Propeller Calibration Powered by Electric Engine in the Indonesian Low Speed Tunnel (ILST)*

Purwadi, Muhammad Taufiq
BPPT
Email : purwadi@bppt.go.id; muhammad.taufiq@bppt.go.id

Abstract: A calibration of a propeller has been conducted during a wind tunnel test of an aircraft model in the Indonesian Low Speed Wind Tunnel (ILST). The purpose of the calibration was to obtain a power (thrust) characteristic of the propeller used for Engine Simulation (Power ON) test in the ILST. A fixed angle 3-blade wooden propeller was used during the calibration, the diameter of the propeller is 35 cm and the fix angle of the blades are 33 cm per revolution. To rotate the propeller, the engine was powered by an electric dc motor with the maximum power .of 5 kW, voltage of 40 V-dc, and the maximum RPM is 12.000 revolution per minute. A 10 kW DC power supply with an adjustable current was used to supply the dc motor engine. The RPM variation is set by means adjusting the current that supplied to the motor through a dc controller. To measure the power of the motor, a current and voltage reader were installed and connected to the conditioning units where then the value of them can be acquired by the data acquisition system. RPM of the propeller was measured by an optical transducer located at behind of the propeller. A reflector was attached in one blade of propeller as rotation reference of the propeller. The propeller was installed at the original position on aircraft model and the force/thrust of the propeller was measured by the ILST External Balance System.
Key Words: Wind Tunnel, Propeller, Engine Simulation, thrust, Aerodynamics, Aeronautics

Nomenclature

j	: advance ratio	
D	: diameter of propeller	(m)
n	: rotation of propeller	(Hz)
V	: free-stream wind speed	(m/s)
ɵ	: pitch angle of blades	(deg)
C_T	:thrust coeficient	
Cd	: drag coeficient	
C_P	: power coeficient	
ŋ	: propeller effeciency	

1. Introduction

In the phase of development of an aircraft, a wind tunnel test playing a very important role in determine the characteristic of the aircraft. One type of the wind tunnel test have to be conducted during this development phase is a propeller/engine simulation test also called engine on wind tunnel test. The purpose of the engine on test is to investigate the influence of the propeller thrust and slipstream on the stability characteristics of the aircraft. A simple measurements on an unpowered model would not give the correct answers on this characteristics. The propellers that will be used in the measurement have to be calibrated in order to obtain of the power characteristics of the propeller. Instead of using air-turbine, a dc motor was applied to rotate the propeller during the calibration process.

Since 1990, several models were designed, fabricated and test for engine on simulation testing in the ILST. Most of them were powered by high pressurized air turbine engine which have high power for high thrust requirement. Another type of engine on simulation test have been done in the ILST was an engine on simulation powered by an electric dc motor. This type of engine on test was applied for UAV (Unmanned Aerial Vehicle) aircraft, with a single pusher propeller located at the rear end of the aircraft model The dc-motor was installed in the aft fuselage of the model and directly connected to the propeller through a shaft.

When having propeller on simulation test in the wind tunnel, it is essential that the thrust of the propeller can be established separately from the overall aerodynamics loads. This requirement controls to some extent the start of the test programme in that very first test runs aim at getting a calibration of

the propeller thrust.
It may be evident, that a proper calibration of the propeller forms an essential part of the test campaign to establish the propeller baseline quantities.

2. Methodology of the Calibration

There are two procedures generally used in the propeller calibration test in the wind tunnel, they are :

1. Calibration propeller where the propeller is mounted on isolated rotasymmetric nacelle. In this way the interference effects from the support are as little as possible. This procedure however requires a separate test campaign.
2. Calibration propeller where the propeller is calibrated while being mounted at its standard/original position on the aircraft model. This mounting position will introduce some interference effects, but does not require a different test set up.

In case of ILST, the procedure number #2 is the most used to calibrate a propeller for engine on simulation.

