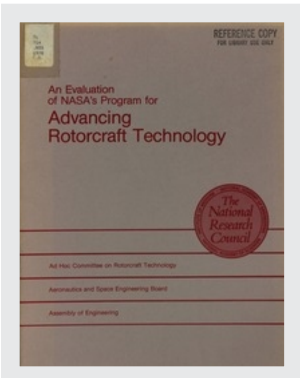

An Evaluation of NASA's Program for Advancing Rotorcraft Technology

DETAILS

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Abstract: This report is a survey of the technological needs and opportunities for improving various types of rotorcraft over the next two decades and the adequacy of NASA's proposed research effort to provide the necessary technology in that period.

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A Report of the
Ad Hoc Committee on Rotorcraft Technology

Aeronautics and Space Engineering Board

Assembly of Engineering
National Research Council

NATIONAL ACADEMY OF SCIENCES
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INTRODUCTION

Rotary-wing aircraft is the generic name for helicopters, and other aircraft, such as the tilt rotor, that are sustained in the air wholly or partly by long, slender "wings" or rotor blades, revolving around an axis. One of the earliest ideas for a rotorcraft goes back to Leonardo da Vinci, whose notebooks reveal that about 1500 he envisaged the possibility of using helical-screw wings for vertical flight. But it was not until 1941, after many attempts by inventors in many countries, that what is considered the first helicopters to be placed in production were designed and built by Igor Sikorsky. Since the 1950's, when helicopters came into prominence for evacuating the wounded in the Korean War, rescuing the victims of floods and earthquakes, and transporting passengers between congested city centers and outlying airports, this type of aircraft has gained acceptance and proved useful for an even larger variety of applications, including crop dusting, construction work, police surveillance, forest and power-line patrol, mineral exploration, offshore oil rig supply, and civil transportation. Even so, the state of development of rotorcraft now in use is roughly analogous to that of the DC-3 in the late 1930's rather than today's 747 or DC-10.

Rotorcraft are characterized by one or more powered, horizontal rotors, enabling them to take off and land vertically, to move in any direction in flight, or to hover stationary in the air. Versatile, reliable, and maneuverable, these aircraft do not require a runway and can operate in places that are often inaccessible to fixed-wing aircraft, such as an oil rig, or ship deck, a rooftop, or a jungle clearing.

If projections hold true for the demand and application of rotorcraft in the 1980's and beyond, many technological advances will be needed to enlarge the capabilities of such aircraft for civil transport, offshore oil and gas operations, environmental monitoring, emergency services, and military activities. Concerned about the future for advanced rotorcraft, the National Aeronautics and Space Administration (NASA) has been strengthening and realigning its research capabilities in rotorcraft technology. Accordingly, NASA has designated the Ames Research Center in Mountain View, California, as its principal rotorcraft research facility. Ames will receive support for rotorcraft structures from Langley Research Center in Hampton, Virginia, and for propulsion from the Lewis Research Center in Cleveland, Ohio.

The federal research laboratories that contributed so greatly to the development of civil and military flight in the United States from 1915 to 1958, under the National Advisory Committee for Aeronautics (NACA), and since then under NASA, continue to perform unique work. Staffed by groups of talented, dedicated, and innovative scientists, engineers, and other technically capable people, these facilities have produced a vast amount of nonproprietary research results, often with potentially widespread applicability, including new techniques, materials, and components. NASA's program of aviation research and development has centered on basic studies and development testing, with the result that its work has been important in stimulating technological advances for both civil and military aircraft.

In its review of NASA's proposed program for rotorcraft research, the committee considered it important to:

- Establish what research and technology are required for advancing the state-of-the-art for rotorcraft in the next two decades.

- Attempt to place some priorities on those requirements.

- Suggest the allocation of resources among the requirements.

RESEARCH AND TECHNOLOGY GOALS

It is patently appropriate for NASA's proposed rotorcraft program to concentrate on basic research of problems relevant to the technology. By developing fundamental theories and analytic design methodologies, NASA can help to construct a sound base from which the rotorcraft manufacturing industry could leap forward in technology. In this connection, research and development for rotorcraft should be centered on areas where technological improvements and change are known to be needed. Thus, the committee considers it important for NASA to:

- Conduct systems analysis studies to identify viable vehicle concepts and define systems needs in order to provide direction and focus for the research effort on a continuing basis.

