AEROSPACE
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SOME MAJOR IMPACTS OF THE NATIONAL SPACE PROGRAM

II. Impacts Upon Aviation and Aeronautics

Prepared for:

I.P. HALPERN
NATIONAL AERONAUTICS AND
SPACE ADMINISTRATION
WASHINGTON, D.C.

June 1968

STANFORD
RESEARCH
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SRI Project MU-7227
NASA Contract NASW-1722

FOREWORD

This is the second in a series of task reports within a brief study of "Some Major Impacts of the National Space Program."

Within this investigation, many candidate impacts were first screened and those that appeared (1) minor, or (2) not likely to yield to sufficient study within the short time available, were eliminated. The remaining impacts were subjected to further study and each is separately reported within this series.*

The results of this study are the first concrete assays within a welter of conflicting, incomplete, exaggerated, and frequently unsupported information. Stanford Research Institute considers its objective study an important task and is looking forward to extend the scope of this study in the future, by application of the background, methodologies, and initial results obtained to date.

John G. Meitner
Project Manager

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* The titles are: "Economic Impacts," "Identification of New Occupations," "Impacts of New Materials Technology," "Impacts upon Aviation and Aeronautics," "Impacts upon Health, Biology, and Medicine," "Some Total Impacts of NASA Capability," "The Impact of the Space Program upon Science--1. Astronomy."

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SUMMARY

Highlights of the NASA aeronautical research program as presented by NASA and as presented to the public through the trade and news press are reviewed here.

We find that while the research and development effort is eminently successful and current as shown by the technical quality and competitive position of U.S. aeronautical equipment, the NASA effort is never presented in a positive light when the message is directed at the general public, nor is it complete when directed toward the technically oriented community.

Since the NASA aeronautical activity is not separated from operational vehicles by more than a few years, direct economic benefits that pay for all of the NASA aeronautical research can be pointed out. Also, since the technology is not far in advance of its application, the new jobs resulting from improvements can be identified; opportunity exists to train the surplus labor (hard core unemployed) for the jobs. These and other benefits are described in some detail in the body of this report.

On the other hand, there are indications that the lead in aeronautical research NASA once had is gone; in fact, some valuable breakthroughs are late. It is also indicated that the advanced programs are important in maintaining a research lead.

INTRODUCTION

The NASA Aeronautics Program work is categorized into three areas, as shown in Table 1 (Ref. 1).

Table 1

STEPS IN THE NASA AERONAUTICAL RESEARCH CYCLE

Step 1 - Advanced Research

Exploration of new ideas not yet related to aircraft.

Aerodynamics
Propulsion
Structures
Operating Environment
System Dynamics

Step 2 - Applied Technology

Study of ideas from disciplines combined to give a new aircraft type.

Aerodynamics
Propulsion
Structures
Operating Environment
System Dynamics

Step 3 - Developmental Technology

Support of other groups in choice of specific vehicles and solution of detail problems.

Aerodynamics
Propulsion
Structures
Operating Environment
System Dynamics
Mission (from DOD, FAA, etc.)

Step 1, advanced research, consists of exploration of new ideas, not related to specific aircraft, in aerodynamics, propulsion, structures, operating environment, and system dynamics and forms the basis for step 2.

The applied technology step consists of the study of new vehicle concepts resulting from the integration of new developments in advanced research. NASA does not develop these vehicles but the definition resulting from this research phase has proved helpful in indicating to the industry, to Congress, and to the public where NASA aeronautics research is leading the country in terms of new aircraft. Step 3, developmental technology, is a supporting activity to the agency responsible for specifying an aircraft mission and developing the aircraft to meet it. This activity absorbs a substantial percentage of the NASA aeronautics effort. Table 2 shows the percentage of NASA aeronautics research activity and professional manpower that has been devoted to answering requests for assistance from military and civil agencies and the industry.

Table 2

NASA DEVELOPMENTAL TECHNOLOGY SUPPORT
FOR GOVERNMENTAL AGENCIES (CY 1965)

	Facility Hours	% of Total	Analysis, Consulting Man-Years	% of Total
NASA total available	69,000	100	374	100
Total NASA support supplied to DOD and other agencies	29,392	42.5	86	23
NASA support of DOD (13 aircraft, 13 missiles, 6 miscellaneous projects)	17,883	25.9	58.2	15.6
NASA support of other agencies (FAA, NSF, etc.) (Proposal evaluations, accident and safety of flight investigations)	11,509	16.6	27.8	7.4

Source: NASA (Ref.1).

AERONAUTICAL TECHNOLOGY TRANSFER PROCESS

NASA's support of DOD, industry, and other governmental agencies is consistent with the capability of the facilities and staff. The support work load at times represents a diversion from basic research, but it is considered important for two reasons: (1) the facilities and staff have been made available for just such purposes and (2) the problem-solving activity can contribute to the development of a research facility or technique or inspire breakthroughs. For example, the data from the high speed research aircraft (Bell X-1, Douglas D-558-II, and Bell X-1-A), beginning in 1947, accentuated the need for research support through laboratory testing in the transonic region. By 1950, a transonic wind tunnel was in operation at the NASA (NACA) Langley Research Center (LaRC); and by 1951, Whitcomb (NASA engineer) began the experimental verification of the area rule (coke bottle) for aircraft fuselage design. This breakthrough, when applied to aircraft design, resulted in speed gains of as much as 25% (Ref. 2). In another effort, LaRC's work, which was partially in support of a British variable sweep wing tactical fighter configuration proposal, led to a breakthrough in design minimizing variation in stability as a result of wing sweep angle for a variable sweep wing airplane. A patent was issued in September 1962 and assigned to NASA (Ref. 3).

