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HELICOPTER TESTING IN A WIND TUNNEL

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The need for aircraft aerodynamic studies is unquestioned. In spite of advances in aerodynamic theory, in spite of numerous collections of data and catalogues on wind-tunnel tests on airfoil sections, aircraft assemblies or entire designs — growing efforts to improve aircraft performance demand execution of an extensive program of wind-tunnel testing. These requirements pertain primarily to an integral aircraft model, as well as testing of distribution of pressures or aerodynamic forces on aircraft elements.

The problem of transferring test results on models to full-size fixed-wing aircraft or sailplanes has been adequately solved.

As for the rotary-wing aircraft, in which the problem of airflow and aerodynamics is considerably more complex than for fixed-wing aircraft (of course excluding the convertiplane, where airflow is more complicated), the erroneous opinion that rotary-wing aircraft are not suitable for model testing, which was predominant until somewhat more than 10 years ago, had a negative effect on helicopter development. The goal of numerous companies, teams and specialists in many countries is to surmount the "speed barrier" for rotary-wing aircraft, which is in the neighborhood of 250-300 kmh.

Tests have shown that the limitation to helicopter speed deriving from assymmetry of rotor airflow is based on burbles forming on the rotating blade and is less determined by the effect of compressibility on the "substream" blade. We must bear in mind that cyclic control of rotor blades and their self-adjusting movement constitute a complex of complicated dynamic phenomena. Thus attempts have been made to effect changes in the rotor itself, to improve rotor performance through complex kinematics -- such as the Derschmidt rotor, or the Lockheed rigid rotor — producing many engineering design difficulties.

Intensive research is continuing on slotted-blade, forced air (gas) airfoils, which will permit higher helicopter speeds while preserving hovering capability -- at the same time improving general operating economy.

On the other hand the helicopter fuselage must be constantly more aerodynamic in shape, as is clearly evident in French rotary-wing aircraft development, from the Alouette to the SA-340; the same trend can be seen in the development of Mil helicopters. The use of an additional airfoil and coupled drive -- through an airscrew providing horizontal thrust -- creates new aerodynamic problems.

Hooper, a British helicopter specialist and designer -- believes that dynamic analogy conditions are essential for model testing; without similarity of internal flow and heat phenomena one loses radial airflow components around the blades. The model must be geometrically and elastically analogous to the full-scale craft.

In view of the difficulty of building full-representation models, tests have been conducted and are being conducted with rigid blades; their suitability for fundamental research has been verified both in the literature and by statements made by rotorcraft experts.

In summarizing the opinions of such scientists as Hooper, Bennet, Pankhurst, and Shapiro, those problems which should be subjected to wind-tunnel testing can be divided into the following categories: 1) aerodynamic forces on helicopter fuselages, particularly in cases where an auxiliary airfoil is used; 2) new or modified blade sections and sections with nadmuch [air or gas ejection along blade to retard burble effect]; 3) improved high-efficiency tail rotors and pusher airscrews, with coupled drives; 4) models of rotors with nadmuch, including rotor head and internal gas line; 5) aerodynamics and kinematics of rotors with dynamic representation; 6) interaction of fuselage and rotor, as well as rotor head proper.

Not all helicopter flight configurations are fully suitable for testing in a wind tunnel; rotor testing requires towers permitting full-scale testing.

The following comments can be made on this testing:

1) absence of blade elasticity simulation may lead to errors as a result of rotor blade torsion;

2) testing and visualization of flow field are desirable for determining induced speed;

3) burble on the blades is an important factor -- the effect of Re scale and number is also important here, and model testing does not always provide full representation of airflow and aerodynamic forces. Profile drag increases with angle of attack faster for rotor airfoils than for a wing;

4) for small models it is difficult to determine autorotation state (the model must have a rotor disk diameter of at least 3 meters);

5) the effect of the wind tunnel is not fully defined for rotorcraft testing;

6) the basis for computing helicopter performance and stability is determination of aerodynamic differential coefficients with respect to time; they can be measured in tunnel tests, but some are difficult to obtain;

7) tests on mutual effect between helicopter fuselage and rotor requires mounting fuselage and rotor on special balances. In principle natural flight conditions should be reproduced, but position reversal (that is rotor down), eliminating blades weight, does not produce a substantial error for rotor kinematics.

