircraft handled by fiscal year 1977, a more than fivefold increase over 1966.

Increased air traffic volume with a greater proportion of larger high-performance aircraft will clearly require new approaches to air traffic control in the future. The forecasts indicate that deficiencies now evident in the nation's air traffic control system will become progressively worse unless strong measures are taken to correct the imbalance of volume of traffic and capability. The Board believes that there are areas where a more vigorous effort to apply existing technology can pay large dividends. At the same time, there are other areas where renewed emphasis on initiating research and development is clearly needed.

The underlying element of safety is implicit in all considerations of the future growth of civil air transportation. It is obvious that a continuing high level of passenger safety must be maintained. Even maintaining present safety levels may not be acceptable as larger aircraft are introduced. An unassailable public image of safety must be maintained to avoid any inhibition to growth.

Although the safety record of scheduled air transportation is impressive and continues to improve in terms of fatalities per passenger miles flown, it is significant to observe that the accident rate has remained nearly constant for almost twenty years at approximately 0.2 accident per 100,000 hours flown (see Bibliography, Ref. G-2). This rate figure has varied very little despite significant increases in airplane size and passenger load. Table 3 illustrates the record for the past seven years in terms of fatal accidents and passenger fatalities for all the member countries of the International Civil Aviation Organization (Ref. G-3).

The trend toward increased size of aircraft in scheduled air transportation, with a constant accident rate, will expose more passengers to each occurrence. It follows that with the introduction of very large aircraft the current accident rate of the scheduled airlines must be reduced below the present average if the total number of fatalities is to be kept near the present levels.

In comparison with other forms of transportation, the safety record of general aviation is relatively poor. Using the measure of fatalities per 100 million passenger miles, the accident rate for general aviation* is more than seven times that of general driving and fourteen times that of turnpike driving. It should be pointed out, however, that over 80 percent of general aviation accidents involve pilot error and that pleasure flying by private pilots is responsible for over two fifths of all civil aviation accidents. Corporation and executive aircraft flown by professional pilots and operated under standards similar to those used by the airlines are involved in less than 2 percent of general aviation accidents.

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* General aviation here includes private, corporate, executive and air-taxi aircraft operations; it excludes commercial airline operations.

It seems clear to the Board that research and development activities aimed at those components of the civil aeronautics system that are beginning to affect critically the safety of scheduled air transportation and general aviation can have profound effects on the growth of civil aviation. Such activities should be given renewed emphasis.

Table 3

FATAL PASSENGER ACCIDENTS

Aircraft Type	1960	1961	1962	1963	1964	1965	1966	7-year Total
Turbojet	3	6	7	5	3	5	6	35
Turbopropeller	7[a]	6	7	5	6	2	5[b]	38
Piston-engine	23[a]	13	14	20[c]	15	17	14[d, e]	116
Total	33	25	28	30	24	24	25	189

PASSENGERS KILLED

Aircraft Type	1960	1961	1962	1963	1964	1965	1966	7-year Total
Turbojet	113	257	424	347	136	250	451	1,978
Turbopropeller	264	192	100	47	252	35	143[b]	1,033
Piston-engine	470	356	241	323	270	399	314[d]	2,373
Total	847	805	765	717	658	684	908	5,384

a. Includes one mid-air collision between a turbojet and a piston-engine aircraft (counted as 2 accidents).

b. Includes one helicopter with 20 passenger fatalities.

c. Includes one helicopter with 3 passenger fatalities.

d. Includes a mid-air collision between two piston-engine aircraft (counted as 2 accidents.

e. Includes one helicopter with 2 passenger fatalities.

(Ref. G-3)

II. Summary of Problems and Recommendations

The results of the Board's studies have been divided into two parts. The first, "General Considerations," expresses the view of the Board on the role and responsibilities of the federal government in civil aviation research and development. The second, "Technical Considerations," outlines in some detail the Board's view on important technical problems and its recommendations for research in civil aviation systems, flight vehicles and airbreathing propulsion, aircraft operations, air traffic control, airport and support facilities, and noise (including sonic boom).

GENERAL CONSIDERATIONS

This section discusses broad issues such as goals and priorities for research and development, government leadership and participation, and implementation of research and development responsibilities.

GOALS AND PRIORITIES FOR RESEARCH AND DEVELOPMENT

In reviewing the progress made by civil aviation during the past decade, the Board noted the randomness by which new technologies found their way into the total air transportation system and the dependence of these new technologies on military research and development. Although there have been previous studies that dealt with elements of civil aviation, the Board was strong in its belief that an essential requirement of the future will be to undertake systems studies of the total civil air transportation system with the objective of identifying and ranking research and development goals. Such studies would begin by relating civil aviation to the nation's transportation system and to national goals. They would end by identifying, analyzing, and ranking research and development goals in terms of safety, time, and economic advantages or penalties to the system as a whole.

GOVERNMENT LEADERSHIP AND PARTICIPATION

Although it has been traditional for most of the aeronautical research and development to be carried out by industry, universities, and nonprofit institutions, strong government leadership will be required in the future in certain areas. Federal involvement in civil aviation research and development will be required in the following ways:

1. Setting research and development goals and priorities through studies of the total transportation system
2. Funding applied research that exceeds the resources of private industry but that serves as a stimulant to the industry and provides a source of fundamental information
3. Funding development programs when private economic resources or motivation is inadequate for achieving national objectives
4. Funding programs associated with public welfare
5. Carrying out programs that require interaction among government agencies

These precepts would suggest that government leadership and participation are needed in certain areas in order to ensure the growth of civil aviation. When the federal government does participate in the research and development process, its principal function is to bear the financial burden of advancing aeronautical technology to the point where the private sector can see the opportunity for profit or where user government agencies can proceed to systems development.

IMPLEMENTATION

The Board concluded that strong government participation and leadership will be required in research and development if civil aviation is to continue to grow as it has in the past. This participation and leadership must come from both the legislative and executive branches of the government through wise policies and their effective implementation. Viewpoints developed by the Board on the government's role in the nation's program of civil aviation research and development are described in the following sections.

