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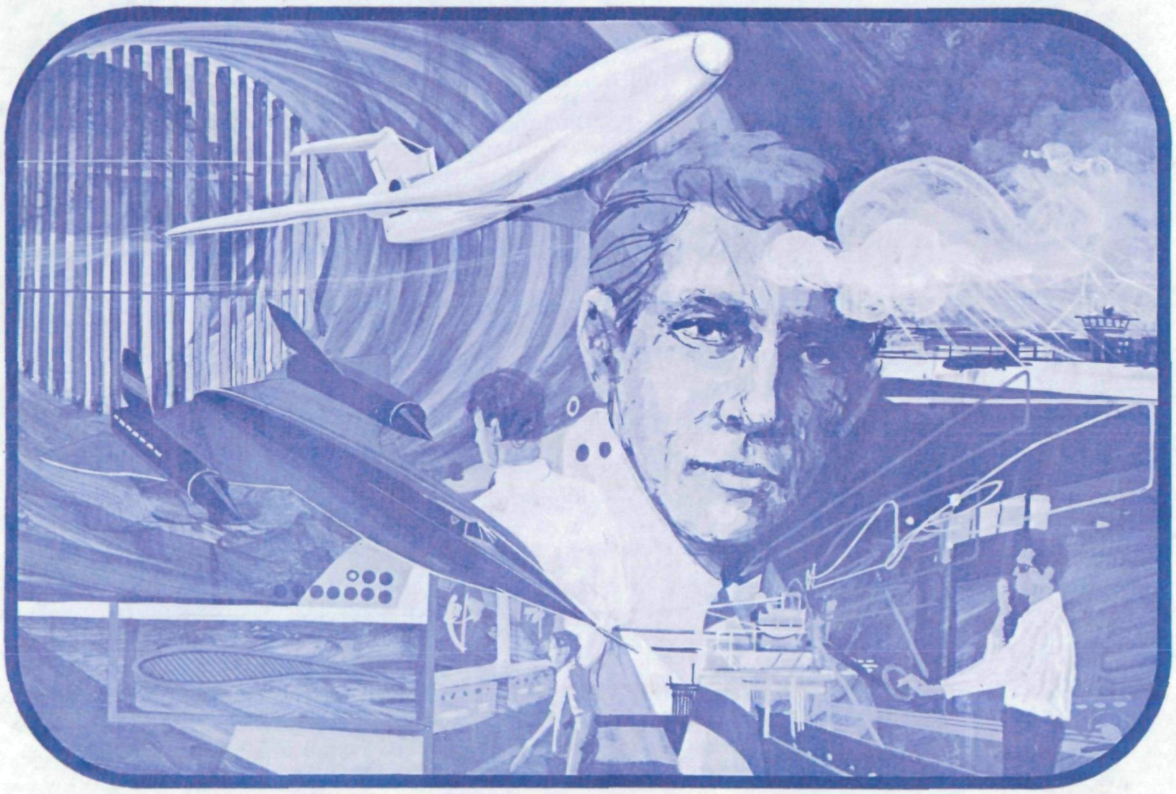
NASA OUTLOOK FOR AERONAUTICS



STUDY REPORT

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. The industry, presently experiencing economic setbacks and faced with rising costs, inflated fuel prices, environmental pressures and other concerns, projects a rather conservative view of the years ahead. The conservative view is understandable, particularly for the immediate future. As the nation's primary aeronautical research and technology agency, however, NASA must direct its effort toward the far term as well as the near future – and it must exercise technical leadership in providing options for both. Thus, the Study presents the cautious view now prevalent, a more optimistic picture of accelerated developments in certain areas, and a glimpse at considerably more visionary possibilities in the farther future.

The anticipated growth in air transportation demand for the remainder of the 20th century is great by even the most conservative projections. I believe our country will respond to this demand, 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 its 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.

The Outlook for Aeronautics Study must now be digested and interpreted in terms of the specific research to be undertaken in each of the major technical disciplines. This process has already begun, and in the one obviously critical area of energy efficiency for subsonic transports the technical program plans have been formulated in detail. Similarly concentrated planning is required in other areas identified in the Study – most notably those associated with supersonic and vertical or short takeoff and landing (V/STOL) technology. The Outlook for Aeronautics Study will have served its purpose when we have translated the results into an aeronautical research and development program which meets the obvious near-term needs, permits accelerated progress for the subsequent decades, and provides a sound basis for revolutionary future advances. With this report and the planning we have already initiated, I believe we are well on the way.

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. The U.S. annual investment in aeronautical R&D increased rapidly in the 1950s, but has remained fairly constant throughout the 1960s and in the 1970s, while industry/government expenditures on aeronautical R&D in the European Economic Community have continued to increase over the past 15 years. 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, 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 civil benefits from its R&D investments in terms of greater productivity, vastly improved air transportation and a favorable contribution to its balance of trade. The U.S. aerospace industry continues to be the largest single manufacturing contributor to the nation's balance of trade partially offsetting the adverse effects of oil imports. For 1975, the value of aviation exports exceeded $6 billion, the greatest contribution coming from transport aircraft.

The military oriented aeronautical research and development programs have enhanced U.S. defense preparedness through significant improvements in strategic air defense, in tactical air superiority and in air mobility. As the potential threats and the assessments of vulnerability have changed, the Department of Defense (DOD) has countered by developing systems with increased performance. These advances have relied heavily on advanced technology and it is anticipated that continued military R&D programs will be necessary to maintain a strong defense posture.

As we look to the future, we can expect that air transportation will be a vital factor in shaping urban development and 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.

Previous studies, such as the Civil Aviation Research and Development (CARD) Study (Reference 1), the National Academy of Engineering Assessment of Government Involvement in Civil Aviation (Reference 2), the study of R&D Contributions to Aviation Progress (RADCAP) (Reference 3), and the Long Range Needs of Aviation Study (Reference 4) were used as background information for the NASA Outlook for Aeronautics Study reported herein. The purpose of the current Study is to make some careful judgments regarding the future outlook for aeronautics, to consider the part that NASA should play in U.S. aviation, (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.

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STUDY APPROACH

The Outlook for Aeronautics Study was requested by the NASA Administrator and conducted during the period of August, 1974 to September, 1975, as an aid to the planning of NASA's future program in aeronautics. The Study includes considerations of the probable and possible directions of civil and military aviation in the period 1980-2000, the role that NASA should play in aeronautical research and development in this period, and the technical advances that may be required.

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, government agencies and the universities. The members devoted approximately 20% of their time to the Study and continued in their normal organizational assignments throughout the period of the Study.

The following participated as members of the Study Group:

Leonard Roberts (Chairman)
Director of Aeronautics and Flight Systems
NASA-Ames Research Center
Moffett Field, California

Robert E. Bower. (Alternate Chairman)
Director of Aeronautics
NASA-Langley Research Center
Hampton, Virginia

William S. Aiken, Jr.
Director, Civil Aircraft Programs Office
NASA Headquarters
Washington, D. C.

Melvin Burke
Special Assistant for Advanced Planning
NASA-Flight Research Center
Edwards, California

C. Wesley Carson
Chief, Policy Analysis Division (Acting)
Federal Aviation Administration
Washington, D. C.

John M. Coulter
Director of Interagency Relations
NASA Headquarters
Washington, D. C.

Bruce G. Jackson
Chief Engineer, Analysis Division
NASA-Lyndon B. Johnson Space Center
Houston, Texas

Gerald G. Kayten
Director, Study, Analysis and Planning Office
NASA Headquarters
Washington, D. C.

Richard L. Kurkowski
Flight Systems Research Division
NASA-Ames Research Center
Moffett Field, California

David J. Sheftel
Deputy Associate Administrator for Engineering and Development (Acting)
Federal Aviation Administration
Washington, D. C.

Warner L. Stewart
Director of Aeronautics
NASA-Lewis Research Center
Cleveland, Ohio

Thomas A. Toll
Distinguished Research Associate
NASA-Langley Research Center
Hampton, Virginia

Mark H. Waters
Manager, Research Aircraft Technology Office
NASA-Ames Research Center
Moffett Field, California

Richard J. Weber
Chief, Mission Analysis Branch
NASA-Lewis Research Center
Cleveland, Ohio

Charles B. Westbrook
Deputy for Studies and Analyses
Flight Aeromechanics Division
Air Force Systems Command
Wright-Patterson Air Force Base

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 two part approach is summarized as follows:

Industry/Government/University Survey: In light of NASA's close involvement with the U.S. aviation industry, with other government agencies (especially the Department of Defense and the Department of Transportation), and with the universities, particular attention was given to their views. While a complete coverage of all of the organizations involved in aviation was not possible, a sufficient number was included to provide a broad representation from each segment, (see Table 1). It was recognized also that the participation of Senior Management at NASA Headquarters, and at the NASA Field Centers involved in aeronautical R&D, was equally important, particularly in discussing the role that NASA should play in aviation and in defining the technical direction of its future programs.

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, namely:

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 subjects.

The Survey findings are given in Appendix A of this Study Report. The detailed results of the Survey are contained in Appendix B (under separate cover), which includes a composite view of each of the segments (industry, government agencies, universities), containing in summary form, the views of many of the organizations that participated.

Concurrent with the Survey described above, the Hudson Institute was asked to analyze the future trends of those factors which have historically influenced the development of aviation. The Hudson Institute Study entitled "Domestic and World Trends (1980-2000) Affecting the Future of Aviation" can be found in Appendix C (under separate cover), and provides long term trends in Economic Growth, Demographic Changes, Travel Demand, International Trade, etc. The results of the Hudson Institute trend analysis permit the Survey findings to be viewed in the broader context of probable world events. Additional sources of information are listed in the Bibliography.

Analysis: Two factors were considered to have the greatest impact on NASA's technical program in the future, namely; the primary trends in civil and military aviation for the remainder of the 20th century, and the character of the NASA role in terms of the relative emphasis on research, technology and development.

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 whis 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.

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

The primary trends 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.

FUTURE DIRECTIONS AND OPPORTUNITIES

Lead times for the application of aeronautical research and technology are generally long and can easily exceed 20 years. It is necessary, therefore, that research and technology programs be based, in part, on postulated requirements for operational civil and military systems in a time frame beyond the normal planning horizons of both the users and the developers. To provide the desired long-term view, a broad set of trends affecting air transportation and defense was considered.

