Exercise 1: Static Performance of a GA Aircraft Propeller

EA 429 Flight Propulsion
USNA Aerospace Engineering

In this laboratory exercise, the performance of a general aviation (GA) aircraft propeller will be measured for different blade pitch settings in the USNA Rotor Laboratory. The static thrust, torque, and power coefficients will be determined from direct measurements.

I. Introduction

The Airmaster variable pitch/constant speed propeller is designed for use in light general aviation aircraft coupled with 80–120 horsepower Jabiru® or Rotax® engines. The carbon fiber blades are variable in pitch by an electric motor and cam system in the spinner. This setup will be tested in the Naval Academy Rotor Laboratory (Ri035H) under static conditions, powered by a speed-controlled AC motor capable of providing up to 150 horsepower. For the purposes of this lab, the propeller will be tested at multiple pitch settings. The fine pitch limit is 15.5 degrees and the coarse pitch limit is 25.5 degrees, measured at the standard location of 75% of the blade radius. The objective is to ascertain the advantage of different pitch settings and to identify an optimum blade pitch for static thrust.

Therefore, the purpose of this laboratory exercise is to:

1. Determine the thrust, torque, and power coefficients from experiment.
2. Validate the experimental trends with propeller RPM.

Figure 1. Propeller installation on the Rotor Lab test tower

II. Facility and Instrumentation

The aircraft propeller to be tested is installed in the Rotor Laboratory, part of the USNA Fluids Laboratory in Rickover Hall. The Rotor Laboratory is a 37x37-ft test cell that has a retractable roof to allow a clean inflow for rotor and propeller testing on the tower. Louvers in the sidewalls at and below the grated floor allow the air to exit the test cell and promote efficient circulation. The facility is shown in Figure 1.

The three elements of essential equipment are the motor and controller, variable-pitch propeller, and the propeller thrust and torque instrumentation. The AC induction motor is capable of providing up to 150 HP and 221 ft-lbs of torque at speeds up to 3,560 RPM for the controlled testing of 72-inch aircraft propellers.

The propeller used is an Airmaster AP332 fully-feathering propeller. The AP332 is designed for light general aviation aircraft and is capable of full pitch variation in-flight. It is constructed of three WarpDrive™ carbon fiber blades each with a protective nickel leading edge strip. The blade cross section resembles a Göttingen 6K airfoil (GOE-6K). At its finest setting, the blade incidence is 32 deg at the root and 12.5 deg at the tip (15.5 deg at $0.75R$). The propeller pitch is electrically adjusted on-the-fly using an Airmaster AC200 controller. This device has two modes: automatic and manual. The automatic mode configures the propeller pitch setting to maintain a constant speed operation. The manual mode (which will be used in this experiment) allows the user to customize the operation of the propeller to very specific pitch settings independent of RPM.

Each test propeller has been custom-balanced prior to running in the Rotor Lab. This was done using a MicroVib II propeller balancer/vibration analyzer, provided by Dynamic Solutions Systems. This unit is also used to monitor propeller RPM and propeller vibration levels during each test. Propeller thrust and torque are measured using a data telemetry system. The model 2100A is a non-contact wireless sensor system supplied by Wireless Data Corporation. Two inline sensors have been configured using induction-powered transmitters, with a thrust range of up to 1,500 lbs and a torque range of up to 250 ft-lbs. Sensitivity is less than 1%.

III. Airfoil Analysis

An airfoil analysis on the GOE-6K geometry was accomplished using version 6.94 of the XFOIL code. The XFOIL code is an airfoil design and analysis code involving a viscous/inviscid method combining an Euler solver with a two-equation integral boundary layer solution. It is valid past the airfoil stall point and is appropriate for transonic Mach numbers. A range of incidence angles was simulated for a freestream Mach number of 0.40 and a Reynolds number of $1.5\text{x}10^6$, conditions which simulate the airfoil performance at the $0.75R$ radial position at a propeller at 1,800 RPM. The basic performance characteristics, in terms of the sectional lift and drag coefficients, are shown in Figure 2. These results will prove useful for a blade element calculation of the propeller performance.

