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Report

Definition of the INO WINDMOOR 12 MW base case floating wind turbine

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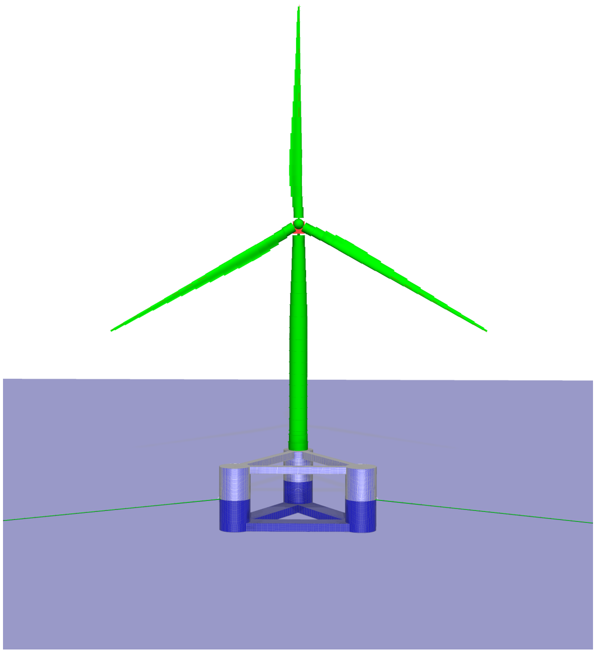

SINTEF Ocean AS
Dept. of Energy and Transport
2022-11-24

SINTEF

WINDMOOR

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ABSTRACT
WINDMOOR is a Competence Building Project (KPN), with the main objective of improving the understanding of loads governing the mooring system design of floating wind turbines (FWTs). As a base case, the project adopts a semi-submersible platform supporting a 12 MW wind turbine. This report describes the platform, mooring system, and wind turbine adopted. A detailed analysis of the platform hydrodynamics is provided, as well as the design of the 12 MW wind turbine developed for the project. Following, a SIMA model for the FWT is presented. The research leading to these results has received funding from the Research Council of Norway through the ENERGIX programme (grant 294573) and industry partners.

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Document History

VERSION	DATE	VERSION DESCRIPTION
1.0	April 3, 2020	First version (project internal report).
1.1	June 3, 2020	Correction of the legends of Tables 3.1 and 3.2. Correction of Table 5.3, with the actual centers of gravity in Z and updated legend.
1.2	January 8, 2021	Update of Table 3.2, with inclusion of the FWT's CG_x and CG_y. Correction of values in Table 5.3, with the actual hub and blades moments of inertia. Update of Table 5.4, with the correct relative positions of sections and complete structural properties,. Minor corrections on platform design procedure and hydrodynamic modelling. Update of wind turbine curves in Appendix B. Inclusion of airfoil coefficients in Appendix C. Adoption of NREL ROSCO controller, with updated description in Section 5.1 and inclusion of documentation in Appendix D.
1.3	Sep 23, 2022	Updated author company affiliation. The WAMIT-result plots showed only every second frequency in Appendix A. The plots have now been updated to show results for all frequencies. Figures of the operational conditions using a general cross-section is included in Appendix E. The table containing the blade properties is split in two tables, Table 5.4 and Table 5.5. The shear center is included in Table 5.5. An error in the torsional stiffness in the definition of the cross section properties is also corrected.
1.4	Nov 24, 2022	Updated the airfoil data. The columns with C_l and C_d were swapped, i.e. lift was given in the column with the C_d.

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Acknowledgements

The research leading to these results has received funding from the Research Council of Norway through the ENERGIX programme (grant 294573) and industry partners Equinor, MacGregor, Inocean, APL Norway and RWE Renewables.

The authors are grateful for the permission to use the INO WINDMOOR semisubmersible, which is jointly designed by Inocean and Equinor.

* Espen Engebretsen is no longer employeed at Inocean.

1 Introduction

1.1 Objective

This report is part of the Research Council funded KPN-project WINDMOOR: Advanced Wave and Wind Load Models for Floating Wind Turbine Mooring System Design. The report describes the INO WINDMOOR 12 MW base case floating wind turbine, and an aero-hydro-servo-elastic model implemented in SIMA.

1.2 Background

WINDMOOR is a 4-year Competence Building Project (KPN) funded by the Research Council of Norway and industry partners [1] (grant 294573). The main objective of the project is to improve the understanding of loads governing the mooring system design of floating wind turbines (FWTs). The scope involves validation of low-frequency hydrodynamic models; better understanding of atmospheric stability and aerodynamic interaction between turbines; and global analysis of FWTs in farm formation, with focus on mooring lines.

The numerical analyses in the project are made with SIMA. By combining SIMO [2] and RIFLEX [3], SIMA merges state-of-art models for hydrodynamic loads, slender structure analysis, and aerodynamics – making it an adequate tool for FWT analysis, especially with focus on mooring systems. When combined with DIWA [4], which generates the wind field in wake situations, SIMA can also be used in wind park configurations. In addition to generating the wake wind field that can be used as input to RIFLEX or SIMO simulations, DIWA can also generate thrust and power time for all the wind turbines in a park.

As a base case for the project, the consortium decided to adopt a semi-submersible platform supporting a 12 MW wind turbine. Different participants provided input data for the platform, mooring system, tower, and turbine. This reports describes the SIMA model developed for the base case, with focus on the hydrodynamic analysis and the 12 MW wind turbine developed for the project.

The semisubmersible substructure for the 12 MW wind turbine, INO WINDMOOR, is presented in Section 3, followed by the hydrodynamic analysis with WAMIT in Section 4. The 12 MW wind turbine, described in Section 5.1, was upscaled from the 10 MW wind turbine presented in [5], in combination with public data of the Haliade X 12 MW wind turbine [6]. The upscaling procedure, control system configuration, and performance curves are presented. Finally, Section 6 describes the modeling approach for implementing the INO WINDMOOR 12 MW FWT in SIMA.

1.3 Software

The following simulation tools are used in this report:

SIMA

SIMA is a workbench that offers a complete solution for simulation and analysis of marine operations and floating systems. It supports the entire process from the definition of the simulation and its execution to the interpretation and documentation of the results. SIMA uses software such as SIMO and RIFLEX as the underlying analysis tools. SIMA is developed and owned by SINTEF Ocean and is commercially available from DNV GL Digital Solutions. See www.sintef.no/en/software/sima for more information.

SIMO

SIMO is a time domain simulation program for study of motions and station keeping of multibody systems. Flexible modelling of station keeping forces and connecting force mechanisms (e.g. anchor lines, ropes, thrusters, fenders, bumbers) is included. The results from the program are presented as time traces, statistics and spectral analysis of all forces and motions of all bodies in the analysed system. SIMO is developed and owned by SINTEF Ocean and is commercially available from DNV GL Digital Solutions. See www.sintef.no/globalassets/project/oilandgas/pdf/simo.pdf for more information.

RIFLEX

RIFLEX is an advanced time domain tool for global hydrodynamic and structural analysis (static and dynamic) of slender marine structures. RIFLEX also has advanced wind turbine aerodynamic models, making it suitable for offshore wind applications. In addition, it can be connected to SIMO for coupled analysis of the mooring system and floater response at each time step. See www.sintef.no/globalassets/project/oilandgas/pdf/riflex.pdf for more information.

WAMIT

WAMIT performs linear and second-order diffraction-radiation analyses of floating and submerged bodies in waves, in the frequency domain, based on the panel method. WAMIT is a commercial engineering tool developed by WAMIT Inc. See www.wamit.com for more information.

2 Coordinate systems

Global (Earth-fixed) coordinate system

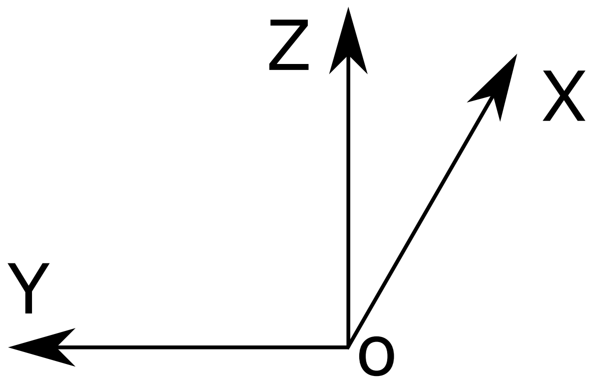
The positions of all the local (body) systems refer to a right-handed, Earth-fixed coordinate system. The XY-plane coincides with the mean water level, and the Z-axis is positive upwards, as shown in Fig. 2.1a. Waves, wind, and current directions are defined such that a incidence direction of 0° corresponds to the positive X-direction.

Local (body-fixed) coordinate system

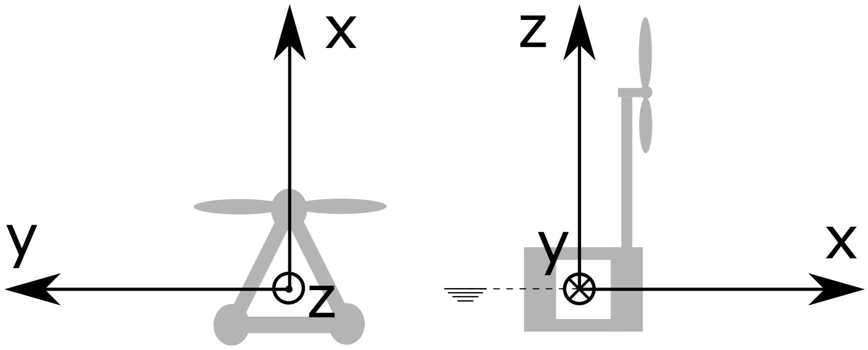
The platform has its own local coordinate system, with origin at mean water level and over the platform's horizontal geometric center (Fig. 2.1b). This system is fixed to the body and translates/rotates along with the body. Load and motion response calculations refer to the local coordinate system.

Water depth

The water depth is 150.0 m, and the sea bottom is assumed to be flat.



(a) Global (Earth-fixed) coordinate system.



(b) Local (body-fixed) coordinate system.

3 Description of the INO WINDMOOR platform.

The floating platform adopted in the project was designed jointly by Inocean and Equinor, and consists of a steel semi-submersible platform with three columns, connected by pontoons and deck beams. The wind turbine tower is installed at the top of one of the columns, as shown in Fig. 3.1. The design was based on an iterative approach with multiple combinations of draft, column diameter/height, pontoon width/height, and columns center-center distance, subjected to constraints on hydrostatics, required ballast, heave/pitch natural periods, and static pitch at rated condition.

Table 3.1 provides the hull main dimensions. The properties for the full system, including tower, wind turbine, and mooring lines, are given in Tab. 3.2. The distances refer to the local coordinate system (Fig. 2.1b).

Figure 3.1: The WINDMOOR 12 MW FWT concept. Figure provided by Inocean.

In addition to the platform, Inocean also provided the baseline mooring system arrangement, consisting of three hybrid (chain + polyester) catenary lines – providing a required pretension of 1050 kN, considering the assumed water depth of 150.0 m. Figure 3.2 shows a bird's-eye view of the mooring system. Tables 3.3 and 3.4 summarize the fairlead/anchor coordinates and the line properties, respectively. The rigid-body FWT natural periods are provided in Tab. 3.5.

Table 3.1: Hull main dimensions and inertia properties (including ballast). The radii of gyration refer to the hull center of gravity (CoG).

Property	Value
Column diameter (m)	15.0
Column height (m)	31.0
Pontoon width (m)	10.0
Pontoon height(m)	4.0
Center-center distance (m)	61.0
Deck beam width (m)	3.5
Deck beam height (m)	3.5
Total substructure mass (t)	11974.0
Total substructure CG_x (m)	-5.91
Total substructure CG_z (m)	-9.7
Total substructure R_{xx} (m)	23.66
Total substructure R_{yy} (m)	18.63
Total substructure R_{zz} (m)	28.10

Table 3.2: Full floating wind turbine main properties. The radii of gyration refer to the FWT CoG, assuming the turbine's own CoG at the tower center.

Property	Value
Displacement (t)	14176.1
Draft (m)	15.5
CG_x^* (m)	[-0.37,0.37]
CG_y^* (m)	[-0.37,0.37]
CG_z (m)	4.23
R_{xx} (m)	43.67
R_{yy} (m)	44.18
R_{zz} (m)	30.26
Static heel angle at rated thrust (deg)	6.4
Still water airgap to column top (m)	15.5
Still water airgap to deck beam bottom (m)	12.0
Still water airgap to blade tip (m)	21.7

* CG_x and CG_y are dependent on the nacelle orientation.
For 0°orientation, $CG_x = 0.37$ m and $CG_y = 0.0$ m.
For 90°orientation, $CG_x = 0.0$ m and $CG_y = 0.37$ m.

Table 3.3: Fairlead and anchor coordinates.

	Fairlead			Anchor			
Mooring line	x (m)	y (m)	z (m)	x (m)	y (m)	z (m)	Azimuth (deg)
ML1	42.7	0.0	0.0	700.0	0.0	-150.0	180
ML2	-21.4	37.0	0.0	-350.0	606.2	-150.0	300
ML3	-21.4	-37.0	0.0	-350.0	-606.2	-150.0	60

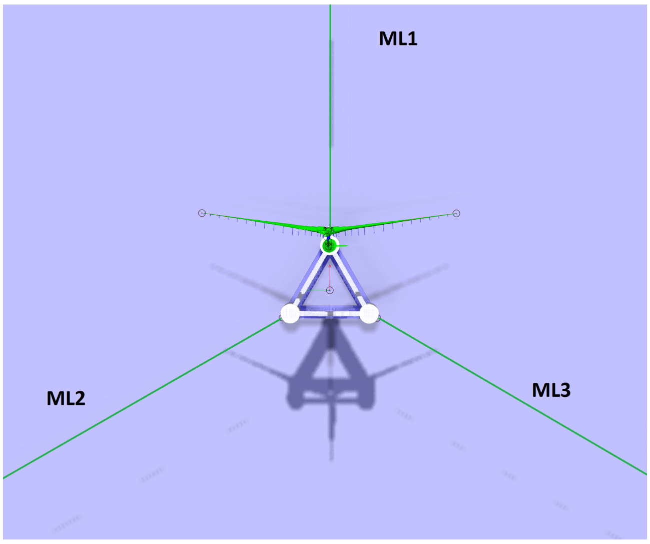


Figure 3.2: Bird's-eye view of the mooring system.

Table 3.4: Mooring line segment properties. The drag coefficients for the chain correspond to the nominal diameter. The mass/length of the first two segments account for additional 100 mm of marine growth, while the two last account for additional 50 mm. The T and L subscripts refer to transversal and longitudinal, respectively.

Seg.	Type	Length (m)	Equiv. diam. (m)	Mass/length (kg/m)	Axial stiff. (MN)	Ca,T (-)	Ca,L (-)	Cd,T (-)	Cd,L (-)
1	130 mm studless chain	25.0	0.234	377.7	1443.0	1.0	0.5	6.1	2.9
2	190 mm polyester	85.0	0.190	60.7	228.0	1.0	0.0	2.5	0.1
3	190 mm polyester	85.0	0.190	46.0	228.0	1.0	0.0	1.8	0.1
4	130 mm studless chain	499.8	0.234	353.6	1443.0	1.0	0.5	4.2	2.0

Table 3.5: FWT rigid-body natural periods, obtained from decay simulations with the SIMA model.

	Surge	Sway	Heave	Roll	Pitch	Yaw
Nat. period (s)	97.3	98.0	16.3	29.5	31.4	88.0

4 Platform hydrodynamic analysis

4.1 Linear diffraction-radiation analysis

The hydrodynamic diffraction-radiation analysis was carried out with WAMIT version 7 [7]. WAMIT is a three-dimensional frequency domain panel code based on linear and second order potential theory for diffraction-radiation analysis of floating and submerged bodies in waves. The purpose of the linear diffraction-radiation analysis is to establish hydrodynamic coefficients such as added mass, wave radiation damping, wave force and drift force coefficients for the SIMA model of the INO WINDMOOR floating wind turbine.

A panel model (see Fig. 4.1) was prepared considering the $x-z$ plane of symmetry ($y = 0$). More properties of the panel model are provided in Tab. 4.1. The panel size is the characteristic length, Δx, of a panel element, and the aim has been to preserve a uniform mesh size where possible. Furthermore, a panel size convergence study was carried out to ensure a reasonable accuracy of the panel model. Results from the convergence study are summarized in Appendix A.1.

The water depth in the analysis was 150.0 m (finite water depth).

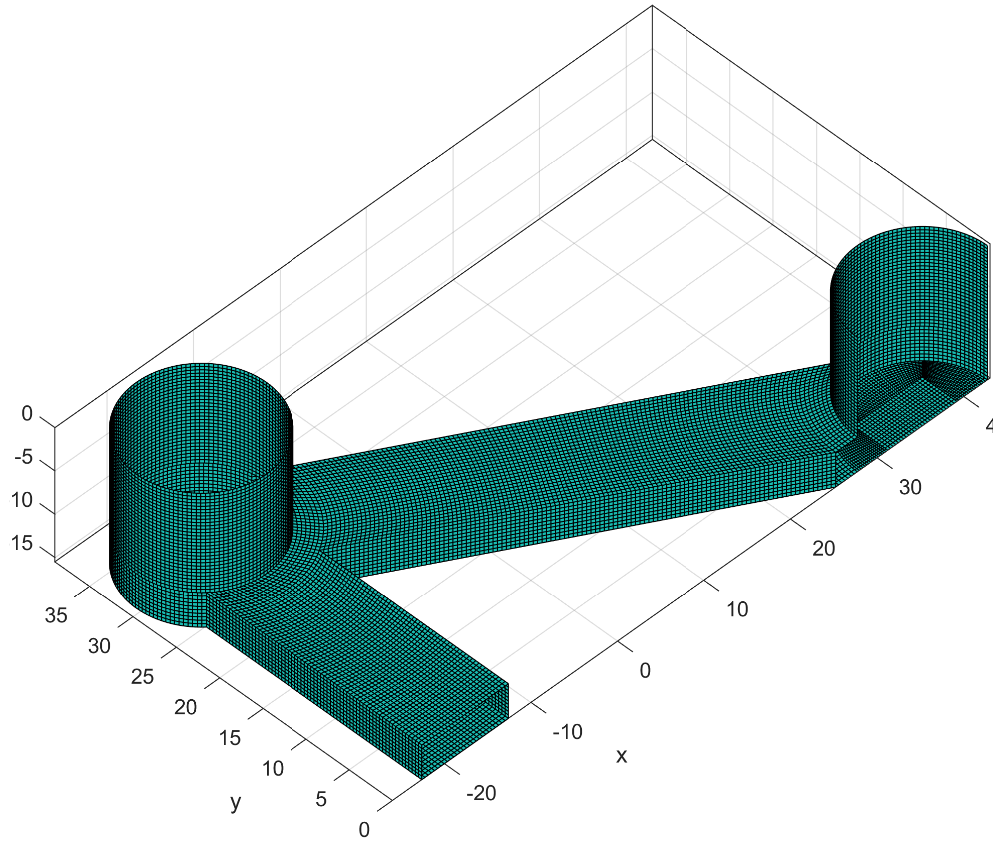


Figure 4.1: WAMIT panel model of the INO WINDMOOR semi with one plane of symmetry.

Table 4.1: Panel model properties.

Panel size [m]	No. of panels [-]	Max aspect ratio [-]	Max panel area [m^2]	Min panel area [m^2]	Submerged volume [m^3]	Waterplane area [m^2]	Vertical centre of buoyancy [m]
0.375	24916	2.6455	0.15309	0.019344	13833.1	530.00	-10.0864

4.2 Mass matrix, linear damping and external stiffness

The radiation-diffraction analysis was carried out assuming a rigid single-body structure (sub-structure, tower, and rotor-nacelle assembly combined). The input mass matrix is the total mass of the floating wind turbine and the values are summarized in Table 4.2. The center of gravity is (0.00, 0.00, 4.23) m.

Table 4.2: Total mass properties of INO WINDMOOR floating wind turbine.

Property	Unit	Value
Mass	kg	14176×10^3
I_{xx}	kg m^2	2.7292×10^{10}
I_{yy}	kg m^2	2.7295×10^{10}
I_{zz}	kg m^2	1.2985×10^{10}

To obtain reasonable motion transfer functions from WAMIT, it is necessary to include some additional linear damping in the computations, as WAMIT only accounts for potential flow and not for viscous damping. In the present case, approximately 5 % of critical heave damping was included in the WAMIT analysis. Similarly, 5 % of critical damping in roll and pitch was also included in the diffraction analysis.

The linear restoring coefficient from the mooring system was included as an external stiffness matrix in the analysis. Only the horizontal components surge, sway and yaw were accounted for with the following values:

$$\begin{aligned} k_{11} &= 89800 \text{ N/m}, \\ k_{22} &= 89800 \text{ N/m}, \\ k_{66} &= 1.2165 \times 10^8 \text{ Nm}. \end{aligned}$$

4.3 Hydrodynamic coefficients – results

Plots of the hydrodynamic coefficients[1] obtained from the WAMIT analysis are shown in Appendix A.2 – A.6. Note that the wave excitation force and the motion transfer functions (RAOs) were calculated using

[1] It is noted that the results do not consider the effect of viscous excitation, which for high sea states and close to the platform's cancellation period (15.2 s) can affect the heave, roll, and pitch responses – and thus the second-order excitation loads. This effect will be assessed more carefully in work package 2 of WINDMOOR.

the diffraction potential. Momentum integration was used for the calculation of mean forces and moment. The iterative solver was used for solving the linear system.

5 Description of the WINDMOOR 12 MW wind turbine

Since a public model for a 12 MW wind turbine was not available, it was decided to upscale one of the well-established reference models available in the literature. In 2013, the Danish University of Technology (DTU) released a model for a 10 MW wind turbine [8], which has been widely accepted by academia. The model includes blade aerodynamic and structural properties; hub, nacelle and drivetrain characteristics; a variable speed/variable pitch (VSVP) control system; and a structural description of the tower (for a land-based wind turbine).

Based on feedback from users of the DTU 10 MW wind turbine, the International Energy Agency Wind Technology Collaboration Programme (IEA Wind TCP) designed a new 10 MW offshore wind turbine model [5]. The main differences from the model issued by DTU are that IEA's turbine has a larger rotor diameter, resulting in a reduced specific power; and that IEA's model uses a direct-drive generator, instead of a medium-speed generator. The model will be hereunder named *IEA 10 MW wind turbine*.

Since the IEA 10 MW wind turbine is more in line with current offshore wind turbine technology, it was chosen as basis for designing the *WINDMOOR 12 MW wind turbine*. The same airfoil shapes are kept, while the blade dimensions and structural properties are increased following standard upscaling laws. The nacelle/hub inertia, on the other hand, are defined based on comparison with public data of GE's *Haliade X* 12 MW wind turbine [6]. In addition, the NREL/ROSCO [9] controller is adopted and configured according to the turbine properties. Table 5.1 summarizes the main properties of the WINDMOOR 12 MW wind turbine, in comparison with the IEA 10 MW model.

5.1 The IEA 10 MW turbine

The specific power of a wind turbine is defined by its nominal rated power divided by the rotor area. By increasing the rotor diameter, the energy capture is increased at below-rated conditions, at the cost of larger loads under higher wind speeds. Despite the structural implications, it has been an industry trend to favor power production by building turbines with lower specific power [10].

With a rotor diameter of 198.0 m (Tab. 5.1), the IEA 10 MW has a specific power of 325 W/m^2 (against 400 W/m^2 for the DTU 10 MW). For comparison, the specific power of the Haliade X 12 MW wind turbine is 315 W/m^2 [6]. The larger rotor area also reduces two other parameters: the rated wind speed; and the rated rotor speed, in order to limit the tip-speed ratio as the blade length increases. The blade prebend is increased, in order to prevent blade collision with the tower. The airfoil series FFA-W3, which is used in the DTU 10 MW model, is also adopted for the IEA 10 MW reference wind turbine.

A direct-drive generator is adopted in the IEA 10 MW model. Despite the higher costs and weight of direct-drive generators, they have already been adopted for large offshore wind turbines (e.g. the Haliade X 12 MW turbine) – presumably to reduce maintenance requirements.

Table 5.1: Main properties of the IEA 10 MW reference wind turbine [5] and of the WINDMOOR 12 MW wind turbine.

Parameter	IEA 10 MW	WINDMOOR 12 MW
Rated electrical power (MW)	10.0	12.0
Specific power (W/m^2)	324.8	324.8
Rotor orientation	Clockwise rotation - upwind	Clockwise rotation - upwind
Number of blades	3	3
Rotor diameter (m)	198.0	216.9
Hub diameter (m)	4.6	5.0
Blade length (m)	96.2	105.4
Blade prebend (m)	6.2	6.8
Shaft tilt (deg)	6.0	6.0
Rotor precone (deg)	-4.0	-4.0
Hub height (m)	119.0	131.7
Cut-in/rated/cut-out wind speed (m/s)	4.0/11.0/25.0	4.0/10.6/25.0
Generator efficiency (%)	94.4	94.4
Cut-in/ rated rotor speed (rpm)	6.0/8.7	5.5/7.8
Maximum Tip Speed (m/s)	90.2	88.6
Blade mass (kg)	3×47,700	3×63,024
Hub mass (kg)	81,707	60,000
Nacelle mass (kg)	621,494	600,000

5.2 Upscaling procedure

The classical upscaling rules for wind turbines were applied to the blades of the IEA 10 MW wind turbine. The upscaling assumes geometric and material similarity, resulting in the scaling procedure of Tab. 5.2 for the rotor dimensions and structural properties [11]. The scaling factor, s, is determined based on the power scaling rule:

$$s = \sqrt{12/10} \approx 1.095\,. \tag{5.1}$$

The scaling rules in Tab. 5.2 are applied to the blade mass distribution[2], but not for the nacelle and hub masses. Instead, for the WINDMOOR 12 MW wind turbine these values are based on public data of

[2]The adopted upscaling rules may not be correct for composite layups, but are assumed to hold in this case.

Table 5.2: Rotor scaling procedure, where s is the scaling factor [11].

Property	Scaling rule
Power	s^2
Mass	s^3
Length	s
Axial stiffness	s^2
Bending stiffness	s^4

the Haliade X 12 MW [12], and the respective moments of inertia are estimated based on the components' masses. As seen in Tab. 5.1, both the hub and nacelle masses are actually reduced compared to the IEA 10 MW turbine, reflecting the current progress in direct-drive generators technology. Table 5.3 shows the centers of mass and moments of inertia of the rotor-nacelle assemble (RNA) components of the WINDMOOR 12 MW model.

Table 5.3: WINDMOOR 12 MW RNA coordinates w.r.t. a frame placed at the tower top (Fig. 5.1), and moments of inertia w.r.t. each component's own CG. The generator inertia is accounted for in the nacelle.

	CG_x (m)	CG_y (m)	CG_z (m)	I_{xx} (kg.m^2)	I_{yy} (kg.m^2)	I_{zz} (kg.m^2)
Hub	10.94	0.00	6.00	1.00×10^6	–	–
Blades	13.23	0.00	6.24	3.25×10^8	1.64×10^8	1.66×10^8
Nacelle	3.30	0.00	3.46	1.00×10^6	7.00×10^6	7.00×10^6

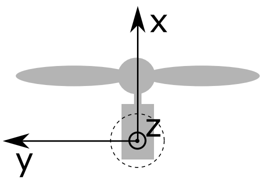
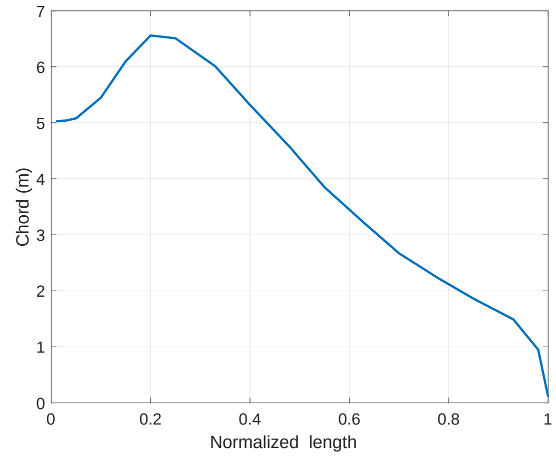


Figure 5.1: RNA coordinate system, placed at the tower top (represented by the dashed circle).

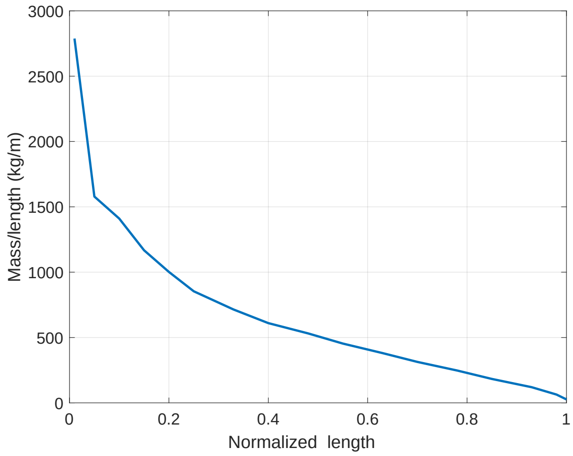
5.3 Rotor

Figure 5.2 shows the chord, mass-per-length, and flapwise/edgewise bending stiffness of the upscaled rotor. The detailed blade properties are provided in Tables 5.4 and 5.5, and the airfoils are available in Appendix C. The rotor eigenfrequencies, obtained from an eigenvalue analysis in SIMA, are provided in Tab. 5.6. For this analysis, the tower base was assumed as cantilevered to the ground. A complete study of blade buckling and fatigue of the rotor has not been performed – the current properties are only based on the scaling laws.

