A NEW FACILITY FOR WIND TUNNEL TESTING OF PROPELLERS

by

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Abstract

In order to investigate the aerodynamic performance of propellers, wind tunnel tests are indispensable. Particularly in the high speed range, it is difficult to bring up the required drive power for the propeller by electric motors, but also a turbine powered drive system brings forth experimental difficulties. The work reported here resulted from the idea, to obtain the drive power from the windstream of the wind tunnel. To this end a wind turbine is mounted downstream and connected to the propeller by a drive shaft. The speed of rotation can be controlled by adjustable stator blades ahead of the wind turbine. The drive shaft is equipped with a torque meter and an rpm-sensor. The propeller thrust can be measured with strain gauge sensors in the ball bearings and, independently, by traversing the propeller wake with pitot probes.

Nomenclatur

A	circular area of propller (m^2)
c_s	thrust coefficient ($S / (\rho/2\ V_\infty^2 A)$)
D	torque value (Nm)
k_d	torque value ($D / (\rho/2\ u^2 AR)$)
k_s	thrust value ($S / (\rho/2\ u_\infty^2 A)$)
M_∞	Mach number
P	power ($D \cdot \omega$)
p_o	stagnation pressure
p_{pit}	Pitot pressure
n	revolutions (1/min)
R	propeller radius (0,2m)
S	thrust (N)
u	rotational velocity ($\frac{m}{s}$)
ω	angular velocity ($\frac{m}{s}$)
V_∞	free stream velocity ($\frac{m}{s}$)
φ	incidence of stator blades (°)
ρ	density ($\frac{kg}{m^3}$)
λ	propeller modulus ($\frac{V_\infty}{u}$)
η	efficiency ($k_s \cdot \frac{\lambda}{k_d}$)
η_{th}	theoretical efficiency ($\frac{2}{1+\sqrt{1+c_s}}$)

1. Introduction

In the high speed regime the drive power for propfans and propellers in wind tunnel tests is difficult to install either by electric motors or by compressed air powered turbines. In particular the blockage of these propulsion devices is usually very high so that large interferences occur. In the case of a compressed air powered turbine the huge air supply is not generally available at the wind tunnels.

As an alternative to these conventional propeller and propfan propulsions a wind-turbine-powered propeller drive was designed, built, and tested in a low - and high speed wind tunnel. The idea is, to obtain the drive power from the wind stream of the wind tunnel. For this purpose the wind turbine is mounted downstream and connected to the propeller by a drive shaft. The speed of rotation can be varied by changing the angle of incidence of eight stator blades.

Wind tunnel tests with the new drive system have been performed in two different test sections of the High Speed Wind Tunnel and in the 3m x 3m Low Speed Wind Tunnel of the DLR Göttingen.

The characteristic values for thrust and torque and the efficiency of the propeller was measured for a wide range of the propeller modulus

λ (= flight speed/rotational speed). Naturally, the wind turbine drive does not allow for static tests or tests at a very low propeller modulus λ. However, the low λ-range can be covered easily by electric motors. Accordingly calibration and comparative measurements have been performed by means of a high performance 3-phase electric motor (SDM-motor).

The advantages of this idea are:
A slim design, yielding low blockage ratios.
A simple construction, thus inexpensive to manufacture.
No air supply and thus no air exhaust.

The disadvantage is that no static tests can be performed.

2. Description of the wind-turbine-powered propeller test rig (PWA)

The PWA consists of a base body fixed on the ground of the test section (Figs. 1 and 2). It is equipped at the upstream end with a propeller and downstream behind adjustable stator blades with a wind turbine (impeller). The adjustable stator blades are fixed to the base body. Propeller and impeller are connected by drive shafts with gear couplings. Between the gear couplings a torque and revolution meter is located. The ball-bearings of the drive shafts and those near the gear couplings are equipped with strain gages for measuring the thrust of the propeller. In addition, a pitot probe rake was used for measuring the wake behind the propeller.

The function of the PWA is as follows: When starting the wind tunnel the propeller and impeller start to rotate. At first in a wind milling mode and with increasing rotational speed of the impeller the propeller begins to generate thrust. Depending on the Mach number and the incidence of the stator blades the impeller is driving the propeller up to the final speed of rotation within a few seconds. For the present study, a two-blade propeller and impeller manufactured from wood were used (Fig. 3 and 4). The geometrical and aerdynamic data of the propeller and impeller are presented in Table 1. The data relate to a velocity of U = 400 km/h (M_∞ = 0,33) and a speed of rotation of n = 8000 rpm. For the variation of the rotational speed within a wide range an 8-blade stator was used with blades having a symmetrical profil NACA 0012. A distance of 60mm between the stator blades and the impeller provides for a good flow qualitiy in front of the impeller (Fig. 2).

3. Measurement techniques

3.1 Torque and revolution measurements

A schematic drawing of the torque sensor is shown in Fig. 5. The torque sensor consists of a torsional body which is screwed to the measurement object by means of two flanges. The hollow shaft which forms the torsional body is equipped with strain gauges. Inside the hollow shaft the electronic circuitry for the bridge excitation voltage and for the transmission of the measurement signals is installed. Furthermore, the shaft housing is equipped with a 30 tooth gear wheel for speed measurement and with transmission elements for the inductive transmission of the supply voltage onto the measurement body as well as elements for capacitive transmission of measured signals from the shaft to the housing of the torque transducer. The rotor, consisting of the actual torsional body and the two flanges, is fitted to the housing by two spindle bearings. The housing also contains preamplifiers for the torque signal and the speed signal, as well as two inductive proximity detectors which serve to detect the speed and the direction of rotation.

3.2 Thrust measurements

The propeller thrust was measured by traversing the propeller wake with a pitot probe rake (Fig. 2). The pitot probe rake was fixed on the ground of the test section and could be moved in axial direction to a position were the static pressure was well-balanced. The wake field was integrated to obtain the characteristic thrust values and plotted versus the speed of rotation (Fig. 7).

A second method to measure the thrust with force measuring bearings (strain gauge sensors on the ball bearings) was less successfull. During the calibration it was observed that the signal from the ball bearings was not steady during a run. Possible reasons may be thermal stresses in the bearings, centrifugal forces and side forces (due to yaw angle of the flow).

