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NASA
OUTLOOK FOR AERONAUTICS

EXECUTIVE SUMMARY
MARCH 1976

THE OUTLOOK FOR AERONAUTICS 1980-2000

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PREFACE

The Outlook for Aeronautics Study has been conducted during a period of uncertainty in the aeronautical community when the industry is concerned with its prospects for the immediate future. NASA, however, as the nation's primary aeronautical research and technology agency, must consider the far term as well as the near future. Thus, this Study presents a balance between the cautious view now prevalent and a more optimistic picture of certain important potential developments. It also provides a glimpse at considerably more visionary possibilities in the farther future. NASA's main thrust should be to provide a firm technical base for near-term developments and for more ambitious advances such as efficient supersonic flight and quiet vertical takeoff and landing.

I believe our country will respond to the growing demand for air transportation, and to the challenge of intensified foreign competition, with a far more aggressive program of development than might be predicted on the heels of a recession. Aviation is vital to our economy and our defense posture, and the United States must retain the ability to pace such development to the maximum national advantage. To do so, it must possess an adequate fund of high-quality, modern technology – which NASA has the obligation, and the capability, to provide. I intend to devote our best efforts to this end.

James C. Fletcher, *Administrator*
National Aeronautics and Space Administration

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INTRODUCTION

The growth of aviation during the past 30 years has brought substantial benefits to the industrial nations of the world, and particularly to the United States. In the period 1940-1970 the use of civil aircraft for transportation has increased approximately tenfold and the importance of air superiority in tactical and strategic defense has continued to stimulate the development of military aircraft and air weapons.

It is generally recognized that this growth has been sustained by timely investments in research and development by the aviation industries and by government, either directly or indirectly. Indeed, the increasing complexity and sophistication of aviation products has required an industry/government partnership of one form or another in every nation that has enjoyed this growth. In the United States, the National Aeronautics and Space Administration (NASA), and its predecessor, the National Advisory Committee for Aeronautics (NACA), have contributed strongly to the technical base that supported these advances in aviation.

The United States, as a leading nation in aviation development, has seen the benefits from its research and development investments in terms of greater productivity, vastly improved air transportation and a favorable contribution to its balance of trade. The military research and development programs of the past two decades have enhanced U.S. defense preparedness through significant improvements in strategic air defense, in tactical air superiority and in air mobility.

As we look to the future, we can expect that air transportation will be a vital factor in shaping urban development and in stimulating national and international commerce. Aeronautical advances will continue to be essential in meeting national defense requirements as they evolve in a changing world environment. It is also possible that new uses for aircraft may add additional impetus to aviation development. However, the factors that will influence the progress of aviation, including the pattern of industry and government relationships, the character of the aircraft to be developed, and the technology advances that will be required, will undoubtedly differ from those of the past.

The purpose of this Study is to make some careful judgements regarding the future outlook for aeronautics, to consider the part that NASA should play in U.S. avaition (i.e., whether changes from the current NASA role are desirable), and to define the emphasis that should be given to its program of aeronautical research and development. The results of this Study will provide information for use by NASA management in the formulation of plans and policies for the future.

STUDY APPROACH

The Outlook for Aeronautics Study was conducted at the request of the NASA Administrator during the period of August, 1974 to September, 1975, as an aid to the planning of NASA's future program in Aeronautics. A Study Group, consisting of NASA Headquarters and Center members, together with representatives from the Department of Defense (DOD) and the Department of Transportation/Federal Aviation Administration (DOT/FAA), was formed to conduct the Study and prepare planning information based on comprehensive discussions with the U.S. aviation industry, other government agencies and the universities. (See Table 1 for list of participants).

The Study was conducted in two parts, comprising (1) a survey of information on a number of related subjects that are expected to influence the future of aviation in general, and NASA's Aeronautics Program in particular, and (2) an analysis of aviation trends and requirements and the definition of potential programs in aeronautical research and technology. During the course of the Study, guidance was provided by NASA management and critical reviews were conducted by two advisory groups, the NASA Research and Technology Advisory Council and the Aeronautics and Space Engineering Board of the National Research Council.

The Survey discussions covered a wide range of topics relating to aviation, but were focused on the two primary subjects of interest to this Study:

The *Future Directions and Opportunities* in Aeronautical Development for the remainder of the 20th Century, and

The *Role of NASA and the Technical Objectives* of its future program in aeronautics.

In many cases, the NASA Study Group was given prepared technical presentations which served to stimulate further discussion on these two subjects.

The results were documented and abstracted by the Study Group in the form of a Survey Report which includes a composite view of each of the segments (industry, government agencies, universities) and thus contains, in summary form, the views of many of the organizations that participated. A summary of the Survey Findings is appended to this Executive Summary.