The following discussion, derived from the Survey Findings and the subsequent analysis, summarizes the projected future trends and their implications relative to civil and military aviation. The projections are presented in terms of the trends and directions that are expected to determine future requirements, with brief descriptions (and estimated introduction dates) of representative probable developments. The broad opportunities that can evolve from advances in air transportation are also discussed; these opportunities represent the far-term promise of aeronautics.

The general pattern of aviation development over the past 30 years and the trends expected for the next 30 years are depicted in Figure 1 in terms of aircraft productivity and Research and Development investment. The increasing research and technology development investment between 1940

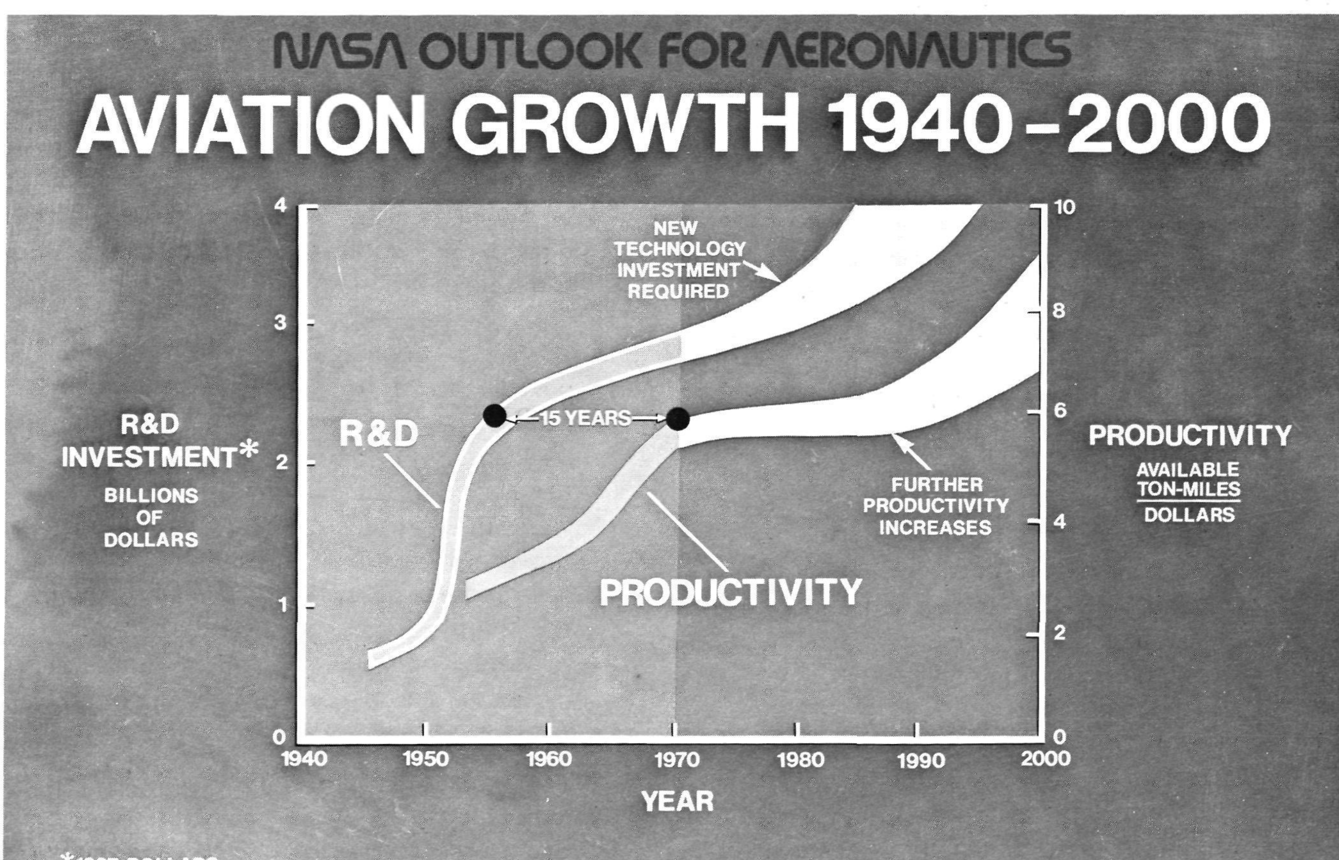

Figure 1. Patterns of U.S. Aeronautical Research and Development Investment and Aircraft Productivity; 1940-2000.

and 1955 brought about the introduction of the jet engine, the swept wing and the wide body structure and as a consequence, major improvements in productivity in the period 1955-1970 (approximately 15 years later). The pattern of increasing research and development investment changed in the late 1950s and 1960s, as shown in the figure, and relatively few new developments can be expected for the period 1970-1985. The following discussion of future trends and directions in aviation supports the belief that new opportunities will exist for advances in aviation in the period 1985-2000, however, it adequate research and technology investments are made in the next decade.

CIVIL AVIATION

The future development of civil aviation is keyed to the demand for air transportation for both business and pleasure travel and for the transfer of cargo. This demand inevitably will result from continued growth of established markets and the development of new markets for these services. The extent to which these demands will grow in the next quarter century will depend on such factors as economics, demographics and resources.

The following is a summary of trends which will influence civil aviation growth:

Economic Factors:

- Gross national product (GNP) is the key factor which measures economic trends. Over a long period of history, the U.S. growth rate of GNP has averaged around 3-4% in real terms. There have been fluctuations for short periods of time such as the greater than average growth of the 1960s. The U.S. may be expected to revert to its historic 3-4% yearly real growth rate for much of the next 25 years while the world rate should average about 5½% through 1985 and decline to about 5% thereafter.

- There will be continued movement, within the developed countries, into the middle class and a consequent pressure for economic growth. The resultant society will be more technology oriented and will reflect increasing affluence, accelerated development of service industries and leisure life style, and a vast increase in disposable income.

- In the under-developed countries, particularly those with an abundance of natural resources, there may be even greater pressures for economic growth to increase living standards and national prestige. Development of an infrastructure of transportation and communications along with an education system and assured food supply will have to precede the development of a widespread middle class society.

- International trade and tourism is expected to increase particularly in the Pacific Basin and between the industrial nations and the resource-rich emerging nations. International tourism was a $29 billion industry in 1974. Most of these travelers used air transportation, for example 96% of overseas visitors to the U.S. arrived by air (Reference 5). The increasing number of trans-national business arrangements should continue with a resulting increase in trade and travel.

Demographic Factors:

- The world growth of population will have severe consequences unless coupled with worldwide economic growth and improved food supply. Although population growth rates are falling in many parts of the world, particularly in the developed countries, including the U.S., stabilization of world population is not likely to occur by the year 2000.

- A shift of population is seen to continue in developed countries in general and the U.S. in particular. Increased middle class economic standards will continue to further the trend toward suburban living with some redevelopment of central city areas. In addition, the desire for warmer climate will promote development of sparsely populated regions in the southern and southwestern U.S. Also, relocation will be sought by business and industry in less densely populated regions.

Resources:

- Crude oil for energy and other uses will be available through the end of the 20th century. It is probable that costs, independent of taxes, will stabilize at approximately 1975 prices. In spite of the short term availability of conventional energy, conservation efforts will continue, and the impetus for deriving new sources of energy will not be lost.

- The search for new fossil energy resources and for other natural resources will intensify and may require the development of new techniques for the identification and exploration of resources at remote sites, (i.e., on the continental shelf, or at inaccessible locations).

- Basic resources other than crude oil should prove adequate, with no serious shortages developing through the end of the 20th century. New sources, coupled with more efficient use of raw materials and development of substitutes, should result in adequate supplies. Some minerals used by the aircraft industry may be subject to cartelization; however, it is felt that the risk of such politically enforced shortages of these materials is significantly less than for oil.

Some of the factors that will influence the air transportation system can be summarized as follows:

- The development of rapid intraurban surface transportation systems, which include the airport as one focal point, will affect passenger air transportation in a positive way; similarly, the establishment of an integrated transportation, warehousing and distribution system will stimulate growth in air cargo service.

- Airside and landside congestion at the major hub airports is anticipated in the 1980s and this problem will be compounded by public resistance to new airports because of sensitivity to increases in noise and pollution in the airport vicinity. These effects will make the siting of new major airports even more difficult than in the past.

- The DOT/FAA is currently upgrading the third-generation air traffic control system, which is expected to meet domestic operational needs through the 1980s. However, a new system will be required before the end of the 20th century, which will need long lead time planning to properly integrate the most modern of avionics systems for communications and navigation.

- The increased use of general aviation aircraft could be constrained by the costs of new equipment, particularly avionics equipment, that may be required to permit aircraft operation in conjunction with the improved air traffic control system. The development of light-weight, low-cost avionics will be necessary in order to assure the maximum benefit to air transportation from general aviation aircraft.

- The increased cost of fuel and its adverse impact on airline operating economics will tend to constrain the growth in demand for air travel. The existence of a large fleet of transport aircraft, whose production costs have not yet been amortized, will tend to delay the introduction of new aircraft that could be substantially more efficient and less costly to operate.

- Faced with a five-to-ten year period of low demand for new equipment, and corresponding low profits, the aircraft industry may have little opportunity to introduce innovative technology and this may make more difficult the task of keeping alive the design competence that has been carefully built up over the past years.

Despite the constraining influence of some of the foregoing factors there are many opportunities for aviation in the future:

- Projections for the future suggest that the domestic trunk airlines have become a "mature" industry and their growth from now on will be roughly comparable to the growth in the gross national product (GNP). This, however, is far from being a negligible growth rate. At 5% the number of passengers carried by trunk airlines would double by 1990, and at 7% the doubling would occur by 1985.

- Although the current profit situation for the scheduled U.S. international air carriers is not good, with high fuel prices and over-capacity having a serious effect, good prospects exist for present markets being stimulated by increased tourism and international business and for new markets opening up in various parts of the world.

- Supplemental and cargo airlines are in an excellent position to take advantage of traffic growth. These airlines are currently showing increases in their international air service, and government policy issues and international agreements will probably play a large role in determining their future growth.