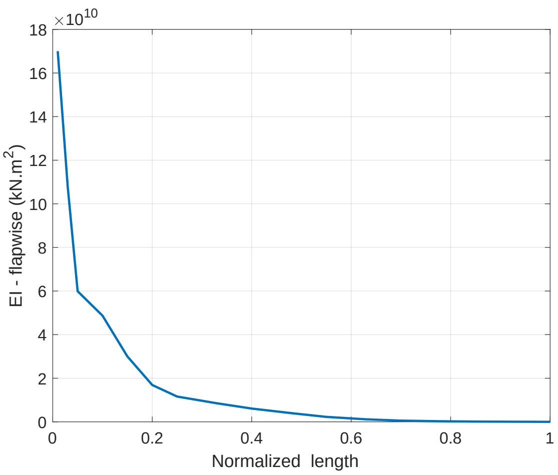
The turbine performance curves, generated with aeroelastic simulations in SIMA (Section 6), are provided in Appendix B. These are generated using an axisymmetric cross-section, with no offset of the area center, mass center and shear center. A comparison of the performance curves generated with the axisymmetric cross-section to the general axisymmetric cross-section is presented in Appendix E.



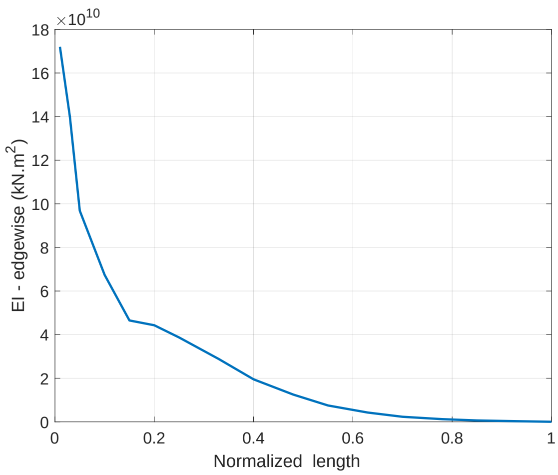
(a) Chord.



(b) Mass-per-length.



(c) Flapwise bending stiffness.



(d) Edgewise bending stiffness.

Figure 5.2: Blade structural properties as a function of normalized length.

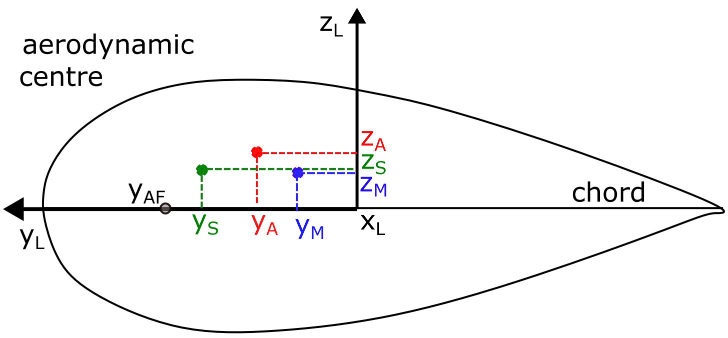


Figure 5.3: Illustration of the airfoil. x_L, y_L, z_L is the elastic (local) coordinate system, y_{AF} is the position of the aerodynamic center relative to the elastic line, y_A and z_A is the location of the area center, y_S and z_S is the location of the shear center and y_M and z_M define the location of the mass center.

Table 5.4: Blade model properties.

Section no	Rel. position	Sec. length (m)	Prebend (m)	Twist (deg)	Chord (m)	y_{AF} (m)
1	0.005	1.06	-0.01	-14.4	5.04	1.26
2	0.020	2.12	-0.02	-14.0	5.04	1.26
3	0.040	2.12	-0.01	-13.6	5.06	1.27
4	0.075	5.29	0.01	-13.1	5.22	1.31
5	0.126	5.29	0.03	-12.0	5.76	1.44
6	0.176	5.29	-0.01	-9.8	6.35	1.59
7	0.226	5.30	-0.08	-7.4	6.56	1.64
8	0.289	7.95	-0.20	-5.5	6.32	1.58
9	0.364	7.95	-0.32	-4.2	5.69	1.42
10	0.440	7.95	-0.47	-3.1	4.97	1.24
11	0.515	7.95	-0.67	-1.9	4.24	1.06
12	0.591	7.95	-0.96	-0.5	3.56	0.89
13	0.666	7.94	-1.39	0.8	2.96	0.74
14	0.741	7.93	-2.03	1.9	2.46	0.62
15	0.816	7.90	-2.98	2.8	2.05	0.51
16	0.891	7.82	-4.43	3.0	1.72	0.43
17	0.955	5.61	-6.03	2.2	1.33	0.33
18	0.991	1.98	-6.80	0.7	0.89	0.22

Table 5.5: Cross section properties. y_A, z_A, y_S, z_S, y_M, z_M and y_{AF} are shown in Figure 5.3.

Section no	Mass (kg/m)	EI_{flp} (N/m^2)	EI_{edg} (N/m^2)	AE (N)	KG (Nm^2/rad)	y_A^* (m)	z_A^* (m)	y_S^* (m)	z_S^* (m)	y_M^* (m)	z_M^* (m)	r_g (m)
1	2787.8	1.70×10^{11}	1.72×10^{11}	5.58×10^{11}	5.23×10^{10}	-0.015	0.000	-0.014	0.000	-0.014	0.000	2.47
2	2185.2	1.08×10^{11}	1.40×10^{11}	4.13×10^{11}	3.87×10^{10}	-0.059	0.001	-0.068	0.007	-0.043	0.001	2.43
4	1578.8	5.99×10^{10}	9.68×10^{10}	2.74×10^{10}	2.60×10^{10}	-0.087	0.005	-0.090	0.019	-0.053	0.006	2.35
3	1410.3	4.87×10^{10}	6.74×10^{10}	2.38×10^{10}	1.80×10^{10}	0.030	0.024	0.146	0.053	0.056	0.025	2.15
5	1167.5	3.00×10^{10}	4.65×10^{10}	1.99×10^{10}	8.37×10^{9}	0.242	0.045	0.646	0.096	0.244	0.048	1.93
6	1001.8	1.69×10^{10}	4.43×10^{10}	1.71×10^{10}	4.01×10^{9}	0.433	0.047	1.061	0.100	0.406	0.051	1.88
7	853.7	1.16×10^{10}	3.87×10^{10}	1.42×10^{10}	2.36×10^{9}	0.565	0.034	1.228	0.083	0.514	0.039	1.87
8	714.5	8.51×10^{9}	2.88×10^{10}	1.17×10^{10}	1.38×10^{9}	0.634	0.021	1.253	0.075	0.558	0.022	1.54
9	610.2	6.09×10^{9}	1.95×10^{10}	1.02×10^{10}	8.71×10^{8}	0.616	0.015	1.130	0.066	0.574	0.027	1.75
10	531.5	3.98×10^{9}	1.25×10^{10}	9.18×10^{9}	5.93×10^{8}	0.532	0.011	0.926	0.051	0.485	0.016	1.30
11	453.7	2.27×10^{9}	7.50×10^{9}	8.19×10^{9}	3.64×10^{8}	0.442	0.009	0.734	0.038	0.410	0.012	1.06
12	380.6	1.15×10^{9}	4.26×10^{9}	7.15×10^{9}	2.04×10^{8}	0.368	0.012	0.583	0.033	0.350	0.015	0.85
13	313.3	5.48×10^{8}	2.32×10^{9}	6.04×10^{9}	1.08×10^{8}	0.310	0.018	0.452	0.033	0.300	0.019	0.68
14	247.5	2.58×10^{8}	1.23×10^{9}	4.84×10^{9}	5.68×10^{7}	0.264	0.021	0.390	0.032	0.260	0.022	0.39
15	182.9	1.23×10^{8}	6.33×10^{8}	3.59×10^{9}	3.01×10^{7}	0.227	0.020	0.376	0.029	0.225	0.020	0.31
16	119.8	5.30×10^{7}	2.90×10^{8}	2.32×10^{9}	1.56×10^{7}	0.185	0.019	0.329	0.026	0.184	0.019	0.21
17	63.4	1.57×10^{7}	1.03×10^{8}	1.17×10^{9}	5.86×10^{6}	0.120	0.017	0.253	0.022	0.116	0.017	0.55
18	26.3	2.26×10^{6}	2.44×10^{7}	4.40×10^{8}	1.24×10^{6}	0.053	0.011	0.149	0.014	0.048	0.011	0.46

* In the SIMA model presented in this document, y_A, z_A, y_S, z_S, y_M, and z_M are set to zero.

Table 5.6: Eigenfrequencies of the WINDMOOR 12 MW rotor, assuming the tower base cantilevered to ground. The modes *edge1* and *edge2* are defined as in [8].

Mode	Eigenfrequency (Hz)	Natural period (s)
1^{st} collective flap mode	0.331	3.02
1^{st} asymmetric flap with yaw	0.348	2.87
1^{st} asymmetric flap with tilt	0.372	2.69
1^{st} collective edge mode	0.573	1.74
1^{st} asymmetric edge1 mode*	0.639	1.56
1^{st} asymmetric edge2 mode*	0.649	1.54
2^{nd} asymmetric flap with yaw	0.893	1.12
2^{nd} asymmetric flap with tilt	0.955	1.05

* edge1: the blade pointing upward is almost still, while the two other blades are asymmetrically excited. edge2: the blade positioned at 120 deg azimuth is almost still, while the two other blades are asymmetrically excited.

5.4 Control system

The *NREL Reference OpenSource COntroller for wind turbine applications* (ROSCO) v. 2.0.1 [9] is adopted for the WINDMOOR 12 MW turbine, due to its several functionalities and convenient modular, and open-source, implementation. The current model uses a variable-speed-variable-pitch (VSVP) control approach, and a peak-shaving strategy near rated speed. The main principles and parameters adopted in the controller are explained below. In addition, some minor changes were implemented in order to include power error feedback to the blade pitch controller.

5.4.1 Below rated

Below the rated rotor speed, the torque is set to optimize power capture, while zero blade-pitch angle is maintained. Close to rotor-speed limits, the torque reference follows a smoothing strategy, as explained by Abbas [13]. Optimal power capture is attained by setting the torque Q_{gen} according to

$$Q_{gen} = K_{br}\bar{\omega}^2 \,, \tag{5.2}$$

where $\bar{\omega}$ is the low-pass filtered generator speed, and the generator torque constant, K_{br}, is a function of the optimal power coefficient ($C_{p,op}$) and optimal tip-speed ratio (λ_{opt}). The constant K_{br} for the WINDMOOR 12 MW turbine is 1.48×10^7 Nm/(rad/s)^2.

5.4.2 Above rated

Above rated wind speed the generator torque may be kept constant at rated torque, Q_0; or vary with the generator speed in order to keep constant power:

$$Q_{gen} = \frac{P_0}{\omega}\,, \tag{5.3}$$

where P_0 is the rated power. The blade-pitch angle β is controlled by a proportional-integral (PI) controller, based on feedback of generator speed:

$$\Delta\beta = k_P e_\omega + k_I \int_0^t e_\omega dt\,, \quad e_\omega = \bar{\omega} - \omega_r\,, \tag{5.4}$$

where ω_r is the rated generator speed. Departing from a single-DOF rotor model [14], the proportional and integral gains, k_P and k_I, may be related to the desired controller natural frequency (f_{ctr},) and damping (ζ_{ctr}) according to:

$$k_P = \frac{4\pi I_{tot}\zeta_{ctr}f_{ctr}}{-\frac{\partial Q_A}{\partial\beta}}\,, \quad k_I = \frac{4\pi^2 I_{tot} f_{ctr}^2}{-\frac{\partial Q_A}{\partial\beta}}\,, \tag{5.5}$$

where I_{tot} is the total (rotor+drivetrain) moment of inertia around the shaft; and $\frac{\partial Q_A}{\partial\beta}$ is the aerodynamic torque sensitivity to blade-pitch angle. Since the latter is a function of β itself, the gains k_P and k_I must be scheduled according to the low-passed filtered blade-pitch angle.

Although the WINDMOOR 12 MW turbine reaches rated power only at 10.5 m/s, the rated rotor speed is reached at around 8.9 m/s. This is in accordance with the IEA 10 MW behavior, and is ensured by adding power error feedback to Eq. (5.4)[15]. For the WINDMOOR 12 MW turbine an integral term is used:

$$\Delta\beta' = \Delta\beta + k_{I,pow} \int_0^t (P - P_0)\, dt,\,, \tag{5.6}$$

where P is the generator power. The gain $k_{I,pow}$ should be tuned carefully, in order to ensure no blade activity just below rated wind speed, while avoiding conflict with the rotor speed error feedback controller after the rated wind speed is exceeded. The controller dynamics should not be significantly affected if constant power is adopted at above rated, following Eq. (5.3). If constant torque is adopted, the relation between the controller frequency and the integral gain in Eq. (5.5) is updated to:

$$k_I + k_{I,pow}Q_0 = \frac{4\pi^2 I_{tot} f_{ctr}^2}{-\frac{\partial Q_A}{\partial\beta}}\,. \tag{5.7}$$

Since the turbine is installed on a floating platform, some measure has to be taken to avoid the motion instability reported in [16]. One option is to “detune” the controller – i.e., to set its natural frequency below the platform pitch natural frequency. A natural frequency of $f_{ctr} = 0.02$ Hz has been shown to stabilize the system, while the controller damping factor ζ_{ctr} is set to 0.7. Table 5.7 shows the corresponding controller gains for zero blade-pitch angle, and the complete controller configuration (including gain scheduling) is provided in Appendix D.

An alternative to detuning the controller, and that is available in ROSCO, is to add a term proportional to the filtered nacelle feedback, $\dot{x}_{nac}$, to Eq. (5.4):

$$\Delta\beta = k_P e_\omega + k_I \int_0^t e_\omega dt + k_{fb}\dot{x}_{nac}\,, \tag{5.8}$$

where k_{fb} can be determined as explained by Lenfest et al. [17]. It is important that the filter applied at the nacelle velocity attenuates WF components satisfactorily, in order to avoid controller response to wave-induced motions. On the other hand, the phase lag induced by the filter can affect the controller stability. It is thus recommended to carefully check that the combination of gain k_{fb} and filter parameters is stable for all wind speeds in the above rated region. This has not been carried out for the current version of the model, which adopts the above-mentioned “detuned” controller.

Table 5.7: Main controller parameters.

Property	Value
K_{br} (N.m/(rad/s^2))	1.48×10^7
k_P (s)	0.7578
k_I (-)	0.0680
$k_{I,pow}$ (rad/(Ws))	9.00×10^{-9}

5.4.3 Thrust peak shaving

Thrust peak shaving (or clipping) consists of limiting the rotor thrust near rated wind speed, by starting to impose a blade-pitch angle before the rotor reaches rated speed. The objective is to limit aerodynamic loads, at the cost of reduced power capture in the transition from below-rated to rated region [18]. The blade-pitch angles are determined based on the low-pass filtered wind speed, as shown in Tab. D.2. Figure 5.4 illustrates the effect of peak shaving on the thrust and power curves. See Appendix B for the complete thrust and power curves.

5.5 Tower

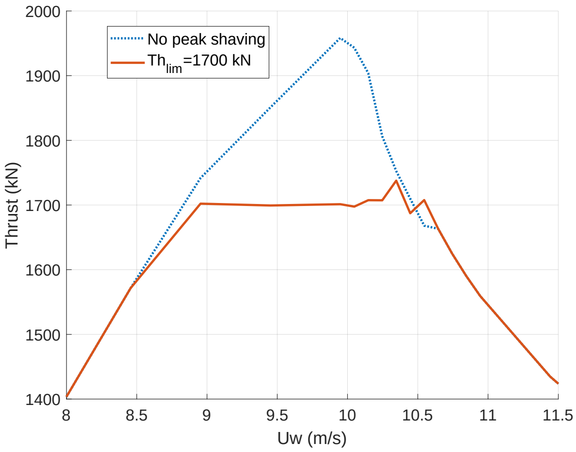
The tower model was provided by Equinor. Its main dimensions are presented in Table 5.8, and distributed properties are given in Table 5.9. When installed on the platform, the 1st fore-aft bending frequency is found to be 0.641 Hz (considering the full system). This is significantly beyond the 3p frequency at rated speed (0.39 Hz). The 6p interval ranges from 0.56 Hz to 0.78 Hz, encompassing the tower’s 1st bending frequency. The tower base is placed at the top of one of the columns, at a height of 15.5 m above mean water level.

Table 5.8: Tower main properties.

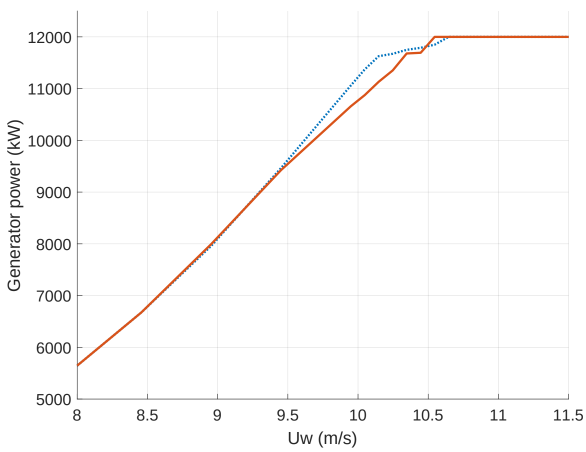
Parameter	Value
Diameter at top (m)	5.97
Diameter at bottom (m)	9.90
Thickness at top (mm)	30.1
Thickness at bottom (mm)	90.0
Length (m)	110.20
Mass (t)	1161.6
CG_z from base (m)	56.65

Table 5.9: Tower model properties.

Element	Length (m)	Diameter (m)	Thickness (mm)	Mass coeff. (kg/m)	EA (N)	EI (N/m^2)
1	4.00	9.90	90.0	21873.5	5.91×10^{11}	7.24×10^{12}
2	4.00	9.50	90.0	20985.7	5.67×10^{11}	6.39×10^{12}
3	2.00	9.10	90.0	20097.9	5.43×10^{11}	5.62×10^{12}
4	5.89	9.00	74.3	16423.1	4.43×10^{11}	4.49×10^{12}
5	5.89	9.00	70.2	15529.1	4.19×10^{11}	4.24×10^{12}
6	5.89	9.00	66.1	14612.6	3.94×10^{11}	3.99×10^{12}
7	5.89	9.00	62.0	13717.8	3.70×10^{11}	3.75×10^{12}
8	5.89	9.00	57.9	12820.1	3.46×10^{11}	3.50×10^{12}
9	5.89	9.00	53.8	11904.9	3.21×10^{11}	3.25×10^{12}
10	5.89	9.00	49.7	11008.8	2.97×10^{11}	3.00×10^{12}
11	5.89	9.00	45.6	10090.3	2.72×10^{11}	2.75×10^{12}
12	5.89	9.00	41.5	9193.4	2.48×10^{11}	2.51×10^{12}
13	5.89	9.00	37.4	8290.5	2.23×10^{11}	2.26×10^{12}
14	5.89	8.82	34.7	7535.0	2.03×10^{11}	1.98×10^{12}
15	5.89	8.40	34.0	7029.7	1.89×10^{11}	1.67×10^{12}
16	5.89	7.96	33.3	6536.8	1.76×10^{11}	1.40×10^{12}
17	5.89	7.54	32.6	6052.4	1.63×10^{11}	1.16×10^{12}
18	5.89	7.11	31.9	5586.4	1.50×10^{11}	9.50×10^{11}
19	5.89	6.68	31.3	5137.4	1.38×10^{11}	7.72×10^{11}
20	5.89	6.25	30.6	4705.5	1.27×10^{11}	6.20×10^{11}



(a) Thrust.



(b) Generator power.

Figure 5.4: Thrust and generator power curves near rated wind speed, with and without the thrust peak shaving strategy as specified in Tab. D.2.

6 SIMA model

Based on the FWT properties shown in the previous sections, a SIMA model of the WINDMOOR 12 MW FWT was created (Fig. 6.1). A rigid-body platform is modeled in SIMO, coupled to a flexible tower, wind turbine, and mooring system, modeled in RIFLEX. The main modeling assumptions and input data are presented below. The model is included as an example in SIMA (starting in version 4.1).

6.1 Platform

The platform is modeled as a SIMO body, subjected to loads from waves and from the FE structures modeled in RIFLEX. The equations of motions are:

$$(\mathrm{m} + \mathrm{A}_\infty)\,\ddot{\mathrm{x}} + \mathrm{D}_1\dot{\mathrm{x}} + \mathrm{Kx} + \int_0^t \mathrm{h}(t-\tau)\dot{\mathrm{x}}(\tau)d\tau = \mathrm{q}(t, \mathrm{x}, \dot{\mathrm{x}})\,, \tag{6.1}$$

where m is the rigid-body inertia matrix, obtained from the platform (steel + ballast) mass and radii of gyration from Tab. 3.1; A_∞ is the infinity-frequency added-mass matrix; D_1 is the linear external damping matrix; K is the hydrostatic restoring matrix; h is a matrix of retardation functions [19]; and q is a vector with external loads:

$$\mathrm{q} = -mg\hat{\mathrm{k}} \times \mathrm{r}_g + \rho g V\hat{\mathrm{k}} \times \mathrm{r}_b + \mathrm{q}_{1st} + \mathrm{q}_{2nd} + \mathrm{q}_{vis,q} + q_{FE}\,, \tag{6.2}$$

where m is the FWT total mass; ρ is the water density; g is the acceleration of gravity; V is the displaced volume; r_g and r_b are the position vectors from the centers of gravity and buoyancy to the origin; q_{1st} is a vector with 1^{st}-order wave loads; q_{2nd} is a vector with 2^{nd}-order wave loads; $\mathrm{q}_{vis,q}$ contains the viscous contributions from the columns and pontoons, by means of the quadratic term of the Morison formulation; and q_{FE} includes the loads imposed to the platform by the mooring system and tower base.

The first term on the r.h.s. of Eq. (6.2) includes the weight of platform, tower, and RNA, while the buoyancy is accounted for as a vertical specified force, applied at the platform center of buoyancy and pointing to the direction of the global Z axis. Since both weight and buoyancy at equilibrium are already considered, the hydrostatic restoring matrix contains only the contribution due to volume variation caused by small motions around equilibrium:

$$\mathbf{K} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & C'_{33} & 0 & 0 & 0 \\ 0 & 0 & 0 & C'_{44} & 0 & 0 \\ 0 & 0 & 0 & 0 & C'_{55} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}. \tag{6.3}$$

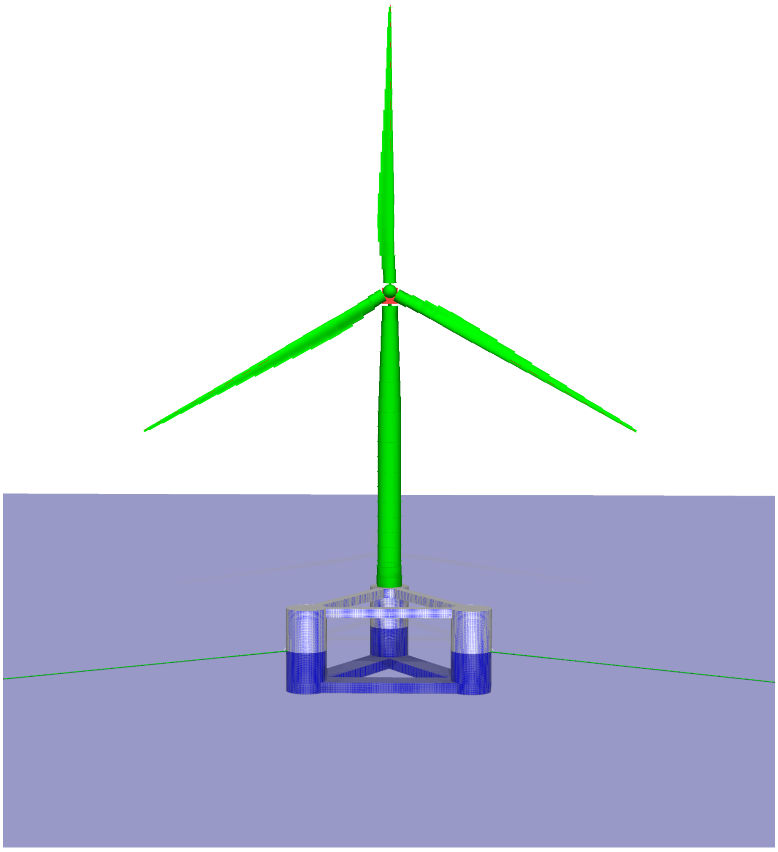


Figure 6.1: Front view of the WINDMOOR 12 MW base case FWT, modeled in SIMA.

The coefficients C'_{ii} are given by [20]

$$\begin{aligned} C'_{33} &= \rho g A_{wp} = 5.33 \times 10^6 \quad \text{N/m} \\ C'_{44} &= \rho g \iint_{A_{wp}} y^2 ds = 3.38 \times 10^9 \quad \text{N.m/rad}\,, \\ C'_{55} &= \rho g \iint_{A_{wp}} x^2 ds = 3.38 \times 10^9 \quad \text{N.m/rad} \end{aligned} \tag{6.4}$$

where A_{wp} is the waterplane area. It is noted that small roll/pitch angles are assumed. This modeling approach was introduced by Kvittem [21] and ensures that the weight of the other FWT components are properly accounted for.

In the present model, the 2nd-order wave loads in vector q_{2nd} are accounted for by providing the wave drift coefficients, and using Newman's approximation [22]. Although this approach provides satisfactory predictions for the LF horizontal motions, full quadratic transfer functions (QTFs) are needed for exciting resonant responses in heave, roll, and pitch.

Vector $q_{vis,q}$ combines all the quadratic viscous drag forces on pontoons and columns, based on Morison formulation. The force per unit length is given by

$$f = \frac{1}{2}\rho C_d D u|u|\,, \tag{6.5}$$

where the characteristic length D is the column diameter or the pontoon width/height. The relative velocity u accounts for wave particle kinematics and platform motion, and the non-dimensional drag coefficients C_d provided in Tab. 6.1 are obtained from DNV-RP-C205 [23].

6.2 Tower

The tower is modeled using 20 beam elements, adopting an axisymmetric cross-section with decreasing diameter from the base towards the top. Steel with density $\rho_{steel} = 7850$ kg/m^3, and modulus of elasticity $E_{steel} = 2.11 \times 10^{11}$ Pa, are considered. The elements length and cross-sectional properties are provided in Tab. 5.9. Two supernodes are used – one at the base and another at the top. The tower base supernode is placed at (35.2;0.0;15.5) w.r.t. the platform origin, to which it is slaved.

Table 6.1: Quadratic drag coefficients for columns and pontoons, following Appendix E of DNV-RP-C205 [23].

	$C_{d,y}$	$C_{d,z}$
Column	1.0	1.0
Pontoon	2.3	1.4

6.3 Wind turbine

A *blade element momentum* (BEM) model for wind turbines [24] is implemented in RIFLEX, with Øye's models for dynamic stall and dynamic wake [25]. Equilibrium is found based on the blade discretization, in the FE model. Hub and tip losses due to a finite number of blades are corrected using Prandtl factor, and Glauert correction for high induction factors is adopted. Tower influence is considered using potential theory.

The wind turbine blades are modeled with 18 beam elements, using double-symmetric cross-sections, as listed in Table 5.4. The distributed cross-sectional properties are shown in Table 5.5. The airfoils for each section are provided in Appendix C.

A nodal body is used for modeling the hub. Its moment of inertia is therefore accounted for in the shaft, which is modeled with an artificial mass coefficient and radius of gyration. The nacelle is modeled with a SIMO body.

The turbine supernodes are defined in a separate reference frame, allowing for easy rotation of the nacelle w.r.t. the tower.

6.4 Mooring system

The mooring line properties in Tab. 3.4 are implemented using bar elements. Table 6.2 describes the number of elements, and element length, used in each segment. The supernodes at the fairleads are slaved to a master supernode at the platform origin.

Table 6.2: Mooring line segments discretization.

Segment	Length (m)	N. elements	Elem. length (m)
1	25.0	5	5.00
2	85.0	17	5.00
3	85.0	9	9.44
4	499.8	45	11.11

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A WAMIT results

This appendix contains WAMIT results for the INO WINDMOOR FOWT semisubmersible platform.

The appendix contains:

- Panel size convergence study
- Added mass and damping coefficients
- Wave excitation force/moment coefficients
- Motion transfer functions - no viscous correction
- Wave drift force coefficients

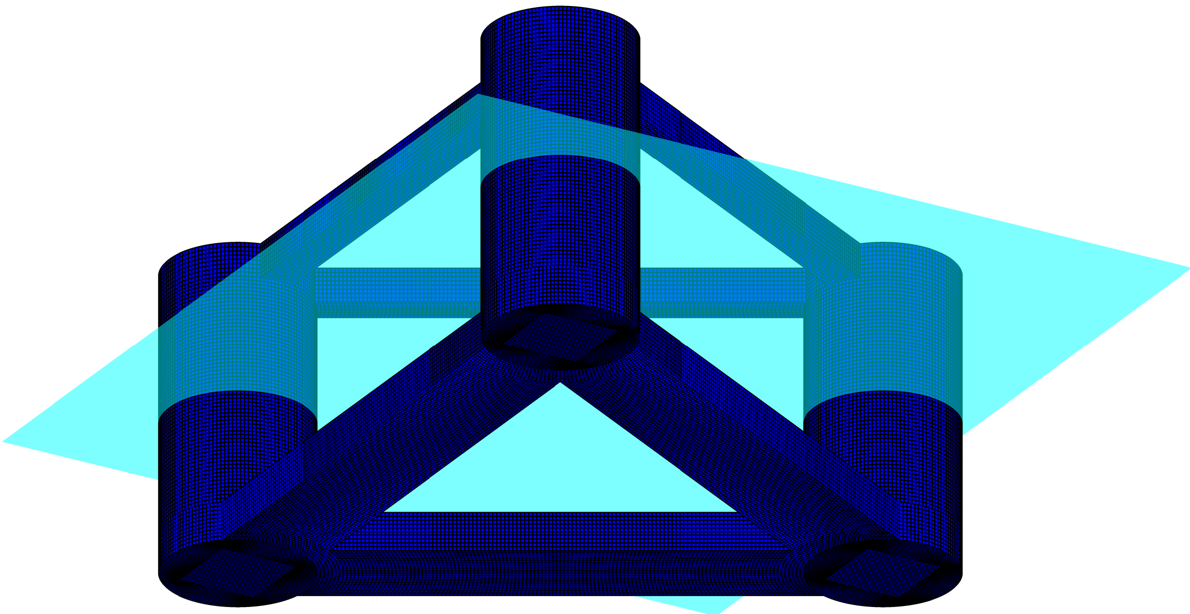


Figure A.1: Illustration of the WAMIT panel model of the INO WINDMOOR semi.

