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NASA's Aeronautics Program: Systems Technology and Experimental Programs

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Ad Hoc Aeronautics Assessment Committee

Aeronautics and Space Engineering Board

Assembly of Engineering

NASA's Aeronautics Program: Systems Technology and Experimental Programs

A Report of the
ad hoc Aeronautics Assessment Committee

Aeronautics and Space Engineering Board

Assembly of Engineering
National Research Council

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P R E F A C E

In the fall of 1976, the National Research Council's Aeronautics and Space Engineering Board (ASEB) was requested by the National Aeronautics and Space Administration to determine whether the agency's research and technology base program was adequately and appropriately supported to meet the nation's needs for aeronautics technology in the future. An ad hoc committee, the Aeronautics Assessment Committee, was established by the National Research Council under its Aeronautics and Space Engineering Board to conduct the study. Members of the committee were appointed by the National Research Council. The study was conducted during 1977 and a report of the committee's finding was published in April 1979.*

The research and technology base in NASA's aeronautics program claims approximately 43 percent of the total research and development funds and 74 percent of the civil service manpower allocated to NASA's aeronautics program. The research and technology base is the embodiment of the data and the methodologies that have been developed within the technical disciplines underlying all aspects of light within the earth's atmosphere. It encompasses basic scientific and engineering research as well as applied research in such areas as structures, materials, aerodynamics, propulsion, and avionics, where the results are applicable to many classes of aircraft and are not restricted to a specific model or type.

Subsequent to the 1977 review of the research and technology base program in aeronautics, NASA requested the Aeronautics and Space Engineering Board to continue the ad hoc Aeronautics Assessment Committee for the purpose of reviewing the remainder of its aeronautics program; namely, the systems technology and experimental programs. The committee was asked to assess the appropriateness and balance of work directed to solving near-term problems and that directed to far-term advances in technology, and of in-house work and out-of-house work. The committee was also asked to recommend improvements to individual programs. This report contains the findings and recommendations of the committee resulting from its assessment.

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*Aeronautics and Space Engineering Board. 1979. NASA's Aeronautics Research and Technology Base. National Research Council, National Academy of Sciences, Washington, D.C.

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I N T R O D U C T I O N

In 1915, Congress created the National Advisory Committee for Aeronautics (NACA). The new committee, consisting of 12 volunteer members, was to "supervise and direct the scientific study of the problems of flight, with a view to their practical solution." Moreover, it was directed to conduct and coordinate laboratory research in aeronautics as the principal way of advancing civil and military aircraft in the U.S. In due course, NACA pioneered the development and operation of research and development facilities, the collection and dissemination of basic research information, and the exploration and testing of new designs and developments. Its work in science and technology contributed to advancing the aerodynamic design of aircraft, airplane engines, and structural innovations for designing, fabricating, and testing many kinds of aircraft.

In 1958, Congress established an extensive space program under the National Aeronautics and Space Administration (NASA), with NACA as its nucleus. Though NACA had been abolished as a separate federal agency, its facilities were integral to the newly formed NASA. NASA took over NACA's aeronautical research establishment at Langley Field in Hampton, Virginia, the Ames Research Center at Moffett Field, California, the Lewis Aircraft Engine Laboratory in Cleveland, Ohio, and the Flight Research Center at Edwards Air Force Base, California, as well as some 8,000 employees.

NASA has grown to meet its responsibilities in both space and aeronautics, and today encompasses nine centers and a number of laboratories, facilities, and special installations in various locations across the nation. NASA's program in aeronautics, however, continues to be conducted primarily at the four research centers where it was originally conducted under NACA: the Langley, Ames, and Lewis Research Centers, and the Dryden Flight Research Center.

In recent years, NASA's aeronautics effort has been organized into four major categories, defined as follows:

- Research and Technology Base -- basic research, discipline technology, the wellspring of ideas.
- Systems Studies -- paper studies to identify areas for focus, provide decision base.
- Systems Technology Programs -- demonstration of technology developed in R&T Base work and definition of Experimental Programs.
- Experimental Programs -- multidisciplinary integration of new technology and concept demonstration - research vehicles and payloads, flight test.

In an earlier study, the National Research Council's Aeronautics Assessment Committee reviewed the R&T Base segment of NASA's aeronautics program. The results of that study are contained in the report NASA's Aeronautics Research and Technology Base, published in April 1979. In that report, the committee expressed general satisfaction with the R&T Base program, cited problems detected in the program, and provided commentary on specific program elements at each of the four research centers.

Ideally, new technology will derive from the results of the fundamental research conducted in the R&T Base program and will mature through the research hierarchy to be proved in an experimental flight test. Eventually, it will be used to provide new and advanced operational aircraft. NASA's unique facilities, test capability, and expert personnel attract demands (that NASA recognizes) for the agency to address immediate and near-term problems. Some work directed to the near term is needed, not only to provide solutions to critical problems, but also to provide a communication link between the researchers and the users of technology. Consequently there is some question about the appropriate division of effort.

Another concern of NASA and some segments of the aviation community, particularly academic institutions, is the amount of research contracted out-of-house. NASA relies on universities and some parts of the industry to provide expert capability to conduct research in specialized areas. This is to the mutual advantage of all the parties involved. Care must be taken, however, to have an appropriate balance in the work done under contract or by grant and that done in-house at NASA. NASA's unique facilities were established to develop advanced technology for progress and improvement in aeronautics. A preponderance of out-of-house work would absorb NASA's researchers as contract monitors at the expense of making effective use of NASA facilities.

The National Research Council's ad hoc Committee on Aeronautics Assessment, having completed its study of the R&T Base portion of NASA's aeronautics program, was requested to undertake a study of the systems technology and experimental programs to determine the appropriateness of the division of effort between that directed to the solution of near-term problems and that directed to long-term technical advances, and between in-house work and out-of-house work. This report presents the committee's principal findings and conclusions.

Because work in the Systems Technology Program and the Experimental Program is often accomplished and supported by a center, or centers, other than the lead center, the program elements have been grouped, where possible, by subject, rather than by research center (as in the committee's first report).

SUMMARY AND CONCLUSIONS

The committee was asked whether the balance of efforts directed to near-term problems and to far-off advances in technology is appropriate. It is the committee's judgment that the overall NASA program in aeronautics is well balanced. There are a few exceptions that are discussed later in this report. Among the exceptions, more programs should be redirected toward basics and far-off results than vice versa -- some NASA programs are more concerned with near-term problems than is desirable.

In some instances, program plans with long-term goals did not have sufficient intermediate progress reviews and assessment points. Even if a program directed to obtaining knowledge and understanding of fundamental phenomena is not expected to provide applicable technology for a number of years, the work should be divided into phases with detailed periodic reviews to assess actual against expected progress. This would permit abandoning relatively unpromising efforts and augmenting those that are more attractive. For example, the energy-efficient engine program at Lewis and the avionics and flight controls efforts at Ames and Langley would benefit from near-term and intermediate planning goals. More specific comments on these and other programs can be found in the sections under "Commentary: Systems Technology and Experimental Programs."

The committee also was asked to judge the appropriateness of the amount of research conducted under NASA contract by universities and some parts of industry (out-of-house) as compared to that conducted by NASA personnel in NASA facilities (in-house). Quite clearly, if most of the work were to be done out-of-house, NASA researchers, rather than conducting research, would be monitors of research done by others under contract. Too much in-house effort would tend to isolate NASA research personnel and lead to inbred thinking that results from a lack of exposure to a broader base of research. Intuition suggests that there should be an optimum mix. However, the optimum mix is a matter of judgment.

The National Aeronautics and Space Act of 1958 as amended states that the Administration, in order to carry out the purpose of the Act shall plan, direct, and conduct aeronautical (and space) activities, i.e., (a) research into, and the solution of, problems of flight within and outside the earth's atmosphere, (b) the development, construction, testing, and operation for research purposes of aeronautical (and space) vehicles. For much of the work NASA undertakes it is apparent from the viewpoint of efficiency and program effectiveness, as to what work should be conducted in-house and what should be accomplished out-of-house. For example, it is clear that the detailed design and construction of a research aircraft is better accomplished out-of-house by industry; similarly, experts in universities that can provide knowledge and capabilities not available in NASA are readily identified.

