NACA-TM-459

TECHNICAL MEMORANDUMS

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 459

VARIABLE PITCH PROPELLERS

By H. L. Milner

From "The Gloster," September-December, 1927

Washington
April, 1928

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VARIABLE PITCH PROPELLERS.*

By H. L. Milner.

It is generally recognized that a variable pitch propeller would greatly improve the performance of an airplane or airship and it is proposed in this report to explain the Gloster Hele-Shaw Beacham Variable Pitch Propeller. Before proceeding to the description we can, with advantage, examine the general flow of air past a propeller blade and the possible effect of varying the pitch.

Consider a fixed pitch propeller rotating at n revolution per second travelling with a forward speed V feet per second. Figure 1 illustrates the flow of air relative to a typical section of the propeller blade at a radius R from the axis of rotation.

This section is travelling in the plane of rotation with a velocity $2\pi Rn$ and simultaneously moving forward with velocity V. A is the fixed angle between the blade section and the plane of rotation. Then according to this elementary theory the velocity of the wind relative to the blade is V_W and the angle between the chord of the blade section and the direction of V_W is the angle of attack (α).

Suppose now that the rotational speed is maintained but the

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*From "The Gloster," Sept.-Dec., 1927, Vol. III, Nos. 3 and 4.

forward speed is reduced to V_1. The relative wind velocity becomes V_{W_1} and the angle of attack α_1.

The modern conception of propeller theory is rather more elaborate than the foregoing, allowance being made for inflow velocity and slip stream rotation which modify our V_W both in direction and magnitude but for the present purpose we can neglect these refinements.

Reverting to Figure 1 we see that the angle of attack α depends on the forward speed V and speed of rotation n. Further, if V and n were reduced in the same ratio α would not be affected.

During a climb the engine R.P.M. are lower than at forward top speed. The airplane speed also falls but more rapidly than the R.P.M. Hence it is clear that the propeller operates at a greater angle of attack during a climb than at top speed.

The efficiency of the propeller depends to a great extent on α and there is a certain critical value of the angle of attack which, other things being equal, will give maximum efficiency. It is this angle which the designer contrives to attain in designing the propeller. Hence it is obvious that a propeller designed for top speed in level flight will not give the best possible results in climbing or at any speed other than the designed condition.

The consideration of take-off is important. When an airplane commences its run, due to the low forward velocity, the propeller efficiency is diminished and, further, the engine revolutions are pulled down owing to the braking effect of the propeller so that the engine gives less than its maximum power. This combined with loss of propeller efficiency seriously reduces the power available.

With a supercharged engine considerably greater variations of forward speed occur and the propeller efficiency correspondingly suffers. There are also big variations in the power available at altitudes.

Let us consider an airplane with a fixed pitch propeller fitted with a supercharged engine giving a constant torque at all air densities up to the designed height h in Figure 2.

Neglecting corrections for slip stream effect, consider points on the "horsepower required curves" related so that the attitude of the airplane is the same at corresponding points of the curves drawn for ground level and height h.

If the velocity and density at height h are denoted by V_h and ρ_h respectively, and V_o, ρ_o refer to ground level, the weight of the airplane W which is regarded as constant

$$= C_1 \rho_h V_h^2 = C_1 \rho_o V_o^2$$

where C_1 is a constant

$$\therefore V_h/V_o = (\rho_o/\rho_h)^{1/2}$$

If H is the horsepower required

$$H = K\rho V^3$$

where K is constant for any given attitude

$$\therefore H_h/H_o = \rho_h V_h^3/\rho_o V_o^3 = V_h/V_o.$$

Hence for similar attitudes in different densities the power required is proportional to the forward velocity V, and if we are given a ground level "power required curve" A_o, B_o, C_o, we can easily construct a similar curve for any height h where the density is ρ_h.

To find the point on the altitude curve corresponding to C_o, we have $OD = V_o$

find OE so that $OE/OD = V_h/V_o = (\rho_o/\rho_h)^{1/2}$.

Join OC_o and produce, where the ordinate from E cuts this line we have a point on the new curve corresponding to C_o.

For any other point P_o on the original curve draw OP_o and produce. Join P_oD and make P_hE parallel to P_oD then P_h is the corresponding point on the new curve for height h.

Now consider the airplane flying at top speed V_h at height h with a fixed pitch propeller designed for that altitude and maximum permissible R.P.M. of n_h.