- Perform flight testing as a means for better understanding of fundamental problems and to provide guidance for the basic research program.

In the development of theory and analytic design methodology, an area of particular importance is the complex flow field created by the rotor geometry. Better understanding is needed of the interaction of this flow field with the rotor to enable a designer to optimize rotor performance, minimize vibration and noise, and determine the effects of the airflow on the airframe. Thus, the committee recommends that a NASA research effort be directed to extending classical aerodynamic theory to include a better understanding of the vortex structure of the wake from its initiation at the rotor blade, and, particularly, at the blade tip, through its interaction with the following blades and with the fuselage, including real fluids effects.

Knowledge of the characteristics of the vortex core, including how it develops and its exact position, is essential for determining the performance, vibration characteristics, and noise levels of any new rotor system. Analytical design methodology should encompass the entire spectrum of performance, loads, vibration, noise, and structural integrity.

Such methodology does not exist for rotorcraft, except through the use of trial and error procedures that are costly, time consuming, and not always productive.

Vibration is a critical problem with rotorcraft. Both civil and military helicopters suffer from high vibratory loads that result in large maintenance and operating costs and contribute to pilot fatigue and passenger discomfort. Better understanding of the basic aerodynamic mechanisms causing vibratory loads would result in significant contributions to theoretical and analytical design methodology. Thus, the committee recommends that NASA's rotorcraft research program should include gaining an understanding of the phenomenon that causes vibration rather than in the development of hardware to absorb or isolate vibration.

A better understanding of the basic aerodynamics, thermal stresses, materials characteristics, and fatigue behavior of compressors and turbines would lead to improvements in the design procedures for the small engines used in helicopters. In its work to develop analytic and computational procedures, NASA is urged to include the problems peculiar to small engines. With the benefit of better analytic tools, improved reliability and maintenance characteristics can be achieved -- critical requirements for rotorcraft in order to satisfy commercial considerations and military needs.

Clearly, NASA needs to concentrate on the development of basic theory, including the development of computational algorithms. The development of large computer programs to apply the theories to specific designs can be conducted by individual industrial contractors to fit their own needs in the design and development of rotorcraft. NASA's effort should be placed on understanding fundamentals and on experimental verification of theory through the use of scale models, using recently developed sensor techniques so ably innovated in the past by NASA.

With regard to systems studies, NASA needs to conduct meaningful analyses of the U.S. transportation system on a worldwide basis in order to maintain a knowledge and understanding of how rotorcraft can satisfy perceived needs to the benefit of the nation. This will help define the requirements for vehicle capability and the characteristics for assessing research priorities and program emphasis. Also, the system studies should be integrated with the planned, extensive flight test program to provide the context for judging flight test results and the efficacy of configuration concepts as determined by economic evaluations.

The NASA rotorcraft program should also be directed to providing the technological know-how for the development of an all-weather capability to improve the safety, usability, and reliability of the aircraft. A critical need here is the technology for reliable sensing devices capable of providing flight data at very low speeds. To operate any rotorcraft, a pilot needs to have precise information about such matters as slide slip, rearward flight, and small rates of climb or descent relative to the air mass and the ground. Sensors would be invaluable for both civil and military rotorcraft during flight operations at night or in adverse weather.

With regard to flight testing, it is essential to test advanced components and complete configurations in flight in order to uncover unexpected problems. Indeed, this is the only way to conduct research into some problems that are associated with aerodynamic and structural dynamic behavior and interaction between components, because the system is called upon to respond dynamically under real and unrestrained conditions. The results obtained in flight testing can not only drive but direct basic research.

NASA is fully capable, as was NACA before it, to conduct flight tests because it has the personnel and facilities, as well as the expertise in instrumentation and data acquisition, to do the job. However, the committee recommends that NASA should avoid development testing of rotorcraft components or specific rotorcraft. Such testing is best done by the industry and military for their specific purposes. It would be wasteful and unproductive to use NASA's uniquely valuable national capabilities for tests that will be run, of necessity, by aircraft manufacturers and military establishments.