The Study Group recognized that the Survey, taken during a period of uncertainty in the aviation community, reflected a generally cautious and conservative view of the future. While this view is realistic for the near term, it was felt that allowance must be made for possible changes in conditions which would justify a more optimistic view of the period beyond 1980. Thus, to provide a more balanced picture in carrying out its analysis for the period 1980-2000, the Study Group examined carefully those developments whose potential importance and technical feasibility suggested more rapid progress.

The primary trends determined from the Survey were expressed in terms of the most probable developments in civil air transportation and air defense (particularly aircraft and weapons systems in the period 1980-2000), and several characteristically different directions for future development were defined. The longer term opportunities created by developments in air transportation, extending into the next century, were also considered.

Within this framework, a preferred NASA role and a preferred set of objectives were then formulated for the research and technology which should be undertaken by NASA during the period 1976-1985. The Study results are summarized in the following sections. A detailed discussion of the results, and relevant supporting material, are contained in the Study Report.

LIST OF SURVEY PARTICIPANTS

INDUSTRY

Aerospace Industries Association of America, Inc.
Air Transport Association of America
American Airlines, Inc.
American Institute for Aeronautics & Astronautics, Inc.
Beech Aircraft Corp.
Bell Helicopter Co.
Boeing Commercial Airplane Co.
Boeing Vertol Co.
Cessna Aircraft Co.
Delta Airlines, Inc.
Douglas Aircraft Co.
Fairchild Industries, Inc.
Flying Tiger Line, Inc.
Frontier Airlines, Inc.
Garrett Corp., The
General Aviation Manufacturers Association
General Dynamics – Fort Worth Division
General Electric Co.
Grumman Aerospace Corp.
Institute for Defense Analyses
Lockheed-California Co.
Lockheed-Georgia Co.
McDonnell Aircraft Co.
Metro Airlines, Inc.
National Air Transportation Association, Inc.
North Central Airlines, Inc.
Northrop Corp.
Northwest Airlines, Inc.
Pan American World Airways, Inc.
Piedmont Aviation, Inc. – Piedmont Airlines Division
Rockwell International Corp.
Rocky Mountain Airways, Inc.
Shell Oil Co.
Society of Automotive Engineers, Inc.
Trans World Airlines, Inc.
United Aircraft Corp. – Pratt & Whitney Aircraft Division
United Aircraft Corp. – Sikorsky Aircraft Division
United Air Lines, Inc.
Vought Corp. – Systems Division
World Airways, Inc.

GOVERNMENT

Delaware Valley Regional Planning Commission
Department of Airports, Los Angeles
Department of Commerce
Department of Defense
- Department of the Air Force
- Department of the Army
- Department of the Navy

Department of State
Department of Transportation
- Federal Aviation Administration

Department of Transportation/CIAP
Environmental Protection Agency
Federal Energy Administration
National Aeronautics & Space Administration
- NASA-Ames Research Center
- NASA-Langley Research Center
- NASA-Lewis Research Center
- NASA-Flight Research Center
- NASA Headquarters
- NASA-Johnson Space Center

National Research Council
Aeronautics and Space Engineering Board
Philadelphia Department of Aviation
Port Authority of New York and New Jersey
Staff of House Committee on Science and Technology
Staff of Subcommittee (HUD-Space-Science-Veterans, etc.) to House Committee on Appropriations
Staff of Senate Committee on Aeronautics and Space Sciences

UNIVERSITIES

California Institute of Technology
Iowa State University
Massachusetts Institute of Technology
New York University
Northwestern University
Princeton University
Stanford University
University of Kansas, The
University of Missouri – Rolla
Washington University

TABLE 1

FUTURE DIRECTIONS AND OPPORTUNITIES

The Outlook for Aeronautics Study indicated that relatively few new major developments can be expected from the present through the early 1980s. It determined, however, that new opportunities will exist for required advances in aviation in the period 1985-2000, if adequate research and technology investments are made in the next decade.

CIVIL AVIATION

The extent to which the demand for air transportation will grow during the next decade will depend on such factors as the stability of the domestic and world economies, demographic changes, the expansion of international commerce and tourism, and on technological progress. The ability of the aviation industry to respond to future demand will depend on the degree to which it can provide safe and efficient air service at a reasonable cost and within the imposed environmental constraints.

The Study concluded that, if the appropriate technology investments are made, future civil aviation developments can be expected to evolve in three primary directions that can be described as follows:

- Toward greater efficiency and economy in passenger and cargo air service at subsonic speeds, and improved utility and safety for general aviation.

Representative aircraft developments in this category for the near term include both derivative or growth versions of midrange and long-range transports, new efficient long-haul transports, and derivative versions of general aviation aircraft; in the far term, large cargo transport aircraft are foreseen. These aircraft will feature fuel efficiency and reduced operating costs, reduced noise and emissions, and greater safety and passenger or customer convenience. They will incorporate new technology, in order to assure the level of service currently provided by U.S. air transportation, within more stringent constraints.

- Toward greatly improved short haul air transportation using turbofan or turboprop aircraft and subsequently, rotorcraft and vertical or short takeoff and landing (V/STOL) aircraft.

