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RATIER METAL PROPELLER WITH PITCH VARIABLE IN FLIGHT

By Pierre Léglise

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Difficulties in Making Aircraft Propellers so Their Pitch Can Be Varied During Flight

The difficulty usually mentioned in connection with the construction of such propellers is that due to the deformations of the bearings under the action of the centrifugal force and the bending stresses in the attachment of the hub. The ball-bearing balls make imprints in the ball races and require considerable force to start them. There is, however, another very serious source of difficulties, which seems to have first attracted the attention of the Ratier Company. This is the turning moment or torque due to the centrifugal force which tends to bring the mean plane of the blades into the plane of rotation. This moment, which is found elsewhere only in propellers with removable blades, is so great that the aerodynamic forces, as regards their effect on the torsion, become entirely negligible in comparison with it.

Amount of the Torque

Let us consider a propeller with removable blades (Figs. 1-3) whose centrifugal force is supported by a thrust bearing with or-

*"L'hélice métallique Ratier à pas variable en vol," from L'Aéronautique, December, 1929, pp. 407-411.

dinary balls. $O_1\ Z_1$ is the axis about which the blade turns in varying the angle of attack, $O_1\ X_1$ the axis of the engine, and $O_1\ Y_1$ an axis perpendicular to the plane $Z_1\ O_1\ X_1$. Starting at the point O on the side z, we draw perpendicularly to $O_1\ Z_1$ two infinitely near planes P_z and P_{z-dz}. These planes enclose a portion of the blade of thickness dz, whose upper section contains the plane XOY, OX being parallel to $O_1\ X_1$ and OY parallel to $O_1\ Y_1$.

In this section let us consider an element of volume

$$V = dx\ \ dy\ \ dz,$$

one of the summits of which is the point M, as defined by the coordinates x, y, z. The mass of this element is

$$m = \frac{dx\ dy\ dz\ \delta}{g} \quad (\delta = \text{density}).$$

The centrifugal force

$F = m\ \omega^2\ R$ (R being the distance from the axis $O_1 X_1$),

is perpendicular to the axis of rotation $O_1 X_1$, but oblique to the plane XOY. Let α denote its angle with the axis OZ. F is resolved into

$$F_z = m\ \omega^2\ R \cos\alpha \quad \text{and} \quad F_y = m\ \omega^2\ R \sin\alpha$$

following the parallels to OZ and OY. F_y generates, on the bearing, a moment

$$F_y = m\ \omega^2\ R \sin\alpha\ \ x,$$

but $\sin\alpha = y/R,$

whence $F_y = m\ \omega^2\ xy.$

It is obvious that, for a given element, this moment is greatest when the factors x and y are equal, i.e., when M is equidistant from OX and OY. The maximum moment for the whole section is produced when the mean profile line follows the bisector of XOY, this conclusion being strictly correct only for symmetrical profiles. On replacing m by its value, we have

$$F_y = \frac{\delta}{g} \omega^2 \; xy \; dx \; dy \; dz.$$

The elementary torque produced by the portion under consideration is therefore given by the double integral

$$\frac{\delta}{g} \omega^2 \; dz \int \int_S xy \; dx \; dy,$$

extended to the whole section S of the portion under consideration. For the whole blade, the moment is given by the triple integral

$$C = \frac{\delta}{g} \omega^2 \int_R^0 dz \int \int_S xy \; dx \; dy$$

extending from the tip of the blade to the hub. This moment, which tends to bring the mean planes of the blades into the plane ZOY, cannot be zero in the case of a propeller with removable blades. Figure 3 shows, in fact, that the components F_{yM} and $F_{yM'}$, due to the two points M and M', symmetrical with respect to O, do not balance each other, as might be imagined at first thought, but combine to turn the ball bearing.

The total moment is very great. It reaches 70 kg-m (506 lb.-ft.) for a propeller of 3.1 m (10.17 ft.) diameter at 1850 r.p.m.

with a 500 hp engine and an air speed of 220 km (137 miles) per hour. For an airplane of the future with a 2000 hp engine at 1850 r.p.m. and an air speed of 300 km (186 miles) per hour, it will reach nearly 300 kg-m (2170 lb.-ft.) with a propeller of 4.1 m (13.45 ft.) diameter.