The variable sweep wing is an example of the natural way the steps in the NASA aeronautical research cycle occur. Variable sweep wing technology has been applied to aircraft capable of flying at supersonic speed efficiently and landing at existing airports safely. In the case of the fighter aircraft (F-111), an additional requirement is met: The aircraft must be capable of flying at high speed at low altitude in order to avoid radar detection, while permitting the pilot to function. The solution is to reduce the lifting surface area or its effectiveness in producing lift so that the aircraft does not respond to the atmospheric turbulence at low altitudes; the pilot is still able to observe terrain, read instruments, and make judgments. In order for the aircraft to fly at supersonic speeds efficiently, the aircraft wing must be of a certain form and small in area; the aircraft must have sufficient wing area and shape in order to land safely on runways typical in military situations. The performance advantages and economy of aeronautical vehicles based on this concept are dependent upon getting both the flight and landing ability from one airframe and from one engine(s). Thus, when the concept was first tried at LaRC in 1945, it led progressively to work at NASA in support of other agencies for two vehicles--the TFX (F-111) and the SST (Ref. 3).

Advanced Research

The advanced research step occurred in the time period from 1945 to 1959 and consisted of work with models in the wind tunnels, flight of several research aircraft, development of a new variable sweep wing concept, and studies of aircraft configuration in which the concept was utilized.

Applied Technology

The applied technology step always overlaps the research step. In this instance it consisted of the time period from 1958 to 1960 and involved work in aircraft configuration and performance studies using the new variable sweep wing concept.

Developmental Technology

The third, or developmental technology step, involved NASA support of other agencies for the F-111 and the SST during the time period from 1959 to the present. The supporting activity included (1) briefings of the staff using the technology and extending it for a specific aircraft mission; (2) assistance to the procurement agency in reviewing industry proposals; and (3) actual testing of a succession of aircraft models in various wind tunnels to evaluate all flight regimes, with variation in armament stowage and delivery, radar antenna location and size, etc.

At the beginning of the supporting activity (developmental technology), NASA is most expert in the technology and in the ability of the experimental method (facilities) to provide information on which to base vehicle design decisions. In the supporting phase, the technology is transferred to the user; in return, NASA obtains perspective on operational aspects of the particular aircraft mission. When the supporting phase is ending, the data are obtained, permitting correlation of wind tunnel and flight performance measurements. The supporting activity is the basis for improvement of the overall capability of the NASA staff and facilities. This activity provides guidance and background for additional basic research or applied technology as the aircraft is developed or improved after it is in operation. Continuing research and development activity performed by the manufacturer, by the user, and by the government (for the people) is usually a natural demand of aircraft operation based on advanced technology, particularly when it is successful. Two of the many possible examples will be given:

1. Operational success of the subsonic jet transport has caused it to be used for purposes and in quantities far greater than forecast. This increase in the operational use brought attention to the noise. More efficient, higher thrust engines (fan) were developed because the demonstrated demand justified the development cost. The fan engines are quieter at the exhaust, but the inlet noise

is more noticeable. So. R&D proceeds; it solves some problems but makes others, and alternative solutions are sought.

2. New, higher thrust engines made it possible to use higher cruise speeds if the critical speed of the airplane could be increased. The critical speed is the speed at which some portions of flow over the airplane become supersonic and cause a rapid drag rise. This need, and perspective based on earlier work, led to a new concept of airfoil design for high subsonic (transonic, supercritical) aircraft. This concept, invention, or discovery was based on understanding the aircraft structural design flexibility and the economic value of increased cruise performance.

Confirmation of NASA's Aeronautical Research Policy

The importance of all three steps in the aeronautical research cycle is indicated by the statement of Dr. John S. Foster, Director, Defense Research and Engineering, before hearings of the Senate Committee on Aeronautical and Space Sciences considering NASA FY 1969 authorizations: ". . . Every military aircraft the Defense Department buys evolves in part from basic and applied research conducted in the facilities of NASA. Industry depends on NASA to extend the aeronautical art and, through systematic research, to provide design data which can be used with confidence in developing new aircraft." (Ref. 4)

VARIABLE SWEEP WING TECHNOLOGY

Work on the variable sweep wing was started at the NASA Langley Research Center in 1945. The concept was considered advantageous in improving the low speed and landing qualities of the then high subsonic airplanes that cruised with highly swept wings (Ref. 3). This concept and its associated technologies, structures testing techniques, and facilities, as well as the perspective and technical familiarity of the staff at NASA, were matured in the design and flight testing of a variable sweep research airplane, in the evaluation of a British variable sweep fighter configuration, and in the work on the TFX (F-111) and SST. In the process of maturing, a patent was granted to NASA engineers for a concept in variable sweep that avoided both translation of the pivot and change in stability with wing sweep angle. This new concept involved moving the wing pivot outboard; the outboard wing pivot is used on the TFX F-111, the SST, and the Russian Mikoyan and Sukhoi variable sweep airplanes (Ref. 5). The stated advantages of the variable sweep wing technology as it has been evolved or developed are confirmed when a competitor expends his resources to copy it.

The NASA accomplishment with regard to the variable sweep wing has been good from the first test of the concept in the 1951 flight of the X-5 variable sweep airplane because of the quality of support given to the airplane development research programs. The technology represented by mature concepts and research and development capability was available in advance of need.

It is important for NASA management to note, that in spite of this, the expressed value of this technology is nonexistent in the trade or news press. More often, the press representations cause a negative reaction with a NASA involvement implied. The direct benefit of the NASA developed variable sweep wing technology as applied to vehicles is shown below.

Application to Military Aircraft

Economic comparison of military aircraft types is not practical because of their complex mission, critical dependence upon ground and on-board systems, disposable ordnance, and logistical and tactical situations. Economic evaluation of the effect of an aeronautical advance on a military aircraft is also impractical; however, if just one element of the performance requirements common to several types of aircraft is considered, a comparison can be made: All aircraft have to land; without lift engines, the maneuver is similar. The variable sweep wing technology permits better compromise between flight and landing; the aircraft flies better at higher speeds and lands better at lower speeds. Without variable sweep wing, the same aircraft would have a lower cruising speed or efficiency and a higher landing speed. With all other factors being equal, the faster landing aircraft will suffer greater losses. Without considering loss of the pilot and loss of system effectiveness, the cost to replace each aircraft lost would be approximately $5 million. The entire NASA aeronautics research expenditure for an entire year could be recovered through avoiding a few of these losses.

Application to Commercial Jet Transports

The variable sweep wing not only improves controllability in low speed approach flight, it is effective in reducing the touchdown speed while maintaining cruise flight efficiency. Low touchdown speed improves safety and reduces maintenance costs on landing gear, wheels, and brakes.