NASA should concentrate on flight research with highly instrumented aircraft for the purpose of understanding basic phenomena. The new Rotor Systems Research Aircraft (RSRA) should prove to be a valuable facility for such studies. Its unique instrumentation and force measuring capability enables it to be a part of an integrated research, analysis, and testing procedure in which tests can be run at small scale and to full scale in a 40-foot by 80-foot wind tunnel and eventually flight tested on the RSRA, if a concept proves technically promising.

The committee also recommends that NASA's plan for flight research should include high-speed rotorcraft concepts -- this being an area the committee considers to hold great potential for the future in both commercial and military fields. The committee endorses NASA's suggested plan to reinforce the programs on the Tilt Rotor, the ABC (Advancing Blade Concept) rotor, and compound aircraft. At the same time, consideration should be given to the possibility of stowed rotors to improve the cruise efficiency of both the tilt rotor aircraft and the compound aircraft (a helicopter which employs a conventional wing along with the rotor and auxiliary propulsion).

The development of composite materials and structures has proceeded in an orderly way from the laboratory to limited use in military and civil aircraft. The rotorcraft industry is aggressively seeking to use composite materials in the construction of rotor blades. NASA is studying the composition and characteristics of composite materials in its Research and Technology Base program and their use and behavior in its Aircraft Energy Efficient program. The committee endorses NASA's plan to study the problems of materials and structures specific to helicopters as part of the proposed rotorcraft program. Even so, the need exists for comprehensive data and understanding of the effects of the operational environment on composite materials over an extended period of time, particularly for helicopters, with their specialized problems relating to attachments for bearing highly concentrated loads and to rotating components subject to intense vibratory stress.

The committee recommends that NASA monitor and study the behavior of materials in the operational flights of new aircraft that are constructed with composite materials. Such an in-service monitoring program would provide the needed data, which, when obtained, analyzed, and documented by NASA, would be available in the public domain by rotorcraft operators as well as manufacturers.

PRIORITIES

The selection of priorities for any program as comprehensive as the one proposed by NASA posed difficulties for the committee. The proposed program is structured around the three basic aeronautical technologies of aeromechanics, structures, and propulsion. To set priorities for the three technologies is not a feasible approach because of the highly integrated nature of rotorcraft. Any meaningful program will need to be a coordinated and integrated effort based on all three technologies. The committee, therefore, elected to focus attention on those critical problems which, if satisfactorily solved, would provide great impetus in achieving improved rotorcraft for both civil and military uses in the future.

Therefore, the committee recommends that program priorities be established in the following order:

1. Develop analytic design methodologies, with particular emphasis on obtaining a basic understanding of the rotor aerodynamic flow field and rotor dynamics.

2. Improve all-weather capability over the full speed regime from hovering to high speed.

3. Reduce noise -- internal and external.

4. Perform systems analyses leading to a better definition of the rotorcraft and other VTOL aircraft needs.

5. Develop composite materials technology applicable to helicopters and other VTOL aircraft.

6. Reduce first cost.

7. Reduce cost of ownership.

ALLOCATION OF RESOURCES

The committee considers NASA's planned rate of buildup of funds for the proposed program to be too rapid. The number of personnel who will be available to do the work under the plan will not justify the financial outlay. Although some scaling down in the proposed rate of funding is suggested now, a significant increase in funding will be necessary at a later stage in the program to achieve the desired advanced rotorcraft technology.

There are two areas in which adjustments in the proposed technical program are recommended and two efforts that the committee considers should be added to the program. First, in the area of design methodology, the committee suggests that the design and development of advanced rotor hubs is a task best undertaken by industrial and military research and development organizations, and, because this practice is expected to continue, there is no need for NASA to initiate the design of new advanced hubs. Also, the committee recommends that the composite airframe work not only be undertaken earlier than planned, but accelerated.

Second, in the area of flight control and avionics systems, full-authority fly-by-wire systems have been demonstrated in both fixed-wing and rotary-wing applications. Therefore, the committee suggests that the deletion of the development of new full-authority fly-by-wire systems would not cause any loss to the effectiveness of the program.