In the committee's opinion, the question of appropriateness of the ratio of the amount of work conducted in-house to that conducted out-of-house is answered by the programs themselves -- by the expected yields and the objectives in light of needs. It would be inefficient and wasteful of valuable resources for NASA to undertake to accomplish tasks that others, through the expertise or capabilities of their personnel or their facilities, would be better equipped to accomplish; conversely it would be wasteful to have others do work that NASA is better equipped to do. The committee believes that the priority must be given to providing an effective technical program and that in conducting such a program the question of the appropriateness of the ratio of in-house to out-of-house effort will be resolved.

Following its review of NASA's aeronautics program, it is the committee's considered judgment that, generally, the work has been appropriately allocated to bring the best effort to bear on the task at hand. Later in this report there are a few instances cited where shifts are recommended. Further, the committee believes that a criteria of appropriateness based on a quantitative ratio of in-house to out-of-house effort could result in a less efficient and less effective program if adhered to slavishly -- as particular efforts are completed and replaced by others, the amount of work done in-house or out-of-house will change, depending on the work involved. The committee believes that whether there is too much effort in-house so as to cause inbred thinking or too much effort conducted out-of-house so as to be wasteful of NASA research personnel and facilities should be questioned by NASA management on a continuing basis. At the time of the committee's review, the committee was satisfied that there was not a significant problem.

During the course of its review, the committee prepared specific comments on each program element and made suggestions for changes, additions, and deletions. These suggestions and recommendations are detailed in subsequent sections of this report. A brief summary of those the committee considers most important follows.

General Aviation

- Structure the program of research in avionics and flight controls for general aviation aircraft into phases aimed at specific milestones in the near future to give visibility and direction to future work.

Propulsive Lift

- Discontinue the Quiet Clean Short-Haul Experimental Engine (QCSEE) Program if there is no evident direct application for the technology.

Energy Efficiency

- Establish some near-term milestones in the laminar flow control program that are directed to a long-term solution of in-service damage and other deteriorating environmental effects on the maintenance of laminar flow.

- Define a flight-test program for a turboprop system to demonstrate structural integrity, installation compatibility, and reliability of the gearbox and propeller controls.

- Make a comprehensive review of various aircraft systems and missions over a range of flight speeds to determine productive roles for turboprops.

- Expand the turboprop flight test program at Dryden to investigate a range of values of fuselage-propeller spacing, propeller solidity, fuselage acoustic impedance, and propeller wake strength.

Supersonic Cruise

- Establish a special task force to detemine and evaluate the technical and economic facts of supersonic cruise aircraft.

- Evaluate the cost/benefit of preserving the YF-12 aircraft in storage rather than having it destroyed.

Rotorcraft

- Carefully monitor the Tilt Rotor Research Aircraft (XV-15) program with critical reviews at appropriate intervals to assure there are no significant technical flaws in the design approach -- the first to be undertaken as soon as the first research tests results become available.

- Undertake an examination of the projected users of the tilt rotor aircraft technology to determine whether there is a market. If not, any significant effort on advanced tilt rotor aircraft systems beyond the XV-15 should not be undertaken.

Materials for Advanced Turbine Engines (MATE)

- Examine the MATE program to see whether revisions should be made to accommodate adverse circumstances (i.e., future availability of scarce materials) that have developed since the program was defined.

Aeroelasticity of Turbine Engines (ATE)

- Expand the ATE program to include forced vibrations such as those caused by struts, turbulence, and wakes.

Stratospheric Cruise Emission Reduction (SCERP)

- Continue combustor work being conducted in the SCERP program.

COMMENTARY: SYSTEMS TECHNOLOGY AND EXPERIMENTAL PROGRAMS

This section presents the committee's commentary on specific elements of NASA's Systems Technology Program and Experimental Program in aeronautics. By definition, most of the work conducted in these program areas focuses on a type or class of aircraft or problem. In most instances, two or more NASA centers are involved in work directed to these same classes of aircraft or problems. For example, Lewis (propulsion), Langley (aerodynamic configuration and flight control), and Ames (avionics and flight controls) all have programs directed to the general aviation class of aircraft. Lewis (propulsion), Langley (aerodynamic and configurations) and Dryden (flight test of winglets) all have programs directed to the problem of energy conservation. The committee believes the presentation and discussion of the various program elements are easier to follow when grouped according to the aircraft class or problem to which they pertain. Accordingly, where it is appropriate to do so, the committee's commentary is presented in this way in the following.

General Aviation Technology

NASA's Systems Technology and Experimental Programs in general aviation encompass elements in propulsion, agricultural aircraft, avionics and flight controls. As indicated above, the program is conducted at the Lewis, Langley, and Ames Research Centers.

Quiet Clean General Aviation Turbofan (QCGAT) -- Lewis

This program has the objective of applying large turbofan engine technology to small general aviation turbofan engines to reduce noise, emissions and fuel consumption. Although the noise levels of existing turbofan-powered general aviation aircraft are generally below the latest limits of the Federal Aviation Administration (FAA), NASA's program may provide further significant noise reduction. A ten-percent improvement in fuel consumption can also be a significant benefit. In working toward these improvements, however, NASA should be sure that reliability and economy of operations are not sacrificed.

This is a near-term program being conducted out-of-house. It involves design and testing of fans and nacelles by two contractors using the core of existing engines. The results of the program would be enhanced by wind tunnel tests to determine the drag of the new nacelles with power on for comparison with that of the baseline engine nacelles, and by flight testing to confirm operating characteristics.

Some basic work in small turbine components will also be useful in improving reliability and fuel consumption of both general aviation power-plants and auxiliary power units that are used in all commercial transports.

<u>Agricultural Aircraft</u> -- Langley and Lewis

This program is a good effort in aerial application of seed, fertilizers, and herbicides. It is integrated among manufacturers, applicators, government regulatory agencies and the chemical industries. A workshop at Langley in August 1978 gave evidence of NASA's grasp of the problems of nozzles, vortex applications, spray patterns, aircraft stall characteristics, and the performance of propellers at low speed. This program brings NASA expertise to an important problem area and a segment of the industry to which such help was not heretofore available. NASA should monitor progress with the view to expanding the program as warranted.

The work performed at Lewis supports the effort at Langley to improve the dispersal of chemicals from aircraft. The committee believes that the experience and knowledge of fuel nozzles accumulated at Lewis can contribute to significant improvements over current delivery systems. Some universities may be able to contribute in this area also. This should be explored.

<u>Avionics and Flight Controls</u> -- Ames and Langley

The objective of this program is to provide information for the design of reliable advanced avionic systems for general aviation. This topic has been the focus of a workshop for industry, government, and university representatives in which NASA's role was defined as supporting basic research, not developing components. The committee believes the program can yield results the general aviation critically needs. Many accidents in general aviation occur because of the high workload imposed on the single pilot in general aviation aircraft during approach and landing under instrument flight conditions. The committee cautions NASA against aiming too high in technology, thereby losing sight of the importance of low cost and reliability to general aviation. It is suggested that acceptable levels of cost be discussed with the manufacturers of general aviation avionics equipment. The committee considers cost and reliability to be much more important than sophisticated technology. Ames has a good relationship with industry and the users in this program. The committee believes, however, that the concentration of avionics in a single center would aid considerably in the development of such programs.

The program, as outlined, must be considered long term because of its very broad scope. The committee recommends that the program be phased, and aimed at specific milestones in the near future. For example, the first step might be the integration of communications and navigation.

The committee believes the general aviation industry, on its own, would rely on evolutionary progression of change. Therefore, NASA work in the general aviation area can provide significant impetus to the application and use of new technology.

The Langley work being done in automatic flight control systems fulfills a direct need of a large number of general aviation pilots who are neither trained nor qualified for instrument flight, and too often find themselves in situations requiring flight by instruments. The result is a disruption of the normal air traffic control process, or an accident.

The thrust of the work at Ames is to demonstrate the feasibility of a low-cost microwave landing system for general aviation aircraft throughout the application of low-cost avionics.

Although the development of a low-cost microwave landing system receiver may be of considerable aid to general aviation, implementation of the system will require installations at thousands of general aviation airports. In the committee's view, this does not apear to be imminent. Development of the receiver does not seem to be appropriate if the associated ground equipment is not on the same schedule. NASA should reassess its program in view of this mismatch, and determine whether to deemphasize work on the low-cost microwave landing system based on FAA's commitment to accelerating its own work on a low-cost ground system.