Balancing of the Moment

Forces of this order, unless balanced by an opposing moment, are practically impossible to overcome. The Ratier Company has very ingeniously devised a helicoidal thrust ball bearing. Its direction of rotation is such that the torque tends to screw the blade into its hub when the centrifugal force tends to unscrew it. Furthermore, the pitch is so adjusted that the reaction of the centrifugal force on a thread just balances the component of the moment along the same thread.

For simplicity we assume that the centrifugal force F_z and the moment C (Figure 4) act on a single ball, though in fact

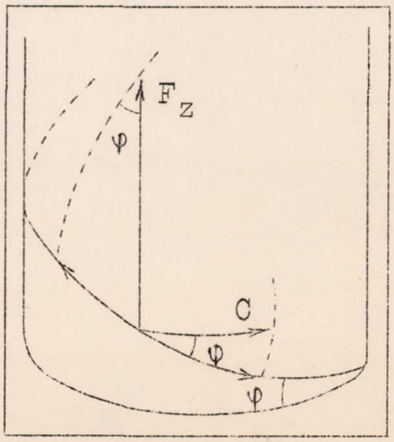

Fig.4

the two forces are divided into as many equal fractions as there are balls. Let φ be the inclination of the thread to be determined. The moment component along this thread is

$$C \cos \varphi ,$$

while the component of the centrifugal force is

$$F_z \sin \varphi .$$

In order to balance the moment, we must have

$$F_z \sin \varphi = C \cos \varphi \quad \text{and}$$

$$\varphi = \text{arc tan} \frac{C}{F_z} .$$

φ is a constant, because C and F_z have the form $k\,\omega^2$ and $k'\,\omega^2$, k and k' being constants. The pitch for which the balancing is done is therefore well determined and independent of the speed of rotation.

The torque due to the centrifugal force is practically nonexistent in two-bladed wooden propellers, because the latter are made of several boards with their glued junction planes parallel to the plane of rotation (Fig. 5). The molecules of each board are, in fact, symmetrical by pairs with respect to the axis of the engine, and the torsional components balance each other. To be more exact, the moment would be zero if the boards were infinitely thin. In practice, however, the chamfer corresponding to the profile on each edge of the board creates a slight torque.

In a three-bladed propeller, on the other hand, the effect of the moment causes a tendency of the boards to slip. It is this tendency which the glue must withstand.

The Ratier Propeller

Mounting the propeller on its hub.- The root of the duralumin propeller blade 8 (Fig. 6) is fitted with a nitrided steel sleeve 6 by means of a groove and key 7. The sleeve 6 is held against a shoulder of the blade root by a threaded sleeve 10. The sleeve 6 and the hub 12, likewise made of nitrided steel, are both provided with screw threads (the small pitch of which was determined by calculation) which leave a free space between them. In the ramp thus provided, there are placed, at the moment of screwing, the balls 9 which constitute a helicoidal ball bearing extending nearly the whole length of the blade root. These balls are held between two stop springs 4 and 11, the former resting against a key and the latter against a screw.

At the base of the blade there is a bearing with 14 rollers surrounding a boss on the propeller hub. This arrangement assures the centering and the guiding of the blade while its pitch is being changed and absorbs the vibrations of the blade root while running. The propeller socket or hub has, at its outer end, a conical part 5 in which there are four saw cuts. The collar 3 presses on this conical part and holds the end of the hub against the balls, thus regulating the play. The propeller blade is held firmly in its socket by the centering rollers at its base and by the pressure of the collar 3 on the conical part.

Mechanism for controlling the pitch.- In each blade root there is engaged a pin 16 terminating in an eye which is joined to the collar 18 by the connecting rod 17. The collar 18 can slide longitudinally on the hub bushing 15, which is keyed to the engine shaft. The displacement is produced by a slide block 19 into which are screwed the ends of three shafts 28 forming jacks 21. One of these jacks, ending in the control shaft 28, moves the other two. For this purpose it is made integral with a small toothed wheel 24 which engages with the intermediate transmission gear 25. The latter in turn actuates small toothed wheels integral with the other two jacks.

The slide block 19 and the collar 18 are connected by a bearing 22 with a sufficiently deep annular groove to form a thrust bearing. A second bearing 22, of the same nature, is interposed between the bushing of the hub and the housing 26 inside of which the gear shafts and control wheels are mounted. The housing case is filled with oil and closed with a cover, tightness being assured by joints such as 27.