- The growth in the regional airlines has remained generally healthy, and they continue to plan for expansion of their non-subsidized routes. Commuter airlines have generally demonstrated rapid growth in recent years; their plans are based on feeder operations from small cities into major hub airports. It is likely that regional and commuter airlines will grow at faster than gross national product (GNP) rates, at least over the next decade, as the demand for air service for smaller cities increases.

- Carrying one out of three domestic intercity air passengers, general aviation aircraft form a viable and important mode of transportation in the U.S. Light aircraft sales increased during the recent energy crisis and are now growing at near-record rates. It is likely that this growth will continue for both business and personal use. In addition, the increased use of light aircraft for utility purposes is expected, particularly in connection with agriculture.

- The increasing use of rotorcraft for such diverse civil applications as resupply to off-shore oil rigs, traffic monitoring and control, medical evacuation, etc., in addition to its military applications, has resulted in a growth of this segment of the industry during the 1970s. It is likely that this growth will continue for the foreseeable future because of continuing domestic and overseas interests in rotorcraft with greater range and payload characteristics.

Consideration of the foregoing factors suggest 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:

(1) *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, together with their likely dates of introduction include:

Derivative and growth versions of transport and general aviation aircraft	(1980)
Efficient long haul transport	(1985)
Large cargo transport	(1995)

These aircraft would feature fuel efficiency and reduced operating costs, thereby offsetting current fare trends; reduced noise and emissions, and greater safety and passenger or customer convenience. They would incorporate new technology in order to assure the level of service currently provided by U.S. air transportation within more stringent constraints. Requirements for new subsonic transport aircraft should materialize first in the form of replacement for, or additions to, the present fleet, with essentially the same performance characteristics. Later, increases in range and in load-carrying ability are anticipated, particularly for the growing cargo markets in the Far Pacific and in the developing nations. Technical requirements for general aviation aircraft will emphasize safety, and environmental and operational improvements.

(2) *Toward greatly improved short-haul air transportation using turbofan or turboprop aircraft and subsequently rotorcraft and V/STOL aircraft.*

Representative aircraft developments contributing to this direction may include:

Efficient short-to-mid range R/STOL transports	(1985)
Medium size utility/business rotorcraft	(1990)
Intercity VTOL aircraft or rotorcraft transport	(1995)

These aircraft and rotorcraft would incorporate advances in technology to achieve greater efficiency and improve operating characteristics and to meet environmental standards. Increasing demand may warrant the development of short to mid-range passenger aircraft designed specifically for efficiency and economy at short stage lengths, and for incorporation of features to alleviate the congestion, delays, noise, and cost penalties. These reduced or short takeoff and landing (R/STOL) aircraft would be used as part of an organized short-haul system, permitting the use of small airports, and would complement, and also provide a feeder service to, the long haul system.

Initially, improved rotorcraft and vertical takeoff and landing (VTOL) aircraft will probably 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. Later, new, rotorcraft and vertical or short takeoff and landing (V/STOL) aircraft are envisioned, both for specialized utility applications and to provide convenient and economical short-range service to centrally located small airport terminals.

(3) *Toward supersonic, and ultimately hypersonic, air transportation for transoceanic long-range flight.*

In the time scale under consideration, representative aircraft developments beyond the Concorde supersonic transport may be concentrated on:

Derivative Concorde	(1985)
Advanced supersonic transport	(1995)

These commercial supersonic aircraft would provide fast reliable service over longer routes than the Concorde and would have an important influence on the establishment of new international business relationships among the Pacific Basin nations, particularly. These 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. Ultimately the hypersonic transport may evolve as a natural extension of supersonic air transportation.

MILITARY AVIATION

To meet defense needs, 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 result from 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 Strategic Arms Limitation Talks of 1972 (SALT) institutionalized the strategic stalemate. Although SALT may tend to stabilize the U.S. demand for military aircraft, the foreign demand will tend to increase. For the ten-year period ending 1982, 122 countries will require an estimated 29,000 new military aircraft with a value of $95 billion. European countries are expected to require almost 40% of this total, and these countries are making strong efforts to capture a large share of the world export market in addition to providing for their own needs (Reference 6).

The primary factors which will influence future military aviation developments may be summarized as follows:

- The two major military powers, the U.S. and the U.S.S.R., are likely to continue to seek and maintain detente. Thus, strategic weapons will continue to be developed, but at a rate that will not disturb the present balance.
- An increased number of secondary powers will emerge, due to their abundance of natural resources and/or technological know-how, whereas progress in the poorer nations may be slower due to over-population problems and lack of food. The combination of more countries competing for political and economic influence may result in localized unrest in several parts of the world throughout the remainder of the 20th century.
- The ability of the U.S. to react, when necessary, to protect national interests and help preserve peace will be limited by the reduction in overseas bases that have in the past been used as staging areas. This situation will tend to emphasize the importance of both long range sea and air logistics and short range tactical and support forces.
- It is probable that these capabilities will be developed within constrained budgets and that new aircraft and weapon developments

will feature minimum life cycle costs and have multi-mission application, wherever this is feasible, in order to reduce development and production costs.

On the basis of these general considerations and as a result of more detailed discussion with the Department of Defense it is believed that aircraft and weapons developments will take the following directions:

(1) *Toward very long-range and long endurance flight requiring more efficient subsonic aircraft.*

Representative developments contributing to this direction, together with likely dates of introduction, are as follows:

Derivative Transport/Tanker aircraft	(1985)
Long Endurance Surveillance and Patrol Aircraft	(1985)
Very large logistic transport	(1995)

These aircraft 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. Long range logistic support and long duration surveillance will become increasingly important.

(2) *Toward more efficient short range support and logistics capabilities requiring multi-mission V/STOL aircraft and rotorcraft.*

Representative aircraft developments in this direction include the following:

Long Range Rotorcraft	(1985)
Subsonic V/STOL Fighter Aircraft	(1985)
Carrier-borne Multi-mission V/STOL Aircraft	(1990)

Mission requirements are expected to lead to the development of a mixture of STOL, VTOL and advanced rotorcraft for the future. 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.

(3) *Toward more effective tactical systems emphasizing the optimum combination of aircraft, advanced weapons and remotely piloted vehicles.*

Included in this direction are potential developments in:

Derivative Fighter Aircraft	(1985)
Maneuvering Missiles and RPVs	(1985)
V/STOL Supersonic Fighters	(1990)
Advanced Fighter/Bomber	(1995)

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 or design integration among airframe, propulsion system and weapons. There will be continued derivative developments of supersonic attack and fighter aircraft, both for all-weather applications and as day fighters; some designs will have V/STOL capability. In addition, missiles and/or remotely piloted vehicles will become increasingly important. In all of these developments technology must provide low cost approaches to offset the increasing cost trends of the past decades. Unconventional weaponry, such as lasers, may lead eventually to greater departures from conventional design.

The foregoing summary categorizes the Controlling Factors in Aviation and the Future Directions in Aeronautical Development for the period 1980-2000. (see Figure 2). It also identifies representative aircraft types which are expected to characterize these likely development directions. These are not intended as firm predictions or recommendations, nor are they meant to be all-inclusive. They are considered sufficiently typical of likely classes of aircraft development to serve as models for the definition of technology requirements and desired readiness dates. While other types of development may materialize in both civil and military aviation, those identified herein are the ones most clearly suggested by the Survey and analysis.

Commonlaity 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.

This trend is suggested by the following examples for subsonic aircraft:

> The need for greater fuel efficiency in air transportation and for longer range in military airlift capability will depend on similar advances in aircraft technology, particularly in the areas of composite structures and improved aerodynamics.
>
> The use of V/STOL aircraft and rotorcraft for military purposes and the use of generally similar vehicles for future short haul transportation and civil utility applications will depend on common technology in many aeronautical disciplines, and especially areas in propulsion, in powered lift and in flight dynamics and control.

By contrast, the following examples illustrate possible differences of requirements for supersonic aircraft.

> The need for clean emission and sonic boom minimization in cruise, and quiet engines for takeoff and landing will place demands on civil supersonic transport aircraft that are characteristically different from the demands that result from the high acceleration and maneuverability needs of supersonic fighter aircraft. The engine design differences for efficient supersonic cruise and low takeoff and approach noise require considerable compromise for a civil aircraft.
>
> The efficiency required for long duration supersonic commercial aircraft depends on advances in cruise aerodynamics and high temperature structures whereas the effectiveness of high speed missiles operating in highly transient conditions call on advances primarily in avionics and controls systems. The load cycle characteristics for civil supersonic transports differ from those for military aircraft and result in differences in structural design criteria.

In planning for future research and technology programs in aeronautics, it will be important to recognize both the commonality and divergence in civil and military aircraft requirements. The commonality aspects should be fully exploited to offset the increases in R&D costs, and the divergence must be recognized and appreciated so as not to compromise the successful development of future aircraft under the false expectation of cost savings.

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. In some cases, improvements must be achieved through careful design and improved technology.