Legislation

With the creation of the Department of Transportation federal agencies and their charters are now structured such that the government can exert its proper leadership role in civil aviation research and development. It is the Board's belief, however, that all civil aviation legislation should be reviewed for consistency to eliminate unnecessary restrictions and duplication and to ensure that sound economic development is fostered.

Systems Studies

It is the consensus of the Board that leadership should be provided by the Department of Transportation (DOT) in carrying out systems studies to identify, analyze, and rank research and development goals. These goals should be formulated with reference to the nation's total transportation system, taking account of the increasing public demand for air transportation as well as the various economic factors that bear on civil aviation. Although an in-house government capability should be developed and maintained by the DOT in transportation systems analysis, it is strongly recommended that industry and other private institutions participate in carrying out these studies.

Research and Development

Lengthy discussions were held by the Board concerning the responsibilities that should be assumed by federal agencies in the sponsorship and conduct of civil aviation research and development. The long record of outstanding performance by NASA and its predecessor, NACA, in research and development clearly suggests that it should play an even greater rôle in this area. The Board believes that NASA's role should be expanded to involve not only flight vehicles and their propulsion systems, which have traditionally occupied its principal attention in the past, but all aspects of research and development of importance to civil aeronautics. It will be important for NASA to adopt a policy of directing its attention to those research and development goals, including the development and construction of carefully selected experimental hardware,* that optimize the productivity of the total civil

* The Board found a variety of terminology applied to experimental hardware as part of the research and development process. The meaning intended by the phrase experimental hardware is that of hardware developed and constructed to explore and demonstrate the feasibility of a new concept.

aviation transportation system. Such expanded activities would involve, for example, the development of new technologies relating to air traffic control as well as to airports and their support facilities. With regard to air traffic control, the Board in no way suggests that the responsibilities and authorities of the DOT and the FAA be diminished. But, unlike NASA, which is oriented toward research and development, the DOT and the FAA are oriented primarily toward regulatory and operational activities. The FAA has been unusually effective as an instrument for the construction, maintenance, and operation of federal aids to air navigation. However, the technologies that formed the basis for the development of these aids were derived largely from military-supported research and development. It is the consensus of the Board that although the DOT and the FAA would continue their traditional role of establishment and operation of air navigation facilities, airspace control, and traffic management, the new technologies that will be required to support this difficult assignment are unlikely to come from research and development sponsored by these agencies. Some will result from continuing Department of Defense research and development activities and others from the private sector. However, in the view of the Board, it will be of primary importance to enlist the talents of NASA in the development of new technologies in air traffic control.

The Board makes this recommendation for several reasons. Recent developments in space technology, including the use of satellites for communications and navigation, offer new opportunities for improving air navigation. NASA's background in vehicle technology, together with its growing capability in the field of avionics, enables it to assess the important trade-offs that must be made between on-board and external avionics systems. For example, the Board believes that these trade-offs should be carefully studied before terminal air navigation facilities are developed for all-weather V/STOL operations. In recommending expanded responsibilities for NASA, the Board assumes that these responsibilities would be implemented by NASA in its traditional way of using its research centers for leadership and making use to the maximum extent possible of the talents of industry, universities, and private institutions.

TECHNICAL CONSIDERATIONS

The following sections summarize the detailed technical recommendations that, in the Board's view, are critical to the future growth of civil aviation. The civil air transportation system is considered initially, followed by flight vehicles and airbreathing propulsion, aircraft operations, air traffic control, airport and support facilities, and noise.

THE CIVIL AIR TRANSPORTATION SYSTEM

A logical approach to the planning of research and development for civil aeronautics requires first the establishment of a framework in which to consider it. Since civil aviation is part of a national transportation system, it is desirable, therefore, to correlate both aviation and transportation goals. Going a step farther, the national transportation system must have goals that are compatible with those of the nation.

Modern methods of systems analysis should be useful in establishing this framework. It does not seem practicable to model the nation's transportation system in all its detail, but reasonable modeling to provide a frame of reference appears possible with today's analytical tools. Subsequently, more detailed modeling of individual elements may be feasible.

Recommendation: Establish and relate the long-term goals of civil aviation to those of the national transportation system and the nation. Conduct cost-benefit analyses to determine the interrelationships and the productive, inhibiting, or limiting effects on civil aviation growth of financing, flight vehicles and their propulsion systems, operational problems, air traffic control, airport control, airport and support facilities, and noise. Analyze, identify, and rank research and development goals. The Mission Analysis Division, located at the NASA Ames Research Center, was formed to analyze prospective space missions to determine the requirements for new technologies. These analyses provide NASA with a basis for establishing the detailed research and development goals required in developing the new technologies. The Board visualizes a similar kind of process applied to the civil air transportation system.

FLIGHT VEHICLES AND AIRBREATHING PROPULSION

The flight vehicle with its propulsion system is only one segment of the total civil aeronautics system, albeit an important one. It is the area that heretofore has received by far the greatest attention in research and development. Attention focused on the air vehicle by military research and development has benefited civil aeronautics since the invention of the airplane. Civil aeronautics was at one time highly dependent upon prior research and development of military aircraft. However, the gap between military and civil aviation is growing. The military is relying increasingly on missiles and highly specialized flight vehicles. At the same time, the peculiar conditions under which civil aviation now operates demand transport aircraft that are specially designed for commercial use.

The need for high economic efficiency and productivity in civil aviation will create the necessity for new aeronautical technology just as forcefully as the need for high performance does in military aviation. Although other aspects of the air transportation system, such as airports and the air traffic control system, demand increasing research and development attention, continued efforts will be required to improve and adapt the flight vehicle and its propulsion system to the requirements of our society.

An examination by the Board of the several areas of technology underlying atmospheric flight vehicles and their propulsion systems led to the following recommendations for continued research and development.* Detailed discussion of these recommendations can be found in the report of the ASEB Ad Hoc Committee on Flight Vehicles and Airbreathing Propulsion (Ref. A-7).