Propulsive Lift Technology

"Propulsive lift" describes the use of an aircraft engine's thrust to augment wing lift at slow airplane speeds. Aircraft using propulsive lift are usually classed as short takeoff and landing (STOL) aircraft. NASA's propulsive-lift technolgy program is comprised of two major parts: 1) the Quiet Propulsive-Lift Technology program at Ames, which includes procuring and flight testing an experimental aircraft, and a cooperative program between Ames and the U.S. Air Force using the Air Force's Advanced Medium Short-Haul Transport (AMST), and 2) development and testing at Lewis of an experimental engine for STOL operations that is environmentally acceptable and economical.

Quiet Propulsive-Lift Technology Program -- Ames

The objective of this program is to generate data to support the design and the certification criteria for practical proplusive-lift aircraft. These data are being obtained from flight tests of the Quiet Short-haul Research Aircraft (QSRA) and the Air Force's AMST.

The QSRA is a propulsive-lift STOL aircraft developed from a De Havilland Buffalo C-8 aircraft, under contract with the Boeing Company. The original wing and twin turboprop engines have been replaced with a newly designed wing and four fan-jet engines. The four fan-jet engines have been mounted on top of the wing in such a way as to cause the jet efflux to discharge over the upper surface of the wing, following its contour and the contour of the deflected trailing flaps. The result is an increase in lift. The increase in lift makes it possible to fly at speeds so slow that conventional controls are ineffective. To provide control, some air is bled from the engines and ducted to the wing-leading edge and the ailerons to provide blowing for boundary layer control to provide airplane control at slow speed and also to delay wing stall to provide additional lift.

At the time of the committee's review, the aircraft was undergoing ground tests preparatory to its first flight.

The AMST aircraft are propulsive-lift prototype STOL aircraft developed under contract for the Air Force by McDonnell-Douglas (the YC-15) and Boeing (the YC-14). The YC-15 has four turbofan engines mounted on the wing in such a location that the jet efflux passes under the wing and is deflected downward by a flap on the trailing edge of the wing, thus providing lift. The YC-14 employes two turbofan engines mounted on the wing to operate similarly to the QSRA described above. A NASA/USAF agreement in 1973 permits NASA to perform tests with and on the AMST prototype aircraft. NASA experiments began in 1974.

The three aircraft provide different flying characteristics. The test results will be applicable to the design of future short-haul transports, and will provide valuable data for flight certification criteria. The committee considers this to be a worthwhile program: more knowledge and data on the noise resulting from propulsive lift is needed, and the present program is one that can provide such information. The combination of analytic and experimental results should be particularly useful.

The AMST program is nearing completion, and NASA has stated that it is phasing out its STOL research effort except for the QSRA project. The committee believes the QSRA has some very interesting flight characteristics that should be explored. NASA should be able to perform flight experiments that will be beneficial to conventional aircraft as well as STOL aircraft, although propulsive lift for short-haul aircraft may have marginal application because of its cost and complexity.

Quite Clean Short-haul Experimental Engine (QCSEE) -- Lewis

The objective of this program is to develop and demonstrate the technology to provide economically and environmentally acceptable powered lift for short-haul aircraft. Two propulsion systems, one for an under-the-wing installation such as that on the AMST YC-15 and one for an over-the-wing installation such as that on the YC-14 and QSRA, were designed, fabricated, tested, and delivered to Lewis by General Electric Company. The design thrust goals for the engines were about 18,000 and 21,000 pounds respectively for the under-and the over-the-wing versions.

At the time of the committee's review, the program was in its fifth year and some testing remained to be performed. Generally, the program had met its objectives. The committee believes that although the direct operating costs of STOL aircraft for short-haul air transport are still unfavorable for the development of a STOL transport system, some of the technology developed in this program may be applicable to conventional aircraft. If no direct applications for the technology can be found, the committee recommends that work on this program be discontinued.

Energy Efficiency Technology

In 1975, NASA initiated the Aircraft Energy Efficiency (ACEE)[1] program. Six major elements comprise the program, three of which are directed to evolutionary improvements in propulsion and aerodynamics: Engine Component Improvement, Energy Efficient Engine, and Energy Efficient Transport.

The other three programs are to develop technology considerably different from that now used in long-range transport aircraft; namely, turboprops, laminar flow control, and composite primary structures. The overall 10-year program is directed to the goal of providing

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[1]Subsequent to this study, the National Research Council, at the request of NASA, undertook a detailed review of NASA's Aircraft Energy Efficiency (ACEE) Program. The results of the study are reported in a National Research Council report. Aeronautics and Space Engineering Board. 1980. An Evaluation of NASA's Program for Improving Aircraft Fuel Efficiency. National Research Council, National Academy of Sciences.

advancements in technology that could lead to a 50-percent reduction in transport aircraft fuel consumption per passenger mile through, for example, improved propulsion systems, lower airframe drag, and lighter structural weight. Five of the elements of the ACEE program are discussed here. The element "composite primary structures" is included later under the subject heading "Composite Materials." An additional element, winglet flight research, is included here that is not part of the NASA ACEE program.

Engine Component Improvement Program -- Lewis

This program recognizes that fuel conservation efforts must begin with engines already in service or with similar engines that will be put in service over the next decade. Over the long term, the fuel savings possible with more advanced engines (such as the Energy Efficiency Engine, discussed later) will be important, but in the near term such new engines will not be available, nor will they immediately replace the engines now flying. Accordingly, NASA's program is aimed at developing components that can be used in existing engines to (1) improve performance and (2) reduce the performance deterioration that causes specific fuel consumption to increase as an engine ages.

In the performance-improvement part of the program, the Lewis center contracted with the two major engine manufacturers to set priorities for the evaluation of concepts. NASA has also involved the airframe manufacturers and several airlines in assessing the concepts in terms of economics, acceptability to the airlines, and the probability of incorporation of the new components in follow-on engine deliveries. About a dozen concepts met the selection criteria and are being pursued.

In the investigation of performance deterioration, the committee considers the problem to be an important one that the aircraft engine industry is not motivated to attack; namely, the significant in-service performance deterioration of the current generation of high-thrust, high-by-pass-ratio turbofan engines. This deterioration is manifested in reduced thrust and increased specific fuel consumption at a given turbine temperature. Engine contractors are motivated by competition to reduce fuel consumption in yet-to-be-delivered engines; they have little incentive to invest in the development of changes that would improve the fuel consumption of engines already in service. The NASA program is important to fill the void.

In this part of the program also, the Lewis center has made excellent use of airline and engine contractor capability. The systematic gathering and analysis of data from in-service engines, the development of analytic models supported by specialized testing, and the evaluation of repairs are essential ingredients in understanding the performance deterioration phenomenon.

In summary, the Engine Component Improvement program is timely, well-managed and productive.

<u>Energy Efficient Engine Program</u> -- Lewis

This program seeks to validate the technology for a new generation of fuel-efficient turbofan engines for commercial transport use. The goal is to demonstrate by the end of 1983 the technology needed for development of an advanced engine that would consume twelve percent less fuel than the engines in the current wide-body fleet, show lower performance deterioration, and incur lower direct operating costs. The program appears to be success-dependent: there are no design alternatives planned for the new compressor, combustor, and turbine concepts proposed. Some of these can be expected not to work well the first time, and NASA should be prepared to modify goals, to seek other approaches when the need and payoff make this an obvious course of action, and to provide schedule flexibility when it is needed to allow time for deciding the correct technical course.

The Lewis center is commended for involving the airlines and airframe manufacturers in the initial evaluation process. This has helped set meaningful objectives.

The improvements sought in this program are significant but the pace of the program is such that they will not be found in a new model transport until nearly 1990. In the meantime, competition will force evolutionary improvements to the engine models now in service and to the models now in development. NASA should be alert to this situation, and be prepared to redirect its research effort when it is indicated to be beneficial to do so. The committee believes it is appropriate for NASA to have the Energy Efficient Engine program reviewed periodically, as well as the Energy Efficient Transport program (discussed next), to see whether circumstances indicate a change in the course of these programs.

<u>Energy Efficient Transport</u> -- Langley

The Energy Efficient Transport program involves the application of advanced aerodynamics and active controls technology to demonstrate its practicality and effectiveness for improving the fuel efficiency of commercial transport aircraft. The program is well under way and includes appropriate participation by industry. It should provide not only the basis for successful application of active controls to future derivatives of today's transport aircraft, but also the technology base for new aircraft. This effort appears to be well directed and should produce good results.