4. Results

4.1 Static tests

In order to perform the static tests a special three phase A.C. motor was flanged to the downstream end of the drive shaft in place of the wind turbine. With the help of this motor torque, thrust and also the electical power consumption was measured. The values are plotted versus the rotational speed in Figure 6.

4.2 Thrust and torque measurements

The wind tunnel tests were performed in the high speed wind tunnel (HKG) and the low speed wind tunnel (NWG) of the DLR. The pitot pressure distribution behind the propeller is shown in Fig. 7. The thrust computed from the pitot pressure distributions is shown in Fig. 8. The measured torque is shown in Fig. 9. From the measured flight speed, rotational speed, thrust, and torque the characteristic thrust and torque values K_s, K_d are calculated and plotted in Fig. 10.

Because of a considerable blockage of 4,5% in the HKG and a possible upstream influence of impeller- and stator blades on the propeller, reference tests have been performed in the NWG (Fig. 11), where the blockage ratio is only 0,36%. In the NWG it is also possible to drive the propeller by an electric motor alternatively so that a possible interference of the wind turbine on the propeller flow can be investigated. Figs. 12 and 13 show a very good agreement of the data obtained using the electric motor drive with those obtained previously by using the wind turbine. Here a possible interference from the wind tunnel and the stator blades can be excluded.

5. Conclusion

The feasibility of a wind-turbine-powered propeller in wind tunnel tests has been demonstrated. All the characteristic values could be measured with the new drive system, where the drive power is obtained from the wind stream of the wind tunnel. While it is extremely difficult to bring up the required drive power for the propeller by electric motors or high pressure powered air turbines, the proposed drive by a wind turbine proved to be simple and inexpensive and probably causes less wind tunnel interferences.

6. Reference

[1] Heddergott, A.; Wedemeyer, E.; Stäger W.; Haselmeyer, H.; Propeller-Prüfstand mit Windrad-Antrieb DLR IB 222 - 92 A 01 (1992)

Table 1 Technical data of propeller and impeller

	propeller (Fig. 3)	impeller (Fig. 4)
diameter [m]	0,40	0,53
power [kw]	18	25,4
thrust [N]	87	-
drag [N]	-	31
torque [Nm]	21,48	30,31
revolutions [1/min]	8000	8000
chord [m]	0,07	0,07
thickness [m]	0,012	0,009