2.1. Propeller

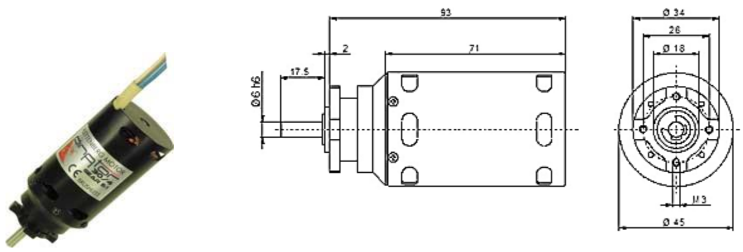
The propeller calibration was done for a 3-blade propeller pusher type, the diameter of the propeller is 35 cm and the thrust is 25cm per revolution, it means one rotation of the propeller be able to push the aircraft 25 cm forward. The propeller is a fixed angle propeller and made from wood.

Fig. 2.1.1. The propeller

2.2 Motor Engine and Power Supply

A DC motor was used as an engine to rotate the propeller during the calibration, the motor was installed and located in the rear fuselage of the wind tunnel model. The specification of the motor are listed below.

Power	5 kW
Maximum Current	125 A(dc)
Diameter	4.5 cm
Length	9.3 cm
Maximum RPM	12000



(a). (b)

Fig. 2.2.1. Adjustable RPM DC motor (a). the dc motor (b) dimention of the dc motor

The power of the motor was suplied by a dc power supply with the maximum power of 10 kW, the power supply is adjustable voltage and current in which a variable power can be feeded to the motor for having variable RPM during the calibration. The maximum voltage is 40 V-dc and the maximum current is 250 A-DC.

Fig. 2.2.2. Programmable Power Supply

2.3. Balance System

Similarly as in normal testing in the ILST, also in calibration of the propeller the forces produced by the propeller is measured by the six-component overhead external balance. This is standard equipment for the ILST with the specification :

Table 2.3.1 Load Specification of External Balance

No.	Component		Max Load	Accuracy	
			N or Nm	N or Nm	
1	K1	Lift	17.500	17,5	0,001
2	K2	Drag	3.500	3,5	0,001
3	K3	Pitching Moment	3.750	5,6	0,0015
4	K4	Side Force	3.500	3,5	0,001
5	K5	Yawing Moment	3.250	3,25	0,001
6	K6	Rolling Moment	3.000	6	0,002

In case of propeller calibration, the force (thrust) generated by the propeller will be sensed by the balance component K2 (drag).

2.4. Engine Monitoring System

Engine Monitoring System (EMS) is a panel instrumentation that consist of several instrumentations to collect the data that resulted from the engine measurement, the data such as RPM of the propeller, the temperature of motor/engine, voltage and current of the dc motor, and vibration of the engine/propeller that used for safety of the engine. All of the data in the EMS are connected to the ILST Data Acquisition System and from this system the data are sent to the Data Processing system where the calculation of the engine data such as thrust, power and efeciency were done. . Fig. 2.4.1 below show us the EMS unit used in the ILST.

Fig. 2.4.1. Engine Monitoring System (EMS)

Fig. 2.4.2 below shows a propeller calibration where the propeller is mounted on the isolated nacelle and Fig. 2.4.3 shows a propeller calibration where the propeller is mounted at original position on the wind tunnel model.

Fig. 2.4.2. Propeller mounted on an isolated nacelle

Fig. 2.4.3. Propeller mounted at original position on the model

As explained above, the procedure number #2 was used during the propeller calibration process in the ILST, i.e the propeller was mounted at the original position on the wind tunnel model (Fig. 2.4.5). To measure the forces of the propeller during the calibration, the model was installed in the external balance test section that equiped with a six-component over head balance. The model was connected to the balance system with a strut support. The strut is a cylinderical shape and have a hole from where the data cables can be routed from the model to out side of the test section. The data cables are connected to the instrumentations in the computer room through a box panel.

Fig. 2.4.4. Propeller calibration set up on the model.