Operation

In order to change the pitch of the propeller in flight, it is only necessary, by means of a distance control, to turn the shaft 28, which determines the longitudinal displacement of the slide block 19. The latter carries with it, through the intermediation of the thrust bearing 22, the collar 18. The connecting rods 17 actuate the pins 16, and the two propeller blades turn in their sockets in opposite directions, while being supported by the balls on the helicoidal ramp. The rotation of a blade is so small that the vertical displacement of the connecting rod 17, resulting from the spiral motion, is negligible.

The Ratier Company is contemplating the control of the pitch variations by electricity. The pilot will have only to press a button, and the duration of the pressure will determine the magnitude of the angular displacement. A new control instrument, the pitch indicator, will take its place on the instrument board. Circuit breakers will automatically limit the displacement of the slide block 19 in case of error.

The first propeller, 3.1 m (10.17 ft.) in diameter, and having about 1700 balls, was mounted on a 450 hp Lorraine 12 E.B. engine. It passed successfully, at the S.T.Aé., an endurance test of 30 hours in periods of 4.5 hours, one hour of which was at the speed of 1850 r.p.m., and 3.5 hours at 1800 r.p.m. The mechanism enabled easy variations in the angle of attack of the order of 20 degrees at all revolution speeds, which corresponds to a variation of about 800 r.p.m. in the engine speed. The force exerted on an ordinary control wheel never exceeded 2 kg (4.4 lb.). It has just passed satisfactorily its first flight test of one hour on a "Potez 25" airplane.

Photographs of assembly and parts of the Ratier metal propeller with pitch variable in flight are shown in Figures 7, 8, 9, and 10.

Translation by Dwight M. Miner,
National Advisory Committee
for Aeronautics.

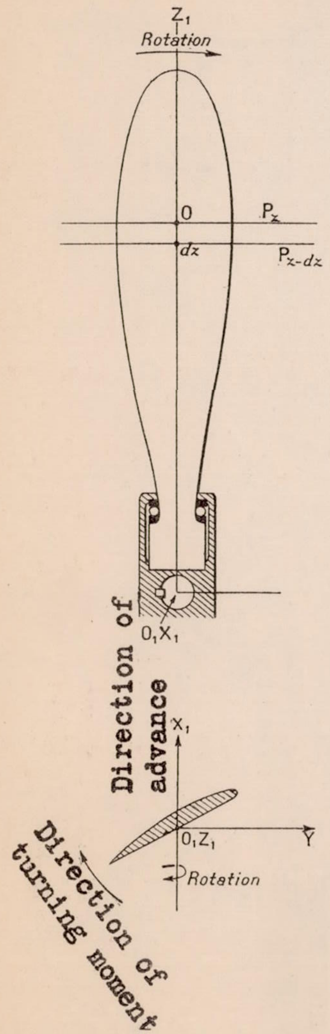

Fig.1

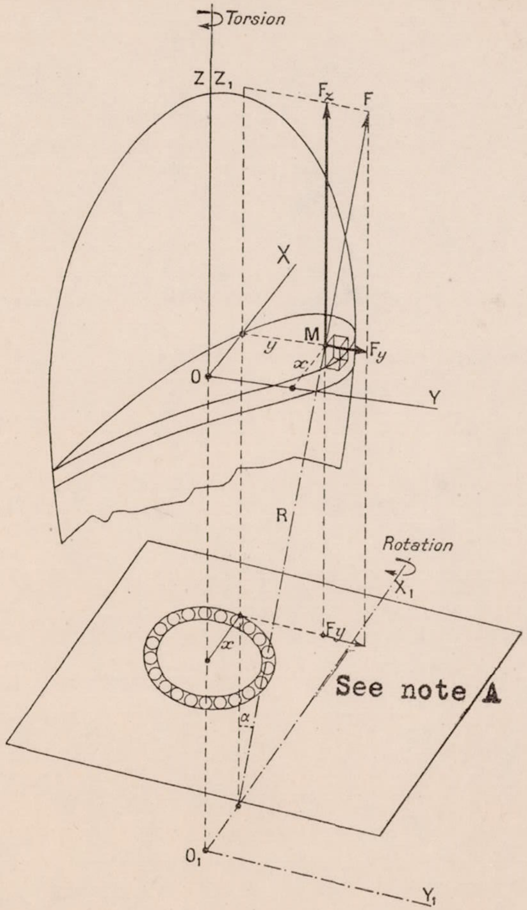

Fig.2

Note A

Plane of the ball bearing in which the turning moment is produced.

