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An Update to the SWiFT V27 Reference Model

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Abstract

A revised Sandia V27 reference model is provided for use with the wind turbine analysis code, FAST, incorporating refined parameters based on blade geometry measurements and performance data collected during the 2017 wake steering campaign at the Scaled Wind Farm Technology (SWiFT) site. The chord, twist, and airfoil section shapes were measured at five span locations on the blades of wind turbine WTGb1. The V27 AeroDyn file was updated with values equal to the measured chord and twist. The measured airfoil shapes deviated over the aft half of the chord compared to the original blade model NACA profiles. Differences in trailing edge camber were converted to an equivalent trailing edge flap effect calculated with thin airfoil theory. These modified airfoil polars were updated in the V27 FAST model. The tip-speed-ratio and root bending moment were measured experimentally in the wake steering campaign at SWiFT on wind turbine WTGa1. The torque constant and collective pitch of the model were tuned so that the model output tip-speed-ratio and thrust, root bending moment matched the experiment across all wind speeds in region 2 operation with minimum error.

Acknowledgment

The authors would like to thank Thomas G. Herges for processing and analyzing data from the wake steering campaign.

Document Revisions

Date	Version	Description
October 17, 2018	1	Initial release, an update to Resor [1]

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Chapter 1

Introduction

After completion of the 2017 wake steering campaign conducted at SWiFT in Lubbock, Texas, there was an opportunity to update the wind turbine reference model to be more representative of the V27 experimental performance. The model updates described in this report are an improvement to the original wind turbine model developed by Resor and LeBlanc in “An Aeroelastic Reference Model for the SWIFT Turbines” [1].

Details of the wake steering campaign are summarized by Naughton [2] which include a rich data set with measurements from two V27 wind turbines, an upstream meteorological tower, and wake measurements from the DTU SpinnerLidar. The wake steering experiment data is available publicly on the U.S. Department of Energy Data Archive and Portal (DAP) [3], allowing modelers to validate their simulation codes.

The content of this report is organized as follows. In Chapter 2, the use of foam templates is described in measuring blade chord, twist, and airfoil shapes. Next, Chapter 3 analyzes the associated airfoil polar modifications arising from the as-measured airfoil shapes. Chapter 4 shows how two input parameters to the FAST model are tuned so that experimental performance of the wind turbine matches the updated model. The appendices provide FAST input files which are updated to be consistent with the measurements and analysis in this report.

Chapter 2

Chord, Twist, and Airfoil Section Measurements

Foam templates were printed, cutout, and placed over the SWiFT wind turbine WTGb1 blades so that chord, twist, and airfoil shapes could be measured. The WTGb1 rotor was removed from the nacelle and placed on the rotor stand while the wake steering campaign was conducted. This made the WTGb1 rotor easily accessible and level on the ground. The following measurements are for WTGb1, and it is assumed the chord, twist, and airfoil shapes are identical on WTGa1 and WTGa2 because they are all Vestas V27 rotors. WTGa1 and WTGa2 were unavailable for ground measurements during the wake steering campaign, but could be updated to specific a1, a2, and b1 FAST models in future updates. The SWiFT site layout and locations of turbines WTGa1, WTGa2, and WTGb1 are seen in Figure 2.1 for reference.

With WTGb1 rotor on the ground, the blades were pitched to -5° (5° degrees beyond run position, the opposite of feather). This is the pitch position of the blades when the crank-arm yoke is bolted to the inside of the hub. The foam templates were placed on the blade at stations 1500 mm, 3600 mm, 5850 mm, 9650 mm, and 12500 mm measured from the blade root as seen in Figure 2.2. When the foam boards were designed and cut, the airfoil chord lines were rotated by the original FAST model twist angle relative to the edges of the foam boards. Therefore, angles not reading -5° indicate an aerodynamic twist that is different from the original FAST model.

The fit of the foam boards around the blade was not identical to the expected airfoil shape. An oscillating saw was used to remove foam where the fit was tight, and spray foam was added to fill the voids as illustrated in Figures 2.3–2.5. In general, the forward 50% chord of each airfoil fit the template well. Most modifications were made aft on the chord to accurately define the camber and trailing edge locations of the modified NACA airfoils. This indicated that additional camber was added to the original NACA airfoils when the V27 was designed.

Next, a digital level (Digi-Pas DWL-3000 XY) was used to measure the angle of the board top relative to gravity. The foam templates were moved between all three blades of WTGb1, and the chord and airfoil shape fit well at the same span stations as blade 1. The identical fit on blades 1–3 of WTGb1 means all blades have the same chord and airfoil shapes (but not twist). The digital level measurement was repeated twice for each span station on all three blades as shown in Table 2.1. The blade position is the distance in mm from the blade root (add 500 mm for rotor radius distance). Measurement 1 (Meas. 1) is the digital level measurement with the LCD screen facing

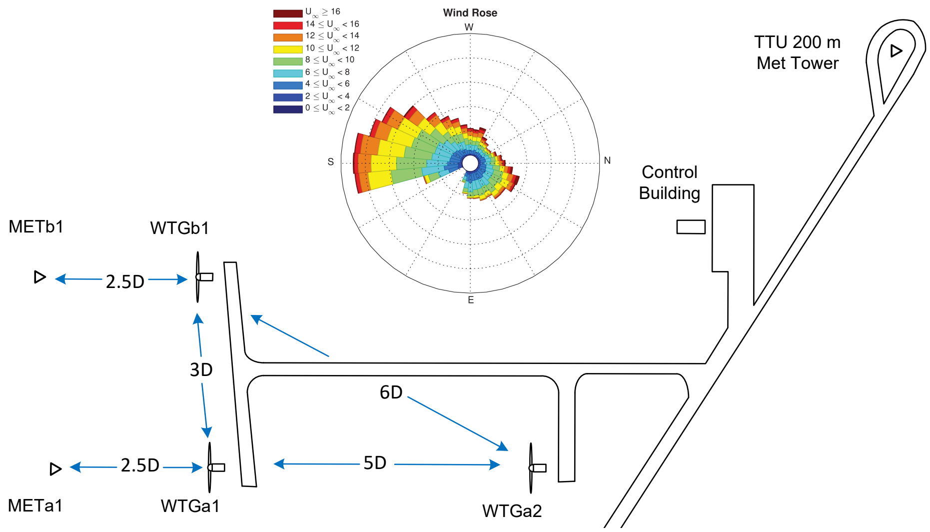

Figure 2.1. SWiFT turbine locations.

Figure 2.2. Foam templates fit onto V27 WTGb1 blade.

Figure 2.3. Where the fit was tight, foam was removed using an oscillating saw.

Figure 2.4. Where there were gaps, spray foam was added.

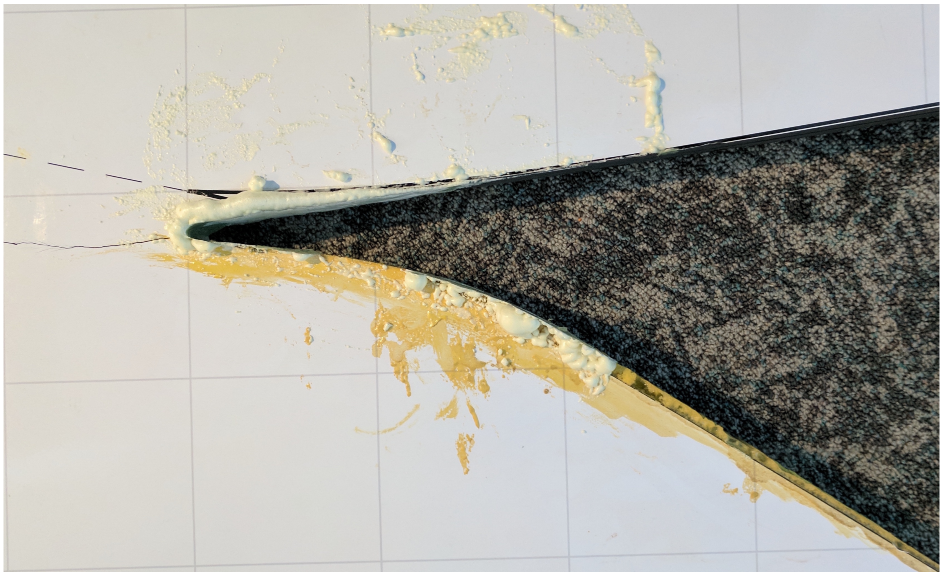

Figure 2.5. Spray foam added, note the movement of trailing edge downward and increased concavity of pressure side.

Table 2.1. Foam Template Chord and Twist Angle (degrees) Measurements

		Blade 1			Blade 2			Blade 3		
Blade position (mm)	Chord (mm)	Meas. 1	Meas. 2	Avg	Meas. 1	Meas. 2	Avg	Meas. 1	Meas. 2	Avg
0 (hub)		0.06	0.08	0.07	0.06	-0.01	0.03	-0.18	-0.11	-0.15
1500	1281.5	-4.33	-4.33	-4.33	-4.44	-4.68	-4.56	-7.53	-7.63	-7.58
3600	1135	-4.40	-4.50	-4.45	-4.67	-4.94	-4.81	-7.12	-7.21	-7.17
5850	976	-3.85	-3.93	-3.89	-4.07	-4.29	-4.18	-6.38	-6.44	-6.41
9650	707	-4.16	-4.14	-4.15	-4.21	-4.48	-4.35	-5.48	-5.62	-5.55
12500	500	-4.48	-4.60	-4.54	-4.63	-4.85	-4.74	-4.56	-4.62	-4.59

toward the blade tip, and Meas. 2 is with the LCD screen pointing towards the blade root. Avg is the average of the two angle measurements for each blade and station. Measurements at blade position 0 correspond to the angle of the hub on each flat flange next to the blade root to indicate hub levelness. Notice how most values are near -5° on blades 1 and 2 indicating the original FAST model was fairly accurate.

Next a coordinate measuring machine was used to digitize the foam template shapes. From the digitized shapes, the new chord, twist, and airfoil shapes were calculated. The coordinate measurement was repeated three times for all five stations. All three profiles were averaged together using the k-nearest neighbor approach, in this case, $k = 1$. Figure 2.6 shows the normalized airfoil sections as measured compared to the old FAST model. The coordinates are tabulated in Appendices A.12–A.16. Most measured airfoils had a greater maximum thickness than modeled. The two thickest airfoils had a large gap on the pressure side trailing edge adding a significant amount of camber. The thinnest airfoil has a significantly thicker trailing edge than the model, likely due

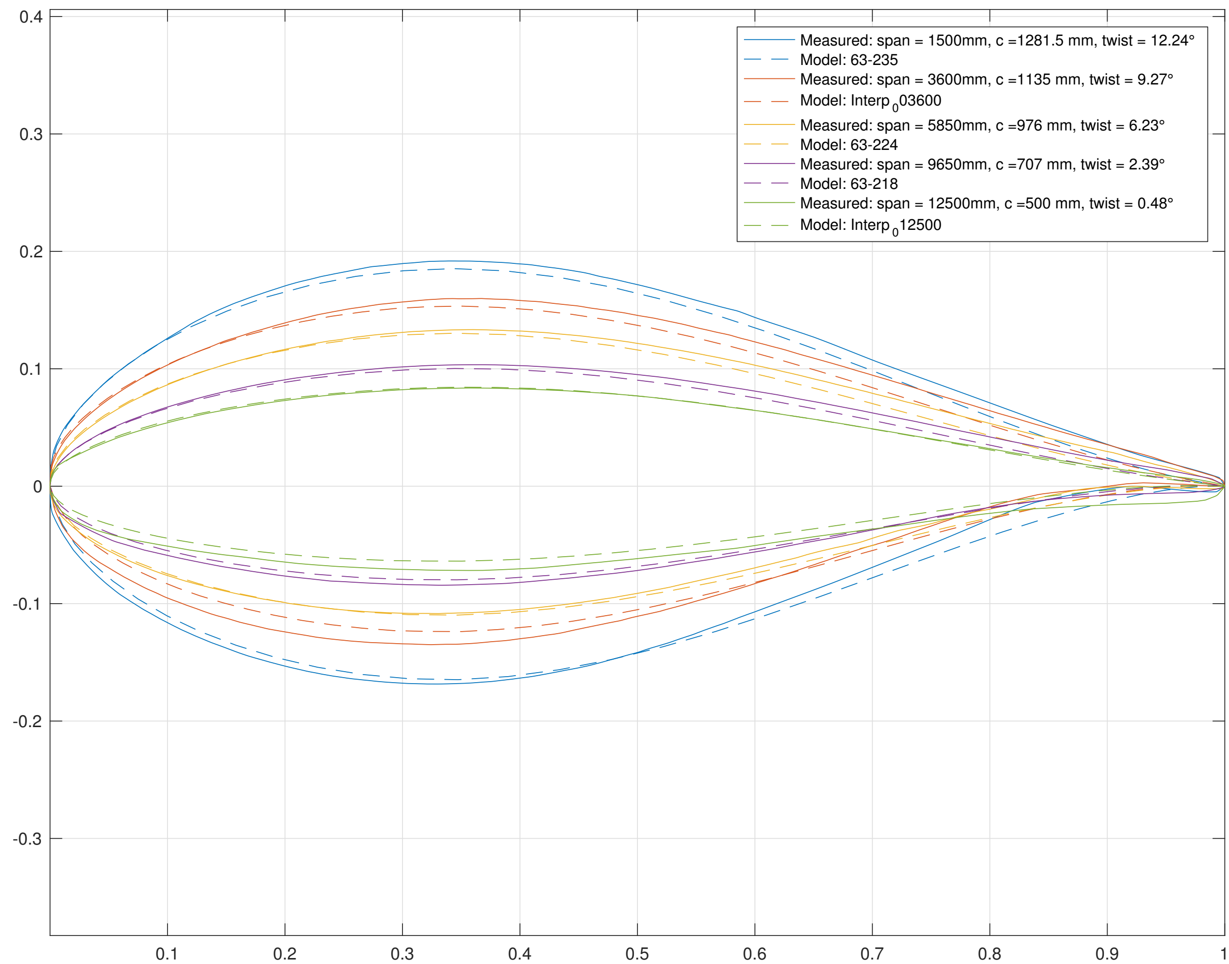

Figure 2.6. Airfoil section shapes.

to the inability to manufacture a small, sharp trailing edge.

The foam templates were analyzed to extract blade twist angle and chord length. The maximum distance between any two points of the measured airfoil were used to define the chord line and twist angle. The chords measured from the foam boards are shown in Figure 2.7 and tabulated in Table 2.1.

The aerodynamic twist of each blade, β, was calculated according to the following formula:

$$\beta = \beta_{level} + 5^\circ + \beta_{cc} - \beta_{hub}. \tag{2.1}$$

In this equation, β_{level} is the angle measured by the digital level of the foam board relative to gravity and presented in the Avg column of Table 2.1. The 5° account for the blades being in the crank-arm yoke locked position, and not run position. β_{cc} is the angle between the cambered chord

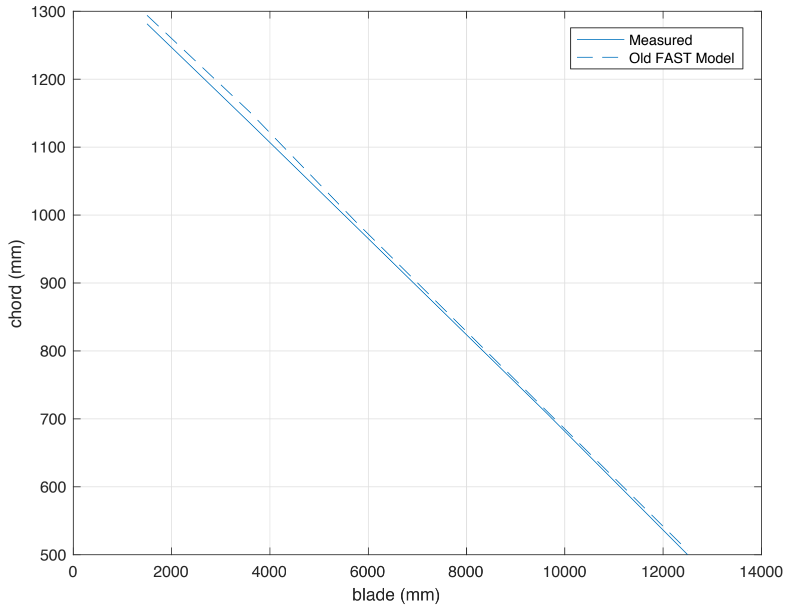

Figure 2.7. Blade chord measurements compared to old FAST model.

line of the digitized foam airfoil shape and the edge of the foam board. This accounts for change in twist angle due to the new trailing edge location. And finally, β_{hub} removes the angle of the rotor on the assembly stand not being perfectly vertical. This calculation was performed using the values in Tables 2.2–2.4 and plotted in Figure 2.8.

Figure 2.8 shows blades 1 and 2 have very similar twist distributions. Blade 3 has a different twist distribution, and it is not offset by a constant. Blade 3 is expected to contribute to aerodynamic rotor imbalance, and the low twist could cause inboard stall on blade 3 of WTGb1. Possible explanations for this twist discrepancy include blade 3 being manufactured in a different mold than blades 1 and 2, or blade 3 having significant repairs changing the twist distribution. The foam template fit was good on all blades 1–3 for each station. Therefore, the chord and airfoil sections between blades matched, just not the twist. The average aerodynamic twist of blades 1 and 2 ($(\beta_1 + \beta_2)/2$) is set as the AeroDyn Fast input file parameter "AeroTwst." Unique twist distributions for blades on the same rotor are not allowed in FAST v7.

The measured chord (AeroDyn parameter "Chord") and twist values were interpolated using pchip to the original V27 FAST model stations ("RNodes") and updated in the input file "SNLV27_AD_mod.ipt." Until twist measurements are analyzed for WTGa1 and WTGa2, it will be assumed that the average twist of blades 1 and 2 on WTGb1 is representative of all blades on all wind turbines at SWiFT.

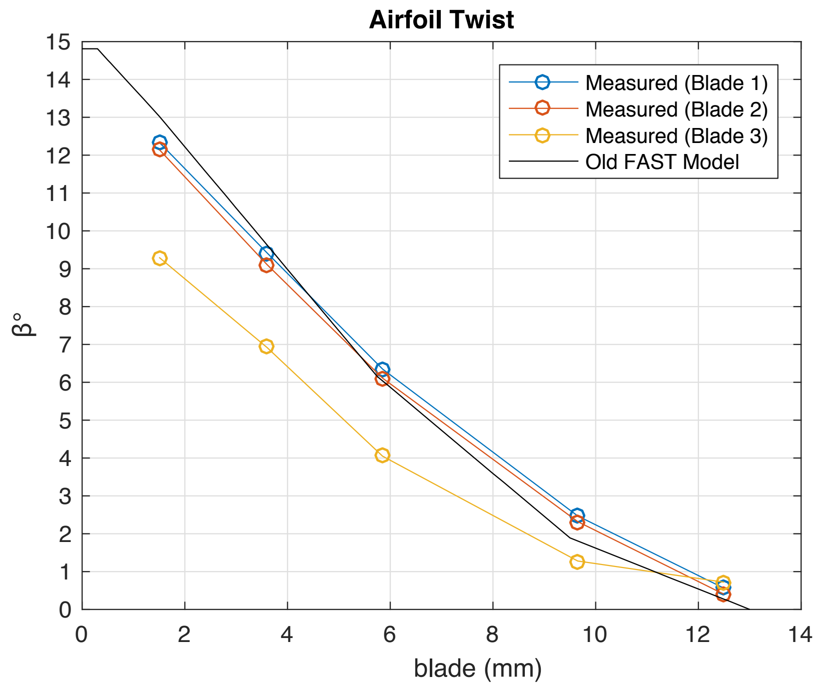

Figure 2.8. Blade aerodynamic twist measurements compared to old FAST model.