Also suppose the airplane to be fitted with a supercharged engine giving a constant torque Q at all heights up to 25,000 feet then

$$Q = F(V/nD)\rho n^2$$

where $F(V/nD)$ is independent of the density and for a given propeller depends only on the ratio V/n.

Let the airplane fly at ground level with the same V/n as at height h but not necessarily at the same attitude. Then $V_o/n_o = V_h/n^h$,

also $\rho_o\, n_o^2 = \rho_h\, n_h^2$ since the torque is constant

$$\therefore \quad \rho_h/\rho_o = (n_o/n_h)^2,$$

but from a consideration of the airplane characteristics we have already seen that at corresponding attitudes and level flight

$$\rho_h/\rho_o = (V_o/V_h)^2$$

$$\therefore \; n_o/n_h = V_o/V_h$$

Hence the condition that V/n should be constant in different densities is satisfied by level flight at constant attitude. If P_h and P_o are the powers available at height h and ground level respectively, since the torque is constant we have

$$P_o/P_h = n_o/n_h = (\rho_h/\rho_o)^{1/2} = V_o/V_h.$$

Thus the available horsepower is proportional to the forward speed for similar attitudes in different densities, and if $L_h\, C_h$ is the "available horsepower curve" at height h, a construction similar to that used for finding the "horsepower required curve" can be employed for deriving the horsepower available curve for any other height.

The construction is shown in dotted lines in the figure, and we arrive at the "power available curve" $L_o\, C_o$ for ground level having given the corresponding curve L_h C_h for height h or vice versa.

Or briefly, if we are given "horsepower required" and "horsepower available" curves for ground level where the density is ρ_o, the corresponding curves for altitude where the density is ρ_h can be obtained by multiplying the coordinates of the original curves by $(\rho_o/\rho_h)^{1/2}$.

With an engine supercharged to 25,000 feet and the propeller designed for top speed at that altitude at maximum permissible revolutions the thrust horsepower at ground level will be reduced to $(\rho_h/\rho_o)^{1/2} = .66$ the power at 25,000 feet.

Thus there is a loss of 34% of the original power and in the case of a supercharged engine giving 500 HP. at 25,000 feet, this loss will be 170 HP. During a climb the loss will be even greater than this and will probably amount to 40% or 200 HP.

This loss can be greatly reduced by the use of a variable pitch propeller running at constant R.P.M., thus giving considerably greater available power for taking off and climb, at the same time permitting increased forward speeds at ground level.

Many attempts have been made to provide a propeller in which the pitch could be changed during flight.

Apart from the propeller to be presently described, these variable pitch propellers can be grouped into two classes:

(a) Those in which the pitch variation is effected by centrifugal force or a combination of centrifugal force and wind pressure.

(b) Propellers in which the pitch is altered by the manual effort of the pilot or the force necessary to change pitch is supplied by the engine through the medium of a relay gear under the pilot's control.

Propellers which come under class (a) suffer from the disadvantage that the pitch increases with engine R.P.M. and that there is no control over the actual pitch. This obviously does not agree with the requirements during take-off where maximum R.P.M. and fine pitch are necessary in order to obtain the greatest thrust. Propellers of class (b) have been used with a certain measure of success but unfortunately apart from the mechanical difficulties involved, they impose additional duty on the pilot, who is already overburdened with instruments, and in most cases, these propellers call for great physical effort.

The <u>Gloster Hele-Shaw Beacham Variable Pitch Propeller</u> is entirely automatic in its action but at the discretion of the pilot the R.P.M. can be varied at will to suit the requirements of the airplane. By means of a control wheel or lever the pilot can set the gear to a given R.P.M. after which these revolutions will be maintained at a constant value automatically. Practically no effort is required to adjust this control and if set on the ground, say, for 2000 R.P.M. the airplane will take off, climb and fly at any altitude at the same R.P.M. If, after reaching a given height, the pilot desires to cruise at some other speed, say, 1800 R.P.M., he can give his control lever the corresponding setting and the mechanism will then maintain 1800 R.P.M. under any condition until the control is again adjusted.

The mechanism is shown more or less diagrammatically in Figure 3.