Safety: The increasing size and speed of aircraft and the increasing density of aircraft in the terminal airspace make improvements in safety an increasingly important goal. It is particularly important that departures from existing design and operational practice introduced to effect improvements in performance or efficiency should not compromise, but if possible enhance, safety. Thus,

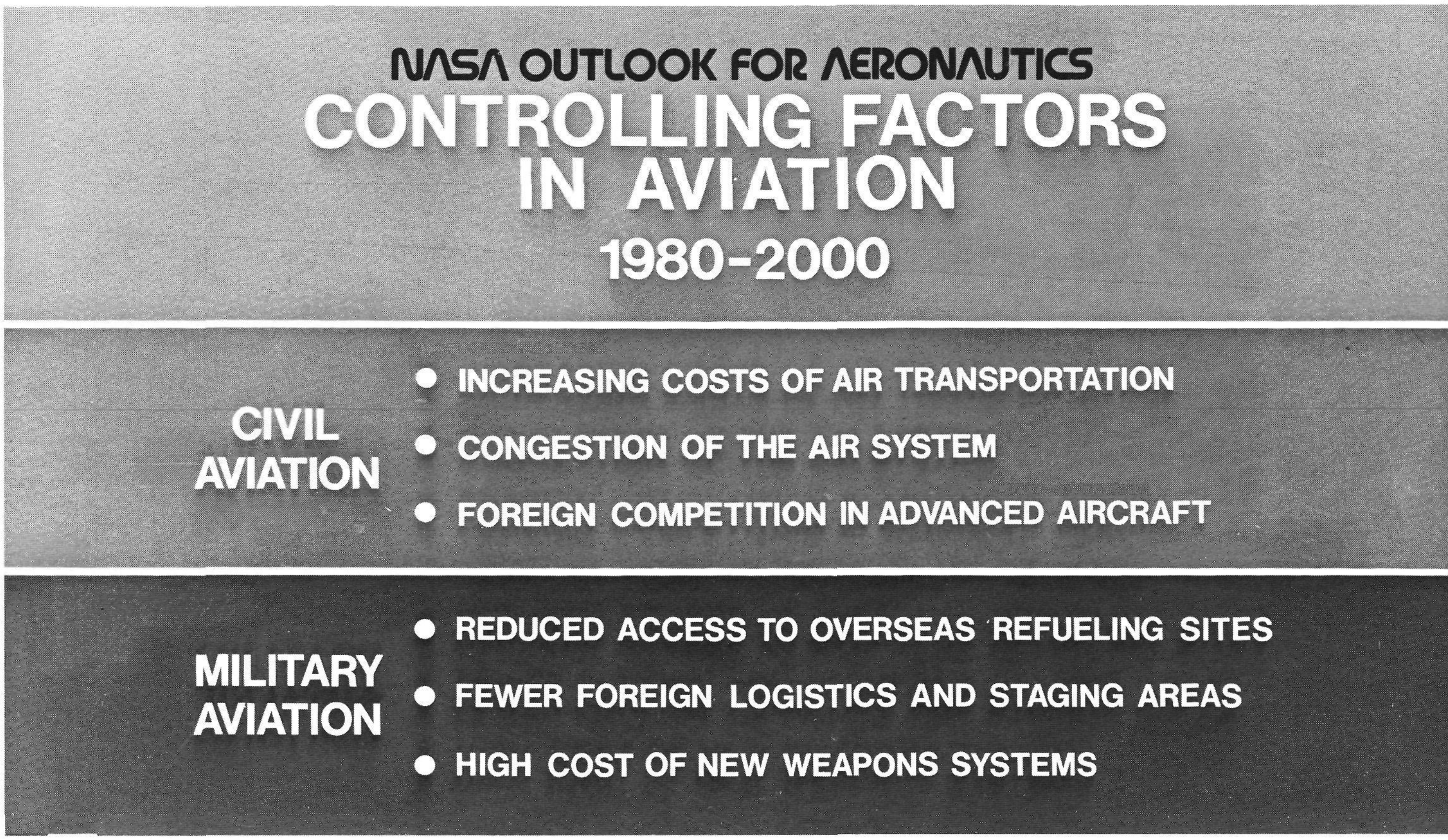

Figure 2. Summary of Controlling Factors in Aviation and Future Directions in Aeronautical Development, 1980-2000.

a thorough understanding is required of changes involving new technology in order to establish a high degree of confidence in its application.

Environmental Impact: The importance of environmental quality has grown in recent years and will continue to play a significant part in the design of civil aircraft, particularly. Technology must be directed toward improvements in air transportation while preserving, and if possible enhancing the environment; aircraft noise and emission, familiar targets for improvement, will continue to be of concern. Regulations must reflect an understanding of the physical phenomena involved and a realistic assessment of the technical and economic feasibility of meeting proposed standards.

Costs: The costs of development, production and operation traditionally have been given close attention in the U.S. aviation industry. The pressure to constrain military budgets, and the more competitive position being attained by foreign civil aviation industries, can only lead to renewed emphasis on costs. While advanced technology should not be inhibited by an over-attention to cost implications (since costs of far term end-products cannot be projected with confidence) proposed near-term technology applications must consider the means whereby the costs of introduction are to be amortized.

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

NASA OUTLOOK FOR AERONAUTICS

FUTURE DIRECTIONS IN AERONAUTICAL DEVELOPMENT

- TOWARD GREATER EFFICIENCY AND ECONOMY IN SUBSONIC PASSENGER AND CARGO AIR SERVICE AND IMPROVED SAFETY IN GENERAL AVIATION
- TOWARD GREATLY IMPROVED SHORT-HAUL AIR SERVICE IN HIGH AND MEDIUM DENSITY POPULATION AREAS
- TOWARD EFFICIENT SUPERSONIC TRANSOCEANIC LONG RANGE FLIGHT

- TOWARD LONG ENDURANCE SURVEILLANCE AND LONG RANGE AIR SUPPLY UTILIZING ADVANCED SUBSONIC AIRCRAFT
- TOWARD MORE EFFECTIVE SHORT RANGE SUPPORT & LOGISTICS CAPABILITIES UTILIZING MULTI-MISSION ROTORCRAFT AND V/STOL AIRCRAFT
- TOWARD MORE EFFECTIVE TACTICAL SYSTEMS COMPRISING FIGHTER AIRCRAFT, ADVANCED WEAPONS & REMOTELY PILOTED VEHICLES

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 the earlier introduction into service of advanced aircraft.

The technical developments aimed at fuel efficiency for subsonic transport aircraft will provide the means of controlling the rising air transportation costs brought about by increases in fuel prices; these technical developments, however, will not result in improvements to the speed and convenience of air transportation. Since these latter factors 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, it is believed that *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 come with the introduction of quiet all-weather VTOL transport aircraft.* The significance to air transportation of these two aircraft, the quiet VTOL and the efficient, long range supersonic transport (SST), is such that the necessary technology should be developed to the point where the U.S. industry can move rapidly and with confidence to build these aircraft. From the standpoint of technology readiness, it should be possible to advance, by 5 years or more, the 1995 date cited in the previous discussion as the likely

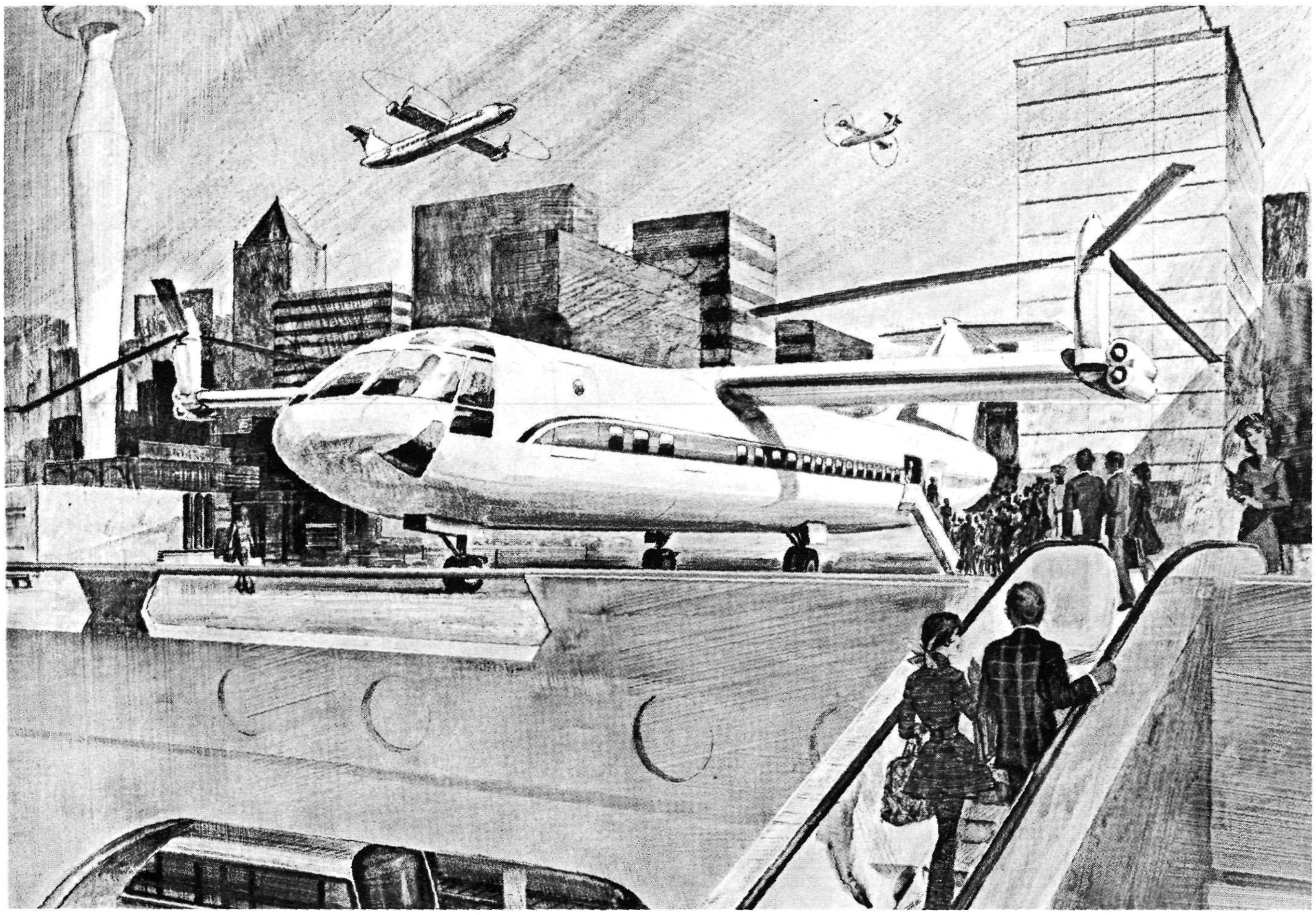

Figure 3. Future Short-haul Urban Airport Utilizing Advanced Rotorcraft. (Artist Concept).

date of introduction.

It is interesting to place these technical developments in the broader context of societal development. The patterns of society have been determined for thousands of years largely by the interaction between trade and transportation. The major trading centers of the world have been located by the nodal points of the transportation system, whether in the interior of Asia or on the seacoasts and rivers of Europe and America, and where these trading centers have flourished they have also become centers of civilization.

As new forms of transportation evolve they will influence whether the trading centers 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 inherent versatility of air transportation, requiring limited use of land and right-of-way, and largely uncoupled from weather conditions, make it almost ideal for such purposes.