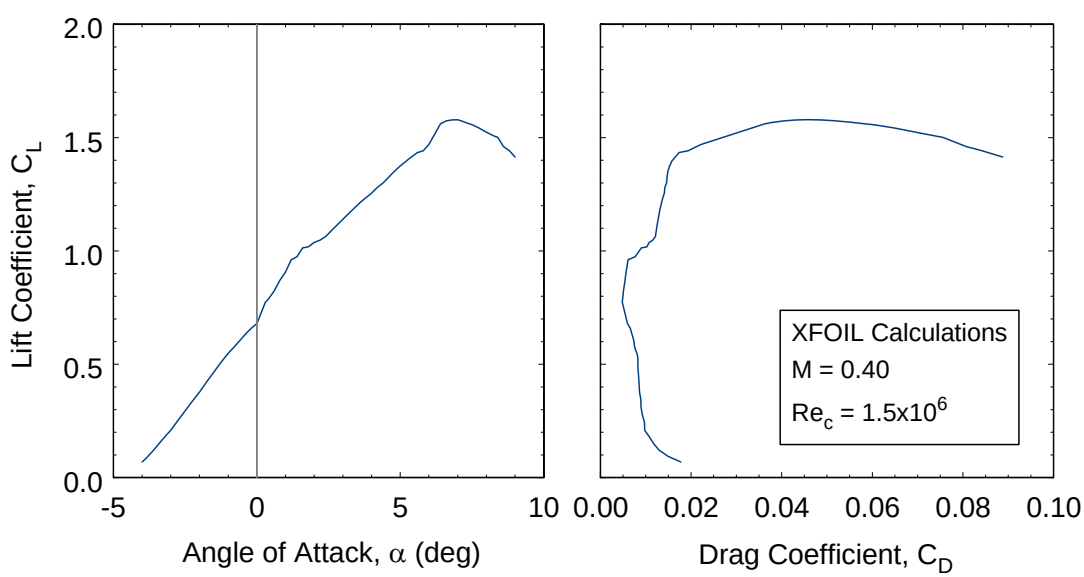

Figure 2. Computed aerodynamic characteristics of the GOE-6K airfoil

The analysis shows that the maximum lift coefficient of 1.58 (shown on the left side of Figure 2) is produced at a local angle of attack of 7.0 deg. In keeping with the expectations of thin airfoil theory, the slope of the lift curve is linear with the exception of the stall point. This provides a reliable predictor of the sectional lift of the GOE-6K. The drag polar (shown on the right side of Figure 2) reveals a minimum drag coefficient of 0.0049 at a lift coefficient around 0.8. This occurs at an angle of attack of around 0.3 deg. Despite its thin shape, the GOE-6K produces a maximum L/D ratio of 162 at 0.6 deg AOA. This characteristic suggests a highly loaded propeller blade at a relatively low incidence angle.

A more detailed analysis is possible by examining the pressure distribution at a high loading condition. Figure 3 shows the distribution in the pressure coefficient, C_p, at 6.5 deg AOA. Of particular note is the suction peak in the pressure coefficient near the leading edge (C_p = -3.87), which indicates a very low pressure and high velocity. The corresponding Mach number at this point is approximately 1.03. The presence of localized sonic flow indicates supercritical airfoil operation, and may be inherently sensitive to shock wave/boundary layer interactions which could limit the airfoil performance to some degree. But for the purpose of this experiment, no strong shocks should be present, as long as the propeller does not exceed approximately 1,800 RPM.

