Wind Tunnel Development of a Tandem-Rotor Helicopter in Australia*

By J R MARSH, B ENG

In response to a request for information on helicopter developments in Australia, the Association received the following paper which will be of interest to members The author is a Scientific Officer of the Aeronautical Research Laboratories, Department of Supply, Melbourne, Australia He has been a member of the Association since 1954

Considerable work has been done on wind tunnel testing of helicopter and autogyro rotors and of specific helicopter fuselages but there is no available information on the wind tunnel development of a complete design prior to construction of a prototype helicopter With interest in the stability and control of helicopters and to assist the development of a specific design the wind tunnel development was undertaken by the Aeronautical Research Laboratories

An experimental approach was decided upon due to the complicated effects of tandem rotor flow interference on performance and stability and control and to the intractibility of theory on this aspect of helicopters The following gives the proposals put forward for such work (Ref 1)

The specific design for a four place, single reciprocating engine powered, tandem-rotor helicopter is that of the Molyneux Helicopter Co , Essendon, Victoria Some details are given in Table 1

TABLE I

COMPARISON OF FULL SCALE AND MODEL PROPERTIES

Property	*Full Scale*	*1/7th Scale Model*
Rotor Diameter	30 ft	4 286 ft
Tip Speed	600 ft /sec	600 ft /sec
Rotational Speed	380—415 r p m	2660—2905 r p m
Weight Gross flying	4,000 lb	82 lb scale lift
Empty	2,800 lb	57 lb scale lift
Power (cruise)	250 h p	5 1 h p
Cruising Speed	100 m p h	147 ft /sec
Maximum Speed	120 m p h	176 ft /sec

A working model of one seventh scale was chosen for the 9′ × 7′ wind tunnel

Model parameters were scaled considering the dynamics of the rotor blades, the parameters considered being aerodynamic, inertia and gravity forces, blade Reynolds and Mach numbers and blade deflection pattern or strain Using blade materials as in the prototype, a compromise was reached in which flight and rotor tip speeds were kept constant between model and full scale This maintains compressibility effects and blade strain constant at the expense of Reynolds number and gravity effects

DESCRIPTION OF THE MODEL

Since the construction of the first model of the four place helicopter, the designers have considered a smaller two place machine Both are

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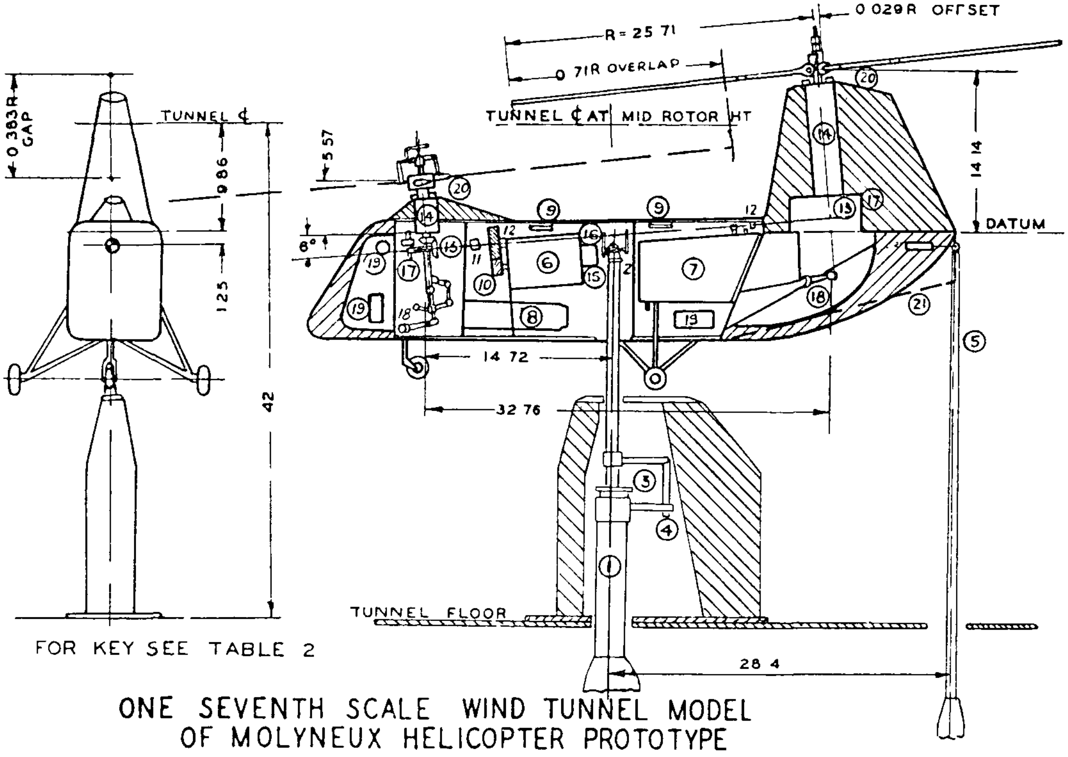