Table 2.2. Blade 1 Measured Twist Angles

Blade 1 Span (mm)	β°_{level}	β°_{cc}	β°_{hub}	β°
hub	0.07	—	—	—
1500	-4.33	11.74	0.07	12.34
3600	-4.45	8.94	0.07	9.42
5850	-3.89	5.31	0.07	6.35
9650	-4.15	1.69	0.07	2.47
12500	-4.54	0.17	0.07	0.56

Table 2.3. Blade 2 Measured Twist Angles

Blade 2 Span (mm)	β°_{level}	β°_{cc}	β°_{hub}	β°
hub	0.03	—	—	—
1500	-4.56	11.74	0.03	12.15
3600	-4.81	8.94	0.03	9.11
5850	-4.18	5.31	0.03	6.11
9650	-4.35	1.69	0.03	2.32
12500	-4.74	0.17	0.03	0.40

Table 2.4. Blade 3 Measured Twist Angles

Blade 3 Span (mm)	β°_{level}	β°_{cc}	β°_{hub}	β°
hub	-0.15	—	—	—
1500	-7.58	11.74	-0.15	9.30
3600	-7.17	8.94	-0.15	6.92
5850	-6.41	5.31	-0.15	4.05
9650	-5.55	1.69	-0.15	1.28
12500	-4.59	0.17	-0.15	0.72

Chapter 3

Modified Airfoil Properties

The foam boards showed that the airfoil shapes had trailing edges with additional camber because the forward section of the airfoil fit the foam templates well, but the trailing edges did not occur at the position expected for the exact NACA airfoil shapes, see Figure 2.5. This note was mentioned by Vestas in a V27 design document [4]. The effect of the additional camber was modeled with a flap using thin airfoil theory and then the V27 FAST airfoil polars were modified accordingly, denoted by "mod," as seen in the airfoil polars file names, "AD_63-235-mod.dat" for example. For thin airfoil theory, the trailing edge flap deflection angle, δ, was found by $\delta = \arctan \frac{y_{te}}{x_f}$, where x_f was the approximate length in the chord direction where the camber of the measured airfoil deviated from the original NACA shape, and y_{te} is the vertical displacement downward of the trailing edge relative to the original NACA airfoil trailing edge. This effective flap due to camber modified lift and moment, ΔC_l and ΔC_m. Drag change, ΔC_d, was modeled by the increase (or decrease for NACA 63_{214}) in projected area at zero lift angle of attack, α_{0l}, due to flap deflection, but was minimal. Additional drag is expected due to the measured finite trailing edge thickness, the increase in airfoil maximum thickness, and roughness. But none of these effects are included in the updated FAST model. The updated lift, drag, and moment coefficients were incorporated into the airfoil polars with aerodynamic properties summarized in Table 3.1. For convenience of the user, the airfoil polars in FAST v7 format are given in Appendices A.7–A.10.

The following figures summarize the new polars with additional camber in comparison to the original XFoil polars. Overall, the increased camber has the effect of increasing the lift coefficient and reducing the moment coefficient (more nose down). The thickest airfoil (AD_63-235_mod.dat) had the largest flap deflection angle, and therefore the largest change in lift and moment coefficient. Two alternatives for the thin airfoil theory modification are left as future work. XFoil simulations of the as-measured airfoil shapes could be run. Or the drag coefficients could be tuned until torque closely matches the experimental data across the rotor speed operating range. This is left as future work because there is remaining uncertainty in calculating edgewise bending moments from strain gauges in the experiment. The generator torque cannot be used to tune the airfoil polars because the generator and gearbox losses are currently unknown.

Table 3.1. Summary of Aerodynamic Properties for Modified V27 Airfoils.

Airfoil name	AD_63-235_mod.dat	AD_63-224_mod.dat	AD_63-218_mod.dat	AD_63-214_mod.dat
x_f/c	0.068	0.088	0.098	0.086
δ°	8.499	4.653	3.318	2.663
ΔC_l	0.242	0.145	0.107	0.082
ΔC_d	1.678×10^{-4}	6.632×10^{-5}	1.289×10^{-5}	-2.066×10^{-5}
ΔC_m	-0.070	-0.042	-0.031	-0.024
α°_{stall}	15.000	15.000	14.000	15.500
α°_{0l}	-3.451	-2.650	-2.413	-2.258
$C_{l_\alpha}/\mathrm{rad}$	6.009	6.976	6.842	6.659
$C_{l_{max}}$	1.415	1.436	1.497	1.610
$C_{l_{min}}$	-0.606	-0.758	-0.936	-0.842
$C_{d_{min}}$	0.009	0.007	0.006	0.005
$\alpha^\circ_{C_{d_{min}}}$	-1.500	-1.500	-1.000	-0.500

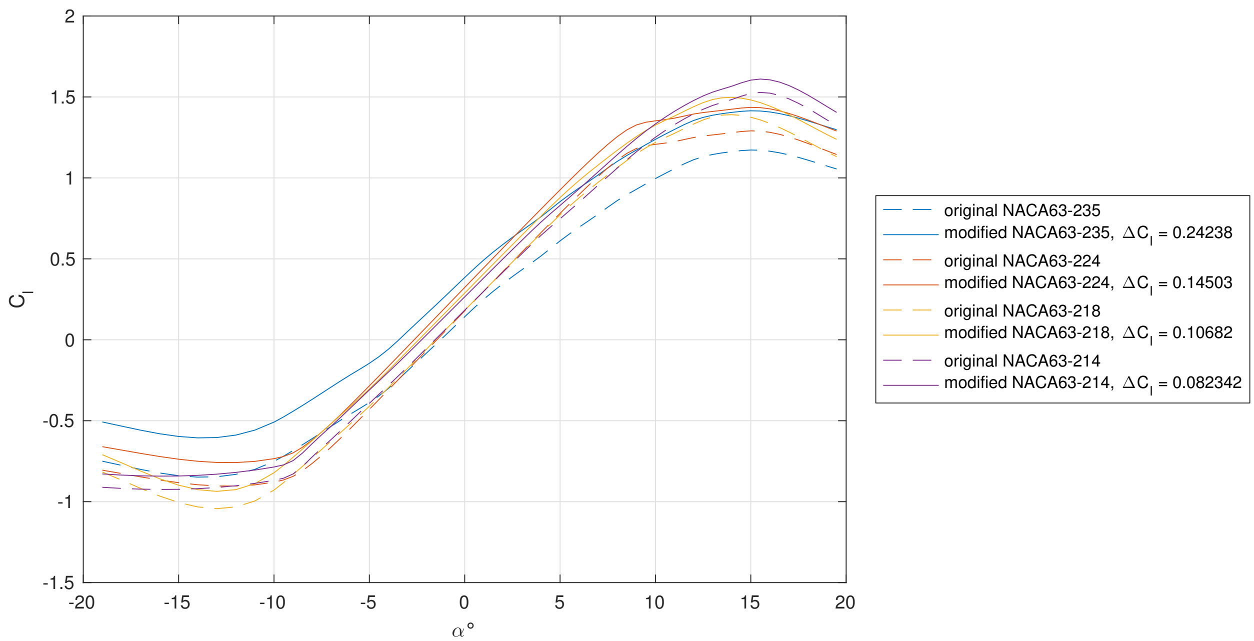

Figure 3.1. Modified airfoil lift coefficients compared to originals.

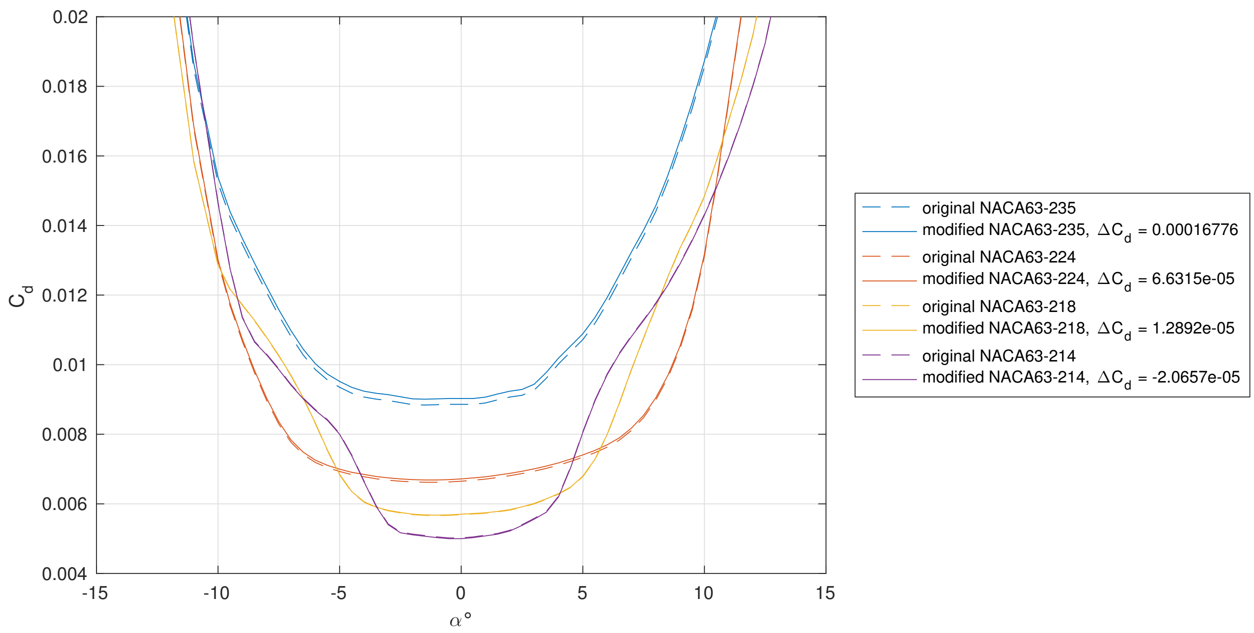

Figure 3.2. Modified airfoil drag coefficients compared to originals.

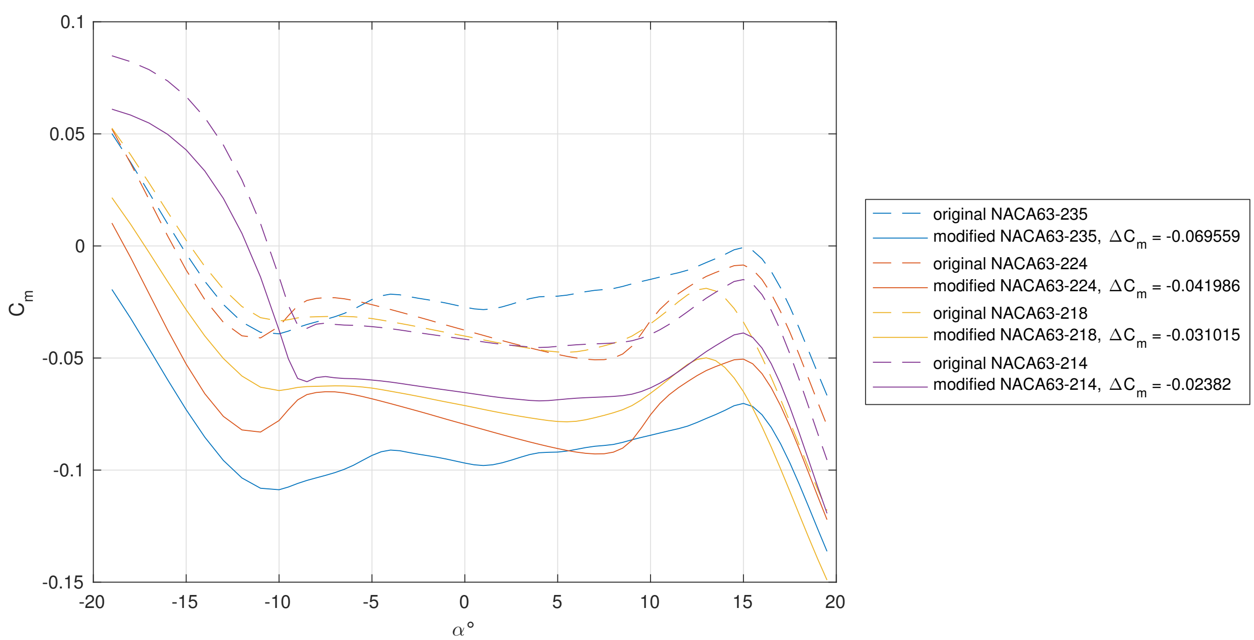

Figure 3.3. Modified airfoil moment coefficients compared to originals.

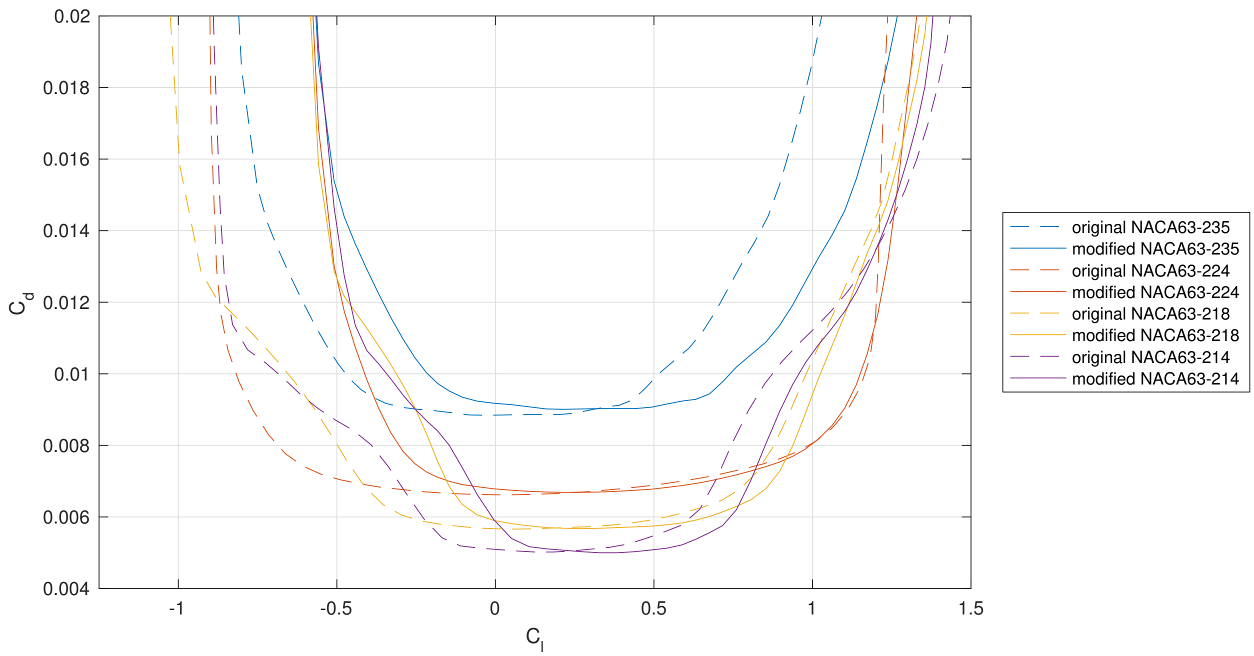

Figure 3.4. Modified airfoil lift/drag coefficients compared to originals.

Chapter 4

Tuning FAST to the Wake Steering Experiment

Root bending moment in the thrust direction (M) and tip-speed-ratio (λ) were chosen as the quantities of interest to match between the wake steering experiment and FAST. Root bending moment is indicative of the integral of thrust loading on the rotor. Tip-speed-ratio ensures that the rotor spins at the correct speed for a given wind speed. In this way, modelers who perform simulations using the FAST model can be confident the rotor thrust matches the experiment, and they can be confident the tip vortex spacing matches the experiment.

The FAST model was run iteratively by adjusting collective blade pitch and torque constant until the FAST output of root bending moment and tip-speed-ratio matched 1-minute averages in the wake steering experiment. The error for moment and tip-speed-ratio was found as the sum of differences between model and experiment at eight wind speeds: U_∞ = [4.5, 5, 5.5, 6, 6.5, 7, 7.5, 8] m/s. These wind speeds were used because they span region 2 operation. The date range of experimental data used for tuning the model was July 3, 2017 06:57:00 through July 13, 2017 06:48:00 local time. The average air density during this time period was $\rho = 1.064$ kg/m^3. No shear or turbulence was used in the wind input file because only 1-minute averages were being compared, and shear increased the convergence time for average bending moment in FAST. The turbine data is from WTGa1, whereas the geometry measurements were from WTGb1. Therefore this updated FAST model is the geometry of WTGb1 with the experimental tuned performance of WTGa1. The iteration was performed as follows.

1. Run FAST model for iteration i
2. Plot the mean root bending moment and tip-speed-ratio from FAST output as a function of wind speed
3. Calculate sum of error between FAST and experiment for moment (e_{M_i}) and tip-speed-ratio (e_{λ_i}) at the eight different wind speeds (U_{∞_j})

$$e_{M_i} = \sum_{j=1}^{8} M(FAST(U_{\infty_j})) - M(experiment(U_{\infty_j})) \tag{4.1}$$

$$e_{\lambda_i} = \sum_{j=1}^{8} \frac{\lambda(FAST(U_{\infty_j})) - \lambda(experiment(U_{\infty_j}))}{\lambda(experiment(U_{\infty_j}))} \tag{4.2}$$

4. Adjust next iteration blade collective pitch ($BlPitch_{i+1}$ and $BlPitchF_{i+1}$) and region 2 torque constant (VS_Rgn2K) in the FAST model according to the error observed. It was seen at $U_\infty = 6.5$ m/s, the change in collective pitch per root bending moment was approximately $\frac{\partial \beta}{\partial M} = 0.41^\circ/$ kNm. And for a set wind speed, the torque constant is proportional to the inverse cubic of rotor speed, $K \propto \frac{1}{\Omega^3}$

$$BlPitch_{i+1} = BlPitchF_{i+1} = BlPitchF_i + 0.41\, e_{M_i} \tag{4.3}$$

$$VS\_Rgn2K_{i+1} = \frac{VS\_Rgn2K_i}{(1 - e_{\lambda_i})^3} \tag{4.4}$$

After 10 iterations the change in collective pitch for the last iteration ($0.41\, e_{M_{10}}$) had reduced to 0.0002° and the torque constant multiplier ($\frac{1}{(1-e_{\lambda_{10}})^3}$) had converged to 1.00004. The updated FAST model performance is plotted to compare against the experiment. Figures 4.1 and 4.2 show that the tuned FAST model matches the experimental data well. Tip-speed-ratio in FAST is a little high for wind speeds 4–5.7 m/s, and a little low for wind speeds 5.7–8.1 m/s. But the model has minimized the error for all wind speeds 4.5–8 m/s. Figure 4.3 shows root bending moment matches the experiment on average for wind speeds 4.5–8 m/s, but FAST is a little high at low wind speeds and below the experiment at higher wind speeds. The error has been minimized by tuning only the torque constant and collective blade pitch.

The updated FAST model torque constant, "VS_Rgn2K," is 4.42067×10^{-4} Nm/rpm^2 as compared to 3.6678×10^{-4} Nm/rpm^2 used by the turbine controller in the wake steering experiment. It was decided that it is better the rotor rotates at the correct angular velocity for a given wind speed, rather than using the experimental torque constant in the FAST model.

The collective blade pitch offset found from tuning is 1.67°. Because collective blade pitch is not a setting in FAST v7, the updated FAST model blade pitch settings are included in the pitch maneuvering parameters "BlPitch(x)" = "BlPitchF(x)" = 1.67°.

The generator slip percentage was also tuned to better match the experimental region 2.5 tip-speed-ratios, wind speeds greater than 8.0 m/s and less than 10.5 m/s. A generator slip of 1% minimized the tip-speed-ratio error in region 2.5. The FAST parameter "VS_SlPc" was changed to 1.

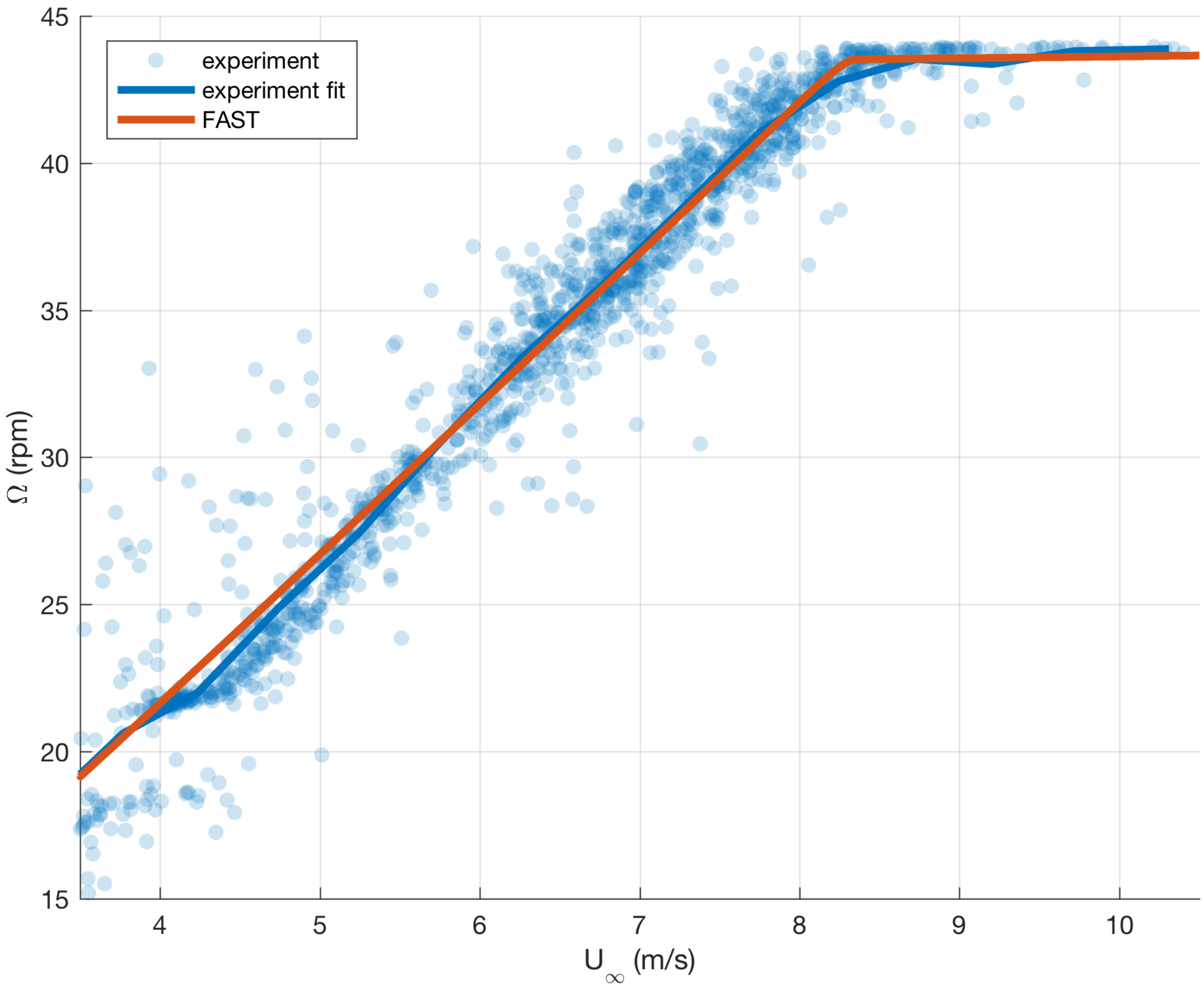

Figure 4.1. Tuned FAST model compared to wake steering experiment.