A is the propeller hub carrying blades B_1 B_2 which can rotate in the hub, the centrifugal force of the blades being taken by ball thrust races. C is the propeller shaft driven by the engine and attached to the hub through a flanged coupling. To the front half of the hub is rigidly attached a piston D working in a cylinder E to which two tie rods F_1 F_2 are fixed. The other ends of the rods are screwed to a sleeve G, arranged concentrically with the propeller shaft so that it can slide fore and aft on bosses projecting from the hub. Short connecting rods H_1 H_2 attach sleeve G to crank pins I_1 I_2 fixed to the blades of the propeller. Thus when the cylinder E is displaced, the crank pin and blades are given a corresponding displacement.

Running through the center of the propeller are three oil pipes 1, 2, and 3. The first two pipes communicate with opposite sides of the piston D; the function of the third pipe will be explained presently. All these pipes rotate with the propeller, a rotating oil-tight joint being provided at R.

Now suppose we supply oil under pressure to pipe No. 1. Because the piston is fixed the cylinder E will move to the left giving a corresponding angular movement to the propeller blades. A reverse displacement will take place if the oil pressure is supplied to pipe No. 2.

We now come to another important part of the mechanism. A variable stroke pump J and governor K are driven by the engine. A peculiarity of this pump is that at steady R.P.M. not only can the delivery be modified by varying the stroke but the flow can be reversed if the stroke is altered sufficiently. The governor is connected through suitable links to the stroke rod of the pump and springs controlling the governor are arranged so that when the latter is running at normal speed there is no stroke and consequently no delivery from the pump. An increase of R.P.M. will cause the governor weights to fly outwards and give stroke to the pump, causing the latter to pump oil in one direction.

A reduction of R.P.M. below the normal will reverse this flow. Pipes 1 and 2 in the hub are connected through the rotating joint R to the pump. Thus when pipe 1 is under pressure from the pump, pipe 2 is on the suction side and vice versa.

Branches from these two pipes lead to non-return valves L_1 L_2 which make up any loss of oil due to leakage.

Let the direction of rotation of the propeller be such that a movement of cylinder E to the left will increase the pitch, then the pump is so arranged that when the governor "opens," oil is pumped into pipe No. 1, and sucked from pipe No. 2. A reduction of R.P.M. reverses this order. To provide control over the speed at which the governor will float, a spring M is incorporated in the governor mechanism. This spring being adjustable by means of a handwheel N thus determines the normal speed at which the governor will assume its mid-position.

Having set the control wheel to any desired R.P.M. with the pitch of the propeller at normal, suppose the forward speed of the airplane to increase. This will involve an increase of R.P.M. of the engine and governor which then causes oil to flow into pipe 1 and thence to the front cylinder, resulting in an increase of pitch accompanied by an increase of propeller torque and this process will continue until the R.P.M. is brought down to normal. Similarly a reduction of forward speed causes a reduction of pitch such that normal R.P.M. is resumed. Thus under all conditions of flight there is only one possible R.P.M. for a given setting of the control wheel.

The maximum travel of the cylinder in either direction from the normal position is limited by suitable stops and in the event of either of these positions being reached very high pressures would occur in the oil system without some provision for releasing the oil. This possibility is avoided by incorporating relief ports P_1 and P_2 in the piston which communicate with the third pipe. When the cylinder approaches its extreme position one of these ports is opened and the oil is permitted to circulate via pipe No. 3 through the non-return valve and back to the pump.

The possibility of a failure of the hydraulic system is remote but should this take place a powerful spring S contained in the sleeve G will return the propeller to normal pitch irrespective of the position of the blades at the time of failure.

It will be noted that there are no glands or packings anywhere in the system, which is kept full of oil by arranging a connection between pipe 3 and an oil tank (usually the engine supply tank), any leakage which may occur being made up by a compensating amount passing one of the two non-return valves, i.e., the valve which at the moment happens to be on the suction side of the pump, and any oil escaping from the system can be led back to the engine crank case, thus ensuring that there is absolutely no waste or loss of oil due to this hydraulic circuit.

The use of oil for the hydraulic medium has one obvious advantage in that all the working surfaces are perfectly lubricated and wear is practically eliminated.

The question now arises, will the propeller be stable in its action or will it tend to hunt like some familiar examples of steam engine, the speed constantly rising and falling but never settling down to a steady state.

