

## PROPELLER PERFORMANCE TEST

The test apparatus shown in Figure 1 is to be used in the open-throat wind tunnel to measure propeller performance. This test rig was designed and built here for the research work of a Ph.D. student. We will be measuring thrust, torque and rate of rotation. Thrust and torque are measured by the strain gauge balance, which serves as the only support for the propeller, drive shaft and motor. The strain gauge output signals are amplified and low-pass filtered by two Measurements Group 2310 signal-conditioning amplifiers. They are then read by a National Instruments data acquisition board (note the model during your lab) and a PC running LabView data acquisition software. The tunnel dynamic pressure, measured to determine freestream velocity, is converted to a voltage by an electronic manometer, which is also read by the A/D board. The thrust signal is converted to a force by means of the calibration factor 18.2 lb/mv. The torque calibration factor is 7.41 lb-ft/mv. The software samples three channels of analog data; the tunnel dynamic pressure from the electronic manometer, the thrust and the torque from the balance inside the prop shroud. The acquired data is then reduced and stored in the specified file. The required performance coefficients are calculated based on the user input atmospheric temperature, pressure and the measured tunnel  $Q$ . Measurements of thrust and torque are to be made for each of several wind tunnel speeds at a constant propeller speed. As the experiment is performed, the coefficients  $K_T$ ,  $K_Q$  and  $\eta$  are plotted on the screen as a function of the advance ratio,  $J$ .

A Strobotac measures the rate of rotation of the propeller. The Strobotac is a strobe light with a variable flashing frequency. When the propeller rotation and strobe light are synchronized at the same frequency, the propeller will appear stationary and revolutions per minute can be read off at the Strobotac. Since we will be testing a multi-bladed propeller, it is possible for the propeller to appear stationary when in fact different blades are illuminated by successive flashes. To help eliminate this error, we will make use of markings on one of the blades. These markings should appear steady, not flashing on and off, when the strobe and prop are synchronized. It is still possible to make an error by obtaining harmonics of the desired frequency.

The propeller we will be testing is a model of a marine propeller constructed by the David Taylor Naval Ship Research and Development Center (now Carderock Division, Naval Surface Warfare Center). It is identified as Prop 4767A. It has a diameter of 1.292 ft and 5 blades. It was constructed of aluminum in 1979 at a cost of \$12K. Details of its geometry were used in a blade element theory code to calculate estimates of its performance. These results are provided in Figure 2 and the accompanying table below.

### EQUIPMENT

- Open throat wind tunnel and circular cylinder model
- Propeller test rig containing motor and strain gauge balance
- Motor speed control
- Strobotac
- Two Measurements Group 2310 signal conditioning amplifiers
- PC with LabView software and National Instruments board
- Reference pitot-static probe and electronic manometer

## PROCEDURE

- 1) Turn on the DAQ computer and load “Prop Lab.vi” if not already running. Make sure the tunnel and prop motor are off.
- 2) Once the VI is loaded, Enter the following information in the control boxes
  - a) Atmospheric Pressure in millibars
  - b) Tunnel temperature in degrees Fahrenheit
  - c) Prop diameter of 1.292 ft
  - d) Number of desired samples per channel (maybe a thousand)
  - e) Desired sample rate (maybe 250 Hz)
- 3) **Optional:** Balance the 2310 amplifiers by depressing the Auto-Balance switches, and then manually trimming the output using the ‘Trim’ pots.
- 4) Run the “Prop Lab” VI by clicking on the “Run” button in the upper left corner of the window.
- 5) With both the propeller motor and wind tunnel off, click the “Tare Tunnel” button to take tare values from the strain gage amplifiers and electronic manometer. These values will be subtracted from the remaining measurements.
- 6) Turn on the propeller motor and Strobotac, which should be set for 1700 RPM. Increase the motor speed until the white line on the propeller blade appears stationary. (Motor voltage should be close to 84% on the motor speed control. You may need to dim the room lights to make the strobe more effective.)
- 7) Enter 1700 RPM on the ‘Propeller RPM’ window.
- 8) Turn on the tunnel and take data at a series of tunnel dynamic pressures ( $q$ 's) adjusting the propeller motor speed control to maintain a constant 1700 RPM as tunnel speed changes and clicking ‘Take Datapoint’ for each measurement. Adjust the wind tunnel speed so that you get about 20 data points reasonably equally spaced over a range of advance ratios,  $J$ , from about 0.4 to 1.4. Be sure to get points out to where both thrust and torque are negative. (Note that once the thrust goes negative, the efficiency is meaningless.) At higher tunnel speeds, you may find that the prop runs greater than 1700 RPM even with the motor speed control turned all the way down to zero. Just use the Strobotac to measure the prop speed and enter that value in the “RPM” window before taking data.
- 9) Based on the graph in the vi window, you should be able to pick out the  $J$  where maximum efficiency occurs. Acquire a few extra data points around that maximum for better definition of this point. Note that any extra data points acquired will be at the END of the data file, so you may need to re-sort the data before plotting them for your lab report.
- 10) When finished acquiring data, first, click the “Save Data” button, and enter a data file name in the dialog box, which appears. Make sure to put the data somewhere where you can find it. Second, click the ‘Stop’ button and shut down the tunnel and prop motor.
- 11) Estimate the accuracy of each of your measurements and perform an overall error estimate for your results. Plot your data with error bars.