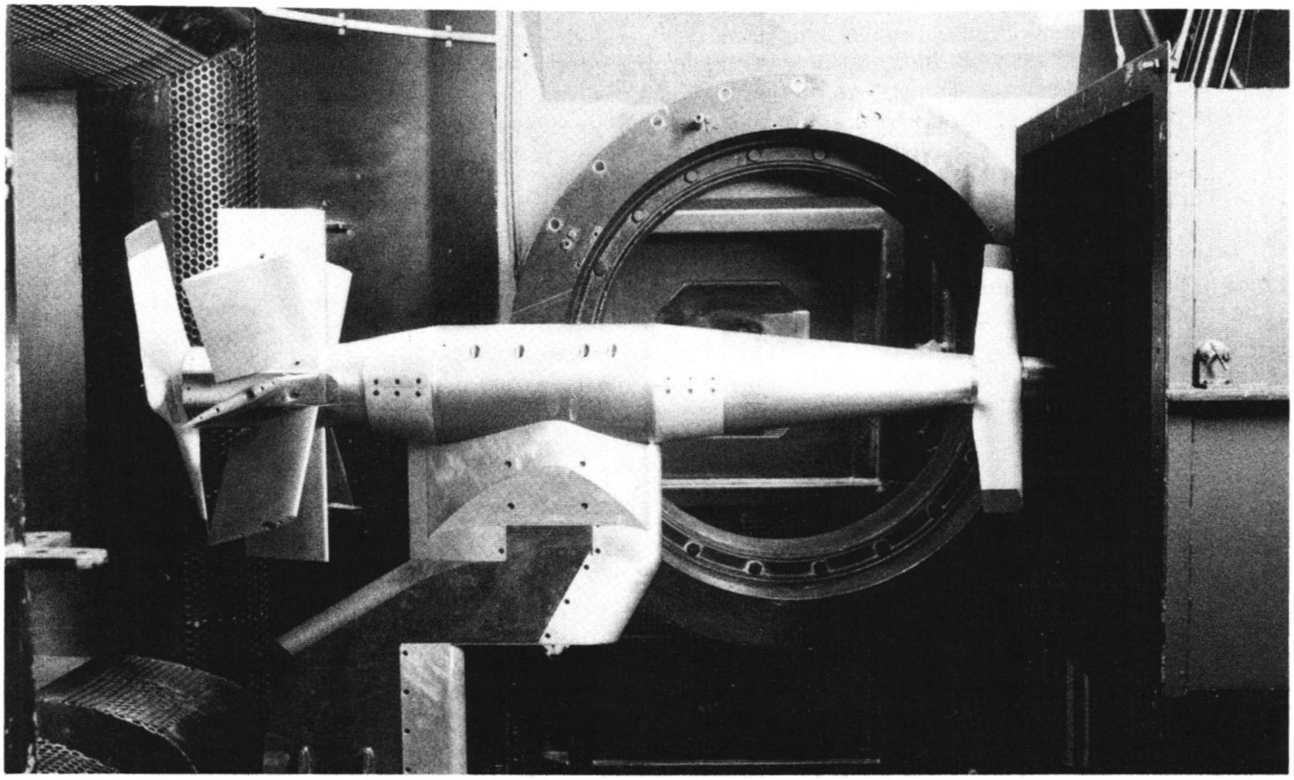


Fig. 1 Photograph of the propeller test rig in the high speed wind tunnel

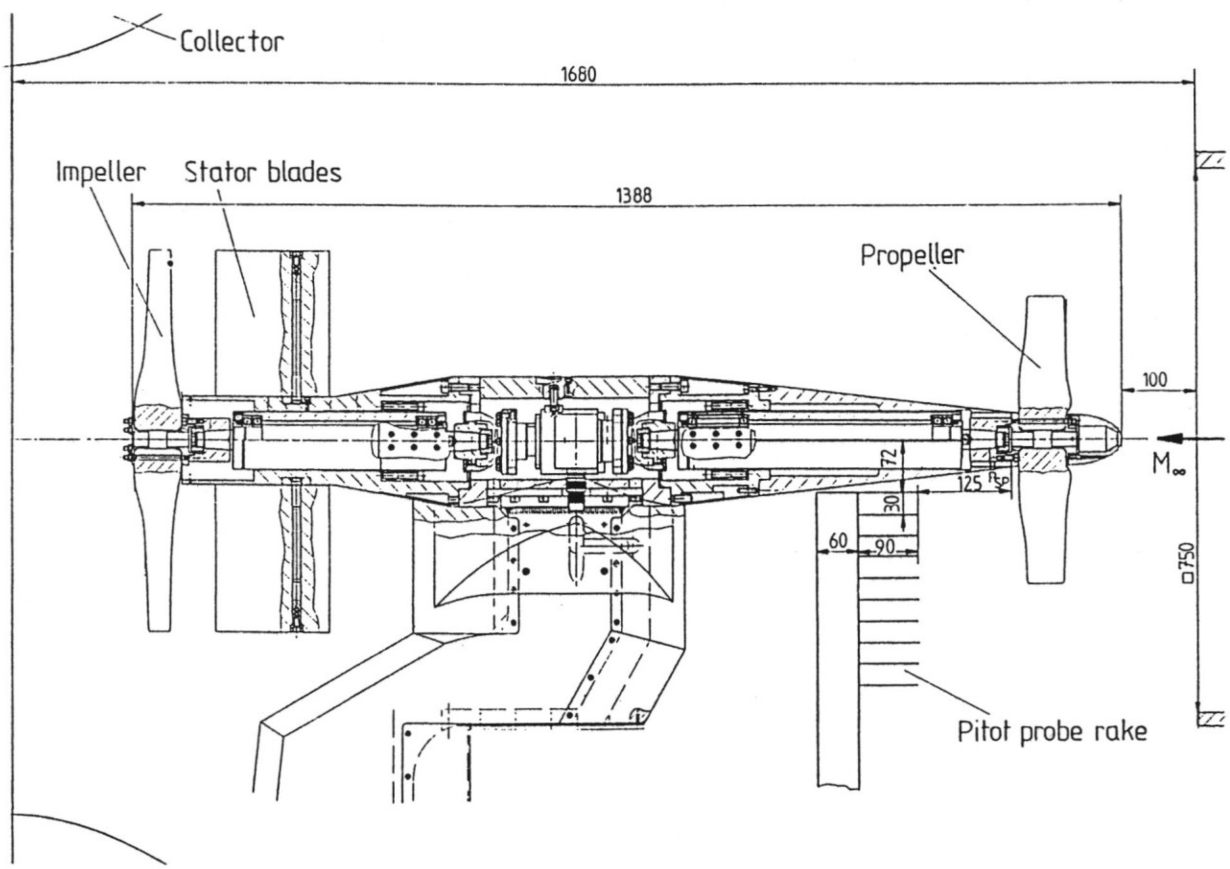


Fig. 2 Sketch of the propeller test rig

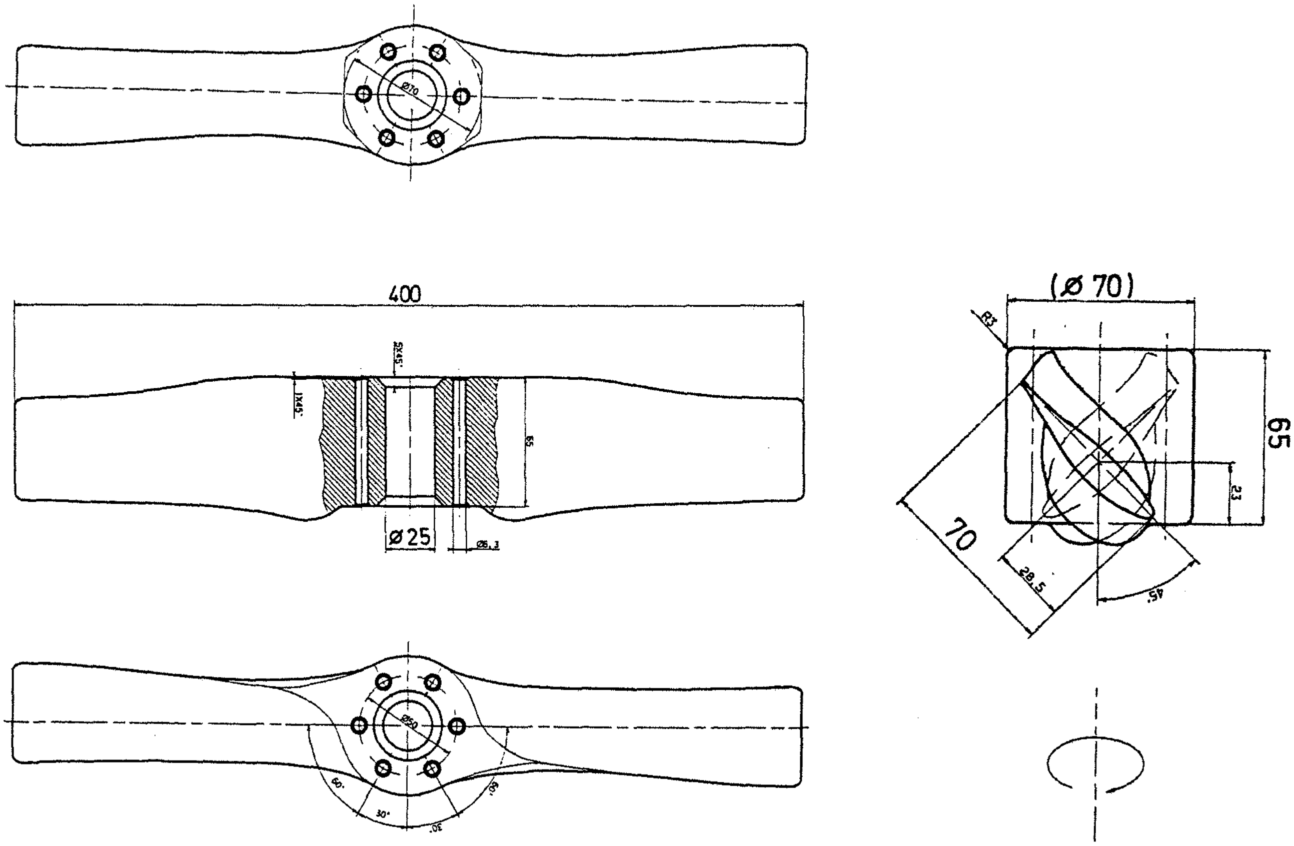


Fig. 3 Propeller

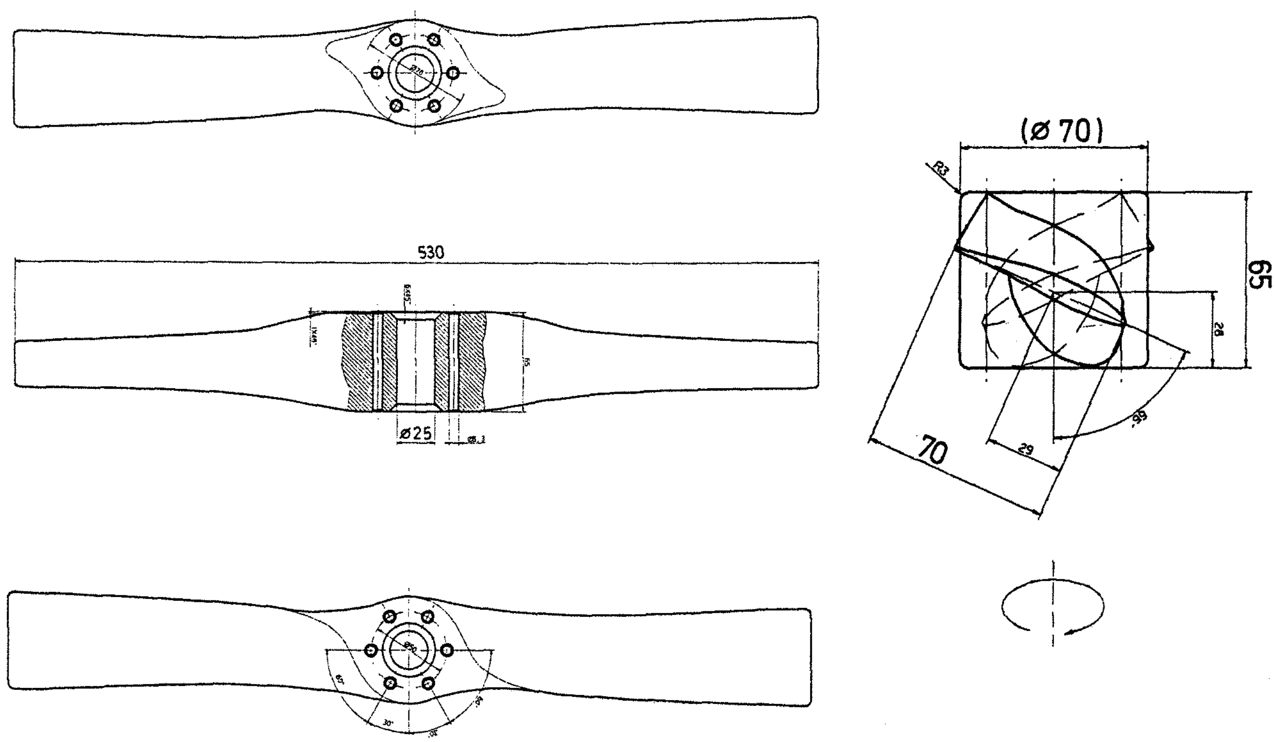
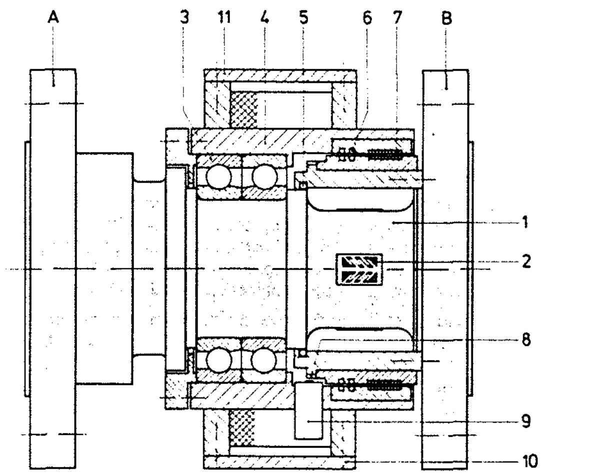


Fig. 4 Impeller



A = mounting flange; **B** = flange for introduction of torque; **1** = torsional body; **2** = strain gauge application; **3** = spindle