A.1 Panel size convergence study

The purpose of a panel size convergence study is to determine the size of the panel elements needed for the results to converge satisfactorily. A convergence study can be carried out with the following steps:

1. Create a panel model using few, but a reasonable number of elements. Carry out analysis with this model
2. Re-mesh the panel model with a denser element distribution, re-calculate with the new panel model, and compare the results to previous panel models.
3. Repeat increasing the number of panel elements (mesh density) and re-calculate until the results converge satisfactorily.

Note that in step 2 above, increasing the number of elements must be done systematically and should be done by reducing the size (length) of each element by a factor of 2. This means that the number of panels increases by a factor of 4 for each refinement.

Table A.1: Panel model properties.

Panel size [m]	No. of panels [-]	Max aspect ratio [-]	Submerged volume [m^3]	Waterplane area [m^2]	Vertical centre of buoyancy [m]
-	∞	-	13836	530.14	-10.085
0.375	24916	2.6455	13833	530.00	-10.086
0.750	5606	2.7917	13824	529.53	-10.090
1.500	1256	3.1366	13784	527.34	-10.105

Three different panel models were consider in the present study. The main geometrical properties of the panel models are summarized in Table A.1 and compared with analytical values. The element density of the panel models are illustrated in Figure A.2. Comparison of the motion transfer functions, wave excitation forces and added mass coefficients are provided in Figures A.3 – A.5, respectively, for the surge, heave and pitch modes obtained with the different panel models. It is evident from the plots that the results are converging as the number of panel elements are increased.

The numerical error due to the panel element size can be estimated by using Richardson extrapolation. The discretization error is estimated as [26]

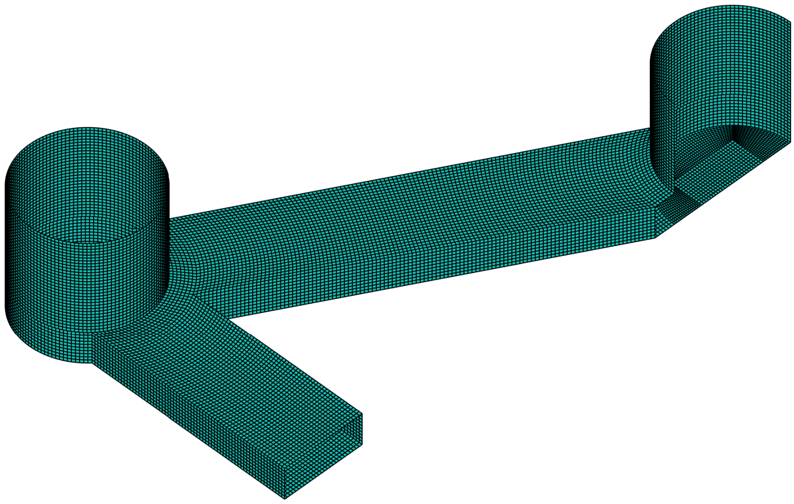
$$\epsilon_h(\phi) = \frac{\phi_h - \phi_{2h}}{2^\gamma - 1}\,, \tag{A.1}$$

where ϕ_h denotes a solution on a panel model with element size $h = \Delta x$. The convergence rate γ can be approximated as

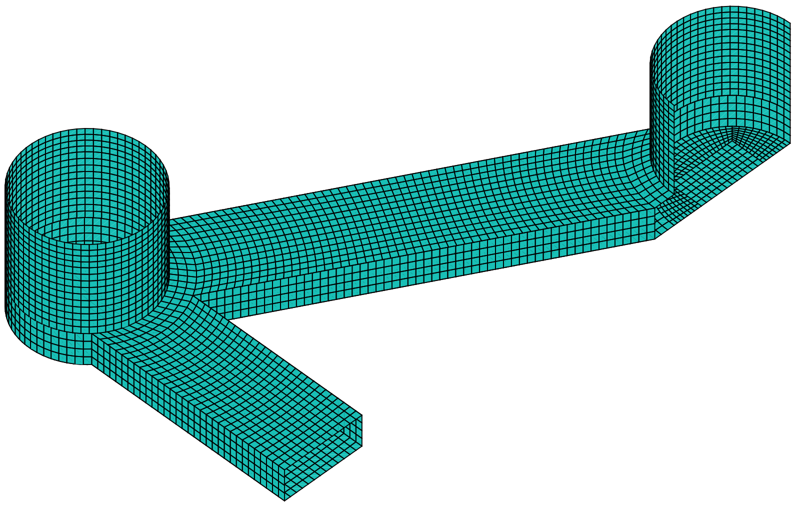
$$\gamma = \frac{\log((\phi_{2h} - \phi_{4h})/(\phi_h - \phi_{2h}))}{\log(2)}\,. \tag{A.2}$$

It should be noted that this method to estimate numerical error is only accurate if the panels are sufficiently fine such that monotone and nearly asymptotic convergence is obtained, the solution is well-behaved without singularities, and that the panel element refinement is systematic and substantial.

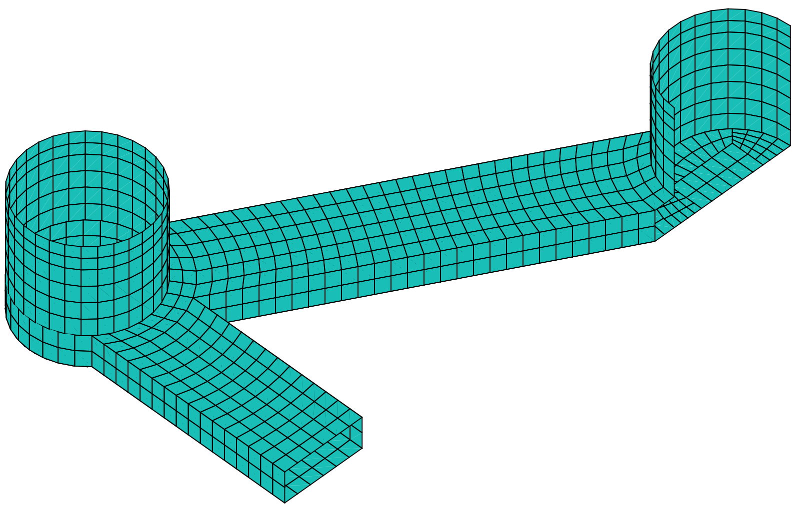
Figure A.6 shows the relative error for the coefficients given in Figures A.3 – A.5. Note that some of the curves do not converge monotonically and asymptotically for all periods, and the relative errors are not plotted for these periods. This happens in regions where the curves cross each other. The relative error for the finest panel model is mostly below 2 % with the exception for the heave wave excitation force and motion transfer function near the cancellation period. In this region, there is a small shift in the peak periods and the curves are quite steep, which gives a relatively large difference for a given period. The relative error is up to nearly 15 %, but drops quickly as the curves move away from the cancellation period.



(a) $\Delta x = 0.375$ m.

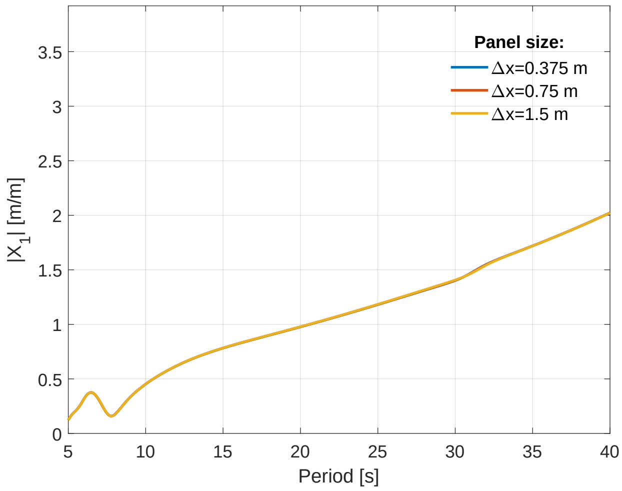


(b) $\Delta x = 0.750$ m.

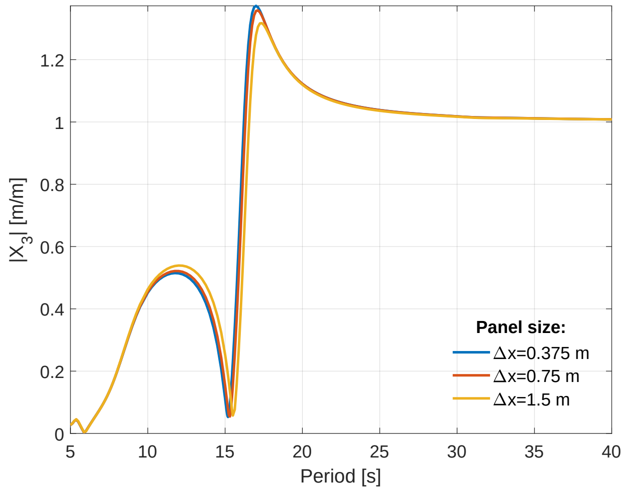


(c) $\Delta x = 1.500$ m.

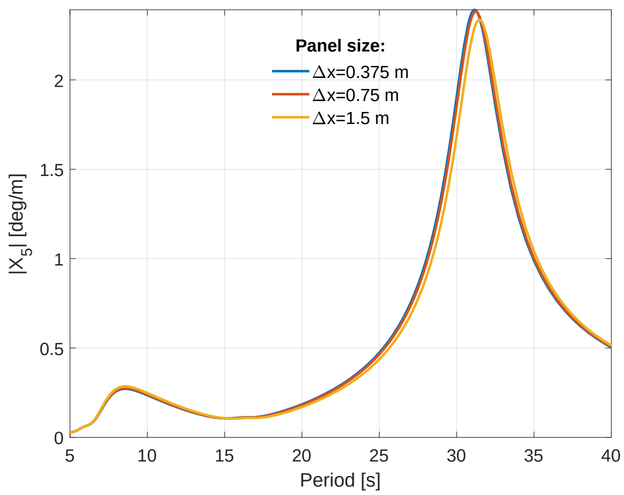
Figure A.2: Panel models for panel size sensitivity study with characteristic panel size Δx.



(a) Surge

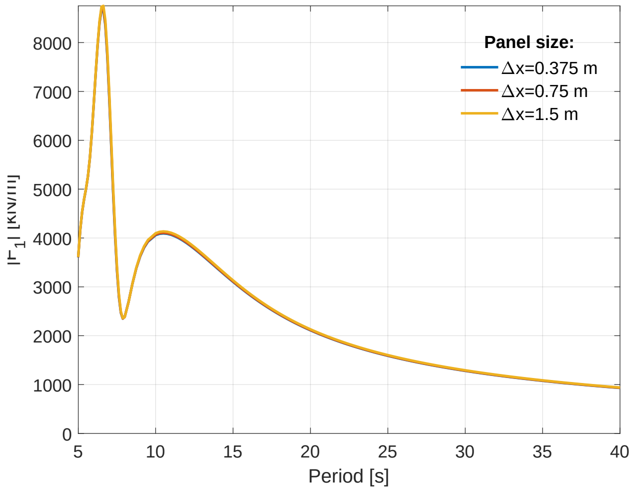


(b) Heave

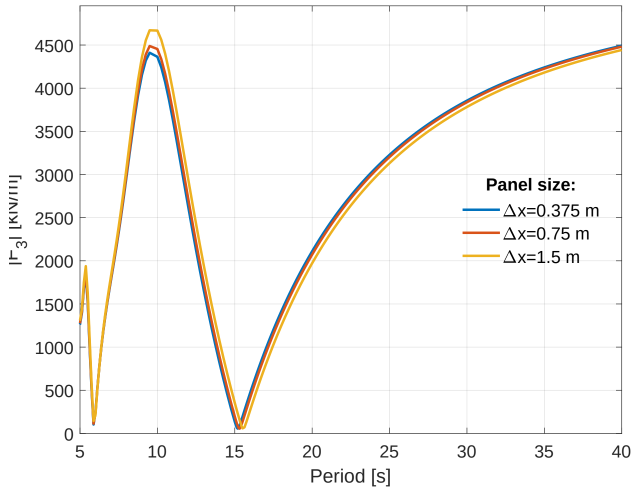


(c) Pitch

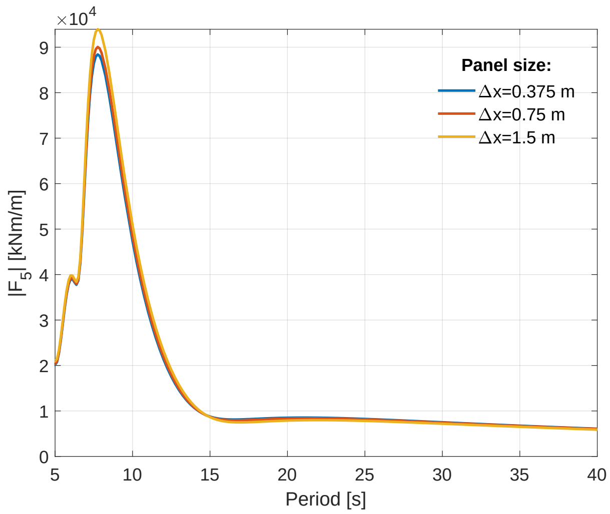
Figure A.3: Panel size sensitivity study. Wave motion transfer functions.



(a) Surge

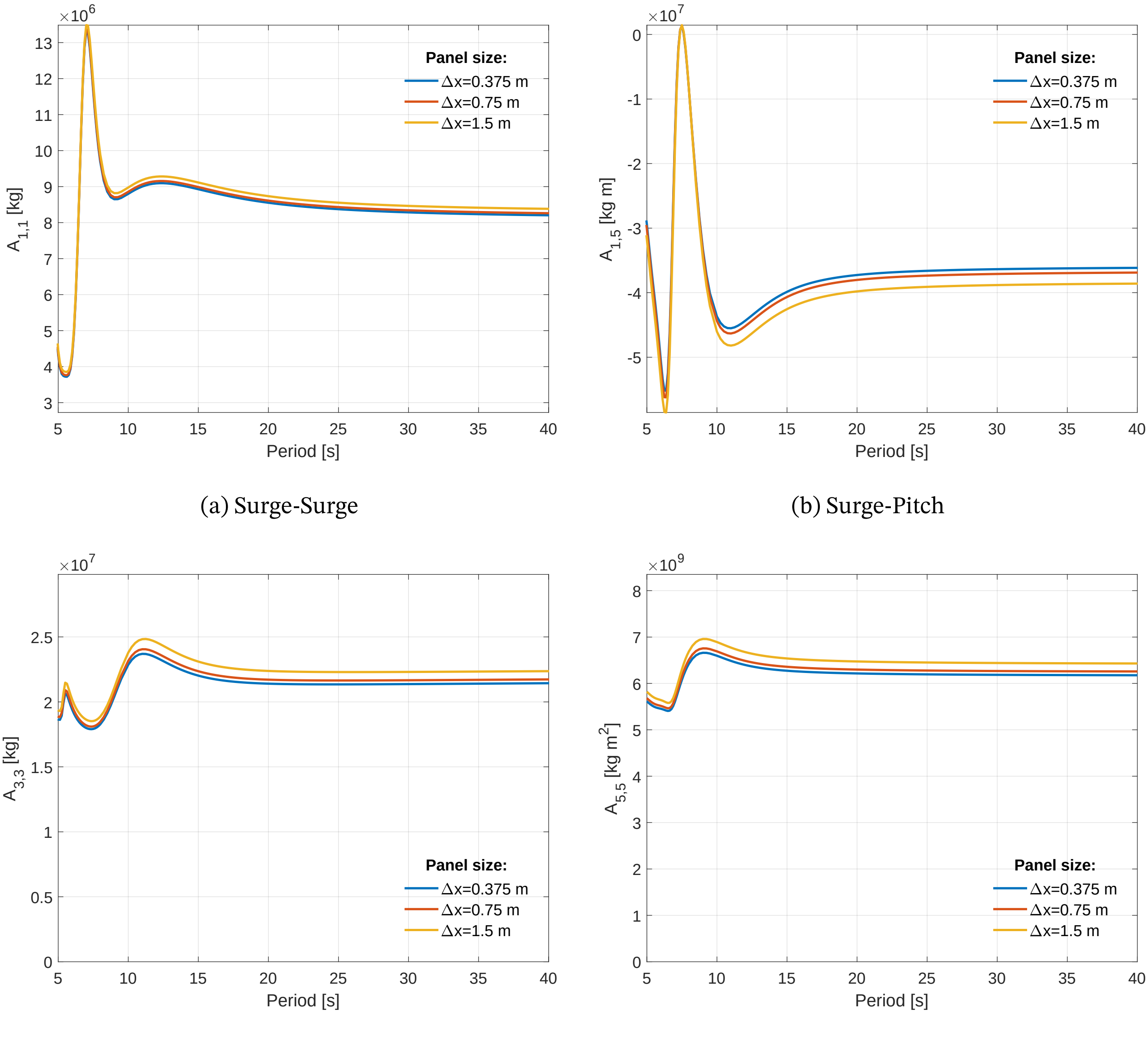


(b) Heave



(c) Pitch

Figure A.4: Panel size sensitivity study. Wave excitation force transfer functions.



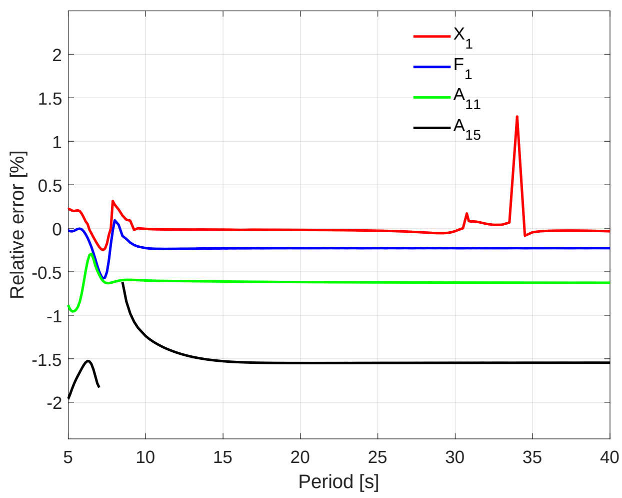
(a) Surge-Surge

(b) Surge-Pitch

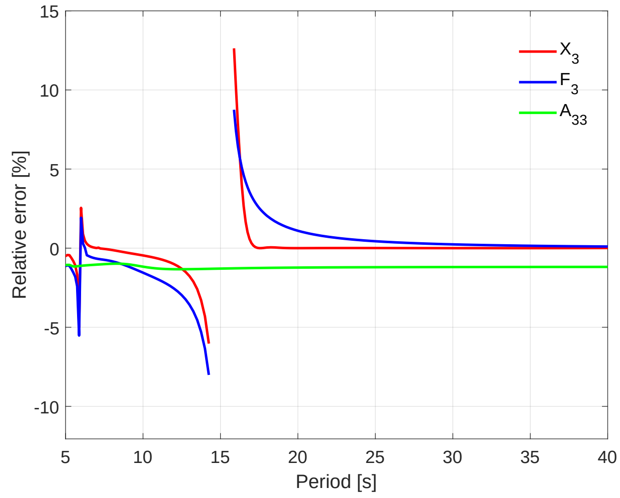
(c) Heave-Heave

(d) Pitch-Pitch

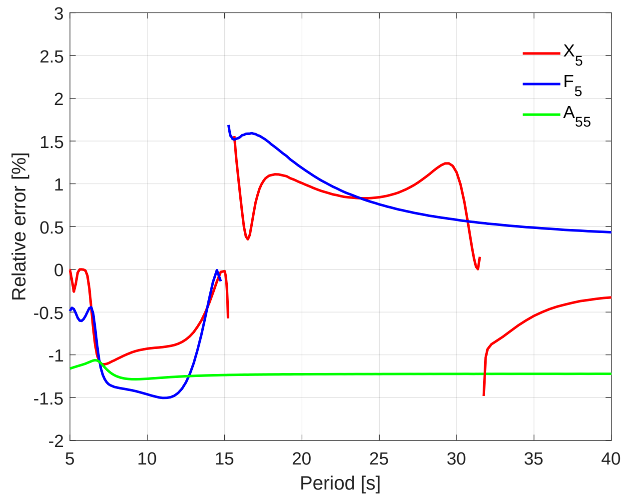
Figure A.5: Panel size sensitivity study. Added mass coefficients.



(a) Surge



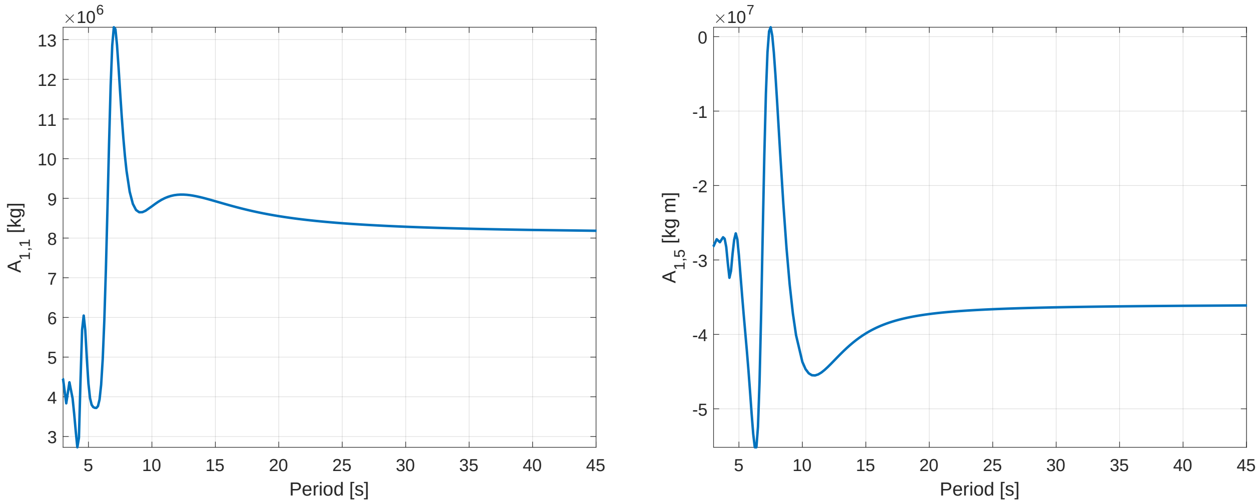
(b) Heave



(c) Pitch

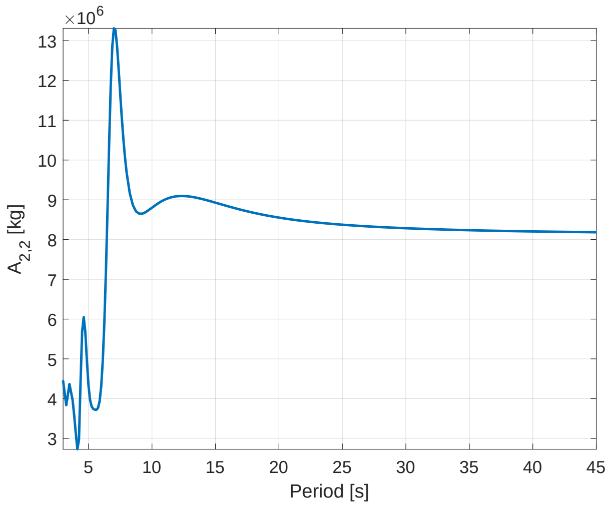
Figure A.6: Panel size sensitivity study. Relative errors.

A.2 Added mass coefficients

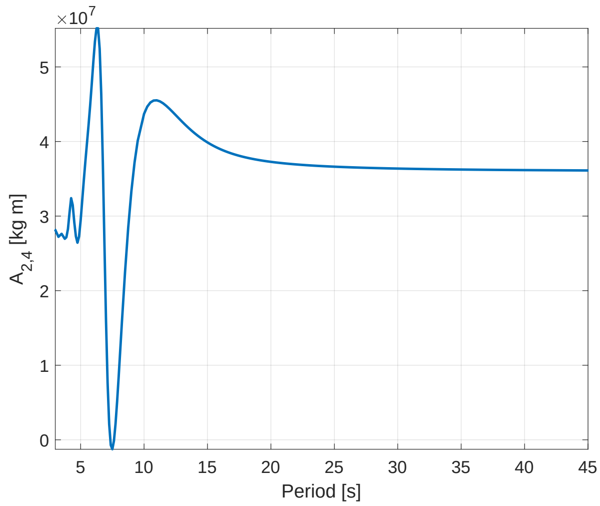


(a) (b)

Figure A.7: Added mass coefficients in surge due to motions in (a) surge and (b) pitch.



(a)



(b)

Figure A.8: Added mass coefficients in sway due to motions in (a) sway and (b) roll.

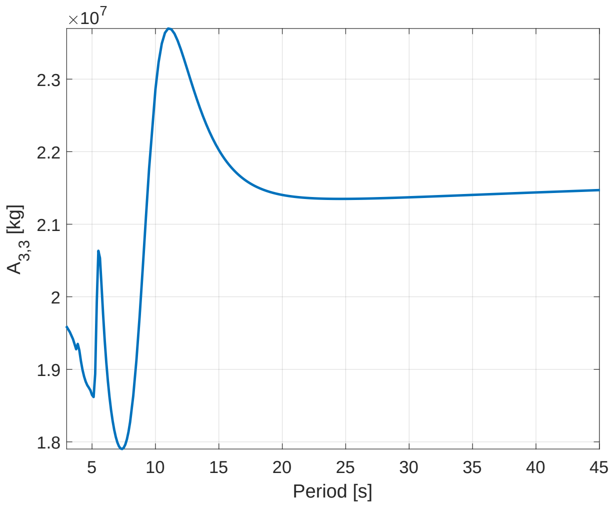
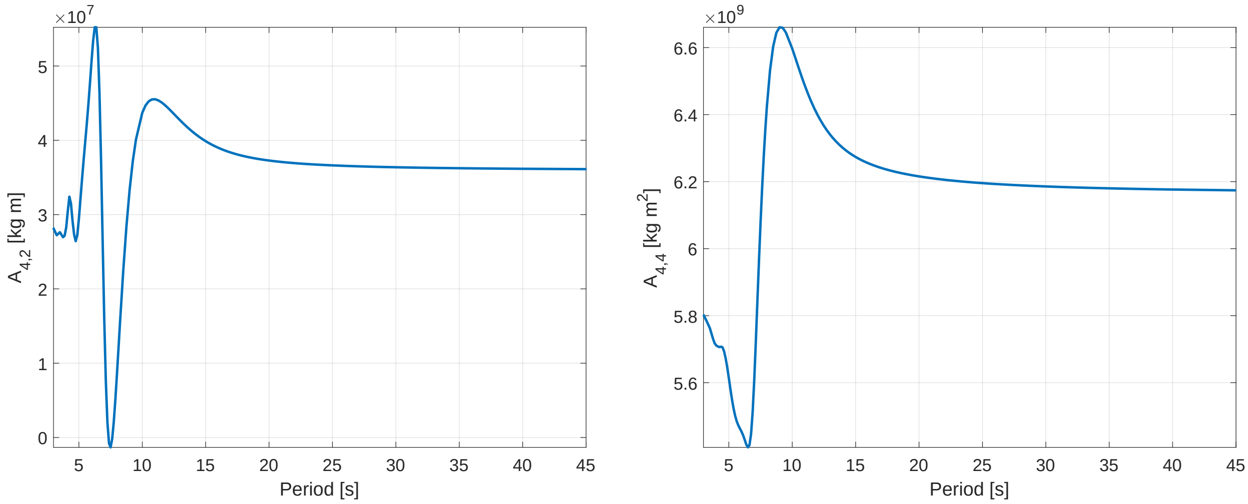
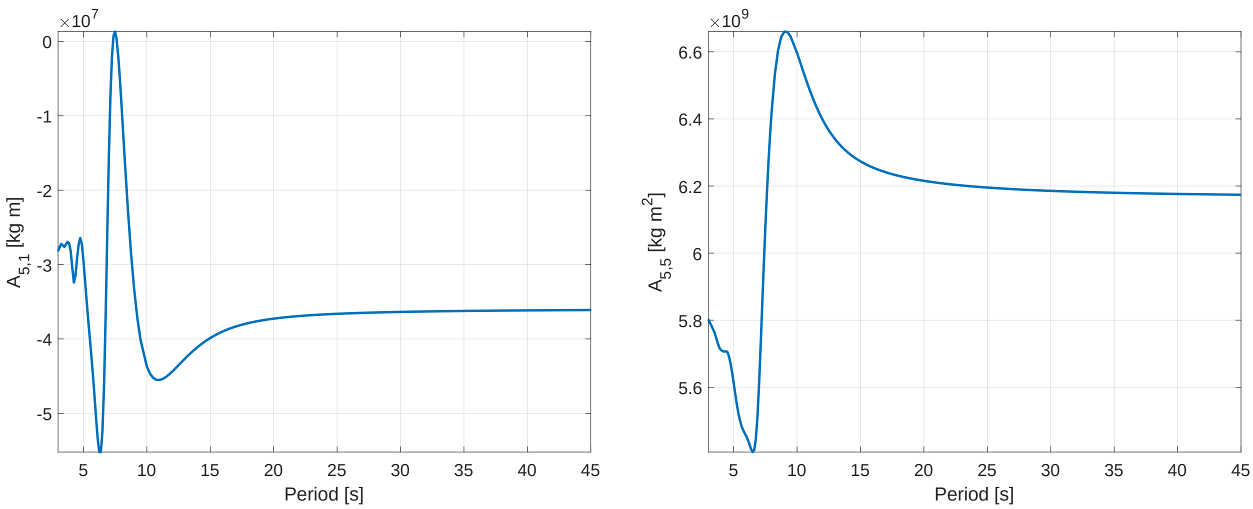


Figure A.9: Added mass coefficients in heave due to motions in heave.



