INTERNATIONAL JOURNAL OF ADVANCE RESEARCH, IDEAS AND INNOVATIONS IN TECHNOLOGY

ISSN: 2454-132X
Impact factor: 4.295
(Volume 5, Issue 6)
Available online at: www.ijariit.com

Design and testing of a helicopter propeller performance

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ABSTRACT

In order to develop the infrastructure (propeller performance test rig) & fulfil the requirement of the University syllabus, an approach has been made to design & testing a helicopter propeller based on the slipstream theory & blade geometry of an aerofoil for study purposes. The test rig was successfully fabricated and tested in the wind tunnel laboratory. The geometry of the propeller, the height of the blade 0.765m, Chord at root 12.8 mm, mean 13.8mm & tip 6.94mm, the thickness of the blade at root 14mm, at mean 9mm & tip 2.55mm have been chosen from the existing conventional blade. This is the in-house project and successfully carried out with small funding support from the present management of the Institution. The angle of attack from 8.2- 31 degrees has been chosen from the blade. The propeller efficiency of 78% has been achieved by conducting a series of experiments in the test rig. Since the test rig was established for conducting the student's experiments and hence we used only a U-tube monometer connected to the Pitot tube for measuring flow &maintained constant speed of the propeller around 500 rpm. The advantage of this test rig was simple in design & operation, an absolute requirement of this test rig because the no suppliers came forward to supply the rig for the student's experiments, reduced vibrations & very least-cost method & economics. Theoretical pressure distribution of the propeller has been studied based on the Euler energy equations by using commercial NISA compressible fluid package & results were compared with the measured results found within the acceptable limits. Presently, Aeronautical engineering branch students conducting experiments using this test rig.

Keywords— *Propeller, Development test rig, NISA CFD package*

1. INTRODUCTION

Propellers are members of extended trubomachines. Design & testing of these members is a quite complicated process requires the knowledge on fluid dynamics, Physics, metallurgy, mechanical & aeronautical aspects. In the present studies, the Slip stream theory [01] & blade element theory have been used. Propeller is one of the propulsion systems works by the application of Bernoulli's theorem &newton's third law. Usually, the propeller produces thrust to propel the ships, submarines, move the aircraft in a forward direction. It is similar to fan that transmits shaft energy into rotational motion into thrust.

Working of Propeller: Propeller are constructed using aerofoil sections using wood or metal to produce aerodynamic force & blades are subjected to lift, drag, vortex parameters, lift/Drag ratio at varying angle attack, pressure distribution etc. An in-flight concept the propeller has rotational velocity added to translational (forward) velocity thus the flight path of any blade section is a spiral path – a helical flight path. Velocity diagram of the propeller cross-section [fig 1] for aero-engine components is acting perpendicular to lift and parallel to drag with respect to the flight path. Aerodynamic force component acting forward with respect to aircraft longitudinal axis is the thrust force & that component acting parallel to the direction of the rotation as the propeller torque force. As we see the lower velocity diagram the component of lift acting in the rotational plane added to the drag to produce the propeller torque force vector. The remaining forward acting portion of the lift is then the thrust. Other force acting on the blades during flight, turning moments that tend to twist the blades and centrifugal force. The air inflow at the face of the propeller disc also affects propeller dynamics.

1.1 Slip Stream theory

The physics of the slipstream theory corresponding derivation of the equations outlined in [01]. One critical component of the propeller blade theory is the prediction of the velocity induced on the propeller disk as a result of lift developed by the blades. Two methods are commonly used to predict this induced velocity. The first method is Goldstein's vortex theory. And another method is the Propeller momentum theory with slipstream rotation. According to this method, the torque must be applied to turn the propeller and that torque must result in rotation of fluid within the slipstream.