## DATA REDUCTION

The wind tunnel speed,  $V_0$ , is determined by

$$\gamma_{H_2O} \cdot q = \frac{1}{2} \rho V_0^2 \quad (1)$$

where  $q$  is the dynamic pressure in inches of water,  $\gamma_{H_2O} = 62.4 \text{ lb/ft}^3$  and

$$\rho = \frac{p}{RT} \text{ slug / ft}^3 \quad (2)$$

where  $p$  is in  $\text{lb/ft}^2$  (note:  $1 \text{ mb} = 2.0884 \text{ lb/ft}^2$ ),  $R = 1715 \text{ lb ft/slug } ^\circ\text{R}$  and  $T$  is in  $^\circ\text{R}$  ( $^\circ\text{R} = ^\circ\text{F} + 460$ ).

The advance coefficient,  $J$ , is

$$J = \frac{V_0}{nD} \quad (3)$$

where  $n$  is revolutions per second,  $D$  is the propeller diameter in feet and  $V_0$  is in  $\text{ft/sec}$ .

The thrust coefficient is

$$K_T = \frac{T}{\rho n^2 D^4} \quad (4)$$

where  $T$  is the thrust in pounds. The torque coefficient is

$$K_Q = \frac{Q}{\rho n^2 D^5} \quad (5)$$

where  $Q$  is the torque in  $\text{lb-ft}$ . And finally, the propeller efficiency is given by

$$\eta = \frac{\text{power out}}{\text{power in}} = \frac{TV_0}{Q\omega} = \frac{K_T}{K_Q} \frac{J}{2\pi} \quad (6)$$

where  $\omega = 2\pi n$ .

The coefficients defined above are used with marine screws. For aircraft propellers, the following are usually defined.

$$\begin{aligned} C_T &= \frac{T}{\rho \omega^2 R^4} && \text{thrust coefficient} \\ C_P &= \frac{P}{\rho \omega^3 R^5} && \text{power coefficient, } P = \omega Q \\ \lambda &= \frac{V_0}{\omega R} && \text{advance ratio} \\ \eta &= \frac{\lambda C_T}{C_P} = \frac{TV_0}{P} && \text{efficiency} \end{aligned} \quad (7)$$

## DATA PRESENTATION AND POINTS FOR DISCUSSION

Plot the performance curves,  $K_T$ ,  $K_Q$ , and  $\eta$  vs.  $J$  (or  $C_T$ ,  $C_p$ , and  $\eta$  vs.  $\lambda$ ). Normally  $10K_Q$  is plotted to make it more the same scale as  $K_T$ , see the figure. Plot curves from both the experiments and the blade element theory analysis. Discuss any differences. We identify regions of this curve as the propeller, air brake and windmill regions depending on the signs of the thrust and torque. Identify and discuss these regions.