The Flight Vehicle: Vehicle Control

The national air traffic control system is designed to sequence aircraft on standard patterns within defined arrival and departure corridors in the terminal area and to provide clearance on point-to-point patterns en route. There are,

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*In a number of areas that the Board has suggested for increased research and development emphasis, NASA has already initiated a program or is in the process of increasing the level of activity. Even so, the Board has chosen to include in its report all of these recommendations.

however, many airborne equipment possibilities that are complementary to air traffic control. This equipment could provide more precise adherence to an assigned pattern and schedule plan, thus allowing increased traffic density with improved safety, reduced holding delay, and less demand on traffic controllers and flight crews.

Recommendation: Research and development effort is recommended on airborne systems that will provide precision navigation and automatic path guidance, "fail-operative" blind landings, accurate displays of the navigation and guidance situation, and a pilot warning indication and collision avoidance capability. These systems are essential for a safe and efficient air traffic control system.

The Flight Vehicle: Electronic Flight Control

Large airplanes operating at high Mach numbers and altitudes will have increasing requirements for stability-augmentation systems and lightweight low-friction flight control command subsystems with high reliability and fail safety.

Recommendation: Research and development is recommended on all-electronic flight control systems. Much more development effort and operational experience will be required to make these systems acceptable as the only means of control for commercial aircraft without mechanical stand-by systems.

The Flight Vehicle: Design for Rough Air Penetration

Rough air penetration continues to be a problem for large high-performance aircraft. Structural integrity standards have improved through the years so that there has been great progress toward elimination of structural failures of airplanes as a result of direct encounter with rough air. The rough air structural problems of commercial aircraft have resulted primarily from upsets in which unusual speeds and attitudes were produced and failures occurred when the pilot attempted to right the airplane.

Recommendation: Emphasize research and development aimed at improving the safety of civil aircraft in rough air. This work should include the definition of refined atmospheric-turbulence models for use as design criteria, development of power-spectral techniques applicable to control problems as well as to load problems in rough air, appraisal of past significant incidents in turbulence, and development of an on-board clear air turbulence detector.

The Flight Vehicle: Aerodynamics

Improved aerodynamic efficiency is required throughout the full speed range of future aircraft.

Recommendation:

1. Emphasize research and development leading to lighter-weight subsonic wings through the use of thicker sections for the same critical Mach number and through improved three-dimensional tailoring.
2. Attempt practical demonstrations of boundary-layer flow control to increase aerodynamic cruise efficiency.
3. Initiate research and development aimed at realizing a more intimate combination of propulsion and aerodynamic systems to provide high-lift capability for takeoff and landing and improved cruise performance.
4. Continue development of an accurate and efficient means for thrust vectoring during takeoff and climb out and for converting the energy potential of the propulsion system to lift at minimum flight speeds.
5. Attempt to integrate airplane propulsion and aerodynamic features to provide improved cruise performance by minimizing interference or producing favorable interference, regenerating retarded boundary-layer air or developing a new propulsion concept that would distribute the propulsion force in some optimum manner over the aerodynamic surfaces.

The Flight Vehicle: Mechanical Systems

The Board has taken note of the fact that as a commercial airplane increases in size and performance, the contribution of mechanical equipment systems to safety and economics becomes increasingly important.

Recommendation:

1. Continue development of predictive-failure techniques.
2. Develop mechanical systems design criteria using a statistical base. A sounder statistical knowledge of requirements would allow design on a basis of the conditions

most likely to be encountered, rather than on the worst possible case.

3. Develop methods to analyze mechanical equipment systems by dynamic-transient analyses in order to improve reliability, maintainability, and weight.

4. Encourage development of fully integrated mechanical systems to take advantage of potential improvements in reliability and maintainability while reducing complexity, weight, and cost.

The Flight Vehicle: Structures

The need for economical operation on the one hand and the increased performance and size of aircraft on the other hand have resulted in a more pressing demand for improved structural efficiency. Higher speeds dictate slenderer structures of lower natural frequencies that are more vulnerable to dynamic effects. The longer lifetime needed for attractive returns on investment requires greater attention to design for fatigue.

Recommendation:

1. Develop flutter analyses that account for wing-body interaction effects and control surface aerodynamics, especially in the transonic region.

2. Develop a working model to provide criteria for pilot behavior under emergency conditions, since piloting technique can have a substantial effect on structural loads, especially during such conditions. These criteria could then be related to the pilot-automatic control interface. Much of this work can be accomplished using moving-base simulators.

3. Increase the effort to develop materials with higher ratios of modulus of elasticity to density to assist designers in solving the severe problem of achieving adequate structural stiffness.

4. Initiate the development needed to demonstrate that structures can be made for production from the new materials now in hand that will perform satisfactorily in service.

5. Establish a continuing and long-term program of research and development for achieving a better understanding of the basic mechanism of materials fatigue and for developing improved methods of fatigue analysis.

6. Develop new methods of joining structures to re-

duce the major weight penalties associated with the use of mechanical fasteners in present structures.

The Flight Vehicle: V/STOL System Development

In viewing the total transportation system requirements for the next decade, it is apparent that increasing overloading of the system in the vicinity of major population centers can be reduced only by well-coordinated employment of all suitable modes of transport. One of the most promising modes that might contribute effectively to a solution is the V/STOL vehicles. Although the reliability and economy of such vehicles and their corresponding air and ground subsystems have not yet reached a level permitting them to play a major role in the nation's transportation system, they offer great flexibility when compared to fixed guideway systems, which are vulnerable to shifts in population and travel patterns. Because of the potential of V/STOL vehicles and because this potential has so far been virtually unfulfilled, increased effort on all aspects of V/STOL system development is warranted.

Recommendation:

1. Conduct a variety of vehicle-oriented research and development efforts aimed at suppressing V/STOL noise, improving handling and operational qualities, improving propulsion cycles, and creating lightweight power transmission systems consistent with the operating environment.
2. Develop instrument landing systems to permit steep gradient approaches for both VTOL and STOL aircraft under conditions consistent with the lowest prevailing weather minimums for fixed-wing aircraft (Category IIIC).
3. Develop airspace utilization systems and, where necessary, segregated air traffic control systems.
4. Develop terminals and intermode connection capabilities on a basis compatible with other modes and capable of attracting and handling a significant traffic flow.