The answer is given by the curve of Figure 4, showing how the R.P.M. vary with time after giving the engine and propeller the maximum impulse possible. At the start when $t = o$ the propeller is supposed to be idling at 1900 R.P.M., with the engine switched off and throttle fully open and the airplane travelling at 290 ft. per sec. The B.HP. of the engine is 520 HP. and moment of inertia of the propeller and rotating parts 240 lb. per sq.ft. The power is suddenly switched on and the revolutions rapidly increase. Within .5 second the hydraulic gear has taken charge and almost as rapidly causes the speed of revolution to fall back to normal. Just before 2 seconds have elapsed from the start the speed becomes normal but the propeller being now slightly overpitched, the R.P.M. fall about 25 per minute below normal, then gradually build up to normal again, overshooting the mark by a very small margin, after which a steady normal speed is maintained.

Even in this extreme case it is clear that the mechanism has complete control over the speed but such a sudden application of power is not likely to occur in practice. It takes an appreciable fraction of a second to open a throttle, and if this is done in a rational manner, we can say that the pitch will adjust itself simultaneously with the throttle so that the R.P.M. would not wander very far from the normal value corresponding to the pilot's setting.

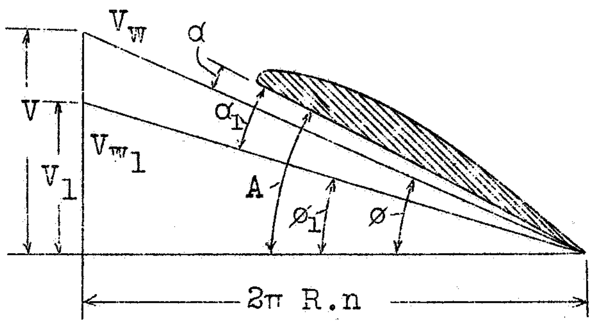

V_W
α
V
α_1
V_W1
V_1
A
ø_1
ø
2π R.n

Fig.1

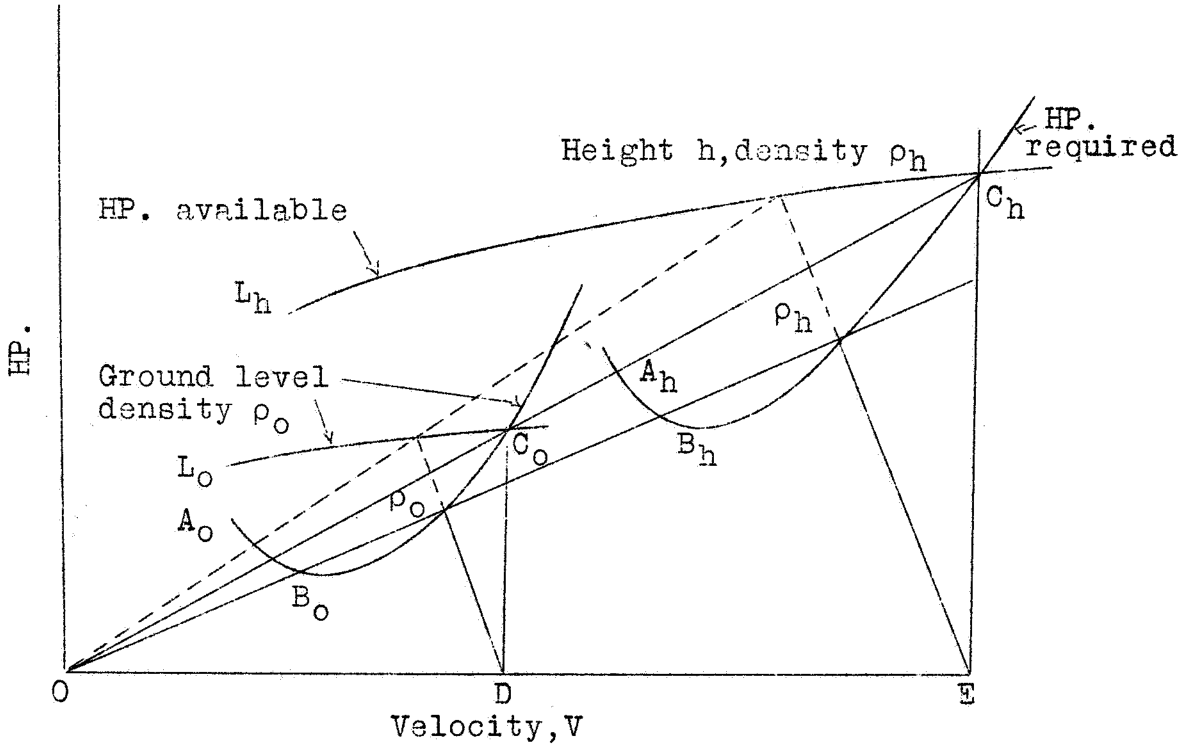
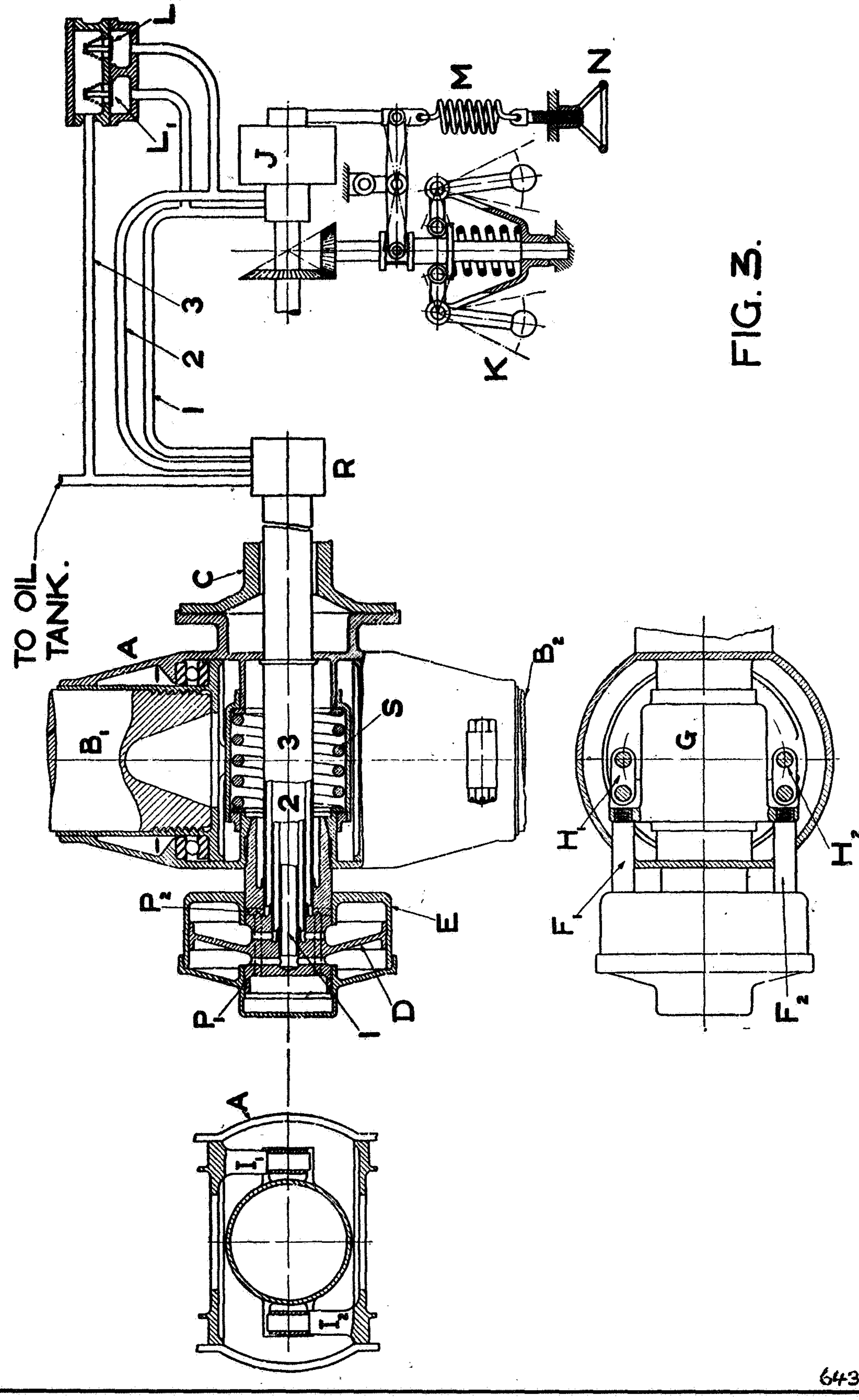

HP. required
Height h, density ρ_h
HP. available
C_h
L_h
ρ_h
HP.
Ground level density ρ_o
A_h
B_h
L_o
C_o
ρ_o
A_o
B_o
O
D
E
Velocity, V

Fig.2



L_2
L_1
J
M
N
K
3
2
1
R
TO OIL TANK.
C
A
B_1
B_2
S
3
2
P_2
E
D
P_1
1
A
I_1
I_2
G
H_1
H_2
F_1
F_2

FIG. 3.