These tests and accompanying difficulties have been the cause of failure and distrust of results obtained. In recent years many studies have been released and many comparisons have been elaborated, comparing the results of model tests and flight tests, as well as analytic computations. We can state that the enormous development of rotary-wing aircraft in the Soviet Union, the United States, Great Britain, and particularly in France, can be credited to wind-tunnel testing.

What sort of a stand should be used to test helicopters with turning rotor, and the rotors proper?

Not too many test stand designs have been published, but it is worth while discussing the matter in order to select the optimal system.

1. Rotors proper are tested on a stand developed by the British Royal Aircraft Establishment in 1949; this stand is used for many rotor tests. The powerplant is firmly mounted directly by the rotor, on a lattice frame arrangement standing on a remote balance. The powerplant can be tilted together with the rotor in relation to wind flow. Measurements must take into account total drag of the mount and total aerodynamic forces on the stand.

2. The Sikorsky Company also has a stand for rotor testing (1964); on this stand thrust and moment are measured directly at the rotor hub. The tests were on blades dynamically analogous to full-scale blades; these produced satisfactory agreement with measurements in flight.

3. In Hooper's (Fairey Aviation Corp.) rotodyne tests, he employed (1953) a fuselage model mounted upside down, with rotating rotor on the bottom. During measurement the fuselage model and rotor are not in contact. The fuselage and rotor can be placed at different angles.

4. The latest equipment -- a special tunnel with relatively low turbulence and with scale equipment -- was built in France in 1965, at the Marignane Helicopter Development Center (Sud-Aviation).

The fuselage is placed on a remote scale, while the rotor and drive are "placed" from above. The fuselage and rotor have a common turning point for angle change. The rotor mounting column moves during position change on a curved guide, whose center of curvature coincides with the fuselage turn point.

The best of the above equipment is the French; its defect is perhaps its small scale, since only small rotors can be tested, not by much exceeding two meters in disk diameter.

Without going into a detailed analysis of the accuracy of measurements on aerodynamic helicopter models, we can state that in the majority of tests an accuracy in the vicinity of 2 percent is obtained. The problem of measurements is difficult in relation to conventional fixed-wing aircraft for two reasons: aerodynamic coefficient changes on a time axis are required (at least for the rotor), and it is necessary to transfer values measured from the rotor head and blades to measurement and recording devices. This requires the recording of readings from measuring elements, primarily tensiometers, on a continuous basis. Transfer from rotating parts makes it necessary to use rings and collector brushes, or to use telemetric devices, which creates additional technical difficulties and reduces measurement accuracy.

Generally optical methods are used to measure blade movement, mostly with a motion picture camera mounted on the rotor head, turning together with the rotor, or laterally mounted, filming the plane of movement of the entire blade.

Computation methods, although rather laborious, can be considered adequately precise for determining characteristics of the main rotor and particularly dynamic blade loads only within a range of low flight velocities. For faster helicopters, however, computation methods have proved to be fairly inaccurate. In-flight testing is the most accurate, but it fails to give all measurement parameters, and is also costly.

A particularly difficult problem in model testing is the hub and blade control. Miniaturization of these complex systems, which must also contain measuring equipment, is not fully possible, and the smaller the model, the relatively larger the hub must be.

We should recall that one of the analogy criteria requires the same tip speeds on the rotor model as on the full-size rotor. Therefore the model rotor must turn faster. The stresses from centrifugal forces are therefore greater. Sometimes one must use stronger materials on model blades than on the full-size rotors, which in turn is disadvantageous for similarity of other dynamic values of the model and full-size rotor. Testing conducted by Sikorsky has indicated conformity with flight tests within limits of 2-3 percent for a large flight spectrum, with the exception of very low and high pitches, while measured stresses on the blades have indicated differences within a range of 10 percent.

The opinions and deliberations presented here indicate that the problems of helicopter aerodynamics are difficult and complicated. Some flight conditions are more difficult for analytic computation, cannot be precisely reproduced and investigated in wind tunnels, but the most important data can be obtained from model testing. This requires the construction of a number of devices of which relatively high measurement accuracy is required.

More and more new helicopter designs are of the "rigid" rotor type, tail rotors are frequently shrouded, and there is increasing conviction of the necessity of controlling blade movement higher harmonics.

The helicopter is currently in a phase of "revolutionary" changes and intensive research. The construction of modern, quality helicopters must be supported by research facilities in the form of wind tunnels with stands for testing helicopters with turning rotors.