Laminar Flow Control -- Langley

The objective of this program is to demonstrate technology that will maintain laminar flow over major portions of an aircraft, particularly the wings. It will validate through flight tests the results of work under way in NASA's research and technology base program. The basic work is scientifically sound, but the committee questions whether the operational maintainability of the systems being examined is adequately treated. It is recommended that NASA examine very carefully the question of operational utility for the laminar flow control systems they are considering and, at least in some conceptual form, identify some near-term milestones in the search for a long-term solution to in-service damage to the surfaces, adherence of bugs and insects, and other deteriorating effects of the environment.

Advanced Turboprop Program -- Lewis, Ames, Dryden

Development of a turbine-powered propeller (turboprop) aircraft was discontinued in the late 1950's in favor of higher-speed turbine-powered jet (turbojet) aircraft.

Interest in the turboprop was rekindled when NASA-sponsored studies showed that significant fuel savings could be achieved with thin, highly loaded propellers operating at eighty percent efficiency at high subsonic cruise speeds (0.8 Mach number). Fuel savings of fifteen to twenty percent over current wide-body jet aircraft were postulated. Due to its inherent lower noise and better takeoff climb, a turboprop aircraft also has promise of lowering community noise.

Lewis is the lead center for NASA's advanced turboprop program. It has the objective of demonstrating technology for practical turboprop aircraft in the flight speed range Mach 0.6 to Mach 0.85. In model tests at Lewis, a propeller efficiency close to the predicted eighty percent has been achieved at Mach 0.8. Nevertheless, many problems must be solved and some significant questions answered before the advanced turboprop can be considered a substitute for today's turbofan propulsion system, viz.:

- Achievement of suitable aerodynamic performance of a full-scale propfan over the whole flight regime.
- Structural integrity of thin, highly-swept blades.
- Freedom from flutter and unacceptable vibratory stresses in the blades and drive system.
- Reliability of pitch change and reversing mechanisms.
- Tolerance to icing conditions.

- Installation compatibility (airplane aerodynamic performance, controllability, and engine-out behavior).

- Gearbox and propeller-control reliability.

- Cabin noise reduction.

- Community noise determination.

The Lewis center has structured a program that generally addresses the problems listed. Experience with the most recent generation of turbine-powered propellers, however, indicates that the important considerations are installation compatibility, structural integrity, and gearbox and propeller-control reliability. If program results show that an integrated turboprop propulsion system is a workable means of achieving significant fuel savings, the committee believes flight tests will be required to demonstrate that the problems have been solved satisfactorily. It is recommended, therefore, that NASA define such a flight test so that preparatory work may be started in time. For example, analysis and testing should take into account that the aircraft must be controllable with an unfeathered propeller and inoperative engine. The windmilling and drag characteristics of the advanced propeller must be evaluated relative to the yaw-induced aircraft structural failure mode, particularly at the high flight speeds proposed, and this requires an effort to define a reasonable range of assumptions about engine configuration.

An important question is whether a new advanced engine is needed for this purpose, or whether modifications to an existing engine will suffice. In either event, a program plan should be developed that provides a suitable engine and airframe at the required time. The most useful application of the turboprop, in the committee's opinion, may be at lower Mach numbers, and for short-haul aircraft with their many takeoffs and landings, rather than for long-range transports that spend most of their flight time cruising at high subsonic speeds. A comprehensive look at various systems over a range of flight speeds is recommended.

At the Ames center, a new program in support of the program at Lewis has been undertaken to study the integration of the airframe turboprop system, the aerodynamic interference between the nacelle and wing due to the propeller flow field. The committee believes that the work at Ames related to airframe integration of advanced turboprop systems addresses an important problem, and will provide an understanding of the aerodynamics of such systems. Nevertheless, the program is too narrow in its emphasis on a single design concept. Multiple nacelle configurations and nacelle-to-wing locations should be evaluated to establish the optimum configuration that minimizes interference effects.

The program, as it is now structured, does not address the question of the engine inlet which must provide high-pressure recovery and acceptable flow distortion behind a multi-bladed propeller. The flow field over the wing and the drag of the propulsion system are likely to be affected by the propeller hub configuration selected, and this should be factored into the integration program. The program as planned appears to be a reasonable one that will have its primary effect in the long term. Aircraft companies are participating in the program, and appreciation at the center of their need for analytic techniques and computational methods should provide a well-balanced program.

At the Dryden center, a model of a propeller being developed at Lewis (eighty percent efficiency at Mach 0.8) will be mounted on top of the fuselage of the Center's Lockheed JetStar test-bed aircraft. The focus of the flight program is on the near-field acoustic characteristics resulting from the transonic speed of the propeller tips in cruise.

The committee believes the Dryden flight test program is too limited, and recommends that it be expanded to investigate a range of values of fuselage-propeller spacing, propeller solidity, fuselage acoustic impedance, and propeller wake strength. The committee also believes the turboprop design should be expanded beyond the single point at Mach 0.8 to include a wide range of operating parameters. A concerted attempt should be made to draw together NASA's best knowledge of propeller acoustics and performance, to establish a comprehensive plan for this program. Substantial contributions to this plan can be made by personnel from Lewis and Langley in acoustics, and from Ames in computational fluid dynamics. The succeeding phases of this program, which are directed to the flight test of a modification of an existing aircraft to incorporate propellers, should be contingent on completion of this plan.

<u>Winglet Flight Research</u> -- Dryden

The concept of the winglet grew out of theoretical analyses and wind tunnel work at Langley. A winglet is a small wing (although they could have a span of 6 to 10 feet for large transport aircraft) attached vertically on the tips of an aircraft wing. The results of wind tunnel tests have shown that the addition of winglets to a wing can reduce the drag of the wing by 5 to 7 percent, thus offering the potential for significant fuel savings. The addition of the winglets, however, increases loads in the wing structure, generally resulting in increased wing weight, which subtracts from the benefits of the winglet's aerodynamics. An increase in the span of the main wing (increased aspect ratio) is somewhat comparable to adding winglets in that this, too, reduces wing drag and creates higher structural loads and weight in the wing. Therefore, a good data base on aerodynamic loads, flutter, buffet, stability, and control is required to make decisions regarding the use of winglets in new aircraft designs or as a retrofit to existing aircraft. The flight test program at Dryden (being conducted jointly with the U.S. Air Force, using an Air Force KC-135 tanker aircraft) will contribute significantly to the needed data base. The KC-135 aircraft appears to have sufficient structural margin in its design to permit the addition of winglets without additional structure, making it relatively simple to add winglets for the flight research program and also to retrofit the Air Force's fleet of KC-135 aircraft if the test results prove the benefits of retrofit.

Supersonic Cruise Technology

The objective of this research effort is to generate the technology base for future civil or military aircraft capable of cruising for long ranges at supersonic speed. Such data will provide a basis for decisions in the future about the practicality and effectiveness of supersonic aircraft and the data required to assess the environmental effects of present and future supersonic cruise aircraft.

The program is broad in that it covers all the major disciplines--materials, structures, propulsion, aerodynamics, and systems studies--but is focused to solve real problems of this class of aircraft; i.e., to provide solutions to many of the technical problems that contributed to the cancellation of the domestic effort to develop a supersonic transport, and to offer proved advanced technology that is ready for application. Parts of the program are conducted at each of the NASA research centers, Langley, Ames, Lewis, and Dryden, with lead-center responsibility vested in the Langley center.

Supersonic Cruise Research Program -- Langley

The committee believes significant progress has been made in providing basic data for the solution of many of the problems of supersonic cruise aircraft. Further progress depends on developing new technology through the application of this data. The committee believes that if continued in its present form, the program will stagnate. Recognizing the political aspects of any government involvement in the development of a supersonic transport, the committee believes that the technical merits and cost/benefits of such a vehicle need to be determined and recommends that NASA establish a special task force to determine and review the facts.

YF-12 Flight Experiments -- Dryden

The YF-12 airplane was acquired from the U.S. Air Force and has been used by NASA since 1969 to provide a test vehicle to explore the very high-speed, high-altitude flight regime. NASA believes that those tests that can be done best with this aircraft have been completed. A symposium summarizing the results obtained from the program was held in the fall of 1978. NASA intends to terminate the use of this airplane for further testing. The committee agrees with this decision, but recommends that inasmuch as the airplane is essentially one of a kind, NASA consider preserving the airplane rather than having it destroyed. In this way, should any further requirements develop, it would be possible to make use of this aircraft again. A cost/benefit analysis would help in making this decision.