Representative aircraft developments in this category for the near term include a new efficient short-to-midrange transport possibly having reduced or short takeoff and landing (R/STOL) field performance. In the far term these aircraft are likely to be complemented and replaced by intercity vertical takeoff and landing (VTOL) aircraft or rotorcraft. In addition, medium size utility and business rotorcraft are foreseen to be in widespread use in the post 1990 time period. These aircraft and rotorcraft will incorporate advances in technology to achieve greater efficiency and improved operating characteristics and to meet environmental standards. They will be used as part of an organized short-haul system using small airports that will complement, and provide a feeder service to, the long-haul system. Additionally, the smaller aircraft and rotorcraft will be used as utility vehicles for transportation to oil rigs at sea, to remote sites on land, for pipeline surveillance, resource exploration, and other purposes.

- Toward supersonic, and ultimately hypersonic, air transportation for transoceanic long range flight.

A potential development in this category is a derivative version of the Concorde supersonic transport. A more likely, but possibly later, development is a more advanced commercial supersonic aircraft providing fast reliable service over longer routes than Concorde. Such service would have an important influence on the establishment of new international business relationships among the Pacific Basin nations, particularly. The aircraft would incorporate significant advances in technology to permit clean and efficient flight at cruise speeds up to 2000 miles per hour and quiet operation in the airport terminal area.

MILITARY AVIATION

It is anticipated that the U.S. will continue to maintain a balance of conventional strategic and tactical forces. The development of new military weapon systems will depend on both the need to maintain a parity in strategic forces and the need to provide tactical and support forces that can effectively uphold U.S. foreign policy. The Study concluded that military weapons developments will take the following directions:

- Toward very long range and long endurance capabilities requiring more efficient subsonic aircraft.

Representative aircraft in this category in the near term include derivative transport/tanker aircraft and long-range aircraft for ocean patrol and surveillance; for the far term, the development of a very large logistics transport aircraft is foreseen. These aircraft will allow long range surveillance from the U.S. and permit U.S. based forces to be deployed, when necessary, without requiring intermediate staging areas, and without the necessity for refueling at the location of force deployment.

- Toward more efficient short range support and logistic capabilities requiring multi-mission V/STOL aircraft and rotorcraft.

Representative aircraft developments in the near term include rotorcraft with considerably increased range, subsonic fighters and multi-mission V/STOL aircraft for carrier-borne operations. These aircraft would expand the radius of control and action about aircraft carrier or supply ships and provide extended support and logistics to forward areas in localized battle situations.

- Toward more effective tactical systems emphasizing the optimum combination of aircraft, advanced weapons and remotely piloted vehicles.

Representative developments foreseen in the near term include maneuvering missiles and/or remotely piloted vehicles (RPV's) for use in tactical missions, followed by a new, manned fighter/bomber aircraft. In the far term a V/STOL supersonic fighter aircraft is foreseen. These aircraft and weapons are aimed at short range air superiority through improved local reconnaissance and greatly improved speed and weapons effectiveness; they require a high degree of design integration between airframe, propulsion system and weapons.

The foregoing summary, discussed more fully in the Study Report, categorizes likely future aircraft developments in terms of three primary civil aviation development directions and three primary military aviation development directions. It also identifies representative aircraft types which are expected to characterize these development directions. These are not intended as firm predictions or recommendations, nor are they meant to be all-inclusive. They are considered sufficiently typical to serve as models for the definition of technology requirements and desired readiness dates. While other developments may materialize in both civil and military aviation, those identified herein are the ones most clearly suggested by the Surveyand analysis.

COMMONALITY AND DIVERGENCE OF TECHNOLOGY DEVELOPMENTS

The development of civil air transportation has in many cases benefited from related developments made initially for military purposes. The use of the turbojet, swept wings, high bypass ratio engines, and wide-body structural design are examples of such developments. This pattern has changed in the past decade primarily because requirements were not sufficient to stimulate the development of new military transport aircraft and partly because of civil noise and environmental considerations.

The recent divergence between civil and military needs may continue in the future, under the pressure of the more stringent safety and environmental standards that must be met by civil aircraft. However, it is also likely that there will be some opportunity for commonality between civil and military aviation in the application of new technology. It appears that common use of technology will more likely be of benefit in the development of subsonic aircraft than supersonic aircraft, for which greater differences exist between civil and military requirements.

Superimposed on these controlling factors, and applicable in varying degrees to both civil and military aviation, are the *concerns for safety, environmental impact and cost.* While these concerns have been present throughout the history of aviation they will demand greater emphasis in the aircraft developments that lie ahead. Improvements must be achieved through both careful design and improved technology.