Fig 1 General arrangement diagram of the Molyneux project

KEY TO FIG 1

1 Main Support Pylon
2 Universal suspension
3 Yaw bearing
4 Yaw clamp
5 Rear spear
6 Driving motors—two side by side
7 Coolant tank
8 Coolant pump—motor
9 Electric terminals
10 Gear reduction 15 84
11 Rubber coupling on main drive shaft
12 Universal joints on main drive shaft
13 Mitre gears
14 Thrust tubes
15 Alternator for rotor speed measurement
16 Thermocouple on motor field winding
17 Collective pitch screws
18 Cyclic pitch screws
19 Pitch control motors
20 Flapping inductance coils
21 Outline of straight sided tail fairing

tandem rotor helicopters powered by reciprocating engines The main part of this paper refers to the model of the larger helicopter, although design changes, particularly in the rotor head in this and the smaller one call for construction of another model This will differ from the original in that dimensions such as rotor vertical and horizontal gaps will be readily changeable The fuselage will be of wood fastened onto a metal framework supporting the working components

Figures 1 and 2 give details of the original model The seventh scale model is powered by two five-horsepower high-frequency liquid-cooled induction motors driving onto a common gear and drive shaft and thence through bevel gears to the two rotors

Each rotor has one collective and two orthogonally mounted cyclic pitch control jacks driven by small reversible D C motors

The rotor blades are constructed similarly to those projected for the prototype, with improved wood leading and balsa trailing edges, the whole being covered with brown paper to simulate the plywood skin on the prototype This construction with slight sanding ensures that the chordwise centre of gravity position is the same as for the full size blade

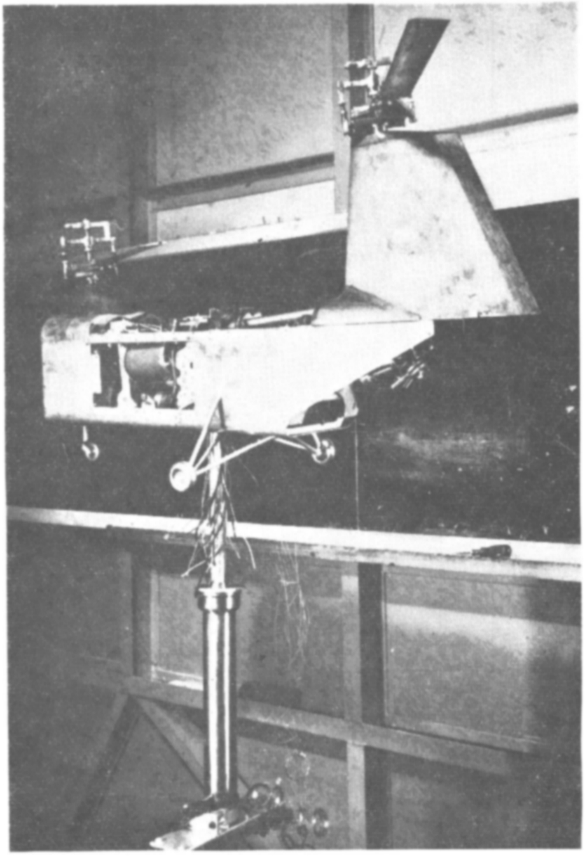

Fig 2 The model helicopter mounted on its universal support

Test Set Up

The model will be mounted on the three component (Lift, Drag and Pitching Moment) balance of the 9′ × 7′ wind tunnel The main central support pylon is connected to the model by a universal joint at the mean c g position allowing freedom in body pitch, roll and yaw A vertical rear spear is connected to the pitching moment balance through universal joints allowing freedom in roll and yaw