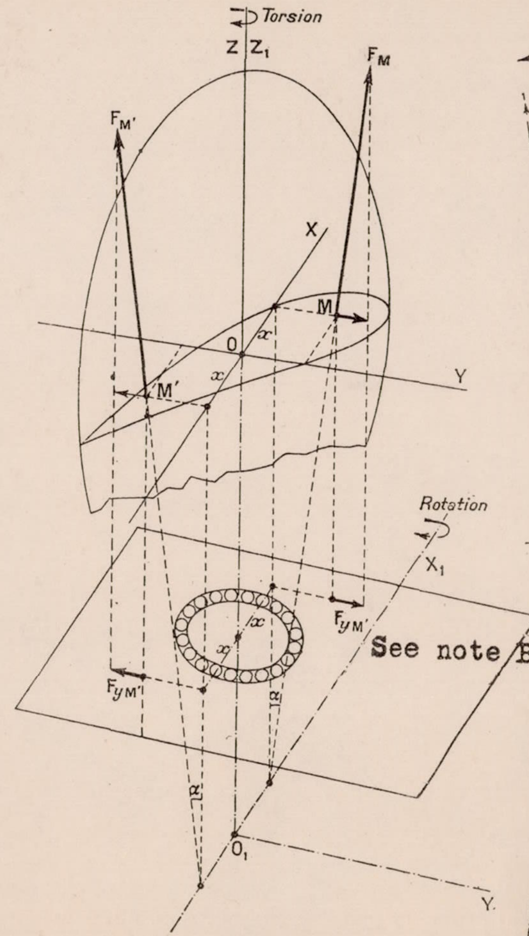

Fig.3

Note B

Plane of the ball bearing in which the turning moment is produced.