Availability of this type of technology, along with the capability to solve new problems quickly, is very effective in competitive situations. It permits one to start last and still end up first. The latecomer can take advantage of solutions to some operational problems and market analysis already performed by competitors, enter the market with promises, and secure the sales required to recover the investment. This is the situation at this time with the U.S. Boeing SST and the Anglo-French Concorde.

In comparing the American SST with the Anglo-French Concorde, an advantage for the SST in earning capacity based on normal usage is disclosed. Salient advantages for the SST are not considered; for example, the SST has growth potential in speed because of its structure--the Concorde does not. The SST approach speed is 148 to 150 knots; the Concorde approach speed is estimated to be between 145 and 165 knots but actual speed can be determined only after flight test where control margins are determined at low speed.

The Boeing SST approach speed is predictable because of actual experience with similar configurations; the Concorde approach speed must be determined by test and will probably tend toward the higher speeds. The basic reasons for this are that the pilot will feel more secure with the aircraft at a lower angle of attack and a higher speed and that the aircraft will respond better to control motion. The pilot will tend to trade the hazard on the approach for the hazard on roll-out.

The higher speed of 165 knots represents 21% more energy to dissipate at touchdown and roll-out, as well as less margin for error and greater potential damage resulting from failure. The higher approach and touchdown speed causes a greater proportion of the potential load carrying ability of the aircraft to be given up to wheels, brakes, landing gear, associated structure, and other arresting equipment. The lower landing speed and more familiar low speed flying qualities are made possible by NASA's aeronautical technology developments associated with the variable sweep wing.

BENEFITS OF NASA AERONAUTICAL RESEARCH

The NASA aeronautics program falls into six categories. The technical content of these program elements has been and is usually described in detail; the way in which the program results benefit people is often not explained. The six program elements are listed below (Ref. 1). Benefits of NASA's aeronautics program are discussed in sections that follow.

1. A continuing SRT (sustaining research and technology) research program directed at obtaining new basic knowledge in the physical sciences underlying advances in aeronautics.

2. A small but explicit effort to provide technical information important to advances in safety and utility of the rapidly growing general aviation activities.

3. A substantial and growing research program in V/STOL (vertical/short take-off and landing) air transports including helicopters, STOL (short take-off and landing) aircraft, and VTOL (vertical take-off and landing) aircraft. One phase of the program is directed toward problems of commercial application; the second, formulated and directed in joint activity with the DOD, is directed toward enabling military application of this capability.

4. As a research program directed at, first, resolving near-time problems of current subsonic jet, concentrating particularly in noise control and flight path control, and second, providing information to enable further exploitation of this valuable capability, including shorter field operation, new and quieter power plants, and increased cruise efficiency.

5. A major effort in support of the national SST (supersonic transport) program. A large element of this is in direct response to the FAA and its contractor requirements. In addition, NASA initiated research will continue to center around advanced propulsion technology and flight dynamics at about the same level as the two previous years.

6. An expanded but basic research program directed at reducing uncertainties in knowledge related to hypersonic cruise flight. Major efforts will be directed at continuing the hypersonic ramjet engine research, at initiating research on light weight structures capable of

operating at high equilibrium temperatures, and at determining the primary scale effects at hypersonic speeds to provide proper interpretation of data from existing ground based facilities.

New Basic Knowledge

The first item above provides the tools for all other activities. The total cost of the problem solution is less if the tools are already available and do not have to be defined (invented), designed, or developed while the problem solution is being attempted. The cost savings are significant and can be represented by a re-entry vehicle that confirmed predicted trajectory, a major aircraft redesign that was not required, the loss of an experimental aircraft that was prevented, or the third and fourth series of wind tunnel tests that were eliminated. Having a problem,solving capability (technology) early in the program saves money since fewer people are at work, and therefore, fewer people have to be reinstructed, less hardware has to be changed or rebuilt to new designs, and there is less chance for error or omission in making the changes.

NASA has a historical record of maintaining a technology base that is generally in advance of industrial and other requirements. The technology base is concerned with testing facilities, theoretical and technique developments, and concept qualifications. This available technology contributes to lower costs (Ref. 2).

Impact on Economy

Anyone who cares about the price of food cares about the productivity of the labor applied to food processing and distribution. We are talking here about the productivity of labor applied in the acquisition of aeronautical vehicles and the productivity of these vehicles, which influences the price of breakfast cereal in two ways: direct--if the advertising account executive has to pay more for his airline ticket, his service and the cereal will cost more; indirect--if labor is generally ineffective, the dollar value will decrease and the cereal will cost more dollars.

General Aviation

The second category of the NASA aeronautics program relates to general aviation aircraft. General aviation applies to all aircraft other than military or scheduled commercial. It is becoming an important element of our culture and economy; it is growing at a remarkable rate, and the growth trend is still rising. The final form of the light aircraft or airborne (smaller) vehicle is not clear; general aviation is not limited by today's technology and it has a bright future. Consider the data in Table 3.

Table 3

GENERAL AVIATION DATA (Ref. 6)

Annual U.S. production of general aviation aircraft	16,000
Value	$500,000,000
Manufacturing labor, people	31,000
Number of U.S. aircraft exported to 70 countries	3,000
Number of aircraft, present active fleet in the United States	100,000
1975 forecast of active fleet in the United States	185,000
Student pilot applications, 1966	90,000
Student pilot applications, 1967	116,000

In comparison with the automobile production rates (9,000,000 units/year, Ref. 7), these data are small. If the general aviation aircraft unit production grows to only 1/100 of the automobile production, it will reach 90,000 units per year; the active fleet will grow, and there will be a profound effect on people. As competing manufacturers improve the performance of equipment to secure their share of the expanding market, the range of the week-end pilot will increase, thus permitting the pilot to fly into unknown territory and environment. As air taxi service is increased, its usability will improve, resulting in more growth. Used aircraft will be operated by new pilots and will be replaced by higher performance new equipment that will be flown by more experienced pilots. All of this will result in demands for service, and the safety problem will grow.