In retrospect, it appears that this program was continued beyond the time when its technical output justified its cost. Such large flight programs should be reviewed frequently for cost-effectiveness.

Variable-Cycle Engine Program -- Lewis

Fundamentally, the variable-cycle engine operates as a high-bypass engine for low noise and high performance at takeoff and subsonic climbout and as a low-bypass, augmented engine for high performance in supersonic flight. Two variable-cycle concepts have been identified, and the ongoing program is aimed at demonstrating some components for these engines. The near-term program will determine whether some of the components needed for this variable-cycle operation are practical and will perform as predicted. In the committee's view, the components involved are not suitable for a variable-cycle engine and will not provide engine noise levels as low as those expected of engines for future subsonic aircraft. Furthermore, the engine and airframe efficiencies that can be predicted now are not good enough to establish clearly the economic feasibility of a commercial supersonic transport. The committee, therefore, recommends that the large-scale engine demonstration program be curtailed, and the long-term research program to provide a research base for solving the critical problems be continued.

Before NASA embarks on any significant supersonic propulsion programs beyond the limited research described above, the review recommended by the committee earlier should be undertaken to establish objectives for a supersonic transport program in general.

Rotorcraft Technology

Rotorcraft, such as helicopters, employ one or more powered horizontal rotors (like long-bladed propellers operating in a horizontal plane) to enable them to take off and land vertically, to move in any direction in flight, or to hover.

In 1977, Ames was assigned lead-center responsibility for NASA's research and technology program for rotorcraft, as part of its more general responsibility for short-haul aircraft. Prior to this, much of NASA's helicopter program had been conducted at the Langley Center. At the time of the committee's visit to Ames, the center was beginning to assimilate its new responsibility and was assimilating a staff and setting up lines of authority. The committee was presented with a short review of rotorcraft systems technology. The program was in a formative stage; nevertheless, the committee was concerned about the apparent lack of analyses. This is a large full-scale-research experimental program and the committee would like to see a much more deliberate and detailed program that integrates analyses with test results.

An overall assessment of advanced rotor system development seems to be lacking. Considering the possible range of configurations that could be investigated and the necessary commitment of resources to such programs over a long period of time, the committee believes it essential that this area of work be well planned to ensure there are adequate benefits to be accrued from the development[2] of major hardware items.

Tilt Rotor Research Aircraft (XV-15) -- Ames

This is a joint Army/NASA program to procure two tilt-rotor research aircraft to be flight-tested by NASA and the Army to prove the validity of the configuration. The tilt-rotor concept combines the hover capability of a helicopter with the cruise efficiency of a transport aircraft such as the Lockheed Electra. The vehicle has a helicopter-like rotor mounted on each wing tip of an otherwise conventional-looking aircraft. After the vehicle takes off, the rotors tilt forward from the horizontal plane to the vertical plane, and operate as two large propellers.

The program was initiated in 1972 with a design competition won by Bell Helicopter, a division of Textron Corporation. At the time of the present review, the first aircraft was being prepared for shipment to the Ames center for wind tunnel tests in the 40-ft x 80-ft Wind Tunnel. The construction of the second aircraft was 70 percent complete.

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[2]Subsequent to this study, NASA defined a rotorcraft program in July 1978. The National Research Council, at the request of NASA, undertook a detailed review of NASA's rotorcraft program. The results of the study are reported in a National Research Council report. Aeronautics and Space Engineering Board. 1978. An Evaluation of NASA's Program for Advancing Rotorcraft Technology. National Research Council, National Academy of Sciences.

The tilt-rotor concept was first studied by the Army and NASA in the early 1950's. In the mid-50's, the XV-3 tilt-rotor research aircraft was designed, built, and flown in a proof-of-concept and research program until 1966 when it was severely damaged in a crash that investigation showed was caused by a dynamic coupling between the rotor-wing-fuselage structure at moderate cruise speed.

The objectives of the present program include verification of the dynamic stability of the rotor-wing combination and aircraft performance, assessment of the handling qualities and gust sensitivity, and assessment of the military mission suitability. The vehicle spans the area between the helicopter and the more conventional wing-supported aircraft--an area of technology that could have a large payoff in the long term. The committee supports this program, with the addition of critical review at appropriate intervals to assure that the program will give results commensurate with its cost. The first research results from this program should become available during the coming year. The committee recommends that a detailed technical review of the program be conducted when test results are available.

Advanced Tilt-Rotor Aircraft Systems -- Ames

Work on the advanced tilt-rotor aircraft system consists of analytical studies of advanced-technology rotor systems, including the definition and preliminary design of advanced control systems. The committee questions the overall appropriateness of this effort. Tilt-rotor systems have been under consideration for the past twenty years, but for a variety of reasons, have failed to reach any operational level or suitability. The committee believes that unsteady aerodynamics, blade structural dynamics, and the complexity of the power train have all contributed to the problems of tilt-rotor aircraft. Until it is demonstrated, through flight tests and experiments with the XV-15 aircraft described above, that these problems have been solved, it is not appropriate to expend effort and resources to develop follow-on systems. The committee recommends that an examination be undertaken of the projected users of this technology to determine whether there is a market for it. Certainly the results of the XV-15 should be analyzed carefully before any significant effort is devoted to additional analytical studies of advanced tilt-rotor concepts.

Rotor Systems Research Aircraft (RSRA) -- Langley

This is a joint Army/NASA program to develop two flight vehicles to serve as research facilities for rotorcraft and rotorcraft components that are more generally of conventional helicopter design than is the XV-15 Tilt-Rotor Research Aircraft. The vehicles are being developed under contract with Sikorsky Aircraft Company by the Langley center. When the vehicles have been developed and tested to verify that they meet the prescribed technical requirements, they will be transferred to the Ames center where they will be used by NASA and the Army at Ames to conduct flight research.

The RSRA vehicles are unique; they can fly and operate as conventional helicopters, as compound helicopters, or as conventional aircraft. Rotor forces can be measured independently of the airframe forces. The vehicles incorporate a crew-escape system, air brakes, and variable-incidence wings that can be removed for pure helicopter operations. The committee considers this program to be well structured and believes it will be a valuable facility that can develop a body of design and operational knowledge for future rotorcraft design.

Helicopter Transmission Systems -- Lewis

This is a new program, projected for five years. Its purpose is to reduce the weight, size, cost, maintenance, and noise of helicopter transmission systems.

The Lewis center is seeking improvements in conventional transmissions through fundamental work on bearings, gears, lubrication and lubricants, and seals. At the same time, it is investigating a hybrid traction drive system that uses friction rollers instead of finite-toothed gears, to determine the potential for significant size and cost reductions. While mechanical transmissions are used in almost every self-propelled vehicle in use today whether on land, sea, or air, the weight and reliability needed by rotorcraft make today's systems far from satisfactory. The committee is pleased to see NASA enter this field, and anticipates that the state of the art can be improved by a detailed scientific approach. An opportunity exists to develop an analytical approach to gear and bearing design to reduce dependence on empirical data.

There are many industrial and military users of this technology, and Lewis should maintain its efforts to ensure technology transfer and information exchange. To a degree, this is achieved through the participants in the out-of-house efforts. Although the committee considers the balance between in-house and out-of-house work in this program to be appropriate, the committee suggests that a greater use of universities in the out-of-house portion would emphasize the analytical portion of the work.

Vertical Takeoff and Landing Aircraft Technology

Vertical takeoff and landing (VTOL) aircraft can take off and land vertically in a manner similar to rotorcraft. The term "VTOL" has come to be applied only to those aircraft that accomplish vertical takeoff and landing by downward-thrusting or downward-deflected jets. NASA's program in VTOL aircraft is primarily in direct support of the Navy's search for a multimission VTOL vehicle. Ames is NASA's lead center for this program; parts of the program are also conducted at Langley and at Lewis.

<u>Operating Systems Technology</u> -- Ames

The main thrust of this study program for VTOL aircraft is to define simulation methods for validating digital flight control systems. The program is directed to both CTOL (Conventional Takeoff and Landing) and VTOL aircraft and appears to have been undertaken, at least partially, at the request of the Federal Aviation Administration to aid in the development of the certification requirements for CTOL. The committee believes that the industry is better equipped to analyze costs and benefits than the center. The committee also questions the scheduling for the efforts for CTOL, with the program for simulation experiments extending into Fiscal Year 1981. The advanced digital flight control system for the DC-9-80 is scheduled for certification in 1980. An effort in this area applied to VTOL may have a greater impact or future development than those applied to CTOL where NASA appears to be running somewhat behind current efforts in industry.