A strain gauge mounted on the main pylon will be used to measure side-force Body bank and yaw angles and rotor control settings will be determined using potentiometer circuits

The total rotor shaft power will be measured on a sensitive wattmeter connected to the electrical input of the driving motors The system will be calibrated against fans mounted on the rotor shafts In the later model each rotor shaft torque will be measured using strain gauges and slip rings

To determine blade coriolis forces the rotor blade flapping will be measured using a small soft iron flag mounted on one blade of each rotor near the flapping pin This will vary the inductance of a stationary coil mounted coaxially with the rotor shaft, and measured on a c r o triggered at rotor circular frequency by a contact mounted on the main drive shaft

PROGRAMME OF INVESTIGATIONS

Parasite Drag

Preliminary tests on the 1/7th scale model have shown that the hub drag represents 70% of the total parasite drag and involves 90 h p at cruising speed This initially caused the change in rotor head design mentioned above

In order to obtain accurate figures for parasite drag, and because of the relatively unknown effects of Reynolds number on spinning bodies, extensive work on parasite drag has been started A quarter scale wooden model of the helicopter fuselage with spinning hubs has been constructed With an increase in tunnel speed above full scale flight speed a Reynolds number of one half full scale may be reached Also, changes in shape are more readily carried out on this model than on the metal and wood 1/7th scale model To extend further the range of Reynolds number on the rotor hubs a full scale wooden hub mounted on an electric motor driven shaft has been constructed

With these models parasite drag will be reduced to an optimum and drag values accurately determined using normal wind tunnel techniques

Mixing of Controls and Performance

The aim is to determine the optimum control settings and powers required for trimmed flight in the following conditions

1 Hovering ,
2 Level flight ,
3 Climbing flight ,
4 Power-on inclined descent ,
5 Autorotative inclined descent

For all of these a general method of testing will be attempted The method if successful will greatly reduce the computing of results compared with standard wind tunnel techniques

The model will be " flown " on its universal support under trimmed conditions For a series of body pitches, rotor and wind speeds and collective pitch on the front rotor the other five rotor controls will be adjusted until

1 The body is free in yaw at zero yaw
2 The body is free in roll at a small angle of bank The model will be balanced about the roll axis to eliminate gravity rolling moment
3 The side force is zero

4 The parasite drag equals the forward thrust of the rotors, *i e*, the drag balance reading is zero when corrected for support drag and true drag as derived from the parasite drag tests, tunnel interference, and scale weight component due to climbing angle
5 The lift is within the scale weight range
6 The pitching moment is small

Attempts will be made to satisfy all of the above conditions for a series of pitching moments and lifts Then the centre of gravity range may be calculated

If it is found difficult to set these conditions, the zero side force condition will be removed and tests done for a series of side forces near zero, the results being interpolated to the zero side force condition

From the results for all flight conditions the most suitable mixing of controls will be selected, attention being paid to the control linkage construction necessary, the nature of control action required by the pilot and control interactions, blade coroilis forces, variations in stability due to longitudinal dihedral with changes in forward speed, and rotor power required Autorotation tests will be carried out only if bench tests show the transmission gear losses to be to scale with those estimated for the prototype

Tandem Rotor Interference

An attempt will be made to determine the effect of rotor vertical gap on rotor power with the model as constructed

The total power required for trimmed flight for a range of body pitches will be determined, the lift, drag and pitching moment balance readings being adjusted to represent the body at zero pitch, and allowance being made for the effective change in rotor vertical gap on rear pylon height

The power required for various vertical gaps then may be compared with the sum of powers required for each rotor alone, the front rotor controls being left as for tests with both rotors on and the rear ones being adjusted to bring forces and moments to trim values when added to those forces and moments derived from tests with front rotor only

Stability

With the mixing of controls determined readings of lift, drag and pitching moment rear trim will be taken to derive speed and altitude static stability

The $\frac{1}{4}$ scale wooden model with rotating hubs will be used to investigate weathercock stability and fuselage longitudinal static stability