At present, the market is absorbing all the units that existing and new manufacturers can produce. Foreign manufacturers are concentrating efforts on development of light aircraft. A significant basic research and development program cannot be undertaken by the manufacturers since they are fully occupied at present and cannot justify consideration of new configurations. Manufacturers, however, are completing development activity to meet FAA requirements for licensing (and customer requirements), and this alone is a significant burden on resources. If a forecast is made, considering the above, research and development might be required to assist in solving these problems:

1. What is NASA's role?

2. How can the general aviation fleet be kept quiet (noise)?

3. How can improved flight control aids be provided?

4. How can general aviation safety be improved?

NASA's Role

NASA's role is the traditional one: to provide the technology necessary for problem solving and to assist as required in problem solving through use of its facilities and experienced staff.

NASA has completed a program to determine the degree to which available technology is employed in general aviation aircraft and has found that in some instances NACA/NASA data were not applied; in others it appeared that new data were required (Ref. 8).

As a result of past efforts, the research capability at NASA already exists in terms of staff and facilities in many areas. Research capability is being acquired by current activity in several new areas.

The total NASA research benefiting general aviation is listed below (Ref. 1):

Biotechnology	- pilot capabilities
Aeronautics	- performance, stability, and control
Electronics	- augmented stability and control
Power plant	- reliable, lightweight, inexpensive, small turbine engine evaluation

Noise Problem

An example of a capability based on past accomplishment is the airplane propeller, which will probably be important to general aviation aircraft for some time. The propeller must be efficient and quiet. The propeller research tunnel was first put into operation by NACA in 1927 and it has been used and improved in development efforts on propellers, engine cowls, and fairing since that time. NASA has completed work in the past to define design parameters for quiet and efficient propellers; thus, the technology is available to industry (Ref. 2).

Flight Control

The technology base for improvement or creation of control devices and other electronic equipment is being provided in part by NASA. The first step is examination of the performance and cost of available equipment. Where new technology is needed to meet equipment performance and cost goals, research is initiated to apply advanced concepts to meet the need. For example, a low-cost, all fluid autopilot for light aircraft is in flight evaluation and development now at the NASA Flight Research Center (Ref. 9).

Safety

General aviation's safety record (Ref. 10) justifies the NASA efforts to provide necessary technology for improvement in safety performance. An example of advanced research in the safety area is the work in biotechnology (to understand pilot capabilities) and simulation research (to generate realistic control tasks in order to obtain useful evaluation of pilots and equipment). This work is responsive to a current need and is based on technology created by the most advanced research in high-speed flight and space flight.

NASA's interest in pilot reaction to difficult and unfamiliar control tasks in research aircraft led to the development of means to measure pilot reactions and the development of simulators with which to remove the unfamiliarity, determine usable limits of control task difficulty, and evaluate biosensors.

NASA has evaluated the controllability of several light aircraft and has found that an undesirable reversal of control input force was required in one aircraft type to cause an abrupt nose down motion. Also, support testing has been performed with stability augmentation devices installed to aid in piloting the aircraft (Ref. 11).

V/STOL Transports

NASA is engaged in exploratory research to evaluate concepts applicable to the unusual V/STOL flight regime. There are many concepts,and the evaluation task is comprehensive. Noise, flight profile, range, speed, size, economy, controllability and biotechnology, approach angle, climb angle, passenger comfort, power plant technology, materials and structures technology, and aerodynamics technology all must be evaluated--at one time. The engine supplies power to the wing to improve or develop lift at low speed; the amount of lift provided by the engine instead of by the wing influences range; and the number of landings and take-offs per trip influences range.

This task is properly assigned to NASA and will benefit the organization since it involves many technologies already in the advanced research phase; the task moves the work into the applied technology phase, where it will be the means by which the technologies are evaluated and the advanced research is directed in the future. The activity will be important in the transfer or utilization of technology developed in the manned space flight program to industry. Use of many data and techniques developed in connection with the lunar landing vehicle program will probably be made.

Justification

The International Air Transport Association reports its operating fleet as consisting of 3,507 airplanes (jets, turboprops, and piston engines) and 34 helicopters (Ref. 12). The U.S. Air Force operates 60 helicopters, and the Navy 12 for rescue service (Ref. 13). Of course, helicopters are used extensively in Vietnam. The helicopter is the only VTOL aircraft that is operational at this time. The STOL types are few and small, and not truly suited to the requirements that exist.

The helicopter, while it certainly operates from the city center, is slow, it vibrates and is small; there are no economically usable STOL aircraft.

Should NASA, through research, support or conduct advanced work to develop these aircraft types? Who will benefit?

The helicopter has been found to be of great military value in Vietnam as a weapon, as a transport, and as a rescue vehicle. The cost/effectiveness of the helicopter can only be expressed qualitatively. The helicopter replaces trucks, troops, airplanes, runways, roads, and ports, and it saves the lives and unburdens forward units of casualties. If the helicopter costs less than the items it replaces (and it probably does by an order of magnitude), then research to improve it is easily justified and the indirect benefit is to the taxpayer. The direct benefit is to the wounded soldier who was transported quickly to the hospital, or the soldier who was saved from injury because of the helicopter, and therefore he lives to enjoy the indirect benefits.

Social and Economic Benefits

The social and economic benefits can be seen by a forecast of transportation requirements of the future. A three-fold increase in world air travel is forecast for the period 1968-1975 (Ref. 12). Because of lead times, planning at some of the major cities of the world is well advanced. At Los Angeles, annual traffic is predicted to increase from 17.2 million to 57.5 million for passengers, from 473,000 to 687,000 for airplane movements, and from 26 million to 86 million for automobile movements. An expenditure of $504 million will be required to accommodate the traffic increase, with $372 million of that total to be spent before 1971. The Los Angeles plan includes rapid economical conveyance from near-home or business centers to the airport. Extensive use of V/STOL aircraft, expected to become available in the 1975-1980 period, is planned. To increase parking spaces from 10,000 to 30,000 for personal automobiles, seven- or eight-level parking structures with roof stress for V/STOL aircraft will be built (Ref. 14). While the

Los Angeles air transportation complex is not critically dependent upon the V/STOL, its efficiency and its initial cost are.

The traveler would be served very well if he could drive his car to a metroport at the city center and end up at another city center without spending as much time driving as flying. The ability to improve service and move the noise away from population centers will also benefit the population centers.