(a) (b)

Figure A.10: Added mass coefficients in roll due to motions in (a) sway and (b) roll.



(a) (b)

Figure A.11: Added mass coefficients in pitch due to motions in (a) surge and (b) pitch.

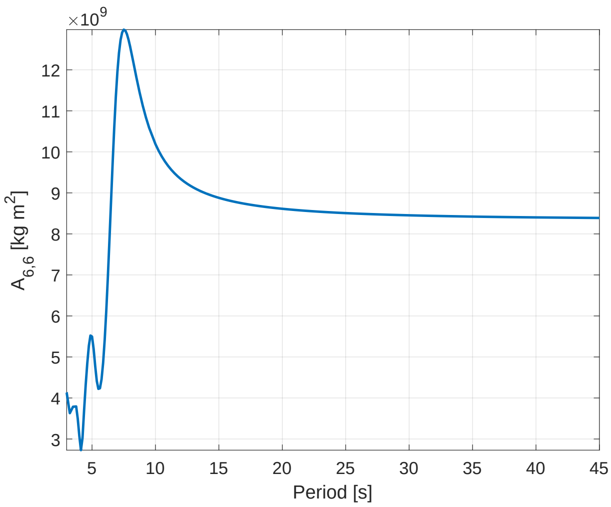


Figure A.12: Added mass coefficients in yaw due to motions in yaw.

A.3 Wave radiation damping coefficients

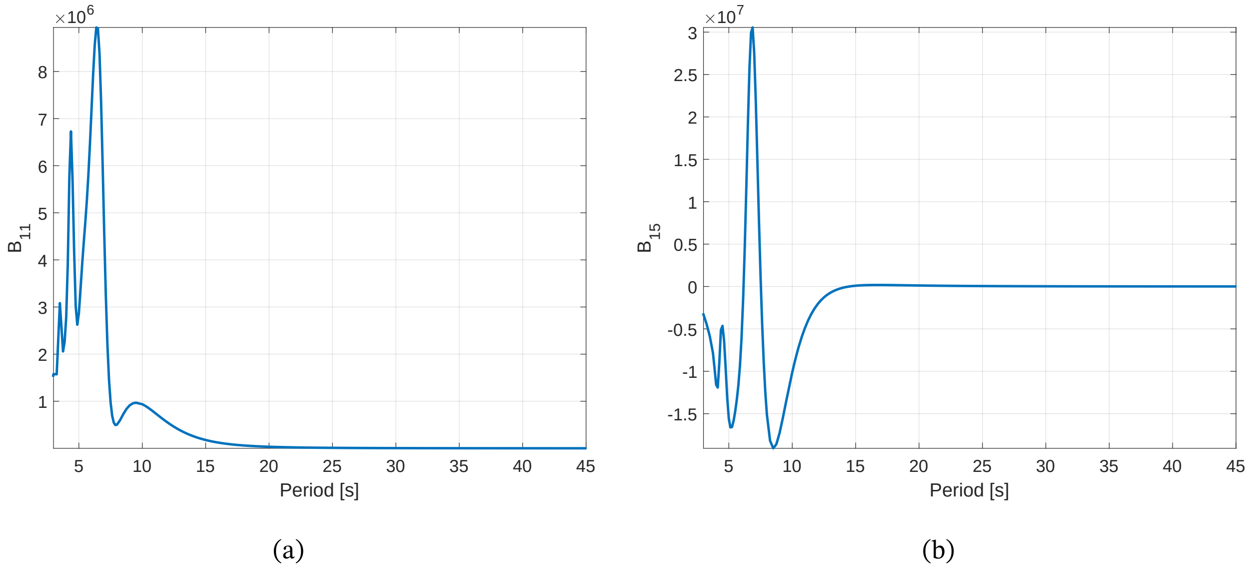
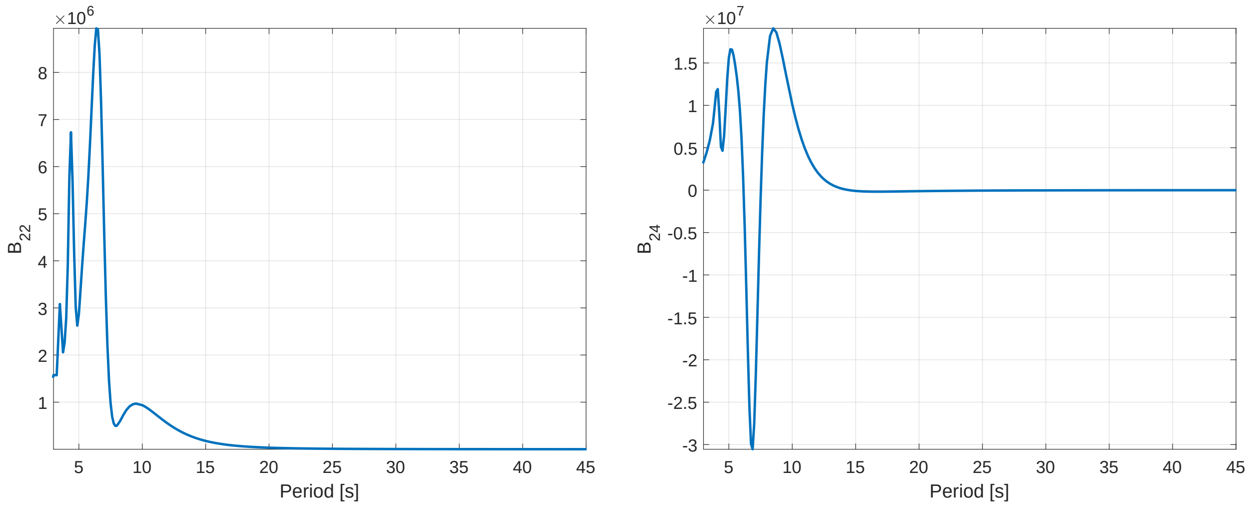


Figure A.13: Wave damping coefficients in surge due to motions in (a) surge and (b) pitch.



(a) (b)

Figure A.14: Wave damping coefficients in sway due to motions in (a) sway and (b) roll.

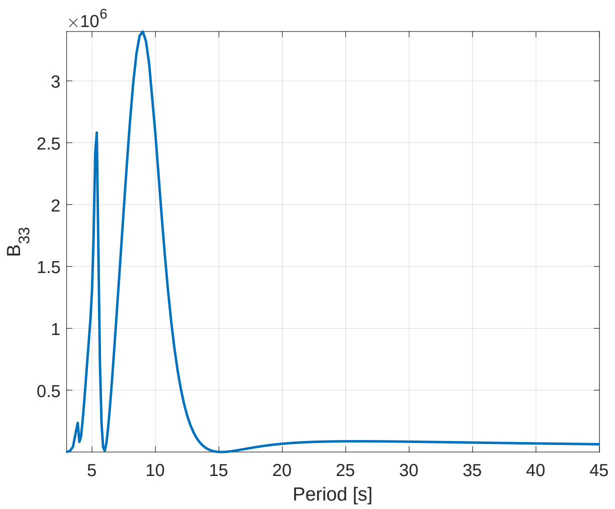
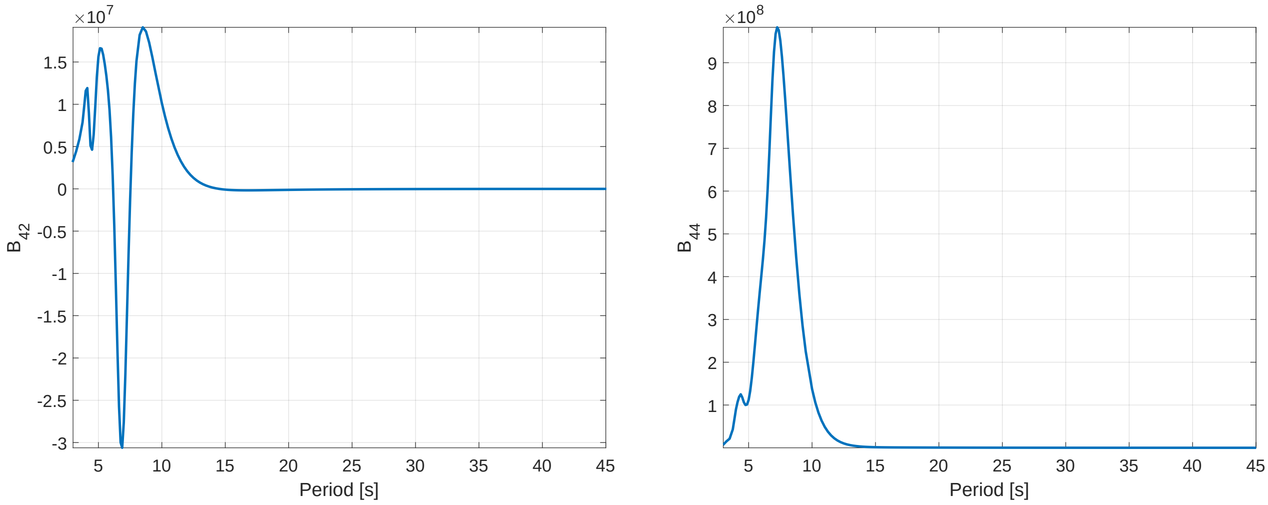
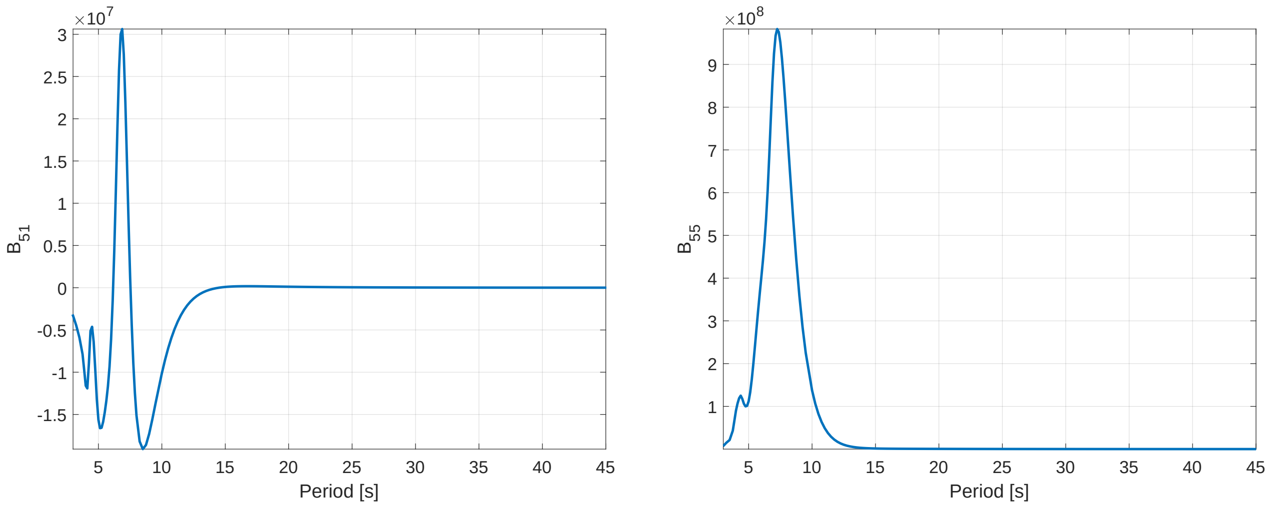


Figure A.15: Wave damping coefficients in heave due to motions in heave.



(a) (b)

Figure A.16: Wave damping coefficients in roll due to motions in (a) sway and (b) roll.



(a) (b)

Figure A.17: Wave damping coefficients in pitch due to motions in (a) surge and (b) pitch.

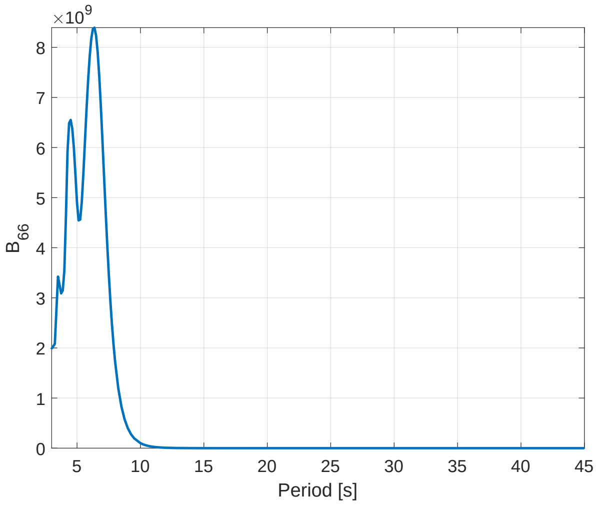


Figure A.18: Wave damping coefficients in yaw due to motions in yaw.

A.4 Wave excitation force transfer functions

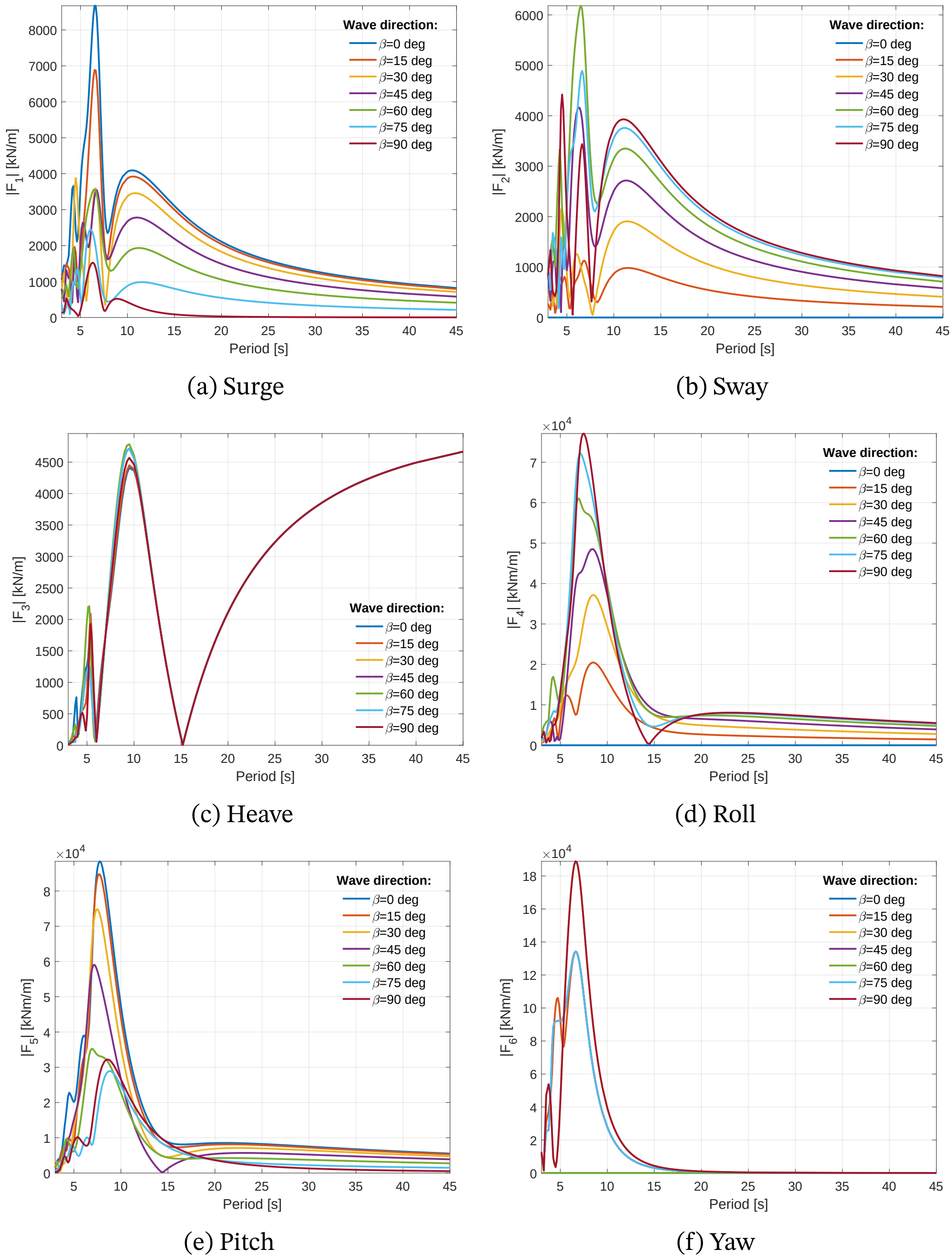
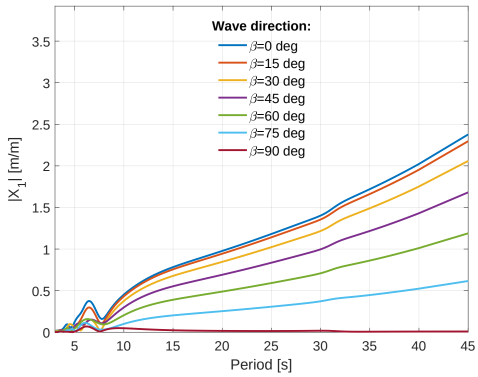
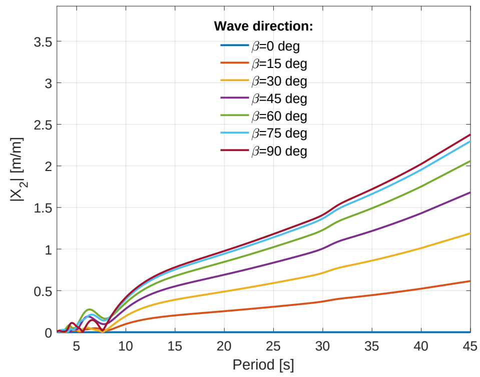


Figure A.19: Wave excitation force transfer functions.

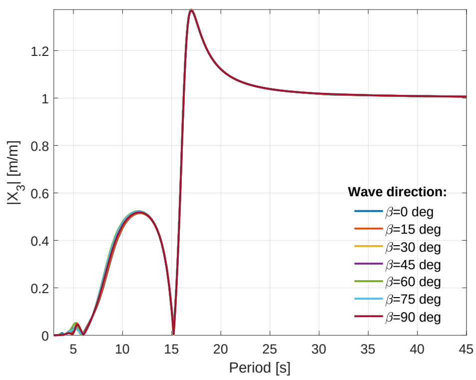
A.5 Wave motion transfer functions (RAOs)



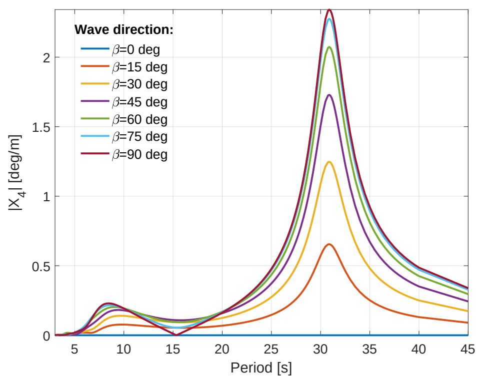
(a) Surge



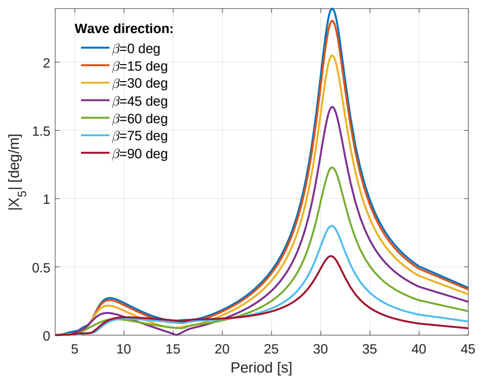
(b) Sway



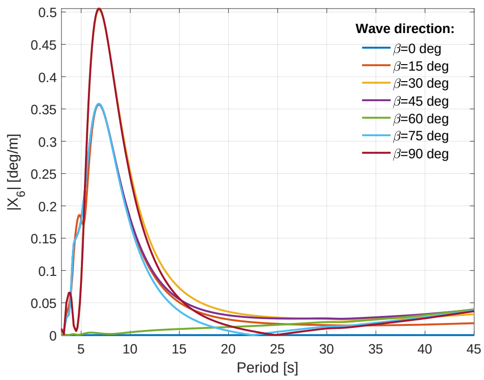
(c) Heave



(d) Roll



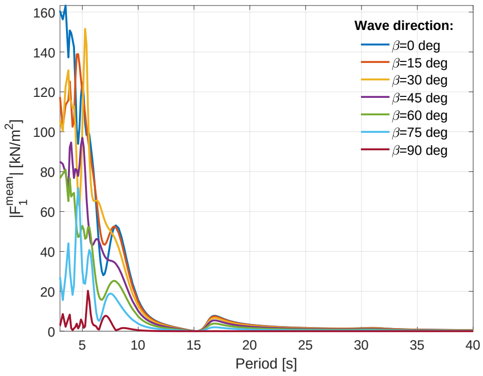
(e) Pitch



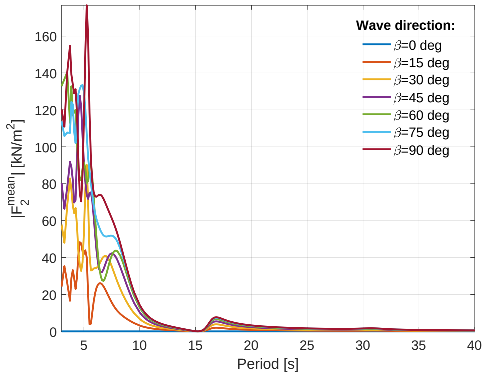
(f) Yaw

Figure A.20: Wave motion transfer functions.

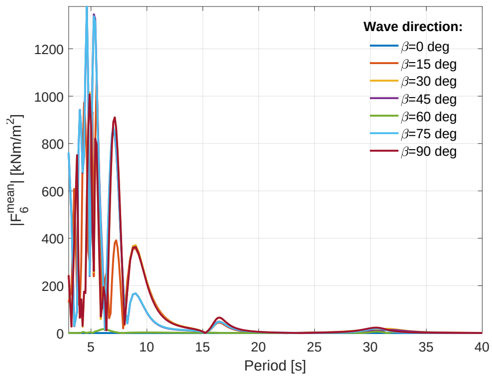
A.6 Wave drift force transfer functions



(a) Surge



(b) Sway



(c) Yaw

Figure A.21: Wave drift force transfer functions.

B WINDMOOR 12 MW turbine performance curves

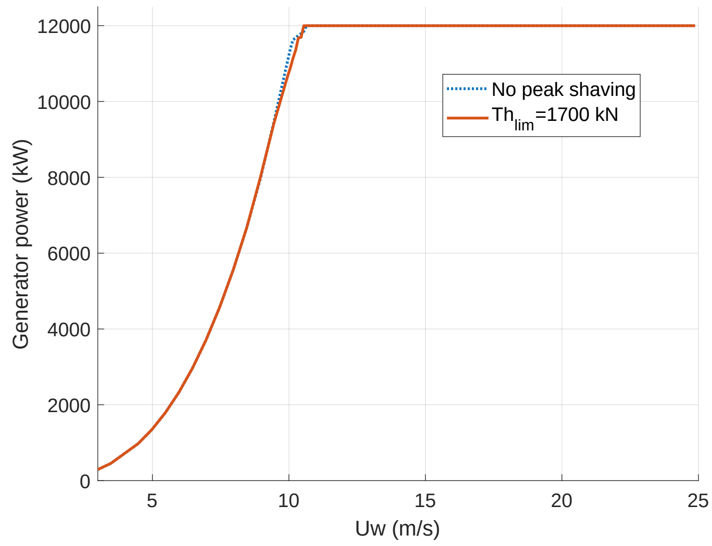


Figure B.1: Generator power.

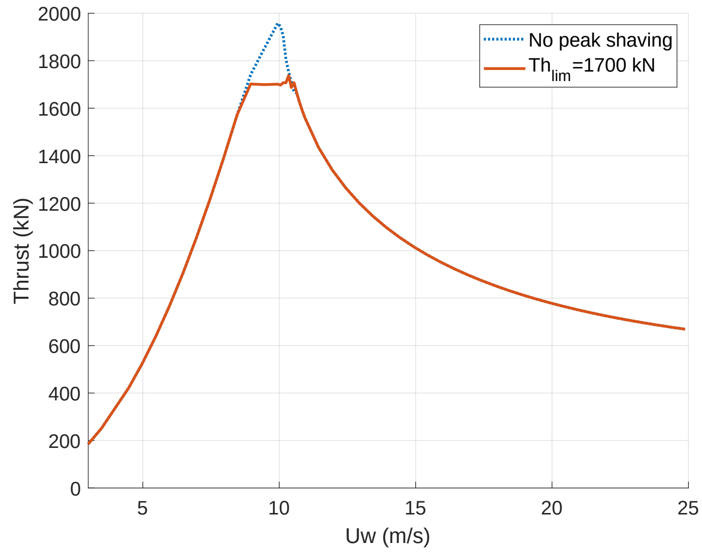


Figure B.2: Rotor thrust.

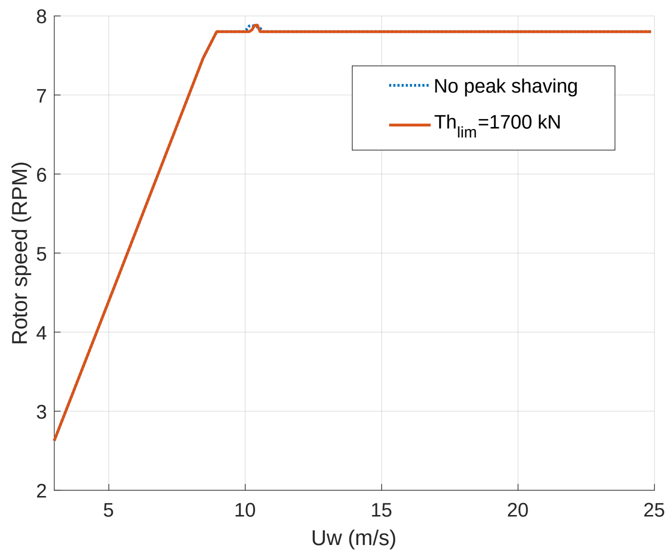


Figure B.3: Rotor speed.

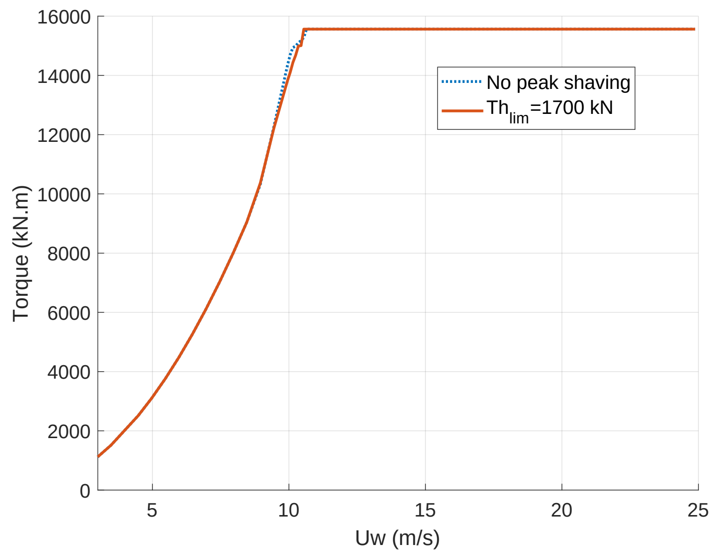


Figure B.4: Generator torque.

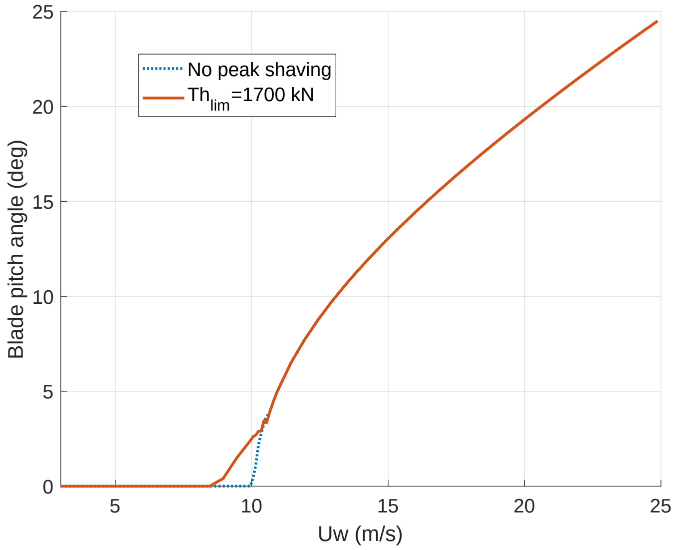


Figure B.5: Collective blade pitch.

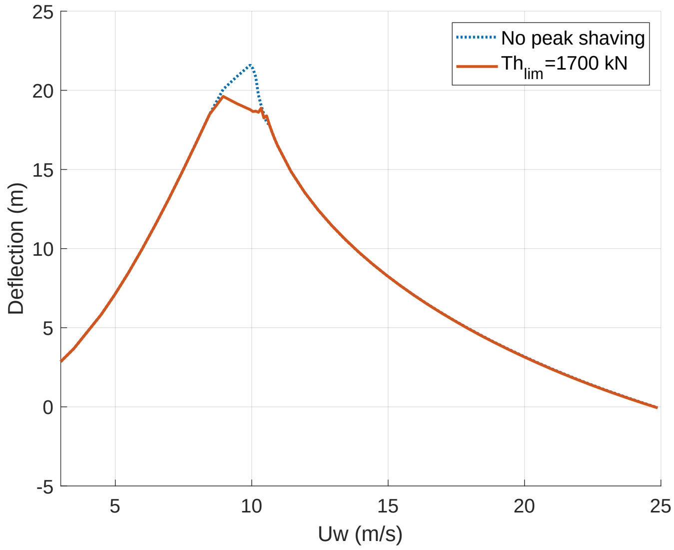


Figure B.6: Out-of-plane mean blade deflection.