bearings; **4** = housing; **5** = elastic seal; **6** = capacitive transmission; **7** = inductive transmission; **8** = gear wheel for speed measurement; **9** = inductive proximity detector; **10** = connection box "speed"; **11** = connection box "torque".

Fig. 5 Mechanical construction of the troque and revolution measuring device

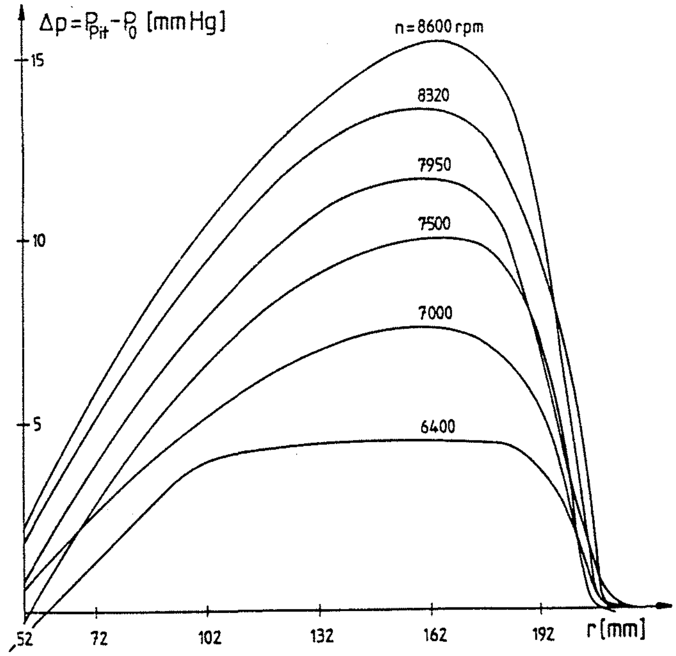


Fig. 7 Pitot pressure contribution behind the propeller at $M_\infty = 0{,}31$ for different revolutions; HKG