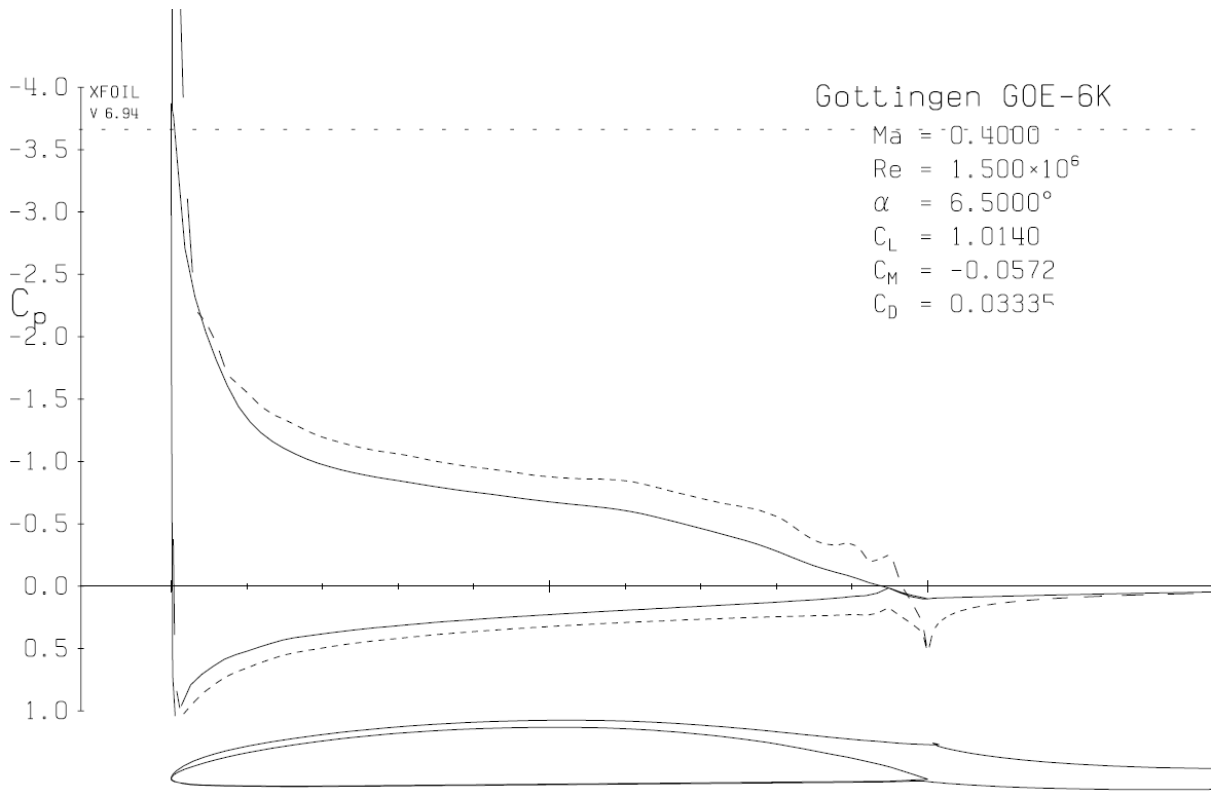

Figure 3. GOE-6K pressure distribution at 6.5 deg AOA

IV. Procedures for the USNA EWT Wind Tunnel

1. Study this handout prior to the start of the laboratory period.
2. Record the barometric pressure and the outside air temperature.
3. Measure and record the propeller diameter. Record the test article serial number.

In Rotor Lab (Ri035H)…

WARNING: Do not enter the Rotor Lab unless the Baldor motor control panel has been powered down (in the cage outside Ri035H). To do this, throw the black and red lever on the cabinet. Upon exiting the Rotor Lab, secure the red door and re-energize the motor control panel.

4. Secure crane and hook to wall.
5. Open vertical sliding vent doors and roof.
6. Inspect propeller blades and hub.
7. Close and latch lab doors.
8. Measure the blade pitch angle.

In Control Room (Ri035J)…

9. Turn on DSS MicroVib II tachometer/vibration analyzer.
10. Turn on Honeywell/Sensotec torque and thrust displays. **NOTE**: Do not change any of the Sensotec display knobs except for the zero adjustment. Verify that the "display scale" and "gain" knobs have been left at 1.21 and 10.1 for the torque unit and 1.19 and 10.1 for the thrust unit.
11. Turn on Agilent 34970A datalogger instrument.
12. Turn on Laptop computer, start up Agilent "34970A DataLogger 3" data acquisition software.
13. Turn on AC200 Airmaster CS Controller (red safety toggle). Verify "manual" mode (not "auto"). Set propeller pitch to fine limit (flashing green).
14. Verify motor speed control pendant toggles are disengaged and knob is set full-counterclockwise ("off").
15. Turn on main motor control panel power (on the Baldor cabinet in the cage outside Ri035H).