Poverty/social programs should take advantage of the employment generated by advances in transportation systems made possible by aeronautical vehicles. The world's airlines currently employ 577,000 people; this will grow to about twice that number in order to handle the increase forecast in air travel by 1975 (Ref. 12). This amounts to 577,000 new jobs in the world airlines alone and does not even reflect increases in jobs in supporting activities. The $372 million expenditure through 1971 for improvements to the Los Angeles airport alone reflects 5,000 jobs for the period and offers another opportunity for training and utilization of new labor.

Subsonic Jet Transports

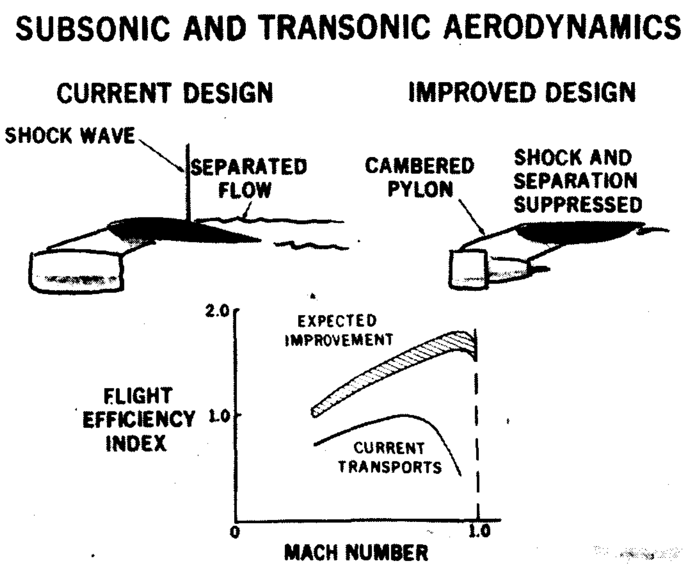
The subsonic jet transport is part of the culture of the world. It is the foundation of the air transport industry and is the reason for the industry's financial success. The subsonic jet transport fleet grows at a rate of over two a day; also the noise problem grows. But the noise problem is partly solved by new, higher thrust, higher efficiency fan engines that are quieter than plain turbojets in two ways: (1) the engine is basically quieter and (2) the aircraft can climb faster, getting the sound away from the people. Incidentally, the fan engine is not benefited in noise reduction by use of jet (tailpipe) sound suppressors developed earlier by NASA and the fan engine makes more noise at the inlet. Also, the new fan engine will permit bigger loads to be carried and aircraft to be "stretched," resulting in old climb rates and the old noise proximity (Ref. 15). These dynamic advances in air transport technology partially define the noise problem, which is part of the continuing NASA work on the subsonic jet transport. The importance of the problem and the problem of keeping pace with changes has caused the NASA approach to involve all possible noise abatement routes, including isolation, insulation, and engine noise suppression. The isolation route includes adjustment of landing approach and climb-out paths. These adjustments require consideration of pilot control tasks and work load and airplane performance changes permitted by high lift devices. These routes can be investigated effectively because of NASA's skills developed in prior work, but the problem is not static.

Advances made in noise abatement are often offset by use of larger, more powerful engines in ever-increasing numbers. The problem seems impossible and the only positive solution appears to be to move the airports away from the communities altogether and legislate against people moving out to the new airport locations. With the airports served by large aircraft moved to remote locations, the cities will be served by many metroports using quiet (relatively) V/STOL and surface vehicles, and the impossible problem will be solved by isolation. On the other hand, the noise generation problem of the high performance engine might be solved by a breakthrough inspired by NASA research in a manner similar to solutions obtained for other "impossible" problems, as below.

Transonic Wing Breakthrough

It was accepted for years that the highest efficiently usable subsonic cruise speed resulted from a thin laminar flow airfoil swept as much as possible. All of the high subsonic airplanes have been designed that way since engines permitted high subsonic speeds to be attained. It was thought that the transonic speed range was not efficiently usable and that aircraft would stay under a critical speed or be supersonic. However, research performed at Langley Research Center by Whitcomb et al. has resulted in a breakthrough in transonic aerodynamics (Ref. 16). Large jet transports of the configurations typical today will be able to increase speed about 15% without increase in power. The basic features of the improved wing are shown in the following figure:

Figure 1



Source: Copyright Aviation Week & Space Technology (Ref. 16)

Flight efficiency index includes contributions from shock and boundary layer suppression; favorable interference, including cambered pylons; and reduction in engine specific fuel consumption.

Economic Impact

The transonic wing breakthrough accomplishes one of the subsonic transport development goals: improved cruise efficiency. It demonstrates the present worth of the investment made by the American people in the NASA facilities and staff. Consider the influence of a 15% improvement in operating costs for the U.S. scheduled airlines for one year (about 1970) where the operating costs are approximately $6 billion.

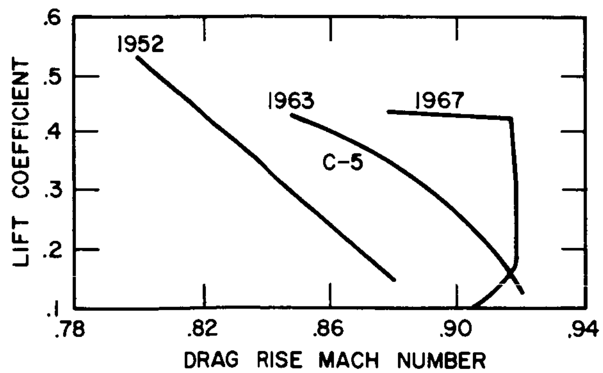
If all of the performance advantage were directed toward reduction of operating cost, the saving would be $900 million, the profits would be increased by $900 million, and the government's share (50% tax rate) would be $450 million. This single potential improvement in tax revenue on profit is equivalent to the entire NASA aeronautics expenditure for three years. Of course, the improvement will not be felt step-wise and the new aircraft utilizing the new technology will not operate on an overall basis at 15% lower cost. Some of the advantage will be reflected in lower freight rates and passenger fares and higher wages for personnel.

