# Chapter 5

# Blades and Pitch Systems

## I Torque

The root of the blade experiences a torque due to the presence of the airfoil in the wind stream. Force is applied to the airfoil throughout the length of the blade, varying with the characteristics and operating conditions along the length. The summation of these forces creates a torque on the blade root, and therefore the main shaft. Vector plots of the system velocity and torque components is portrayed in Fig. 5.1. It is important to notice that lift and drag components are not shown here, as this depicts only the summation of all lift and drag components. The incoming,

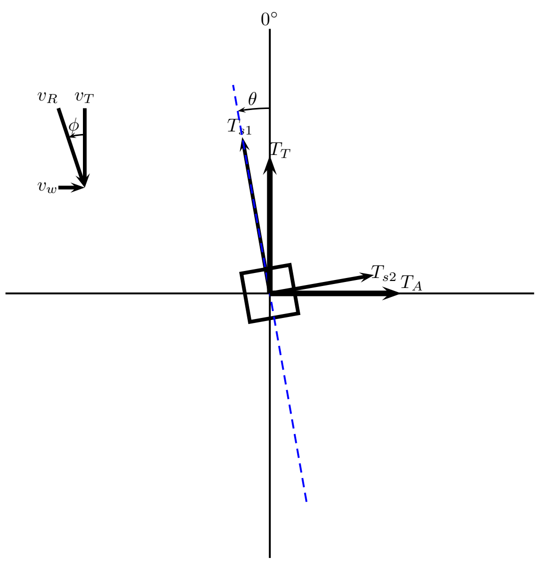


Figure 5.1: Torque components at the root of the blade. Radially varying velocity components are included as well.

upstream wind speed is denoted by $v_w$, the apparent incoming tangential velocity is $v_T = -\Omega_h r$, and $v_R$ is the relative incoming velocity. The pitch angle is defined so the ”lift” strain guage, $T_{s1}$ is along the rotor plane, and the “Drag” strain guage, $T_{s2}$, is perpendicular to that and positive in the direction of the wind stream. Since there are three blades, the total torque applied to the hub shaft is $T_h = 3T_T$.

With knowledge of the pitch angle, $\theta$, the tangential and axial torque components, $T_T$ and $T_A$, respecitvely, can be resolved. A series of tests can be performed on the blade to estimate the performance of the blade at various rotor speeds and pitch angles. In doing so, the angle that maximizes tangential torque can be identified, and thus maximize power transfer to the shaft. This is left as an excercise in this chapter's experiments.

## II Experiments

These exercises will provide working insight as to how the blades are operating in the wind stream. They will give you exposure to sensor-based measurements, and will require post-data collection analysis. Measurements on the blades during operating conditinos will reinforce and supplement topics discussed in lecture.

### Experiment 5.1: Blade Forces and Maximum Torque

For this exercise, you will run the Wind Turbine Simulator (WTS) and measure forces acting on the root of a blade. You will run the machine at a variety of pitch angles and rotor speeds, and collect data related to the hub. From the raw data, you will resolve the tangential torque component, plot its magnitude at each test conditions, and determine a pitch angle that is most desireable to transfer power to the shaft.

**Goals:** Understand the forces acting on a wind turbine blade. Identify major components of the hub and pitch system. Understand theory of operation and limitations that may apply. Operate the blade at a variety of conditions and observe the system behavior.

**Procedure:**

1. Setup the wind turbine simulator (WTS) trailer in a location conducive to operating the wind turbine with the prime-mover. Setup the control and data acquisition system to measure the blade forces, hub torque, rotor speed, and pitch angle. Remove the hub cover and inspect the pitch system. Identify and note the location of the strain guages on the shaft of blade 1; one of them should be aligned with the rotor plane when pitched to $0°$. As a group, discuss the components of the system and how they work to support the system.

2. Turn the hub so blade 1 is vertical, and record the strain guage measurements; this is the “zero-strain” value that can be offset from the data during processing.

3. Pitch the blades to $0°$ and set the prime mover to run the hub at 200 rpm. The generator terminals should remain disconnected, so the only torque applied to the generator-side of the hub torque sensor is that due to friction and windage of the rotating drivetrain. Measure the forces on the blade at angles of $0°$, $8°$, $9°$, $10°$, $11°$, $12°$, and $15°$. In addition to measuring the average values using the DAQ, also capture a high-resolution image using the oscilloscope, for the sake of analyzing the harmonic components; use the FFT function of an oscilloscope.