Propulsion System: The Combustor

Research and development in combustors offers potential gains in airbreathing engine performance, reduction in engine weight, and improvement in smoke control. Such work should be commensurate with efforts in other fields directed toward improving airplane efficiency.

Recommendation:

1. Seek further improvements in gas-turbine combustor design concepts through the use of variable geometry primary zones and air atomization fuel injection.

2. Develop fluid dynamics control of the high-Mach-number flow from the compressor so that pressure recovery can be obtained locally in the combustor mixing jets.

3. Combine ramjet and scramjet principles in the gas-turbine combustor system. As pressures and temperatures of the cycle increase, it becomes more feasible to inject fuel into the compressor to acheive an isothermally compressed combustible mixture.

Propulsion System: The Compressor

Current compressor technology is characterized by a need for more detailed understanding of the flow phenomena inside a compressor. In the next decade, it will be necessary to describe compressor performance much more accurately than at present, and at the same time to significantly reduce the long development or redevelopment times for compressors.

Recommendation:

1. Develop detailed analysis techniques, including the use of stations inside blade rows, for steady-state performance prediction. These techniques must, in particular, be brought to bear on off-design cases.

2. Develop new analytic techniques for predicting compressor surge, both with steady-state and dynamic inflow conditions.

3. Develop analytic tools that will predict the behavior of compressors under dynamic inflow conditions.

4. Develop analytic methods to predict compressor and fan noise as a function of fundamental fluid-flow parameters such as relative Mach number, angle of attack change, blade loading, and turbulence level of inflowing air.

Propulsion System: Installed Performance

The prediction of installed propulsion system performance has become a major problem complicated by the introduction of high-bypass-ratio engines for subsonic airplanes, the need for an efficient supersonic transport, and the conflicting requirements of multimission military aircraft. The very large sums of money involved in correcting installed performance efficiencies make it highly desirable that the current state of the art be significantly approved.

Recommendation:

1. Conduct a systematic experimental program to verify methods of predicting steady-state installed performance. A generally applicable philosophy should be developed out of this program for correlating model and full-scale installed propulsion system performance.

2. Perform studies to evaluate the penalties on installed propulsion system performance caused by dynamic effects.

Propulsion System: Instrumentation

With continued development of advanced instrumentation, control systems and monitoring systems could be developed for improved maintenance procedures and for compatibility with the general trend toward automatic controls.

Recommendation:

1. Develop new sensors that are rugged, reliable, and fundamental to propulsion system control and health monitoring.

2. Develop for research purposes miniaturized probes and transducers for detailed study of the flow phenomena in inlets, compressors, burners, turbines, and nozzles.

3. Strive to develop technology for both electronic and fluidic propulsion system controls, concentrating on systems that are more compatible with overall airplane automatic control systems.

4. Develop a new concept for engine health monitoring and its relationship with engine maintenance, including new sensors, improved specific diagnostic techniques, and improved hardware to keep records of engine health data with a minimum of human participation.

Propulsion System: Fuels

The development of new fuels offers possibilities of improved efficiency, reduced weight, increased safety, and reduced air pollution, although no single new fuel will be likely to possess all of these improvements. Some of the new fuels may require the development of new engine cycles in order to realize fully the benefits to be obtained.

Recommendation:

1. Encourage research and development to achieve practical availability of new fuels providing for the best combination of efficiency, weight, safety, and pollution characteristics.

2. Encourage research and development of propulsion systems compatible with the characteristics of any promising new fuels developed.

AIRCRAFT OPERATIONS

The term aircraft operations is used to describe air transportation problems that relate to the environment of the flight vehicle, the role of man in the operation and maintenance of flight vehicles, the limitation of materials, and the interface between the flight environment and that of other systems. An examination by the Board of the current problems of aircraft operations led to a number of recommendations for research and development, as described by the following paragraphs. Detailed discussion of these recommendations can be found in the report of the ASEB Ad Hoc Committee on Aircraft Operations (Ref. B-6).

Aircraft Operations: The Atmospheric Environment

It has become more important to achieve a better understanding of the atmospheric environment in which civil aircraft operate because of advances in the speed and altitude capability of all classes of civil aircraft and the improving capability of instrumentation that permits penetration into increasingly severe environments. It is necessary that warning be given reliably to civil aircraft concerning the character of the environment in which they will fly. Even if the atmospheric environment is fully known, there is an additional problem of timely distribution of information to those who need it in such a form that safe flight is maintained.

Recommendation: Survey the atmospheric environmental field and initiate research and development programs aimed at the most limiting environmental problems in the foreseeable future. Clear air turbulence, lightning, and warm air fog are likely early candidates that limit air transport operations.

Low-altitude turbulence and ice limit private-owner operation.

Aircraft Operations: Human Factors

Throughout the Board's discussion of limitations to future aviation progress, there was a recurring awareness concerning human failure in aircraft operations that extended substantially beyond "pilot error." The conclusion is inescapable that more and more automation will expand man's usefulness and that the man-operations interface will change. The Board believes that this conclusion holds not only for transport aircraft but for private aircraft as well. The human-machine problems may be even more important for the private-sector pilot; there should be a solid base of information to assist airplane design and certification. This information should include analyses of pilot-error accidents to ascertain the real pilot-machine problems. These analyses could lead to significant safety improvements through intelligent design changes.

Recommendation: The Board recommends a strong research and development role for NASA in the area of human factors including such activities as accident injury prevention and man-machine relationships, taking advantage wherever possible of new knowledge gained from space-related activities. In particular, the flight simulation activities of NASA should be reviewed to determine whether they could be organized into a major national flight simulation laboratory serving both industry and regulatory agencies. Such a program should include facilities to explore transport problems and those affecting the private-sector pilot.

Aircraft Operations: Materials

The Board found a number of materials problems that generally are not considered to be part of flight vehicles and propulsion. These include problems relating to fuels, cleaning agents, corrosion prevention, and prediction of failures.