Social Impact

The Lockheed Georgia Company's Galaxy (C-5) Air Force heavy transport (764,000 lb. max. gross) represents an advanced aeronautical vehicle. Even before it is operational, it is seen by Lockheed engineers as pointing the way to even more advanced technologies (Ref. 17). In the C-5 program NASA acted as consultant/collaborator; NASA and other government wind tunnel facilities provided aerodynamic data. The advances made permit new transport designs to be based on improved wing designs, as below:

Figure 2

TRANSONIC WING TECHNOLOGY ADVANCE



The figure indicates development of a transonic wing that is suited to the large transport mission and that provides a significant improvement in overall performance of more advanced transport aircraft. During the operational life of the C-5 aircraft and the potential production of more than 200 airplanes, developmental changes will be made. The transport capability will be improved and military missions added. The C-5 will not only be the data source for its own development, but its size and availability may permit tests of nuclear power plants.

The importance of meeting military requirements is not definable in economic terms. The importance of the C-5 is of greater scope. The airplane can air drop four 50,000 lb. packages in a single pass or fly 2,500 nm, drop 100,000 lbs. and fly back 2,500 nm without refueling (Ref. 18). This capability means much if the load is food or survival equipment for people in need, and it is not possible to apply a dollar value to this feature. In international relations the goodwill obtainable with this capability may exceed that gained by other forms of aid.

Long Range National Benefits

Of far greater importance to a powerful general economy is the forecast of what application of advanced aeronautical technology will do for a commercial air transport aircraft to be available in the 1975-1980 period. The commercial version of the C-5 will show a direct operating cost of $ .0125 per ton statute mile. A person could ship his car by air to Yokohama from San Francisco for $100. He can do the same today, by ship. The difference is that by air it would take 14 hours (with stop) whereas, by ship, it would take 14 days. What this means is that the U.S. is developing an ability to replace the ocean-going shipbuilding industry with an airborne cargo shipbuilding industry. The advances in aeronautical technology extend up to payloads in excess of 300,000 lbs. and gross weights over 1,000,000 lbs., according to Lockheed studies (Ref. 17). The advantages to nations possessing the technology and the industrial capability through which it is implemented should be obvious.

National SST Program

NASA support for the SST activity has been traditional and is continuing in the several specialized areas. These areas are listed below.

Aerodynamics

Flight dynamics
- Biotechnology
- Simulators
- Avionics
  - Pilot displays
  - Guidance/navigation
  - Stability augmentation
  - Collision avoidance

Structure
- Materials

Propulsion
- Noise
- Performance and reliability

The work involves problem solving based on available technology as well as advancing technology to meet the needs of the SST program. The nature of the work is direct support of the national SST program and indirect support resulting from work on other programs.

Impact on the American Public

The national supersonic transport development has already and will continue to influence people in many ways. Many people believe that the SST will have no effect upon them at all, except for the sonic boom. These people should be shown that the technology advance represented by the SST also has an influence on the value of their fixed amount retirement funds. The results of a survey conducted by the Air Transport Association of America (ATA) showed that the U.S. airlines, by expending $7.7 billion for equipment, will increase the dollar value of their equipment by 1.5 times in the five-year period from 1966 through 1970. In releasing this information, the president of ATA stated ". . . the investment by the airlines in new and more efficient equipment has helped to minimize the inflationary impact of continually increasing costs of the labor and material and supplies the airlines need." (Ref. 19). New and more efficient equipment is based, of course, on advancing technology. The ATA statement can be interpreted to mean that the new equipment permits the operator to pay higher wages to his employees without increasing the cost of the service to the passengers. This means that the dollar paid for the ticket buys the same number of miles; the dollar value has not changed and therefore there has been no inflation, although higher wages are paid to the people providing the service. The technology advance has permitted them to produce more.

Investors might look at the activity made possible by the continuing development of aeronautical vehicles as a growth industry. Forecasts indicate a growth of revenue passenger miles by a factor of 2 in the period 1968 to 1975 (Ref. 12). In order to meet the competitive demands for this growth market, reinvestment of earnings has been required. The U.S. aircraft manufacturers are in good economic and technical health; they supply 82.6% of the world market (Ref. 20). This share is apt to grow in the future since the new U.S. aircraft types and technical quality becoming available meet the user requirements better than the foreign aircraft.

When new equipment is necessary simply to meet demand for service, it must be the highest earning type permitted by the status of technology. If fare increases are necessary and new equipment is not becoming operational, several fare increases might be necessary in the lead time required to obtain new equipment (5 years). Profits will be reduced, and the ability to purchase new equipment will be diminished, leading to an inability to handle the market at the same quality level. The company or industry moves from a growth to a static character, profits diminish, and the ability to recover does not exist. Then, the demand diminishes or is sold elsewhere at higher quality level at lower costs.

This is certainly not the case with the U.S. industry, which is based on the most advanced and still advancing aeronautical technology. The advanced research completed by NASA and led by NASA policy, the applied technology that exhibits the products of the research effort in usable form, and the development activity performed in support of other programs have been basic to the present advanced status of aeronautical technology in the U.S. This status, along with military and commercial need, is basic to the present advantage U.S. equipment has over that of other countries. The research capability that has been built is also current and advancing, and work is being done in many advanced and supporting areas. This fact is demonstrated by the large number of advanced research and technology programs that have a practical application to the U.S. SST program.

Application of Advanced Research and Technology

NASA's advanced research and technology programs are listed below (Ref. 21):

Fluid Physics

1. Aerodynamic Flight Regimes*
2. High Speed Reentry Heating*
3. Boundary Layer Research*
4. Rocket Nozzle Heat Transfer
5. Non-Newtonian Fluids
6. Plasma Physics

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* Applicable to the SST program.