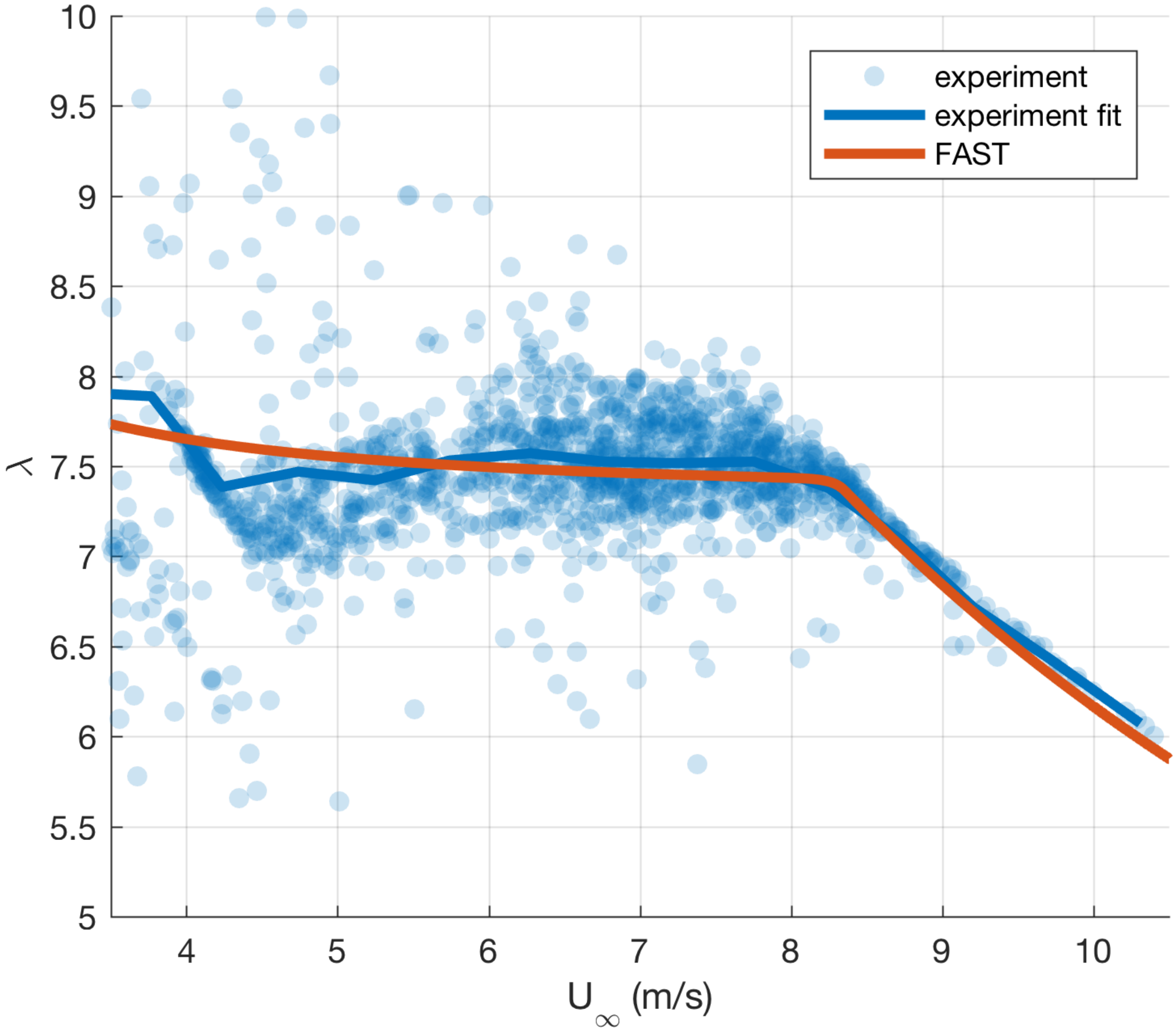

Figure 4.2. Tuned FAST model compared to wake steering experiment.

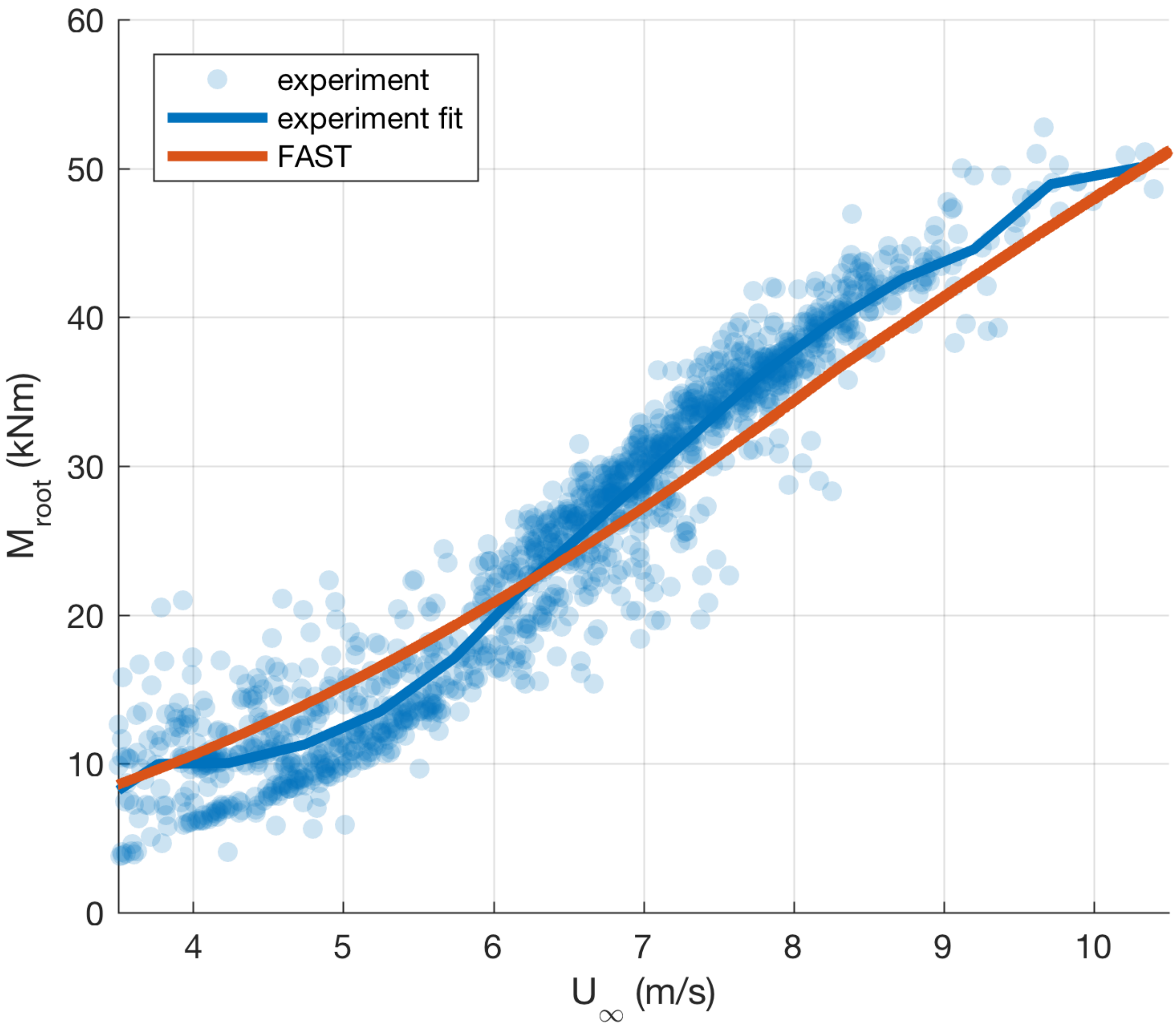

Figure 4.3. Tuned FAST model compared to wake steering experiment.

Chapter 5

Conclusions

This update is a modification to the original V27 model developed by Resor and LeBlanc [1]. The updates include new measurements of chord, twist, and airfoil shapes using foam templates on WTGb1 blades. The airfoil shapes showed a camber increase from the NACA airfoils on the aft 50% chord because the leading edge shape fit well but the trailing edge had moved down. These shape changes were incorporated into the airfoil polars by approximating the camber change as a flap using thin airfoil theory. Finally, thrust root bending moment and tip-speed-ratio were chosen as the quantities of interest to tune the FAST model to the wake steering experiment performance of WTGa1. The torque constant and collective blade pitch inputs to FAST were tuned so that the quantities of interest matched the experiment across all wind speeds in region 2 as close as possible. The appendices provide updated FAST input files and the airfoil shape measurements tabularized.

Chapter 6

Caveats and Future Work

There are numerous methods and approaches to tune a model to experimental data. For example, one could make every input used in a model match the experiment. However, then the output of the model may not match the experiment. At the other extreme, an optimization algorithm could be used to tune every single input until all the outputs match the experiment as close as possible. The approach in this paper is the former, where the inputs except torque constant and collective blade pitch, match between FAST and experiment.

The current approach tuned the torque constant to a value not used in the actual experiment. Perhaps, a better approach would be to modify lift, drag, and moment coefficients of the airfoil polars until the chosen quantities of interest match between the model and experiment demonstrated by Bak [5]. This may change the shape of bending moment versus wind speed curve seen in Figure 4.3. Or similarly, one could rerun the as-measured airfoil shapes in XFoil or a similar model to predict the aerodynamic forces.

Additional improvements to the new model that are not currently implemented (and by no means exhaustive) include the following approaches given more time and effort.

- Using blade edge strain gauge data to tune airfoil drag coefficients
- Adding airfoil surface roughness and Reynolds number effects to the FAST model
- Incorporating section stiffness and inertia changes into the FAST blade structural model due to the as-measured airfoil shapes
- Developing new model functionality to use unique twist distributions between blades not able to be implemented in FAST v7
- Analyzing WTGa1 and WTGa2 blade twist measurements to create FAST models for each individual rotor

References

[1] Brian R. Resor and Bruce LeBlanc. An aeroelastic reference model for the swift turbines. *Sandia National Laboratories*, SAND2014-19136, 2014.

[2] Brian Thomas Naughton. Test plan for the wake steering experiment at the scaled wind farm technology (swift) facility. *Sandia National Laboratories*, SAND2017-1730, 2017.

[3] Brian Naughton, Scott Schreck, and Alan Wright. Wake: Wake steering experiment. October 2018. https://a2e.energy.gov/projects/wake.

[4] Ouo rotor blade.pdf vestas design document, no.88-12-15/ab, v27.5.

[5] Christian Bak, Peter Fuglsang, Niels N Sørensen, Helge Aagaard Madsen, Wen Zhong Shen, and Jens Nørkær Sørensen. Airfoil characteristics for wind turbines. *Risø-Reports*, 1999.

Appendix A

FAST Input Files

A.1 SNLV27_mod.fst

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--------------------------------------------------------------------------------
------- FAST INPUT FILE --------------------------------------------------------
SNL SWiFT FAST Model Input File, version 2.0 As described in 'An Update to the SWiFT V27 Reference Model,' Kelley and White, 2018.
Created on 4-October-2018
---------------------- SIMULATION CONTROL --------------------------------------
False            Echo        - Echo input data to "echo.out" (flag)
1                ADAMSPrep   - ADAMS preprocessor mode {1: Run FAST, 2: use FAST as a preprocessor to create an ADAMS model, 3: do both} (switch)
1                AnalMode    - Analysis mode {1: Run a time-marching simulation, 2: create a periodic linearized model} (switch)
3                NumBl       - Number of blades (-)
1000             TMax        - Total run time (s)
0.005            DT          - Integration time step (s)
---------------------- TURBINE CONTROL -----------------------------------------
0                YCMode      - Yaw control mode {0: none, 1: user-defined from routine UserYawCont, 2: user-defined from Simulink} (switch)
9999.9           TYCOn       - Time to enable active yaw control (s) [unused when YCMode=0]
0                PCMode      - Pitch control mode {0: none, 1: user-defined from routine PitchCntrl, 2: user-defined from Simulink} (switch)
0                TPCOn       - Time to enable active pitch control (s) [unused when PCMode=0]
1                VSContrl    - Variable-speed control mode {0: none, 1: simple VS, 2: user-defined from routine UserVSCont, 3: user-defined from Simulink} (switch)
1207.61          VS_RtGnSp   - Rated generator speed for simple variable-speed generator control (HSS side) (rpm) [used only when VSContrl=1]
1790.49          VS_RtTq     - Rated generator torque/constant generator torque in Region 3 for simple variable-speed generator control (HSS side) (N-m) [used only when VSContrl=1]
0.000442067      VS_Rgn2K    - Generator torque constant in Region 2 for simple variable-speed generator control (HSS side) (N-m/rpm^2) [used only when VSContrl=1]
1                VS_SlPc     - Rated generator slip percentage in Region 2 1/2 for simple variable-speed generator control (%%) [used only when VSContrl=1]
1                GenModel    - Generator model {1: simple, 2: Thevenin, 3: user-defined from routine UserGen} (switch) [used only when VSContrl=0]
True             GenTiStr    - Method to start the generator {T: timed using TimGenOn, F: generator speed using SpdGenOn} (flag)
True             GenTiStp    - Method to stop the generator {T: timed using TimGenOf, F: when generator power = 0} (flag)
9999.9           SpdGenOn    - Generator speed to turn on the generator for a startup (HSS speed) (rpm) [used only when GenTiStr=False]
0                TimGenOn    - Time to turn on the generator for a startup (s) [used only when GenTiStr=True]
9999.9           TimGenOf    - Time to turn off the generator (s) [used only when GenTiStp=True]
1                HSSBrMode   - HSS brake model {1: simple, 2: user-defined from routine UserHSSBr} (switch)
9999.9           THSSBrDp    - Time to initiate deployment of the HSS brake (s)
9999.9           TiDynBrk    - Time to initiate deployment of the dynamic generator brake [CURRENTLY IGNORED] (s)
9999.9           TTpBrDp(1)  - Time to initiate deployment of tip brake 1 (s)
9999.9           TTpBrDp(2)  - Time to initiate deployment of tip brake 2 (s)
9999.9           TTpBrDp(3)  - Time to initiate deployment of tip brake 3 (s) [unused for 2 blades]
9999.9           TBDepISp(1) - Deployment-initiation speed for the tip brake on blade 1 (rpm)
9999.9           TBDepISp(2) - Deployment-initiation speed for the tip brake on blade 2 (rpm)
9999.9           TBDepISp(3) - Deployment-initiation speed for the tip brake on blade 3 (rpm) [unused for 2 blades]
9999.9           TYawManS    - Time to start override yaw maneuver and end standard yaw control (s)
9999.9           TYawManE    - Time at which override yaw maneuver reaches final yaw angle (s)
0                NacYawF     - Final yaw angle for yaw maneuvers (degrees)
9999.9           TPitManS(1) - Time to start override pitch maneuver for blade 1 and end standard pitch control (s)
9999.9           TPitManS(2) - Time to start override pitch maneuver for blade 2 and end standard pitch control (s)
9999.9           TPitManS(3) - Time to start override pitch maneuver for blade 3 and end standard pitch control (s) [unused for 2 blades]
9999.9           TPitManE(1) - Time at which override pitch maneuver for blade 1 reaches final pitch (s)
9999.9           TPitManE(2) - Time at which override pitch maneuver for blade 2 reaches final pitch (s)
9999.9           TPitManE(3) - Time at which override pitch maneuver for blade 3 reaches final pitch (s) [unused for 2 blades]
1.665913124      BlPitch(1)  - Blade 1 initial pitch (degrees)
1.665913124      BlPitch(2)  - Blade 2 initial pitch (degrees)
1.665913124      BlPitch(3)  - Blade 3 initial pitch (degrees) [unused for 2 blades]
1.665913124      BlPitchF(1) - Blade 1 final pitch for pitch maneuvers (degrees)
1.665913124      BlPitchF(2) - Blade 2 final pitch for pitch maneuvers (degrees)
1.665913124      BlPitchF(3) - Blade 3 final pitch for pitch maneuvers (degrees) [unused for 2 blades]
---------------------- ENVIRONMENTAL CONDITIONS --------------------------------
9.80285          Gravity     - Gravitational acceleration (m/s^2)
---------------------- FEATURE FLAGS -------------------------------------------
True             FlapDOF1    - First flapwise blade mode DOF (flag)
True             FlapDOF2    - Second flapwise blade mode DOF (flag)
True             EdgeDOF     - First edgewise blade mode DOF (flag)
False            TeetDOF     - Rotor-teeter DOF (flag) [unused for 3 blades]
True             DrTrDOF     - Drivetrain rotational-flexibility DOF (flag)
True             GenDOF      - Generator DOF (flag)
False            YawDOF      - Yaw DOF (flag)
True             TwFADOF1    - First fore-aft tower bending-mode DOF (flag)
True             TwFADOF2    - Second fore-aft tower bending-mode DOF (flag)
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True             TwSSDOF1    - First side-to-side tower bending-mode DOF (flag)
True             TwSSDOF2    - Second side-to-side tower bending-mode DOF (flag)
True             CompAero    - Compute aerodynamic forces (flag)
False            CompNoise   - Compute aerodynamic noise (flag)
---------------------- INITIAL CONDITIONS ------------------------------------
0                OoPDefl     - Initial out-of-plane blade-tip displacement, (meters)
0                IPDefl      - Initial in-plane blade-tip deflection, (meters)
0                TeetDefl    - Initial or fixed teeter angle (degrees) [unused for 3 blades]
0                Azimuth     - Initial azimuth angle for blade 1 (degrees)
43.81            RotSpeed    - Initial or fixed rotor speed (rpm)
0                NacYaw      - Initial or fixed nacelle-yaw angle (degrees)
0                TTDspFA     - Initial fore-aft tower-top displacement (meters)
0                TTDspSS     - Initial side-to-side tower-top displacement (meters)
---------------------- TURBINE CONFIGURATION ---------------------------------
13.5             TipRad      - The distance from the rotor apex to the blade tip (meters)
0.5              HubRad      - The distance from the rotor apex to the blade root (meters)
1                PSpnElN     - Number of the innermost blade element which is still part of the pitchable portion of the blade for partial-span pitch control [1 to BldNodes] [
      CURRENTLY IGNORED] (-)
0                UndSling    - Undersling length [distance from teeter pin to the rotor apex] (meters) [unused for 3 blades]
-0.093           HubCM       - Distance from rotor apex to hub mass [positive downwind] (meters)
-1.88            OverHang    - Distance from yaw axis to rotor apex [3 blades] or teeter pin [2 blades] (meters)
0.64             NacCMxn     - Downwind distance from the tower-top to the nacelle CM (meters)
0.08             NacCMyn     - Lateral  distance from the tower-top to the nacelle CM (meters)
0.13             NacCMzn     - Vertical distance from the tower-top to the nacelle CM (meters)
31               TowerHt     - Height of tower above ground level [onshore] or MSL [offshore] (meters)
1.5              Twr2Shft    - Vertical distance from the tower-top to the rotor shaft (meters)
0                TwrRBHt     - Tower rigid base height (meters)
-4.05            ShftTilt    - Rotor shaft tilt angle (degrees) (negative for upwind turbines)
0                Delta3      - Delta-3 angle for teetering rotors (degrees) [unused for 3 blades]
0                PreCone(1)  - Blade 1 cone angle (degrees)
0                PreCone(2)  - Blade 2 cone angle (degrees)
0                PreCone(3)  - Blade 3 cone angle (degrees) [unused for 2 blades]
0                AzimB1Up    - Azimuth value to use for I/O when blade 1 points up (degrees)
---------------------- MASS AND INERTIA --------------------------------------
50               YawBrMass   - Yaw bearing mass (kg)
6909.5           NacMass     - Nacelle mass (kg)
1165             HubMass     - Hub mass (kg)
0                TipMass(1)  - Tip-brake mass, blade 1 (kg)
0                TipMass(2)  - Tip-brake mass, blade 2 (kg)
0                TipMass(3)  - Tip-brake mass, blade 3 (kg) [unused for 2 blades]
13294            NacYIner    - Nacelle inertia about yaw axis (kg m^2)
50               GenIner     - Generator inertia about HSS (kg m^2)
69.1             HubIner     - Hub inertia about rotor axis [3 blades] or teeter axis [2 blades] (kg m^2)
---------------------- DRIVETRAIN --------------------------------------------
100              GBoxEff     - Gearbox efficiency (%%)
100              GenEff      - Generator efficiency [ignored by the Thevenin and user-defined generator models] (%%)
27.5647          GBRatio     - Gearbox ratio (-)
False            GBRevers    - Gearbox reversal {T: if rotor and generator rotate in opposite directions} (flag)
2700             HSSBrTqF    - Fully deployed HSS-brake torque (N-m)
0.9              HSSBrDT     - Time for HSS-brake to reach full deployment once initiated (sec) [used only when HSSBrMode=1]
""               DynBrkFi    - File containing a mech-gen-torque vs HSS-speed curve for a dynamic brake [CURRENTLY IGNORED] (quoted string)
5e+07            DTTorSpr    - Drivetrain torsional spring (N-m/rad)
1e+06            DTTorDmp    - Drivetrain torsional damper (N-m/s)
---------------------- SIMPLE INDUCTION GENERATOR ----------------------------
9999.9           SIG_SlPc    - Rated generator slip percentage (%%) [used only when VSContrl=0 and GenModel=1]
9999.9           SIG_SySp    - Synchronous (zero-torque) generator speed (rpm) [used only when VSContrl=0 and GenModel=1]
9999.9           SIG_RtTq    - Rated torque (N-m) [used only when VSContrl=0 and GenModel=1]
9999.9           SIG_PORt    - Pull-out ratio (Tpullout/Trated) (-) [used only when VSContrl=0 and GenModel=1]
---------------------- THEVENIN-EQUIVALENT INDUCTION GENERATOR ---------------
9999.9           TEC_Freq    - Line frequency [50 or 60] (Hz) [used only when VSContrl=0 and GenModel=2]
9999.9           TEC_NPol    - Number of poles [even integer > 0] (-) [used only when VSContrl=0 and GenModel=2]
9999.9           TEC_SRes    - Stator resistance (ohms) [used only when VSContrl=0 and GenModel=2]
9999.9           TEC_RRes    - Rotor resistance (ohms) [used only when VSContrl=0 and GenModel=2]
9999.9           TEC_VLL     - Line-to-line RMS voltage (volts) [used only when VSContrl=0 and GenModel=2]
9999.9           TEC_SLR     - Stator leakage reactance (ohms) [used only when VSContrl=0 and GenModel=2]
9999.9           TEC_RLR     - Rotor leakage reactance (ohms) [used only when VSContrl=0 and GenModel=2]
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9999.9           TEC_MR      - Magnetizing reactance (ohms) [used only when VSContrl=0 and GenModel=2]
---------------------- PLATFORM MODEL ------------------------------------------
0                PtfmModel   - Platform model {0: none, 1: onshore, 2: fixed bottom offshore, 3: floating offshore} (switch)
""               PtfmFile    - Name of file containing platform properties (quoted string) [unused when PtfmModel=0]
---------------------- TOWER ---------------------------------------------------
10               TwrNodes    - Number of tower nodes used for analysis (-)
"SNLV27_Tower.dat" TwrFile - Name of file containing tower properties (quoted string)
---------------------- NACELLE-YAW ---------------------------------------------
0                YawSpr      - Nacelle-yaw spring constant (N-m/rad)
0                YawDamp     - Nacelle-yaw damping constant (N-m/rad/s)
0                YawNeut     - Neutral yaw position--yaw spring force is zero at this yaw (degrees)
---------------------- FURLING -------------------------------------------------
False            Furling     - Read in additional model properties for furling turbine (flag)
""               FurlFile    - Name of file containing furling properties (quoted string) [unused when Furling=False]
---------------------- ROTOR-TEETER --------------------------------------------
0                TeetMod     - Rotor-teeter spring/damper model {0: none, 1: standard, 2: user-defined from routine UserTeet} (switch) [unused for 3 blades]
0                TeetDmpP    - Rotor-teeter damper position (degrees) [used only for 2 blades and when TeetMod=1]
0                TeetDmp     - Rotor-teeter damping constant (N-m/rad/s) [used only for 2 blades and when TeetMod=1]
0                TeetCDmp    - Rotor-teeter rate-independent Coulomb-damping moment (N-m) [used only for 2 blades and when TeetMod=1]
0                TeetSStP    - Rotor-teeter soft-stop position (degrees) [used only for 2 blades and when TeetMod=1]
0                TeetHStP    - Rotor-teeter hard-stop position (degrees) [used only for 2 blades and when TeetMod=1]
0                TeetSSSp    - Rotor-teeter soft-stop linear-spring constant (N-m/rad) [used only for 2 blades and when TeetMod=1]
0                TeetHSSp    - Rotor-teeter hard-stop linear-spring constant (N-m/rad) [used only for 2 blades and when TeetMod=1]
---------------------- TIP-BRAKE -----------------------------------------------
0                TBDrConN    - Tip-brake drag constant during normal operation, Cd*Area (m^2)
0                TBDrConD    - Tip-brake drag constant during fully-deployed operation, Cd*Area (m^2)
0                TpBrDT      - Time for tip-brake to reach full deployment once released (sec)
---------------------- BLADE ---------------------------------------------------
"SNLV27_Blade.dat" BldFile(1) - Name of file containing properties for blade 1 (quoted string)
"SNLV27_Blade.dat" BldFile(2) - Name of file containing properties for blade 2 (quoted string)
"SNLV27_Blade.dat" BldFile(3) - Name of file containing properties for blade 3 (quoted string) [unused for 2 blades]
---------------------- AERODYN -------------------------------------------------
"SNLV27_AD_mod.ipt"  ADFile     - Name of file containing AeroDyn input parameters (quoted string)
---------------------- NOISE ---------------------------------------------------
""               NoiseFile   - Name of file containing aerodynamic noise input parameters (quoted string) [used only when CompNoise=True]
---------------------- ADAMS ---------------------------------------------------
"SNLV27_ADAMS.dat" ADAMSFile  - Name of file containing ADAMS-specific input parameters (quoted string) [unused when ADAMSPrep=1]
---------------------- LINEARIZATION CONTROL -----------------------------------
"SNLV27_Linear.dat" LinFile    - Name of file containing FAST linearazation parameters (quoted string) [unused when AnalMode=1]
---------------------- OUTPUT --------------------------------------------------
True             SumPrint    - Print summary data to "<RootName>.fsm" (flag)
1                OutFileFmt  - Format for tabular (time-marching) output file(s) (1: text file [<RootName>.out], 2: binary file [<RootName>.outb], 3: both) (switch)
True             TabDelim    - Generate a tab-delimited tabular output file. (flag)
"ES10.3E2"       OutFmt      - Format used for tabular output except time.  Resulting field should be 10 characters. (quoted string)  [not checked for validity!]
0                TStart      - Time to begin tabular output (s)
1              DecFact     - Decimation factor for tabular output {1: output every time step} (-)
10               SttsTime    - Amount of time between screen status messages (sec)
0                NcIMUxn     - Downwind distance from the tower-top to the nacelle IMU (meters)
0                NcIMUyn     - Lateral  distance from the tower-top to the nacelle IMU (meters)
0                NcIMUzn     - Vertical distance from the tower-top to the nacelle IMU (meters)
0.5              ShftGagL    - Distance from rotor apex [3 blades] or teeter pin [2 blades] to shaft strain gages [positive for upwind rotors] (meters)
3                NTwGages    - Number of tower nodes that have strain gages for output [0 to 5] (-)
1,4,9            TwrGagNd    - List of tower nodes that have strain gages [1 to TwrNodes] (-) [unused if NTwGages=0]
2                NBlGages    - Number of blade nodes that have strain gages for output [0 to 5] (-)
1,2              BldGagNd    - List of blade nodes that have strain gages [1 to BldNodes] (-) [unused if NBlGages=0]
                 OutList     - The next line(s) contains a list of output parameters.  See OutList.txt for a listing of available output channels, (-)
TSR
RotCt
RotCp
GenPwr
RotSpeed
WindVxi
BldPitch1
BldPitch2
BldPitch3
RootMyc1
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RootMyc2
RootMyc3
END of FAST input file (the word "END" must appear in the first 3 columns of this last line).
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A.2 SNLV27_AD_mod.ipt