Recommendation: Consideration should be given to expansion of materials research in order to serve both industry and government certification activities by assessing the suitability over long periods of time of both new and frequently used materials. Particular emphasis should be placed on safety implications (fuel and combustible materials), fatigue, and corrosion. An effort should be made to develop a store of information usable for failure prediction as well as for failure prevention.

Aircraft Operations: Interface Problems

The Board encountered a number of problems that did not lend themselves to specific categorization. After some study, it was concluded that in nearly every case these problems were encountered when the aircraft was experiencing a change of environment involving an interface with other systems. Examples of these interface problems are fire after crash, varying conditions at the airport surface, and contaminants and smoke.

Recommendation: A series of operating interface problems involving the aircraft-airport interface suggests that some suitable facility for specialized flight experiments in landing and takeoff may be useful. Activities in all government agencies and the applicability of existing facilities should be reviewed before any new specialized facility is contemplated. The unique problems of the transport airplane, the small private aircraft, and V/STOL aircraft should all be considered.

AIR TRAFFIC CONTROL

The volume of air traffic is already far greater in many en route and terminal areas than the present system can handle effectively. Estimates for the future indicate that the deficiency will become progressively worse unless strong measures are taken to correct the imbalance of volume of traffic and capability. The Board is convinced that there are obstacles preventing the efficient application of the talents of government, industry, and the academic communities toward providing an adequate air traffic system. There are areas where a more vigorous effort to apply existing technology will pay large dividends. In other areas, renewed emphasis on initiating needed research and development is clearly needed.

In a number of instances, recommendations made by previous study groups to correct traffic control problems have not yet been implemented. The Board has included in its report several past recommendations that appear still valid in the present traffic control environment. This has been done with the hope that progress can be made by again bringing them to the attention of the agencies now responsible for implementation. Other Board recommendations include long-range actions believed necessary to correct the traffic system deficiencies; measures aimed at rapidly introducing existing technologies into the present air traffic control system; and provision for accommodating new modes of air transport that have been or are being introduced into the national transportation system since the earlier studies.

These recommendations are covered below in the sections concerned with clarification of government responsibility and with technology. Detailed discussion of these recommendations can be found in the report of the ASEB Ad Hoc Committee on Air Traffic Control (Ref. C-7).

Air Traffic Control: Government Responsibility and Authority

Safe, efficient use of the airspace – a national resource – is clearly one of the nation's air transportation goals. In order that the government-industry-academic resources may be efficiently applied toward solving the critical problems facing the air traffic system, clear delineation of government agency responsibilities and authority is required. In the nearly two years since the DOT was established, there has been an opportunity to assess the effectiveness of the new legislation. In the Board's view, assurance is needed that legislation, the National Air Space System Plan, and long-range plans for the future traffic system needs are current and adequate. Without each of these elements operating in an effective fashion, timely incorporation of existing technology into the present system and initiation of research and development aimed at alleviating long-range problems will be hampered.

Recommendation:

1. Review the implementation of the FAA Act of 1958 and its relation to the DOT Act of 1966 to assure that the FAA has sufficient responsibility, talent, and authority to plan for and regulate airspace; to fund, design, construct, operate, and maintain the air traffic system; and to accomplish or arrange through other agencies, such as NASA, for the accomplishment of research and development necessary for continuous improvement of the air traffic system.

2. Review previous documents, including the 1961 Project Horizon Study, the 1962 Project Beacon Study, the 1962 Plan for Utilization of the National Air Space, and the policy document generated by former FAA Administrator N. E. Halaby. Review and issue an updated National Air Space System Plan that relates anticipated traffic to available technology and that provides for special attention to reducing the time required for incorporation of needed new technology. It is suggested that a full-time working group be convened to study thoroughly and plan the needed future program.

3. Review regulations and concepts for the use of public airspace and recommend changes required as a result of traffic growth.

Air Traffic Control: Technology

The assessment of need for research, for development, and for implementation of timely improvements in the air traffic system involves accurate forecasting of traffic growth and system capability, establishment of long-range requirements, and a testing and evaluation capability. To gain the necessary time for an orderly approach to quantum improvements needed in the air traffic system, the life span of the present system must be increased by rapid application of existing technology. These short-term modifications may include engineering modifications or incorporation of simplified and improved procedures.

Recommendation:

1. Refine techniques for forecasting traffic growth and define both air and ground system capacity by analysis, modeling simulation, and other approaches. Primary attention should be given to the terminal area. The FAA should undertake this task as a national program. With the ability to estimate traffic volume and define system capacity accurately, an analysis planning tool would be available to study specific applications. The method of determining system capacity must be broad enough to encompass various types of flight and ground equipment as well as multiple runway arrangements.

2. Increase emphasis on the planning and initiation of needed research and development for a quantum improvement to the air traffic system. For these long-term improvement efforts, DOT and its FAA should take the lead in

setting technical requirements but should place major dependence for conduct of the research and development on NASA, other government agencies, and industry. As part of these programs, provision should be made for appropriate live test and evaluation. The following elements are involved:

Navigation. Establish and support research and development leading to high-precision en route and terminal navigation aids and equipment providing all-weather zero-zero operation. Emphasis should be placed on improved remote-area or over-ocean navigation (outside the range of line-of-sight navigation aids) allowing for spacing similar to that used in the domestic routes.

Communications. For the long-term solution to the air traffic control communications problem, increase research and development effort to accelerate system improvement and use system analysis to select from the following alternatives or combinations thereof:

a. Ground-air-ground or a one-way air-ground data link

b. Automatic air-ground telemetering of additional vehicle data (i. e., heading, speed, altitude, and weather)

c. Integrated communications with navigation, surveillance, and possibly hazard-avoidance signals

d. Satellite relays for communications either as a single function or as a multiple function

Weather. Establish a national program with supporting research and development to provide closer to real-time integration of meteorological information into the air traffic system. Provide severe-weather data, including forecasting of clear air turbulence, and those data required for safe and efficient operation of supersonic transports.

Airborne Collision Avoidance System. Continue and increase emphasis on research and development to provide for a practical system that will allow flight crews to recognize when they are on a collision course with other aircraft and that will indicate to crews in both aircraft the corrective actions open to them.