**Deliverables:**

1. Sketch a diagram of the forces acting on the blade at each test condition; use MATLAB to plot the components. Use the measurements for each condition in the procedure to calculate these forces; include the magnitude and angle of resulting forces. Plot the tangential and axial torque component magnitude vs pitch angle, and if you ran the test at multiple speeds, include the speed as a third dimension in the plot. What is the blade angle that maximizes tangential torque? Does it change with rotor speed?

2. Are there frequency components that exist in one strain gauge that do not exist in the other? What are the frequency components you observe? If you can, identify what system is contributing to that harmonic.

3. What do you find most interesting about this activity, and based on your experience with the blades, what else are you curious about?

*Hint:* You may use the following set of MATLAB code to read data from the file generated by WindQuest:

```
TestSpeed = [100 200 300]; %**Test Speeds (rpm)
TestAngle = [0 1 2 3 4 5 6 7 8 9 10 11 12 13 14]; %**Test Angles (deg)

%% Load data from files; first examine the .csv data file using notepad.
LiftMult = 0.021120; %Multiplier to convert voltage to N.
DragMult = 0.021020; %Multiplier to convert voltage to N.
AngleMult = pi/180; %Multiplier to convert voltage to rad.
TorqueMult = 0.366901; %Multiplier to convert voltage to Nm.
SpeedMult = 0.166666; %Multipilier to convert voltage to rpm.

for spdIND = 1:1:length(TestSpeed) %For each speed tested
    speedlevelstr = int2str(TestSpeed(spdIND)); %Test speed (rpm)

    for angIND = 1:1:length(TestAngle) %For each angle tested
        anglestr = int2str(TestAngle(angIND)); %Test angle (deg)

        %% Get Data
        fid = fopen(['ExtractedTestData/100-400rpm_nofieldvolt/' speedlevelstr 'rpm_' angle
        data = textscan(fid, '%f %f %f %f %f %f %f %f', 'delimiter', ',', 'headerlines', 1

        %Extract Time Measurement
        traw = data{1,1};
        dt = traw(2) - traw(1); %Time interval (s)
        clear t; %remove variable from previous test file
        t(1,1) = 0; %Initialize new time vector with correct values

        %Fix time measurement, saved as windows with each starting at 0
        for n = 2:1:length(traw)
            t(n,1) = t(n-1,1) + dt;
        end

        %Extract other measurements
        liftraw = -data{1,2}*LiftMult;
        dragraw = -data{1,3}*DragMult;
        torqueraw = data{1,4}*AngleMult;
        speedraw = data{1,5}*TorqueMult;
        angleraw = data{1,6}*SpeedMult;

        fclose(fid);

        %Resolve torque components and make plots

end
```

## Experiment 5.2: 3-D Blade Scan and Analysis

**Goals:** Understand the physical shape of the blade geometry by scanning the surface with a 3-D mapping tool. Identify differences in blade characteristics at different locations along the length of the blade.

**Procedure:**

1. Attach the blade to a sturdy fixture in a position conducive to scanning the surface with the scanning tool. Ensure the scan tool is also in a sturdy position. Any movement of either the blade or scanner will be evident in the resulting image.

2. Use the scanner software to clean up the image and create a CAD file. Take slices of the CAD drawing to create a profile of the blade geometry at different locations along the length.

3. Use MATLAB or similar software to apply the BEM to the resulting data.

4. Use XFLR5 to operate on the point-cloud to calculate lift and drag coefficients.

**Deliverables:**

1. Compare the blade shape to reference shaps available online; you search for them. Identify a blade shape for whithc lift and drag coefficients have been experimentally determined.

2. Estimate the lift and drag forces, and resulting performance coefficient, for various tip-speed ratios. What is a desireable tip-speed ratio to operate the blade at, and what is the maximum performance coefficient? Also plot the torque (or power) vs speed curve for the blade, assuming a fixed-angle pitch system (you specify the angle). Estimate the performance coefficient for the above condition.