There are two specific items that NASA's program plan does not include, but that the committee considers to be vital and can best be attained by NASA. The first is helicopter control technology, which is now seriously limited by inadequate knowledge of the stability derivatives of rotors and the factors controlling them. The development of feedback gains, as it is now accomplished in flight, is expensive and time-consuming and will be extremely difficult for the high-gain systems that will be required for active control applications. The committee recommends that measurements of the stability derivatives of rotors be made in the 40-foot by 80-foot full-scale wind tunnel and on the RSRA to develop the methodology for predicting them.

The second is the evaluation of de-icing systems. To confirm the need for them is currently expensive and time consuming because of the difficulty of finding natural icing conditions. Even the Army's CH-47 icing simulator has serious shortcomings in simulating the problem realistically. The development of an adequate icing simulator is a challenging technical task, which, if successful, would be of significant value to both civil and military aircraft development. The committee recommends, therefore, that NASA undertake an effort to develop an icing simulator that will effectively simulate or reproduce realistic icing conditions.

If it is found necessary to reduce funding on some aspects of the program in order to maintain a steady funding level for the higher priorities, the committee recommends that the following steps be taken:

- Postpone some of the early effort and redistribute funds over the later time periods.
- Reduce the effort to develop specific techniques for vibration reduction.
- Possibly eliminate the tests of the integrated engine component systems, because this program may be adequately covered by the Army's Advanced Turbine Demonstration Engine (ATDE) program.

It was the committee judgment that the rotorcraft propulsion program is too large in comparison with the airframe and rotor programs. However, the committee recognizes that in the past the NASA helicopter propulsion effort has been paltry and, indeed, the committee endorses an expanded effort by the Lewis Center on rotorcraft propulsion and power transfer technology.

COMMENTS ON SPECIFIC NASA QUESTIONS

1. How far should development technology be taken to enable effective technology transfer?

NASA's prime objective should be to develop basic theory and analytical and experimental methodology. If confidence in the application of a new technical concept or innovation to operational vehicles has not been achieved at an earlier stage, demonstration should be carried through full-scale flight if necessary so long as the new technology continues to show promise. Flight testing also provides the means of defining important areas that require basic research. This applies to subsystems such as stability augmentation, vibration reduction, and composite structures, as well as to full-scale aircraft concepts.

2. Is NASA overlooking any critical needs?

The program plan presented by the NASA task force does not appear to omit any critical area.

3. Should emphasis be on evolution or revolution?

The committee urges that emphasis should be placed on evolutionay approaches. Revolution requires invention breakthroughs, or, at the least, highly creative approaches that cannot be scheduled in advance and usually cannot be accelerated, even by lavish funding. By contrast, evolution is bound to take place in a step-by-step research program. By creating a viable program in the field, NASA should be able to create an environment for innovative ideas, some of which may very well be revolutionary. It must be recognized, however, that a supportive environment must prevail to achieve major breakthroughs. Consequently, a small portion of the budget should go to encouraging creativity by limited funding of revolutionary approaches. Possibly, a few of these approaches should be pursued vigorously.

CONCLUSIONS AND RECOMMENDATIONS

The committee concludes that NASA has planned a comprehensive and potentially effective program that can lead to major technical advances in rotorcraft. Highest priority should be placed on developing the basic theory for constructing new design concepts, including full-scale flight testing, which would validate theory and provide proof of concept for new aircraft and subsystems. Also, high priority should be given to systems analyses to identify viable vehicle concepts and define systems needs to provide direction and focus to the research effort.

The ASEB's ad hoc Committee on Rotorcraft Technology endorses as sound the proposed program described in NASA's task force report, dated July 18, 1978. In keeping with the emphasis on basic theory and design methodology, the committee urges NASA to avoid pressures that could detract from its main mission. In two areas, hub/rotor systems and fly-by-wire systems, NASA needs to maintain highest priority on innovative concepts and basic research to provide technical options for the industry to proceed with the development of advanced systems. In reference to the unique technology needed for the application of composite materials to rotorcraft structures, the committee recommends that NASA accelerate its composite airframe program.