With respect to VTOL aircraft, the examination of innovative navigation, guidance and control displays, and operating techniques for both civil and military vehicles is worthwhile. The committee considers that the long-range potential of this work is sufficient to support an accelerated and expanded program on the basis of its long-term payoffs.

<u>Vehicle Technology</u> -- Ames and Lewis

This program consists largely of analysis, wind tunnel tests, and flight simulations in Ames' ground-based simulators. The committee believes that this work is extremely important to the U.S. Navy, and could also serve other potential civil and military applications. The effort is short term, funded by the Navy, and is aimed directly at the specific Navy application. NASA, however, should be pursuing a broader and longer-term objective of a much more generic nature. This requires that NASA carry out a program of its own design. The committee believes NASA should appeal the ruling that restricts its funding to that provided by the Navy.

A relatively low-level effort in propulsion is funded by the Navy at the Lewis center. In the committee's view, the problems of developing a satisfactory propulsion system for a VTOL fighter airplane are formidable. Very high thrust-to-weight ratios, control of thrust direction, and integration of the engine control with the aircraft control system are some of the technical problems specific to this class of aircraft. The resources applied by Lewis to these problems are consistent with the funds provided by the Navy, but it is the committee's view that they are not appropriate to the size of the problem. It is uncertain whether a VTOL airplane that would perform the desired mission can ever be achieved, but VTOL does seem to be an area in which NASA could take the initiative and make a positive contribution, in addition to working within Navy requirements.

VTOL Approach and Landing Technology (VALT) Program -- Langley

This program is concerned with the development and flight validation of the technology for systems that integrate the navigation, guidance, control, and flight-management subsystems to provide maximum effectiveness for VTOL aircraft and helicopters. The development of such integrated systems involve a variety of technical areas, including aircraft flying qualities, operating procedures, human factors, avionics, and automatic control systems. The equipment associated with this program is of general use in automatic landing technology, and is maintained as such by Langley. As a result of NASA's naming Ames the lead center for helicopter and other VTOL aircraft research, that part of the VALT program pertaining specifically to helicopters will be transferred to Ames. The remaining portion of the program, particularly those parts appropriate to general aviation, will be carried through to early completion at Langley. The committee agrees with the work and planning for this program.

Wake Vortex Minimization

The wake of a lifting wing is characterized by two trailing vortices that emanate from the wing tips. The strength of these trailing or wake vortices is proportional to the lift of the generating wing. For large transport aircraft such vortices persist in the atmosphere for several miles behind the aircraft with sufficient strength to upset and, in extreme cases, to cause the structural design limits of smaller aircraft to be exceeded. The problem is particularly critical on the approach and landing and takeoff paths around airports. Thus, for safety, added spacing is required between aircraft and, as a result, the number of aircraft that can be accommodated at busy airports is restricted.

Research to find ways to reduce the vorticity (strength) of the wake vortices, or possibly eliminate them, is conducted at the Langley and Ames Research Centers and the Dryden Flight Research Center.

The purpose of this program is to gain basic understanding of the wake vortex phenomena, with the objective of achieving significant reduction in the strength of wake vortices. The basic effort is well structured and laudable progress is being made. The committee recognizes that there are some gaps. Specifically, although the FAA has the responsibility for wake avoidance, NASA should have a research effort to support the FAA.

The committee notes that the wake vortex minimization effort has been underway for five years and the airlines still have the same problem they had five years ago. The basic and theoretical work that NASA is doing in defining wake structures, their formation, and dissipation is good, but the program should proceed with a greater sense of urgency in recognition of the airlines' operating problems, and seek solutions more quickly.

The wake vortex minimization effort at Ames is directed to reducing the hazard presented by the wake vortices shed by large transport aircraft. In its earlier review of NASA's research and technology base, the committee commented that the Ames wake vortex minimization program was too "cut and try." In this subsequent review, the committee finds the program has been supplemented with analytic and computational work.

Ames has tested solutions in the wind tunnel that reduce the strength of the trailing vortices up to about one and a half miles behind a B-747. Ames believes that flight tests are required to validate the solutions for wake vortices to 5 miles or more behind the generating aircraft because of recombination effects that cannot be simulated in the wind tunnel. The center has carried out a reasonable program using in-house and out-of-house activities, and plans to phase out its wake vortex work as it applies to CTOL aircraft and confine its efforts to rotorcraft and STOL and VTOL aircraft. Langley will increase its efforts in the CTOL area. This is appropriate in light of the shift of responsibilities within NASA.

The work at Dryden is an important part of this program. It provides information on wake development far behind the generating aircraft and the effects of Reynolds number not available from wind tunnel tests. The committee understands that the role of lead center for this work is now assigned to Langley. Dryden may well have an important role in the establishment of new and appropriate flight-test techniques in this area, and the programs Dryden plans appear to be properly defined. In this case, however, NASA management should assure that the lead center establishes overall controls and goals for the program. One appropriate goal, for example, would be to halve the spacing now required for the aircraft. Besides investigation of suppressing or modifying the wake vortex, work toward this goal must include associated operational aspects. The work conducted so far has not properly taken into consideration the increase in approach-noise level that results from operational use of some of the proposed configurations to suppress the wake vortex. Part of the solution to the wake vortex problem may be in detection and avoidance procedures. Current efforts in this direction should be carefully examined for payoffs that may exceed the efforts to suppress or modify wakes.

Composite Materials

In its earlier report on NASA's research and technology base in aeronautics, the committee commended NASA on its program to apply carbon fiber materials to commercial transport hardware, and concluded that NASA could make even more significant contributions by applying its talents to the basic technology. NASA's effort in this area is now virtually at a standstill, having been superseded by the mandate to join the government-wide program (managed by the Department of Commerce) to study potential problems accompanying the use of graphite fiber material in aircraft structures, particularly the hazards involved with the release of the fibers in the event of a crash fire. NASA's assigned tasks in the overall program include an assessment of the risk in the use of graphite fiber materials in aircraft, and studies to define the materials that might be used instead. Langley has prime responsibility for NASA's risk assessment. Langley, Ames, and Lewis are each investigating alternative materials.[3]

The committee, while cognizant of NASA's position, is concerned that NASA's capability for research is being misdirected. NASA should complete its tasks as soon as possible so that its manpower and resources can be directed to the fundamentals of advanced materials and structures.

Improved Resin Matrix Composites -- Lewis

This program was initiated to develop composites that present less hazard of carbon-fiber release. The Lewis work appears to overlap that being done at Ames and Langley, indicating a need for better overall coordination. In the committee's view, the Lewis work should be terminated.

Materials and Structures Systems Technology -- Ames

A major portion of this program is directed to the fire characteristics of aircraft materials and increased survivability. Other significant work is on advanced composites materials, and materials for tires and fuel tank sealants.

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[3] Subsequent to this study the results of the NASA analysis were reported in NASA Conference Publication No. 2119 Assessment of Carbon Fiber Electrical Effects, An Industry/Government Briefing held at Langley Research Center, Hampton, Virginia, December 4-5, 1979.

Within the past year, a significant amount of Ames' effort has been directed to the hazards of the release of graphite fibers resulting from fire. The committee recognizes the need for the work done on the release of composite fibers from a fire, and agrees that a short-term, high-level effort is required in order to provide much needed technical data. However, the committee does not believe the fiber-release question is a major problem and urges that this effort be periodically reviewed to ensure that the effort in the fiber release program is reduced as soon as possible, and a more balanced research effort reinstituted.

Composite Primary Structures -- Langley

The purpose of this program is to accelerate the acceptance and use of composite materials in commercial airplane design and construction by proof-testing aircraft components in flight during routine aircraft service operations. The major transport aircraft manufacturers (Boeing, Douglas, Lockheed-California, Lockheed-Georgia) are participating in the program as are two helicopter manufacturers (Sikorsky, Bell). This program is one of six major elements of NASA's Aircraft Energy Efficiency (ACEE) program.[4] It is providing the impetus to industry to increase the quantity and quality of composite structures in aircraft. Because of the concern over the release of carbon fibers in the event of fire however, NASA indicates its large-scale-wing program has been postponed. The committee considers the flight phase of the program an important one that should be completed. The basic work on composite structures such as fracture mechanics should certainly continue.

Materials for Advanced Turbine Engines (MATE)

This program, conducted at the Lewis center, has the objective of accelerating the application of advanced materials in aircraft gas turbines to achieve improved engine performance and reliability.