AIRPORT AND SUPPORT FACILITIES

The airport complex, including the terminal and all its supporting facilities, is a key element in the air transportation system. Despite the obvious importance of this element to the continued growth of civil aviation, it appears to the Board that far too little attention has been given to the problem of matching present and future airport capacities to the ever-increasing demands of civil aviation.

There are at least two major obstacles hindering the required development of an adequate national airport system. Financing certainly has to rank as one of the major problems; planning is another. Since major emphasis in this study has been placed on research and development requirements for civil aviation, the question of methods for acquiring and allocating funds for airport development has been left to those agencies now engaged in studies of this issue.

Summarized below are some general problems of airport development including planning and other specific areas where, in the opinion of the Board, increased research and development effort will be profitable. Detailed discussion of these recommendations can be found in the report of the ASEB Ad Hoc Committee on Airport and Support Facilities (Ref. D-4).

Overall Planning for Airports

Before any effective action can be taken to solve the airport problem, it is essential to have a plan that will assess the present capabilities, estimate the demand, identify the deficiencies, and outline the steps necessary to meet the requirements for existing and future airports. The proposed national airport plan would take into account several factors, such as the characteristics of future civil aircraft, airport layout to include runway and approach arrangements, and passenger accommodations to include ticketing and baggage handling. An expanded Federal Aid to Airports Program could be used as a basis for such a master plan for airport development; this plan, in turn, could contribute to the formulation of a national transportation system plan that would integrate all elements of an air transportation system, including ground transportation interfaces, local and national economic trends, and applicable new technology. The Board notes that the 1952 Doolittle report, "The Airport and Its Neighbors," very clearly pointed to the need for integrated municipal and airport planning, for an expanded Federal Aid to Airports Program, and for involvement of the federal government in overall airport planning and development coordination. While such efforts were undertaken, the Board believes that renewed emphasis on the solution to these problems is appropriate.

Recommendation: Formulate a long-range national plan for airport development that will provide facilities to keep pace with the projected growth of air traffic.

Government-Industry Airport Steering Group

The complexity of the airport problem requires participation and support of both government and industry. Appropriate representatives of these groups might be brought together for a coordinated attack on the national airport problem through a joint government-industry steering group. Included in such a group should be representatives from the DOT and the FAA, the Air Transport Association, the Airport Operator's Council International, the Aerospace Industries Association, the American Institute of Architects, the American Association of Airport Executives, and the American Society of Civil Engineers. Such an organization can assist the appropriate government agencies in setting up and reviewing a national airport development plan, and in offering advice on the technology needed to implement the plan. Such a procedure might make it possible to shorten dramatically the time from identification of needed airport facilities to completion of the required construction.

Recommendation: Create a government-industry steering group to advise the interested government agencies on airport planning and development.

Airports: Educational Programs

The national airport development problem involves federal, state, and local governments and is further complicated by the social, economic, and political factors that influence the major decisions of airport design and location. Educational programs could be developed to acquaint all interested parties with the many interrelated factors involved in airport development.

Recommendation: Establish university programs to acquaint local officials, industry representatives, and airport managers and developers with all factors involved in airport development.

Airport Runway and Taxiway Capacity

A growing number of airports in high-density traffic areas either will soon reach capacity, are at capacity, or have already exceeded their original limits for aircraft acceptance and departure rates. Recognizing the long lead-time necessary to design and construct new airports, the Board suggests that it would be profitable to determine if increased use of existing facilities could be achieved. For this purpose the Board urges a critical examination of several major operational airports. New technology and techniques as well as improved traffic criteria and procedures may permit a significant increase in the capabilities of existing airports.

Recommendation:

1. Realistically reappraise parallel runway spacing to determine if the present 5,000-ft minimum can be reduced to allow additional runways on existing airports.
2. Determine optimum operational acceptance and departure rates based on a study of selected airports that exceed theoretical capacity or that are below capacity.
3. Reexamine the effectiveness of high-speed turnoffs with a view toward improving their design.
4. Review ratio of gates to total aircraft capacity.
5. Study orientation and location of terminals related to runway configuration for both IFR and VFR including V/STOL aircraft.
6. Increase research and development on runway and taxiway lighting elements.
7. Expedite augmentation of visual aids with electronic devices for landing and taxiing.
8. Expedite the development of automatic taxiway systems, and consider the use of existing hardware to reduce time and cost of installation.

Airport Standards

To maintain the currency of airport standards and to provide proper guidance for airport operators and users, airport standards should be available that reflect the latest information on all types of current and future aircraft.

Recommendation: Government standards for airports should be periodically reviewed and updated.

Airports: Freight

Recent forecasts of the growth in the air cargo market indicate that over the next fifteen years the demand for air cargo service may increase by an order of magnitude. To provide for this expansion, consideration should be given to separation of air freight and passenger facilities.

Recommendation:

1. For the immediate future, develop segregated air cargo areas with direct truck access independent of airport automobile access roads and with ready accessibility to passenger loading areas.

2. For the long-term, study the desirability of providing special freight airports, particularly for large containerized shipments.

Airports: Interface Between Terminal and Ground Transportation

Ground transportation systems represent a major constraint to an effective air transportation system. The airport access problem should be studied using a systems approach, recognizing it as a part of the total urban problem of moving people and goods. More research on various ground transportation systems is necessary to determine the best possible approaches to the urban transit and airport access problems. The result of these studies would serve to guide local community planners.

Recommendation:

1. Study the capacity of interchanges adjacent to airports.

2. Update the statistics indicating numbers and types of ground vehicles requiring access to airports.

3. Study airport parking facilities for ground vehicles, with attention to parking times, extended-time parking facilities, and facilities for air travelers and airport visitors.

4. Increase analytical studies of all modes of local transportation systems serving the airport.

Airports: General Aviation

The impact of general aviation on airport facilities is now considerable and will become an even greater factor if the present forecasts for the expansion of general aviation

Noise Generation and Propagation

Two areas of concern for jet noise suppression are the high-speed jet as used by the SST and the low-speed jets generated by current turbofan engines. Recent research has shown that the sources of noise for jets of high and low velocity are different and that different techniques are required for suppression.