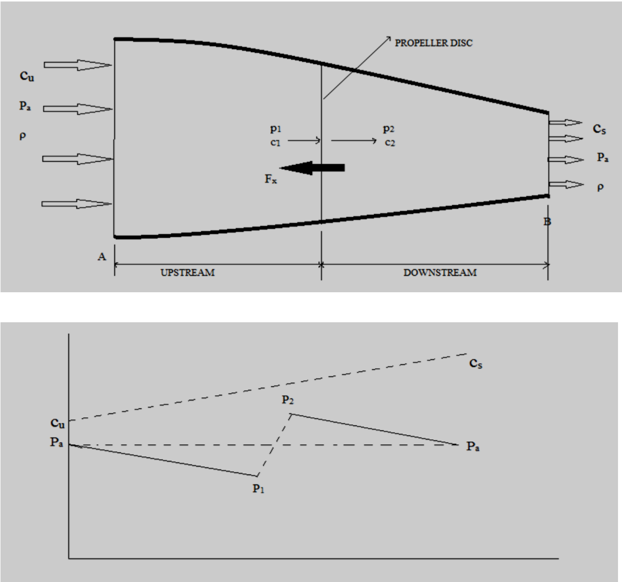


Fig. 1: Slip Stream theory

2. WORKING OF PROPELLER PERFORMANCE TEST RIG

A photographic view of the propeller performance test rig as shown in figure 2. It consists of a rotating Propeller which is mounted on a shaft with supporting bushed bearing & pulley. A motor is mounted on a frame in-turn connected to supply, pulley, motor & V-belt. Whole mechanical arrangements have been mounted on a frame & a stationery duct. The main function of the duct is to produce streamline flow to the propeller. A two holes metal probe connected to a U-tube monometer in order to measure the static pressure at upstream and downstream of the duct.

3. DESIGN AND FABRICATION OF THE COMPONENTS' OF THE RIG

3.1 Propeller

A scrap helicopter propeller has been adopted in the present study.

3.2 Design of Duct

The main function of the duct is to streamline the flow passing over the blades. The effect of the duct on the propeller in two ways namely, inducing an increment of velocity through the propeller in a forward direction & negating tip effects if the gap between the inner wall and the propeller tip is very small i.e. 0.03 inch.

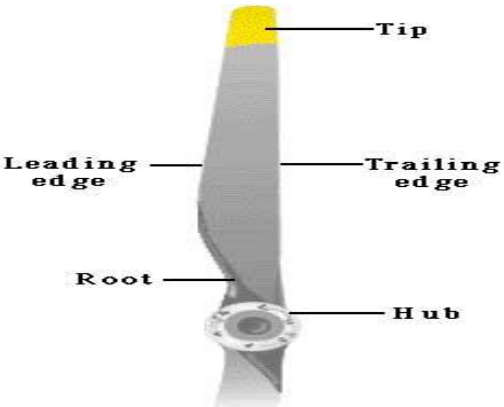


Fig. 2: Design of Duct

The diameter of the duct fixed based on the diameter of the Propeller& clearance between propeller ducts. Other design parameters like material type of welding chosen arbitrary & recommended designed values are as given below.

S No	Design Parameters	Dimensions in mm
01	Duct Inlet Diameter	2460
02	Duct Outlet Diameter	2100
03	Duct thickness	1.5
04	Material	GI & MS

Fig. 3: Propeller performance rig

3.3. Bearings

Bearings are the machine elements that constrain relative motion & reduce the friction between rotating components to only desired motion. The main function of the bearings is to absorb the radial and axial loads. In the present study, a tapered roller bearing is used to absorb the radial and axial loads. Major factors to be considered for the design of tapper roller ball bearing are shaft speed and load including the weight of the propeller. The material for this type of bearing is steel iron. Equivalent load of bearing $P = (XF_r + YF_a)$ S & Dynamic capacity, $C = (L/L_{10})P^{1/\mu}$ Where X = Radial factor, Y = Thrust factor, L = life of bearing in millions of revolutions, L_{10}= Life of bearing for 90% survival at one million revolutions.

3.4 Motor

A star delta 5 HP A.C motor is used to drive the propeller. The main function of the motor is to converts electrical energy into mechanical energy in the form of rotation. The maximum rotation of the motor is limited to 1440 rpm the speed of the propeller can be controlled by using a belt drive mechanism. The present speed of the propeller shall be reduced to 500 rpm.