Corrections to the Tests

The increase in blade drag coefficient with decrease in Reynolds number between full scale and model will be neglected as regards its influence on rotor drag and side forces, these being small compared with those produced by thrust tilt However, the rotor power will be considerably affected Hovering tests on one rotor will give a mean blade drag coefficient determined by subtracting a calculated induced power from the total rotor power as in Ref 2 and this will be compared with that calculated for the full size rotor from published data on the NACA 0012 section at full scale Reynolds numbers As the increase in profile drag power up to cruising speed is small compared with that while hovering, the same correction will be applied at all speeds

Normal wind tunnel interference corrections will be applied considering the lift system as two elliptically loaded wings in tandem

PRESENT STATE OF THE WORK

Much difficulty is being experienced in obtaining efficient and continuous performance from the driving rotors When this is overcome hovering tests will be commenced on a balance consisting of a frame extending between two platform scales to measure lift and pitching moment and with slight spring stiffness in the drag and side force directions In this way it is hoped to determine the suitability of the proposed " trimmed " method of testing Then the later model will be used for the full investigation in the wind tunnel

The work on parasite drag is in progress

REFERENCES

1 MARSH, J R — " A Proposed Programme for Wind Tunnel Development of a Tandem Rotor Helicopter " *A R L Aero Tech Memo* 116, March, 1955

2 SQUIRE, H B , FAIL, R A *and* EYRE, R C W — " Wind Tunnel Tests on a 12 ft diameter Helicopter Rotor " *R A E Report Aero* 2324, April, 1949

Book Review

Helicopter Navigation Requirements

Prepared by F DORN BARCLAY and GORDON S WILEY, of the
Stanford Research Institute, Menlo Park, California

The chief aim of this study is directed towards the establishment of the basic performance requirements, for an integrated Navigation System for the types of Helicopters that are expected to become operational in the period 1958/60 Navigation as dealt with by the authors, encompasses Radio Navigation Aids, Communications Systems, Flight Instruments, Auto-pilots and Meteorology In expanding these headings they have produced one of the best surveys to date, the success being due to the fact that pilots, operators, manufacturers, and government regulatory organisations were consulted to the full

Twenty-six figures and graphs are presented with the text covering such widely differing features as Vortex ring state, Approach success patterns, Speech interference levels, Suggested Helicopter Traffic Routes in the New York Area and Visual Recognition Ranges

The Study does not appear to reach any definite conclusions on the type of Navaid needed for Helicopters and it blames its inability to do so on the present indecision in the U S on separation standards for the future, however, one gathers that equipment will be airborne and not ground controlled which is in line with our thoughts on United Kingdom Civil Helicopter Navigation

Other conclusions of note are

1 Helicopter air carrier operations will not generally be intermixed with fixed-wing traffic
2 Minimum terrain clearance will be 300—500 feet
3 Safe range of approach angles will be approximately between 0—20° from the horizontal depending on obstacle clearance requirements
4 Vertical flight to and from en route altitudes appears to be unnecessary as a standard operation requiring a separate Navaid
5 A Navaid will not pay for itself solely on the basis of increased flights per year (derived from recorded weather statistics) but the increased safety in maintaining proper separation, and the increase in regularity of service, should provide operating efficiency which will largely offset the additional weight of equipment

J A C

The scene at Dunsborough Park, Ripley Surrey portrayed by Claude Muncaster
This picture will be used to illustrate the Association Christmas card for 1956

The Rally and Garden Party at Ripley

An informal function took place at Ripley, Surrey, on July 28th, 1956, when members were invited by Mr and Mrs Charles Hughesdon to hold a Rally and Garden Party in the grounds of their residence, Dunsborough Park

Over 300 members and guests were present including some 30 who arrived in the eight helicopters which took part in the Rally Unfortunately, the weather was not as kind as it might have been, the afternoon beginning with low cloud and slight rain However, this cleared by about 3 30 p m giving way to brighter conditions and a little sunshine

There was no official flying programme but a number of informal flights were made during the course of the afternoon to give our hostess the experience of helicopter flying, and for photographic purposes Another item of interest was a ‘ fly-over ’ by a Bristol 173 tandem rotor helicopter during the course of a B E A routine test flight from Gatwick Airport nearby

The function was a notable success and the Association is greatly indebted to Mr and Mrs Hughesdon for making available the facilities for a Rally in such delightful surroundings, and also for providing tea for the whole assembled gathering We are also indebted to Shell-Mex and B P Ltd who provided special refuelling facilities in the grounds for those helicopters which had come from a long distance

B H A