NEW OPPORTUNITIES IN AVIATION

The future directions for aviation have been described thus far in terms of the kinds of aircraft that are likely to be introduced in the period 1980-2000. These projections reflect the generally conservative view of the aviation community at a time of economic recession, and reflect some uncertainty with regard to the nation's ability to make the necessary investments in air transportation and defense. Such a cautious view tends to be realistic about what can be accomplished in the near term, but also tends to underestimate what is possible in the long term. The result is that some very important developments have been predicted as occurring in the 1990s, whereas it is possible that they could occur perhaps five or ten years earlier.

Recognizing that it is part of NASA's purpose to identify and help bring about the most promising potential developments in aviation, the projections previously described were reviewed to determine which developments could be accelerated through appropriate advances in technology. It was felt that the U.S. should have this technology on hand in order to provide the option for earlier introduction into service of advanced aircraft.

Since speed and convenience will continue to provide the stimulus for competition in the air transportation marketplace, they must be recognized as being of primary importance in the long term. In this context, the greatest impact on long range air transportation will result from the introduction of an efficient, environmentally acceptable supersonic transport; and the most significant improvements in short range air transportation will result from the introduction of quiet all-weather VTOL transport aircraft. The necessary technology should be developed to the point where the U.S. industry can move rapidly and with confidence to build these aircraft.

These technical developments should be viewed in the broader context of societal development. As new forms of transportation evolve, they will influence whether the centers of trade and civilization of today will prosper or decay; and part of the purpose of air transportation should be to assure both the survival of our cities and the establishment of new centers of trade in the future.

The most direct use of air transportation may be in revitalizing the centers of commerce within our existing cities. *With the advent of very quiet VTOL aircraft that can operate from small landing sites, perhaps 10 acres in area (or 4 city blocks), the potential exists for using small city airports as the nuclei for redevelopment and for creating centers of commerce that would revitalize our cities.* These aircraft could provide both intraurban and interurban passenger service and serve as versatile high speed links to major hub airports.

Perhaps the most far-reaching outcome to be expected from aeronautical technology is the evolution of a truly global air transportation system. *The use of long range supersonic aircraft, allowing intercontinental flight to distances of 6000 to 8000 miles within a flight time of four hours, would stimulate world trade and communication.*

These advanced supersonic transports may lead ultimately to longer-range, hydrogen-fueled hypersonic transports. The airports for these post-2000 transports might conceivably be located 20 to 30 miles offshore, on man-made islands or island-lagoons built up from the sea floor on the continential shelf. At such locations, noise would be of little concern and the generation of hydrogen fuel from sea water through dedicated nuclear energy plants would simplify the problem of fuel distribution. A world wide intercontinental air system could be implemented with as few as 20 of these airports.

The large scale movement of goods by air is also seen as a significant outgrowth of air transportation. With reduced transfer times and accessibility to remote areas, air cargo may have many different uses in the future. For example, the large scale shipment of livestock, the transportation of major quantities of agricultural nutrients, and large scale disaster relief may become possible. Dedicated cargo aircraft, weighing 1000 tons or more and operating between intermodal cargo points would permit the rapid distribution of materials and products between centers of production and centers of consumption, and greater flexibility in the location of processing and manufacturing industries. It is also conceivable that even larger amphibious cargo craft, fueled either by hydrogen or nuclear reactors, or modern lighter-than-air craft could operate from the coastal or island terminals described previously.

These examples of new opportunities and the corresponding advances in the aviation system give some idea of the versatility of air transportation and provide a glimpse of how it can be used to shape the future. These developments are not planned, but are in the main very credible extensions of current technology and could grow directly from the efforts which NASA will undertake in the next decade.

THE ROLE OF NASA AND ITS TECHNICAL OBJECTIVES

As part of this analysis, the Study Group considered the question of the role that NASA should play to assure that progress is made in the directions outlined above. The need to establish an adequate base of technology for various potential future aircraft developments and the need to conduct a continuing research effort in support of aeronautics, more generally, were given primary consideration.

The role of government in aviation research and development is seen to serve three purposes:

- To assure that adequate research and development take place to meet the needs of national defense.
- To assure U.S. leadership in civil aviation and the continuing development of an efficient air transportation system in the public interest.
- To support government decisions with respect to safety, environmental protection, and other regulatory responsibilities in aviation.

In recent years, a number of factors have arisen which give added emphasis to the importance of a continuing involvement of government in aeronautical research and development. The increasing pressure to adopt more stringent standards that will make air transportation safer and more accepted environmentally, the growing pressure of foreign, government-backed competition, and the increasing cost of making adequate R&D investments, including facilities investments, all point to the importance of future government involvement.