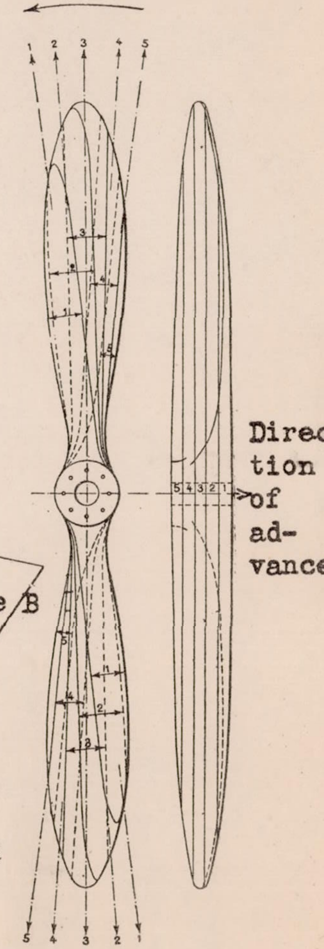

Fig.5

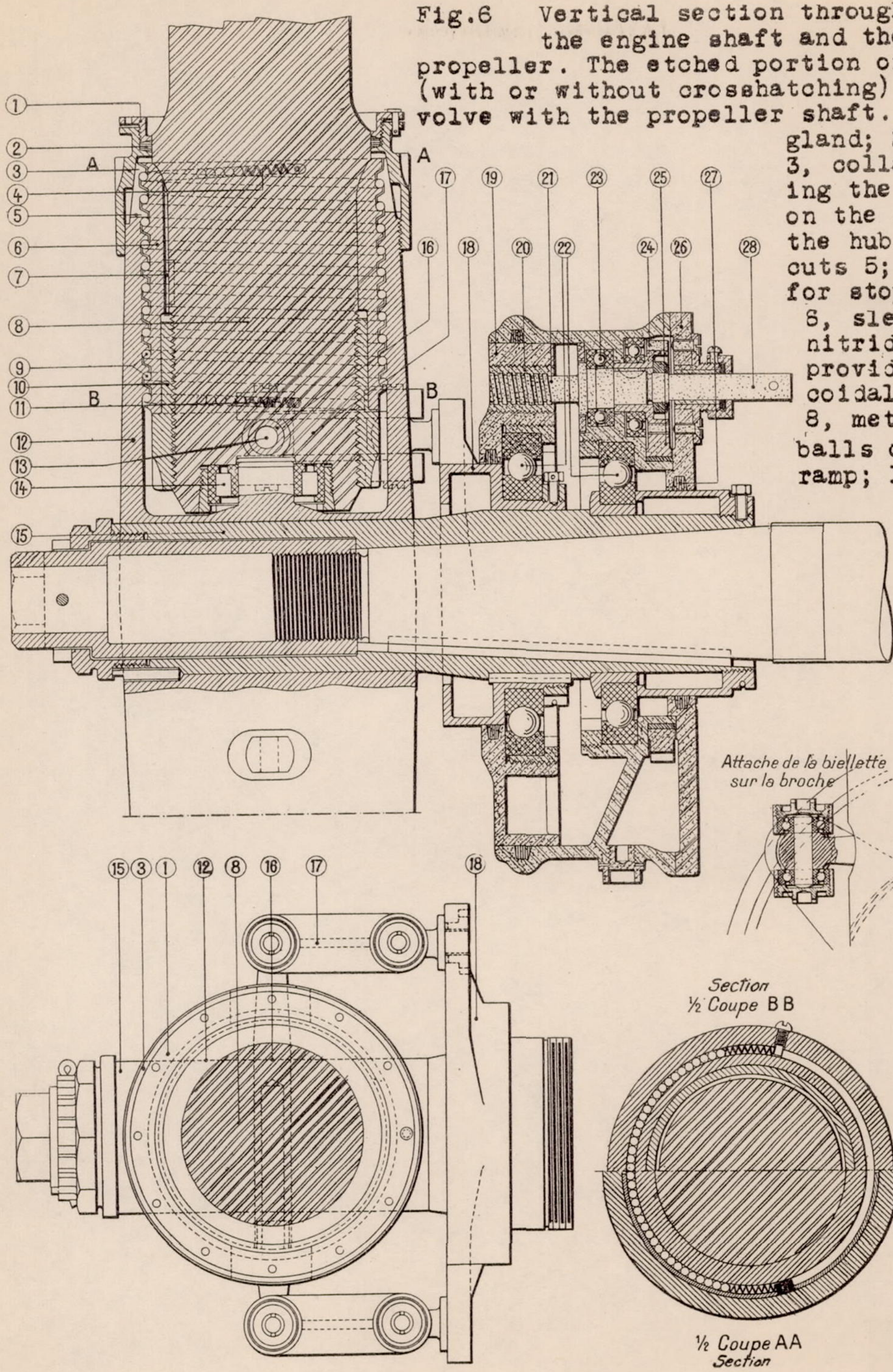

Fig.6 Vertical section through the axis of the engine shaft and the axis of the propeller. The etched portion of the mechanism (with or without crosshatching) does not revolve with the propeller shaft. 1, packing gland; 2, felt packing; 3, collar for regulating the play by acting on the conical end of the hub which has saw cuts 5; 4, upper spring for stopping the balls; 6, sleeve made of nitrided steel and provided with a helicoidal thread; 7, key; 8, metal blade; 9, balls on the helicoidal ramp; 10, sleeve for holding the root of the blade; 11, lower spring for stopping the balls; 12, nitrided-steel hub with helicoidal thread for receiving root of blade; 13, socket for head of pin 16; 14, centering piece for the blade root mounted on rollers; 15, hub bushing; 17, connecting rod articulated on pin 16 and on the collar 18 which turns with the propeller shaft; 19, slide block receiving, in three bronze grooves 20, the the ends of the shafts 28 forming jacks 21; 22, ball bearings with deep grooves; 23, thrust bearing absorbing the reaction of the jack 21; 24, small toothed wheel keyed to shaft 28; 25, large transmission gear driven by 24 and in turn actuating the two small control wheels of the other two jacks not shown in the cut; 26, cover of the fixed casing; 27, felt packing between fixed and revolving portions; 28, shaft for controlling the pitch. At the bottom, cuts perpendicular to the axis of a blade, made at different distances from the axis of the proppeller shaft. Just above the latter, ball-and-socket joint between connecting rod 17 and pin 16.