Electrophysics
1. Thin Film Behavior
2. Acoustic Wave Attenuation
3. Laser Physics
4. Tornado Formation*
5. Nuclear Physics Research*

Materials
1. Surface Physics
2. Materials Strengthening*
3. Structure of Polymers
4. "Splat" Quenching*
5. Flexible Polymers
6. Surface Reflectance Degradation
7. Stress Corrosion*
8. Temperature Effects on Metal Fatigue*
9. Supersonic Transport Materials*

Applied Mathematics
1. Better Computational Techniques*
2. Stable Lunar Satellites
3. Precise Calculation of Trajectories
4. Energy Requirements for Mars Vehicles

In the area of Fluid Physics, direct applicability of the research to the SST effort exists in three of the categories. In Electrophysics, two of the categories are directly applicable; in Materials, five are directly applicable; and in Applied Mathematics, one is directly applicable. Because of upgrading the staff facilities and techniques, all of the work bears on the SST program in an indirect way.

Hypersonic Cruise Aircraft

NASA's hypersonic cruise aircraft program concentrates on ramjet performance, hot structures, and aerodynamic efficiency. The X-15 research aircraft is the primary research facility in the NASA hypersonic aircraft program (Ref. 1). This effort could be associated with the design, development, and manufacture of a hypersonic cruise commercial transport aircraft. Several public reactions are possible: (1) We don't need one; (2) It won't help the ghettos; (3) We don't even have an SST yet; (4) We haven't even solved the problems with the subsonic transports; (5) Don't spend the money now; (6) What is a hypersonic transport? On the other hand, the effort could be thought of as a technological development goal builder--then it becomes part of NASA's SRT program (i.e., a director of work to obtain new basic knowledge underlying advances in aeronautics); the hypersonic flight research

* Applicable to the SST program

vehicle structures the work by providing a project-like atmosphere, points to subtle details in the research airplane, supplies a schedule, and inspires competition and communication in support of a diffcult problem solving task. High morale speeds the work, and the existence of a research aircraft provides physical accomplishments to display to users and the public. Inspiration and speed are necessary if the technology applied to an aircraft is not obsolete by the time of roll out. Consider the C-5 timetable as shown in Table 4 (Ref. 22):

Table 4

C-5 SCHEDULE

Start definition phase	December 1964
End definition phase	September 1965
Contract award	October 1965
First parts made	August 1966
First airplane assembly	January 1967
Roll-out first airplane	February 1968

The contract was signed in October 1965 after the proposal and definition phase, which ended in September 1965. The development of the design (performance optimizing, weight reduction, drag reduction) proceeded along with placing of subcontracts and the procurement of tooling. The first parts were made in August 1965; the first airplane was assembled during 1967 and early 1968. The first airplane was rolled out in February 1968.

It is optimum if all technology needed to meet performance requirements is available at the start and if the requirements are based on the most advanced technology consistent with development span times. At the time when the first C-5 was being assembled, the improved transonic or supercritical wing/airfoil concept was just recently discovered and was being confirmed or characterized in wind tunnels by Lockheed and NASA staffs. It would have produced serious delay to the C-5 program if any attempt had been made to change the wing to the new design and re-examine all other design items. Lockheed feels that the new wing technology, which was first available in 1967, is applicable to 1975-1980 operational aircraft (Ref. 22). Since the problem of drag rise with conventional wings was apparent for many years prior to 1967 and the drag rise had an important bearing on many military and commercial aircraft in extensive operation, it seems that a vigorous pursuit of a solution would have led to an earlier find. It could also be possible that it took a special combination of requirements such as exists in the C-5 to highlight the need, emphasize a requirement, or place certain individuals in communication/collaboration/competition in order to make the discovery. The research aircraft plays an equivalent role since it demands attention, demands firming-up requirements considered unattainable, causes coalescing of individuals, and leads to maintaining the technology in advance of requirement so that the first aircraft rolled out at the end of a four-year design and prototype manufacturing process is not obsolete.

In presenting NASA's aeronautics program, Aviation Week & Space Technology highlights the planned termination of the X-15 research aircraft flight program. The article, entitled "NASA Reshapes Aeronautics Role," states in part (Ref. 23):

> The X-15 program itself, according to a NASA official, "has looked to outsiders for the past couple of years as if we were just barely keeping it alive. Before we decided to cancel the flight program we asked ourselves--and we were asked by the budget people as well--'do we want to keep going with a pretty esoteric program?'--and no one is really interested in hypersonic development right now--or 'do we want to pursue a basic aeronautical research program?' One had to be sacrificed for the other."
>
> The growing trend, he said, is that government participating in basic research and development should be that which is "clearly to the national good, with private industry becoming more involved wherever possible".

Obsolescence is not to the national good. The value of the esoteric program demonstrated in the past, i.e., X-15, B-70, manned space flight, is to the national good. The tradition of the esoteric program in NASA and its role as definer of advanced goals should be maintained and strengthened. The NASA goal should remain that of developing technology five to ten years in advance of the requirement.

COMMENTS ON PRESS ATTITUDE

Because of the press attitude, public reaction to the value of the aeronautical advance represented by the variable sweep wing concept could be negative. The F-111 has been given a great amount of negative press coverage since its beginnings, and the news media have presented facts considered readable by the nontechnically oriented citizen in language that has proven effective--such as, "Swing-Wing Fighter Program for Navy Cancelled. Controversial . . ."

An Associated Press business analyst writes under the heading, "Supersonic Jet Project Under Review," that "Design and construction problems that have delayed completion of the American supersonic airliner one year to the Spring of 1972 are resulting now in a complete review of the program by the Boeing Company, the builder." Also, ". . . Included in the new design studies is a cockpit developed by the NASA for an even thinner, needlelike, idealized design that would have fixed rather than moveable wings." (Ref. 24).

From the above press releases, variable sweep does not appear to be very effective in application to aircraft; perhaps the expenditures for the research entailed were wasted.

But under another heading, "Navy to Initiate VFX-1 Definition," we find that the canceled "controversial" F-111B is being replaced with a similar, lighter aircraft with a variable-geometry wing that will cost about the same as the F-111B. The new aircraft will simply be specially tailored to the Navy mission, and the variable sweep wing is important in meeting these mission requirements (Ref. 25). The research expenditures are of value after all.