The most direct use of air transportation may be in revitalizing the centers of commerce within our existing cities. It is well recognized that the introduction of a new airport can, within a few years, generate a local increase in property values and become an attractive focal point for new business enterprise. The rate of construction of commercial buildings in the vicinity of existing airports gives a clear indication of this effect. *With the advent of very quiet VTOL aircraft that can operate from small landing sites (see Figure 3), 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.*

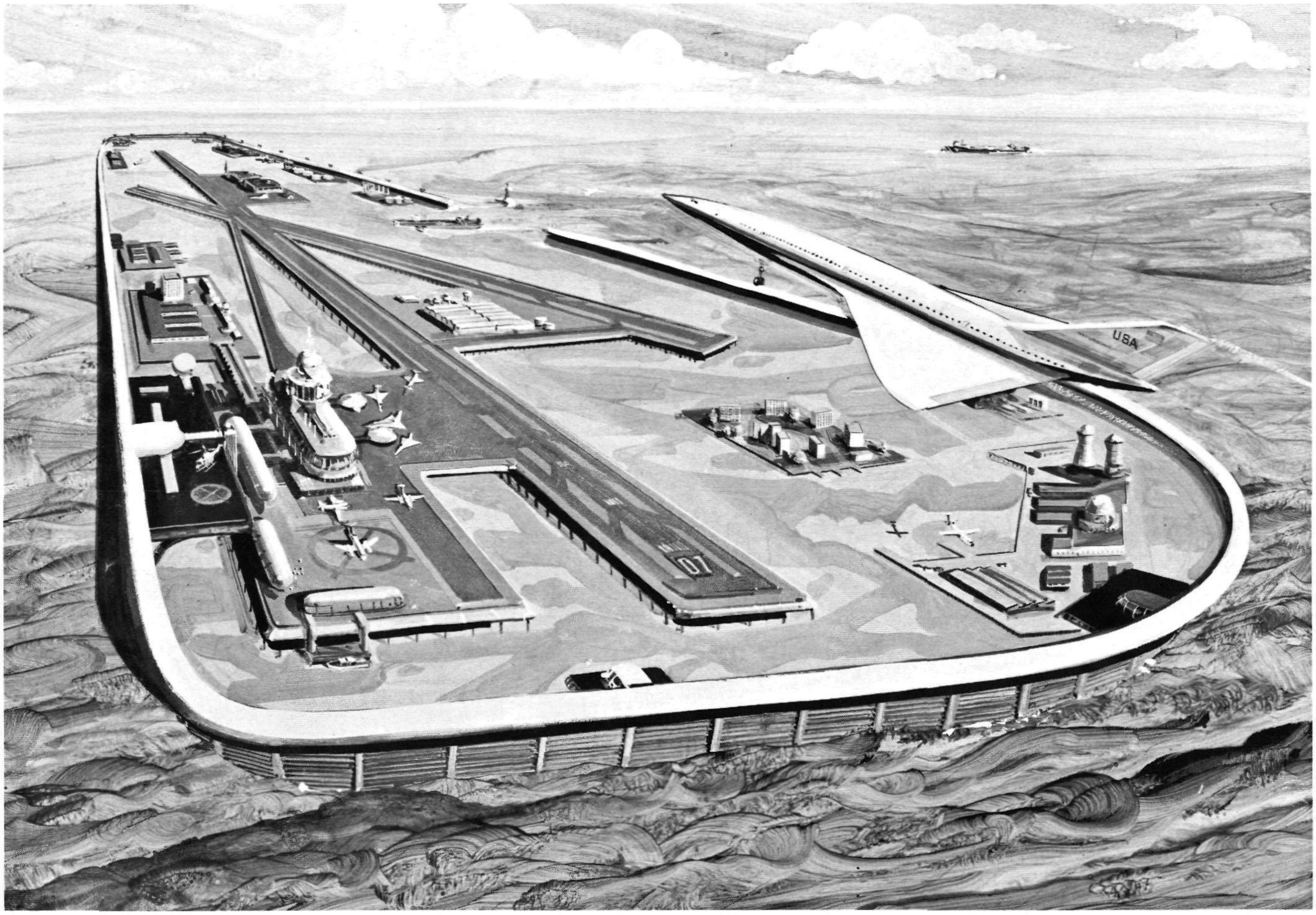

Figure 4. Future Offshore Airport Terminal to Service International Air Traffic. (Artist Concept).

These VTOL aircraft could provide both intra-urban and interurban passenger service and serve as versatile high speed links to major hub airports. The development of such VTOL aircraft will require improvements in fuel efficiency, operating costs, noise levels, control systems, and ride quality over present vehicles. This will require advances in all the basic aeronautical disciplines including, for example, aerodynamics, propulsion, structural design and the use of advanced materials.

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.*

The development of these advanced supersonic transports may lead ultimately to longer-range hydrogen fueled hypersonic transports. In the event that environmental or other considerations prohibit the use of convenient airport sites for these future intercontinental transports, it is conceivable that the airports would be located offshore, on man-made islands or island-lagoons built up from the sea floor on the continental shelf (see Figure 4). At such locations, perhaps 20 to 30 miles offshore, 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.

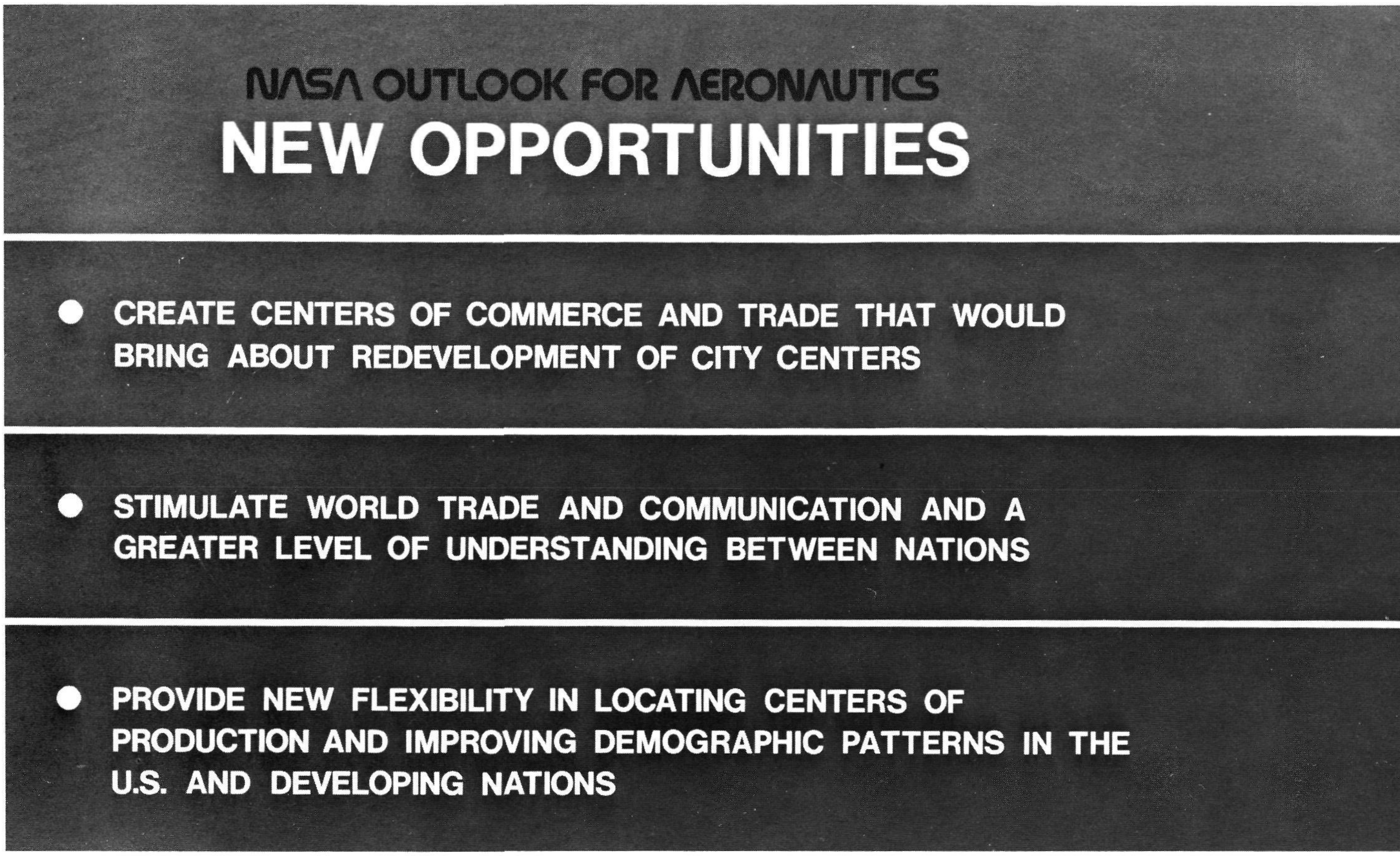

Figure 5. New Opportunities in Aeronautics and the Future Aviation System

Basic extensions to the state-of-the-art will be required in many of the aeronautical disciplines for hydrogen fueled hypersonic aircraft. In addition, there will be technology requirements not encountered on previous transport aircraft developments. The combination of severe aerodynamic heating and cryogenic fuel requires a sophisticated thermal protection system and imposes severe demands on structures and materials. Dual propulsion systems must be developed, (e.g., turboaccelerators for takeoff and climb and ramjets or scramjets for high Mach number climb and cruise).

The larger 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 airships, could operate from the coastal or island terminals described previously.

These examples of new opportunities and the corresponding aviation systems (see Figures 5 and 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

NASA OUTLOOK FOR AERONAUTICS

AVIATION SYSTEM

- AN INTERCITY AIR SYSTEM USING SMALL AIRPORTS AND QUIET VTOL AIRCRAFT
- FAST INTERCONTINENTAL AIR SYSTEM USING OFFSHORE TERMINALS AND LONG RANGE SUPERSONIC AIRCRAFT
- AN INTEGRATED AIR CARGO, WAREHOUSING AND DISTRIBUTION SYSTEM USING VERY LARGE CARGO AIRCRAFT

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 trends and directions described above, covering primarily the period 1980-2000 but also anticipating the longer term opportunities, provide the broad context for a discussion of the NASA role and for the definition of technical programs that would be undertaken in the next decade. The details (for example, specific vehicle developments and their dates of introduction) may or may not be accurate, but the need for advancement in the several preferred directions, both civil and military, identified in this analysis can be stated with some confidence. Moreover, the opportunities that can be created through new forms of air transportation by the end of the 20th century are very significant for society as a whole and deserve NASA's attention.