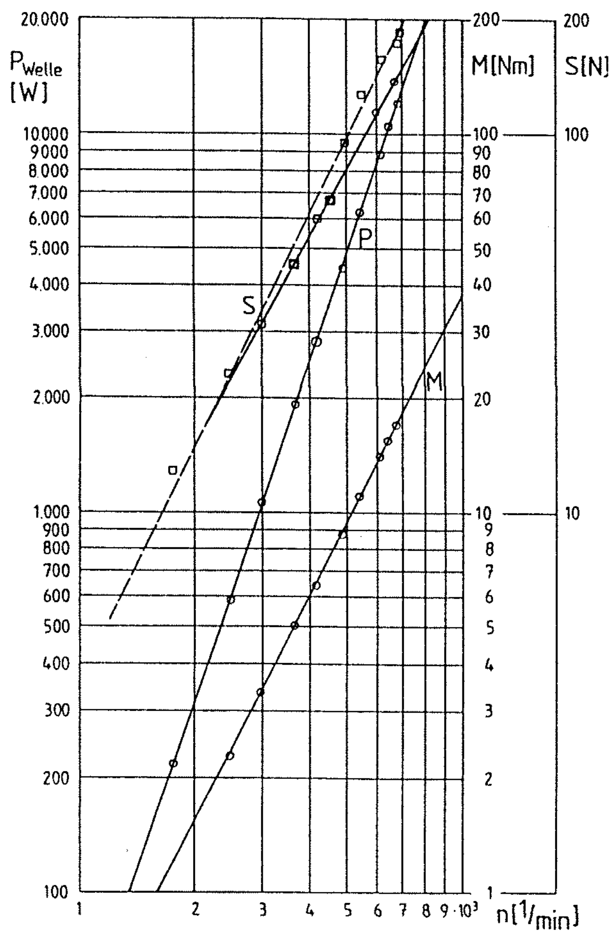


Fig. 6 Power, torque and thrust at static test

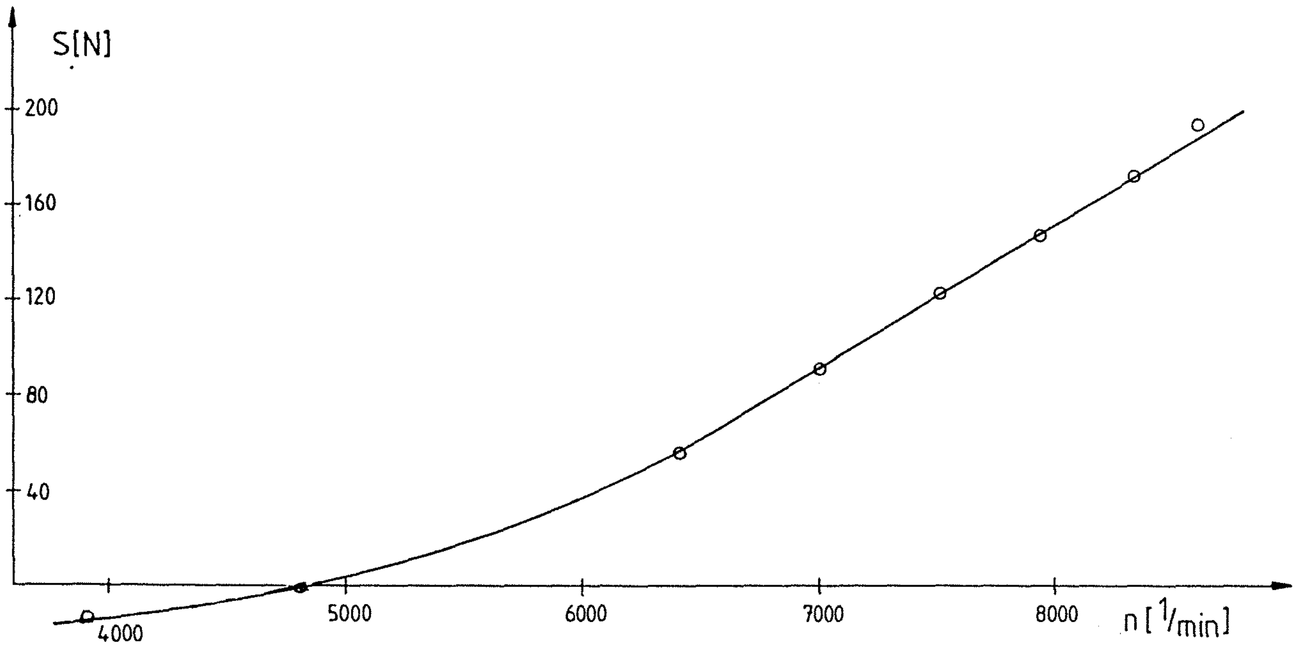


Fig. 8 Thrust S versus revolutions n at $M_{\infty} = 0{,}31$; HKG

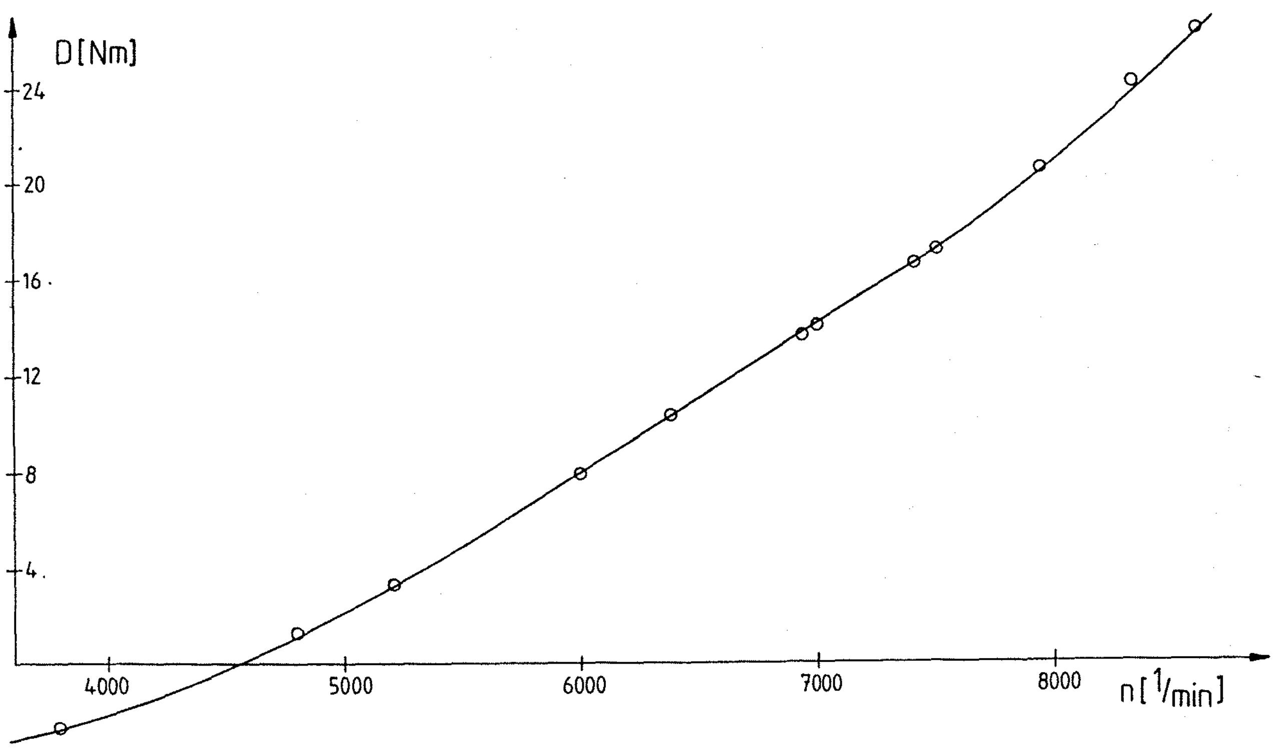