C WINDMOOR 12 MW turbine airfoil coefficients

Figures C.1-C.1 show the airfoil coefficients as a function of the angle of attack. The coefficients are provided in Tables C.1-C.18.

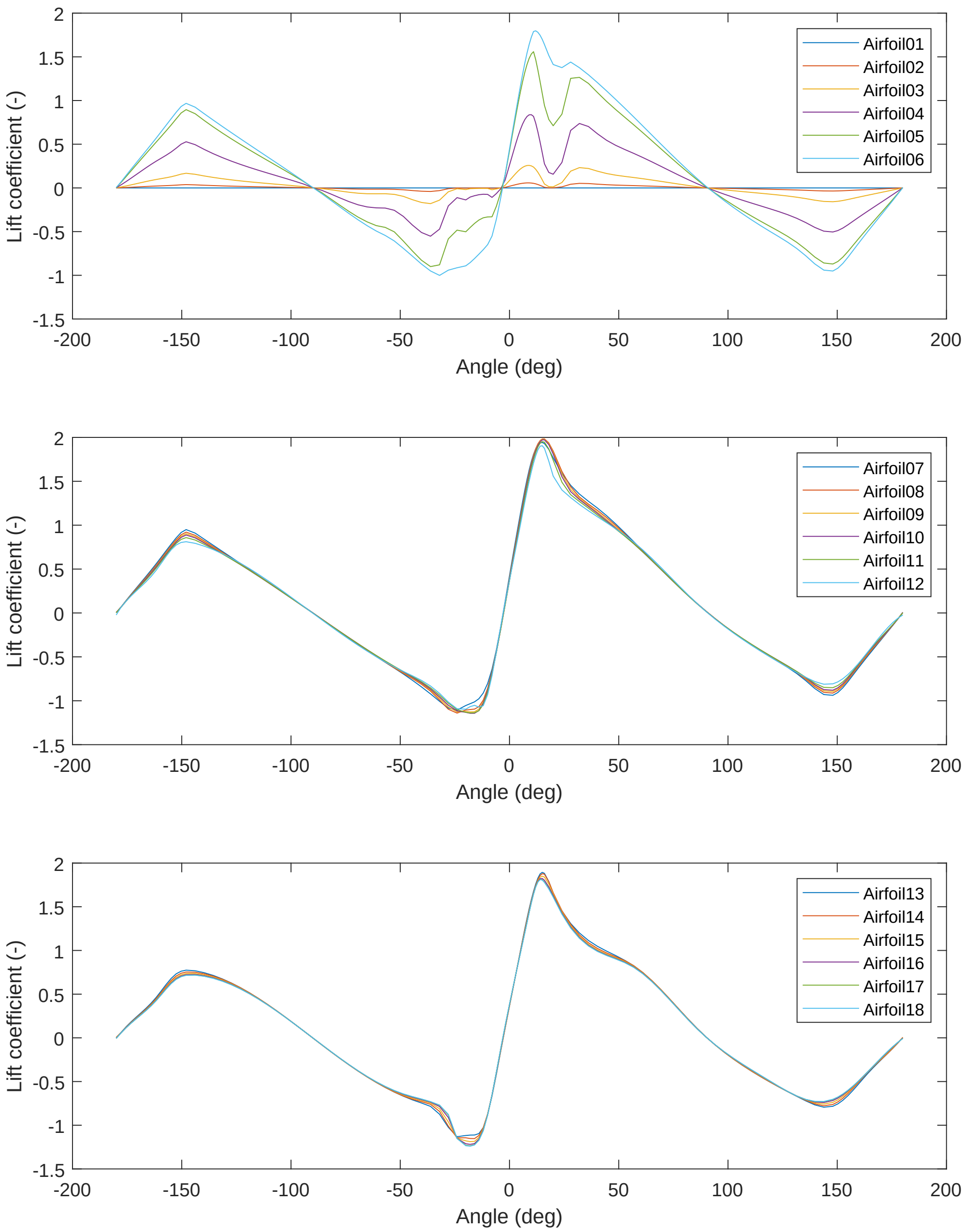


Figure C.1: Airfoil lift coefficient curves for different angles of attack.

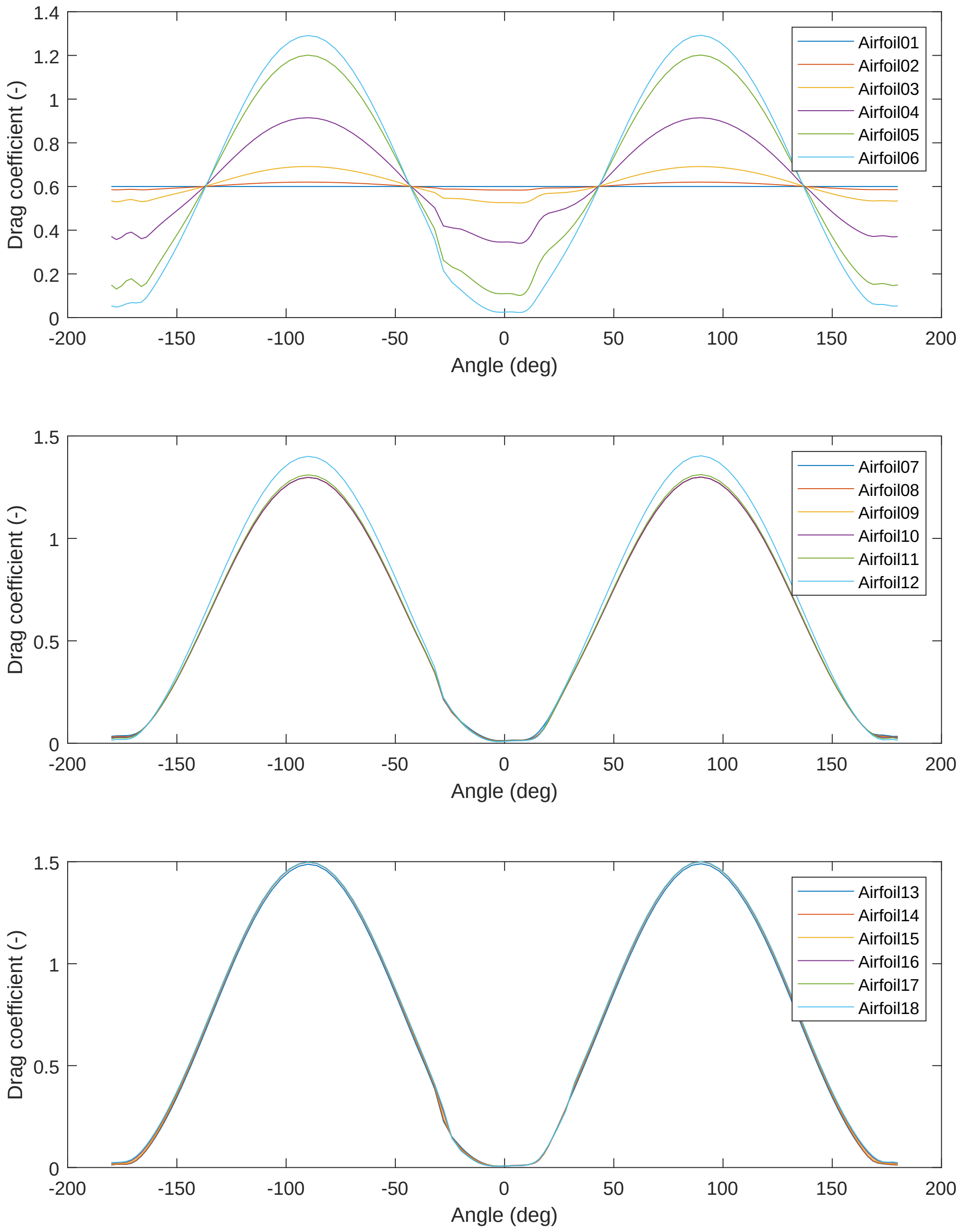


Figure C.2: Airfoil drag coefficient curves for different angles of attack.

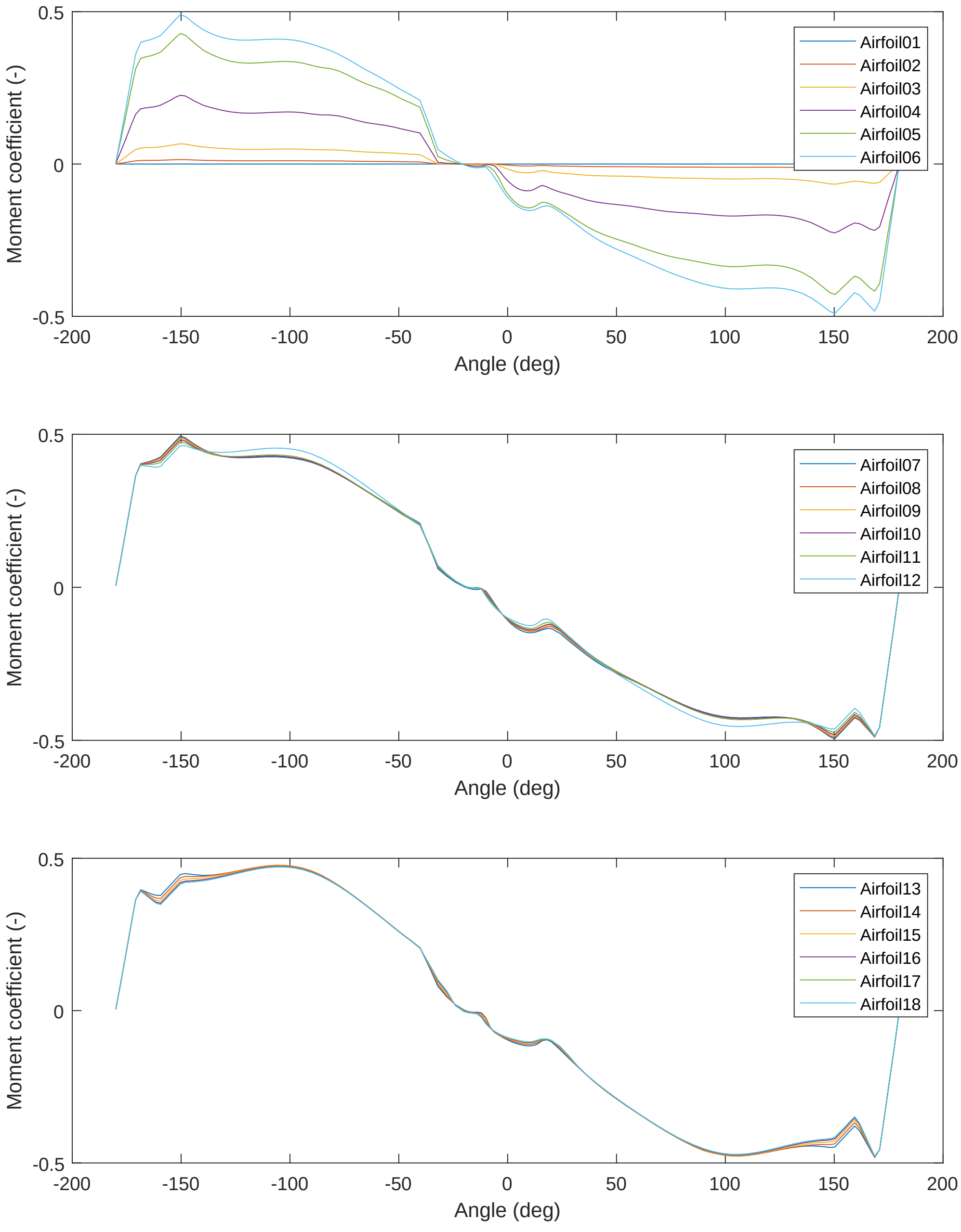


Figure C.3: Airfoil moment coefficient curves for different angles of attack.

Table C.1: Aerodynamic properties of Airfoil01.

Angle (deg)	Cl (-)	Cd (-)	Cm (-)
-180.00	0.00000E+00	6.00000E-01	0.00000E+00
-177.71	0.00000E+00	6.00000E-01	0.00000E+00
-175.43	0.00000E+00	6.00000E-01	0.00000E+00
-173.14	0.00000E+00	6.00000E-01	0.00000E+00
-170.86	0.00000E+00	6.00000E-01	0.00000E+00
-168.57	0.00000E+00	6.00000E-01	0.00000E+00
-166.29	0.00000E+00	6.00000E-01	0.00000E+00
-164.00	0.00000E+00	6.00000E-01	0.00000E+00
-161.71	0.00000E+00	6.00000E-01	0.00000E+00
-159.43	0.00000E+00	6.00000E-01	0.00000E+00
-157.14	0.00000E+00	6.00000E-01	0.00000E+00
-154.86	0.00000E+00	6.00000E-01	0.00000E+00
-152.57	0.00000E+00	6.00000E-01	0.00000E+00
-150.29	0.00000E+00	6.00000E-01	0.00000E+00
-148.00	0.00000E+00	6.00000E-01	0.00000E+00
-143.86	0.00000E+00	6.00000E-01	0.00000E+00
-139.71	0.00000E+00	6.00000E-01	0.00000E+00
-135.57	0.00000E+00	6.00000E-01	0.00000E+00
-131.43	0.00000E+00	6.00000E-01	0.00000E+00
-127.29	0.00000E+00	6.00000E-01	0.00000E+00
-123.14	0.00000E+00	6.00000E-01	0.00000E+00
-119.00	0.00000E+00	6.00000E-01	0.00000E+00
-114.86	0.00000E+00	6.00000E-01	0.00000E+00
-110.71	0.00000E+00	6.00000E-01	0.00000E+00
-106.57	0.00000E+00	6.00000E-01	0.00000E+00
-102.43	0.00000E+00	6.00000E-01	0.00000E+00
-98.29	0.00000E+00	6.00000E-01	0.00000E+00
-94.14	0.00000E+00	6.00000E-01	0.00000E+00
-90.00	0.00000E+00	6.00000E-01	0.00000E+00
-85.86	0.00000E+00	6.00000E-01	0.00000E+00
-81.71	0.00000E+00	6.00000E-01	0.00000E+00
-77.57	0.00000E+00	6.00000E-01	0.00000E+00
-73.43	0.00000E+00	6.00000E-01	0.00000E+00
-69.29	0.00000E+00	6.00000E-01	0.00000E+00
-65.14	0.00000E+00	6.00000E-01	0.00000E+00
-61.00	0.00000E+00	6.00000E-01	0.00000E+00
-56.86	0.00000E+00	6.00000E-01	0.00000E+00
-52.71	0.00000E+00	6.00000E-01	0.00000E+00
-48.57	0.00000E+00	6.00000E-01	0.00000E+00
-44.43	0.00000E+00	6.00000E-01	0.00000E+00
-40.29	0.00000E+00	6.00000E-01	0.00000E+00
-36.14	0.00000E+00	6.00000E-01	0.00000E+00
-32.00	0.00000E+00	6.00000E-01	0.00000E+00
-28.00	0.00000E+00	6.00000E-01	0.00000E+00
-24.00	0.00000E+00	6.00000E-01	0.00000E+00
-20.00	0.00000E+00	6.00000E-01	0.00000E+00
-18.00	0.00000E+00	6.00000E-01	0.00000E+00
-16.00	0.00000E+00	6.00000E-01	0.00000E+00
-14.00	0.00000E+00	6.00000E-01	0.00000E+00
-12.00	0.00000E+00	6.00000E-01	0.00000E+00
-10.00	0.00000E+00	6.00000E-01	0.00000E+00
-8.00	0.00000E+00	6.00000E-01	0.00000E+00
-6.00	0.00000E+00	6.00000E-01	0.00000E+00
-4.00	0.00000E+00	6.00000E-01	0.00000E+00
-2.00	0.00000E+00	6.00000E-01	0.00000E+00
-1.00	0.00000E+00	6.00000E-01	0.00000E+00
0.00	0.00000E+00	6.00000E-01	0.00000E+00
1.00	0.00000E+00	6.00000E-01	0.00000E+00
2.00	0.00000E+00	6.00000E-01	0.00000E+00
3.00	0.00000E+00	6.00000E-01	0.00000E+00
4.00	0.00000E+00	6.00000E-01	0.00000E+00
5.00	0.00000E+00	6.00000E-01	0.00000E+00
6.00	0.00000E+00	6.00000E-01	0.00000E+00
7.00	0.00000E+00	6.00000E-01	0.00000E+00
8.00	0.00000E+00	6.00000E-01	0.00000E+00
9.00	0.00000E+00	6.00000E-01	0.00000E+00
10.00	0.00000E+00	6.00000E-01	0.00000E+00
11.00	0.00000E+00	6.00000E-01	0.00000E+00
12.00	0.00000E+00	6.00000E-01	0.00000E+00
13.00	0.00000E+00	6.00000E-01	0.00000E+00
14.00	0.00000E+00	6.00000E-01	0.00000E+00
15.00	0.00000E+00	6.00000E-01	0.00000E+00
16.00	0.00000E+00	6.00000E-01	0.00000E+00
18.00	0.00000E+00	6.00000E-01	0.00000E+00
20.00	0.00000E+00	6.00000E-01	0.00000E+00
24.00	0.00000E+00	6.00000E-01	0.00000E+00
28.00	0.00000E+00	6.00000E-01	0.00000E+00
32.00	0.00000E+00	6.00000E-01	0.00000E+00
36.14	0.00000E+00	6.00000E-01	0.00000E+00
40.29	0.00000E+00	6.00000E-01	0.00000E+00
44.43	0.00000E+00	6.00000E-01	0.00000E+00
48.57	0.00000E+00	6.00000E-01	0.00000E+00
52.71	0.00000E+00	6.00000E-01	0.00000E+00
56.86	0.00000E+00	6.00000E-01	0.00000E+00
61.00	0.00000E+00	6.00000E-01	0.00000E+00
65.14	0.00000E+00	6.00000E-01	0.00000E+00
69.29	0.00000E+00	6.00000E-01	0.00000E+00
73.43	0.00000E+00	6.00000E-01	0.00000E+00
77.57	0.00000E+00	6.00000E-01	0.00000E+00
81.71	0.00000E+00	6.00000E-01	0.00000E+00
85.86	0.00000E+00	6.00000E-01	0.00000E+00
90.00	0.00000E+00	6.00000E-01	0.00000E+00
94.14	0.00000E+00	6.00000E-01	0.00000E+00
98.29	0.00000E+00	6.00000E-01	0.00000E+00
102.43	0.00000E+00	6.00000E-01	0.00000E+00
106.57	0.00000E+00	6.00000E-01	0.00000E+00
110.71	0.00000E+00	6.00000E-01	0.00000E+00
114.86	0.00000E+00	6.00000E-01	0.00000E+00
119.00	0.00000E+00	6.00000E-01	0.00000E+00
123.14	0.00000E+00	6.00000E-01	0.00000E+00
127.29	0.00000E+00	6.00000E-01	0.00000E+00
131.43	0.00000E+00	6.00000E-01	0.00000E+00
135.57	0.00000E+00	6.00000E-01	0.00000E+00
139.71	0.00000E+00	6.00000E-01	0.00000E+00
143.86	0.00000E+00	6.00000E-01	0.00000E+00
148.00	0.00000E+00	6.00000E-01	0.00000E+00
150.29	0.00000E+00	6.00000E-01	0.00000E+00
152.57	0.00000E+00	6.00000E-01	0.00000E+00
154.86	0.00000E+00	6.00000E-01	0.00000E+00
157.14	0.00000E+00	6.00000E-01	0.00000E+00
159.43	0.00000E+00	6.00000E-01	0.00000E+00
161.71	0.00000E+00	6.00000E-01	0.00000E+00
164.00	0.00000E+00	6.00000E-01	0.00000E+00
166.29	0.00000E+00	6.00000E-01	0.00000E+00
168.57	0.00000E+00	6.00000E-01	0.00000E+00
170.86	0.00000E+00	6.00000E-01	0.00000E+00
173.14	0.00000E+00	6.00000E-01	0.00000E+00
175.43	0.00000E+00	6.00000E-01	0.00000E+00
177.71	0.00000E+00	6.00000E-01	0.00000E+00
180.00	0.00000E+00	6.00000E-01	0.00000E+00

Table C.2: Aerodynamic properties of Airfoil02.

Angle (deg)	Cl (-)	Cd (-)	Cm (-)
-180.00	1.00597E-04	5.85552E-01	1.54783E-04
-177.71	2.46098E-03	5.84590E-01	2.63901E-03
-175.43	5.02762E-03	5.85246E-01	5.16383E-03
-173.14	7.80377E-03	5.86511E-01	7.94596E-03
-170.86	1.06980E-02	5.87006E-01	1.04067E-02
-168.57	1.36186E-02	5.85935E-01	1.15274E-02
-166.29	1.64749E-02	5.84804E-01	1.17665E-02
-164.00	1.91746E-02	5.85201E-01	1.18633E-02
-161.71	2.16265E-02	5.86562E-01	1.20242E-02
-159.43	2.38111E-02	5.87988E-01	1.23463E-02
-157.14	2.59921E-02	5.89313E-01	1.28917E-02
-154.86	2.85060E-02	5.90563E-01	1.34221E-02
-152.57	3.16894E-02	5.91765E-01	1.41433E-02
-150.29	3.54150E-02	5.92941E-01	1.45099E-02
-148.00	3.77059E-02	5.94118E-01	1.43463E-02
-143.86	3.49429E-02	5.96330E-01	1.31444E-02
-139.71	3.05557E-02	5.98729E-01	1.22065E-02
-135.57	2.67111E-02	6.01181E-01	1.16485E-02
-131.43	2.33414E-02	6.03906E-01	1.11720E-02
-127.29	2.03786E-02	6.06549E-01	1.07884E-02
-123.14	1.77553E-02	6.09124E-01	1.05646E-02
-119.00	1.54035E-02	6.11559E-01	1.04824E-02
-114.86	1.32557E-02	6.13781E-01	1.05027E-02
-110.71	1.12440E-02	6.15718E-01	1.05863E-02
-106.57	9.30075E-03	6.17310E-01	1.06918E-02
-102.43	7.35822E-03	6.18543E-01	1.07683E-02
-98.29	5.34868E-03	6.19416E-01	1.07623E-02
-94.14	3.20439E-03	6.19928E-01	1.06202E-02
-90.00	1.62593E-04	6.20079E-01	1.03453E-02
-85.86	-1.74933E-03	6.19868E-01	1.01684E-02
-81.71	-4.71418E-03	6.19293E-01	1.02020E-02
-77.57	-7.97413E-03	6.18360E-01	1.00080E-02
-73.43	-1.11040E-02	6.17093E-01	9.58262E-03
-69.29	-1.35681E-02	6.15523E-01	9.07583E-03
-65.14	-1.48307E-02	6.13683E-01	8.63774E-03
-61.00	-1.47333E-02	6.11602E-01	8.37173E-03
-56.86	-1.45644E-02	6.09312E-01	8.18501E-03
-52.71	-1.61632E-02	6.06844E-01	7.94712E-03
-48.57	-2.12899E-02	6.04230E-01	7.53794E-03
-44.43	-3.02699E-02	6.01186E-01	7.12820E-03
-40.29	-3.76979E-02	5.98736E-01	6.82235E-03
-36.14	-4.07516E-02	5.96311E-01	3.42152E-03
-32.00	-3.07564E-02	5.93934E-01	2.91727E-05
-28.00	-8.89487E-03	5.88264E-01	1.38375E-05
-24.00	-6.37298E-04	5.88027E-01	3.22194E-06
-20.00	-2.97959E-03	5.87743E-01	-1.03866E-04
-18.00	-5.99309E-04	5.87257E-01	-3.31183E-04
-16.00	-4.91843E-04	5.86702E-01	-4.87226E-04
-14.00	-4.14603E-04	5.86113E-01	-5.46024E-04
-12.00	-3.84092E-04	5.85527E-01	-4.81607E-04
-10.00	-4.14740E-04	5.84980E-01	-6.55930E-06
-8.00	-4.05540E-03	5.84500E-01	-1.27260E-05
-6.00	-2.09270E-03	5.84140E-01	-3.21150E-05
-4.00	-4.75020E-05	5.83910E-01	-1.16240E-03
-2.00	6.63590E-03	5.83850E-01	-2.48100E-03
-1.00	1.29300E-02	5.83860E-01	-3.12420E-03
0.00	1.92670E-02	5.83870E-01	-3.73620E-03
1.00	2.56160E-02	5.83880E-01	-4.31160E-03
2.00	3.19470E-02	5.83870E-01	-4.83790E-03
3.00	3.82280E-02	6.00000E-01	1.38780E-17
4.00	4.39980E-02	5.83750E-01	-5.69400E-03
5.00	4.89810E-02	5.83630E-01	-6.00200E-03
6.00	5.29870E-02	5.83510E-01	-6.22890E-03
7.00	5.58460E-02	5.83460E-01	-6.37990E-03
8.00	5.73840E-02	5.83540E-01	-6.46000E-03
9.00	5.74300E-02	5.83800E-01	-6.47190E-03
10.00	5.58120E-02	5.84270E-01	-6.40870E-03
11.00	5.23561E-02	5.84971E-01	-6.26160E-03
12.00	4.66215E-02	5.85934E-01	-6.02132E-03
13.00	3.88158E-02	5.87149E-01	-5.68960E-03
14.00	2.93821E-02	5.88496E-01	-5.31131E-03
15.00	1.88378E-02	5.89833E-01	-4.96217E-03
16.00	7.69388E-03	5.91017E-01	-4.79826E-03
18.00	9.94608E-04	5.92601E-01	-5.34270E-03
20.00	8.63394E-04	5.93343E-01	-6.05872E-03
24.00	1.21188E-02	5.93628E-01	-6.80005E-03
28.00	4.20139E-02	5.94071E-01	-7.22270E-03
32.00	5.21037E-02	5.95071E-01	-7.71307E-03
36.14	4.99768E-02	5.96636E-01	-8.25657E-03
40.29	4.26954E-02	5.98680E-01	-8.54025E-03
44.43	3.65808E-02	6.01113E-01	-8.67594E-03
48.57	3.23097E-02	6.03808E-01	-8.73836E-03
52.71	2.91475E-02	6.06577E-01	-8.79296E-03
56.86	2.63599E-02	6.09253E-01	-8.90518E-03
61.00	2.33509E-02	6.11694E-01	-9.11997E-03
65.14	2.00776E-02	6.13858E-01	-9.39641E-03
69.29	1.66357E-02	6.15726E-01	-9.67950E-03
73.43	1.31209E-02	6.17282E-01	-9.91135E-03
77.57	9.62885E-03	6.18508E-01	-1.00523E-02
81.71	6.25512E-03	6.19386E-01	-1.01422E-02
85.86	3.09397E-03	6.19899E-01	-1.02401E-02
90.00	2.10722E-04	6.20034E-01	-1.03873E-02
94.14	-2.39759E-03	6.19804E-01	-1.05545E-02
98.29	-4.81164E-03	6.19224E-01	-1.06951E-02
102.43	-7.07446E-03	6.18312E-01	-1.07624E-02
106.57	-9.23886E-03	6.17083E-01	-1.07273E-02
110.71	-1.13576E-02	6.15556E-01	-1.06319E-02
114.86	-1.34836E-02	6.13746E-01	-1.05358E-02
119.00	-1.56695E-02	6.11670E-01	-1.04984E-02
123.14	-1.79865E-02	6.09352E-01	-1.05711E-02
127.29	-2.05793E-02	6.06848E-01	-1.07724E-02
131.43	-2.36108E-02	6.04221E-01	-1.11125E-02
135.57	-2.72440E-02	6.01228E-01	-1.16018E-02
139.71	-3.13468E-02	5.98874E-01	-1.22669E-02
143.86	-3.46055E-02	5.96261E-01	-1.32006E-02
148.00	-3.54116E-02	5.93773E-01	-1.42821E-02
150.29	-3.43206E-02	5.92477E-01	-1.45382E-02
152.57	-3.23231E-02	5.91249E-01	-1.41235E-02
154.86	-2.97486E-02	5.90097E-01	-1.34552E-02
157.14	-2.69268E-02	5.89030E-01	-1.28480E-02
159.43	-2.41291E-02	5.88057E-01	-1.23806E-02
161.71	-2.13932E-02	5.87187E-01	-1.25098E-02
164.00	-1.86985E-02	5.86430E-01	-1.29857E-02
166.29	-1.60263E-02	5.85826E-01	-1.36176E-02
168.57	-1.33654E-02	5.85544E-01	-1.38543E-02
170.86	-1.07062E-02	5.85669E-01	-1.31790E-02
173.14	-8.03945E-03	5.85817E-01	-9.84735E-03
175.43	-5.35568E-03	5.85644E-01	-6.42314E-03
177.71	-2.64546E-03	5.85415E-01	-3.34367E-03
180.00	1.00597E-04	5.85552E-01	1.54783E-04

Table C.3: Aerodynamic properties of Airfoil03.