ROLE OF NASA

With regard to NASA's Role, the National Aeronautics and Space Act of 1958, as amended states that,

> *"The general welfare and security of the United States requires that adequate provision be made for aeronautical and space activities"*

While recognizing that the Department of Defense has responsibility for R&D necessary to the nation's security, the Act goes on the say that,

> *"The aeronautical and space activities of the United States shall be conducted so as to contribute materially to one or more of the following objectives: (1) The expansion of human knowledge of phenomena in the atmosphere and space; (2) The improvement of the usefulness, performance, speed, safety, and efficiency of aeronautical and space vehicles; (3) The preservation of the role of the United States as a leader in aeronautical and space science and technology and in the application thereof to the conduct of peaceful activities within and outside the atmosphere . . . ."*

The potential role of NASA was discussed by the Study Group and a preferred role was defined within the context of this existing legislation in terms of *Research, Technology* and *Development.* The nature of the desired relationships between NASA and the universities, between NASA and other government agencies, and between NASA and the industry were also characterized. *Research* refers to advances in the technical disciplines, independent of aircraft type. *Technology* is directly applicable to specific classes of aircraft and is time-critical with respect to readiness for aircraft development. *Development* involves effort directly related to a product or production prototype.

The Study Group concluded that NASA's role should be:

- To conduct research in the technical disciplines, so as to provide a firm base for future aeronautical developments.

- To assure timely technology readiness for application to generic classes of future civil and military aircraft.

- If the necessity arises, to participate with the industry in civil aircraft prototype development without compromising its primary mission in research and technology.

In carrying out this role, NASA would be the focal point for Research and Technology in aeronautics within the government; would work closely with the universities, would serve as an independent consultant to industry and to other government agencies that require technical information (i.e., Department of Defense (DOD), Department of Transportation/ Federal Aviation Administration (DOT/FAA), Environmental Protection Agency (EPA), Federal Energy Administration (FEA)) and would make available its unique research facilities. NASA would also continue to engage in cooperative research projects with appropriate foreign entities, where such cooperation is mutually beneficial and consistent with our national interests.

The relationship between NASA and industry should be such that the technology developed by NASA is readily incorporated into future aviation products at the appropriate time. Thus, joint efforts between NASA and the industry, aimed at demonstrating technical readiness for use, are desirable.

It is recognized that technical advances are also required to improve and extend the air system (i.e., airways, air traffic control system, airports, etc.); in this regard the DOT/FAA has primary responsibility and NASA involvement would be oriented toward aircraft-related research required to assure proper integration of future aircraft into the air system.

This description of NASA's role in aeronautics reflects the views expressed frequently to the Study Group during the Survey, that NASA should continue in its traditional role as a research and technology agency, reemphasizing many of the functions that characterized NACA. It also reflects the suggestions for improved working arrangements between NASA and the rest of the aviation community. The relative emphasis within NASA's programs may change with time and will depend on the nation's needs in aviation.

NASA TECHNICAL OBJECTIVES, 1976-1985

The framework for consideration of NASA's program for the future has been outlined in the preceding discussion. The Survey findings and the subsequent analysis have described the broad directions in air transportation and defense that are likely to be followed in the next 25 years, and have also suggested some examples of the long term opportunities that can be created through advanced technology. The NASA program should be responsive to these directions and opportunities.

Recognizing that advances in technology may also bring about new directions that cannot yet be identified, the NASA program should also include research and technology having broad aeronautical application, so that these new directions can be exploited more readily when they are first perceived. In this way, NASA can contribute to the currently defined needs in aviation and also provide the groundwork for the future.

The following guidelines for the NASA program in aeronautical research and technology are suggested:

- The technical effort for the period 1976-1985 should support near-term developments; provide the basis for the next significant developments in aviation, which are most likely to occur in the period 1985-2000; and should also give attention to the long-term opportunities in aviation.

- The program should provide for disciplinary research appliable to those flight regimes that are known to be important to aeronautical progress, even in the absence of specific current requirements.

- The program should pursue advances in technology, relevant to the primary directions of aeronautical development that have been identified, and applicable to generic classes of aircraft.

- The program should recognize commonality of application of the technology to future civil and military aircraft, when this exists, and should include cooperative or collaborative efforts, as appropriate, with other agencies, in order to encourage a transfusion of technical results.

- The program should involve the universities and the industry in ways consistent with their particular capabilities in basic research and in design and development.

The technical program objectives defined for the period 1976-1985 are summarized in the following paragraphs:

Research Program Objectives

For the Research Program, three characteristically different flight regimes were defined that require continuing efforts in order to extend the state-of-the-art and thereby build a technical base for use in the future: low-speed flight, long-range flight, and high-speed flight. The objective for each is summarized briefly as follows:

Low-Speed Flight Regime

Objective: Provide an improved understanding of the factors that affect the performance, flying qualities, control characteristics, and environmental impact of aircraft and rotorcraft in low speed flight, with emphasis on takeoff and approach & landing, to permit safe and efficient operation in the terminal area; improved accuracy of flight path under normal and adverse weather conditions; a reduction of the wake vortex upset moments on following aircraft; a reduction in landing speed and required field length; and a reduction in aircraft noise and environmental impact on the community.