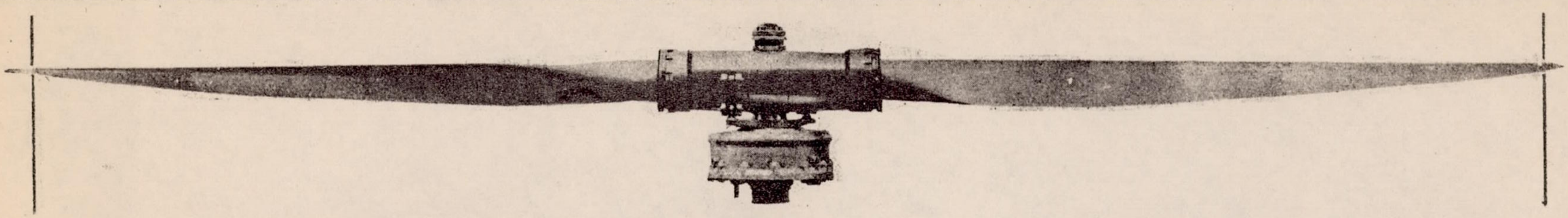

Fig.7

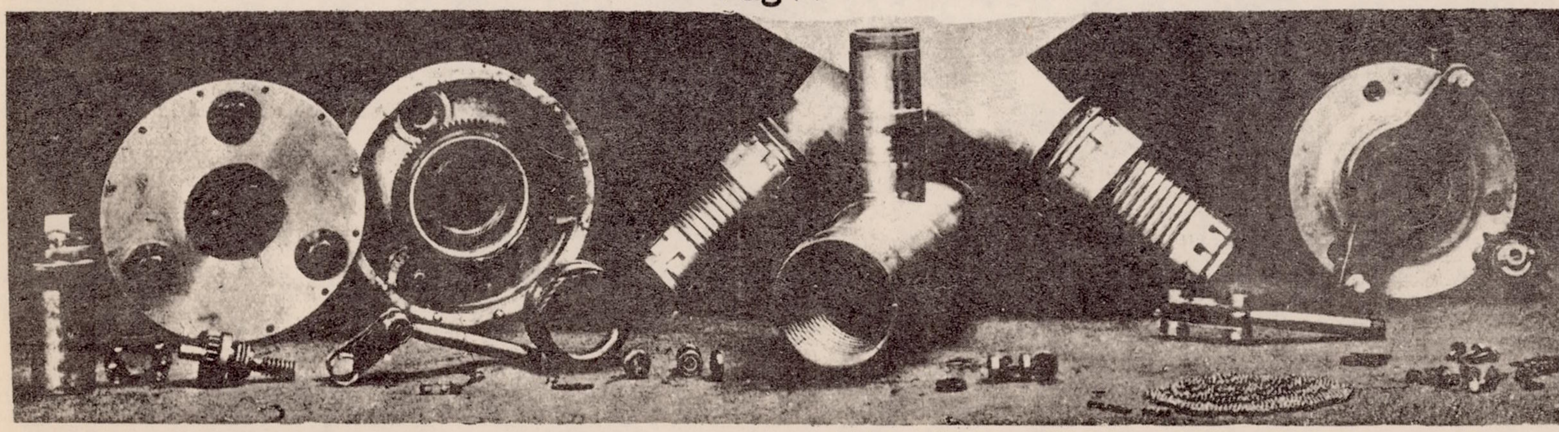

Fig.8

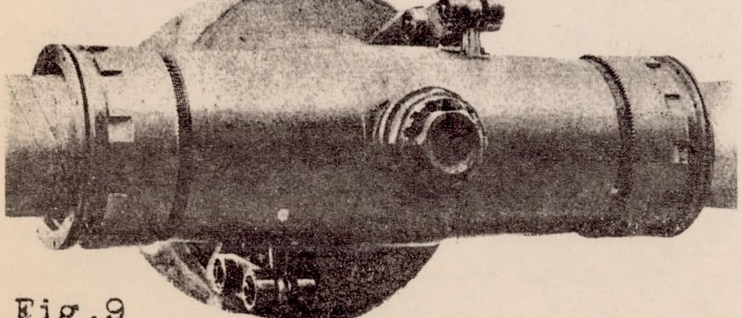

Fig.9

View of rear side of hub showing the fixed housing of the mechanism for controlling the pitch. Note the three jack bearings with the control shaft projecting from one of them.

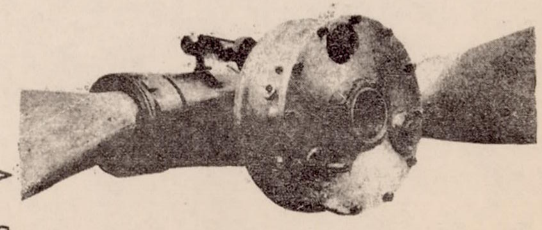

Fig.10

Figs.7,8,9,10 Photographs.
Assembly and parts of the Ratier metal propeller with pitch variable in flight.