Angle (deg)	Cl (-)	Cd (-)	Cm (-)
-180.00	4.56966E-04	5.33975E-01	7.00130E-04
-177.71	1.10522E-02	5.29644E-01	1.20372E-02
-175.43	2.25622E-02	5.32604E-01	2.35718E-02
-173.14	3.49119E-02	5.38269E-01	3.62341E-02
-170.86	4.77329E-02	5.40479E-01	4.75034E-02
-168.57	6.06564E-02	5.35722E-01	5.26191E-02
-166.29	7.33173E-02	5.30635E-01	5.36749E-02
-164.00	8.53440E-02	5.32479E-01	5.41260E-02
-161.71	9.63688E-02	5.38654E-01	5.48668E-02
-159.43	1.06316E-01	5.45137E-01	5.62895E-02
-157.14	1.16260E-01	5.51161E-01	5.87605E-02
-154.86	1.27571E-01	5.56852E-01	6.11645E-02
-152.57	1.41618E-01	5.62327E-01	6.43639E-02
-150.29	1.57805E-01	5.67697E-01	6.60853E-02
-148.00	1.67694E-01	5.73073E-01	6.53295E-02
-143.86	1.55761E-01	5.83180E-01	6.00025E-02
-139.71	1.36745E-01	5.94124E-01	5.57347E-02
-135.57	1.19980E-01	6.05212E-01	5.31974E-02
-131.43	1.05183E-01	6.17642E-01	5.10375E-02
-127.29	9.20733E-02	6.29715E-01	4.93061E-02
-123.14	8.03691E-02	6.41466E-01	4.83003E-02
-119.00	6.97893E-02	6.52572E-01	4.79341E-02
-114.86	6.00525E-02	6.62709E-01	4.80281E-02
-110.71	5.08774E-02	6.71555E-01	4.84048E-02
-106.57	4.19826E-02	6.78838E-01	4.88771E-02
-102.43	3.30868E-02	6.84495E-01	4.92163E-02
-98.29	2.39087E-02	6.88517E-01	4.91819E-02
-94.14	1.41668E-02	6.90893E-01	4.85328E-02
-90.00	7.17651E-04	6.91614E-01	4.72831E-02
-85.86	-7.99775E-03	6.90669E-01	4.64661E-02
-81.71	-2.12545E-02	6.88048E-01	4.65917E-02
-77.57	-3.56459E-02	6.83768E-01	4.56949E-02
-73.43	-4.94945E-02	6.77949E-01	4.37518E-02
-69.29	-6.05688E-02	6.70739E-01	4.14392E-02
-65.14	-6.66369E-02	6.62285E-01	3.94371E-02
-61.00	-6.70356E-02	6.52735E-01	3.82160E-02
-56.86	-6.65403E-02	6.42236E-01	3.72884E-02
-52.71	-7.38530E-02	6.30935E-01	3.60811E-02
-48.57	-9.65986E-02	6.18980E-01	3.41618E-02
-44.43	-1.34673E-01	6.05236E-01	3.22745E-02
-40.29	-1.66391E-01	5.94157E-01	3.07894E-02
-36.14	-1.79981E-01	5.83109E-01	1.56410E-02
-32.00	-1.39573E-01	5.72234E-01	4.24384E-04
-28.00	-4.46043E-02	5.46705E-01	2.04286E-04
-24.00	-9.18573E-03	5.45316E-01	5.01022E-05
-20.00	-1.92199E-02	5.43959E-01	-4.58445E-04
-18.00	-8.63522E-03	5.41740E-01	-1.46177E-03
-16.00	-7.15355E-03	5.39215E-01	-2.15052E-03
-14.00	-6.07822E-03	5.36542E-01	-2.41004E-03
-12.00	-5.63349E-03	5.33880E-01	-2.12572E-03
-10.00	-6.01180E-03	5.31390E-01	-9.48020E-05
-8.00	-2.12300E-02	5.29230E-01	-1.87130E-04
-6.00	-1.15020E-02	5.27570E-01	-4.61910E-04
-4.00	-7.12100E-04	5.26560E-01	-5.43440E-03
-2.00	2.92900E-02	5.26280E-01	-1.13290E-02
-1.00	5.70710E-02	5.26300E-01	-1.41590E-02
0.00	8.50420E-02	5.26370E-01	-1.67880E-02
1.00	1.13070E-01	5.26410E-01	-1.92570E-02
2.00	1.41010E-01	5.26370E-01	-2.15150E-02
3.00	1.68730E-01	5.26190E-01	-2.35120E-02
4.00	1.94330E-01	5.25830E-01	-2.51950E-02
5.00	2.16640E-01	5.25270E-01	-2.65250E-02
6.00	2.34870E-01	5.24730E-01	-2.75110E-02
7.00	2.48270E-01	5.24500E-01	-2.81740E-02
8.00	2.56100E-01	5.24850E-01	-2.85330E-02
9.00	2.57610E-01	5.26030E-01	-2.86000E-02
10.00	2.52070E-01	5.28160E-01	-2.83480E-02
11.00	2.38722E-01	5.31342E-01	-2.77371E-02
12.00	2.13158E-01	5.35664E-01	-2.67311E-02
13.00	1.78735E-01	5.41082E-01	-2.53370E-02
14.00	1.37723E-01	5.47058E-01	-2.37428E-02
15.00	9.23376E-02	5.52958E-01	-2.22652E-02
16.00	4.47003E-02	5.58169E-01	-2.15549E-02
18.00	1.43917E-02	5.65183E-01	-2.37646E-02
20.00	1.25535E-02	5.68570E-01	-2.67420E-02
24.00	6.14565E-02	5.70213E-01	-3.00140E-02
28.00	1.91617E-01	5.72546E-01	-3.20356E-02
32.00	2.32234E-01	5.77297E-01	-3.43427E-02
36.14	2.22425E-01	5.84544E-01	-3.68691E-02
40.29	1.91315E-01	5.93908E-01	-3.82984E-02
44.43	1.64946E-01	6.04917E-01	-3.90790E-02
48.57	1.46116E-01	6.17221E-01	-3.95267E-02
52.71	1.31811E-01	6.29818E-01	-3.99242E-02
56.86	1.19020E-01	6.41989E-01	-4.05544E-02
61.00	1.05297E-01	6.53118E-01	-4.16127E-02
65.14	9.04795E-02	6.63011E-01	-4.28923E-02
69.29	7.49717E-02	6.71578E-01	-4.41863E-02
73.43	5.91789E-02	6.78730E-01	-4.52490E-02
77.57	4.35063E-02	6.84380E-01	-4.59021E-02
81.71	2.83590E-02	6.88436E-01	-4.63271E-02
85.86	1.41232E-02	6.90812E-01	-4.67892E-02
90.00	1.02373E-03	6.91444E-01	-4.74705E-02
94.14	-1.07148E-02	6.90387E-01	-4.82378E-02
98.29	-2.16920E-02	6.87720E-01	-4.88809E-02
102.43	-3.19964E-02	6.83522E-01	-4.91903E-02
106.57	-4.18487E-02	6.77875E-01	-4.90364E-02
110.71	-5.14698E-02	6.70858E-01	-4.86087E-02
114.86	-6.10805E-02	6.62552E-01	-4.81759E-02
119.00	-7.09018E-02	6.53037E-01	-4.80057E-02
123.14	-8.12399E-02	6.42426E-01	-4.83299E-02
127.29	-9.27428E-02	6.30973E-01	-4.92344E-02
131.43	-1.06144E-01	6.18962E-01	-5.07699E-02
135.57	-1.22177E-01	6.05420E-01	-5.29865E-02
139.71	-1.40265E-01	5.94755E-01	-5.60079E-02
143.86	-1.54595E-01	5.82874E-01	-6.02582E-02
148.00	-1.58043E-01	5.71532E-01	-6.50618E-02
150.29	-1.53137E-01	5.65622E-01	-6.62035E-02
152.57	-1.44210E-01	5.60018E-01	-6.42812E-02
154.86	-1.32721E-01	5.54760E-01	-6.13033E-02
157.14	-1.20132E-01	5.49890E-01	-5.85774E-02
159.43	-1.07644E-01	5.45449E-01	-5.64354E-02
161.71	-9.54287E-02	5.41479E-01	-5.70785E-02
164.00	-8.34003E-02	5.38020E-01	-5.92672E-02
166.29	-7.14796E-02	5.35258E-01	-6.20985E-02
168.57	-5.96146E-02	5.33963E-01	-6.32415E-02
170.86	-4.77602E-02	5.34513E-01	-6.01064E-02
173.14	-3.58710E-02	5.35178E-01	-4.49448E-02
175.43	-2.39019E-02	5.34393E-01	-2.93206E-02
177.71	-1.18076E-02	5.33360E-01	-1.52339E-02
180.00	4.56966E-04	5.33975E-01	7.00130E-04

Table C.4: Aerodynamic properties of Airfoil04.

Angle (deg)	Cl (-)	Cd (-)	Cm (-)
-180.00	1.54817E-03	3.70890E-01	2.33891E-03
-177.71	3.60343E-02	3.57241E-01	4.13302E-02
-175.43	7.33746E-02	3.66700E-01	8.11771E-02
-173.14	1.12316E-01	3.84308E-01	1.24304E-01
-170.86	1.52134E-01	3.91166E-01	1.63529E-01
-168.57	1.92104E-01	3.76918E-01	1.81119E-01
-166.29	2.31513E-01	3.61132E-01	1.84348E-01
-164.00	2.69626E-01	3.67937E-01	1.86004E-01
-161.71	3.05721E-01	3.88475E-01	1.88622E-01
-159.43	3.39687E-01	4.10246E-01	1.92991E-01
-157.14	3.73782E-01	4.30557E-01	2.01294E-01
-154.86	4.10890E-01	4.49886E-01	2.09377E-01
-152.57	4.53891E-01	4.68636E-01	2.19367E-01
-150.29	5.00561E-01	4.87163E-01	2.25818E-01
-148.00	5.28319E-01	5.05801E-01	2.23120E-01
-143.86	4.94742E-01	5.40896E-01	2.06689E-01
-139.71	4.40465E-01	5.78618E-01	1.92423E-01
-135.57	3.91425E-01	6.15969E-01	1.83910E-01
-131.43	3.46962E-01	6.58648E-01	1.76774E-01
-127.29	3.06414E-01	7.00302E-01	1.71166E-01
-123.14	2.69122E-01	7.40706E-01	1.67971E-01
-119.00	2.34422E-01	7.78831E-01	1.66856E-01
-114.86	2.01656E-01	8.13648E-01	1.67207E-01
-110.71	1.70161E-01	8.44128E-01	1.68424E-01
-106.57	1.39276E-01	8.69397E-01	1.69893E-01
-102.43	1.08341E-01	8.89201E-01	1.70888E-01
-98.29	7.66936E-02	9.03442E-01	1.70647E-01
-94.14	4.36736E-02	9.12023E-01	1.68399E-01
-90.00	2.19892E-03	9.14844E-01	1.64175E-01
-85.86	-2.78125E-02	9.11809E-01	1.61187E-01
-81.71	-7.02342E-02	9.02817E-01	1.61080E-01
-77.57	-1.14359E-01	8.87883E-01	1.57725E-01
-73.43	-1.57181E-01	8.67466E-01	1.50991E-01
-69.29	-1.93378E-01	8.42135E-01	1.43046E-01
-65.14	-2.17631E-01	8.12459E-01	1.36084E-01
-61.00	-2.28325E-01	7.79010E-01	1.31652E-01
-56.86	-2.30568E-01	7.42357E-01	1.27526E-01
-52.71	-2.56055E-01	7.03069E-01	1.22029E-01
-48.57	-3.26032E-01	6.61718E-01	1.14855E-01
-44.43	-4.24852E-01	6.16044E-01	1.08171E-01
-40.29	-5.09832E-01	5.78741E-01	1.02076E-01
-36.14	-5.52750E-01	5.40868E-01	5.43621E-02
-32.00	-4.71323E-01	5.02927E-01	5.29979E-03
-28.00	-2.05953E-01	4.19626E-01	2.67071E-03
-24.00	-1.11305E-01	4.10883E-01	7.54955E-04
-20.00	-1.37248E-01	4.05027E-01	-1.40470E-03
-18.00	-1.04514E-01	3.97350E-01	-4.47896E-03
-16.00	-8.92777E-02	3.88793E-01	-6.58931E-03
-14.00	-7.77813E-02	3.79841E-01	-7.38450E-03
-12.00	-7.21921E-02	3.70979E-01	-6.51332E-03
-10.00	-7.42170E-02	3.62710E-01	-1.15920E-03
-8.00	-1.08200E-01	3.55540E-01	-2.41700E-03
-6.00	-6.45560E-02	3.50010E-01	-5.55750E-03
-4.00	-9.73570E-03	3.46670E-01	-2.05470E-02
-2.00	8.97450E-02	3.45730E-01	-3.91400E-02
-1.00	1.74870E-01	3.45810E-01	-4.76010E-02
0.00	2.60570E-01	3.46020E-01	-5.48280E-02
1.00	3.46440E-01	3.46170E-01	-6.15930E-02
2.00	4.32060E-01	3.46060E-01	-6.77760E-02
3.00	5.17000E-01	3.45520E-01	-7.32570E-02
4.00	5.96890E-01	3.44340E-01	-7.79150E-02
5.00	6.68950E-01	3.42520E-01	-8.16570E-02
6.00	7.31040E-01	3.40770E-01	-8.44990E-02
7.00	7.81050E-01	3.40020E-01	-8.64840E-02
8.00	8.16910E-01	3.41160E-01	-8.76550E-02
9.00	8.36530E-01	3.45020E-01	-8.80330E-02
10.00	8.37810E-01	3.51940E-01	-8.75530E-02
11.00	8.18686E-01	3.62153E-01	-8.61272E-02
12.00	7.41432E-01	3.75791E-01	-8.36677E-02
13.00	6.40318E-01	3.92559E-01	-8.01967E-02
14.00	5.25228E-01	4.10718E-01	-7.61756E-02
15.00	4.02064E-01	4.28406E-01	-7.23727E-02
16.00	2.75836E-01	4.43971E-01	-7.03463E-02
18.00	1.76642E-01	4.65525E-01	-7.49073E-02
20.00	1.56509E-01	4.77320E-01	-8.19390E-02
24.00	2.91575E-01	4.87438E-01	-9.19647E-02
28.00	6.57699E-01	4.99584E-01	-9.99425E-02
32.00	7.37395E-01	5.18578E-01	-1.08642E-01
36.14	7.02525E-01	5.45097E-01	-1.17840E-01
40.29	6.18953E-01	5.78018E-01	-1.24245E-01
44.43	5.45236E-01	6.15126E-01	-1.28713E-01
48.57	4.87788E-01	6.57492E-01	-1.32052E-01
52.71	4.39989E-01	7.00379E-01	-1.35059E-01
56.86	3.95219E-01	7.41772E-01	-1.38531E-01
61.00	3.48133E-01	7.79921E-01	-1.43034E-01
65.14	2.98503E-01	8.14152E-01	-1.47691E-01
69.29	2.47373E-01	8.44060E-01	-1.52244E-01
73.43	1.95793E-01	8.69239E-01	-1.56054E-01
77.57	1.44808E-01	8.89284E-01	-1.58557E-01
81.71	9.54664E-02	9.03788E-01	-1.60341E-01
85.86	4.86323E-02	9.12347E-01	-1.62227E-01
90.00	4.35008E-03	9.14675E-01	-1.64748E-01
94.14	-3.43420E-02	9.10971E-01	-1.67464E-01
98.29	-7.16587E-02	9.01555E-01	-1.69708E-01
102.43	-1.06851E-01	8.86747E-01	-1.70818E-01
106.57	-1.40457E-01	8.66866E-01	-1.70393E-01
110.71	-1.73014E-01	8.42232E-01	-1.69051E-01
114.86	-2.05059E-01	8.13165E-01	-1.67660E-01
119.00	-2.37131E-01	7.79985E-01	-1.67082E-01
123.14	-2.70079E-01	7.43118E-01	-1.68069E-01
127.29	-3.05998E-01	7.03426E-01	-1.70944E-01
131.43	-3.47295E-01	6.61874E-01	-1.75926E-01
135.57	-3.96377E-01	6.16607E-01	-1.83233E-01
139.71	-4.51569E-01	5.80409E-01	-1.93303E-01
143.86	-4.94866E-01	5.39944E-01	-2.07528E-01
148.00	-5.04180E-01	5.01028E-01	-2.22478E-01
150.29	-4.88104E-01	4.80718E-01	-2.26105E-01
152.57	-4.59488E-01	4.61440E-01	-2.19163E-01
154.86	-4.22860E-01	4.43341E-01	-2.09717E-01
157.14	-3.82748E-01	4.26564E-01	-2.00844E-01
159.43	-3.42889E-01	4.11251E-01	-1.93376E-01
161.71	-3.03867E-01	3.97542E-01	-1.96178E-01
164.00	-2.65473E-01	3.85576E-01	-2.03892E-01
166.29	-2.27505E-01	3.75979E-01	-2.13049E-01
168.57	-1.89778E-01	3.71315E-01	-2.17775E-01
170.86	-1.52112E-01	3.72854E-01	-2.06305E-01
173.14	-1.14327E-01	3.74899E-01	-1.54632E-01
175.43	-7.62420E-02	3.72325E-01	-1.00994E-01
177.71	-3.76771E-02	3.68955E-01	-5.21129E-02
180.00	1.54817E-03	3.70890E-01	2.33891E-03

Table C.5: Aerodynamic properties of Airfoil05.

Angle (deg)	Cl (-)	Cd (-)	Cm (-)
-180.00	2.90342E-03	1.49133E-01	4.30732E-03
-177.71	6.42108E-02	1.30653E-01	7.88217E-02
-175.43	1.30285E-01	1.44080E-01	1.55722E-01
-173.14	1.96389E-01	1.68123E-01	2.36811E-01
-170.86	2.62420E-01	1.77936E-01	3.13098E-01
-168.57	3.28268E-01	1.60817E-01	3.46580E-01
-166.29	3.93847E-01	1.41895E-01	3.51700E-01
-164.00	4.59034E-01	1.56895E-01	3.55110E-01
-161.71	5.23728E-01	1.92100E-01	3.60280E-01
-159.43	5.88060E-01	2.30147E-01	3.67396E-01
-157.14	6.52972E-01	2.66716E-01	3.82801E-01
-154.86	7.19669E-01	3.02558E-01	3.97814E-01
-152.57	7.89348E-01	3.38241E-01	4.14520E-01
-150.29	8.57347E-01	3.74209E-01	4.28099E-01
-148.00	8.95680E-01	4.10858E-01	4.22707E-01
-143.86	8.49085E-01	4.80146E-01	3.96936E-01
-139.71	7.71527E-01	5.53782E-01	3.72827E-01
-135.57	6.98096E-01	6.25915E-01	3.57946E-01
-131.43	6.28251E-01	7.07310E-01	3.46046E-01
-127.29	5.61450E-01	7.87223E-01	3.37220E-01
-123.14	4.97150E-01	8.64411E-01	3.32478E-01
-119.00	4.34811E-01	9.37102E-01	3.31073E-01
-114.86	3.73889E-01	1.00353E+00	3.31884E-01
-110.71	3.13842E-01	1.06191E+00	3.33830E-01
-106.57	2.54130E-01	1.11072E+00	3.35848E-01
-102.43	1.94210E-01	1.14938E+00	3.36852E-01
-98.29	1.33540E-01	1.17756E+00	3.35725E-01
-94.14	7.15784E-02	1.19492E+00	3.31325E-01
-90.00	3.56857E-03	1.20112E+00	3.23617E-01
-85.86	-5.50467E-02	1.19582E+00	3.16914E-01
-81.71	-1.27477E-01	1.17869E+00	3.13556E-01
-77.57	-1.99164E-01	1.14965E+00	3.05352E-01
-73.43	-2.69684E-01	1.10968E+00	2.92128E-01
-69.29	-3.34412E-01	1.06001E+00	2.77005E-01
-65.14	-3.88720E-01	1.00189E+00	2.63170E-01
-61.00	-4.31097E-01	9.36546E-01	2.52924E-01
-56.86	-4.51907E-01	8.65220E-01	2.42017E-01
-52.71	-5.02694E-01	7.89149E-01	2.28346E-01
-48.57	-6.08479E-01	7.09571E-01	2.13287E-01
-44.43	-7.21720E-01	6.26038E-01	2.00061E-01
-40.29	-8.27391E-01	5.54047E-01	1.86090E-01
-36.14	-9.00415E-01	4.81074E-01	1.07439E-01
-32.00	-8.80231E-01	4.05365E-01	2.41465E-02
-28.00	-5.83093E-01	2.62173E-01	1.30086E-02
-24.00	-4.83153E-01	2.31506E-01	4.34853E-03
-20.00	-5.01953E-01	2.13653E-01	-2.27965E-03
-18.00	-4.52811E-01	1.98670E-01	-7.26877E-03
-16.00	-4.06359E-01	1.82889E-01	-1.06936E-02
-14.00	-3.67566E-01	1.66984E-01	-1.19841E-02
-12.00	-3.41853E-01	1.51636E-01	-1.05703E-02
-10.00	-3.32090E-01	1.37560E-01	-5.10820E-03
-8.00	-3.30340E-01	1.25500E-01	-1.15750E-02
-6.00	-2.09700E-01	1.16270E-01	-2.38380E-02
-4.00	-5.02830E-02	1.10700E-01	-4.70320E-02
-2.00	1.45640E-01	1.09090E-01	-7.60090E-02
-1.00	2.83790E-01	1.09240E-01	-8.83930E-02
0.00	4.22880E-01	1.09630E-01	-9.79330E-02
1.00	5.62230E-01	1.09970E-01	-1.06800E-01
2.00	7.01170E-01	1.09960E-01	-1.14880E-01
3.00	8.39030E-01	1.09300E-01	-1.22100E-01
4.00	9.72510E-01	1.07680E-01	-1.28340E-01
5.00	1.09920E+00	1.05080E-01	-1.33530E-01
6.00	1.21640E+00	1.02540E-01	-1.37670E-01
7.00	1.32130E+00	1.01450E-01	-1.40770E-01
8.00	1.41080E+00	1.03190E-01	-1.42850E-01
9.00	1.48220E+00	1.08940E-01	-1.43920E-01
10.00	1.53260E+00	1.19200E-01	-1.43920E-01
11.00	1.55903E+00	1.34161E-01	-1.42782E-01
12.00	1.46831E+00	1.53849E-01	-1.40436E-01
13.00	1.34795E+00	1.77619E-01	-1.36918E-01
14.00	1.21643E+00	2.02986E-01	-1.32673E-01
15.00	1.08028E+00	2.27602E-01	-1.28416E-01
16.00	9.43795E-01	2.49659E-01	-1.25523E-01
18.00	7.83111E-01	2.83320E-01	-1.27089E-01
20.00	7.11240E-01	3.07215E-01	-1.32976E-01
24.00	8.44030E-01	3.42544E-01	-1.49247E-01
28.00	1.25379E+00	3.81124E-01	-1.66905E-01
32.00	1.26489E+00	4.28263E-01	-1.85329E-01
36.14	1.19559E+00	4.86220E-01	-2.04105E-01
40.29	1.09100E+00	5.53137E-01	-2.19851E-01
44.43	9.90063E-01	6.24705E-01	-2.32586E-01
48.57	8.97492E-01	7.05787E-01	-2.43201E-01
52.71	8.09436E-01	7.86714E-01	-2.52807E-01
56.86	7.22050E-01	8.64718E-01	-2.62512E-01
61.00	6.32326E-01	9.37325E-01	-2.73148E-01
65.14	5.40612E-01	1.00323E+00	-2.83116E-01
69.29	4.48093E-01	1.06143E+00	-2.92688E-01
73.43	3.55956E-01	1.11092E+00	-3.01176E-01
77.57	2.65388E-01	1.15067E+00	-3.07750E-01
81.71	1.77575E-01	1.17969E+00	-3.13184E-01
85.86	9.32399E-02	1.19696E+00	-3.18510E-01
90.00	1.14131E-02	1.20177E+00	-3.24332E-01
94.14	-5.97251E-02	1.19453E+00	-3.29963E-01
98.29	-1.30011E-01	1.17597E+00	-3.34443E-01
102.43	-1.96684E-01	1.14679E+00	-3.36825E-01
106.57	-2.60250E-01	1.10772E+00	-3.36559E-01
110.71	-3.21214E-01	1.05946E+00	-3.34650E-01
114.86	-3.80082E-01	1.00274E+00	-3.32477E-01
119.00	-4.37358E-01	9.38260E-01	-3.31399E-01
123.14	-4.94186E-01	8.66924E-01	-3.32648E-01
127.29	-5.54255E-01	7.90361E-01	-3.36929E-01
131.43	-6.21896E-01	7.10384E-01	-3.44834E-01
135.57	-7.01436E-01	6.26951E-01	-3.56954E-01
139.71	-7.90393E-01	5.55925E-01	-3.74098E-01
143.86	-8.59045E-01	4.78757E-01	-3.98182E-01
148.00	-8.70857E-01	4.04256E-01	-4.22136E-01
150.29	-8.42013E-01	3.65322E-01	-4.28363E-01
152.57	-7.92239E-01	3.28327E-01	-4.14319E-01
154.86	-7.29025E-01	2.93544E-01	-3.98140E-01
157.14	-6.59864E-01	2.61236E-01	-3.82367E-01
159.43	-5.90968E-01	2.31663E-01	-3.67854E-01
161.71	-5.23428E-01	2.05082E-01	-3.74598E-01
164.00	-4.57056E-01	1.81748E-01	-3.89782E-01
166.29	-3.91630E-01	1.62759E-01	-4.05916E-01
168.57	-3.26781E-01	1.52585E-01	-4.17593E-01
170.86	-2.62106E-01	1.53519E-01	-3.93277E-01
173.14	-1.97204E-01	1.56146E-01	-2.95641E-01
175.43	-1.31670E-01	1.51886E-01	-1.93904E-01
177.71	-6.51016E-02	1.46427E-01	-9.89300E-02
180.00	2.90342E-03	1.49133E-01	4.30732E-03

Table C.6: Aerodynamic properties of Airfoil06.

Angle (deg)	Cl (-)	Cd (-)	Cm (-)
-180.00	3.30884E-03	5.34544E-02	4.86467E-03
-177.71	7.12982E-02	4.81985E-02	9.05594E-02
-175.43	1.44393E-01	5.36182E-02	1.80261E-01
-173.14	2.15865E-01	6.28363E-02	2.71938E-01
-170.86	2.86293E-01	6.83949E-02	3.60977E-01
-168.57	3.56253E-01	6.72744E-02	3.99095E-01
-166.29	4.26343E-01	6.99850E-02	4.04143E-01
-164.00	4.97124E-01	9.06167E-02	4.08200E-01
-161.71	5.69178E-01	1.22823E-01	4.14235E-01
-159.43	6.42847E-01	1.58747E-01	4.21745E-01
-157.14	7.17364E-01	1.96309E-01	4.39208E-01
-154.86	7.91759E-01	2.35602E-01	4.56236E-01
-152.57	8.65051E-01	2.76648E-01	4.74142E-01
-150.29	9.31653E-01	3.19409E-01	4.90443E-01
-148.00	9.67682E-01	3.63836E-01	4.84115E-01
-143.86	9.23716E-01	4.48382E-01	4.60548E-01
-139.71	8.48847E-01	5.37326E-01	4.40086E-01
-135.57	7.75505E-01	6.27284E-01	4.25973E-01
-131.43	7.03461E-01	7.20801E-01	4.15896E-01
-127.29	6.32486E-01	8.12874E-01	4.09513E-01
-123.14	5.62354E-01	9.01629E-01	4.06682E-01
-119.00	4.92835E-01	9.85135E-01	4.06440E-01
-114.86	4.23700E-01	1.06146E+00	4.07648E-01
-110.71	3.54723E-01	1.12868E+00	4.09178E-01
-106.57	2.85673E-01	1.18510E+00	4.09998E-01
-102.43	2.16324E-01	1.23001E+00	4.09411E-01
-98.29	1.46447E-01	1.26295E+00	4.06790E-01
-94.14	7.58125E-02	1.28343E+00	4.01502E-01
-90.00	3.75711E-03	1.29100E+00	3.93319E-01
-85.86	-6.73239E-02	1.28519E+00	3.83611E-01
-81.71	-1.42912E-01	1.26551E+00	3.73239E-01
-77.57	-2.18436E-01	1.23184E+00	3.59899E-01
-73.43	-2.93344E-01	1.18535E+00	3.43903E-01
-69.29	-3.65348E-01	1.12755E+00	3.26646E-01
-65.14	-4.32164E-01	1.05993E+00	3.09552E-01
-61.00	-4.92909E-01	9.84004E-01	2.93676E-01
-56.86	-5.44236E-01	9.01275E-01	2.77404E-01
-52.71	-6.07042E-01	8.13247E-01	2.59950E-01
-48.57	-6.91794E-01	7.21426E-01	2.41892E-01
-44.43	-7.80633E-01	6.27414E-01	2.26433E-01
-40.29	-8.71104E-01	5.37685E-01	2.09095E-01
-36.14	-9.50161E-01	4.51178E-01	1.31114E-01
-32.00	-1.00109E+00	3.57455E-01	4.80717E-02
-28.00	-9.41256E-01	2.15248E-01	2.75858E-02
-24.00	-9.13750E-01	1.60607E-01	1.04823E-02
-20.00	-8.91597E-01	1.26645E-01	-2.40009E-03
-18.00	-8.54541E-01	1.08710E-01	-7.65280E-03
-16.00	-8.08184E-01	9.15589E-02	-1.12586E-02
-14.00	-7.58238E-01	7.55511E-02	-1.26172E-02
-12.00	-7.06551E-01	6.10478E-02	-1.11287E-02
-10.00	-6.49000E-01	4.84230E-02	-9.82110E-03
-8.00	-5.50950E-01	3.80670E-02	-2.41740E-02
-6.00	-3.58140E-01	3.03880E-02	-4.44810E-02
-4.00	-1.12000E-01	2.58080E-02	-6.69500E-02
-2.00	1.53340E-01	2.44180E-02	-9.00950E-02
-1.00	2.98780E-01	2.45530E-02	-1.00250E-01
0.00	4.45220E-01	2.49800E-02	-1.08880E-01
1.00	5.91930E-01	2.55010E-02	-1.16850E-01
2.00	7.38210E-01	2.59190E-02	-1.24110E-01
3.00	8.83360E-01	2.60360E-02	-1.30620E-01

Angle (deg)	Cl (-)	Cd (-)	Cm (-)
4.00	1.02640E+00	2.56510E-02	-1.36340E-01
5.00	1.16610E+00	2.47020E-02	-1.41240E-01
6.00	1.30010E+00	2.37010E-02	-1.45290E-01
7.00	1.42570E+00	2.33160E-02	-1.48480E-01
8.00	1.54020E+00	2.42190E-02	-1.50790E-01
9.00	1.64080E+00	2.70100E-02	-1.52210E-01
10.00	1.72500E+00	3.20650E-02	-1.52710E-01
11.00	1.78994E+00	3.96515E-02	-1.52265E-01
12.00	1.79738E+00	4.99624E-02	-1.50857E-01
13.00	1.78056E+00	6.29114E-02	-1.48516E-01
14.00	1.74699E+00	7.75904E-02	-1.45517E-01
15.00	1.69982E+00	9.31218E-02	-1.42269E-01
16.00	1.64134E+00	1.08840E-01	-1.39479E-01
18.00	1.51549E+00	1.39675E-01	-1.37364E-01
20.00	1.41227E+00	1.70449E-01	-1.40002E-01
24.00	1.37627E+00	2.33730E-01	-1.57132E-01
28.00	1.44021E+00	3.00893E-01	-1.78760E-01
32.00	1.37568E+00	3.72685E-01	-2.00934E-01
36.14	1.29451E+00	4.52253E-01	-2.23183E-01
40.29	1.20441E+00	5.37293E-01	-2.43210E-01
44.43	1.11020E+00	6.26113E-01	-2.60153E-01
48.57	1.01316E+00	7.19425E-01	-2.74679E-01
52.71	9.13695E-01	8.11928E-01	-2.87839E-01
56.86	8.12197E-01	9.01035E-01	-3.00681E-01
61.00	7.09152E-01	9.84374E-01	-3.14025E-01
65.14	6.05390E-01	1.06044E+00	-3.27244E-01
69.29	5.01832E-01	1.12794E+00	-3.40327E-01
73.43	3.99394E-01	1.18560E+00	-3.52884E-01
77.57	2.98996E-01	1.23211E+00	-3.64437E-01
81.71	2.01555E-01	1.26619E+00	-3.75003E-01
85.86	1.07808E-01	1.28656E+00	-3.84671E-01
90.00	1.77340E-02	1.29228E+00	-3.93394E-01
94.14	-6.54542E-02	1.28387E+00	-4.00770E-01
98.29	-1.45722E-01	1.26221E+00	-4.06324E-01
102.43	-2.22081E-01	1.22818E+00	-4.09587E-01
106.57	-2.94826E-01	1.18265E+00	-4.10346E-01
110.71	-3.64251E-01	1.12651E+00	-4.09405E-01
114.86	-4.30653E-01	1.06063E+00	-4.07815E-01
119.00	-4.94325E-01	9.85893E-01	-4.06620E-01
123.14	-5.56320E-01	9.03371E-01	-4.06844E-01
127.29	-6.20709E-01	8.14933E-01	-4.09438E-01
131.43	-6.92324E-01	7.22643E-01	-4.15335E-01
135.57	-7.75992E-01	6.28375E-01	-4.25471E-01
139.71	-8.69255E-01	5.38109E-01	-4.40637E-01
143.86	-9.40494E-01	4.47512E-01	-4.61123E-01
148.00	-9.50800E-01	3.60862E-01	-4.83817E-01
150.29	-9.18657E-01	3.15632E-01	-4.90592E-01
152.57	-8.64102E-01	2.72625E-01	-4.74015E-01
154.86	-7.95118E-01	2.32111E-01	-4.56434E-01
157.14	-7.19683E-01	1.94360E-01	-4.38941E-01
159.43	-6.44432E-01	1.59639E-01	-4.22120E-01
161.71	-5.70609E-01	1.28214E-01	-4.30636E-01
164.00	-4.98112E-01	1.00351E-01	-4.48340E-01
166.29	-4.26773E-01	7.71153E-02	-4.66147E-01
168.57	-3.56162E-01	6.27745E-02	-4.83002E-01
170.86	-2.85783E-01	5.97821E-02	-4.51748E-01
173.14	-2.15143E-01	6.02781E-02	-3.40071E-01
175.43	-1.43744E-01	5.66542E-02	-2.24860E-01
177.71	-7.10918E-02	5.23135E-02	-1.13412E-01
180.00	3.30884E-03	5.34544E-02	4.86467E-03

Table C.7: Aerodynamic properties of Airfoil07.