During the test, the thrust of the propeller is controlled by the following variables :

ɵ → pitch anggle setting (in this case is fix)

$$J = \frac{V}{nD} \quad (1.)$$

→ advance ratio where :

V : free stream wind speed		(m/s)
n : rotation propeller per second		(Hz)
D : diameter of propeller		(m)

This equation is used to calculate and determined the real time thrust of the propeller during the measurement.

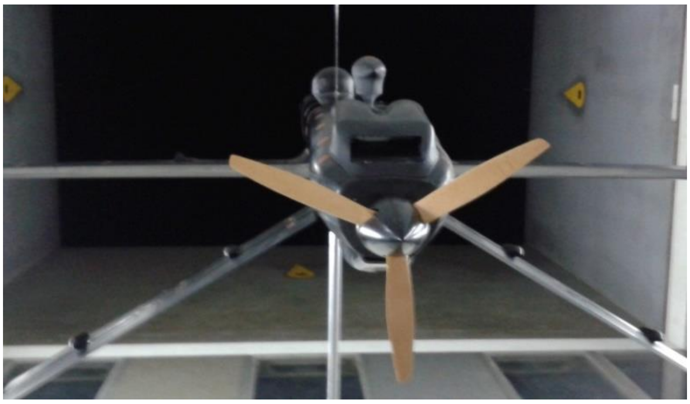


Fig. 2.4.5. The position of calibrated propeller in ILST

During the calibration, the procedure number 2 was selected. In short the following steps had to be taken to obtain the required thrust calibration data.

a. the model was stripped down to a "minimum drag" configuration e.g. tail off, flaps up, wheel bay fairing, all of accessories and propeller are off (disassembled).
b. on this configuration an alpha polar (pitching angle variable) is performed to determine the minimum drag situation, i.e. the alpha at which minimum drag occurs. Since the propeller thrust is assumed to act along the propeller shaft, the orientation of this shaft should be taken into consideration when selecting the minimum drag alpha.
c. with the model set at this selected alpha, a speed run is made over the range of speeds to be expected for the powered runs.
d. the C_D values obtained in this manner and related to the body axes system are transfered into a polynomial : $C_D = f(q)$;
e. a power on run is made with the propeller set as specified rotational speed (n), while changing the tunnel speed (V), starting at the high end of the speed range.
f. another run is made with specified wind speed (V), while changing the rotational of the propeller (n), starting from the low end of the rotational to the maximum rotational of the propeller.
g. in the corresponding data reduction the aerodynamic loads, generated by the model itself (and as determined in the C_{Dmin}-test) is subtractied from the measured load data, resulting in a set data relates to the propeller thrust only :

   $T_{eff} = F_{bal} - D_o$

h. aside from the thrust the data processing package determines futher the following propeller-related quantities :

   * $C_T = \frac{T}{\rho n^2 D^4} = f(\theta , J)$ (2.)

   *..........$C_P = \frac{P}{\rho n^3 D^3} = f(\theta , J)$ (3.)

   in this case electrical motor engine was used, the power is obtained from equation :

   * $P = V * I$, (4.)

where ; V = DC voltage of supply (volt), and I = DC current of supply (ampere).

* $$\eta = \frac{T*v}{P} = J* \frac{C_T}{C_P} = f(\theta , J) \quad (5.)$$

To have a characteristic of thrust, a set of equation as written above were used. Further the values obtain from the calculation were converted to the thrust coeficient (C_T) and advance ratio (J) of the propeller. Table 2.4.1 shows the result of the proppeller calibration.

Table 2.4.1. C_T and J values produce from the Propeller Calibration.