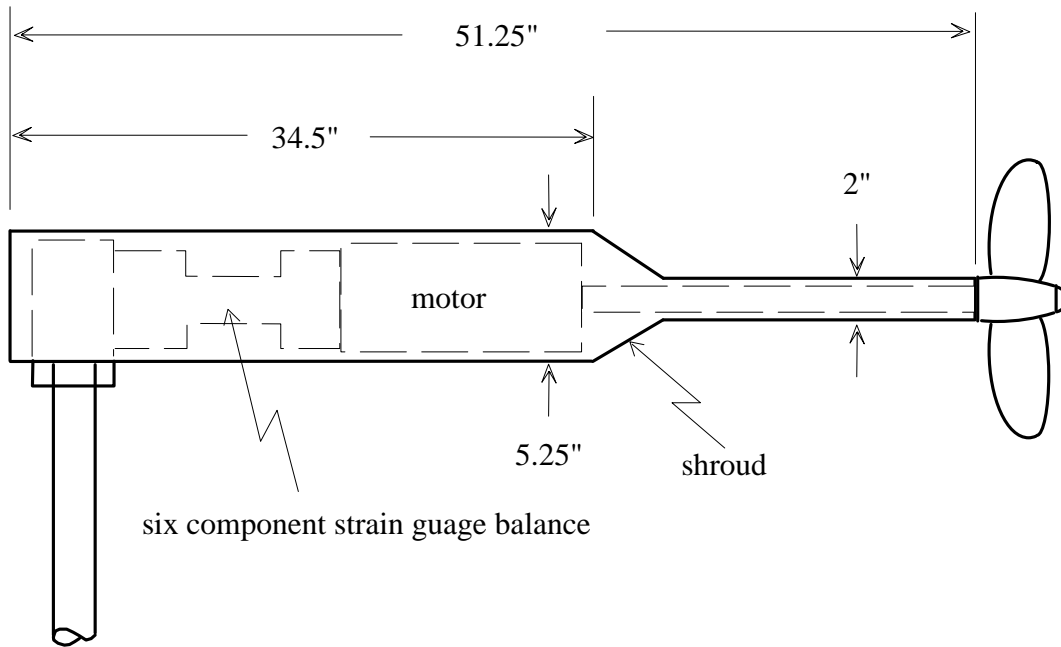
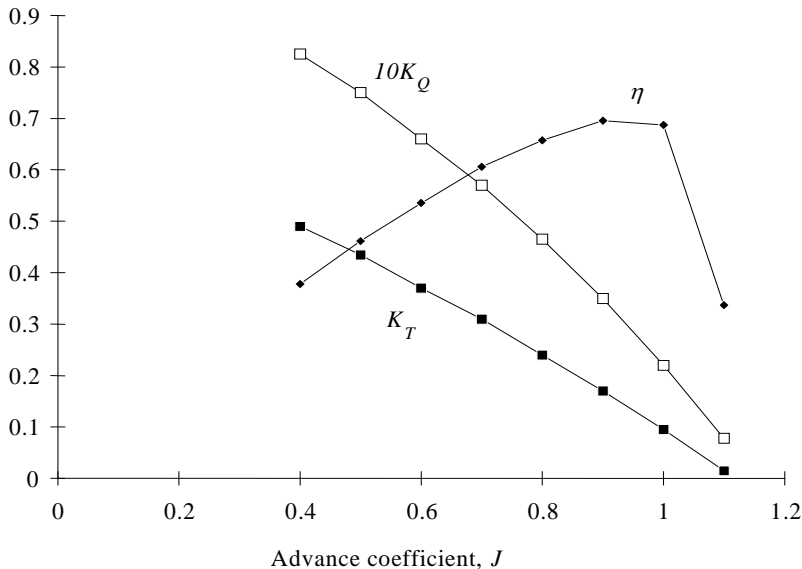


Figure 1. Schematic of propeller test rig.



$J$	$K_T$	$10K_Q$
0.4	0.490	0.825
0.5	0.435	0.750
0.6	0.370	0.660
0.7	0.310	0.570
0.8	0.240	0.465
0.9	0.170	0.350
1.0	0.095	0.220
1.1	0.015	0.078

Figure 2. Blade element theory analysis.

## Report Expectations for Propeller Lab

Title Page and Abstract

Introduction

Description of Experiment

- A. Describe test rig with strain guage balance.
- B. Describe type of propeller used.
- C. Mention wind tunnel, computer with A/D board.
- B. Mention amplifiers, pressure transducer.
- D. Describe the Strobotac.
- E. Discuss the procedure.

Results of Experiment

- A. Define  $J$ ,  $K_T$ ,  $K_Q$ ,  $\eta$ .
- B. Plot of  $K_T$ ,  $K_Q$ ,  $\eta$ . vs  $J$  and comparison with blade element results, discuss differences.
- C. Discuss propeller, airbrake and windmill regions.
- D. Derive error estimates on your results.

Conclusion

- Repeat major findings.
- What did the lab show you?