One might look at the technological advance represented by the SST and technology in general as does Wilbur H. Ferry, a vice president of the Fund for the Republic, Inc. (Ref. 26). He sees the SST as an unprecedented attack on ourselves that we, as taxpayers, are paying for. He sees the SST as a source of ear pollution caused by sonic "boombardment." He sees the Senate as silly for authorizing an additional $143 million for SST development at the same time it was reducing expenditures on programs for people. Mr. Ferry states ". . .Technology is the villain." He credits technology with a great ability but argues that it must be regulated and that its regulation is the most important intellectual and political task on the American agenda. He sees, as an example of that regulation, that the government should fund the development of a fume-free car instead of placing a man on the moon or adding to the din of modern life that neurophysiologists warn is making us deaf and ravaging sensibilities and nervous systems. ". . .This is part of the price already being exacted by technology; and with SST we are choosing, as a nation, to raise the price enormously."

The SST may be reviewed by some as the valuable objective that paces, inspires, and directs advanced research, applied technology, and development activity in all areas for civil and commercial purposes and at a scale and scope formerly confined to the military weapons systems. For this reason alone, even though the SST will have military value, it is a step in a direction that Mr. Ferry would approve. There are other areas of the NASA aeronautical program that Mr. Ferry would see as benefiting people and, therefore, would approve as well.

Mr. Ferry would approve of new jobs generated by expanded use of new equipment with high productivity. He would approve if the expanded use resulted in moving the noisy airplanes away from the people and serving the cities with "quiet" vehicles that serve many "metroports," all made possible by development of aeronautical technology.

FUTURE STUDY PROGRAM

In line with our recommendation that NASA take maximal advantage of the opportunity that exists for benefiting economically depressed areas through employment in general aviation, we propose a follow-on study, as outlined below.

Introduction

General aviation is technology generating employment in labor surplus areas. Light aircraft manufacture utilizes much labor, and the product is automotive. With improvements to lower costs and increase performance, the market could probably absorb three times the current production of light aircraft (16,000), which in turn would at least double the current work force (31,000). Through incentives, light aircraft manufacturers might expand production by locating assembly plants in labor surplus areas. Light aircraft manufacture does not require large investment in special purpose tools which means that smaller plants (5,000 work force) would be able to perform competitively. Input material shipping costs are no greater than for many existing plants, and the product transports itself away. It flies away and continues to consume labor and products of other industries in a wide geographic area.

Suggested Tasks

SRI proposes a study consisting of the following tasks:

1. To assist NASA in design of aeronautical research programs that are developmental in nature, for example, light aircraft configurations could be optimized for ground rules, such as the following: high wing, low wing, single engine, engines and wing, engines and fuselage, improved pilot visibility, passenger capacity. The role of NASA should not be to assume responsibilities of the light aircraft developers and manufacturers but to speed application of existing or new technology into the production of light aircraft with better and more suitable performance at lower costs.

2. To determine, with the general aviation aircraft developers and manufacturers, a route by which new plants could be built and labor forces could be trained in economically depressed areas where new facilities and skills match production requirements on the new designs and technology. The route must not

constitute a government subsidy of a nature that replaces industrial initiative resulting from competitive pressures.

3. To present all findings to NASA in a manner that permits implementation by appropriate state and federal agencies and that displays NASA's essential role in the program for benefit of economically depressed areas through job creation and education.

Method of Approach

Task 1

We propose to accomplish this task by on-site survey of the status of technology currently employed in the design, manufacture, and test of light aircraft and by comparing it with new technology and new equipment items available or emerging from the research and development stage. Attention would be given to items ranging from the extent to which use is made of high capacity production equipment to application of fiber reinforced plastic materials. The industry's efforts in design of new products would be examined to determine how a NASA effort could speed industry development and production of the new designs.

Task 2

In order to accomplish this task we propose to (1) identify labor surplus areas and (2) identify the magnitude of the training task from an assessment of available skill levels and the training program outline and evaluation procedures as is required in order to determine the level of subsidy that will inspire competition among manufacturers for the new plants.

Task 3

In this task we would present the programs recommended for NASA implementation in such a way that individual manufacturers would not be associated with any recommended program element and the resulting technology would be available to all, as is consistent with present practice.

CONCLUSIONS AND RECOMMENDATIONS

- NASA's aeronautical research programs are directed toward solution of today's problems and tomorrow's technology needs. Historically, the direction has been effective and it is based on tradition established by many years of work experience in the research/industry interface.

- The variable sweep wing technology that was pioneered by NASA in 1945 is now being applied to military and commercial aircraft. This technology was available in advance of the need.

- NASA's activity in support of aircraft development programs of other agencies is generally beneficial; it constitutes the first direct step in technology transfer and utilization and guides future work at NASA.

- Cost savings resulting from maintaining a sustaining research and technology activity are significant; the savings are passed on to the taxpayer.

- NASA's role in general aviation research and technology development is current and responsive to need. The work is appropriate, considering the economic and social importance of the light aircraft for personal and business use.

- The forecast increase in production of general aviation equipment provides opportunity for new plant location in economically depressed areas. We recommend that NASA take maximal advantage of the opportunities for implementation of social programs resulting from expansion in the manufacture of vehicles and equipment for the general aviation market. (See Future Study Program).

- V/STOL technology is late. The research and technology tasks must cover a wide range of concepts; testing must cover a variety of flight regimes from hover to high-speed flight, including controllability and human factors.

- The sound suppression program that is part of NASA's continuing work on the subsonic jet transport is of critical importance to the community; the findings are important to transportation system planning.

- The transonic wing breakthrough announced by NASA and Lockheed will have an important bearing on the economy of subsonic jet transport aircraft operation.

- Aeronautical technology advances have resulted in the development of the C-5 cargo aircraft. The technology permits forecast of an even more capable cargo carrier and a realizable step into a peaceful airman's world.

- NASA's support of the SST program is extensive. The demands made upon aeronautical technology influence NASA's advanced research programs.

- NASA is developing research skills and doing research work in several areas associated with hypersonic cruise aircraft. We are led to the conclusion, however, that this effort will not be emphasized.

- We have observed that the transonic wing breakthrough was late relative to its availability for application to the C-5 cargo aircraft.

- We conclude that aeronautical technology will continue to fall behind need if advanced programs are not pursued.

- Because of its success, NASA's role in aeronautics and aviation should be strengthened and expanded to keep pace with the increasing use of aeronautical vehicles.

- The quality and tone of the press coverage does not present NASA in a manner consistent with the activity.

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