The approach to jet noise suppression must be reexamined both theoretically and experimentally and redirected toward a better understanding of noise generation. The major objectives in jet noise research are an understanding of jet-noise-generating mechanisms and quantitative descriptions of how radiated noise and aerodynamic mixing characteristics of jets are related and of how they are both dependent on the geometric configuration and flow velocity of the nozzle (or suppressor).

No method exists that completely identifies the physical principles of noise production in a rotor-stator set. Until the aerodynamic characteristics of the blades can be related to the noise generation, design of a quiet compressor will be a matter of trial and error, and predictions of engine noise output will be educated guesses. It is important that the noise-generating mechanisms be identified so that the compressor and turbine can be designed to meet minimum noise criteria.

Engineering data have been gathered in the past eight years on the design of acoustic liners for compressor noise suppression. But the physics of the problem – such as the propagation of high-intensity noise through the moving turbulent medium, and the energy dissipation, in a porous material, of high-intensity noise superposed on airflow – has received little attention. The study of noise attenuation by porous linings requires extension to include high-intensity sound waves and the investigation of aerodynamic devices for improving the absorptive properties of the linings in high-speed airflow.

The most identifiable and most annoying feature of some types of helicopter and V/STOL aircraft is the impulsive noise, commonly referred to as blade slap, which can be generated under conditions of blade vortex interaction, critical Mach number, and severe blade stall. A second problem sometimes involved with the conventional helicopter is the nonimpulsive rotational (and vortex) noise are correct. At the same time, general aviation aircraft are expected to become not only more numerous, but larger and faster. This increasingly significant segment of civil aviation must be provided with adequate facilities if it is to contribute to and not impede the growth of civil aviation.

Recommendation:

1. Provide general aviation strips on existing airports using a traffic pattern and facilities different from those used by commercial aviation.

2. For the future, study the desirability of providing specialized airports for general aviation, complete with all necessary support facilities.

NOISE

Basically, one may view the "aircraft noise problem" as a "noise pollution" or community environmental problem. The major problems considered by the Board result from noise produced by flight operations of aircraft. For most conventional aircraft, noise during takeoffs and landings is of primary concern, although noise from cruise-flight operations is of concern for some types of V/STOL aircraft flying at relatively low en route altitudes.

Noise produced by ground runup operations presents a problem in a limited number of localities. In general, however, means of limiting noise for extended ground runup operations are available, and no urgent technical problems appear to exist in this area.

However, the Board's survey of current and potential problems associated with aircraft noise resulted in the general conclusion that although emphasis and funds for noise research and development are increasing, the projected rate of progress may fall short of providing solutions when they are needed. The Board assessed the status of present and planned programs and made recommendations aimed at increasing research and development in the broad area of aircraft noise, including that associated with the sonic boom created by the supersonic transport. These recommendations are summarized below. Detailed discussion of the recommendations relating to noise can be found in the report of the ASEB Ad Hoc Committee on Noise (Ref. F-5).

generated by the main and antitorque-producing tail rotor blades. As the disk loading and tip speed of either of these rotor systems are increased, both types of noise (nonimpulsive rotational and vortex) increase and become more annoying and objectionable.

Much information has been gathered on the propagation of noise through the atmosphere and along the surface of the earth, but only the coarser parameters of the atmosphere affecting propagation have been considered. Such parameters as surface temperature, humidity, and wind velocity are certainly of prime importance, but consideration of these parameters alone greatly limits accuracy of predicting the propagation characteristics of the atmosphere (particularly near the ground) and of the earth surface.

Recommendation:

1. Jet Noise: Identify the noise-producing mechanisms of jet noise in terms of appropriate flow and geometric factors for mean jet velocities less than 1,500 ft/sec and mean jet velocities greater than 2,000 ft/sec. Pursue a noise-suppressor development program based upon knowledge gained from the above research.

2. Turbomachinery: Identify the noise-producing mechanisms and their quantitative description in terms of related geometric and aerodynamic parameters. Identify and describe the modes of sound propagation internal to engine and nacelle configurations under conditions of high sound intensity, high temperature, and shock-wave generation.

3. Noise Suppression: Evaluate the noise-absorption characteristics of materials suitable for use in engine noise suppression. Develop new materials having higher absorption, lower weight, and increased service life.

4. Rotors and Propellers: Develop blade tip and multiple rotor configurations to minimize noise generation.

5. Prediction Methods: Develop methods for predicting the noise produced by vehicles in motion on the ground or in flight. Make more extensive use of and solicit industry participation in flight programs conducted at existing government aircraft test ranges, such that data acquired from a specific test will be useful in other analyses. Develop improved techniques for predicting noise propagation through the atmosphere in both air-to-ground and ground-to-ground cases.

6. New Concepts: Conduct design studies and exploratory experimental programs pertaining to advanced concepts in airframe and propulsion design, engine cycle selection, and the use of unconventional component design features that can directly or indirectly lead to lower noise production.

Noise: Flight Operations

The results of several series of NASA-FAA tests clearly show that reasonable noise abatement takeoff procedures reduce noise over important segments of the takeoff path. The resulting amount of noise reduction will vary widely with the type of jet aircraft and with operating conditions.

The increased glide angle approach during landing appears to reduce moderately the aircraft noise levels. However, the procedure tends to create several other technical problems that may require considerable study.

In the case of V/STOL aircraft, attention should be given to landing and takeoff instrumentation aids that will permit operation under a variety of weather and traffic conditions at relatively high takeoff and landing gradients.

Recommendation:

1. Fixed-wing Aircraft Flight Procedures: Continue present studies of the effect of variations in takeoff and approach procedures on minimizing noise, including direct lift control and other means for increasing aircraft altitude over communities. These efforts should take into account their effect on air traffic control.

2. V/STOL Aircraft Flight Procedures: Develop flight procedures that will minimize noise exposure over populated areas, particularly for lower-altitude operations, consistent with safety and air traffic control requirements.