Fig. 4: Motor

3.5 Flanges

A flange is a forged or cast ring of steel designed to connect propeller in order to provide structural support to avoid vibrations. Flanges are joined to each other by using the bolt and welded or threaded to the propeller assembly. The size of the flange is 90x100 mm & material recommended Mild steel.

3.6 Propeller Block

The main function of the propeller block is to support & maintain the dimensional accuracy to propeller assembly. The material used to block is Cast Iron.

3.7 Materials sued for the frame fabrication

ISMC Channel of (100 × 50)
30 inch - 2 pieces
6 inch - 2 pieces
Extension for the frame of 14" width and 2.5" length

For the channel fabrication:
Plumber block of cast iron SS13series285 mm length
80 mm width
120 mm bearing diameter
Tapper roller bearing 22213 K, H313 sleeve
Flange (100 × 90)
Outer diameter 150 mm
The shaft of 62 × 22 inch
Break bar – no. 1

4. FABRICATION OF TEST RIG

(a) After the detailed studies & fusibility of development of the Test rig, recommended Materials with recommended dimensions of the parts have been purchased for fabrication.
(b) Fabrication of the duct as per the recommended dimensions.
(c) The plumber block assembly is fixed rigidly on the frame at the end of the channel.
(d) The sleeve is attached to the shaft along with the bearing and tightens with the nuts this is to avoid unusual movement of the motor.
(e) The flange should be welded along with the part which entering from the shaft.
(f) Pulleys are connected for smooth working.
(g) The motor is connected to the pulley by means of V-belt drives. Different diameters of the follower pulley are used to reduce the speed of the motor.
(h) The probe is placed in such a way that it is not in contact with the propeller blade so that it won't get damaged. The probe is placed in order to sense the pressure at the upstream, downstream of the propeller blade. The readings are taken at the mean section, where the losses are small

5. EXPERIMENTAL STUDIES

5.1 Experimental Procedure

1. Check all electrical connections & switch on the Motor.
2. Check the monometer & probe, remove any air bubbles in the monometer.
3. After switching on the motor, weight for 10 minutes, until the flow reaches the study state condition.
4. Keep the probe at the Upstream of the propeller, care must be taken that probe should not touch the rotating propeller & note down the inlet monometer reading.
5. Keep the probe at the downstream of the propeller, care must be taken that probe should not touch the rotating propeller & note down the outlet monometer reading.
6. Repeat the step 4 & 5 at different places and note the monometer reading.
7. Note down the speed of the propeller using speedometer.
8. Use the formulae of slipstream theory & determine the efficiency of the propeller.

5.2 Calculation

At the Inlet,

Manometer reading in cm of H_2O, $\Delta h = 0.2$ cm = 0.002m
dynamic pressure,

$$P_1 = \Delta h \times 9.81$$
$$= 0.002 \times 9.81 = 0.01962 \text{ N/m}^2$$

At the Exit

Manometer reading in cm of H_2O, $\Delta h = 0.5$ cm = 0.005m
Dynamic pressure,

$$P_2 = \Delta h \times 98.1$$
$$= 0.005 \times 9.81 = 0.04905 \text{ N/m}^2$$

We know that,

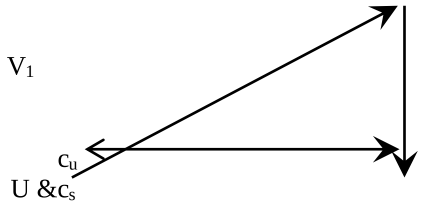
$$p_2 - p_1 = \frac{1}{2}\rho\,(c_s^2 - c_u^2) = 0.04905 - 0.01962 = 0.02493 \text{N/m}^2$$