No	V_0 (m/s)	C_T	J	ŋ	RPM
1	20.17	0.1915	0.6035	52.65	5700
2	21.54	0.1500	0.6479	53.56	5702
3	25.05	0.0884	0.7531	52.65	5702
4	28.02	0.0501	0.8427	41.02	5699
5	30.03	0.0282	0.9028	41.02	5700
6	40.01	0.0028	0.9798	16.70	5702

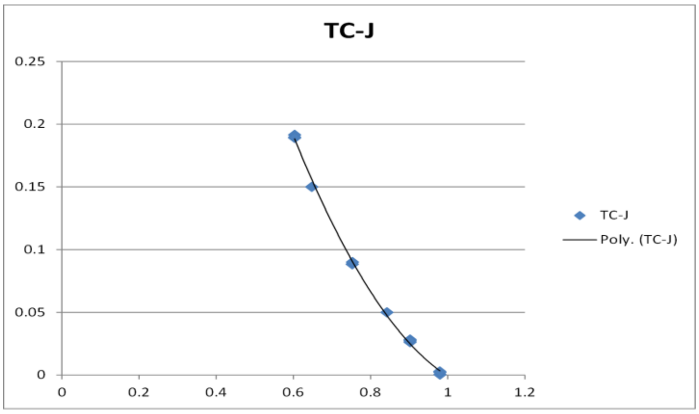


Fig. 2.4.6. TC-J Curve

The characteristic of the propeller thrust is described by Fig. 2.4.6, the TC-J curve resulted from the calibration measurement. The shape of the curve must be equivalent with the characteristic of the real propeller (full scale) of the aircraft. Several runs must be conducted to obtain this equivalent TC-J curve. Normally the are two ways to adjust the curve shape during the calibration, first by adjusting the pitch angle of the blade and second by RPM variation. The first method could not been done in this calibration due to the fixed pitch angle of the propeller used in this experiment. The second method then applied and several RPM variation runs have been done to get the similarity curve between the real full scale propeller and the model calibrated propeller.

The value of C_T that required in the normal engine on test is 0.5, this value will be applied for whole of the normal engine on test campaign. From the data calibration, it can be seen that C_T value 0.5 achieved at the wind speed 28.02 m/s and the propeller RPM is 5699 ≈ 5700. Higher wind speed of the wind tunnel can be applied to the normal engine on test to have higher Reynold number, however, the RPM of the propeller must be also increased. But some time types of propeller available in the market have a maximum RPM limitation.

3. Conclusions

A DC motor can be used to replace the standard air-turbine for conducting engine/propeller simulation test in the ILST. It can be used for type of test which require small thrust of propeller for example for light aircraft, UAV etc. The main key of the test is the propeller, adjustable pitch angle propeller is more advantage to be used in order to achieve thrust curve easily and also to have higher thrust at lower propeller RPM.

References

1) Jewel B. Barlow, William H. Rae, Jr., Alan Pope: *Low Speed Wind Tunnel Testing*, John Willey & Sons, INC. 3rd edition.
2) O. De Vries: *Equations for Data Processing of the ILST*, NLR TR 87122 L, 1987.
3) Fariduzzaman and Surjatin Wiriadidjaja: *Towards a Multipurpose Low Speed Wind Tunnel*, 3rd Indonesian-Taiwan Workshop on Science, Technology and Industry of Aeronautics and Astronautics, Bandung, December 2002.
4) Barnes W. Mc. Cormick: *Aerodynamics, Aeronautics, and Flight Mechanics*, John Wiley & Sons, New York 1979.
5) Surjatin Wiriadidjaja: *ILST Empty Test Section Calibration*, LAGG TR 870007, 1987.
6) John J. Bertin and Michael L.Smith: *Aerodynamics for Engineers*, Prentice Hall Inc. New Jersey, 1979.
7) Jack D. Mattingly: *Elements of Gas Turbine Propulsion*, Mc Graw Hill, International Edition, 1996.
8) A.C. Kermode: *Mechanics of Flight*, Pitman Publishing INC, 1982.
9) P. Bolstianky,E.E.: *Wind Tunnels and Their Instrumentation*, IPST, Jerusalem 1966. .
10) Thomby Layukallo: *Short Guideline to N250 Power On Testing in the ILST*, LAGG 1991.