Angle (deg)	Cl (-)	Cd (-)	Cm (-)
-180.00	3.32982E-03	3.37894E-02	4.87549E-03
-177.71	7.08969E-02	3.64348E-02	9.14662E-02
-175.43	1.43453E-01	3.69224E-02	1.82728E-01
-173.14	2.13623E-01	3.70988E-02	2.74598E-01
-170.86	2.82307E-01	3.98874E-02	3.65194E-01
-168.57	3.50402E-01	4.79450E-02	4.03515E-01
-166.29	4.18826E-01	6.28691E-02	4.08221E-01
-164.00	4.88462E-01	8.53847E-02	4.12380E-01
-161.71	5.60212E-01	1.13812E-01	4.18520E-01
-159.43	6.34509E-01	1.46211E-01	4.25804E-01
-157.14	7.09745E-01	1.81934E-01	4.43336E-01
-154.86	7.83877E-01	2.20686E-01	4.60435E-01
-152.57	8.54855E-01	2.62171E-01	4.77940E-01
-150.29	9.16932E-01	3.06077E-01	4.94719E-01
-148.00	9.49710E-01	3.52105E-01	4.88268E-01
-143.86	9.09616E-01	4.39956E-01	4.67379E-01
-139.71	8.40414E-01	5.31964E-01	4.50326E-01
-135.57	7.71305E-01	6.26242E-01	4.37560E-01
-131.43	7.02236E-01	7.20888E-01	4.29171E-01
-127.29	6.33153E-01	8.14001E-01	4.24592E-01
-123.14	5.64005E-01	9.03677E-01	4.23031E-01
-119.00	4.94738E-01	9.88014E-01	4.23468E-01
-114.86	4.25299E-01	1.06511E+00	4.24824E-01
-110.71	3.55635E-01	1.13306E+00	4.26020E-01
-106.57	2.85694E-01	1.19021E+00	4.26106E-01
-102.43	2.15422E-01	1.23579E+00	4.24647E-01
-98.29	1.44767E-01	1.26930E+00	4.21342E-01
-94.14	7.36762E-02	1.29024E+00	4.15885E-01
-90.00	2.09582E-03	1.29809E+00	4.07955E-01
-85.86	-7.00265E-02	1.29233E+00	3.97152E-01
-81.71	-1.42744E-01	1.27247E+00	3.83436E-01
-77.57	-2.15943E-01	1.23832E+00	3.68013E-01
-73.43	-2.88845E-01	1.19111E+00	3.51455E-01
-69.29	-3.60506E-01	1.13239E+00	3.34086E-01
-65.14	-4.29982E-01	1.06372E+00	3.16224E-01
-61.00	-4.96770E-01	9.86650E-01	2.98139E-01
-56.86	-5.62136E-01	9.02741E-01	2.79887E-01
-52.71	-6.27788E-01	8.13549E-01	2.61470E-01
-48.57	-6.95432E-01	7.20631E-01	2.42892E-01
-44.43	-7.66565E-01	6.25858E-01	2.27159E-01
-40.29	-8.41833E-01	5.32354E-01	2.09067E-01
-36.14	-9.21667E-01	4.43635E-01	1.36243E-01
-32.00	-1.00650E+00	3.45624E-01	6.02645E-02
-28.00	-1.08360E+00	2.12921E-01	3.63904E-02
-24.00	-1.10637E+00	1.48238E-01	1.63767E-02
-20.00	-1.05411E+00	1.07250E-01	1.83607E-03
-18.00	-1.03327E+00	8.87772E-02	-3.08882E-03
-16.00	-1.01244E+00	7.19402E-02	-6.38102E-03
-14.00	-9.76828E-01	5.68968E-02	-7.16840E-03
-12.00	-9.11668E-01	4.38041E-02	-5.73318E-03
-10.00	-8.03020E-01	3.28200E-02	-1.20190E-02
-8.00	-6.40310E-01	2.41000E-02	-3.14640E-02
-6.00	-4.18990E-01	1.78040E-02	-5.34040E-02
-4.00	-1.55350E-01	1.40870E-02	-7.39890E-02
-2.00	1.30590E-01	1.29110E-02	-9.23720E-02
-1.00	2.77380E-01	1.30300E-02	-1.00660E-01
0.00	4.24600E-01	1.34500E-02	-1.08330E-01
1.00	5.70640E-01	1.40430E-02	-1.15380E-01
2.00	7.14270E-01	1.46810E-02	-1.21800E-01
3.00	8.55740E-01	1.52360E-02	-1.27570E-01

Angle (deg)	Cl (-)	Cd (-)	Cm (-)
4.00	9.95660E-01	1.55810E-02	-1.32700E-01
5.00	1.13410E+00	1.56460E-02	-1.37160E-01
6.00	1.26920E+00	1.55910E-02	-1.40940E-01
7.00	1.39840E+00	1.56350E-02	-1.43990E-01
8.00	1.51920E+00	1.59990E-02	-1.46290E-01
9.00	1.62930E+00	1.69120E-02	-1.47810E-01
10.00	1.72610E+00	1.86600E-02	-1.48540E-01
11.00	1.80729E+00	2.15372E-02	-1.48482E-01
12.00	1.87027E+00	2.58409E-02	-1.47638E-01
13.00	1.91323E+00	3.18192E-02	-1.46041E-01
14.00	1.93671E+00	3.95279E-02	-1.43858E-01
15.00	1.94182E+00	4.89747E-02	-1.41318E-01
16.00	1.92969E+00	6.01676E-02	-1.38741E-01
18.00	1.86272E+00	8.75380E-02	-1.34842E-01
20.00	1.76714E+00	1.20280E-01	-1.34858E-01
24.00	1.58912E+00	1.95305E-01	-1.50559E-01
28.00	1.45450E+00	2.74351E-01	-1.74692E-01
32.00	1.35450E+00	3.55550E-01	-1.97541E-01
36.14	1.27182E+00	4.42335E-01	-2.20317E-01
40.29	1.19436E+00	5.32278E-01	-2.41418E-01
44.43	1.10901E+00	6.25351E-01	-2.59573E-01
48.57	1.01520E+00	7.19667E-01	-2.75294E-01
52.71	9.15507E-01	8.12883E-01	-2.89542E-01
56.86	8.12497E-01	9.02650E-01	-3.03276E-01
61.00	7.08439E-01	9.86787E-01	-3.17259E-01
65.14	6.04365E-01	1.06377E+00	-3.31482E-01
69.29	5.01003E-01	1.13224E+00	-3.45738E-01
73.43	3.99080E-01	1.19083E+00	-3.59821E-01
77.57	2.99325E-01	1.23818E+00	-3.73483E-01
81.71	2.02463E-01	1.27294E+00	-3.86309E-01
85.86	1.09222E-01	1.29375E+00	-3.97837E-01
90.00	2.01798E-02	1.29962E+00	-4.07660E-01
94.14	-6.46834E-02	1.29108E+00	-4.15560E-01
98.29	-1.45537E-01	1.26905E+00	-4.21372E-01
102.43	-2.22551E-01	1.23445E+00	-4.24929E-01
106.57	-2.95894E-01	1.18818E+00	-4.26224E-01
110.71	-3.65737E-01	1.13116E+00	-4.25895E-01
114.86	-4.32248E-01	1.06431E+00	-4.24739E-01
119.00	-4.95596E-01	9.88523E-01	-4.23553E-01
123.14	-5.56726E-01	9.04920E-01	-4.23180E-01
127.29	-6.19676E-01	8.15383E-01	-4.24644E-01
131.43	-6.89259E-01	7.21988E-01	-4.29018E-01
135.57	-7.70288E-01	6.26813E-01	-4.37371E-01
139.71	-8.60455E-01	5.31936E-01	-4.50429E-01
143.86	-9.28966E-01	4.39434E-01	-4.67530E-01
148.00	-9.37904E-01	3.51385E-01	-4.88129E-01
150.29	-9.05887E-01	3.05453E-01	-4.94800E-01
152.57	-8.51973E-01	2.61764E-01	-4.77859E-01
154.86	-7.83940E-01	2.20570E-01	-4.60556E-01
157.14	-7.09564E-01	1.82127E-01	-4.43171E-01
159.43	-6.35319E-01	1.46689E-01	-4.26115E-01
161.71	-5.62458E-01	1.14509E-01	-4.35062E-01
164.00	-4.90928E-01	8.58425E-02	-4.53060E-01
166.29	-4.20601E-01	6.16681E-02	-4.70716E-01
168.57	-3.51038E-01	4.58644E-02	-4.89416E-01
170.86	-2.81725E-01	4.08208E-02	-4.56229E-01
173.14	-2.12147E-01	4.00691E-02	-3.43658E-01
175.43	-1.41788E-01	3.70398E-02	-2.28136E-01
177.71	-7.01341E-02	3.36149E-02	-1.14435E-01
180.00	3.32982E-03	3.37894E-02	4.87549E-03

Table C.8: Aerodynamic properties of Airfoil08.

Angle (deg)	Cl (-)	Cd (-)	Cm (-)
-180.00	4.23592e-03	2.97177e-02	4.86706e-03
-177.71	6.94415e-02	3.40343e-02	9.14545e-02
-175.43	1.40356e-01	3.35074e-02	1.82762e-01
-173.14	2.08450e-01	3.20915e-02	2.74553e-01
-170.86	2.74735e-01	3.47076e-02	3.65211e-01
-168.57	3.40307e-01	4.48701e-02	4.03212e-01
-166.29	4.06355e-01	6.23116e-02	4.07259e-01
-164.00	4.74026e-01	8.54260e-02	4.10889e-01
-161.71	5.44465e-01	1.13360e-01	4.16582e-01
-159.43	6.18124e-01	1.45273e-01	4.23246e-01
-157.14	6.92687e-01	1.80691e-01	4.40552e-01
-154.86	7.65371e-01	2.19292e-01	4.57491e-01
-152.57	8.33479e-01	2.60751e-01	4.74492e-01
-150.29	8.91069e-01	3.04725e-01	4.91276e-01
-148.00	9.20751e-01	3.50885e-01	4.85215e-01
-143.86	8.84605e-01	4.39031e-01	4.65597e-01
-139.71	8.21227e-01	5.31268e-01	4.49387e-01
-135.57	7.56606e-01	6.25689e-01	4.37535e-01
-131.43	6.91067e-01	7.20410e-01	4.29973e-01
-127.29	6.25182e-01	8.13546e-01	4.26062e-01
-123.14	5.58311e-01	9.03213e-01	4.24997e-01
-119.00	4.90558e-01	9.87529e-01	4.25699e-01
-114.86	4.22038e-01	1.06461e+00	4.27127e-01
-110.71	3.52868e-01	1.13257e+00	4.28295e-01
-106.57	2.83154e-01	1.18976e+00	4.28317e-01
-102.43	2.12977e-01	1.23542e+00	4.26769e-01
-98.29	1.42409e-01	1.26903e+00	4.23355e-01
-94.14	7.15370e-02	1.29006e+00	4.17776e-01
-90.00	5.68536e-04	1.29798e+00	4.09660e-01
-85.86	-7.05826e-02	1.29228e+00	3.98553e-01
-81.71	-1.41988e-01	1.27242e+00	3.84483e-01
-77.57	-2.13054e-01	1.23822e+00	3.68746e-01
-73.43	-2.83780e-01	1.19092e+00	3.51951e-01
-69.29	-3.53967e-01	1.13208e+00	3.34408e-01
-65.14	-4.23557e-01	1.06328e+00	3.16299e-01
-61.00	-4.92921e-01	9.86076e-01	2.97832e-01
-56.86	-5.60323e-01	9.02050e-01	2.78992e-01
-52.71	-6.25489e-01	8.12772e-01	2.59983e-01
-48.57	-6.87522e-01	7.19812e-01	2.41004e-01
-44.43	-7.47085e-01	6.25059e-01	2.24863e-01
-40.29	-8.12228e-01	5.31664e-01	2.06317e-01
-36.14	-8.89946e-01	4.42783e-01	1.36683e-01
-32.00	-9.91871e-01	3.44513e-01	6.47082e-02
-28.00	-1.09618e+00	2.15942e-01	4.00170e-02
-24.00	-1.14050e+00	1.48163e-01	1.91781e-02
-20.00	-1.10553e+00	1.04173e-01	4.40200e-03
-18.00	-1.10000e+00	8.46878e-02	-4.31680e-04
-16.00	-1.09487e+00	6.75229e-02	-2.82721e-03
-14.00	-1.06700e+00	5.26051e-02	-2.49120e-03
-12.00	-9.92150e-01	3.99946e-02	-3.15417e-03
-10.00	-8.56170e-01	2.97100e-02	-1.48860e-02
-8.00	-6.67460e-01	2.17000e-02	-3.56770e-02
-6.00	-4.37730e-01	1.60100e-02	-5.64650e-02
-4.00	-1.75290e-01	1.26990e-02	-7.54870e-02
-2.00	1.07420e-01	1.16760e-02	-9.22860e-02
-1.00	2.52610e-01	1.18070e-02	-9.97350e-02
0.00	3.97970e-01	1.22190e-02	-1.06540e-01
1.00	5.41940e-01	1.28000e-02	-1.12770e-01
2.00	6.83000e-01	1.34410e-02	-1.18450e-01
3.00	8.21400e-01	1.40340e-02	-1.23570e-01

Angle (deg)	Cl (-)	Cd (-)	Cm (-)
4.00	9.58700e-01	1.44730e-02	-1.28150e-01
5.00	1.09570e+00	1.47000e-02	-1.32190e-01
6.00	1.23090e+00	1.48120e-02	-1.35680e-01
7.00	1.36170e+00	1.49330e-02	-1.38570e-01
8.00	1.48610e+00	1.51750e-02	-1.40850e-01
9.00	1.60170e+00	1.57090e-02	-1.42480e-01
10.00	1.70660e+00	1.68010e-02	-1.43410e-01
11.00	1.79920e+00	1.87026e-02	-1.43614e-01
12.00	1.87251e+00	2.16362e-02	-1.43048e-01
13.00	1.92718e+00	2.58322e-02	-1.41737e-01
14.00	1.96374e+00	3.15534e-02	-1.39865e-01
15.00	1.98245e+00	3.90612e-02	-1.37606e-01
16.00	1.98343e+00	4.86809e-02	-1.35017e-01
18.00	1.93724e+00	7.50195e-02	-1.29710e-01
20.00	1.84502e+00	1.08760e-01	-1.27985e-01
24.00	1.61267e+00	1.88632e-01	-1.43545e-01
28.00	1.43786e+00	2.70681e-01	-1.69074e-01
32.00	1.32171e+00	3.53519e-01	-1.92388e-01
36.14	1.23997e+00	4.41246e-01	-2.15303e-01
40.29	1.16773e+00	5.31660e-01	-2.36903e-01
44.43	1.08780e+00	6.24916e-01	-2.55813e-01
48.57	9.98224e-01	7.19228e-01	-2.72438e-01
52.71	9.02327e-01	8.12343e-01	-2.87599e-01
56.86	8.02356e-01	9.02010e-01	-3.02118e-01
61.00	7.00944e-01	9.86122e-01	-3.16666e-01
65.14	5.99081e-01	1.06315e+00	-3.31223e-01
69.29	4.97325e-01	1.13172e+00	-3.45732e-01
73.43	3.96317e-01	1.19044e+00	-3.60106e-01
77.57	2.97073e-01	1.23794e+00	-3.74153e-01
81.71	2.00777e-01	1.27282e+00	-3.87412e-01
85.86	1.08277e-01	1.29371e+00	-3.99350e-01
90.00	1.97772e-02	1.29960e+00	-4.09435e-01
94.14	-6.43665e-02	1.29104e+00	-4.17483e-01
98.29	-1.44707e-01	1.26896e+00	-4.23384e-01
102.43	-2.20663e-01	1.23427e+00	-4.27024e-01
106.57	-2.93138e-01	1.18790e+00	-4.28433e-01
110.71	-3.62108e-01	1.13077e+00	-4.28205e-01
114.86	-4.27700e-01	1.06380e+00	-4.27073e-01
119.00	-4.90080e-01	9.87928e-01	-4.25763e-01
123.14	-5.50128e-01	9.04258e-01	-4.25043e-01
127.29	-6.11443e-01	8.14673e-01	-4.26052e-01
131.43	-6.78234e-01	7.21243e-01	-4.29831e-01
135.57	-7.54712e-01	6.26039e-01	-4.37423e-01
139.71	-8.40294e-01	5.31132e-01	-4.49543e-01
143.86	-9.04563e-01	4.38591e-01	-4.65724e-01
148.00	-9.12348e-01	3.50488e-01	-4.85083e-01
150.29	-8.81751e-01	3.04517e-01	-4.91342e-01
152.57	-8.30222e-01	2.60783e-01	-4.74446e-01
154.86	-7.64750e-01	2.19546e-01	-4.57546e-01
157.14	-6.92232e-01	1.81063e-01	-4.40460e-01
159.43	-6.18481e-01	1.45596e-01	-4.23522e-01
161.71	-5.45562e-01	1.13430e-01	-4.33083e-01
164.00	-4.74847e-01	8.48921e-02	-4.51663e-01
166.29	-4.06987e-01	6.06814e-02	-4.69652e-01
168.57	-3.40645e-01	4.40438e-02	-4.89185e-01
170.86	-2.74475e-01	3.68724e-02	-4.56155e-01
173.14	-2.07608e-01	3.49291e-02	-3.43654e-01
175.43	-1.39416e-01	3.28905e-02	-2.28191e-01
177.71	-6.91384e-02	3.07843e-02	-1.14397e-01
180.00	4.23592e-03	2.97177e-02	4.86706e-03

Table C.9: Aerodynamic properties of Airfoil09.

Angle (deg)	Cl (-)	Cd (-)	Cm (-)
-180.00	5.89757e-03	2.76309e-02	4.88544e-03
-177.71	6.82994e-02	3.19304e-02	9.14806e-02
-175.43	1.37933e-01	3.14854e-02	1.82686e-01
-173.14	2.04729e-01	3.04213e-02	2.74663e-01
-170.86	2.69608e-01	3.34640e-02	3.65148e-01
-168.57	3.33694e-01	4.40348e-02	4.02558e-01
-166.29	3.98308e-01	6.18390e-02	4.05690e-01
-164.00	4.64710e-01	8.53281e-02	4.08190e-01
-161.71	5.34138e-01	1.13575e-01	4.12904e-01
-159.43	6.07005e-01	1.45694e-01	4.18833e-01
-157.14	6.80665e-01	1.81226e-01	4.35893e-01
-154.86	7.52145e-01	2.19869e-01	4.52701e-01
-152.57	8.18680e-01	2.61318e-01	4.69626e-01
-150.29	8.74139e-01	3.05247e-01	4.85992e-01
-148.00	9.02367e-01	3.51341e-01	4.80796e-01
-143.86	8.68286e-01	4.39358e-01	4.61737e-01
-139.71	8.07923e-01	5.31504e-01	4.46237e-01
-135.57	7.45631e-01	6.25870e-01	4.35639e-01
-131.43	6.82105e-01	7.20564e-01	4.29082e-01
-127.29	6.18627e-01	8.13692e-01	4.25851e-01
-123.14	5.53630e-01	9.03365e-01	4.25079e-01
-119.00	4.87290e-01	9.87691e-01	4.25870e-01
-114.86	4.19785e-01	1.06478e+00	4.27330e-01
-110.71	3.51301e-01	1.13274e+00	4.28519e-01
-106.57	2.82010e-01	1.18992e+00	4.28587e-01
-102.43	2.12068e-01	1.23555e+00	4.27085e-01
-98.29	1.41620e-01	1.26913e+00	4.23672e-01
-94.14	7.08244e-02	1.29012e+00	4.18010e-01
-90.00	1.05388e-04	1.29802e+00	4.09736e-01
-85.86	-7.08403e-02	1.29230e+00	3.98556e-01
-81.71	-1.42007e-01	1.27243e+00	3.84562e-01
-77.57	-2.12506e-01	1.23826e+00	3.68814e-01
-73.43	-2.82438e-01	1.19098e+00	3.51849e-01
-69.29	-3.51635e-01	1.13218e+00	3.33970e-01
-65.14	-4.20026e-01	1.06342e+00	3.15566e-01
-61.00	-4.87895e-01	9.86266e-01	2.96934e-01
-56.86	-5.53796e-01	9.02285e-01	2.78013e-01
-52.71	-6.17483e-01	8.13045e-01	2.58877e-01
-48.57	-6.78308e-01	7.20112e-01	2.39594e-01
-44.43	-7.37764e-01	6.25362e-01	2.22908e-01
-40.29	-8.01658e-01	5.31903e-01	2.04220e-01
-36.14	-8.76374e-01	4.42940e-01	1.36472e-01
-32.00	-9.71879e-01	3.45213e-01	6.58939e-02
-28.00	-1.07075e+00	2.19044e-01	4.09324e-02
-24.00	-1.12675e+00	1.50190e-01	1.95674e-02
-20.00	-1.12231e+00	1.03422e-01	4.47105e-03
-18.00	-1.12657e+00	8.28511e-02	-4.30424e-04
-16.00	-1.12465e+00	6.51075e-02	-2.30019e-03
-14.00	-1.09517e+00	5.00299e-02	-1.24694e-03
-12.00	-1.01348e+00	3.76430e-02	-4.19604e-03
-10.00	-8.69890e-01	2.78440e-02	-1.87100e-02
-8.00	-6.76180e-01	2.03600e-02	-3.80960e-02
-6.00	-4.43880e-01	1.51380e-02	-5.75040e-02
-4.00	-1.80510e-01	1.21520e-02	-7.57400e-02
-2.00	9.82830e-02	1.12710e-02	-9.17640e-02
-1.00	2.40430e-01	1.14200e-02	-9.88770e-02
0.00	3.82660e-01	1.18240e-02	-1.05350e-01
1.00	5.24560e-01	1.23760e-02	-1.11280e-01
2.00	6.64930e-01	1.29740e-02	-1.16660e-01
3.00	8.03040e-01	1.35160e-02	-1.21510e-01

Angle (deg)	Cl (-)	Cd (-)	Cm (-)
4.00	9.40350e-01	1.39050e-02	-1.25860e-01
5.00	1.07760e+00	1.40880e-02	-1.29700e-01
6.00	1.21310e+00	1.41660e-02	-1.33030e-01
7.00	1.34450e+00	1.42620e-02	-1.35850e-01
8.00	1.46960e+00	1.44920e-02	-1.38130e-01
9.00	1.58620e+00	1.50140e-02	-1.39840e-01
10.00	1.69200e+00	1.60480e-02	-1.40870e-01
11.00	1.78567e+00	1.77984e-02	-1.41113e-01
12.00	1.86081e+00	2.04457e-02	-1.40441e-01
13.00	1.91763e+00	2.41978e-02	-1.38830e-01
14.00	1.95633e+00	2.93713e-02	-1.36541e-01
15.00	1.97657e+00	3.62853e-02	-1.33858e-01
16.00	1.97777e+00	4.54067e-02	-1.30921e-01
18.00	1.92770e+00	7.17568e-02	-1.25324e-01
20.00	1.82825e+00	1.06233e-01	-1.23803e-01
24.00	1.58075e+00	1.88263e-01	-1.40672e-01
28.00	1.40758e+00	2.71358e-01	-1.66004e-01
32.00	1.30449e+00	3.54387e-01	-1.89619e-01
36.14	1.22461e+00	4.41839e-01	-2.12504e-01
40.29	1.14802e+00	5.31917e-01	-2.34100e-01
44.43	1.06654e+00	6.25004e-01	-2.53208e-01
48.57	9.79450e-01	7.19291e-01	-2.70230e-01
52.71	8.89122e-01	8.12460e-01	-2.85874e-01
56.86	7.94662e-01	9.02199e-01	-3.00852e-01
61.00	6.97098e-01	9.86352e-01	-3.15747e-01
65.14	5.97434e-01	1.06339e+00	-3.30562e-01
69.29	4.96644e-01	1.13193e+00	-3.45267e-01
73.43	3.95774e-01	1.19062e+00	-3.59810e-01
77.57	2.96177e-01	1.23806e+00	-3.74027e-01
81.71	1.99344e-01	1.27289e+00	-3.87431e-01
85.86	1.06488e-01	1.29374e+00	-3.99441e-01
90.00	1.82387e-02	1.29961e+00	-4.09589e-01
94.14	-6.50766e-02	1.29104e+00	-4.17690e-01
98.29	-1.44676e-01	1.26896e+00	-4.23632e-01
102.43	-2.19544e-01	1.23429e+00	-4.27304e-01
106.57	-2.90843e-01	1.18795e+00	-4.28732e-01
110.71	-3.58719e-01	1.13085e+00	-4.28500e-01
114.86	-4.23446e-01	1.06393e+00	-4.27327e-01
119.00	-4.85325e-01	9.88109e-01	-4.25931e-01
123.14	-5.45209e-01	9.04495e-01	-4.25075e-01
127.29	-6.06024e-01	8.14965e-01	-4.25689e-01
131.43	-6.71158e-01	7.21583e-01	-4.28844e-01
135.57	-7.44002e-01	6.26413e-01	-4.35582e-01
139.71	-8.26058e-01	5.31519e-01	-4.46611e-01
143.86	-8.86810e-01	4.38965e-01	-4.61933e-01
148.00	-8.94155e-01	3.50811e-01	-4.80450e-01
150.29	-8.65402e-01	3.04797e-01	-4.86127e-01
152.57	-8.16509e-01	2.61020e-01	-4.69580e-01
154.86	-7.53471e-01	2.19751e-01	-4.52753e-01
157.14	-6.82140e-01	1.81261e-01	-4.35780e-01
159.43	-6.07584e-01	1.45831e-01	-4.19143e-01
161.71	-5.33005e-01	1.13795e-01	-4.29385e-01
164.00	-4.61821e-01	8.55833e-02	-4.48961e-01
166.29	-3.95941e-01	6.14926e-02	-4.68141e-01
168.57	-3.32798e-01	4.39475e-02	-4.88381e-01
170.86	-2.69803e-01	3.47829e-02	-4.56295e-01
173.14	-2.05453e-01	3.14126e-02	-3.43674e-01
175.43	-1.38819e-01	3.06868e-02	-2.28067e-01
177.71	-6.90046e-02	3.00663e-02	-1.14480e-01
180.00	5.89757e-03	2.76309e-02	4.88544e-03

Table C.10: Aerodynamic properties of Airfoil10.