6438 A.S.

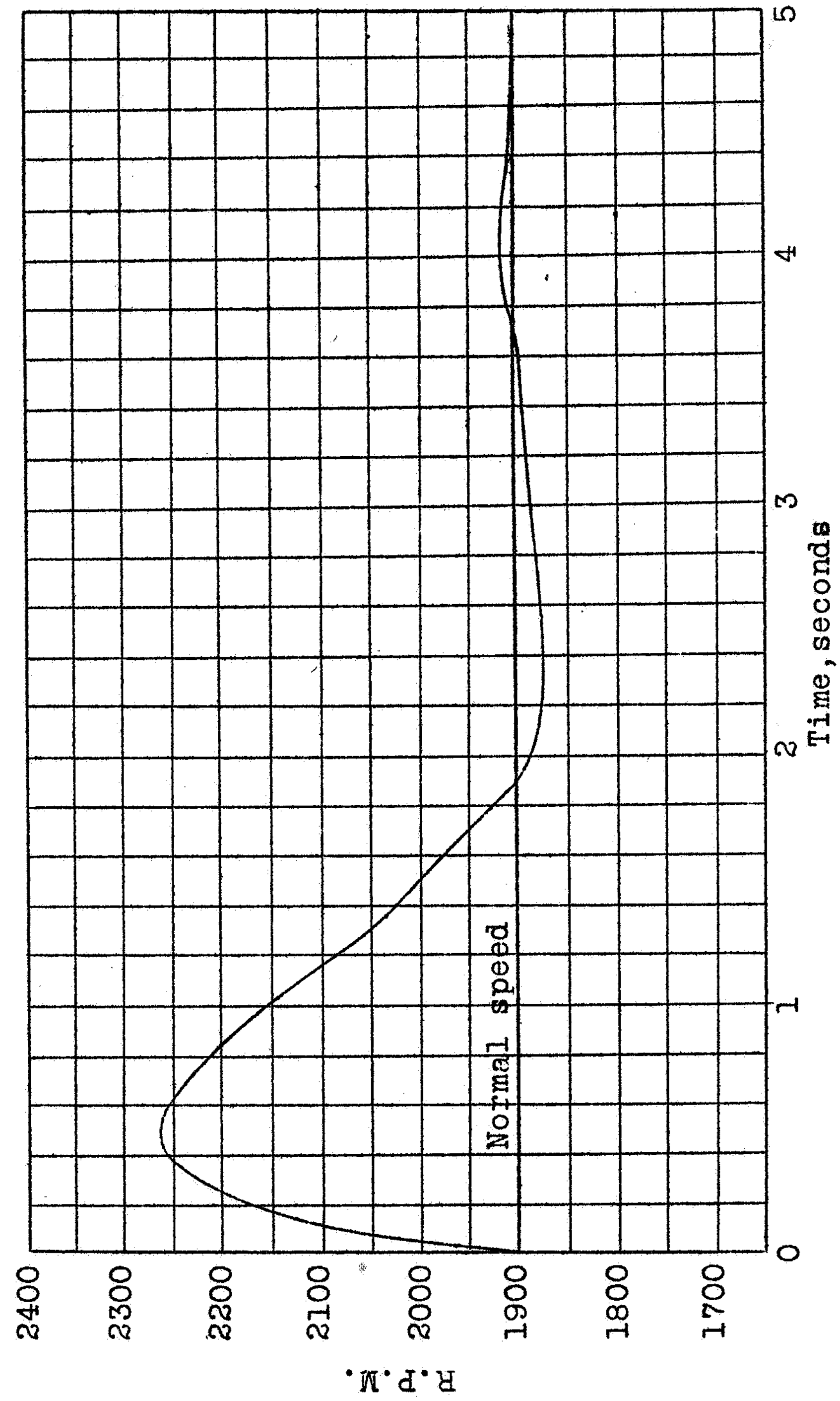


Fig.4 Variation of R.P.M. with time,due to instantaneous appliciation of power.