Long-Range Flight Regime

Objective: Provide an improved understanding of the factors that affect the performance and flight characteristics of long-range aircraft, with emphasis on cruise efficiency, to permit significant reductions in fuel consumption; reductions in aircraft weight through the use of composite structures; expansion in the aircraft operational envelope, through active controls; and possible use of nuclear and hydrogen fuels.

High-Speed Flight Regime

Objective: Provide an improved understanding of the factors that determine the optimum configuration of high speed vehicles, in order to permit increases in speed while maintaining aircraft efficiency; improved environmental impact on the ground and in the stratosphere; and improved maneuvering of military aircraft and missiles.

These objectives are developed in greater detail in the Study Report. In carrying out these research tasks NASA would work closely with universities and research groups within the industry.

Technology Program Objectives

Consistent with the primary directions of aeronautical development discussed previously, four categories were defined, corresponding to generic classes of aircraft which have characteristically different needs for advanced technology. These are short-range subsonic aircraft, long-range subsonic aircraft, short range supersonic aircraft, and long range supersonic aircraft. The Technology Program Objectives are oriented toward broad classes of aircraft rather than single aircraft types, but are responsive to defined needs and may in some instances be time-critical. The broad objectives are summarized briefly as follows:

Short-Range Subsonic Aircraft

Objective: Provide the technology that will permit more effective use, for both civil and military purposes, of future aircraft and rotorcraft operating at subsonic speeds up to 1,000 mile range. This will be accomplished by improving aerodynamic performance and reducing noise for conventional, STOL and VTOL aircraft; by investigating advanced concepts utilizing experimental engines compatible with advanced aircraft configurations; by developing more efficient structural concepts; by developing the technology for systems and procedures that will enable safer, quieter, and more efficient operations; and by better guidance and control in confined airspace.

Long-Range Subsonic Aircraft

Objective: Provide the technology that will permit effective use, for civil and military purposes, of long-range subsonic aircraft operating at ranges from 1,000 miles up to global range. This will be accomplished by improving the aerodynamic performance of conventional and very large transport aircraft; by investigating and demonstrating propulsion concepts using experimental engines; to permit significantly reduced fuel consumption and reduced noise at takeoff and landing; through improved materials and more efficient components; by investigating the applicability of composite and other advanced materials; by utilizing active control systems to improve performance; and by developing improved procedures that will enable safer and more efficient en route operations.

Short-Range Supersonic Aircraft

Objective: Provide the technology support that will permit more effective military use of short-range aircraft and missiles with supersonic speed capability. This will be accomplished by developing improved design approaches to increased maneuverability; by having in-flight thrust vectoring capability; by the development of the technology for variable-cycle engines; by improved structural concepts; and by the development of the technology for control-configured aircraft.

Long-Range Supersonic Aircraft

Objective: Provide the technology that will permit the development of efficient, environmentally accepted supersonic cruise aircraft. This will be accomplished through the use of advanced configurations and improved integration of their propulsion systems to achieve increased range and reduced sonic-boom; by the development of the technology for variable-cycle experimental engines; by the development of the technology for new lightweight materials; by investigating the applicability and reliability of active control systems; and by improving navigation and fuel-management techniques.

Whereas research objectives for the several flight regimes are disciplinary in nature and are aimed at improved understanding of the phenomena encountered in these flight regimes, the technology objectives relate to advances in the several technologies that contribute to the development of new aircraft, (i.e., aircraft configuration, aircraft structures, engines, controls and avionics, and operations). In pursuing the technology objectives, NASA would work closely with the industry and with other government agencies, as appropriate, to gain a proper appreciation of the practical constraints, such as safety, environmental impact and cost that should influence, and be reflected in, the resulting technology advances.

AERONAUTICAL FACILITIES

Success in conducting research and in developing advanced technology for the future depends directly on the quality of the available methods and techniques employed. In most instances, the critical issue is that of facilities. This is particularly true in aeronautics where safety and economic considerations dictate that a high level of confidence be achieved before new technology is incorporated into the end-product. The U.S. aircraft that have been introduced into service since 1955 benefited from the aeronautical facility investment (over $560 million*) made by the NACA, the predecessor agency to NASA, in the years 1940 to 1955.

Since 1955, however, the pattern of facility investment has been markedly different. In the 15 year period 1955-1970, investments in aeronautical facilities amounted to only $130 million,* with the result that our ground-based facilities can no longer adequately simulate the conditions that will be experienced by the next generations of civil and military aircraft. The highest priority must be given in the years ahead to the construction of modern aeronautical facilities that can provide the basic information necessary for the design of our future aircraft.

Improvements in the state of technology over the past 15 years now provide the basis for a new generation of techniques and facilities that will make it possible to ascertain the performance and flight behavior of advanced aircraft much earlier in their design cycle, thereby reducing the cost and risk of future developments. NASA can, and should play an essential role in the creation of new methods, techniques and facilities that will serve the aviation industry for the remainder of the 20th century.