Materials that maintain their strength at temperatures of about 2500°F are key to the advancement of gas turbine technology. Nickel-based super-alloys, precision-cast turbine airfoils, and

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[4]Subsequent to this study, the National Research Council, at the request of NASA, undertook a review of NASA's Aircraft Energy Efficiency (ACEE) Program in August 1979. The results of the study are reported in a National Research Council report. Aeronautics and Space Engineering Board. 1980. An Evaluation of NASA's Program for ACEE Technology. National Research Council, National Academy of Sciences.

high-strength titanium alloys are necessary for today's military and commercial aircraft. Unlike other industries that tend to rely on materials already developed, the gas turbine industry is unique in its development of new materials to solve its design problems. Future engine advancements to reduce weight, lower fuel consumption, and extend engine life will need materials improvements of the kind sponsored by NASA's MATE program. Another important aspect of materials development is the development of alloys that will minimize or eliminate the nation's dependence on cobalt and chromium. Denial of the use of these two materials through war or other action not controllable by the U.S. could cripple the nation.

Reduced availability of cobalt has caused a "grey market" in the metal to exist. Cobalt prices have risen over 300 percent in recent months. Considering this evidence of future scarcity, and the fact that the U.S. government stockpile of cobalt stands at less than 50 percent of the established goal, the committee recommends that NASA examine ongoing projects to see whether program revisions should be made to accommodate these adverse conditions (which have occurred since the MATE program was defined). Cobalt has been used freely for gas-turbine high-temperature alloys. The U.S. aerospace industry is the largest user of cobalt, nearly 60 percent of which comes from Zaire. Unlike chromium, whose replacement in high-temperature alloys has not been found, a cobalt alternative can generally be found by formulating another alloy or by revising the engine configuration to permit the use of alternative alloys. Both aspects should receive NASA's attention, and in this respect, the MATE program should put more emphasis on the long term.

NASA has used the talents and resources of both engine designers and materials suppliers to good advantage in the MATE program to date.

Seven projects under contract to three engine companies are yielding encouraging results. In one project, the hot isostatic pressing of a cobalt-alloyed turbine disk has been qualified for production, and will result in significant savings in raw material.

Aeroelasticity of Turbine Engines (ATE)

The objective of this program, being conducted at Lewis, is to develop an analytical method for the design of flutter-free compressors and fans. Flutter in turbojet engine compressor systems is an exceedingly complex phenomenon, involving not only the aerodynamic interaction of multiple blades and stators, but also the structural dynamic interaction of blades, disks, stators, and ducts. Certain rules of thumb to avoid flutter have evolved from experience, but following these rules does not lead to flutter-free operation in new designs.

The results of this program to date are encouraging. Design techniques that avoid flutter in the supersonic stall/unstall region have been demonstrated. This prompts confidence in finding solutions for flutter in other operating regimes.

The development of analytic criteria for flutter-free designs will result in significant savings in engine development time and cost by avoiding the 12 to 24 months required to redesign, procure, and retest a stage when a major flutter problem is encountered. The committee is encouraged that this program is being carried out cooperatively with the Air Force's Aeropropulsion Laboratory and Office of Scientific Research and the Office of Naval Research. Participation by academic institutions and industry appears excellent, but more analytical effort should be undertaken within Lewis.

Another important problem is the forced vibration of compressor blades caused by the influence of stationary struts, turbulence, and wakes. This aspect of aeroelastic behavior should not be overlooked, and the committee recommends that NASA expand the ATE program to include forced vibrations. Furthermore, the structural analysis of the overall system; i.e., the rotor/case response to "g" load, gyroscopic moments, shocks, unbalance, and aerodynamic loading. This program needs to be planned as a long-term fundamental effort.

Avionics and Flight Control

The role of NASA in avionics and controls technology for transport aircraft is to develop options that can be exploited by the principal users to ensure safe and efficient air transportation. Two flight programs comprise NASA's systems technology and experimental programs in this area, one each at the Langley and Dryden centers.

Terminal-Configured Vehicle (TCV) Program -- Langley

This program is conceived to explore the usefulness of modern avionics equipment in the environment immediately around an airport. The objectives of the program are to increase terminal-area capacity and efficiency, improve adverse-weather operations and reduce noise through operating procedures. This is one of the more important Langley programs; the kind of program that can bring together the efforts of many manufacturers and government agencies (in particular, the FAA) in an overall effort that no one else is capable of accomplishing. This program can have a very powerful effect on the overall economics of the air transport system. In general, time saved and efficiencies achieved in the air traffic control system have high leverage on the economies of airplane operation. It should be noted that the most modern wide-body civil transports, however, are quite capable of essentially automatic operation throughout the entire flight mission and are now beginning to be used in that way.

Digital Fly-by-Wire Program (F8-DFBW) -- Dryden

This is a flight research program using a Navy F-8 aircraft that has been modified by applying major elements of the Apollo spacecraft digital electronic control system in the F-8 aircraft to supplant the original control system to demonstrate and evaluate the feasibility and advantages of digital fly-by-wire control systems for aircraft. It is an application of the digital control techniques pioneered in the Apollo program. The two-phased program, started in 1971, is scheduled for completion in 1979. Phase I, completed in 1973, demonstrated the feasibility of a digital fly-by-wire system in a simplex configuration. Phase II is assessing the performance and reliability of an all-electronic digital system in which reliability is obtained by triple redundancy. The program has made important contributions to the Space Shuttle, and is expected to contribute substantially to advanced transport designs.

The committee considers this an important program and recommends it be extended to the problems of fault-tolerant systems, including the pilot interface and operational restrictions. Thorough assessment should be made of the software burden imposed by fault-tolerance requirements and the digital fly-by-wire system should be evaluated against competing concepts through a rigorous reliability analysis.

Small Transport Aircraft Technology (STAT)

This Ames program has as its objective the identification and demonstration of cost-effective applications of advanced technologies for the development of a significantly improved small, short-haul transport aircraft. This aircraft could be a conventional takeoff and landing aircraft, or could include a small amount of augmented lift. It is designed to fill a gap in commuter airline requirements.

The program includes the integration of aerodynamics, structures, avionics, and propulsion to achieve a low-cost, high-efficiency, and high-performance airplane design. The direction of this effort appears to be toward the design of an aircraft. The committee questions whether an effort of this sort is appropriate, and whether the effort to identify and demonstrate cost-effective applications of the aircraft extends beyond NASA's basic responsibilities and capabilities. The committee believes NASA should explore concepts. The committee fully supports the studies of concepts and technology integration, but the specific aircraft design and configuration should be left to industry. If there is a market for such an airplane, it will attract a commercial supplier.

Integrated Program for Aerospace Vehicle Design (IPAD)

U.S. industry, aerospace particularly, could improve productivity by integrating interactive computer-aided design with computer-aided manufacture (not to be confused with automated drafting and numerically controlled machine tools). Phase I of NASA's IPAD program is intended to provide an operating system or a set of instructions for the types of computers now generally used in the aerospace industry. The Phase I program focuses on the interactive design process and the integration of a common data base that can be used for computer-aided manufacture.

NASA should continue to sponsor IPAD to make these operating systems available to all of the U.S. aerospace industry. No computer manufacturer is likely to find development of such a system profitable. In fact, only a few large aerospace manufacturers have the resources to accomplish such a development. Competitive advantages are transient, but the U.S. export position in aerospace, and superior defense weaponry will be less vulnerable to erosion if a system such as this is available to U.S. industry.

The committee believes the most important problems to be solved are the development of an efficient computer management system for very large engineering data bases, and the integration of these data bases into interactive engineering and manufacturing environments. The integration of NASA's IPAD system with the USAF's ICAM (Integrated Computer-Aided Manufacturing) program is essential to achieving the lead-time and cost reductions sought. The committee commends NASA's recognition of this need, and the effort that has gone into coordination with both potential users and computer suppliers.

Stratospheric Cruise Emission Reduction (SCERP)

This Lewis program was initiated in Fiscal Year 1976 in support of the Department of Transportation's Climatic Impact Assessment Program, and has the objective of reducing emissions of nitrogen oxides from aircraft engines during cruise. The work in this program encompasses some fundamental research in lean-burning combustion, and has been worthwhile in providing more efficient combustor concepts. Subsequent to the initiation of the program, some doubt has arisen about the need to control nitrous oxide at cruise altitudes. However, the committee recommends that the combustor work be continued even if the original purpose for the program no longer exists. The reason for this recommendation is that the lean-burning combustor concepts developed by Lewis may help improve combustor durability (a limitation in most modern high-temperature engines, both military and commercial) or improve the tolerance of combustors to the variations in fuel properties that will exist in the near future.