THE ROLE OF NASA AND ITS TECHNICAL OBJECTIVES

As part of the 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, again considering the Survey Findings and the subsequent discussions. 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 R&D 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.

The current posture of the United States air defense and the existence of a modern air transportation system are the result of past R&D investments made in part by the government. An additional outcome of these investments has been the significant favorable contribution to the U.S. balance of trade through the sales of civil and military aircraft.

The general pattern of responsibilities that has evolved over a period of more than 50 years of aviation development can be summarized as follows:

- The manufacturing and air transportation industries carry the responsibility, respectively, for the design, development and production, and for the promotion and operation of the civil air transportation system.
- The research and technology that supports the evolution of the air transportation systems (civil and military) comes from the manufacturing community and the government.
- The academic group has carried the burden of education and basic research, the latter supported primarily by the government.
- The government itself has assumed the prime responsibilities for: broad aeronautical research and technology – (NASA); civil transportation policy – (DOT); civil air transportation safety, and the development and operation of the airways – (FAA); civil air transportation routes, scheduling, and fares (CAB); and military systems research, technology, development and procurement – (DOD).

In recent years, a number of factors has 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 foreign-government backed competition, and the increasing cost of making adequate R&D investments, including facilities investments, all point to the importance of a continuing government involvement.

A large majority of the world's commercial transport aircraft are of U.S. manufacture. These aircraft are operated by 150 airlines in more than 60 countries. If the U.S. is to retain its present position in civil aviation product development and sales, it is clear that the government must continue its support of research and advanced technology. It may be necessary also for the government to sponsor the initial design and development efforts for some future civil aircraft, in order to permit the industry to be in a strong competitive position.

ROLE OF NASA

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

> *"the general welfare and security of the United States require 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 national security, the Act goes on to say

> *"The aeronautical and space activities of the United States shall be conducted so as to contribute materially to one or more 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 Study group discussed the potential role of NASA and defined a preferred role within the context of this existing legislation, in terms of *Research, Technology,* and *Development*, as defined below. 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: Research in the disciplines that have known application to aeronautics, including aerodynamics, structures, propulsion, flight dynamics and control, avionics, and human factors. This work extends the level of understanding in these disciplines and permits greater confidence in their application to aeronautics; results are applicable generally and are independent of aircraft type. Use of both ground based facilities and research aircraft may be required.

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

Technology: Advancement of technology to the point where its applicability to aircraft configurations and aircraft subsystems is established (i.e., wing aerodynamics, rotor blade structures, engines, automatic control systems, etc.). This work extends the state of the technology for a given class of aircraft (i.e., subsonic transports, or supersonic fighter aircraft, or V/STOL aircraft) as opposed to all aircraft, and is time-critical with respect to readiness for aircraft development. The use of ground and flight facilities is required.

NASA, in pursuing advances in technology would identify the potential benefits of technical advances in order to guide the direction of its programs, would work closely with industry and with the DOD and DOT/FAA as appropriate, would utilize its unique ground based facilities and would acquire, through the industry, experimental aircraft and engines for the purpose of advancing and demonstrating the state of aeronautical technology.

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 systems, 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 the future aircraft into the air system.

Development — In considering the potential NASA role in development, the following definition was used: The integration of technologies into a product or production prototype in order to demonstrate its technical feasibility. The primary goal is to incorporate the most recent improvements in the state of technology, were applicable. This work requires extensive ground and flight testing to establish a high level of confidence.

In this event, NASA would participate with the industry in government-sponsored design and development through the prototype phase, of civil aircraft, and would play a technical management role. The financing of such programs would be either a NASA responsibility or that of another agency.

The Study Group concluded that the preferred role of NASA, in terms of the foregoing definitions, 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 civil and military aircraft foreseen for the future; and
- If the necessity arises, to participate with the industry in civil aircraft prototype development without compromising NASA's primary role in research and technology.

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 depending 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 applicable 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 government 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.

Consistent with these guidelines, technical program objectives for the period 1976-1985 were defined in two basic categories, *Research* and *Technology.* This should not be considered a comprehensive description of the NASA program in aeronautics, but rather a compilation of critical areas for the period 1976-1985. No specific objectives in civil aircraft development were formulated in view of the need for further consideration by NASA of its role in this area.

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.* These efforts are not aimed at a specific vehicle or class of vehicles, but are disciplinary in nature and seek an understanding of phenomena that are encountered in these flight regimes.

The broad objectives and the program of research in each category are summarized as follows:

Low-Speed Flight Regime

Objectives: Provide an improved understanding of the factors that effect the performance, flying qualities, control characteristics, and environmental impact of aircraft and rotorcraft in low speed flight, with emphasis on takeoff and approach & landing, in order to permit:

More complete utilization of the potential capabilities of future vehicles to operate safely, efficiently, and comfortably in the airport terminal area.

Improved accuracy of flight path under normal and adverse weather conditions, through advances in control theory and application, leading to predictive techniques, gust alleviation, flare control, and four-dimensional guidance.

Reduction of wake vortex upset moments on following aircraft and as a consequence more efficient use of terminal airspace.

Reduction in landing speed and field length through the use of high-lift aerodynamic devices and propulsive lift.

Reduction in aircraft noise and community impact through constructive interference between aerodynamic and propulsive flows, the use of new acoustic suppression materials, and optimal flight path control.

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, in order to permit:

Significant reductions in fuel consumption through the development of more efficient subsonic aerodynamics and advanced propulsion concepts.

Improved structural efficiency through the broad utilization of composite materials and new structural concepts.

Reductions in aircraft weight and expansion in the operational envelope through implementation of practical active control systems to reduce the requirements for aerodynamic stabilizing surfaces, reduce gust and maneuvering loads, and inhibit buffet onset.

The use of hydrogen and nuclear fuels to provide very long range and endurance.

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 through efficient aerodynamics, advanced propulsion concepts and structural approaches capable of withstanding the associated high temperatures.

Improved public acceptance through reduction of sonic-boom levels at the ground and reduction in atmospheric contamination due to engine exhaust.

Improved maneuvering of aircraft and missiles through the interaction of aerodynamic and propulsive forces.

In carrying out this research, NASA would work closely with the 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.* The technology objectives are oriented toward broad classes of aircraft (as opposed to a single type of aircraft), are generally responsive to well-defined needs, and may be critical with respect to timeliness of accomplishment.

The broad objectives for the Technology Program in each category are summarized 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.

Improve aerodynamic performance and reduce noise for conventional, STOL, and VTOL aircraft throughout their operating range (takeoff, transition, cruise and landing) by advancing the technology for wing/flap systems, wing/engine interactions, and rotor and propeller aerodynamics and dynamics.

Utilize experimental engines, compatible with advanced aircraft configurations, to investigate concepts for increased efficiency in cruise and reduced noise at takeoff and landing by incorporating improvements in materials and component performance.

Develop more efficient structural concepts compatible with the dynamic and acoustic loading and temperatures encountered in high thrust-to-weight aircraft.

Develop procedures that will enable safe, quiet, and efficient operations with emphasis on the use of new avionics to provide better guidance and control in restricted airspace (i.e., in the terminal area near civil airports and in the vicinity of small landing sites for military aircraft).

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:

Improve the aerodynamic performance of conventional and very large transport aircraft throughout their operating range through advanced wing design and reduction of skin friction drag.

Investigate the feasibility of experimental engines with significantly reduced fuel consumption and reduced noise at takeoff and landing through improved materials and more efficient components.

Investigate the applicability of composite materials and other advanced materials to practical, long-life aircraft structures to achieve significantly reduced weight.

Utilize active control systems to improve performance through more precise flight control, reduced aerodynamic stability requirements, and alleviation of dynamic in-flight loads.

Investigate procedures that will enable safer and more efficient en route operations using area navigation and improved meteorological information.

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:

Improve design approaches for improving the maneuverability of fighter aircraft through advanced configurations and devices to reduce buffet and flow separation at high angles of attack.

Demonstrate advanced engine nozzles with in-flight thrust vectoring capability and variable-cycle engines with more optimum combinations of subsonic/supersonic performance.

Improve structural concepts to reduce the weight of very-highly-loaded aircraft structures and increase their damage tolerance.

Extend the technology to improve the combat capabilities of control-configured aircraft with minimal stabilizing surfaces, direct-life and side-force controls, and vectored thrust.

Long-Range Supersonic Aircraft

Objective: Provide the technology that will permit the development of efficient, environmentally accepted supersonic cruise aircraft:

Increase the range of supersonic aircraft and reduce their sonic boom through the use of advanced configurations and improved integration of their propulsion systems.

Develop variable-cycle engine technology for increased efficiency and low exhaust emissions at cruise, improved subsonic performance, and reduced noise at takeoff.

Investigate new lightweight materials, including composites, suitable for the elevated temperatures encountered during supersonic cruise.

Investigate active control systems to improve performance and handling characteristics through reduced aerodynamic stability requirements, alleviation of gust and maneuvering loads, suppression of structural modes and buffet, and more precise flight control.

Improve navigation and fuel-management techniques to promote safe, reliable, and fuel-efficient supersonic operations.

These objectives involve 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). All areas are important to each aircraft class, although some become more critical in specific applications.

In carrying out its technical effort, 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 made by the NACA (the predecessor agency to NASA) in the years 1940 to 1955; over $560 million* were invested in the construction of facilities in that 15 year period.

Since 1955, however, the pattern of facility investment has been markedly different. In the 15 year period 1955-1970 investment 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 future aircraft. The following discussion addresses more specifically the need for new techniques and facilities for research and technology development.

Wind tunnels and research aircraft, the traditional tools of aeronautical research, have in recent years been augmented by the introduction of flight simulators and large capacity digital computers.

*1975 dollars

The purpose of each kind of facility, and the associated methods and techniques that are used with them, differ, but all four are critical in providing design information for aeronautical development.

In general the NASA objectives are to investigate new methods, techniques and facilities to permit:

> The modeling of complex fluid flows around aircraft and within propulsion systems, of acoustic phenomena, of the dynamic behavior of structures, and of control system design and operation.
>
> The simulation of visual scene and motion experienced in aircraft flight and the investigation of man-machine interactions.
>
> The measurement, through direct and indirect means, of aerodynamic and acoustic phenomena, of material and structural properties and control effects.
>
> The construction of ground based and flight facilities including research or "proof of concept" aircraft required to investigate and test at conditions representative of those anticipated for aircraft of advanced design.