Fig. 9 Torque D versus revolutions n at $M_{\infty} = 0{,}31$; HKG

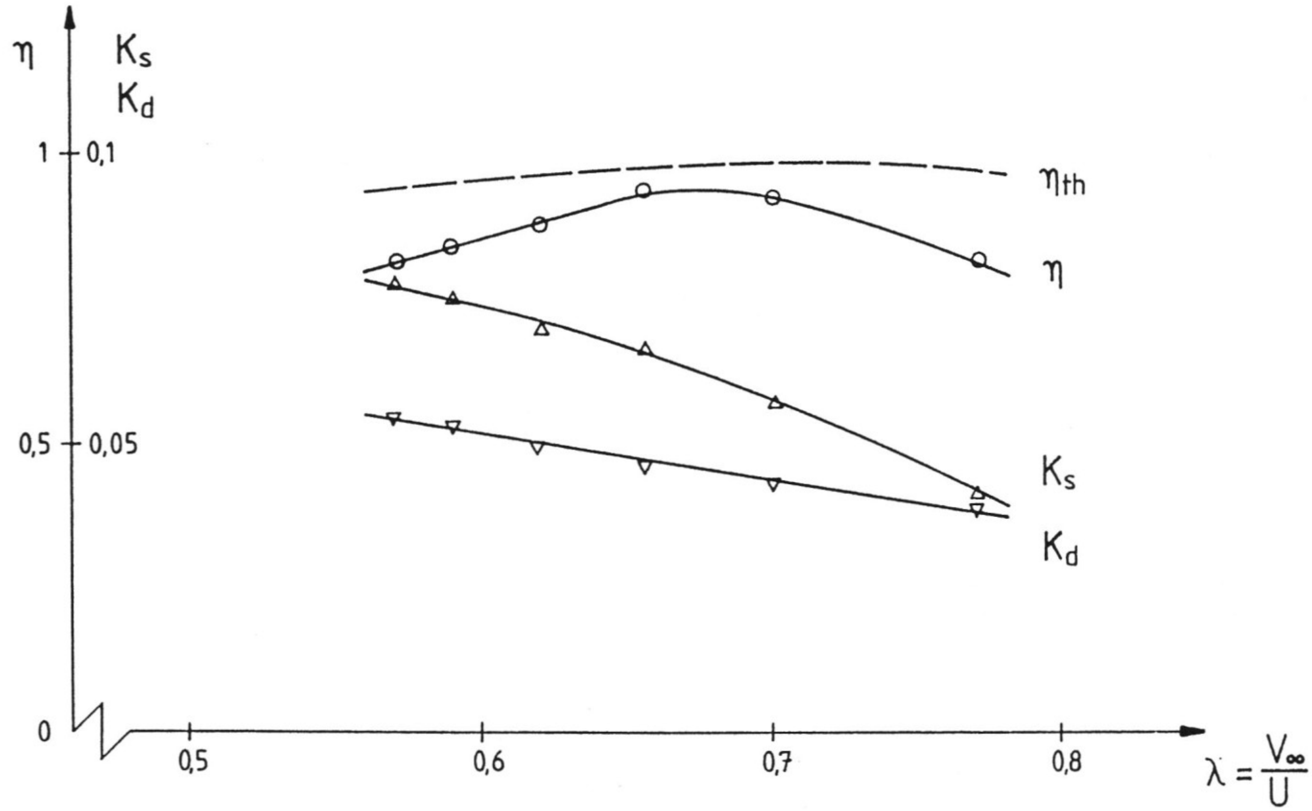


Fig. 10 Characteristic thrust and torque values and efficiency versus propeller modulus at $M_\infty = 0,31$; HKG