Running the Propeller Tests…

16. Ensure speed control knob is off (fully counterclockwise).
17. Engage the top "run" toggle to "fwd."
18. Ensure propeller is not spinning. Adjust torque and thrust "zero display" knobs to read "000." Click the green "Start/Stop" button in the software to record the "zero" datapoint.
19. Slowly turn knob clockwise to increase speed (displayed as a percentage of 3,560 maximum motor RPM). Set the propeller to approximately 350 RPM (touching the metal faceplate provides a ground and may stabilize the readout).
20. Click the green "Start/Stop" button in the software to record data points for this setting.
21. When the data logging is complete, the "Scan and Log Data Summary" dialog box will be displayed. Click the "Edit Fields" button to add comments to the data file. Under "Comments," enter β and RPM for that data point and click the "OK" button. Click the "Export Data" button to open the export dialog box. Click "Export to File" without changing any settings. After overwriting the file, click "Close" and "Close" again. The data files are automatically stored in CSV format under "My Documents."
22. Record the actual RPM setting from the MicroVib II instrument. In addition, you should monitor accelerometer readings on the MicroVib to ensure vibration levels do not exceed 1 in/sec.

    Caution: If vibration levels exceed 1 in/sec, reduce speed <u>immediately</u> and consult lab instructor.

23. Repeat steps 19–22 at 700, 1050, 1400, 1750, and 0 RPM (again).

    Caution: Do <u>not</u> run motor beyond 50% or about 1,800 RPM for this experiment.

24. When done, ensure speed control knob is off (fully counterclockwise) and disengage the top "run" toggle to prepare for a blade pitch change. Verify that the propeller is stationary and secure the speed control pendant.
25. Disengage the main motor control panel power and enter the Rotor Lab to execute a blade pitch setting change.

WARNING: Do not enter the Rotor Lab unless the Baldor motor control panel has been powered down (in the cage outside Ri035H). To do this, throw the black and red lever on the cabinet. Upon exiting the Rotor Lab, secure the red door and re-energize the motor control panel.

26. Repeat steps 16–23 at blade pitch settings of 15.5 (fine pitch), 17.5, 19.5, 21.5, 23.5, and 25.5 deg (coarse pitch). **NOTE**: You should measure the angle using the digital inclinometer, measuring the blade at the $0.75R$ radial position.

Secure Lab and Equipment…

27. Set speed controller knob and toggles to the off position.
28. Reset prop pitch to fine.
29. Turn off all instrumentation and the laptop.
30. Turn off main motor controller power.
31. Close sliding rooftop and doors. Turn off door power breaker. Close and latch doors.
32. Move your data files to a unique folder name, and copy onto removable storage.

V. Calculations

Determine the following for the model:

- Propeller diameter and disk area.

Calculate the following for each blade pitch tested:

- Average values for T, Q and P for each RPM setting (i.e., data file).
- Values for the measurement uncertainty (ε_T, ε_Q and ε_P) for each RPM setting. You should base the ε values on the standard deviation of your sets of data points (e.g., $\varepsilon_m = \sigma_m / \overline{m}$, where m is the measured quantity).
- Plot T and Q as functions of n^2. Use a linear regression to determine C_T and C_Q. What is the quality of each curvefit?
- Plot P as a function of n^3. Use a linear regression to determine C_P. What is the quality of the curvefit?
- Plot ε_T, ε_Q and ε_P as functions of n, all on the same plot. What does this plot indicate about the data uncertainty? How might this affect your results and conclusions?

Determine the following for this propeller:

- Plot C_T, C_Q, and C_P as functions of $\beta_{0.75R}$, all on the same plot. Do the plots follow the expected trends from theory? Can you identify a blade pitch setting which maximizes the static thrust coefficient? What about the torque and power coefficients? Discuss the implication of these observations (what is happening and why).
- Discuss how C_T, C_Q, and C_P vary with advance ratio. What are the implications?
- What are a "climb prop" and a "cruise prop?" How do these experimental results support the respective operating conditions for these types of propellers?

VI. Deliverables

Unless otherwise directed by your instructor, you need to deliver an <u>individual</u> informal report on your findings. Consider it an abbreviated technical report with an abstract, a results section, and a brief conclusions section.