**1975 dollars*

The rapid increases in capacity and speed of digital computers during the past two decades have made it possible to calculate, approximately, the aerodynamic performance and structural behavior of aircraft early in their conceptual design. With continued progress, it can be expected that large special-purpose digital computers will play an increasingly important role in aircraft design and in aircraft guidance and navigation systems design, including the modeling of air traffic patterns in the terminal area of large airports.

The increasing size, speed and complexity of modern aircraft in recent years have outstripped the capability of our wind tunnel facilities to provide representative test conditions. A major task in the years ahead will be to update the nation's wind tunnel test capabilities to the point where they can once again provide data on conditions close to those experienced in flight.

The piloted flight simulator is the primary tool used in the fields of flight dynamics, control system development and human factors. Flight simulators will play an increasingly important role in the future, particularly if the state-of-the-art of simulation technology continues to progress at the current rate. The greatest need, in the immediate future, is for a major improvement in the fidelity of the visual display systems to complement the motion systems now available.

Despite the many investigations that can be conducted in ground facilities, it is frequently necessary to pursue flight-test programs in the conduct of research and the development of technology. The pattern of research and experimental aircraft development that permitted the exploration of new flight situations in the 1950s must be reinstituted if rapid progress is to be made toward the next generation of advanced aircraft for the 1980s and 1990s.

These research or "proof of concept" aircraft also create an opportunity to involve industry teams in the design of aircraft incorporating advanced technology without the necessity for a commitment of large capital resources to production. In a period when the production of new aircraft in large numbers is not anticipated, this involvement of the industry in "proof of concept" aircraft design and construction may be particularly important as a mechanism for retaining and exercising design competences.

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CONCLUDING REMARKS

The Outlook for Aeronautics Study is, in large part, the result of a great deal of candid discussion between NASA and organizations that have a significant interest in the future progress of aviation in the United States. By this means, NASA has gained a greater appreciation of the importance of our aviation industry to the nation's economy and defense. NASA has also gained additional insight into the current problems and future prospects for aviation for the remainder of the 20th century.

The primary conclusions of the Study are as follows:

> Significant developments in civil aviation are most likely to be directed toward greater efficiency in long haul subsonic aircraft, toward greatly improved short haul aircraft, and toward economically viable supersonic transport aircraft. Significant developments in military aviation will probably include: very long range and long endurance subsonic aircraft, more effective short range support and logistics capabilities, and more cost-effective defense systems combining aircraft and advanced weapons.
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> Two aeronautical developments that are critically important to U.S. leadership in aviation deserve to be highlighted. (1) *quiet vertical take-off and landing and* (2) *efficient flight at supersonic speeds.* These two developments would revitalize air transportation and provide new capabilities in air defense and air mobility.
>
> To permit future progress in aviation, and to realize the attendant benefits to the U.S. economy and defense, a new generation of aeronautical technology must be created within the next decade. NASA has an essential part to play in the creation of this technology. Its primary role is to provide a firm technical base for future developments in civil and military aviation. New aeronautical facilities are required for NASA to fulfill this role.

Aviation has been intimately intertwined with economic progress and military defense throughout its short history. It is unlikely that its importance will diminish in the next 25 years. The degree to which aviation can continue to contribute to the national well-being, however, will depend on further investments in research and development by both industry and government. It has been the purpose of this Study to define the character of the investment that NASA must make in the future in order to assure continuing progress in U.S. aviation for the remainder of the 20th century.

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APPENDIX
SURVEY FINDINGS

The primary results distilled by the NASA Study Group from the Survey are given here in the form of Findings. They depict, in summary form, the composite views of the organizations that participated (see Table 1) rather than the views of the NASA Study Group itself, and are categorized in terms of General Findings, and Findings that relate to Future Directions of aeronautical development, the Role of NASA, and the Technical Programs that may be required in aeronautics.

GENERAL FINDINGS

The following represent the most general findings with respect to aeronautical development in the next 25 years:

- The future directions of aeronautical development in the United States will be determined by the needs for and benefits from: safer, more acceptable air transportation; greater military preparedness; and world leadership in aviation products.

- The next decade, 1975-1985, may be characterized more by derivative development and product improvement than by the introduction into service of new civil and military aircraft. In the period 1985-2000, civil and military aircraft of advanced design will be required in order to meet the needs of air transportation and defense.

- If the foregoing needs are to be met, and the benefits to the U.S. economy and defense are to be realized, a new generation of technology must be brought into being within the next decade; there is a strong belief that NASA must play an essential role in accomplishing the necessary research and technology.

FINDINGS – FUTURE DIRECTIONS

The following Findings relate to the factors that strongly influence the rate and direction of growth in aviation, and the most probable aircraft developments that are foreseen for civil and military aviation.

With respect to the factors that will influence civil aviation:

- It is anticipated that the demand for air transportation will grow at an average rate exceeding 5% annually, leading to a fourfold or greater increase in air traffic by the end of the 20th century.