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SNL SWiFT V27 AeroDyn Input File, version 2.0, created on 16-October-2018
SI               SysUnits - System of units for used for input and output [must be SI for FAST] (unquoted string)
BEDDOES          StallMod - Dynamic stall included [BEDDOES or STEADY] (unquoted string)
USE_CM           UseCm    - Use aerodynamic pitching moment model? [USE_CM or NO_CM] (unquoted string)
EQUIL            InfModel - Inflow model [DYNIN or EQUIL] (unquoted string)
SWIRL            IndModel - Induction-factor model [NONE or WAKE or SWIRL] (unquoted string)
0.005            AToler   - Induction-factor tolerance (convergence criteria) (-)
PRANDtl          TLModel  - Tip-loss model (EQUIL only) [PRANDtl, GTECH, or NONE] (unquoted string)
PRANDtl          HLModel  - Hub-loss model (EQUIL only) [PRANdtl or NONE] (unquoted string)
"steady_wind.wnd"  WindFile - Name of file containing wind data (quoted string)
32.1             HH       - Wind reference (hub) height [TowerHt+Twr2Shft+OverHang*SIN(ShftTilt)] (m)
0.3              TwrShad  - Tower-shadow velocity deficit (-)
1                ShadHWid - Tower-shadow half width (m)
1.87542          T_Shad_Refpt - Tower-shadow reference point (m)
1.064032027823   Rho      - Average Air density at SWiFT(kg/m^3)
1.5e-05          KinVisc  - Kinematic air viscosity [CURRENTLY IGNORED] (m^2/sec)
0.005            DTAero   - Time interval for aerodynamic calculations (sec)
5                NumFoil  - Number of airfoil files (-)
"AeroData\normalstall\AD_cylinder.dat" FoilNm   - Names of the airfoil files [NumFoil lines] (quoted strings)
"AeroData\normalstall\AD_63-235_mod.dat"
"AeroData\normalstall\AD_63-224_mod.dat"
"AeroData\normalstall\AD_63-218_mod.dat"
"AeroData\normalstall\AD_63-214_mod.dat"
20               BldNodes - Number of blade nodes used for analysis (-)
RNodes    AeroTwst  DRNodes  Chord  NFoil  PrnElm
 0.82500  13.9573    0.65000  0.589   1   PRINT
 1.47500  13.0025    0.65000  0.979   2   PRINT
 2.12500  12.0596    0.65000  1.2728  2   PRINT
 2.77500  11.1288    0.65000  1.2276  2   PRINT
 3.42500  10.2102    0.65000  1.1823  2   PRINT
 4.07500  9.3046     0.65000  1.1368  3   PRINT
 4.72500  8.3928     0.65000  1.091   3   PRINT
 5.37500  7.4834     0.65000  1.045   3   PRINT
 6.02500  6.6249     0.65000  0.999   3   PRINT
 6.67500  5.8527     0.65000  0.953   3   PRINT
 7.32500  5.1189     0.65000  0.9072  3   PRINT
 7.97500  4.4182     0.65000  0.8614  3   PRINT
 8.62500  3.7563     0.65000  0.8155  4   PRINT
 9.27500  3.1393     0.65000  0.7694  4   PRINT
 9.92500  2.5731     0.65000  0.7231  4   PRINT
10.57500  2.0579     0.65000  0.6764  4   PRINT
11.22500  1.5793     0.65000  0.6295  4   PRINT
11.87500  1.1394     0.65000  0.5823  4   PRINT
12.52500  0.7418     0.65000  0.5348  5   PRINT
13.17500  0.3900     0.65000  0.4871  5   PRINT
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A.3 SNLV27_Blade.dat

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---------------------- FAST INDIVIDUAL BLADE FILE ------------------------------
Properties generated using NuMAD2PreComp2FASTBlade on 29-May-2014
---------------------- BLADE PARAMETERS ----------------------------------------
34              NBlInpSt    - Number of blade input stations (-)
F               CalcBMode   - Calculate blade mode shapes internally {T: ignore mode shapes from below, F: use mode shapes from below} [CURRENTLY IGNORED] (flag)
1.5             BldFlDmp(1) - Blade flap mode #1 structural damping in percent of critical (%%)
1.5             BldFlDmp(2) - Blade flap mode #2 structural damping in percent of critical (%%)
1.5             BldEdDmp(1) - Blade edge mode #1 structural damping in percent of critical (%%)
---------------------- BLADE ADJUSTMENT FACTORS --------------------------------
1               FlStTunr(1) - Blade flapwise modal stiffness tuner, 1st mode (-)
1               FlStTunr(2) - Blade flapwise modal stiffness tuner, 2nd mode (-)
1               AdjBlMs     - Factor to adjust blade mass density (-)
1               AdjFlSt     - Factor to adjust blade flap stiffness (-)
1               AdjEdSt     - Factor to adjust blade edge stiffness (-)
---------------------- DISTRIBUTED BLADE PROPERTIES ----------------------------
BlFract  AeroCent  StrcTwst  BMassDen  FlpStff       EdgStff       GJStff        EAStff        Alpha  FlpIner  EdgIner  PrecrvRef  PreswpRef  FlpcgOf  EdgcgOf  FlpEAOf  EdgEAOf
(-)      (-)       (deg)     (kg/m)    (Nm^2)        (Nm^2)        (Nm^2)        (N)           (-)    (kg m)   (kg m)   (m)        (m)        (m)      (m)      (m)      (m)
0.00000  0.250     14.810     90.500   5.26800e+07   5.23200e+07   1.27200e+07   1.34400e+09   0.000    3.565    3.541  0.000      0.000      0.000    0.000    0.000    0.000
0.00769  0.250     14.810     90.500   5.26800e+07   5.23200e+07   1.27200e+07   1.34400e+09   0.000    3.565    3.541  0.000      0.000      0.000    0.000    0.000    0.000
0.01538  0.250     14.810     90.500   5.26800e+07   5.23200e+07   1.27200e+07   1.34400e+09   0.000    3.565    3.541  0.000      0.000      0.000    0.000    0.000    0.000
0.02308  0.250     14.810    101.000   5.07600e+07   6.10000e+07   1.20600e+07   1.48900e+09   0.000    3.439    4.170  0.000      0.000      0.000    0.001    0.000    0.000
0.03846  0.238     14.510     80.250   4.60600e+07   3.59300e+07   4.01400e+06   1.11300e+09   0.000    3.258    2.748  0.000      0.000      0.000    0.007    0.000    0.005
0.04231  0.235     14.440     78.980   4.45400e+07   3.69800e+07   4.09200e+06   1.08800e+09   0.000    3.172    2.857  0.000      0.000      0.000    0.008    0.000    0.006
0.06923  0.215     13.920     87.170   4.46600e+07   5.59700e+07   4.99500e+06   1.18600e+09   0.000    3.214    4.624  0.000      0.000      0.003    0.019    0.003    0.011
0.09231  0.198     13.480     89.640   4.03600e+07   6.29000e+07   4.49900e+06   1.19700e+09   0.000    2.925    5.809  0.000      0.000      0.007    0.030    0.007    0.013
0.11538  0.180     13.030     80.090   3.12400e+07   4.63500e+07   3.11900e+06   1.03100e+09   0.000    2.299    5.245  0.000      0.000      0.013    0.050    0.013    0.021
0.12308  0.184     12.870     79.500   2.95600e+07   4.57800e+07   2.93200e+06   1.02400e+09   0.000    2.174    5.196  0.000      0.000      0.013    0.050    0.013    0.020
0.15385  0.199     12.220     76.060   2.50700e+07   4.17900e+07   2.55800e+06   9.72800e+08   0.000    1.850    4.876  0.000      0.000      0.015    0.051    0.016    0.020
0.18462  0.214     11.570     72.560   2.12000e+07   3.76300e+07   2.21900e+06   9.21700e+08   0.000    1.570    4.510  0.000      0.000      0.017    0.051    0.017    0.020
0.20000  0.221     11.250     70.100   1.93700e+07   3.48300e+07   2.06100e+06   8.84700e+08   0.000    1.439    4.270  0.000      0.000      0.017    0.052    0.017    0.020
0.21538  0.228     10.930     68.930   1.78200e+07   3.33400e+07   1.91100e+06   8.69500e+08   0.000    1.325    4.104  0.000      0.000      0.017    0.052    0.017    0.020
0.23077  0.236     10.600     67.710   1.63900e+07   3.18200e+07   1.77000e+06   8.53800e+08   0.000    1.220    3.932  0.000      0.000      0.017    0.051    0.017    0.020
0.24615  0.243     10.280     65.230   1.49100e+07   2.91200e+07   1.63600e+06   8.17000e+08   0.000    1.113    3.683  0.000      0.000      0.017    0.052    0.017    0.020
0.27692  0.258      9.630     59.580   1.19300e+07   2.46500e+07   1.39700e+06   7.32300e+08   0.000    0.902    3.236  0.000      0.000      0.016    0.053    0.017    0.021
0.28462  0.262      9.470     58.970   1.14200e+07   2.39700e+07   1.34200e+06   7.24600e+08   0.000    0.864    3.151  0.000      0.000      0.016    0.053    0.016    0.021
0.30769  0.273      8.980     56.090   9.94300e+06   2.11600e+07   1.19100e+06   6.83800e+08   0.000    0.756    2.857  0.000      0.000      0.015    0.053    0.016    0.020
0.38462  0.311      7.360     47.640   6.04000e+06   1.47000e+07   7.89800e+05   5.67100e+08   0.000    0.468    2.083  0.000      0.000      0.012    0.052    0.012    0.020
0.43846  0.337      6.230     42.690   4.20400e+06   1.17500e+07   5.90800e+05   4.99500e+08   0.000    0.332    1.701  0.000      0.000      0.009    0.052    0.010    0.021
0.44231  0.339      6.150     42.520   4.18800e+06   1.16100e+07   5.97900e+05   4.97400e+08   0.000    0.331    1.682  0.000      0.000      0.009    0.052    0.010    0.021
0.46154  0.344      5.870     39.940   3.49900e+06   1.06100e+07   5.22500e+05   4.59200e+08   0.000    0.280    1.561  0.000      0.000      0.009    0.053    0.009    0.022
0.53846  0.365      4.730     36.130   2.19600e+06   8.10600e+06   3.41400e+05   4.14200e+08   0.000    0.178    1.208  0.000      0.000      0.008    0.050    0.009    0.021
0.61538  0.386      3.590     32.480   1.34000e+06   6.08300e+06   2.18300e+05   3.71100e+08   0.000    0.110    0.918  0.000      0.000      0.008    0.048    0.008    0.020
0.63077  0.390      3.370     31.770   1.20900e+06   5.72800e+06   1.99100e+05   3.62600e+08   0.000    0.100    0.867  0.000      0.000      0.008    0.047    0.008    0.019
0.73077  0.417      1.890     27.330   6.09500e+05   3.79900e+06   1.09600e+05   3.10400e+08   0.000    0.052    0.584  0.000      0.000      0.007    0.043    0.007    0.018
0.76923  0.417      1.620     25.690   4.62300e+05   3.20400e+06   8.44300e+04   2.91100e+08   0.000    0.039    0.496  0.000      0.000      0.006    0.041    0.007    0.017
0.84615  0.418      1.080     22.520   2.57400e+05   2.22500e+06   5.04500e+04   2.53900e+08   0.000    0.023    0.349  0.000      0.000      0.006    0.038    0.006    0.016
0.87692  0.419      0.860     21.270   1.96400e+05   1.90100e+06   3.99300e+04   2.39300e+08   0.000    0.018    0.299  0.000      0.000      0.005    0.036    0.006    0.015
0.92308  0.419      0.540     19.440   1.24400e+05   1.48200e+06   2.70100e+04   2.18100e+08   0.000    0.011    0.235  0.000      0.000      0.005    0.034    0.005    0.014
0.96154  0.420      0.270     16.160   7.00200e+04   1.13300e+06   1.92600e+04   1.74000e+08   0.000    0.007    0.184  0.000      0.000      0.005    0.036    0.005    0.016
0.96923  0.420      0.220     14.810   1.16300e+05   1.08400e+06   2.42100e+04   1.74000e+08   0.000    0.009    0.155  0.000      0.000      0.005    0.030    0.005    0.015
1.00000  0.420      0.000     14.090   9.03200e+04   9.61400e+05   1.88300e+04   1.73300e+08   0.000    0.007    0.130  0.000      0.000      0.004    0.029    0.004    0.015
---------------------- BLADE MODE SHAPES ---------------------------------------
0.226263        BldFl1Sh(2) - Flap mode 1, coeff of x^2
0.574967        BldFl1Sh(3) -            , coeff of x^3
-1.10416        BldFl1Sh(4) -            , coeff of x^4
3.01593         BldFl1Sh(5) -            , coeff of x^5
-1.713          BldFl1Sh(6) -            , coeff of x^6
-2.66918        BldFl2Sh(2) - Flap mode 2, coeff of x^2
14.2938         BldFl2Sh(3) -            , coeff of x^3
-46.2537        BldFl2Sh(4) -            , coeff of x^4
58.3088         BldFl2Sh(5) -            , coeff of x^5
-22.6796        BldFl2Sh(6) -            , coeff of x^6
```