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 in future developments. NASA can, and should play a leading role in the creation of new methods, techniques and facilities that will serve the aviation industry for the remainder of the 20th century.

Computers: 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. While an adequate representation by this means still requires the use of much semi-empirical information, an initial evaluation can be made of the performance and weight of new aircraft configurations.

The use of computers to make accurate performance calculations will depend on a better understanding of the basic aerodynamic phenomena, particularly the properties of turbulent flow, and on further improvements in computer technology that will permit increases in speed and capacity. With continued progress in these areas it can be expected that the large special purpose digital computer will play an important role in aircraft design. These computers will also find application in aircraft guidance and navigation and the modeling of air traffic patterns in the terminal area of large airports.

Wind Tunnels: 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. The design of new aircraft, such as VTOL aircraft, which utilize combination of aerodynamic and propulsive forces will require accurate and detailed information that can be gained only through the use of larger wind tunnels. Similarly, the need to reduce the cruise drag on large commercial and military aircraft requires a more accurate representation of the aerodynamic flow conditions (i.e., the pressure and viscous forces) than can be provided by current facilities. A more detailed understanding of the structural dynamics of aircraft and rotorcraft is required in order to permit reductions in weight and this again gives rise to the need for new facilities.

A major task in the years ahead will be to update the nation's wind tunnel test capabilities to the point where they once again provide data on conditions close to those experienced in flight. Fortunately, substantial progress has been made during the past five years in creating the diagnostic tools, for example, on the use of laser instrumentation, and in the rapid processing of data. However, the construction of larger and more versatile facilities is now required to assure that the best design information is made available for the next generation of aircraft.

Flight Simulators: The piloted flight simulator is the primary tool used in the fields of flight dynamics, control system development and human factors. The understanding of the flight characteristics of new aircraft, the development of certification criteria, the validation of aircraft control concepts and the formulation of new approaches to air traffic control procedures are examples of the many uses of the modern flight simulator. Research in air system safety is also possible through the use of these techniques.

The emphasis on the control of development costs and operational training costs suggests that 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 its 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.

Research Aircraft: 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. This is particularly true when the flight conditions are too complex to permit simulation, or involve an environment that is too severe to duplicate in ground facilities. 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.

An additional purpose in the development of these research or "proof of concept" aircraft is the opportunity created 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.

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.

This Study will aid NASA in making rational judgments with respect to the most probable future needs for aeronautical development and with respect to the role it should play to assure that those developments occur in a timely fashion. The technical information summarized in the Study provides a basis for defining the directions of NASA's future aeronautics program.

The primary specific 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 systems combining aircraft and advanced weapons.
>
> Two aeronautical developments that are critically important to U.S. leadership in aviation deserve to be highlighted as major opportunities in the next two decades. They are (1) *quiet vertical take-off and landing, and* (2) *efficient flight at supersonic speeds.* The acceleration of these two developments would revitalize air transportation and provide essential new capabilities in air defense and air mobility.
>
> A number of specific technical advances are required in order to bring about the aircraft developments foreseen for the 1980s and 1990s and to provide the technical springboard for new opportunities in aviation. These include: composite structures, new propulsion cycles, synthetic fuels, new aerodynamic configurations, the use of active controls and improved operational procedures, and the development of new design techniques employing computational and stimulation methods.
>
> Thus, to permit such 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 important 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, and new aeronautical facilities will be 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 continuing investments in research and development by both the industry and the 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 A
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 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 safety and public impact of air transportation are seen by the airlines, the airport authorities and the FAA as a continuing focus for technology advancement, particularly in the light of increases in the volume of air traffic, the introduction of large aircraft and the continuing public resistance to the siting of new airports. Improved aircraft for safe, all-weather operations, efficient utilization of airspace, and minimum noise impact on local communities are all achievable through further technological progress, and deserve continued attention by NASA.

The current excess of capacity over demand for civil air transportation, combined with the lack of fundamental technological advances over the past decade provide little prospect for the introduction of more efficient aircraft in the near-term. Most industry leaders feel that the next 10 years will see the continued production of existing transport aircraft types and the development of derivatives thereof, but that no major new U.S. transport aircraft will be introduced into service. Beyond this time, however, it is very probable that market opportunities will lead to all-new transports of advanced design, providing that a substantial amount of new technology can be incorporated. These transports will have significantly better efficiency and performance than those of current design.

With respect to military aviation, the reduced number of overseas bases and the limited access to staging and refueling sites will have a significant influence on future sea and air forces. The need for long range aircraft and air-capable ships will require major improvements in the performance of subsonic transport and tanker aircraft and give impetus to multipurpose VTOL aircraft capable of operation from aircraft carriers and smaller ships.

A program of research and advanced technology that helps provide a broad base for military defense in the future is underscored by all three military services as a critical long-term investment that must be made in the national interest. NASA is strongly encouraged, as a primary aeronautical research agency, to involve itself with the DOD in the provision of this research and technology base, and particularly in those areas where it can contribute unique skills and facilities.

The ability of the U.S. aircraft industry to maintain its position of world leadership, and the benefits that accrue to the nation from this position, depend on a readily available inventory of technical information, and a continuing flow of innovative technology advancements, that permit the industry to take advantage of market opportunities as they arise. It is the view of the U.S. industry that NASA must play a greater part in assuring that the necessary information and technology advances are generated.

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, however, 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 a significant role in accomplishing the necessary research and technology.*

Findings — Future Directions in Civil Aviation

The demand for air transportation will have a strong impact on the future of the industry. The trunk and international airlines have experienced a reduced growth rate in the past year after several years of sustained growth; Regional airlines, however, have seen consistent growth over the past five years with prospects for continued near term growth. While the production rate of transport aircraft is currently well below the peak production rate experienced in 1968, general aviation production is now approaching the peak levels experienced in 1966, and rotorcraft production is at an all-time high with production rates still increasing.

Future demand for short haul domestic air transportation will be stimulated by changing demographic patterns, increasing suburbanization and an increasing need to relieve traffic congestion at major hub airports. Long haul traffic growth will depend on international trade and tourism and particularly on the evolution of the Pacific Basin as a trading area; long haul air cargo is expected to grow at twice the rate of passenger traffic (exceeding 10% annually) and may lead to new approaches to combined transportation, warehousing and distribution centers.

The airline and manufacturing segments of the aviation industry are necessarily cautious and conservative in their estimates of future air transportation growth and predict that annual growth rates for the next 25 years will not achieve the levels seen in the period 1950 to 1975 (during which period a tenfold increase took place). This view results, in part, from the currently poor economic condition of the airline industry, but is also based on longer term projections (5 to 10 years) of the probable demand for business and pleasure travel, and the probable cost of producing and operating aircraft in the future.

The general aviation aircraft growth rate currently exceeds the average for the industry, a trend which is expected to continue; the increasing use of small aircraft for business travel is in part a result of restrictions on speed of surface transportation and on frequency of airlines schedules. The increasing use of small rotorcraft for transportation and utility purposes is seen as a continuing trend, and will be sustained by the demand for greater speed and range in such applications as supply to oil rigs at sea, pipeline and utility line inspection, natural resource development, etc.

The increasing cost of air transportation (due to higher maintenance, labor and fuel costs, and to reduced passenger load factors) that has been experienced in the past 5 years is expected to continue in the near term. The price of aviation fuel in the future is uncertain but is not expected to fall below current levels. Improved aircraft fuel efficiency is a significant factor that will encourage the introduction of short haul and long haul aircraft of advanced design provided that their overall operating costs are sufficiently low and provided that the retirement of existing aircraft does not carry too great a penalty. Their design should aim at improvements of at least 30% in efficiency.

It is generally believed that the capacity of major airports can be extended to meet the projected demand for the early 1980s, provided the wake vortex problem, which currently prevents closer aircraft spacing, in the airport terminal area is solved. Many airport officials feel, however, that the landside capacity, even with currently planned expansions, will be insufficient to accommodate the passenger demand projected for the early 1980s. The ability of airport authorities to acquire alternate airport sites will be affected by community noise and land-use policies and these in turn will have implications for the design of future aircraft.

The development of airways and airport systems as part of a broader intermodal transportation system is seen by many in government and industry as important to the nation. It will be necessary to consider the total system of aircraft, airways, airports, ground access and ground transportation in future planning, in order to provide a system that meets safety, service, and energy objectives within environmental and cost constraints.

The air traffic control system is currently being upgraded by the FAA/DOT in order to meet the operational needs of the nation's aviation system into the 1980s. These improvements can be expected to bring the following changes in operational capabilities at major airports; reduction in longitudinal and lateral aircraft spacing; improved delivery accuracy; use of dual-lane runways; use of curved approaches and departures; semi-automated surface traffic control; and an increase in IFR operations of 50-80% over present values. However, it is probable that traffic increases will outstrip these improvements and that additional development in traffic control, communication and navigation that incorporate advanced technology must be planned for the period 1985-2000. Such developments must consider both the airborne and ground based functions of traffic control and may require greater degrees of automation as a means of assuring safety and reasonable cost of operation.

In summary, the following are the findings with respect to major 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 siting 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 terminal area operation.*

- *The air traffic system, as part of an integrated transportation network, will require substantial improvement to meet the projected future 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.*

Turning now to possible future civil aviation developments, the most probable early development in short haul air travel is expected to be an efficient, short-to-mid range subsonic transport. For high density short haul routes the development of both V/STOL aircraft and high speed ground transportation may evolve in the far term.

In long haul air transportation the most probable new aircraft developments include passenger and cargo aircraft derived from current configurations followed by a 200-250 passenger mid-to-long range aircraft having fuel efficiency characteristics that represent substantial improvements over current aircraft. A later development may a large aircraft (perhaps around 1,000,000 pound gross weight) designed for dedicated cargo use.

The prospects for a U.S. supersonic transport will depend on the impact that Concorde has on scheduled first class travel on the North Atlantic routes, on the influence of fuel costs and environmental considerations, and on the willingness of industry and the government to undertake its development. When efficient long-range supersonic transports are developed, it is expected that they will have a major influence on world travel and trade. Development of more advanced concepts such as hypersonic and hydrogen or nuclear fueled transports are not expected before the end of the 20th century.