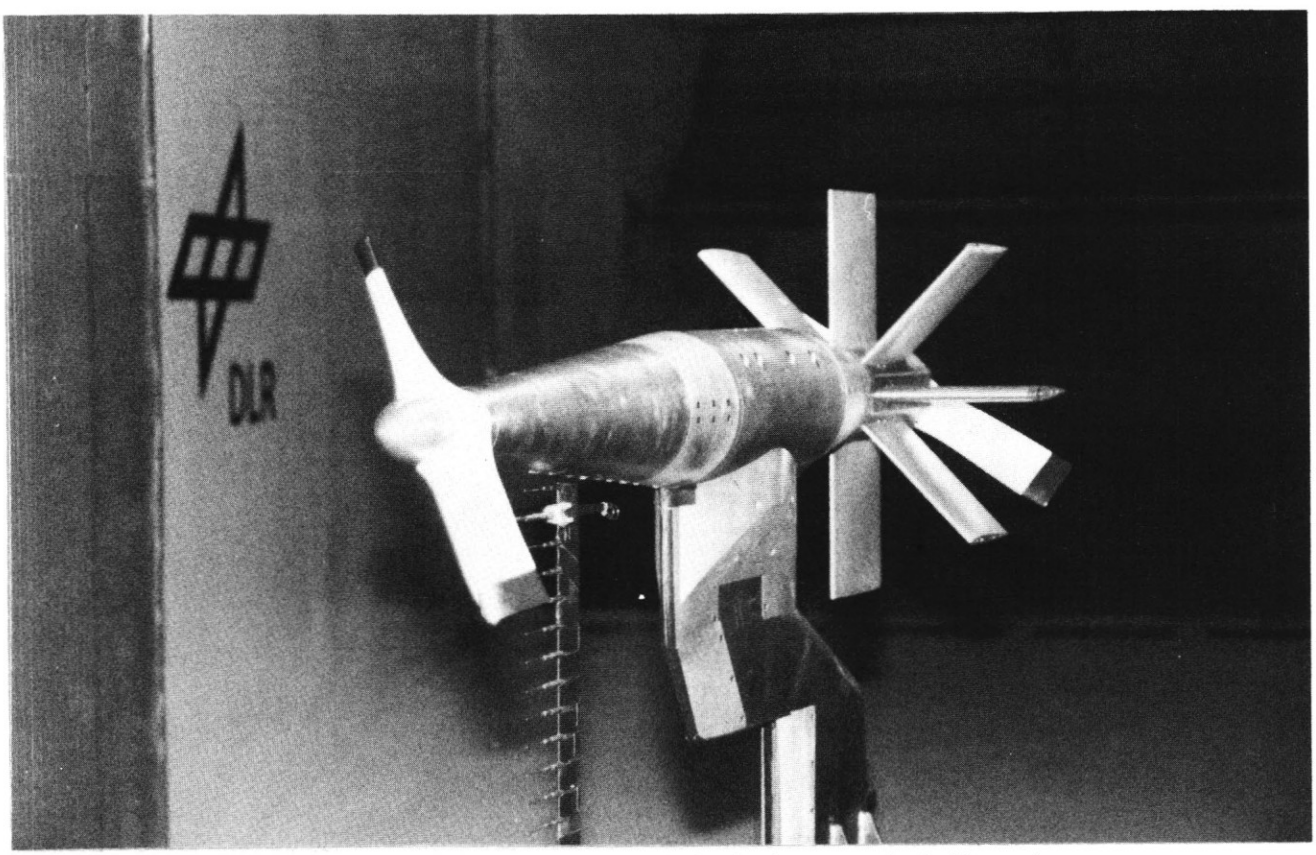


Fig. 11 Photograph of the propeller test rig in the low speed wind tunnel

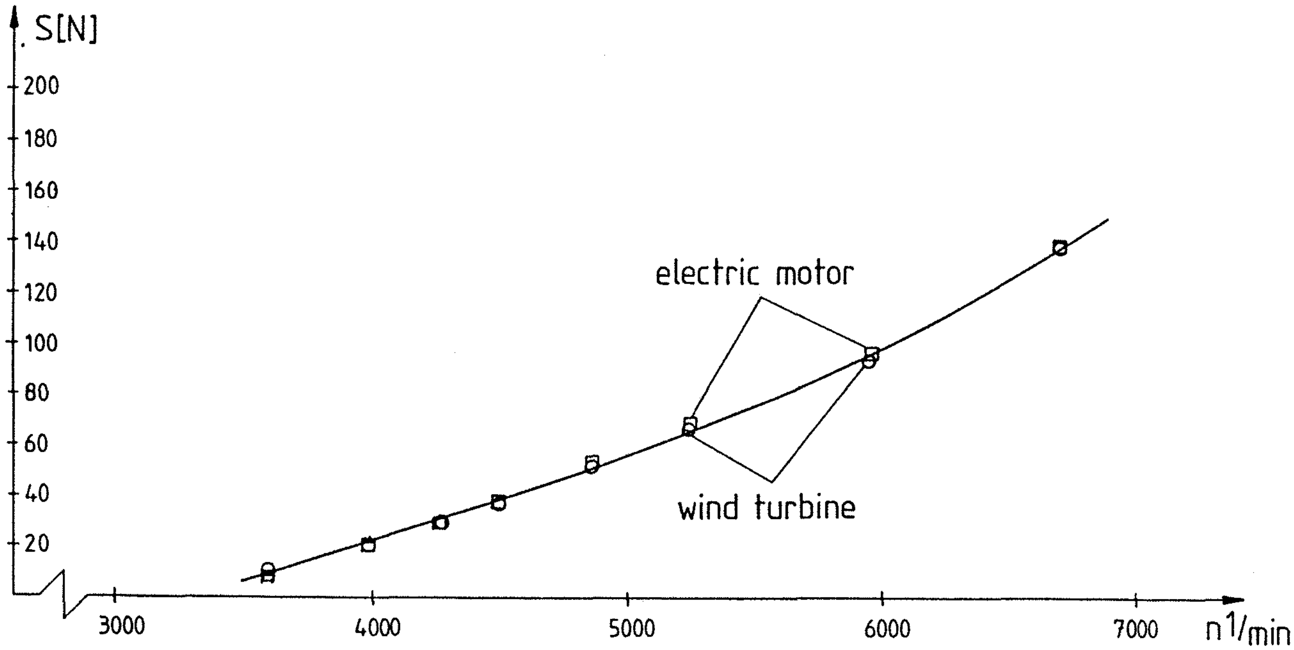


Fig. 12 Thrust S versus revolutions n at V_∞ = 60m/sec; NWG