```
1.16475         BldEdgSh(2) - Edge mode 1, coeff of x^2
-2.13038        BldEdgSh(3) -            , coeff of x^3
5.37387         BldEdgSh(4) -            , coeff of x^4
-4.84372        BldEdgSh(5) -            , coeff of x^5
1.43549         BldEdgSh(6) -            , coeff of x^6
```

A.4 SNLV27_Tower.dat

```
--------------------------------------------------------------------------------
---------------------- FAST TOWER FILE -----------------------------------------
SNL SWiFT Tower Input File created on 08-May-2014
---------------------- TOWER PARAMETERS ----------------------------------------
17               NTwInpSt    - Number of input stations to specify tower geometry
False            CalcTMode   - Calculate tower mode shapes internally {T: ignore mode shapes from below, F: use mode shapes from below} [CURRENTLY IGNORED] (flag)
1.5              TwrFADmp(1) - Tower 1st fore-aft mode structural damping ratio (%%)
1.5              TwrFADmp(2) - Tower 2nd fore-aft mode structural damping ratio (%%)
1.5              TwrSSDmp(1) - Tower 1st side-to-side mode structural damping ratio (%%)
1.5              TwrSSDmp(2) - Tower 2nd side-to-side mode structural damping ratio (%%)
---------------------- TOWER ADJUSTMUNT FACTORS --------------------------------
1                FAStTunr(1) - Tower fore-aft modal stiffness tuner, 1st mode (-)
1                FAStTunr(2) - Tower fore-aft modal stiffness tuner, 2nd mode (-)
1                SSStTunr(1) - Tower side-to-side stiffness tuner, 1st mode (-)
1                SSStTunr(2) - Tower side-to-side stiffness tuner, 2nd mode (-)
1                AdjTwMa     - Factor to adjust tower mass density (-)
1                AdjFASt     - Factor to adjust tower fore-aft stiffness (-)
1                AdjSSSt     - Factor to adjust tower side-to-side stiffness (-)
---------------------- DISTRIBUTED TOWER PROPERTIES ----------------------------
HtFract  TMassDen  TwFAStif      TwSSStif      TwGJStif      TwEAStif      TwFAIner  TwSSIner  TwFAcgOf  TwSScgOf
(-)      (kg/m)    (Nm^2)        (Nm^2)        (Nm^2)        (N)           (kg m)    (kg m)    (m)       (m)
0.00000   656.400   1.04300e+10   1.04300e+10   7.98300e+09   1.46100e+10   468.60    468.60   0.000     0.000
0.06129   642.000   9.81100e+09   9.81100e+09   7.43700e+09   1.42900e+10   440.90    440.90   0.000     0.000
0.12258   495.900   7.07500e+09   7.07500e+09   5.36300e+09   1.10400e+10   317.90    317.90   0.000     0.000
0.18387   478.200   6.34200e+09   6.34200e+09   4.80800e+09   1.06400e+10   285.00    285.00   0.000     0.000
0.24516   460.500   5.66100e+09   5.66100e+09   4.29200e+09   1.02500e+10   254.40    254.40   0.000     0.000
0.30645   437.600   4.82900e+09   4.82900e+09   3.69700e+09   9.73800e+09   217.00    217.00   0.000     0.000
0.36903   426.600   4.49900e+09   4.49900e+09   3.41100e+09   9.49300e+09   202.20    202.20   0.000     0.000
0.43161   410.900   4.01900e+09   4.01900e+09   3.04600e+09   9.14400e+09   180.60    180.60   0.000     0.000
0.49419   395.800   3.59200e+09   3.59200e+09   2.72300e+09   8.80900e+09   161.40    161.40   0.000     0.000
0.55677   381.700   3.21900e+09   3.21900e+09   2.44000e+09   8.49300e+09   144.60    144.60   0.000     0.000
0.61935   364.100   2.77700e+09   2.77700e+09   2.12600e+09   8.10200e+09   124.80    124.80   0.000     0.000
0.68290   268.000   1.98400e+09   1.98400e+09   1.50400e+09   5.96400e+09    89.17     89.17   0.000     0.000
0.74613   259.500   1.80200e+09   1.80200e+09   1.36600e+09   5.77500e+09    80.96     80.96   0.000     0.000
0.80968   251.200   1.63400e+09   1.63400e+09   1.23900e+09   5.59000e+09    73.42     73.42   0.000     0.000
0.87323   242.900   1.47700e+09   1.47700e+09   1.11900e+09   5.40600e+09    66.36     66.36   0.000     0.000
0.93645   234.400   1.32700e+09   1.32700e+09   1.00600e+09   5.21700e+09    59.64     59.64   0.000     0.000
1.00000   223.500   1.14300e+09   1.14300e+09   8.75000e+08   4.97400e+09    51.36     51.36   0.000     0.000
---------------------- TOWER FORE-AFT MODE SHAPES ------------------------------
0.894474         TwFAM1Sh(2) - Mode 1, coefficient of x^2 term
1.23308          TwFAM1Sh(3) -       , coefficient of x^3 term
-2.22157         TwFAM1Sh(4) -       , coefficient of x^4 term
1.59799          TwFAM1Sh(5) -       , coefficient of x^5 term
-0.503972        TwFAM1Sh(6) -       , coefficient of x^6 term
-4.17834         TwFAM2Sh(2) - Mode 2, coefficient of x^2 term
-0.955842        TwFAM2Sh(3) -       , coefficient of x^3 term
14.7676          TwFAM2Sh(4) -       , coefficient of x^4 term
-8.63886         TwFAM2Sh(5) -       , coefficient of x^5 term
0.00543437       TwFAM2Sh(6) -       , coefficient of x^6 term
---------------------- TOWER SIDE-TO-SIDE MODE SHAPES --------------------------
0.894474         TwSSM1Sh(2) - Mode 1, coefficient of x^2 term
1.23308          TwSSM1Sh(3) -       , coefficient of x^3 term
-2.22157         TwSSM1Sh(4) -       , coefficient of x^4 term
1.59799          TwSSM1Sh(5) -       , coefficient of x^5 term
-0.503972        TwSSM1Sh(6) -       , coefficient of x^6 term
-4.17834         TwSSM2Sh(2) - Mode 2, coefficient of x^2 term
-0.955842        TwSSM2Sh(3) -       , coefficient of x^3 term
14.7676          TwSSM2Sh(4) -       , coefficient of x^4 term
-8.63886         TwSSM2Sh(5) -       , coefficient of x^5 term
0.00543437       TwSSM2Sh(6) -       , coefficient of x^6 term
```

A.5 Pitch.ipt

```
 Speed controller JCB 12/17/2014 - SNL V27
   3        CntrlRgn - Control region {2 = power control, 3 = speed control}
  11        NCSNT    - Number of constants used in controls
  -1.0      CNST(1)  - Gain on TF 1
  43.89672  CNST(2)  - Rotor speed set point, RPM
   0.3      CNST(3)  - Integrator anti-windup gain
   0.0      CNST(4)  - Minimum pitch angle, deg
  88.0      CNST(5)  - Maximum pitch angle, deg
   0.025    CNST(6)  - Time interval for pitch control, sec ( >= DT )
   0.0454   CNST(7)  - Pitch angle at start of gain scheduling, (must be > 0) rad
   0.5      CNST(8)  - Pitch angle at end of gain scheduling (GSPit2>GSPit1), rad
   0.213    CNST(9)  - Power law gain sched. coefficient
  -0.500    CNST(10) - Power law gain sched. exponent
   0        CNST(11) - Write pitcntrl.plt file?  0=no, 1=yes

   1        Order of tf #1 (highest power of s), input=Rotor speed (RPM), output=Integral Pitch demand (deg)
 35.4    0.0            Numerator coefficients   (Order+1 values, ascending powers of s)
 0.0     1.0            Denominator coefficients (Order+1 values, ascending powers of s)

   1        Order of tf #2 (highest power of s), input=Rotor speed (RPM), output=PD Pitch demand (deg)
 5.0     0.10           Numerator coefficients   (Order+1 values, ascending powers of s)
 1.0     0.02           Denominator coefficients (Order+1 values, ascending powers of s)

   0        Order of tf #3, input=Tower accel, output=pitch (deg) (Use 0 to not include tower feedback cntrl)
 9.64    1.4            Numerator coefficients   (Order+1 values, ascending powers of s)
 0.358   1.0            Denominator coefficients (Order+1 values, ascending powers of s)

   0        Order of tf #4, input=Pitch demand(deg), output=pitch (deg) (Use 0 for ADAMS to not include actuator)
85.696   0.0    0.0     Numerator coefficients   (Order+1 values, ascending powers of s)
85.696  14.812  1.0     Denominator coefficients (Order+1 values, ascending powers of s)
```

A.6 steady_wind.wnd

```
!-----------------------------------------------------------
! Time  Wind     Wind     Vertical  Horiz.      Pwr.Law     Lin.Vert.   Gust
!          Speed          Dir      Speed     Shear     Vert.Shr    Shear       Speed
! (sec) (m/s)    (deg)    (m/s)                                                    (m/s)
0.000       11    0.000    0.000  0.000   0       0.000   0.000
1000.000    3     0.000    0.000  0.000   0       0.000   0.000
```

A.7 AD_63-235_mod.dat

```
63-235
CK Modified based on foam template measurements and thin af theory modifications (May 10, 2018)
1        Number of airfoil tables in this file
2         Reynolds number in millions
15        Stall angle (deg)
0         No longer used, enter zero
0         No longer used, enter zero
0         No longer used, enter zero
-3.4508   Zero lift angle of attack (deg)
6.0086    Cn slope for zero lift (dimensionless)
1.4145    Cn at stall value for positive angle of attack
-0.60586  Cn at stall value for negative angle of attack
-1.5      Angle of attack for minimum CD (deg)
0.0090078 Minimum CD value
-180            0         0.01            0
-175      0.32314     -0.00353      0.32311
-170      0.54698         0.01          0.4
-165      0.67904      0.04941      0.33924
-160      0.72682      0.11352      0.24942
-155      0.70579      0.20019      0.21399
-150      0.66314      0.30328      0.21602
-145      0.64074      0.41646       0.2214
-140      0.62742      0.53657      0.22794
-135      0.60342      0.66092      0.23986
-130      0.56773      0.78571      0.25508
-125      0.52323      0.90699      0.27055
-120       0.4696       1.0213      0.28536
-115      0.40619       1.1252      0.29905
-110       0.3342       1.2155      0.31072
-105      0.25541       1.2893      0.31947
-100      0.17213       1.3458      0.32503
-95      0.08657       1.3833      0.32702
```

-90	0	1.3971	0.32417
-85	-0.08656	1.3833	0.31555
-80	-0.17213	1.3458	0.30236
-75	-0.25546	1.2893	0.2861
-70	-0.3342	1.2155	0.26733
-65	-0.40601	1.1252	0.24646
-60	-0.4696	1.0213	0.22406
-55	-0.52392	0.90698	0.20089
-50	-0.56773	0.78571	0.17812
-45	-0.60083	0.66096	0.15651
-40	-0.62742	0.53657	0.13462
-35	-0.65043	0.41631	0.1123
-30	-0.66314	0.30328	0.09674
-25	-0.66962	0.20078	0.08937
-21	-0.70796	0.12951	0.07031
-20	-0.72682	0.11352	0.06129
-19	-0.75	0.09836	0.05014
-18	-0.77544	0.08411	0.0374
-17	-0.80056	0.07088	0.02375
-16	-0.82279	0.05876	0.00988
-15	-0.83954	0.04787	-0.00351
-14	-0.84824	0.03829	-0.01574
-13	-0.84632	0.03013	-0.02611
-12	-0.83119	0.0235	-0.03394
-11	-0.80027	0.0185	-0.03853
-10	-0.751	0.01522	-0.0392
-9.5	-0.71909	0.01422	-0.03799
-9	-0.6841	0.01346	-0.0364
-8.5	-0.64783	0.01275	-0.03504
-8	-0.6106	0.01207	-0.0339
-7.5	-0.57249	0.01141	-0.03279
-7	-0.53411	0.01081	-0.03158
-6.5	-0.4962	0.01028	-0.03012
-6	-0.4595	0.00986	-0.0283
-5.5	-0.42412	0.00956	-0.02608
-5	-0.3876	0.00935	-0.0239
-4.5	-0.3471	0.00918	-0.02225
-4	-0.3007	0.00907	-0.0215
-3.5	-0.24776	0.00901	-0.0218
-3	-0.1918	0.00897	-0.0226
-2.5	-0.13644	0.00891	-0.02334
-2	-0.0816	0.00885	-0.024
-1.5	-0.02642	0.00884	-0.0247
-1	0.0294	0.00885	-0.0255
-0.5	0.08586	0.00886	-0.0264
0	0.1423	0.00886	-0.0273
0.5	0.19775	0.00886	-0.02807
1	0.2507	0.0089	-0.0284
1.5	0.29998	0.00899	-0.02807
2	0.3462	0.00907	-0.0272
2.5	0.39032	0.00912	-0.02601
3	0.4328	0.00927	-0.0247
3.5	0.4744	0.00961	-0.02349
4	0.5176	0.01002	-0.0227
4.5	0.56413	0.01037	-0.02249
5	0.6109	0.01072	-0.0224
5.5	0.65458	0.01119	-0.02194
6	0.6956	0.01176	-0.0212
6.5	0.73547	0.01241	-0.02041
7	0.7762	0.01307	-0.0198
7.5	0.81879	0.0137	-0.01946
8	0.8598	0.0144	-0.019
8.5	0.896	0.01528	-0.01806
9	0.9295	0.01629	-0.0169
9.5	0.96294	0.01737	-0.01587
10	0.9957	0.01856	-0.0149
10.5	1.0268	0.01989	-0.01389
11	1.0569	0.02131	-0.0129
11.5	1.0864	0.02282	-0.01196
12	1.1121	0.02457	-0.0108
12.5	1.1312	0.02672	-0.00919
13	1.1447	0.02927	-0.0074
13.5	1.1545	0.03216	-0.00568
14	1.1622	0.03527	-0.0038
14.5	1.1686	0.03854	-0.00171
15	1.1721	0.04229	-0.0007
15.5	1.1708	0.04684	-0.00206
16	1.1648	0.05218	-0.00574
16.5	1.155	0.05824	-0.01141
17	1.1421	0.06492	-0.01869
17.5	1.1267	0.07215	-0.02722
18	1.1096	0.07984	-0.03664
18.5	1.0915	0.0879	-0.0466
19	1.0731	0.09626	-0.05673
19.5	1.0551	0.10483	-0.06667
20	1.0383	0.11352	-0.07607
20.5	1.0232	0.12227	-0.08463
21	1.0099	0.13107	-0.09233
21.5	0.99831	0.13992	-0.09923
22	0.9882	0.14882	-0.10538
22.5	0.97954	0.15779	-0.11084
23	0.9722	0.16683	-0.11566

```
23.5      0.96608      0.17593     -0.11989
  24      0.96106      0.18512     -0.12359
24.5      0.95704      0.19439      -0.1268
  25      0.95391      0.20374     -0.12959
25.5      0.95156      0.21319       -0.132
  26      0.94987      0.22274      -0.1341
26.5      0.94875      0.23239     -0.13592
  27      0.94808      0.24215     -0.13753
27.5      0.94774      0.25202     -0.13899
  28      0.94764      0.26202     -0.14033
  30      0.94734      0.30328      -0.1457
  35      0.92992      0.41551     -0.16709
  40      0.89632      0.53657      -0.1936
  45       0.8581      0.66117     -0.21672
  50      0.81105      0.78571     -0.23738
  55      0.74863      0.90692     -0.25819
  60      0.67085       1.0213     -0.27886
  65      0.57957       1.1252     -0.29854
  70      0.47743       1.2155     -0.31693
  75      0.36653       1.2893     -0.33391
  80      0.24591       1.3458     -0.34957
  85      0.11777       1.3833     -0.36364
  90            0       1.3971     -0.37438
  95     -0.09246       1.3833     -0.38013
100     -0.17213       1.3458     -0.38128
105     -0.25384       1.2893      -0.3786
110      -0.3342       1.2155     -0.37248
115     -0.40661       1.1252      -0.3633
120      -0.4696       1.0213      -0.3519
125     -0.52312      0.90699     -0.33918
130     -0.56773      0.78571     -0.32579
135     -0.60345      0.66092     -0.31277
140     -0.62742      0.53657     -0.30302
145     -0.64073      0.41646     -0.29879
150     -0.66314      0.30328     -0.29801
155     -0.70579      0.20019     -0.30444
160     -0.72682      0.11352     -0.34975
165     -0.67904      0.04941     -0.44614
170     -0.54698         0.01         -0.5
175     -0.32314     -0.00353      -0.3913
180            0         0.01            0
```

A.8 AD_63-224_mod.dat

```
63-224
CK Modified based on foam template measurements and thin af theory modifications (May 10, 2018)
1        Number of airfoil tables in this file
2         Reynolds number in millions
15        Stall angle (deg)
0         No longer used, enter zero
0         No longer used, enter zero
0         No longer used, enter zero
-2.6501   Zero lift angle of attack (deg)
6.9763    Cn slope for zero lift (dimensionless)
1.4356    Cn at stall value for positive angle of attack
-0.75848  Cn at stall value for negative angle of attack
-1.5      Angle of attack for minimum CD (deg)
0.0066863 Minimum CD value
-180            0         0.01            0
-175      0.35806     -0.00423      0.32028
-170      0.60228         0.01          0.4
-165      0.74192      0.05068      0.34357
-160      0.78623      0.11579      0.25543
-155      0.75343      0.20258      0.21644
-150      0.69765      0.30537      0.21327
-145      0.66686      0.41839       0.2158
-140      0.64843      0.53841      0.22114
-135       0.6199      0.66264      0.23195
-130      0.58014      0.78727      0.24619
-125      0.53241      0.90837      0.26104
-120      0.47624       1.0225      0.27553
-115      0.41075       1.1262      0.28907
-110      0.33707       1.2163      0.30072
-105      0.25699         1.29       0.3096
-100      0.17284       1.3462      0.31536
-95      0.08682       1.3834       0.3176
-90            0       1.3971      0.31508
-85     -0.08681       1.3834      0.30687
-80     -0.17284       1.3462      0.29412
-75     -0.25703         1.29       0.2783
-70     -0.33707       1.2163      0.26003
-65      -0.4106       1.1262       0.2397
-60     -0.47624       1.0225      0.21789
-55     -0.53296      0.90836      0.19533
-50     -0.58014      0.78727      0.17342
-45     -0.61786      0.66269      0.15297
-40     -0.64843      0.53841      0.13189
```

-35	-0.67449	0.41819	0.10988
-30	-0.69765	0.30537	0.09678
-25	-0.72498	0.20332	0.09478
-21	-0.76956	0.13195	0.0758
-20	-0.78623	0.11579	0.06539
-19	-0.8054	0.10038	0.05218
-18	-0.82599	0.08582	0.03695
-17	-0.84665	0.07221	0.0207
-16	-0.86602	0.05967	0.00447
-15	-0.88274	0.0483	-0.01075
-14	-0.89547	0.03822	-0.02392
-13	-0.90284	0.02953	-0.03404
-12	-0.90351	0.02235	-0.04009
-11	-0.89611	0.01679	-0.04104
-10	-0.8793	0.01295	-0.0359
-9.5	-0.86594	0.01168	-0.0311
-9	-0.8437	0.01067	-0.0267
-8.5	-0.80841	0.00977	-0.02432
-8	-0.7639	0.00897	-0.0234
-7.5	-0.71501	0.00829	-0.02305
-7	-0.6626	0.00777	-0.0231
-6.5	-0.60678	0.00742	-0.02356
-6	-0.5487	0.00719	-0.0243
-5.5	-0.48956	0.00704	-0.0252
-5	-0.4298	0.00693	-0.0262
-4.5	-0.36966	0.00684	-0.02726
-4	-0.30923	0.00678	-0.02835
-3.5	-0.24855	0.00672	-0.02947
-3	-0.1877	0.00668	-0.0306
-2.5	-0.12672	0.00665	-0.03174
-2	-0.0657	0.00663	-0.0329
-1.5	-0.0047	0.00662	-0.0341
-1	0.0563	0.00662	-0.0353
-0.5	0.11731	0.00663	-0.03646
0	0.1783	0.00665	-0.0376
0.5	0.23924	0.00668	-0.03875
1	0.3001	0.00671	-0.0399
1.5	0.36087	0.00676	-0.04106
2	0.4215	0.00681	-0.0422
2.5	0.48193	0.00687	-0.04331
3	0.5422	0.00694	-0.0444
3.5	0.60232	0.00702	-0.04547
4	0.6622	0.00711	-0.0465
4.5	0.72173	0.00722	-0.04748
5	0.7809	0.00734	-0.0484
5.5	0.83967	0.00747	-0.04925
6	0.89762	0.00763	-0.04997
6.5	0.9543	0.00783	-0.05051
7	1.0092	0.00811	-0.0508
7.5	1.0616	0.00848	-0.05073
8	1.1098	0.00898	-0.05
8.5	1.1513	0.00963	-0.0482
9	1.1819	0.01047	-0.0447
9.5	1.1987	0.01157	-0.03926
10	1.2074	0.01311	-0.0333
10.5	1.2147	0.0152	-0.02832
11	1.224	0.01756	-0.0244
11.5	1.2367	0.01993	-0.02125
12	1.2494	0.02249	-0.0185
12.5	1.2585	0.02545	-0.01588
13	1.2654	0.02877	-0.0136
13.5	1.2721	0.03236	-0.01185
14	1.2793	0.03616	-0.0103
14.5	1.2864	0.04018	-0.0088
15	1.2906	0.04462	-0.0085
15.5	1.2889	0.04968	-0.01058
16	1.2815	0.05536	-0.01498
16.5	1.2693	0.0616	-0.02134
17	1.2532	0.06833	-0.02929
17.5	1.234	0.0755	-0.03846
18	1.2126	0.08304	-0.0485
18.5	1.19	0.0909	-0.05903
19	1.1669	0.09902	-0.06969
19.5	1.1444	0.10734	-0.08012
20	1.1232	0.11579	-0.08995
20.5	1.1041	0.12434	-0.09889
21	1.0872	0.13296	-0.10692
21.5	1.0722	0.14167	-0.1141
22	1.0591	0.15047	-0.12049
22.5	1.0478	0.15936	-0.12614
23	1.038	0.16834	-0.13111
23.5	1.0297	0.17741	-0.13545
24	1.0228	0.18659	-0.13922
24.5	1.0171	0.19586	-0.14248
25	1.0125	0.20524	-0.14529
25.5	1.0088	0.21473	-0.14769
26	1.0059	0.22432	-0.14975
26.5	1.0037	0.23403	-0.15153
27	1.0021	0.24386	-0.15307
27.5	1.0009	0.2538	-0.15444
28	0.99997	0.26386	-0.1557
30	0.99665	0.30537	-0.16066