The following finding relates to civil aircraft developments in the period 1980-2000:

- *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.

A 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.

Findings — Future Directions in Military Aviation

It is thought that developments in new defense systems may be made less frequently in the future and that choices must be made between maintenance and updating of current weapons systems and their derivatives and the introduction of improved weapons which could provide defense readiness with reduced total cost and reduced manpower. In the near term, the outcome is likely to be an emphasis on product improvement and the introduction of multiple use aircraft, when this is feasible. In the long term, new equipment will be developed on the basis of minimum life cycle costs.

The following finding summarizes in general terms, the factors 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.*

It is anticipated that new short range subsonic and supersonic military aircraft of advanced design will be needed in the next 25 years. Naval V/STOL aircraft and advanced military rotorcraft having range capabilities of several hundred miles are seen as significant developments. These aircraft and rotorcraft will be used for a variety of purposes including short range logistics, anti-submarine warfare, air-sea rescue, and escort gunships.

Due to the probability of reduced access to overseas bases in the future, long range logistic support and long endurance patrol and surveillance will become increasingly important. Large cargo and tanker aircraft having extended range (15,000 miles or more) may be required in order to provide military logistics. The use of long range aircraft for airborne missile carriers, for airborne command, and control, and for high-capacity airlift may ultimately lead to the development of nuclear-powered aircraft.

Air combat superiority has in the past depended on such performance parameters as speed and altitude capability, maneuverability, acceleration capability and weapon systems effectiveness. The current "lightweight fighters" represent the culmination of this trend and have markedly superior air combat performance as compared with older designs. In the next decade, there will be continued improvements, including all weather capability in manned supersonic attack and fighter aircraft. Ultimately, the development of maneuvering missiles, remotely piloted vehicles, and laser weapons may significantly change the nature of air combat and may reduce the need for conventional manned aircraft for this mission.

- *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

A large majority of industry, and particularly in the manufacturing segments, strongly urges that NASA give renewed attention to its "NACA" role, – to the conduct of basic research and technology programs, including the exploration of new flight regimes, that extend the state-of-the-art of aeronautical technology and provide the fundamental information required for future aircraft developments; and to the provision of consultant services to the industry and to other government agencies. This view was also held by the Department of Defense, the Department of Transportation and the universities.

The need for closer cooperation, including the joint funding of technical programs, between NASA and DOD, is stressed. The period of greatest progress in U.S. aviation occurred when civil aircraft developments benefited from technology investments made initially for military purposes; it is believed, therefore, that new technology should be directed, whenever possible, so that it serves military and civil needs simultaneously. The technology for future aircraft will also be influenced by the need for an integrated air transportation system, compatible with other modes, and its direction, therefore, requires close cooperation between NASA and DOT.

The sponsorship of advanced technology programs by foreign governments within their aircraft industries will provide severe competition for the U.S. aircraft industry and is a source of concern. Recognizing that foreign governments are in a position to determine which aircraft will be used in their own airline fleets, it is probable that U.S. companies may be required to enter into joint, (e.g., coproduction), arrangements with foreign aircraft manufacturers. The importance of advanced technology to the U.S. industry is recognized, both as a means of meeting foreign competition or as a bargaining tool in the process of arriving at joint arrangements. While direct involvement of the U.S. government in the production and operation of civil aircraft is discouraged, the view was expressed that a new relationship between industry and government may be required in order to provide technology investments that the industry cannot currently make in its own behalf.

It was generally felt that NASA facilities, particularly its wind tunnel facilities, have in the past contributed to the strong position currently held by the U.S. industry. NASA is encouraged to give futher emphasis to the development of new facilities required for future progress in aviation and to make these readily available to the industry, either on a cooperative or fee basis, during the predevelopment and development phases of new aircraft. In view of the increasing costs of construction and operation of ground-based and flight-test facilities, improved coordination, and possibly consolidation of facilities, between NASA and the DOD was suggested, particularly with respect to their management and utilization.

The federal government has a considerable investment in aeronautical research facilities. Most of these facilities are under the jurisdiction of the Department of Defense and NASA, whose combined investments totaled about $1.3 billion by 1969 (with a worth in 1969 dollars of $2.5 billion). In addition, the government owns facilities managed by the FAA and has financed facilities at the universities, and within the industry.

As requirements change, there is a continuing demand for the modification and modernization of existing facilities and the construction of new facilities. The recently formulated National Aeronautical Facilities Program recommends the following developments: construction of the Aeropropulsion System Test Facility (U.S. Air Force), the Transonic Research Tunnel (NASA), and modification of the 40- by 80-foot Subsonic Tunnel (NASA). Cooperation between NASA and the DOD in the use of such facilities is essential because of the high cost.

Many participants in the Survey, particularly those associated with the universities, expressed concern over the recent trends in aerospace employment levels and university enrollments. Although the total number of scientists and engineers in the U.S. has been fairly constant over the last ten years, the number employed in the aircraft and missile industries dropped significantly between 1969 and 1972. The impact has been most severe on the younger segment of the work force as reflected by the fact that currently only 20% of the membership of the American Institute for Aeronautics & Astronautics (AIAA) is under 35 years of age.

The decline in the number of young professionals entering the aerospace field is consistent with the reduced enrollment for a number of leading universities over the past few years. Although the low point seems to have been reached in 1974, the substantial decline in enrollment experienced prior to that period may cause severe personnel shortages by the end of the decade. It was suggested that, since the U.S. government is dependent on civil and military aviation, it has a responsibility to help ensure an adequate supply of qualified manpower.

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

- *It is generally believed that NASA's role be characterized by: basic and applied research in aeronautics; the advancement of aeronautical technology in cooperation with other government agencies, and particularly with 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 risks may necessitate government participation in selected civil aircraft 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 university 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 is trained to meet the needs of U.S. aviation in the 1980s.*

Findings — Technical Programs

A stronger commitment by NASA to the R&T base, or disciplinary, segment of its program is required in order to replenish the storehouse of fundamental technical information that has been depleted and overtaken by two decades of rapid development in aeronautics. The dependence of all future developments, in both civil and military aircraft systems, on a vastly improved understanding of aerodynamics, acoustics, structural and material properties, combustion processes, and on information and control theory, demands that these disciplines receive dedicated attention and support within NASA and the university community.

The emphasis on vehicle performance, which in the past has been a significant driving force for advanced technology, is not expected to play so dominant a role in the future. Increasing development costs will result in fewer new aircraft developments unless the technology can be directed toward lower-cost approaches to achieving the desired performance. A greater appreciation is required by NASA of the manufacturing and operational cost implications of proposed technical developments including those that address improvements in safety and environmental impact.

With respect to the incorporation of advanced technology into aircraft configurations, NASA should engage in the reduction to practice, and if necessary, in subsequent demonstration of technology only in close cooperation with the industry or the responsible government agency. In general, NASA is not encouraged to assume responsibility for end-product or prototype demonstration as a means of promoting early introduction into commercial service.

The following reflects the finding 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.

The manufacturing and airline industries emphasize the need for continued technical improvements that will allow greater productivity and lower costs in air transportation. Advances in composite structures that can reduce aircraft weight, improvements in specific fuel consumption and aerodynamic refinements that permit overall performance improvements and the use of active controls to permit greater freedom of design are all encouraged within the NASA program. The rate of introduction of this technology into new aircraft design will be determined by the industry as a result of both cost and performance considerations. An evaluation of the potential benefit of these advances in technology and their use in aircraft design can be accelerated through design techniques employing computational and flight simulation methods that allow aircraft performance to be determined accurately prior to manufacture.

The development of composite structural materials to achieve reduced structural weight has proceeded in an orderly manner from laboratory-scale experiments to the present limited use in military and civil aircraft. The long life times of civil transports require substantial experience with a new material before an aircraft manufacturer will commit to its use for primary structure. Potential structural weight savings of about 25%, fuel savings of the order of 10-15%, and some reduction in fabrication costs are expected from the large-scale use of composites. Vehicles which are relatively more performance critical, such as SSTs, VTOL aircraft and rotorcraft may show greater benefits from the application of composites.

The need for improved fuel economy has added new impetus to the study of advanced propulsion systems for every type of aircraft. In the early 1960s, an era of cheap petroleum, the higher productivities and passenger appeal associated with jets made them the universal choice for the trunk airlines. Some improvement to current jet engines may be achieved through increases in turbofan engine cycle pressure ratio and temperature or through unconventional cycles such as regeneration. With the substantially higher fuel prices of today, the propeller is receiving renewed attention because of its high propulsive efficiency. The need for improved propulsion system cycles is particularly acute for the advanced supersonic transport aircraft and several engine cycles are currently under study employing various amounts of variable geometry in an effort to achieve low takeoff and approach noise levels and good cruise efficiency.

The best prospect for reducing the dependence on petroleum based fuels in the near term is the development of synthetic jet fuels from shale-oil or coal, or both. Domestic jet fuel prices in the last two years have increased from 12¢/gallon to 30¢/gallon and could increase further. At a price of 50¢/gallon synthetic jet fuel from shale becomes competitive. The cost of liquid hydrogen as an alternate fuel makes it a relative far-term solution to the aircraft fuel problem.

Refinements in aerodynamic design, in conjunction with higher aspect ratio wings with increased thickness and lower wing sweep, give the promise of increasing wing efficiency. The development of practical methods of laminar flow control would bring about fuel savings of 20% or more for transport aircraft.

Active control technology can be applied to achieve stability augmentation, maneuver load alleviation, gust load alleviation, ride quality improvement, and flutter suppression. The use of sensors and electronic feedback control techniques can allow the relaxation of critical design constraints and result in lighter weight structures. The benefits of this technology depend on the aircraft configuration and its mission.

The desire for NASA to provide a broad information base from which the industry could establish performance sensitivity to design changes, as opposed to specific aircraft point design information, was expressed by the industry. Such an information base should include parametric data on wing and rotor aerodynamics, aerodynamic-propulsive interactions, aircraft handling qualities, variation in material properties with temperature and stress, and the influence of alternate structural approaches on weight.

The technical advances which should provide focal points for future efforts within NASA are suggested in the following findings:

- *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 decade. These include:*

  Composite structures that will reduce both the weight 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 and are substantiated by the more detailed Survey Report. (see Appendix B under separate cover).

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