- Higher growth rates will occur in short-haul demand, particularly in the commuter and regional segments, in long-haul cargo and supplemental carrier traffic, in the use of general aviation business aircraft, and in the use of light aircraft and rotorcraft for utility purposes.

- Cost and environmental factors will continue to constrain air transportation growth and will affect both the design and operation of new aircraft and the location of new airports; the increased cost of fuel is an important factor that is expected to influence future aircraft design toward greater efficiency in cruise and in airport terminal area operations.

- The air traffic system, as part of an integrated transportation network, will require substantial improvement to meet the projected growth. The need for improved air traffic control will require the development of new communication and navigation equipment, permitting a greater degree of automation, in order to meet safety and cost objectives.

- The most probable new developments in civil air transportation, beyond the anticipated derivative aircraft of the 1970s, are:

  An efficient, small, short- to medium-range subsonic transport, followed later by the *introduction of quiet V/STOL aircraft for high-density short-haul routes.*

Passenger and cargo long-haul aircraft having fuel efficiency characteristics that are substantially better than those of current aircraft.

Supersonic transport aircraft that can satisfy fuel, cost and environmental constraints; the introduction of such an aircraft would have a major influence on world travel.

The following summarizes, in general terms, the developments that will influence military aviation in the next decades:

- The need to maintain and update strategic weapons is seen in order to assure a continuing global force balance. A reduction in the number of overseas bases will tend to emphasize the importance of naval forces, including air-capable ships, and of surveillance, logistics and air mobile tactical forces with substantially longer range capabilities than currently exists.

- Vehicle and system developments that may result, beyond the improvements anticipated for the 1970s, are:

  V/STOL aircraft and advanced rotorcraft of greater range and speed employed for a variety of short-range missions, and particularly for Navy and Army logistics and support.

  Long-range subsonic surveillance aircraft and cargo/tanker aircraft that may be required for military logistics in the absence of overseas bases.

  Maneuvering missiles, remotely piloted vehicles (RPVs) and possibly laser weapons, that may reduce the need for further major improvements in fighter maneuverability; advanced fighter/bomber aircraft designed to assure tactical air superiority.

FINDINGS – ROLE OF NASA

The following findings result from the Survey with respect to the Role of NASA:

- It is generally believed that NASA's role should be characterized by: basic and applied research in aeronautics; the advancement of aeronautical technology in cooperation with other government agencies, and particularly with the DOD; and a closer involvement with and responsiveness to, the nation's air transportation and defense industries.

- It is expected that capital constraints and development risk may necessitate government participation in selected civil development programs. There is no general agreement as to the nature or extent of NASA involvement, but it is generally agreed that such involvement should not compromise NASA's primary role in research and technology

- NASA should continue to operate and further develop the ground-based facilities and research aircraft that will be required for the exploration of new concepts and new flight regimes anticipated for the future. Such facilities should be viewed as a National resource and developed in response to both civil and military needs.

- Reduced enrollment, in the period 1970-1975 in the Schools of Engineering may create critical personnel shortages in the aerospace industry by the end of the decade. The universities believe that NASA should assist in assuring that an adequate number of well-qualified scientists and engineers be trained meet the needs of U.S. aviation in the 1980s.

FINDINGS – TECHNICAL PROGRAMS

The following reflects the findings of the Survey with respect to the suggested content of NASA's technical program:

- The NASA program in aeronautics should comprise the following:

  Disciplinary research that improves the level of understanding in those areas that are known to have a strong influence on aeronautical progress.

Technology advances that directly affect the safety, cost and performance of future aircraft and aircraft-related systems.

The reduction to practice and operational demonstration of technical solutions when this is deemed to be in the public interest.

More particularly, the technical advances which should provide the focal points for future efforts within NASA are suggested in the following finding:

- A number of specific technical advances, which will lead to significant improvements in air transportation and military defense in the period 1985-2000, require concentrated efforts for the next five to seven years. These include:

  Composite structures that will reduce both the weight and cost of future aircraft and may be particularly important to the design of longer range aircraft.

  Propulsion cycles that permit aircraft to operate efficiently over a wider range of flight speeds and altitudes; such advances in propulsion may be particularly important to the success of future supersonic aircraft.

  Synthetic JP fuels, and possibly non-fossil fuels, that reduce the dependence of aircraft on currently available fuels, the cost of which may increase in the future.

  Aerodynamic advances, including the use of aerodynamic/propulsive interactions, that permit greater efficiency and flexibility of operation for subsonic aircraft and rotorcraft.

  Active controls, embodying advances in information processing and computer architecture, that may improve the flying qualities of current aircraft and permit a relaxation of configurational constraints on future aircraft.

  Design techniques employing computational and simulation methods that predict more accurately the performance of aircraft configurations prior to manufacture, thereby reducing development cost and risk.

These Findings are the result of discussions with leaders of industry, the government and the universities who are ultimately responsible for aviation progress in the United States. The Findings reflect considerable thought and preparation on the part of those who participated in the Survey.

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