Criteria for Noise

A primary psychoacoustic problem for evaluating the human response to aircraft noise is the selection of physical measures of noise that may be most useful in the development of scales to assess human reactions to noise stimulation. Over the past ten years most of the work in psychoacoustics related to aircraft noise has been concerned with the application of the perceived noise level concept. Little initial consideration was given to such factors as the structure of the sound wave in terms of its time history, duration effects, the presence of impulsive spectra, and tonal components of the noise. Current work is being pursued to combine the effects of level, duration, and spectral irregularity, i.e., tone components, into a measure that is presently called "effective perceived noise level."

Psychoacoustic measures are generally obtained by comparing different sounds in a laboratory environment. The methodology for predicting psychological reactions of a populace as a whole from laboratory or contrived field experiments is very unsatisfactory. One of the most difficult aspects of developing valid community noise criteria is the restricted ability to identify those other elements of aircraft operations, community environment, and semantic content that result in the gross reaction of a community to noise (referred to as "community response") and that are not physical dimensions of the noise.

Recommendation: Extend present knowledge of the physical parameters of sound that influence individual reactions to aircraft noise. Develop psychoacoustic measures suitable for use in aircraft and engine certification requirements. Develop more psychological and sociological techniques for predicting community response to aircraft noise.

Noise: Land Use

There is a need for careful analysis and planning of land use around airports to provide for activities that are compatible with aircraft operations. Proper land use near airports requires the coordinated and educated efforts of urban planners and public administrators at all levels. With understanding of the complex problem of airport noise, appropriate zoning and coding actions can be taken at the community level.

Several small-scale engineering studies sponsored by the Federal Housing Administration and NASA indicate a relatively high cost for improving noise insulation in most existing houses, although in some localities the cost for noise-insulating new homes might be considered moderate. The feasibility of improving house insulation as a means of alleviating noise should be based on economic trade-off studies.

Recommendation:

1. Analysis of Noise Exposure and Land Use: Prepare estimates of noise exposure around all airports expecting jet aircraft operations. Extend existing procedures for estimating noise exposure produced by helicopter and other V/STOL operations. Inventory land usage around a selected set of existing airports (e.g., ten) and use these data to evaluate possible administrative and economic bases for making such land use more compatible with aircraft operations.

2. Education: Establish an educational program on aircraft noise and land usage for headquarters and field staffs of FAA and the Department of Housing and Urban Development to enable them to consult more knowledgeably with local government agencies on aircraft noise problems. Stimulate inclusion of subject matter pertaining to aircraft noise and land usage in university curricula for architects, urban planners, and public administrators; encourage universities to present symposia on those topics to local public officials.

3. Public Administration: Develop guidelines for zoning practices and building codes for use by local authorities. Develop educational, public relations, and economic programs to encourage local authorities to adopt appropriate zoning procedures and building codes. Establish procedures requiring adequate noise analyses of all airport and heliport sites where federal funds or operational approval is involved.

4. Building Requirements: Develop noise-reduction requirements and appropriate building code recommendations pertaining to control of aircraft noise inside new buildings. Develop low- and medium-cost structures and techniques for reducing aircraft noise that now penetrates inside existing houses. Develop moderately priced air-conditioning equipment suitable for making existing houses livable after such noise-reduction modifications are employed. Further develop criteria for land-use categories, in terms of noise exposure and suitability for zoning of property for residential, commercial, industrial, and public assembly purposes.

Noise: Sonic Boom

The National Academy of Sciences-National Research Council Committee on SST-Sonic Boom conducted studies on sonic-boom generation and propagation, physical effects, and human response and has made recommendations in each area.

These are summarized below. Detailed discussion can be found in the respective reports of the Subcommittees on Research, Physical Effects, and Human Response (Ref. F-2, 3, 4).

Recommendation:

1. Sonic-boom Generation and Propagation: Initiate more theoretical work, together with a program of controlled experiments in the laboratory and the full atmosphere, on the problem of shock-wave propagation through turbulent atmospheric ground layers. Give more research attention to topographical effects. An important first step in such research is the construction of a facility in which various types of topography may be simulated and studied in the laboratory. Establish controlled laboratory and flight tests to evaluate the ability to predict theoretically the effects of accelerations and maneuvers. Continue both government and industry design studies aimed at minimizing sonic boom with emphasis on unconventional as well as conventional aircraft configurations. Emphasize the gathering of overall statistical overpressure and impulse data, relating them to the maximum extent possible to atmospheric, flight, and topographical conditions. Exploit the small reductions to be obtained in the intensity of sonic boom through better understanding of theory, design refinements of conventional aircraft, and improvements in propulsive efficiency and operating procedures.

2. Physical Effects of Sonic Boom: Design and construct at least two types of sonic-boom simulators capable of testing panels on the order of 8 ft square of typical construction materials and cubic assemblies of about 20 ft on a side. Undertake and pursue a physical response research program comprising the following elements in descending order of importance:

a. Repetitive tests in simulators of a wide range of damage-susceptible materials and assemblies

b. Static and dynamic laboratory tests of commonly used glass and glass systems

c. Acceleration and expansion of sonic-boom studies by the Environmental Science Services Administration

d. A count, by sample survey, of window panes in selected cities

e. Evaluation of environmental parameters of material and building responses to natural phenomena

f. Theoretical study of critical earth structures

Appoint an interdisciplinary group, including engineers and lawyers, to study legal-structural considerations of commercial SST operations. Contract with several competent companies specializing in instrument-data-recording-and-retrieval systems to propose the characteristics for an economical monitoring system and to develop preliminary cost-effectiveness analyses of the proposed system.

3. Human Response to Sonic Boom: Continue laboratory studies of the properties of the sonic boom most important to an understanding of such human reactions as annoyance and being startled. Renovate existing facilities where necessary and construct specialized new facilities for better simulation of sonic boom to accommodate the additional qualified investigators who seek to make specific laboratory studies of human response to the sonic boom. Study human response to the sonic boom during sleep. Continue studies of reactions of individuals and of organized communities to overflights at different sonic-boom levels, if and when military overflight programs provide the opportunities. Develop organizational arrangements and methodological work needed to support the research proposed above.

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Appendix I

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