```
  35      0.96979      0.41767     -0.18118
  40      0.92633      0.53841     -0.20695
  45      0.88096      0.66283     -0.22924
  50      0.82878      0.78727     -0.24909
  55      0.76193      0.90832     -0.26921
  60      0.68034       1.0225     -0.28933
  65      0.58603       1.1262     -0.30857
  70      0.48153       1.2163     -0.32662
  75       0.3688         1.29     -0.34337
  80      0.24691       1.3462     -0.35886
  85       0.1181       1.3834      -0.3728
  90            0       1.3971     -0.38347
  95     -0.09272       1.3834     -0.38923
100     -0.17284       1.3462     -0.39045
105     -0.25541         1.29     -0.38788
110     -0.33707       1.2163     -0.38194
115     -0.41117       1.1262     -0.37308
120     -0.47624       1.0225      -0.3621
125      -0.5323      0.90837     -0.34993
130     -0.58014      0.78727     -0.33753
135     -0.61993      0.66264      -0.3261
140     -0.64843      0.53841     -0.31767
145     -0.66686      0.41839     -0.31445
150     -0.69765      0.30537      -0.3184
155     -0.75343      0.20258     -0.33498
160     -0.78623      0.11579     -0.38376
165     -0.74192      0.05068     -0.46657
170     -0.60228         0.01         -0.5
175     -0.35806     -0.00423     -0.37937
180            0         0.01            0
```

A.9 AD_63-218_mod.dat

```
63-218
CK Modified based on foam template measurements and thin af theory modifications (May 10, 2018)
1        Number of airfoil tables in this file
2         Reynolds number in millions
14        Stall angle (deg)
0         No longer used, enter zero
0         No longer used, enter zero
0         No longer used, enter zero
-2.4131   Zero lift angle of attack (deg)
6.8415    Cn slope for zero lift (dimensionless)
1.4974    Cn at stall value for positive angle of attack
-0.93634  Cn at stall value for negative angle of attack
-1        Angle of attack for minimum CD (deg)
0.0056729 Minimum CD value
-180           0         0.01            0
-175     0.50327      -0.0049      0.32384
-170     0.74157         0.01          0.4
-165     0.80231      0.05188      0.33742
-160     0.77292      0.11793      0.24505
-155     0.72788      0.20484      0.20679
-150     0.68992      0.30734      0.20634
-145       0.665       0.4202      0.21012
-140     0.64372      0.54016      0.21567
-135     0.61514      0.66426      0.22683
-130     0.57736      0.78873       0.2415
-125     0.53064      0.90968      0.25663
-120     0.47475       1.0236       0.2713
-115     0.40965       1.1272      0.28499
-110     0.33643       1.2171      0.29678
-105     0.25666       1.2906      0.30577
-100     0.17268       1.3466      0.31163
-95     0.08675       1.3836      0.31395
-90           0       1.3971      0.31154
-85    -0.08674       1.3836      0.30349
-80    -0.17268       1.3466      0.29094
-75    -0.25672       1.2906      0.27529
-70    -0.33643       1.2171      0.25713
-65     -0.4094       1.1272      0.23688
-60    -0.47475       1.0236      0.21515
-55    -0.53156      0.90965      0.19269
-50    -0.57736      0.78873      0.17068
-45    -0.61169      0.66435      0.14989
-40    -0.64372      0.54016      0.12901
-35    -0.67787      0.41985      0.10797
-30    -0.68992      0.30734      0.09376
-25    -0.67985      0.20613      0.08788
-21    -0.73854      0.13447      0.07101
-20    -0.77292      0.11793      0.06279
-19    -0.81672      0.10199      0.05255
-18    -0.86637      0.08679      0.04078
-17    -0.91732      0.07251       0.0281
-16    -0.96502      0.05933      0.01514
-15     -1.0049       0.0474      0.00252
-14     -1.0325      0.03692     -0.00913
```

-13	-1.0432	0.02805	-0.01918
-12	-1.0324	0.02097	-0.02701
-11	-0.99566	0.01584	-0.03199
-10	-0.9284	0.01285	-0.0335
-9.5	-0.88271	0.01215	-0.0329
-9	-0.8325	0.01171	-0.0321
-8.5	-0.78129	0.01126	-0.03172
-8	-0.7296	0.01077	-0.0316
-7.5	-0.6773	0.01025	-0.03149
-7	-0.6247	0.00968	-0.0314
-6.5	-0.57207	0.00904	-0.03143
-6	-0.5192	0.00831	-0.0316
-5.5	-0.46566	0.00753	-0.03192
-5	-0.4107	0.00683	-0.0324
-4.5	-0.35376	0.00634	-0.03306
-4	-0.2954	0.00605	-0.0338
-3.5	-0.23635	0.00589	-0.03454
-3	-0.1769	0.0058	-0.0353
-2.5	-0.11721	0.00574	-0.0361
-2	-0.05737	0.00569	-0.03694
-1.5	0.00252	0.00567	-0.03778
-1	0.0624	0.00566	-0.0386
-0.5	0.1222	0.00567	-0.0394
0	0.182	0.00569	-0.0402
0.5	0.24185	0.00571	-0.04104
1	0.3017	0.00573	-0.0419
1.5	0.36145	0.00577	-0.04273
2	0.42105	0.00582	-0.04353
2.5	0.48045	0.0059	-0.04429
3	0.5396	0.006	-0.045
3.5	0.59846	0.00613	-0.04567
4	0.657	0.00628	-0.0463
4.5	0.715	0.00647	-0.04688
5	0.7716	0.00678	-0.0473
5.5	0.82588	0.00727	-0.04744
6	0.8774	0.00798	-0.0472
6.5	0.92608	0.00888	-0.04654
7	0.9729	0.00985	-0.0456
7.5	1.0188	0.01076	-0.04456
8	1.0637	0.01164	-0.0434
8.5	1.1071	0.01252	-0.04204
9	1.1482	0.01334	-0.0402
9.5	1.1859	0.01405	-0.03767
10	1.2193	0.01483	-0.0347
10.5	1.2481	0.01586	-0.03158
11	1.2754	0.01701	-0.0283
11.5	1.3042	0.01816	-0.02488
12	1.3327	0.01948	-0.02179
12.5	1.358	0.02119	-0.01961
13	1.3772	0.02352	-0.0189
13.5	1.388	0.02665	-0.02012
14	1.3905	0.03058	-0.02318
14.5	1.3859	0.03524	-0.02788
15	1.3747	0.04058	-0.03399
15.5	1.3581	0.04653	-0.04132
16	1.3368	0.05303	-0.04964
16.5	1.3117	0.06003	-0.05875
17	1.2837	0.06747	-0.06843
17.5	1.2537	0.07528	-0.07847
18	1.2226	0.08341	-0.08867
18.5	1.1912	0.0918	-0.0988
19	1.1604	0.10039	-0.10866
19.5	1.1311	0.10912	-0.11804
20	1.1042	0.11793	-0.12672
20.5	1.0803	0.12677	-0.13454
21	1.0595	0.13564	-0.14151
21.5	1.0415	0.14455	-0.14768
22	1.0263	0.15349	-0.1531
22.5	1.0135	0.16248	-0.15784
23	1.0029	0.17152	-0.16194
23.5	0.99447	0.18063	-0.16546
24	0.98791	0.1898	-0.16845
24.5	0.98304	0.19904	-0.17098
25	0.97966	0.20836	-0.17308
25.5	0.9776	0.21777	-0.17483
26	0.97664	0.22727	-0.17626
26.5	0.97659	0.23686	-0.17745
27	0.97727	0.24657	-0.17843
27.5	0.97848	0.25638	-0.17927
28	0.98001	0.26631	-0.18002
30	0.9856	0.30734	-0.18322
35	0.96612	0.41926	-0.20058
40	0.9196	0.54016	-0.22427
45	0.87442	0.66451	-0.24491
50	0.8248	0.78873	-0.26332
55	0.75933	0.90961	-0.28214
60	0.67822	1.0236	-0.30101
65	0.58448	1.1272	-0.31899
70	0.48061	1.2171	-0.33574
75	0.36832	1.2906	-0.35116
80	0.24669	1.3466	-0.36526
85	0.11801	1.3836	-0.37778

```
  90           0       1.3971     -0.38701
  95    -0.09265       1.3836     -0.39142
100     -0.17268       1.3466     -0.39134
105     -0.25508       1.2906     -0.38751
110     -0.33643       1.2171     -0.38036
115     -0.41007       1.1272     -0.37032
120     -0.47475       1.0236     -0.35825
125     -0.53053      0.90968     -0.34506
130     -0.57736      0.78873     -0.33145
135     -0.61517      0.66426     -0.31846
140     -0.64372      0.54016     -0.30886
145     -0.66499       0.4202     -0.30485
150     -0.68992      0.30734     -0.30482
155     -0.72788      0.20484     -0.31263
160     -0.77292      0.11793     -0.35777
165     -0.80231      0.05188     -0.45071
170     -0.74157         0.01         -0.5
175     -0.50327      -0.0049     -0.38873
180            0         0.01            0
```

A.10 AD_63-214_mod.dat

```
63-214
CK Modified based on foam template measurements and thin af theory modifications (May 10, 2018)
1        Number of airfoil tables in this file
2         Reynolds number in millions
15.5      Stall angle (deg)
0         No longer used, enter zero
0         No longer used, enter zero
0         No longer used, enter zero
-2.2583   Zero lift angle of attack (deg)
6.6592    Cn slope for zero lift (dimensionless)
1.6104    Cn at stall value for positive angle of attack
-0.84224  Cn at stall value for negative angle of attack
-0.5      Angle of attack for minimum CD (deg)
0.0049993 Minimum CD value
-180           0         0.01            0
-175     0.42615     -0.00013      0.31258
-170     0.71013         0.01          0.4
-165     0.86456      0.04328      0.35613
-160     0.90209      0.10263      0.27481
-155     0.84634      0.18871       0.2301
-150     0.76497      0.29324      0.21674
-145     0.71781      0.40723      0.21381
-140      0.6894      0.52768      0.21704
-135     0.65204      0.65265      0.22591
-130     0.60435      0.77826      0.23835
-125     0.55032      0.90035      0.25219
-120     0.48919       1.0155      0.26633
-115     0.41963       1.1203      0.27987
-110     0.34265       1.2115      0.29181
-105     0.26006       1.2863      0.30124
-100     0.17421       1.3437      0.30783
-95     0.08729       1.3826      0.31109
-90           0       1.3971      0.30947
-85    -0.08728       1.3826      0.30174
-80    -0.17421       1.3437      0.28934
-75    -0.26007       1.2863      0.27404
-70    -0.34265       1.2115      0.25641
-65    -0.41957       1.1203      0.23682
-60    -0.48919       1.0155      0.21607
-55    -0.55052      0.90036        0.195
-50    -0.60435      0.77826      0.17436
-45    -0.65128      0.65261      0.15481
-40     -0.6894      0.52768      0.13699
-35    -0.72063      0.40737      0.12141
-30    -0.76497      0.29324       0.1082
-25    -0.83578      0.18818       0.0971
-21    -0.89121      0.11759      0.08898
-20    -0.90209      0.10263      0.08696
-19    -0.91112      0.08892      0.08484
-18    -0.91804      0.07644      0.08223
-17    -0.92261      0.06513      0.07865
-16    -0.92458      0.05495      0.07361
-15    -0.92371      0.04584      0.06665
-14    -0.91976      0.03775      0.05728
-13    -0.91248      0.03064      0.04504
-12    -0.90162      0.02446      0.02943
-11    -0.88694      0.01914      0.00999
-10     -0.8682      0.01466     -0.01376
-9.5     -0.85518      0.01276     -0.02653
  -9      -0.8288      0.01137      -0.0353
-8.5     -0.78141      0.01067     -0.03674
  -8       -0.724       0.0103      -0.0349
-7.5     -0.66896      0.00988     -0.03444
  -7      -0.6156      0.00943       -0.035
-6.5     -0.56081      0.00904      -0.0353
```

-6	-0.5048	0.00871	-0.0354
-5.5	-0.4485	0.00842	-0.03564
-5	-0.3925	0.00802	-0.036
-4.5	-0.33708	0.0074	-0.03641
-4	-0.2817	0.00666	-0.0369
-3.5	-0.22568	0.00595	-0.03748
-3	-0.1687	0.00542	-0.0381
-2.5	-0.11065	0.00519	-0.03871
-2	-0.052	0.00513	-0.0393
-1.5	0.00673	0.00509	-0.03988
-1	0.06545	0.00505	-0.04045
-0.5	0.12414	0.00502	-0.04102
0	0.1828	0.00502	-0.0416
0.5	0.24144	0.00505	-0.0422
1	0.3001	0.0051	-0.0428
1.5	0.35873	0.00515	-0.04338
2	0.417	0.00524	-0.0439
2.5	0.47465	0.0054	-0.04432
3	0.5321	0.00558	-0.0447
3.5	0.58944	0.00578	-0.04509
4	0.6449	0.00622	-0.0453
4.5	0.69703	0.00706	-0.04516
5	0.7475	0.00807	-0.0448
5.5	0.79838	0.00898	-0.04442
6	0.8501	0.00973	-0.0441
6.5	0.90262	0.01033	-0.04387
7	0.95554	0.01083	-0.04369
7.5	1.0084	0.01129	-0.04352
8	1.0607	0.01177	-0.0433
8.5	1.1119	0.01231	-0.04296
9	1.1611	0.01292	-0.0423
9.5	1.2075	0.01359	-0.04113
10	1.251	0.01432	-0.03948
10.5	1.2915	0.01512	-0.0374
11	1.3291	0.016	-0.03497
11.5	1.3637	0.01697	-0.03225
12	1.3954	0.01804	-0.0293
12.5	1.4239	0.01926	-0.02623
13	1.4476	0.02091	-0.0233
13.5	1.4661	0.02317	-0.02069
14	1.4839	0.02569	-0.0182
14.5	1.5046	0.02817	-0.01585
15	1.5217	0.03109	-0.015
15.5	1.528	0.03502	-0.01698
16	1.5235	0.03996	-0.02172
16.5	1.5097	0.04582	-0.02878
17	1.4882	0.05246	-0.03772
17.5	1.4606	0.05979	-0.04811
18	1.4287	0.06768	-0.05951
18.5	1.3939	0.07603	-0.0715
19	1.3579	0.08471	-0.08363
19.5	1.3223	0.09361	-0.09547
20	1.2887	0.10263	-0.10659
20.5	1.2585	0.11166	-0.11664
21	1.2317	0.12069	-0.1256
21.5	1.2081	0.12974	-0.13353
22	1.1875	0.13881	-0.14051
22.5	1.1697	0.1479	-0.1466
23	1.1545	0.15703	-0.15188
23.5	1.1416	0.16621	-0.1564
24	1.1309	0.17544	-0.16024
24.5	1.1222	0.18473	-0.16347
25	1.1152	0.19409	-0.16615
25.5	1.1096	0.20352	-0.16835
26	1.1054	0.21304	-0.17013
26.5	1.1023	0.22265	-0.17157
27	1.1	0.23237	-0.17274
27.5	1.0984	0.24219	-0.1737
28	1.0972	0.25213	-0.17451
30	1.0928	0.29324	-0.17773
35	1.0506	0.40579	-0.19563
40	0.98485	0.52768	-0.22005
45	0.92472	0.65304	-0.24059
50	0.86336	0.77826	-0.25854
55	0.78809	0.90025	-0.27722
60	0.69885	1.0155	-0.2963
65	0.59856	1.1203	-0.31478
70	0.48951	1.2115	-0.33231
75	0.37323	1.2863	-0.34876
80	0.24888	1.3437	-0.36422
85	0.11873	1.3826	-0.37835
90	0	1.3971	-0.38908
95	-0.09321	1.3826	-0.39452
100	-0.17421	1.3437	-0.39526
105	-0.25847	1.2863	-0.39239
110	-0.34265	1.2115	-0.3864
115	-0.42005	1.1203	-0.37774
120	-0.48919	1.0155	-0.36721
125	-0.5502	0.90035	-0.35579
130	-0.60435	0.77826	-0.34503
135	-0.65207	0.65265	-0.33639
140	-0.6894	0.52768	-0.33052

```
145       -0.7178       0.40723      -0.32954
150      -0.76497       0.29324      -0.34226
155      -0.84634       0.18871      -0.37708
160      -0.90209       0.10263      -0.43389
165      -0.86456       0.04328      -0.49739
170      -0.71013          0.01          -0.5
175      -0.42615      -0.00013      -0.36109
180             0          0.01             0
```

A.11 AD_cylinder.dat