Human/Vehicle Systems Technology

This area, a growing one, and an important effort of the Ames Center, is primarily concerned with the question of human factors in aviation safety. The program supports the recommendation of the committee in its earlier report that NASA should create a unique center of excellence at Ames that could take a leadership role for the country in this area. The committee was impressed with Ames' approach to the problem, and urges that research into the personal and mental capabilities that make a good flight and ground crew be emphasized.

This complex program is unique, and in its early phase it lacks focus. The committee suggests that a statement of near-term goals would help to focus the program and give it direction. The committee recognizes that it is difficult to staff the in-house portion of this program due to lack of specifically trained personnel, but the program appears to have made a good start on a reasonable path.

Fighter Aircraft Technology

Highly Maneuverable Aircraft Technology (HiMAT) Program -- Langley and Dryden

This program is intended to advance the state of the art of designing highly maneuverable fighter aircraft by the simultaneous application of advancements in various disciplines to complement and augment one another. An approximately 3/8-scale model of a fighter aircraft design incorporating such advancements is being constructed and will be flight-tested at the Dryden Flight Research Center using the remotely piloted research vehicle test technique developed by Dryden.

The Highly Maneuverable Aircraft Technology (HiMAT) program is exciting for several reasons. It represents an attempt to design a vehicle beyond the bounds of demonstrated technology, and proceed to in-flight evaluation. The Langley Center has the lead responsibility for technical direction of the HiMAT program, and Dryden has the responsibility for the vehicle construction and flight test. This division uses the special capabilities of the two centers to advantage.

High-lift techniques, aeroelastic tailoring by use of composites in primary structure, and the application of computational fluid dynamics techniques in the design process will all be subject to experimental verification by the flight research program, as will the techniques of flight evaluation. The program has a large potential payoff.

The committee considers the HiMAT program a good example of long-term, exploratory flight research that Dryden should emphasize.

The Langley Center had the lead responsibility for the program during the technology development and vehicle design stages and, as stated above, continues to have responsibility for technical direction of the program, although lead responsibility for the program during the vehicle construction and flight-test phases is vested in the Dryden center. The committee considers this program a good example of how the centers should collaborate, but the process is faltering. It appears Langley interest in the program has waned with the transfer of responsibility to Dryden. The committee considers that both Langley and Ames must continue to be intimately involved in the HiMAT program if the benefits of the program are to be realized. The program should be evaluated to assure that the original goals of the program are being accomplished.

Transonic Aircraft Technology (TACT) -- Dryden

This flight program uses an F-111 variable wing-sweep fighter aircraft equipped with a new wing that incorporates supercritical airfoil sections. The F-111 TACT program is part of a three-pronged program to evaluate supercritical airfoil technology in the real environment of full-scale flight. The first in-flight study was a joint NASA/Navy flight test of a thickened unswept wing on a Navy T2-C aircraft. The tests showed that the internal volume of a straight wing could be significantly increased with no loss in airplane performance by thickening the wing and employing a supercritical airfoil. The thick supercritical wing was first flown in November 1970. A second was a swept wing with supercritical airfoil sections, simulating a commercial jet transport wing in its dimensions, that was flown in March 1971. This wing was installed on an F-8 aircraft, replacing the original F-8 fighter wing. Flight test results verified the predictions of wind tunnel test results for a significant increase in the wing drag-rise Mach number. The third part of the program, the F-111 TACT airplane, first flown in November 1973, was a joint NASA/U.S. Air Force investigation of the application of supercritical airfoil technology to a maneuvering fighter aircraft with variable-sweep wings.

The final phase of flight testing of the supercritical wing on the F-111 was scheduled for completion in September 1978. A symposium was held in August 1978 to report the final results of this program, which was begun in 1969. The program has demonstrated substantial improvements in constant-altitude turning radius and sustained "g" climb capability. Since 1975, the TACT aircraft has been used for more detailed investigations focusing on leading edge separation and vortex flow characteristics, the collection of high Reynolds number data on three-dimensional boundary layer characteristics, two-dimensional flow separation, and wing buffet.

This has been a successful and worthwhile program, and since the airplane will be rebuilt to satisfy different requirements for an Air

Force program, a critical review should be made to see if there is more that can or should be done on these important problems before major modifications block any further work on the F-111 TACT airplane configuration.

F-15 Program -- Dryden

The problems of aft-body drag and thrust prediction that are being addressed by this flight-measurement program are among the most important facing the designers of high-performance aircraft. There is still much uncertainty surrounding the effects of inlet flow distortion on engine stall. The F-15 aircraft was selected by NASA as representative of its class of aircraft, and as having the potential for adding significantly to the data base on these important problems.

The F-15 will be used by Dryden to verify prediction techniques which were used for the specific design of the F-15. It will also be used for some boundary-layer transition research, and for testing a simple in-flight thrust-measuring technique.

Spin Research Vehicle -- Dryden

This program, using the remotely piloted research vehicle capability developed by Dryden, fills a need for data at controlled flight conditions close to wing stall and spin entry, and post-stall. Models of sufficient scale are used to permit prediction of full-scale aircraft behavior and the definition of spin-recovery techniques.

The Spin Research program, using an unpowered 3/8th-scale model of the F-15, is a cooperative program with the Langley center. This important flight-test technique will add valuable data to the technology base in the areas of scaling and flow-separation effects. The work is well coordinated between Langley and Dryden, and between wind tunnel, flight, and computational approaches. In this program, a Dryden engineer will participate in the Langley wind tunnel work and also in the analysis of the flight data when he returns to Dryden, in a fashion similar to that recommended by the committee in its earlier report on NASA's Aeronautics Research Technology Base Program. Such personnel movement between Dryden and other aeronautical centers is highly desirable.

Oblique Wing Flight Evaluation

The oblique wing is straight, and mounted on an aircraft fuselage so that it can be pivoted about its mid-point from a position at which the wing is at right angles to the fuselage, as on any conventional straight-wing aircraft, to form angles of up to 60 degrees with the fuselage with one half of the wing swept forward and the other half swept back. Forward sweep and backward sweep are about equally effective in reducing compressibility drag, and the pivoted oblique wing offers a means of providing variable wing sweep. They differ markedly in their stability and flutter characteristics, however. The concept has undergone analytical and wind tunnel studies at the Ames Research Center with results that indicate substantial fuel savings for supersonic cruise aircraft with the wing highly swept, and efficient, quiet takeoff and landing with the wing unswept. Because the pivoting oblique wing concept is a dramatic departure from conventional aircraft design, Dryden has initiated the present flight program, using a small manned aircraft, to explore the piloting problems associated with the concept. The program will also provide an assessment of a low-cost approach to developing flight-test vehicles. The aircraft will have a gross weight of 1800 pounds, a wing span of 30 feet, and an engine thrust of about 400 pounds. The aircraft, being procured under contract for $218,000, will be flown at speeds up to 150 knots to explore low-speed flying qualities and piloting problems.

There are many questions of handling and flying qualities, controls and aeroelasticity to be answered, and the committee believes the pivoted-wing flight test is appropriate as a low-cost exploratory investigation of these aspects of this novel concept at low Mach number.

Drone for Aerodynamic and Structural Testing (DAST)

This is a flight program that uses a Firebee drone aircraft as a test bed. The Firebee has been modified to be remotely piloted from the ground, compatible with the capability developed by Dryden for its remotely piloted research vehicle program. An especially designed wing has been constructed and installed on the Firebee vehicle in place of the original wing to study airloads and flutter suppression techniques. The program fulfills a research need at Langley, the center that established the research objectives and defined the program. This is an excellent example of the combination of flight research capabilities at Dryden with disciplinary capability at another center that the committee encourages. The program is well managed and should add considerably to the understanding of flutter by allowing tests that would not be as productive in a wind tunnel and would not be safe with a pilot in the aircraft.

The objectives of the program are to demonstrate a flutter suppression system at speeds up to 20 percent above flutter speed and to validate flutter prediction techniques.

The committee considers it essential that proper attention be paid to validation of current flutter prediction techniques and to comparison between the experimental results and unsteady aerodynamic theory. In this way, the program can make substantial contributions to active control technology.

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