In light of the above, how can we evaluate aerodynamic research being conducted at the Aviation Institute? In spite of the comparatively recent introduction of the helicopter topic, the research spectrum is rather broad:

1. Aerodynamic measurements on helicopter fuselage models over a full 360°, as well as for a limited range of angles. These measurements have been on aerodynamic forces and moments, as well as airflow visualization. We have studied the effect of an additional airfoil in various positions, as well as various types of landing gear. A special series of tests involved auxiliary tanks, containers and aerial application equipment. These tests were conducted minus downwash from the turning rotor.

2. Testing of tail rotors is fairly advanced. The aim is to establish the optimal tail rotor geometry, which is of great importance for control effectiveness, particularly in a hover situation. We have built equipment enabling us to measure thrust, moment and revolutions, both in place and in the wind tunnel, at various angles of attack. We have conducted initial tests without full blade dynamic representation. An analysis of measurement accuracy which has been conducted has enabled us to draw conclusions for building new measuring equipment. We will be using larger, improved equipment and stand, presently under construction, for testing larger-scale blade models, with fuller blade dynamic representation.

3. The next helicopter-related topic is airfoil tests with jet flap and nadmuch on the upper camber, for the purpose of delaying burble. We have effected optimization of geometry and slot placement.

According to an article by Dorand, popularizer and designer of helicopters with jet flap rotors, the rotor shaft mechanical drive with gas agent feed to the blades and circulation increase on the airfoils with slot discharge greatly improves helicopter performance and economy. Tests conducted at the Aerodynamics Establishment at the initiative of WSK-Swidnik, indicate that even a small discharge at an optimal selected slot position provides substantial burble delay and an increase in maximum angle of attack. Additional tests will be conducted on blade models on a rotary stand.

On the Mi-2 turbine helicopter the turbine exhaust gases can be used as the hot blast gas, or a compressor can be installed for a compressed-air stream. The gaseous agent can be carried through the hollowed shaft and rotor blades -- ejection can occur toward the tip, where burble on the "rotating" blade begins. Design changes for a helicopter such as the experimental Mi-2 are quite feasible.

4. Tests on a modification of the Mi-2 fuselage have indicated the necessity of improving fuselage-tail boom transition to reduce drag and fuselage aerodynamic moment.

5. Aerodynamic measurements on the rotor sections and their modifications, with the aim of testing possible aerodynamic changes on these sections by certain fillet modifications.

6. An important and urgent task involving helicopters is the building of scale equipment to measure rotors alone and fuselages with turning rotor. The plan calls for mounting the fuselage on the present upper mount, while "placing" the rotor on a column from below.

The rotor-bearing column and fuselage point of rotation will coincide due to a column-mount guide. The rotor will be powered by an ac motor and regulated by a frequency converter.

The rotor head will contain spring measuring elements with attached tensiometers. Rotor blade control will be effected by rotor axis change; there will be no "swash plate," so that angle changes will take place "at standstill." Rotor measurements will involve two components: thrust and moment. It is also planned to measure torsion moment at the blade root and blade oscillation angles.

One difficult problem is the transfer of measurement impulses from the rotating components, as mentioned above. A ring-brush and telemetric method are being analyzed.

The Mi-2 helicopter rotor blade model has already been designed with dynamic representation. Rotor measurements will be connected with a newly-built bottom scale in a tunnel 5 meters in diameter.

Thanks to the excellent comprehension of the problem and good cooperation with the Communications Equipment Factory in Swidnik, equipment improvement at the Aerodynamics Establishment should enable us to meet the needs of industry for aerodynamic testing for the purpose of further Polish helicopter development.

PHOTO CAPTIONS*

1. p 7. Helicopter fuselage being wind-tunnel tested (upside down).

*Translator's Note: Photos are not reproducible.

2. p 8. Soviet rotor tests in CAGI.

3. p 9. Sud-Aviation rotary-wing aircraft development.

4. p 10. Fairey rotodyne tests (model inverted).

5. p 10. British rotor test stand (Royal Aircraft Establishment).

6. p 11. SA-340 helicopter.

7. p 11. Tail rotors tested in wind tunnel.

ABSTRACT

Problems encountered in wind-tunnel testing of helicopters are described. Possible solutions in terms of test procedures and adopted test-bed equiptment are proposed. A summary is given of the helicopter wind-tunnel test program conducted in Poland for the domestic helicopter industry. (A69-32075)