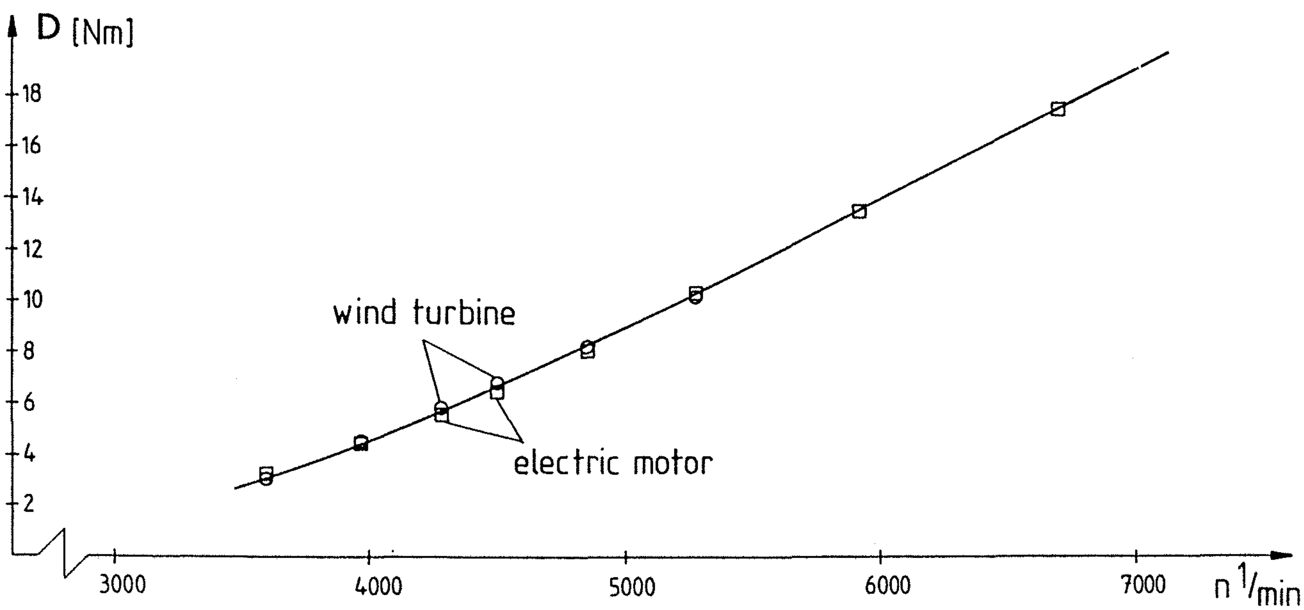


Fig. 13 Torque D versus revolutions n at V_∞ = 60m/sec; NWG

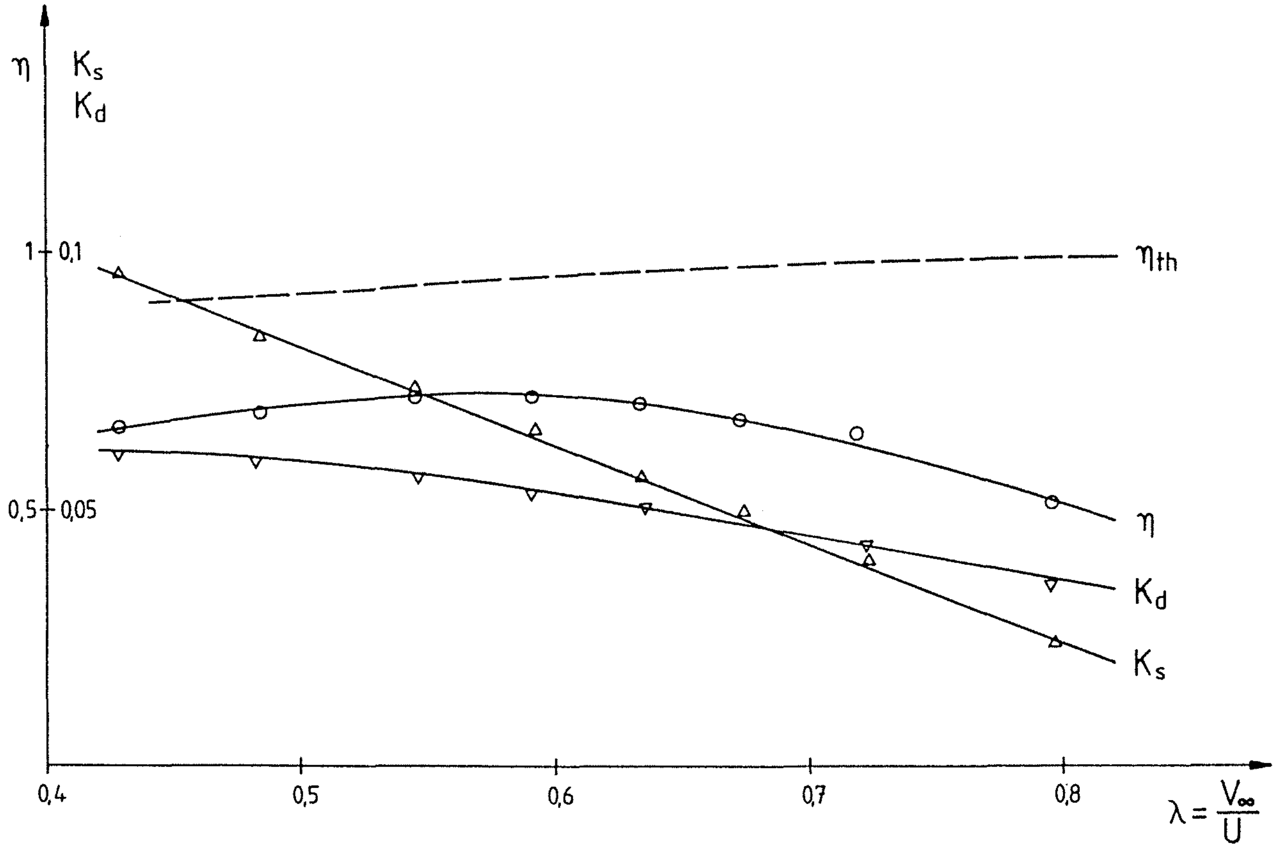


Fig. 14 Characteristic thrust and torque values and efficiency versus propeller modulus
V_∞ = 60m/sec; NWG