```
Round Root Section
File:  WTCRound.dat
  1         Number of airfoil tables in this file
  0        Table ID parameter (Reynolds number in millions).  For efficiency, make very large if only one table.
 14.0      Stall angle (deg)
  0
  0
  0
  0.0      Zero lift angle of attack (deg)
  0.0      Cn slope for zero lift (dimensionless)
  0.0      Cn at stall value for positive angle of attack
  0.0      Cn at stall value for negative angle of attack
  0.0      Angle of attack for minimum CD (deg)
  1.0      Minimum CD value
 -180.0    0.0   0.5   0.0
    0.0    0.0   0.5   0.0
  180.0    0.0   0.5   0.0
```

A.12 Airfoil 1 Measured Coordinates ($\frac{x}{c}$,$\frac{y}{c}$)

1.0000000e+00	0.0000000e+00	4.9115100e-01	1.7369500e-01	4.3110000e-03	3.3314000e-02
9.9288000e-01	8.1380000e-03	4.8019300e-01	1.7624300e-01	1.6220000e-03	2.2418000e-02
9.8215600e-01	1.1537000e-02	4.6915800e-01	1.7843300e-01	3.4200000e-04	1.1245000e-02
9.7133800e-01	1.4628000e-02	4.5823200e-01	1.8111300e-01	0.0000000e+00	0.0000000e+00
9.6047900e-01	1.7571000e-02	4.4717200e-01	1.8316400e-01	3.2600000e-04	-1.1090000e-02
9.4960700e-01	2.0468000e-02	4.3606200e-01	1.8494000e-01	1.6230000e-03	-2.2091000e-02
9.3874500e-01	2.3401000e-02	4.2491200e-01	1.8643600e-01	6.1720000e-03	-3.2198000e-02
9.2791800e-01	2.6459000e-02	4.1376500e-01	1.8796200e-01	1.1592000e-02	-4.1877000e-02
9.1720900e-01	2.9908000e-02	4.0258100e-01	1.8914400e-01	1.7684000e-02	-5.1150000e-02
9.0652600e-01	3.3439000e-02	3.9137000e-01	1.9008300e-01	2.4554000e-02	-5.9841000e-02
8.9586100e-01	3.7022000e-02	3.8014000e-01	1.9076000e-01	3.2077000e-02	-6.7997000e-02
8.8520900e-01	4.0644000e-02	3.6890300e-01	1.9131500e-01	3.9912000e-02	-7.5853000e-02
8.7456600e-01	4.4292000e-02	3.5766000e-01	1.9171300e-01	4.8193000e-02	-8.3238000e-02
8.6392700e-01	4.7953000e-02	3.4640900e-01	1.9177100e-01	5.6843000e-02	-9.0187000e-02
8.5328800e-01	5.1613000e-02	3.3515900e-01	1.9171500e-01	6.6005000e-02	-9.6438000e-02
8.4269500e-01	5.5403000e-02	3.2391100e-01	1.9148400e-01	7.5362000e-02	-1.0240000e-01
8.3211400e-01	5.9229000e-02	3.1269700e-01	1.9059000e-01	8.4932000e-02	-1.0800900e-01
8.2154200e-01	6.3078000e-02	3.0147900e-01	1.8973000e-01	9.4607000e-02	-1.1344000e-01
8.1097400e-01	6.6940000e-02	2.9028700e-01	1.8858300e-01	1.0446300e-01	-1.1853800e-01
8.0040900e-01	7.0808000e-02	2.7909400e-01	1.8744400e-01	1.1443600e-01	-1.2339800e-01
7.8984300e-01	7.4674000e-02	2.6796200e-01	1.8589000e-01	1.2457200e-01	-1.2791100e-01
7.7927300e-01	7.8530000e-02	2.5691700e-01	1.8374700e-01	1.3481400e-01	-1.3218100e-01
7.6869800e-01	8.2370000e-02	2.4587500e-01	1.8159200e-01	1.4520100e-01	-1.3608200e-01
7.5811900e-01	8.6200000e-02	2.3484100e-01	1.7939300e-01	1.5558700e-01	-1.3998700e-01
7.4753900e-01	9.0027000e-02	2.2389000e-01	1.7682600e-01	1.6603800e-01	-1.4371300e-01
7.3696000e-01	9.3859000e-02	2.1294500e-01	1.7422300e-01	1.7666300e-01	-1.4690500e-01
7.2638600e-01	9.7702000e-02	2.0210200e-01	1.7122500e-01	1.8734500e-01	-1.4990800e-01
7.1581900e-01	1.0156400e-01	1.9138700e-01	1.6779200e-01	1.9807600e-01	-1.5273300e-01
7.0526100e-01	1.0545200e-01	1.8070600e-01	1.6425700e-01	2.0886100e-01	-1.5533700e-01
6.9477200e-01	1.0952200e-01	1.7006000e-01	1.6062000e-01	2.1968000e-01	-1.5780100e-01
6.8431300e-01	1.1366800e-01	1.5950600e-01	1.5672300e-01	2.3057200e-01	-1.5991700e-01
6.7385800e-01	1.1782500e-01	1.4909900e-01	1.5245300e-01	2.4150400e-01	-1.6181500e-01
6.6338400e-01	1.2193400e-01	1.3882100e-01	1.4787700e-01	2.5248600e-01	-1.6340800e-01
6.5286800e-01	1.2593400e-01	1.2874500e-01	1.4287600e-01	2.6350600e-01	-1.6469300e-01
6.4225300e-01	1.2966000e-01	1.1885200e-01	1.3752300e-01	2.7454400e-01	-1.6583000e-01
6.3158000e-01	1.3321800e-01	1.0927400e-01	1.3162100e-01	2.8559200e-01	-1.6685600e-01
6.2090300e-01	1.3676600e-01	9.9666000e-02	1.2576800e-01	2.9666500e-01	-1.6755900e-01
6.1021400e-01	1.4027800e-01	9.0110000e-02	1.1983000e-01	3.0774600e-01	-1.6810500e-01
5.9956300e-01	1.4389900e-01	8.0599000e-02	1.1382200e-01	3.1883900e-01	-1.6839200e-01
5.8903100e-01	1.4785800e-01	7.1449000e-02	1.0727600e-01	3.2993400e-01	-1.6847700e-01
5.7822300e-01	1.5093700e-01	6.2273000e-02	1.0076600e-01	3.4102800e-01	-1.6827800e-01
5.6732600e-01	1.5373600e-01	5.3390000e-02	9.3862000e-02	3.5211900e-01	-1.6792300e-01
5.5644500e-01	1.5659700e-01	4.4945000e-02	8.6437000e-02	3.6319400e-01	-1.6726000e-01
5.4559400e-01	1.5956800e-01	3.6833000e-02	7.8642000e-02	3.7426200e-01	-1.6647100e-01
5.3475100e-01	1.6257200e-01	2.8979000e-02	7.0587000e-02	3.8529200e-01	-1.6526900e-01
5.2389400e-01	1.6552000e-01	2.1671000e-02	6.2037000e-02	3.9630600e-01	-1.6393000e-01
5.1303800e-01	1.6847300e-01	1.4779000e-02	5.3147000e-02	4.0731200e-01	-1.6252000e-01
5.0211500e-01	1.7117000e-01	8.8940000e-03	4.3580000e-02	4.1825400e-01	-1.6068400e-01

4.2916400e-01	-1.5865800e-01
4.4005600e-01	-1.5654100e-01
4.5095800e-01	-1.5447900e-01
4.6177900e-01	-1.5202400e-01
4.7249700e-01	-1.4915500e-01
4.8319500e-01	-1.4621000e-01
4.9388500e-01	-1.4323700e-01
5.0453200e-01	-1.4013300e-01
5.1511300e-01	-1.3679800e-01
5.2574600e-01	-1.3362600e-01
5.3623800e-01	-1.3001500e-01
5.4676800e-01	-1.2651700e-01
5.5715100e-01	-1.2260500e-01
5.6761200e-01	-1.1890300e-01
5.7805300e-01	-1.1515600e-01
5.8840600e-01	-1.1116300e-01
5.9885200e-01	-1.0742400e-01
6.0924500e-01	-1.0353500e-01
6.1964600e-01	-9.9670000e-02
6.3005300e-01	-9.5820000e-02
6.4046100e-01	-9.1971000e-02
6.5086400e-01	-8.8111000e-02
6.6125800e-01	-8.4227000e-02
6.7161700e-01	-8.0250000e-02
6.8195200e-01	-7.6210000e-02
6.9228000e-01	-7.2154000e-02
7.0260400e-01	-6.8085000e-02
7.1292300e-01	-6.4007000e-02
7.2324000e-01	-5.9921000e-02
7.3355500e-01	-5.5832000e-02
7.4387100e-01	-5.1743000e-02
7.5418400e-01	-4.7649000e-02
7.6445000e-01	-4.3439000e-02
7.7468000e-01	-3.9139000e-02
7.8489400e-01	-3.4804000e-02
7.9511500e-01	-3.0486000e-02
8.0536700e-01	-2.6239000e-02
8.1567000e-01	-2.2119000e-02
8.2604500e-01	-1.8185000e-02
8.3651200e-01	-1.4502000e-02
8.4728500e-01	-1.1897000e-02
8.5815400e-01	-9.6670000e-03
8.6904400e-01	-7.5350000e-03
8.7995900e-01	-5.5390000e-03
8.9090500e-01	-3.7200000e-03
9.0188600e-01	-2.1230000e-03
9.1290200e-01	-8.0000000e-04
9.2395900e-01	-7.0000000e-05
9.3503200e-01	-7.7900000e-04
9.4608600e-01	-1.7500000e-03
9.5713100e-01	-2.8160000e-03
9.6818100e-01	-3.8210000e-03
9.7925100e-01	-4.5870000e-03
9.9034200e-01	-4.8340000e-03
1.0000000e+00	0.0000000e+00

A.13 Airfoil 2 Measured Coordinates ($\frac{x}{c}$,$\frac{y}{c}$)

1.0000000e+00	0.0000000e+00
9.9317900e-01	7.4550000e-03
9.8281300e-01	1.0909000e-02
9.7229700e-01	1.3947000e-02
9.6179800e-01	1.7038000e-02
9.5138000e-01	2.0400000e-02
9.4100700e-01	2.3899000e-02
9.3051700e-01	2.7023000e-02
9.1992600e-01	2.9791000e-02
9.0935800e-01	3.2648000e-02
8.9884400e-01	3.5696000e-02
8.8829700e-01	3.8631000e-02
8.7775000e-01	4.1560000e-02
8.6720500e-01	4.4501000e-02
8.5667800e-01	4.7506000e-02
8.4619700e-01	5.0665000e-02
8.3567000e-01	5.3669000e-02
8.2519700e-01	5.6859000e-02
8.1469300e-01	5.9940000e-02
8.0418900e-01	6.3022000e-02
7.9371800e-01	6.6215000e-02
7.8326000e-01	6.9450000e-02
7.7276600e-01	7.2566000e-02
7.6228300e-01	7.5720000e-02
7.5178900e-01	7.8839000e-02
7.4133900e-01	8.2100000e-02
7.3089000e-01	8.5363000e-02
7.2040000e-01	8.8493000e-02
7.0992500e-01	9.1674000e-02
6.9941700e-01	9.4743000e-02
6.8890800e-01	9.7808000e-02
6.7842000e-01	1.0094800e-01
6.6791500e-01	1.0402500e-01
6.5738200e-01	1.0700700e-01
6.4684100e-01	1.0996200e-01
6.3629900e-01	1.1291200e-01
6.2581800e-01	1.1607500e-01
6.1523300e-01	1.1886400e-01
6.0464700e-01	1.2165300e-01
5.9407300e-01	1.2448600e-01
5.8349500e-01	1.2730100e-01
5.7288900e-01	1.2998800e-01
5.6220000e-01	1.3235200e-01
5.5152100e-01	1.3475600e-01
5.4090000e-01	1.3741000e-01
5.3020500e-01	1.3974300e-01
5.1949300e-01	1.4200200e-01
5.0873700e-01	1.4402800e-01
4.9794800e-01	1.4587700e-01
4.8718900e-01	1.4789600e-01
4.7636800e-01	1.4955800e-01
4.6551900e-01	1.5100600e-01
4.5469700e-01	1.5264800e-01
4.4385000e-01	1.5408800e-01
4.3296300e-01	1.5523800e-01
4.2208700e-01	1.5647700e-01
4.1119000e-01	1.5748200e-01
4.0026300e-01	1.5815200e-01
3.8935200e-01	1.5903800e-01
3.7841000e-01	1.5933800e-01
3.6747400e-01	1.5984800e-01
3.5652900e-01	1.5969100e-01
3.4558200e-01	1.5971500e-01
3.3463800e-01	1.5961000e-01
3.2371000e-01	1.5896300e-01
3.1280000e-01	1.5807300e-01
3.0190000e-01	1.5705600e-01
2.9100800e-01	1.5596300e-01
2.8011700e-01	1.5485400e-01
2.6929900e-01	1.5317400e-01
2.5846400e-01	1.5161700e-01
2.4767200e-01	1.4978700e-01
2.3691000e-01	1.4778400e-01
2.2617700e-01	1.4563600e-01
2.1556300e-01	1.4296100e-01
2.0492300e-01	1.4038300e-01
1.9435300e-01	1.3753500e-01
1.8383100e-01	1.3451500e-01
1.7330900e-01	1.3149300e-01
1.6289800e-01	1.2811000e-01
1.5243700e-01	1.2488800e-01
1.4218900e-01	1.2105200e-01
1.3202300e-01	1.1699300e-01
1.2186100e-01	1.1292400e-01
1.1177100e-01	1.0867600e-01
1.0182900e-01	1.0409600e-01
9.1989000e-02	9.9297000e-02
8.2297000e-02	9.4208000e-02
7.2775000e-02	8.8818000e-02
6.3441000e-02	8.3099000e-02
5.4325000e-02	7.7041000e-02
4.5416000e-02	7.0680000e-02
3.6821000e-02	6.3902000e-02
2.8625000e-02	5.6649000e-02
2.0823000e-02	4.8971000e-02
1.3801000e-02	4.0575000e-02
7.7850000e-03	3.1446000e-02
3.2320000e-03	2.1501000e-02
4.8000000e-04	1.0934000e-02
0.0000000e+00	0.0000000e+00
1.8160000e-03	-1.0627000e-02
4.4710000e-03	-2.1074000e-02
8.9740000e-03	-3.0886000e-02
1.4805000e-02	-3.9937000e-02
2.1818000e-02	-4.8122000e-02
2.9643000e-02	-5.5560000e-02
3.8172000e-02	-6.2176000e-02
4.7280000e-02	-6.7966000e-02
5.6527000e-02	-7.3544000e-02
6.5924000e-02	-7.8860000e-02
7.5490000e-02	-8.3874000e-02
8.5189000e-02	-8.8616000e-02
9.5021000e-02	-9.3081000e-02
1.0501100e-01	-9.7171000e-02
1.1512700e-01	-1.0095100e-01
1.2530700e-01	-1.0455800e-01
1.3546700e-01	-1.0821600e-01
1.4581700e-01	-1.1129200e-01
1.5620300e-01	-1.1424800e-01
1.6662300e-01	-1.1707200e-01
1.7713100e-01	-1.1956600e-01
1.8766200e-01	-1.2195200e-01
1.9830100e-01	-1.2380400e-01
2.0894500e-01	-1.2563500e-01
2.1960300e-01	-1.2737500e-01
2.3026800e-01	-1.2906000e-01
2.4099100e-01	-1.3034000e-01
2.5173500e-01	-1.3144100e-01
2.6249400e-01	-1.3236600e-01
2.7326300e-01	-1.3317100e-01
2.8405500e-01	-1.3359300e-01
2.9484400e-01	-1.3405100e-01
3.0563900e-01	-1.3436800e-01
3.1643200e-01	-1.3474000e-01
3.2722700e-01	-1.3489100e-01
3.3802400e-01	-1.3465100e-01
3.4882000e-01	-1.3449000e-01
3.5960400e-01	-1.3390400e-01
3.7036400e-01	-1.3297900e-01
3.8112300e-01	-1.3204200e-01
3.9187200e-01	-1.3101400e-01
4.0257800e-01	-1.2959900e-01
4.1329100e-01	-1.2824100e-01
4.2397600e-01	-1.2666900e-01
4.3465400e-01	-1.2506400e-01
4.4520200e-01	-1.2274800e-01
4.5576700e-01	-1.2050800e-01
4.6634500e-01	-1.1833200e-01
4.7692400e-01	-1.1615900e-01
4.8749300e-01	-1.1395600e-01
4.9795400e-01	-1.1127700e-01
5.0850100e-01	-1.0895800e-01
5.1904100e-01	-1.0660400e-01
5.2944400e-01	-1.0370600e-01
5.3987000e-01	-1.0089100e-01
5.5022400e-01	-9.7820000e-02
5.6060400e-01	-9.4843000e-02
5.7097500e-01	-9.1832000e-02
5.8132900e-01	-8.8759000e-02
5.9166500e-01	-8.5629000e-02
6.0195000e-01	-8.2339000e-02
6.1225600e-01	-7.9112000e-02
6.2260200e-01	-7.6013000e-02
6.3288100e-01	-7.2700000e-02
6.4311800e-01	-6.9261000e-02
6.5336200e-01	-6.5842000e-02
6.6359200e-01	-6.2384000e-02
6.7380000e-01	-5.8857000e-02
6.8401000e-01	-5.5339000e-02
6.9430300e-01	-5.2071000e-02
7.0467700e-01	-4.9067000e-02
7.1501200e-01	-4.5933000e-02
7.2525600e-01	-4.2517000e-02
7.3542300e-01	-3.8875000e-02
7.4564300e-01	-3.5386000e-02
7.5586300e-01	-3.1895000e-02
7.6608700e-01	-2.8416000e-02
7.7637400e-01	-2.5133000e-02
7.8670500e-01	-2.1984000e-02
7.9695000e-01	-1.8567000e-02
8.0728300e-01	-1.5429000e-02
8.1772000e-01	-1.2656000e-02
8.2821900e-01	-1.0124000e-02
8.3874000e-01	-7.6860000e-03
8.4940000e-01	-5.9910000e-03
8.6012600e-01	-4.7410000e-03

8.7086800e-01	-3.6170000e-03
8.8163300e-01	-2.7710000e-03
8.9232000e-01	-1.2170000e-03
9.0301400e-01	2.8700000e-04
9.1372200e-01	1.6930000e-03
9.2448700e-01	2.5230000e-03
9.3527700e-01	2.7300000e-03
9.4607000e-01	2.3590000e-03
9.5686000e-01	1.9010000e-03
9.6765100e-01	1.4870000e-03
9.7842800e-01	7.8100000e-04
9.8921100e-01	1.7800000e-04
1.0000000e+00	0.0000000e+00

A.14 Airfoil 3 Measured Coordinates ($\frac{x}{c}$,$\frac{y}{c}$)

1.0000000e+00	0.0000000e+00
9.9070200e-01	4.7780000e-03
9.8052200e-01	8.0840000e-03
9.7023400e-01	1.1054000e-02
9.5991800e-01	1.3924000e-02
9.4953800e-01	1.6549000e-02
9.3911300e-01	1.8984000e-02
9.2877700e-01	2.1785000e-02
9.1846800e-01	2.4681000e-02
9.0819100e-01	2.7685000e-02
8.9773800e-01	2.9989000e-02
8.8728800e-01	3.2323000e-02
8.7684000e-01	3.4668000e-02
8.6641100e-01	3.7101000e-02
8.5598800e-01	3.9555000e-02
8.4556100e-01	4.1995000e-02
8.3516600e-01	4.4563000e-02
8.2477700e-01	4.7162000e-02
8.1437700e-01	4.9708000e-02
8.0401400e-01	5.2405000e-02
7.9364500e-01	5.5081000e-02
7.8326200e-01	5.7699000e-02
7.7291200e-01	6.0445000e-02
7.6255600e-01	6.3172000e-02
7.5218000e-01	6.5819000e-02
7.4182200e-01	6.8535000e-02
7.3143900e-01	7.1153000e-02
7.2108700e-01	7.3889000e-02
7.1069000e-01	7.6449000e-02
7.0030100e-01	7.9043000e-02
6.8992900e-01	8.1698000e-02
6.7954100e-01	8.4299000e-02
6.6912300e-01	8.6773000e-02
6.5874200e-01	8.9399000e-02
6.4832200e-01	9.1867000e-02
6.3793100e-01	9.4455000e-02
6.2749800e-01	9.6865000e-02
6.1707100e-01	9.9301000e-02
6.0661700e-01	1.0162100e-01
5.9616600e-01	1.0395200e-01
5.8568300e-01	1.0613200e-01
5.7517600e-01	1.0820100e-01
5.6468500e-01	1.1034200e-01
5.5417700e-01	1.1240500e-01
5.4364600e-01	1.1434400e-01
5.3309900e-01	1.1619400e-01
5.2253700e-01	1.1795900e-01
5.1198400e-01	1.1977900e-01
5.0140200e-01	1.2141400e-01
4.9082400e-01	1.2307100e-01
4.8022100e-01	1.2457300e-01
4.6959800e-01	1.2592300e-01
4.5896300e-01	1.2716500e-01
4.4832100e-01	1.2834600e-01
4.3765500e-01	1.2930500e-01
4.2699600e-01	1.3032800e-01
4.1632000e-01	1.3113900e-01
4.0563600e-01	1.3185400e-01
3.9493700e-01	1.3226400e-01
3.8424000e-01	1.3275100e-01
3.7353600e-01	1.3306400e-01
3.6283100e-01	1.3330500e-01
3.5212400e-01	1.3325700e-01
3.4141700e-01	1.3308000e-01
3.3071600e-01	1.3268400e-01
3.2001700e-01	1.3223000e-01
3.0932100e-01	1.3172700e-01
2.9864600e-01	1.3088600e-01
2.8797900e-01	1.2994500e-01
2.7731800e-01	1.2894200e-01
2.6668400e-01	1.2768400e-01
2.5606700e-01	1.2630700e-01
2.4548700e-01	1.2466000e-01
2.3487600e-01	1.2323000e-01
2.2435000e-01	1.2126900e-01
2.1381500e-01	1.1934600e-01
2.0331000e-01	1.1727500e-01
1.9284300e-01	1.1501600e-01
1.8242000e-01	1.1256000e-01
1.7203600e-01	1.0994400e-01