Area of cross section of the disc = $A = (\pi D^2)/4 = 2.77$ m^2

The axial thrust due to the pressure difference,

$$F_X = A\,(p_2 - p_1) = 2.77 \times 0.02493 = 0.0668061 \text{ N}$$

At the immediate upstream of the propeller blade. To determine the absolute velocity at the upstream of the blade. From the velocity triangles (Velocity triangles shall be drawn on graph sheets)



V1 = Relative velocity at the inlet, U= speed & cu & cs absolute velocity at upstream & downstream of the propeller.

$$U = 2\pi r N/60 = 59 \text{ m/s}$$

From velocity triangle $c_u = 37$ m/s & $c_s = 59$ m/s
From the slip stream theory,

$$c = \frac{1}{2}\,(c_s + c_u)$$
$$c = ½\,(37 + 59) = 48 \text{ m/s}$$

Propeller efficiency,

$$\eta_p = c_u / c = 37/48 = 0.77084$$
$$\eta_p \text{ in \%} = 77.084\ \%$$

6. THEORETICAL ANALYSIS USING NISA 3D CFD PACKAGE

The analysis of the propeller is done using the software NISA.

6.1 Geometric modeling

The first step in the process of analysing an object or process is to capture, the geometry of the objects involved. This usually consists of a mathematical description of the boundary and interior of the object. To achieve this, NISA provides facilities to define locations in space (called grids), straighten or curved line segments called lines), surfaces (called patches) and solids (called hyper patches). The entire above are referred to as geometric entities. Lower order entities like grids may be used to construct higher-order entities like lines. Conversely, lower-order entities may be extracted from the higher-order entities. Entities may also be copied, mirrored, translated, rotated etc. In NISA, an element is defined by nktp and nordr, where nktp indicates the element type number and nordr indicates a number of nodes. Elements have ideal shapes, which involve little or no error in the numerical computation of individual stiffness matrices. However, it is almost impossible to model complex systems with a mesh of ideally shaped elements. The ratio between the longest and shortest dimensions is called aspect ratio. An aspect ratio of 1:1 is used for elements in a general stress field with gradients in all directions.

6.2 Meshing

Mesh or grid is defined as a discrete cell or elements into which the domain or model is divided. All the flow variables and any other variables are solved at centers of these discrete cells. This entire process of breaking up the physical domain into smaller sub-domains (elements or cells) is called mesh generation. The easiest classification of mesh is based upon the connectivity of a mesh or on the type of elements present. Also, the theoretical methods that are used for any CFD study like fine difference method (FDM), finite element method (FEM), and the finite volume method (FVM) actually solve the variable at these discrete cells or nodes. The most basic form of mesh classification is structured meshes, unstructured meshes, and hybrid meshes. Meshes can also be classified based upon the dimension and type of elements presented. Depending upon analysis type and solver requirements, meshes generated could be two dimensional or three dimensional.

7. RESULTS AND DISCUSSIONS

After conducting the performance analysis on a propeller using the DISPLAY III program of NISA software and practical experiment on the propeller, a conclusion is obtained that the pressure across the propeller blade has increased. The pressure at the immediate upstream and downstream of the propeller blade has taken using pitot tubes and calculations are done on the basis of slipstream theory. Hence the amount of pressure rise and velocity increment is obtained. From this data, the efficiency and thrust of this particular propeller are calculated. The performance analysis results are then compared with the concept of slipstream theory. From the experimental data, it is clear that pressure is increased after the blade of the propeller and the velocity has no significant change across the blade as suggested by the slipstream theory. The project is mainly based on the propeller slipstream theory, and the findings of the project are similar to that of slipstream theory. The propeller has an efficiency of 78 %. The propeller gives an axial thrust of 40.847 N. The thrust obtained will be more if we increase the speed of rotation of the propeller. Here, the propeller is rotated at a slow speed as a matter of safety since more suction will increase the chances of accidents.

Fig. 5: Results and discussion

8. CONCLUSION

The development of the propeller performance test rig has been carried out successfully for conducting student's experiments. Present propeller efficiency found 78% at the propeller speed of 500 rpm. Since limited funding in the project measurement of density postponed to the next part of the research work.

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