1.6168800e-01	1.0719200e-01
1.5138300e-01	1.0427900e-01
1.4116000e-01	1.0109400e-01
1.3097100e-01	9.7803000e-02
1.2085100e-01	9.4303000e-02
1.1080100e-01	9.0609000e-02
1.0082400e-01	8.6721000e-02
9.0955000e-02	8.2566000e-02
8.1262000e-02	7.8014000e-02
7.1615000e-02	7.3366000e-02
6.2173000e-02	6.8319000e-02
5.2943000e-02	6.2891000e-02
4.3865000e-02	5.7213000e-02
3.5085000e-02	5.1084000e-02
2.6685000e-02	4.4447000e-02
1.8719000e-02	3.7296000e-02
1.1680000e-02	2.9237000e-02
5.6690000e-03	2.0387000e-02
1.4000000e-03	1.0597000e-02
-0.0000000e+00	-0.0000000e+00
1.4140000e-03	-1.0420000e-02
5.7230000e-03	-2.0050000e-02
1.2363000e-02	-2.8272000e-02
2.0209000e-02	-3.5380000e-02
2.8548000e-02	-4.1898000e-02
3.7206000e-02	-4.7988000e-02
4.6404000e-02	-5.3228000e-02
5.5832000e-02	-5.8049000e-02
6.5360000e-02	-6.2662000e-02
7.5100000e-02	-6.6813000e-02
8.4936000e-02	-7.0733000e-02
9.4869000e-02	-7.4401000e-02
1.0495500e-01	-7.7621000e-02
1.1507500e-01	-8.0737000e-02
1.2528700e-01	-8.3536000e-02
1.3554100e-01	-8.6174000e-02
1.4584600e-01	-8.8611000e-02
1.5616700e-01	-9.0977000e-02
1.6652900e-01	-9.3153000e-02
1.7690900e-01	-9.5245000e-02
1.8733800e-01	-9.7072000e-02
1.9779100e-01	-9.8757000e-02
2.0822700e-01	-1.0052300e-01
2.1872700e-01	-1.0189000e-01
2.2923600e-01	-1.0318800e-01
2.3975500e-01	-1.0439700e-01
2.5029400e-01	-1.0541500e-01
2.6085200e-01	-1.0622300e-01
2.7141000e-01	-1.0701900e-01
2.8198700e-01	-1.0749500e-01
2.9256600e-01	-1.0793900e-01
3.0315000e-01	-1.0824800e-01
3.1373800e-01	-1.0837500e-01
3.2432600e-01	-1.0841700e-01
3.3491200e-01	-1.0833200e-01
3.4549600e-01	-1.0802500e-01
3.5608300e-01	-1.0781900e-01
3.6665800e-01	-1.0729300e-01
3.7723200e-01	-1.0673200e-01
3.8778800e-01	-1.0590500e-01
3.9834800e-01	-1.0513100e-01
4.0888400e-01	-1.0408800e-01
4.1941200e-01	-1.0295200e-01
4.2992900e-01	-1.0172800e-01
4.4044800e-01	-1.0051500e-01
4.5094300e-01	-9.9110000e-02
4.6142100e-01	-9.7589000e-02
4.7188900e-01	-9.5992000e-02
4.8235200e-01	-9.4382000e-02
4.9277600e-01	-9.2520000e-02
5.0319900e-01	-9.0655000e-02
5.1360300e-01	-8.8686000e-02
5.2400700e-01	-8.6720000e-02
5.3434200e-01	-8.4424000e-02
5.4466900e-01	-8.2083000e-02
5.5499600e-01	-7.9743000e-02
5.6533000e-01	-7.7433000e-02
5.7566800e-01	-7.5143000e-02
5.8600100e-01	-7.2831000e-02
5.9631000e-01	-7.0415000e-02
6.0660300e-01	-6.7934000e-02
6.1689000e-01	-6.5425000e-02
6.2717500e-01	-6.2908000e-02
6.3745200e-01	-6.0371000e-02
6.4762100e-01	-5.7422000e-02
6.5789200e-01	-5.4848000e-02
6.6820500e-01	-5.2447000e-02
6.7857100e-01	-5.0288000e-02
6.8889800e-01	-4.7959000e-02
6.9897600e-01	-4.4712000e-02
7.0908500e-01	-4.1565000e-02
7.1925300e-01	-3.8610000e-02
7.2957700e-01	-3.6280000e-02
7.3995600e-01	-3.4182000e-02
7.5029100e-01	-3.1886000e-02
7.6049400e-01	-2.9053000e-02
7.7067700e-01	-2.6152000e-02
7.8089400e-01	-2.3369000e-02
7.9124900e-01	-2.1183000e-02
8.0165800e-01	-1.9240000e-02
8.1197700e-01	-1.6866000e-02
8.2228900e-01	-1.4461000e-02
8.3262100e-01	-1.2145000e-02
8.4293300e-01	-9.7390000e-03
8.5328200e-01	-7.5000000e-03
8.6365300e-01	-5.3640000e-03
8.7405200e-01	-3.3740000e-03
8.8453600e-01	-1.9090000e-03
8.9509300e-01	-1.1410000e-03
9.0567400e-01	-7.2900000e-04
9.1625400e-01	-3.1700000e-04
9.2684000e-01	-8.5000000e-05
9.3741500e-01	-5.8100000e-04
9.4799900e-01	-9.0600000e-04
9.5857700e-01	-1.3520000e-03
9.6915800e-01	-1.7560000e-03
9.7973900e-01	-2.1370000e-03
9.9032800e-01	-2.2230000e-03
1.0000000e+00	-0.0000000e+00

A.15 Airfoil 4 Measured Coordinates ($\frac{x}{c}$,$\frac{y}{c}$)

1.0000000e+00	0.0000000e+00
9.9092100e-01	5.1800000e-03
9.8083800e-01	7.9350000e-03
9.7053100e-01	9.9720000e-03
9.6022500e-01	1.2010000e-02
9.4991800e-01	1.4044000e-02
9.3954000e-01	1.5681000e-02
9.2915900e-01	1.7300000e-02
9.1878700e-01	1.8972000e-02
9.0842400e-01	2.0705000e-02
8.9807400e-01	2.2504000e-02
8.8773700e-01	2.4384000e-02
8.7741600e-01	2.6348000e-02
8.6709800e-01	2.8328000e-02
8.5678400e-01	3.0330000e-02
8.4648400e-01	3.2397000e-02
8.3620000e-01	3.4547000e-02
8.2590800e-01	3.6656000e-02
8.1560100e-01	3.8697000e-02
8.0531300e-01	4.0825000e-02
7.9504000e-01	4.3026000e-02
7.8473800e-01	4.5086000e-02
7.7443900e-01	4.7163000e-02
7.6415100e-01	4.9294000e-02
7.5387300e-01	5.1470000e-02
7.4359500e-01	5.3647000e-02
7.3330700e-01	5.5776000e-02
7.2300000e-01	5.7815000e-02
7.1269500e-01	5.9861000e-02
7.0239500e-01	6.1930000e-02
6.9210000e-01	6.4027000e-02
6.8178700e-01	6.6032000e-02
6.7146500e-01	6.7993000e-02
6.6115200e-01	6.9996000e-02
6.5083000e-01	7.1952000e-02
6.4048800e-01	7.3807000e-02
6.3016200e-01	7.5744000e-02
6.1984100e-01	7.7708000e-02
6.0948000e-01	7.9445000e-02
5.9911100e-01	8.1140000e-02
5.8874500e-01	8.2848000e-02
5.7835300e-01	8.4392000e-02
5.6796400e-01	8.5959000e-02
5.5758100e-01	8.7560000e-02
5.4718200e-01	8.9060000e-02
5.3678100e-01	9.0544000e-02
5.2638100e-01	9.2029000e-02
5.1595300e-01	9.3307000e-02
5.0550800e-01	9.4440000e-02
4.9506300e-01	9.5574000e-02
4.8461200e-01	9.6650000e-02
4.7416200e-01	9.7728000e-02
4.6369900e-01	9.8681000e-02
4.5322900e-01	9.9558000e-02
4.4275400e-01	1.0036800e-01
4.3226900e-01	1.0102200e-01
4.2177900e-01	1.0161400e-01
4.1129000e-01	1.0220600e-01
4.0079400e-01	1.0267900e-01
3.9029500e-01	1.0304800e-01
3.7979200e-01	1.0330500e-01
3.6928700e-01	1.0345700e-01
3.5878100e-01	1.0344000e-01
3.4827500e-01	1.0336400e-01
3.3777000e-01	1.0318800e-01
3.2726800e-01	1.0290000e-01
3.1676900e-01	1.0252100e-01
3.0627800e-01	1.0195200e-01
2.9578800e-01	1.0136700e-01
2.8530400e-01	1.0069900e-01
2.7484200e-01	9.9729000e-02
2.6438000e-01	9.8772000e-02
2.5392600e-01	9.7729000e-02
2.4348500e-01	9.6561000e-02
2.3306200e-01	9.5243000e-02
2.2264700e-01	9.3860000e-02
2.1222700e-01	9.2517000e-02
2.0184200e-01	9.0933000e-02
1.9148700e-01	8.9160000e-02
1.8113800e-01	8.7348000e-02
1.7082600e-01	8.5336000e-02
1.6055900e-01	8.3109000e-02
1.5029000e-01	8.0890000e-02
1.4006600e-01	7.8471000e-02
1.2988300e-01	7.5884000e-02
1.1973800e-01	7.3155000e-02
1.0962000e-01	7.0327000e-02
9.9562000e-02	6.7289000e-02
8.9581000e-02	6.4012000e-02
7.9667000e-02	6.0537000e-02
6.9829000e-02	5.6849000e-02
6.0109000e-02	5.2864000e-02
5.0555000e-02	4.8495000e-02
4.1141000e-02	4.3841000e-02
3.2014000e-02	3.8637000e-02
2.3168000e-02	3.2972000e-02
1.4933000e-02	2.6464000e-02
7.4840000e-03	1.9080000e-02
1.8620000e-03	1.0255000e-02
0.0000000e+00	0.0000000e+00
2.1100000e-03	-1.0140000e-02
6.5940000e-03	-1.9550000e-02
1.4031000e-02	-2.6457000e-02
2.3060000e-02	-3.1670000e-02
3.2227000e-02	-3.6639000e-02
4.1615000e-02	-4.1174000e-02
5.1131000e-02	-4.5438000e-02
6.0984000e-02	-4.8814000e-02
7.0999000e-02	-5.1721000e-02
8.1024000e-02	-5.4587000e-02
9.1186000e-02	-5.6924000e-02
1.0134900e-01	-5.9260000e-02
1.1152500e-01	-6.1535000e-02
1.2173800e-01	-6.3639000e-02
1.3196500e-01	-6.5675000e-02
1.4220100e-01	-6.7665000e-02
1.5248300e-01	-6.9394000e-02
1.6278700e-01	-7.0996000e-02
1.7307500e-01	-7.2692000e-02
1.8339100e-01	-7.4212000e-02
1.9371100e-01	-7.5707000e-02
2.0405500e-01	-7.7027000e-02
2.1442000e-01	-7.8168000e-02
2.2479100e-01	-7.9253000e-02
2.3515500e-01	-8.0399000e-02
2.4555600e-01	-8.1090000e-02
2.5596800e-01	-8.1649000e-02
2.6637900e-01	-8.2252000e-02
2.7679400e-01	-8.2747000e-02
2.8721200e-01	-8.3201000e-02
2.9763100e-01	-8.3616000e-02
3.0805300e-01	-8.3963000e-02
3.1848000e-01	-8.4078000e-02
3.2890500e-01	-8.4291000e-02
3.3933200e-01	-8.4258000e-02
3.4975800e-01	-8.4080000e-02
3.6018100e-01	-8.3762000e-02
3.7060300e-01	-8.3435000e-02
3.8102600e-01	-8.3116000e-02
3.9143800e-01	-8.2572000e-02
4.0183600e-01	-8.1786000e-02
4.1222700e-01	-8.0910000e-02
4.2261100e-01	-7.9954000e-02
4.3299600e-01	-7.9019000e-02
4.4338300e-01	-7.8099000e-02
4.5375200e-01	-7.6992000e-02
4.6412300e-01	-7.5912000e-02
4.7449500e-01	-7.4837000e-02
4.8486000e-01	-7.3699000e-02
4.9520800e-01	-7.2409000e-02
5.0554100e-01	-7.1009000e-02
5.1586200e-01	-6.9527000e-02
5.2617600e-01	-6.7992000e-02
5.3646300e-01	-6.6284000e-02
5.4676900e-01	-6.4695000e-02
5.5708000e-01	-6.3143000e-02
5.6738000e-01	-6.1519000e-02
5.7765700e-01	-5.9755000e-02
5.8794000e-01	-5.8019000e-02
5.9822500e-01	-5.6304000e-02
6.0851300e-01	-5.4604000e-02
6.1877900e-01	-5.2776000e-02
6.2901200e-01	-5.0769000e-02
6.3924800e-01	-4.8779000e-02
6.4951400e-01	-4.6953000e-02
6.5977800e-01	-4.5110000e-02
6.7004100e-01	-4.3269000e-02
6.8026200e-01	-4.1206000e-02
6.9048500e-01	-3.9148000e-02
7.0071800e-01	-3.7142000e-02
7.1094600e-01	-3.5111000e-02
7.2113700e-01	-3.2906000e-02
7.3132800e-01	-3.0696000e-02
7.4154400e-01	-2.8605000e-02
7.5176000e-01	-2.6514000e-02
7.6198400e-01	-2.4467000e-02
7.7224900e-01	-2.2635000e-02
7.8253500e-01	-2.0919000e-02
7.9282300e-01	-1.9221000e-02
8.0312300e-01	-1.7597000e-02
8.1344400e-01	-1.6107000e-02
8.2377200e-01	-1.4670000e-02
8.3411500e-01	-1.3343000e-02
8.4446600e-01	-1.2081000e-02
8.5483800e-01	-1.1017000e-02
8.6522500e-01	-1.0096000e-02
8.7562000e-01	-9.2760000e-03
8.8602000e-01	-8.5190000e-03
8.9642500e-01	-7.8250000e-03
9.0684000e-01	-7.3090000e-03
9.1725800e-01	-6.8760000e-03
9.2767900e-01	-6.5100000e-03
9.3810200e-01	-6.1970000e-03
9.4852600e-01	-5.9230000e-03
9.5895100e-01	-5.6680000e-03
9.6937400e-01	-5.3900000e-03
9.7975600e-01	-4.4280000e-03
9.9008800e-01	-3.0350000e-03
1.0000000e+00	0.0000000e+00

A.16 Airfoil 5 Measured Coordinates ($\frac{x}{c}$,$\frac{y}{c}$)

1.0000000e+00	0.0000000e+00
9.9029500e-01	3.1390000e-03
9.8009400e-01	5.1140000e-03
9.6982400e-01	6.6560000e-03
9.5951200e-01	7.9400000e-03
9.4920100e-01	9.2230000e-03
9.3888900e-01	1.0507000e-02
9.2858000e-01	1.1808000e-02
9.1828800e-01	1.3244000e-02
9.0799700e-01	1.4681000e-02
8.9770600e-01	1.6118000e-02
8.8741600e-01	1.7562000e-02
8.7714700e-01	1.9148000e-02
8.6688800e-01	2.0805000e-02
8.5662300e-01	2.2417000e-02
8.4636600e-01	2.4082000e-02
8.3611400e-01	2.5774000e-02
8.2586100e-01	2.7463000e-02
8.1561500e-01	2.9192000e-02
8.0538000e-01	3.0986000e-02
7.9515100e-01	3.2816000e-02
7.8491100e-01	3.4581000e-02
7.7465800e-01	3.6272000e-02
7.6440700e-01	3.7970000e-02
7.5416100e-01	3.9703000e-02
7.4391300e-01	4.1422000e-02
7.3366800e-01	4.3153000e-02
7.2342900e-01	4.4928000e-02
7.1318700e-01	4.6680000e-02
7.0293400e-01	4.8370000e-02
6.9268500e-01	5.0083000e-02
6.8244100e-01	5.1823000e-02
6.7219000e-01	5.3523000e-02
6.6193200e-01	5.5184000e-02
6.5167000e-01	5.6818000e-02
6.4139600e-01	5.8372000e-02
6.3112300e-01	5.9936000e-02
6.2085800e-01	6.1545000e-02
6.1058300e-01	6.3099000e-02

6.0028600e-01	6.4492000e-02
5.8998000e-01	6.5821000e-02
5.7967600e-01	6.7162000e-02
5.6937300e-01	6.8514000e-02
5.5907300e-01	6.9883000e-02
5.4877200e-01	7.1250000e-02
5.3846000e-01	7.2525000e-02
5.2814400e-01	7.3777000e-02
5.1782900e-01	7.5029000e-02
5.0749400e-01	7.6108000e-02
4.9715400e-01	7.7132000e-02
4.8680100e-01	7.8027000e-02
4.7643900e-01	7.8805000e-02
4.6607400e-01	7.9533000e-02
4.5570500e-01	8.0208000e-02
4.4533500e-01	8.0873000e-02
4.3496200e-01	8.1477000e-02
4.2457900e-01	8.1911000e-02
4.1419900e-01	8.2379000e-02
4.0381300e-01	8.2702000e-02
3.9342700e-01	8.3030000e-02
3.8303900e-01	8.3303000e-02
3.7265100e-01	8.3525000e-02
3.6226000e-01	8.3601000e-02
3.5186900e-01	8.3564000e-02
3.4147900e-01	8.3398000e-02
3.3109000e-01	8.3208000e-02
3.2070200e-01	8.2954000e-02
3.1031500e-01	8.2654000e-02
2.9993600e-01	8.2169000e-02
2.8956500e-01	8.1537000e-02
2.7919700e-01	8.0837000e-02
2.6883300e-01	8.0092000e-02
2.5846800e-01	7.9349000e-02
2.4811300e-01	7.8487000e-02
2.3776800e-01	7.7505000e-02
2.2743800e-01	7.6386000e-02
2.1711800e-01	7.5171000e-02
2.0680800e-01	7.3876000e-02
1.9650400e-01	7.2534000e-02
1.8621500e-01	7.1082000e-02
1.7595100e-01	6.9465000e-02
1.6569700e-01	6.7780000e-02
1.5545300e-01	6.6039000e-02
1.4522300e-01	6.4213000e-02
1.3501200e-01	6.2288000e-02
1.2486400e-01	6.0057000e-02
1.1474500e-01	5.7694000e-02
1.0464700e-01	5.5243000e-02
9.4587000e-02	5.2644000e-02
8.4596000e-02	4.9787000e-02
7.4636000e-02	4.6826000e-02
6.4733000e-02	4.3680000e-02
5.4926000e-02	4.0251000e-02
4.5263000e-02	3.6430000e-02
3.5668000e-02	3.2445000e-02
2.6242000e-02	2.8070000e-02
1.6874000e-02	2.3574000e-02
7.9000000e-03	1.8347000e-02
1.7140000e-03	1.0191000e-02
0.0000000e+00	-0.0000000e+00
2.4270000e-03	-1.0028000e-02
7.7830000e-03	-1.8901000e-02
1.5657000e-02	-2.5574000e-02
2.4486000e-02	-3.1055000e-02
3.3947000e-02	-3.5332000e-02
4.3731000e-02	-3.8811000e-02
5.3709000e-02	-4.1718000e-02
6.3778000e-02	-4.4297000e-02
7.3957000e-02	-4.6375000e-02
8.4183000e-02	-4.8231000e-02
9.4410000e-02	-5.0083000e-02
1.0465200e-01	-5.1850000e-02
1.1488600e-01	-5.3665000e-02
1.2515400e-01	-5.5269000e-02
1.3544300e-01	-5.6740000e-02
1.4573900e-01	-5.8153000e-02
1.5606300e-01	-5.9353000e-02
1.6638400e-01	-6.0574000e-02
1.7670200e-01	-6.1829000e-02
1.8701200e-01	-6.3145000e-02
1.9733700e-01	-6.4328000e-02
2.0766600e-01	-6.5484000e-02
2.1801700e-01	-6.6419000e-02
2.2838000e-01	-6.7218000e-02
2.3874500e-01	-6.7979000e-02
2.4911900e-01	-6.8607000e-02
2.5950000e-01	-6.9132000e-02
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2.8026200e-01	-7.0146000e-02
2.9064600e-01	-7.0579000e-02
3.0103500e-01	-7.0885000e-02
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3.5299300e-01	-7.1746000e-02
3.6338600e-01	-7.1746000e-02
3.7377600e-01	-7.1511000e-02
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4.0492500e-01	-7.0124000e-02
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4.3601100e-01	-6.7754000e-02
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4.8774700e-01	-6.2862000e-02
4.9809400e-01	-6.1886000e-02
5.0843400e-01	-6.0825000e-02
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5.2910000e-01	-5.8591000e-02
5.3943600e-01	-5.7501000e-02
5.4977500e-01	-5.6436000e-02
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5.7045000e-01	-5.4279000e-02
5.8079000e-01	-5.3223000e-02
5.9109600e-01	-5.1890000e-02
6.0137000e-01	-5.0320000e-02
6.1163700e-01	-4.8702000e-02
6.2192000e-01	-4.7190000e-02
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6.4248800e-01	-4.4180000e-02
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6.6307700e-01	-4.1317000e-02
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7.0430200e-01	-3.5944000e-02
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8.7986400e-01	-1.6879000e-02
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9.6294100e-01	-1.3686000e-02
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9.8362300e-01	-1.1761000e-02
9.9322900e-01	-7.8290000e-03
1.0000000e+00	-0.0000000e+00

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