Angle (deg)	Cl (-)	Cd (-)	Cm (-)
-180.00	7.14845e-03	2.59535e-02	4.89934e-03
-177.71	6.75233e-02	3.01116e-02	9.15003e-02
-175.43	1.36287e-01	2.98188e-02	1.82628e-01
-173.14	2.01987e-01	2.91402e-02	2.74747e-01
-170.86	2.65626e-01	3.25398e-02	3.65102e-01
-168.57	3.28431e-01	4.33920e-02	4.01962e-01
-166.29	3.91837e-01	6.14087e-02	4.04277e-01
-164.00	4.57223e-01	8.52296e-02	4.05785e-01
-161.71	5.25934e-01	1.13788e-01	4.09573e-01
-159.43	5.98406e-01	1.46123e-01	4.14886e-01
-157.14	6.71687e-01	1.81785e-01	4.31760e-01
-154.86	7.42449e-01	2.20487e-01	4.48488e-01
-152.57	8.07588e-01	2.61937e-01	4.65413e-01
-150.29	8.60927e-01	3.05827e-01	4.81437e-01
-148.00	8.87707e-01	3.51856e-01	4.77034e-01
-143.86	8.55366e-01	4.39738e-01	4.58615e-01
-139.71	7.97708e-01	5.31780e-01	4.43865e-01
-135.57	7.37656e-01	6.26084e-01	4.34213e-01
-131.43	6.75995e-01	7.20746e-01	4.28411e-01
-127.29	6.14141e-01	8.13867e-01	4.25692e-01
-123.14	5.50428e-01	9.03545e-01	4.25147e-01
-119.00	4.85070e-01	9.87883e-01	4.26015e-01
-114.86	4.18284e-01	1.06498e+00	4.27504e-01
-110.71	3.50290e-01	1.13294e+00	4.28712e-01
-106.57	2.81300e-01	1.19010e+00	4.28824e-01
-102.43	2.11521e-01	1.23571e+00	4.27367e-01
-98.29	1.41153e-01	1.26924e+00	4.23958e-01
-94.14	7.04031e-02	1.29020e+00	4.18216e-01
-90.00	-2.40430e-04	1.29807e+00	4.09799e-01
-85.86	-7.10892e-02	1.29232e+00	3.98558e-01
-81.71	-1.42029e-01	1.27246e+00	3.84629e-01
-77.57	-2.12206e-01	1.23829e+00	3.68874e-01
-73.43	-2.81672e-01	1.19105e+00	3.51773e-01
-69.29	-3.50241e-01	1.13230e+00	3.33640e-01
-65.14	-4.17759e-01	1.06359e+00	3.15013e-01
-61.00	-4.84238e-01	9.86491e-01	2.96258e-01
-56.86	-5.48883e-01	9.02562e-01	2.77317e-01
-52.71	-6.11456e-01	8.13366e-01	2.58133e-01
-48.57	-6.71639e-01	7.20464e-01	2.38644e-01
-44.43	-7.31332e-01	6.25717e-01	2.21564e-01
-40.29	-7.94405e-01	5.32183e-01	2.02802e-01
-36.14	-8.66773e-01	4.43126e-01	1.36313e-01
-32.00	-9.55811e-01	3.45988e-01	6.67193e-02
-28.00	-1.05033e+00	2.21280e-01	4.15353e-02
-24.00	-1.11543e+00	1.51960e-01	1.98214e-02
-20.00	-1.13220e+00	1.02997e-01	4.50452e-03
-18.00	-1.14273e+00	8.17109e-02	-4.29829e-04
-16.00	-1.14248e+00	6.35579e-02	-2.02009e-03
-14.00	-1.11165e+00	4.83526e-02	-5.35989e-04
-12.00	-1.02669e+00	3.60665e-02	-5.01295e-03
-10.00	-8.79370e-01	2.65250e-02	-2.17650e-02
-8.00	-6.82380e-01	1.93650e-02	-3.99680e-02
-6.00	-4.47510e-01	1.44610e-02	-5.83030e-02
-4.00	-1.83490e-01	1.17150e-02	-7.59320e-02
-2.00	9.27310e-02	1.09490e-02	-9.13330e-02
-1.00	2.32760e-01	1.11160e-02	-9.81750e-02
0.00	3.72760e-01	1.15170e-02	-1.04410e-01
1.00	5.12870e-01	1.20530e-02	-1.10100e-01
2.00	6.52200e-01	1.26240e-02	-1.15250e-01
3.00	7.89800e-01	1.31320e-02	-1.19900e-01
4.00	9.26920e-01	1.34830e-02	-1.24060e-01
5.00	1.06410e+00	1.36290e-02	-1.27750e-01
6.00	1.19970e+00	1.36700e-02	-1.30970e-01
7.00	1.33140e+00	1.37410e-02	-1.33720e-01
8.00	1.45680e+00	1.39710e-02	-1.35990e-01
9.00	1.57370e+00	1.45070e-02	-1.37760e-01
10.00	1.67990e+00	1.55260e-02	-1.38850e-01
11.00	1.77344e+00	1.71944e-02	-1.39099e-01
12.00	1.85007e+00	1.96704e-02	-1.38307e-01
13.00	1.90883e+00	2.31525e-02	-1.36403e-01
14.00	1.94930e+00	2.80073e-02	-1.33702e-01
15.00	1.97067e+00	3.46154e-02	-1.30584e-01
16.00	1.97182e+00	4.35167e-02	-1.27318e-01
18.00	1.91754e+00	6.98980e-02	-1.21679e-01
20.00	1.81083e+00	1.04828e-01	-1.20647e-01
24.00	1.55162e+00	1.88080e-01	-1.38723e-01
28.00	1.38231e+00	2.72063e-01	-1.63869e-01
32.00	1.29158e+00	3.55309e-01	-1.87719e-01
36.14	1.21324e+00	4.42508e-01	-2.10702e-01
40.29	1.13337e+00	5.32217e-01	-2.32263e-01
44.43	1.05092e+00	6.25108e-01	-2.51472e-01
48.57	9.66065e-01	7.19366e-01	-2.68733e-01
52.71	8.79828e-01	8.12599e-01	-2.84681e-01
56.86	7.89460e-01	9.02424e-01	-2.99951e-01
61.00	6.94657e-01	9.86624e-01	-3.15065e-01
65.14	5.96469e-01	1.06367e+00	-3.30064e-01
69.29	4.96273e-01	1.13218e+00	-3.44918e-01
73.43	3.95476e-01	1.19082e+00	-3.59588e-01
77.57	2.95632e-01	1.23821e+00	-3.73933e-01
81.71	1.98358e-01	1.27298e+00	-3.87446e-01
85.86	1.05142e-01	1.29378e+00	-3.99517e-01
90.00	1.70514e-02	1.29962e+00	-4.09721e-01
94.14	-6.57472e-02	1.29104e+00	-4.17870e-01
98.29	-1.44661e-01	1.26897e+00	-4.23851e-01
102.43	-2.18817e-01	1.23431e+00	-4.27552e-01
106.57	-2.89269e-01	1.18800e+00	-4.28996e-01
110.71	-3.56357e-01	1.13095e+00	-4.28758e-01
114.86	-4.20479e-01	1.06409e+00	-4.27547e-01
119.00	-4.82049e-01	9.88324e-01	-4.26074e-01
123.14	-5.41892e-01	9.04775e-01	-4.25100e-01
127.29	-6.02440e-01	8.15309e-01	-4.25416e-01
131.43	-6.66498e-01	7.21982e-01	-4.28100e-01
135.57	-7.36871e-01	6.26850e-01	-4.34195e-01
139.71	-8.15272e-01	5.31969e-01	-4.44404e-01
143.86	-8.72707e-01	4.39395e-01	-4.58870e-01
148.00	-8.79486e-01	3.51183e-01	-4.76510e-01
150.29	-8.52252e-01	3.05119e-01	-4.81629e-01
152.57	-8.05599e-01	2.61291e-01	-4.65363e-01
154.86	-7.44697e-01	2.19984e-01	-4.48543e-01
157.14	-6.74589e-01	1.81483e-01	-4.31623e-01
159.43	-5.99827e-01	1.46084e-01	-4.15224e-01
161.71	-5.24360e-01	1.14137e-01	-4.26054e-01
164.00	-4.52759e-01	8.61036e-02	-4.46524e-01
166.29	-3.87792e-01	6.21032e-02	-4.66796e-01
168.57	-3.26522e-01	4.38708e-02	-4.87669e-01
170.86	-2.65757e-01	3.31323e-02	-4.56400e-01
173.14	-2.03471e-01	2.86450e-02	-3.43690e-01
175.43	-1.38266e-01	2.89192e-02	-2.27974e-01
177.71	-6.88885e-02	2.94768e-02	-1.14543e-01
180.00	7.14845e-03	2.59535e-02	4.89934e-03

Table C.11: Aerodynamic properties of Airfoil11.

Angle (deg)	Cl (-)	Cd (-)	Cm (-)
-180.00	2.82341e-03	2.18577e-02	4.90915e-03
-177.71	6.71065e-02	2.58750e-02	9.15134e-02
-175.43	1.35310e-01	2.57604e-02	1.82592e-01
-173.14	1.98647e-01	2.56613e-02	2.74786e-01
-170.86	2.59040e-01	2.97713e-02	3.65113e-01
-168.57	3.18420e-01	4.13839e-02	4.00824e-01
-166.29	3.78799e-01	6.01804e-02	4.01523e-01
-164.00	4.42169e-01	8.49275e-02	4.01492e-01
-161.71	5.10511e-01	1.14393e-01	4.03261e-01
-159.43	5.84514e-01	1.47513e-01	4.07585e-01
-157.14	6.59799e-01	1.83831e-01	4.24301e-01
-154.86	7.30918e-01	2.23074e-01	4.41070e-01
-152.57	7.92424e-01	2.64967e-01	4.58075e-01
-150.29	8.38035e-01	3.09224e-01	4.73922e-01
-148.00	8.58889e-01	3.55569e-01	4.71019e-01
-143.86	8.31029e-01	4.43997e-01	4.55205e-01
-139.71	7.81588e-01	5.36690e-01	4.42743e-01
-135.57	7.28738e-01	6.31761e-01	4.34350e-01
-131.43	6.72610e-01	7.27275e-01	4.29540e-01
-127.29	6.12991e-01	8.21294e-01	4.27566e-01
-123.14	5.50827e-01	9.11879e-01	4.27681e-01
-119.00	4.86476e-01	9.97093e-01	4.29034e-01
-114.86	4.20222e-01	1.07500e+00	4.30801e-01
-110.71	3.52353e-01	1.14365e+00	4.32218e-01
-106.57	2.83158e-01	1.20136e+00	4.32563e-01
-102.43	2.12928e-01	1.24737e+00	4.31295e-01
-98.29	1.41953e-01	1.28118e+00	4.27913e-01
-94.14	7.05294e-02	1.30227e+00	4.21921e-01
-90.00	-1.20379e-03	1.31015e+00	4.12975e-01
-85.86	-7.27040e-02	1.30429e+00	4.01377e-01
-81.71	-1.43658e-01	1.28420e+00	3.87527e-01
-77.57	-2.14020e-01	1.24971e+00	3.71619e-01
-73.43	-2.83454e-01	1.20205e+00	3.54138e-01
-69.29	-3.51707e-01	1.14279e+00	3.35661e-01
-65.14	-4.18540e-01	1.07349e+00	3.16640e-01
-61.00	-4.83710e-01	9.95736e-01	2.97477e-01
-56.86	-5.46977e-01	9.11094e-01	2.78183e-01
-52.71	-6.08101e-01	8.21135e-01	2.58673e-01
-48.57	-6.66788e-01	7.27431e-01	2.38858e-01
-44.43	-7.23194e-01	6.31805e-01	2.21358e-01
-40.29	-7.83156e-01	5.37083e-01	2.02148e-01
-36.14	-8.52181e-01	4.46907e-01	1.36577e-01
-32.00	-9.35802e-01	3.50346e-01	6.83721e-02
-28.00	-1.02773e+00	2.23031e-01	4.25668e-02
-24.00	-1.10096e+00	1.55019e-01	2.05012e-02
-20.00	-1.13119e+00	1.03577e-01	4.51794e-03
-18.00	-1.13839e+00	8.15960e-02	-4.58088e-04
-16.00	-1.13649e+00	6.29328e-02	-1.99466e-03
-14.00	-1.11342e+00	4.74073e-02	-3.98028e-04
-12.00	-1.04322e+00	3.48258e-02	-5.75763e-03
-10.00	-9.00910e-01	2.49800e-02	-2.57610e-02
-8.00	-6.95920e-01	1.77450e-02	-4.34170e-02
-6.00	-4.49150e-01	1.29700e-02	-6.03460e-02
-4.00	-1.80980e-01	1.04650e-02	-7.66770e-02
-2.00	9.36950e-02	9.92030e-03	-9.08180e-02
-1.00	2.30910e-01	1.01700e-02	-9.69880e-02
0.00	3.67590e-01	1.06390e-02	-1.02610e-01
1.00	5.03110e-01	1.12300e-02	-1.07720e-01
2.00	6.36980e-01	1.18500e-02	-1.12340e-01
3.00	7.70400e-01	1.24010e-02	-1.16520e-01
4.00	9.04350e-01	1.27870e-02	-1.20280e-01
5.00	1.03920e+00	1.29530e-02	-1.23650e-01
6.00	1.17330e+00	1.29960e-02	-1.26630e-01
7.00	1.30410e+00	1.30570e-02	-1.29230e-01
8.00	1.42940e+00	1.32740e-02	-1.31430e-01
9.00	1.54680e+00	1.37860e-02	-1.33190e-01
10.00	1.65400e+00	1.47320e-02	-1.34280e-01
11.00	1.74867e+00	1.62516e-02	-1.34427e-01
12.00	1.82848e+00	1.84861e-02	-1.33355e-01
13.00	1.89095e+00	2.16609e-02	-1.30904e-01
14.00	1.93307e+00	2.63312e-02	-1.27399e-01
15.00	1.95182e+00	3.31076e-02	-1.23344e-01
16.00	1.94573e+00	4.25338e-02	-1.19445e-01
18.00	1.86857e+00	7.01889e-02	-1.14532e-01
20.00	1.74014e+00	1.06447e-01	-1.15625e-01
24.00	1.48988e+00	1.89787e-01	-1.36197e-01
28.00	1.34706e+00	2.74610e-01	-1.61424e-01
32.00	1.26942e+00	3.58949e-01	-1.85624e-01
36.14	1.19384e+00	4.47060e-01	-2.09566e-01
40.29	1.11499e+00	5.37440e-01	-2.31447e-01
44.43	1.03664e+00	6.31012e-01	-2.51028e-01
48.57	9.57669e-01	7.26032e-01	-2.68695e-01
52.71	8.75899e-01	8.20081e-01	-2.85069e-01
56.86	7.88612e-01	9.10734e-01	-3.00770e-01
61.00	6.95942e-01	9.95736e-01	-3.16302e-01
65.14	5.98707e-01	1.07353e+00	-3.31713e-01
69.29	4.98625e-01	1.14273e+00	-3.46938e-01
73.43	3.97437e-01	1.20195e+00	-3.61910e-01
77.57	2.96892e-01	1.24982e+00	-3.76486e-01
81.71	1.98740e-01	1.28494e+00	-3.90221e-01
85.86	1.04789e-01	1.30594e+00	-4.02604e-01
90.00	1.60786e-02	1.31181e+00	-4.13126e-01
94.14	-6.71674e-02	1.30311e+00	-4.21557e-01
98.29	-1.45288e-01	1.28077e+00	-4.27642e-01
102.43	-2.19237e-01	1.24574e+00	-4.31330e-01
106.57	-2.89365e-01	1.19896e+00	-4.32741e-01
110.71	-3.56196e-01	1.14136e+00	-4.32415e-01
114.86	-4.20268e-01	1.07389e+00	-4.30999e-01
119.00	-4.82144e-01	9.97473e-01	-4.29139e-01
123.14	-5.42664e-01	9.13243e-01	-4.27533e-01
127.29	-6.03233e-01	8.23063e-01	-4.27215e-01
131.43	-6.65731e-01	7.28981e-01	-4.29146e-01
135.57	-7.32260e-01	6.33049e-01	-4.34307e-01
139.71	-7.99479e-01	5.37314e-01	-4.43371e-01
143.86	-8.47324e-01	4.43826e-01	-4.55540e-01
148.00	-8.51073e-01	3.54636e-01	-4.70390e-01
150.29	-8.26478e-01	3.08010e-01	-4.74123e-01
152.57	-7.84476e-01	2.63632e-01	-4.58030e-01
154.86	-7.28732e-01	2.21820e-01	-4.41127e-01
157.14	-6.63018e-01	1.82889e-01	-4.24150e-01
159.43	-5.91318e-01	1.47150e-01	-4.07899e-01
161.71	-5.17665e-01	1.14894e-01	-4.19879e-01
164.00	-4.45844e-01	8.63582e-02	-4.42032e-01
166.29	-3.78706e-01	6.21357e-02	-4.64175e-01
168.57	-3.15261e-01	4.29466e-02	-4.86467e-01
170.86	-2.53660e-01	2.94390e-02	-4.56478e-01
173.14	-1.93550e-01	2.33918e-02	-3.43699e-01
175.43	-1.32135e-01	2.47294e-02	-2.27911e-01
177.71	-6.72319e-02	2.70004e-02	-1.14587e-01
180.00	2.82341e-03	2.18577e-02	4.90915e-03

Table C.12: Aerodynamic properties of Airfoil12.

Angle (deg)	Cl (-)	Cd (-)	Cm (-)
-180.00	-2.27254e-02	1.44279e-02	4.90989e-03
-177.71	6.74863e-02	1.82654e-02	9.15122e-02
-175.43	1.35652e-01	1.82458e-02	1.82607e-01
-173.14	1.95143e-01	1.85919e-02	2.74701e-01
-170.86	2.49500e-01	2.35916e-02	3.65322e-01
-168.57	3.02241e-01	3.65942e-02	3.98839e-01
-166.29	3.56871e-01	5.72132e-02	3.96562e-01
-164.00	4.16868e-01	8.41186e-02	3.94344e-01
-161.71	4.85733e-01	1.15966e-01	3.92227e-01
-159.43	5.64731e-01	1.51626e-01	3.95063e-01
-157.14	6.45936e-01	1.90634e-01	4.11943e-01
-154.86	7.19139e-01	2.32716e-01	4.29157e-01
-152.57	7.74097e-01	2.77599e-01	4.46475e-01
-150.29	8.03508e-01	3.24989e-01	4.62832e-01
-148.00	8.11515e-01	3.74608e-01	4.62465e-01
-143.86	7.93511e-01	4.69310e-01	4.52525e-01
-139.71	7.61169e-01	5.68658e-01	4.45262e-01
-135.57	7.21711e-01	6.70632e-01	4.41551e-01
-131.43	6.75744e-01	7.73146e-01	4.40670e-01
-127.29	6.23951e-01	8.74112e-01	4.41885e-01
-123.14	5.66947e-01	9.71444e-01	4.44495e-01
-119.00	5.05321e-01	1.06306e+00	4.47799e-01
-114.86	4.39702e-01	1.14686e+00	4.51094e-01
-110.71	3.70713e-01	1.22078e+00	4.53678e-01
-106.57	2.98981e-01	1.28297e+00	4.54877e-01
-102.43	2.25131e-01	1.33261e+00	4.54141e-01
-98.29	1.49789e-01	1.36913e+00	4.50945e-01
-94.14	7.35728e-02	1.39196e+00	4.44769e-01
-90.00	-2.87105e-03	1.40053e+00	4.35261e-01
-85.86	-7.89259e-02	1.39426e+00	4.22757e-01
-81.71	-1.53981e-01	1.37259e+00	4.07773e-01
-77.57	-2.27444e-01	1.33533e+00	3.90822e-01
-73.43	-2.98920e-01	1.28384e+00	3.72266e-01
-69.29	-3.68055e-01	1.21985e+00	3.52426e-01
-65.14	-4.34499e-01	1.14513e+00	3.31625e-01
-61.00	-4.97900e-01	1.06140e+00	3.10184e-01
-56.86	-5.57907e-01	9.70389e-01	2.88423e-01
-52.71	-6.14168e-01	8.73841e-01	2.66662e-01
-48.57	-6.66328e-01	7.73486e-01	2.45222e-01
-44.43	-7.15471e-01	6.71147e-01	2.26227e-01
-40.29	-7.67917e-01	5.68994e-01	2.04291e-01
-36.14	-8.31631e-01	4.72118e-01	1.39766e-01
-32.00	-9.15674e-01	3.69835e-01	7.15583e-02
-28.00	-1.01465e+00	2.23567e-01	4.40451e-02
-24.00	-1.09089e+00	1.58357e-01	2.15690e-02
-20.00	-1.09600e+00	1.07649e-01	4.41544e-03
-18.00	-1.06666e+00	8.45302e-02	-8.23129e-04
-16.00	-1.05206e+00	6.46987e-02	-3.21962e-03
-14.00	-1.07226e+00	4.80309e-02	-2.64200e-03
-12.00	-1.05593e+00	3.43975e-02	-6.13085e-03
-10.00	-9.30990e-01	2.36860e-02	-2.88100e-02
-8.00	-7.13970e-01	1.57830e-02	-4.88290e-02
-6.00	-4.42930e-01	1.05590e-02	-6.50320e-02
-4.00	-1.56100e-01	7.88630e-03	-7.88960e-02
-2.00	1.15800e-01	7.51400e-03	-9.03290e-02
-1.00	2.45840e-01	7.95350e-03	-9.52150e-02
0.00	3.73250e-01	8.65620e-03	-9.96200e-02
1.00	4.98980e-01	9.50760e-03	-1.03600e-01
2.00	6.24100e-01	1.03890e-02	-1.07210e-01
3.00	7.49650e-01	1.11850e-02	-1.10500e-01
4.00	8.76610e-01	1.17790e-02	-1.13530e-01
5.00	1.00540e+00	1.20980e-02	-1.16340e-01
6.00	1.13440e+00	1.22380e-02	-1.18900e-01
7.00	1.26140e+00	1.23380e-02	-1.21140e-01
8.00	1.38420e+00	1.25390e-02	-1.23030e-01
9.00	1.50070e+00	1.29790e-02	-1.24470e-01
10.00	1.60870e+00	1.38000e-02	-1.25210e-01
11.00	1.70594e+00	1.51381e-02	-1.24939e-01
12.00	1.79041e+00	1.71342e-02	-1.23371e-01
13.00	1.85833e+00	2.00647e-02	-1.20282e-01
14.00	1.89974e+00	2.47435e-02	-1.15751e-01
15.00	1.90537e+00	3.21311e-02	-1.10241e-01
16.00	1.87483e+00	4.31890e-02	-1.05475e-01
18.00	1.72860e+00	7.69846e-02	-1.03120e-01
20.00	1.55958e+00	1.18426e-01	-1.08966e-01
24.00	1.40126e+00	1.98813e-01	-1.33370e-01
28.00	1.31431e+00	2.82904e-01	-1.59269e-01
32.00	1.23682e+00	3.72662e-01	-1.84084e-01
36.14	1.16384e+00	4.70244e-01	-2.09728e-01
40.29	1.09539e+00	5.70821e-01	-2.34154e-01
44.43	1.02850e+00	6.72709e-01	-2.56030e-01
48.57	9.60171e-01	7.74248e-01	-2.75718e-01
52.71	8.87352e-01	8.73768e-01	-2.93996e-01
56.86	8.07711e-01	9.69599e-01	-3.11638e-01
61.00	7.18736e-01	1.06007e+00	-3.29253e-01
65.14	6.22038e-01	1.14352e+00	-3.46761e-01
69.29	5.20057e-01	1.21826e+00	-3.63914e-01
73.43	4.15228e-01	1.28263e+00	-3.80463e-01
77.57	3.09987e-01	1.33494e+00	-3.96161e-01
81.71	2.06767e-01	1.37354e+00	-4.10760e-01
85.86	1.07989e-01	1.39673e+00	-4.24014e-01
90.00	1.56485e-02	1.40332e+00	-4.35563e-01
94.14	-7.05739e-02	1.39392e+00	-4.44627e-01
98.29	-1.51274e-01	1.36962e+00	-4.50673e-01
102.43	-2.27170e-01	1.33152e+00	-4.53919e-01
106.57	-2.98956e-01	1.28070e+00	-4.54780e-01
110.71	-3.67328e-01	1.21826e+00	-4.53750e-01
114.86	-4.32975e-01	1.14528e+00	-4.51344e-01
119.00	-4.96583e-01	1.06285e+00	-4.48078e-01
123.14	-5.58629e-01	9.72230e-01	-4.44540e-01
127.29	-6.18898e-01	8.75416e-01	-4.41611e-01
131.43	-6.76883e-01	7.74561e-01	-4.40246e-01
135.57	-7.32108e-01	6.71826e-01	-4.41396e-01
139.71	-7.81301e-01	5.69372e-01	-4.45763e-01
143.86	-8.11547e-01	4.69359e-01	-4.52909e-01
148.00	-8.07048e-01	3.73947e-01	-4.61997e-01
150.29	-7.84753e-01	3.24053e-01	-4.62939e-01
152.57	-7.49158e-01	2.76530e-01	-4.46443e-01
154.86	-7.02317e-01	2.31689e-01	-4.29217e-01
157.14	-6.46277e-01	1.89845e-01	-4.11814e-01
159.43	-5.83072e-01	1.51311e-01	-3.95218e-01
161.71	-5.14717e-01	1.16405e-01	-4.09269e-01
164.00	-4.43217e-01	8.54157e-02	-4.34366e-01
166.29	-3.70615e-01	5.88084e-02	-4.59413e-01
168.57	-2.98991e-01	3.77152e-02	-4.84652e-01
170.86	-2.30326e-01	2.33792e-02	-4.56479e-01
173.14	-1.66393e-01	1.67685e-02	-3.43699e-01
175.43	-1.09190e-01	1.74050e-02	-2.27908e-01
177.71	-6.06552e-02	1.91337e-02	-1.14590e-01
180.00	-2.27254e-02	1.44279e-02	4.90989e-03

Table C.13: Aerodynamic properties of Airfoil13.

Angle (deg)	Cl (-)	Cd (-)	Cm (-)
-180.00	3.07792e-03	1.19277e-02	4.91830e-03
-177.71	6.34936e-02	1.54632e-02	9.15415e-02
-175.43	1.27683e-01	1.53487e-02	1.82505e-01
-173.14	1.84388e-01	1.53021e-02	2.74933e-01
-170.86	2.36728e-01	2.01154e-02	3.64977e-01
-168.57	2.87744e-01	3.35372e-02	3.96615e-01
-166.29	3.40395e-01	5.51766e-02	3.90638e-01
-164.00	3.97618e-01	8.35992e-02	3.83591e-01
-161.71	4.62393e-01	1.17089e-01	3.78772e-01
-159.43	5.35839e-01	1.54594e-01	3.78217e-01
-157.14	6.11189e-01	1.95733e-01	3.95430e-01
-154.86	6.79569e-01	2.40218e-01	4.12961e-01
-152.57	7.32026e-01	2.87756e-01	4.30538e-01
-150.29	7.62415e-01	3.38034e-01	4.47137e-01
-148.00	7.74466e-01	3.90750e-01	4.49730e-01
-143.86	7.67546e-01	4.91509e-01	4.45964e-01
-139.71	7.45465e-01	5.97344e-01	4.43872e-01
-135.57	7.14190e-01	7.06075e-01	4.45017e-01
-131.43	6.74392e-01	8.15466e-01	4.48546e-01
-127.29	6.27701e-01	9.23281e-01	4.53429e-01
-123.14	5.74549e-01	1.02729e+00	4.59022e-01
-119.00	5.15330e-01	1.12527e+00	4.64672e-01
-114.86	4.50845e-01	1.21500e+00	4.69726e-01
-110.71	3.81887e-01	1.29425e+00	4.73533e-01
-106.57	3.09252e-01	1.36106e+00	4.75485e-01
-102.43	2.33732e-01	1.41452e+00	4.75168e-01
-98.29	1.56122e-01	1.45395e+00	4.72211e-01
-94.14	7.71166e-02	1.47870e+00	4.66248e-01
-90.00	-2.27525e-03	1.48809e+00	4.56944e-01
-85.86	-8.12769e-02	1.48145e+00	4.44110e-01
-81.71	-1.59306e-01	1.45812e+00	4.27898e-01
-77.57	-2.35486e-01	1.41790e+00	4.09451e-01
-73.43	-3.09211e-01	1.36233e+00	3.89338e-01
-69.29	-3.79909e-01	1.29341e+00	3.67914e-01
-65.14	-4.47010e-01	1.21310e+00	3.45532e-01
-61.00	-5.09942e-01	1.12334e+00	3.22515e-01
-56.86	-5.68134e-01	1.02594e+00	2.99072e-01
-52.71	-6.21015e-01	9.22715e-01	2.75382e-01
-48.57	-6.68001e-01	8.15507e-01	2.51628e-01
-44.43	-7.09834e-01	7.06351e-01	2.30017e-01
-40.29	-7.45729e-01	5.97783e-01	2.06698e-01
-36.14	-7.84222e-01	4.95018e-01	1.44421e-01
-32.00	-8.74257e-01	3.85075e-01	7.90684e-02
-28.00	-1.02343e+00	2.27315e-01	4.54414e-02
-24.00	-1.13151e+00	1.49663e-01	1.94581e-02
-20.00	-1.11760e+00	1.00700e-01	1.86826e-03
-18.00	-1.11296e+00	7.95243e-02	-3.39377e-03
-16.00	-1.11202e+00	6.12401e-02	-5.56341e-03
-14.00	-1.09568e+00	4.57377e-02	-4.93210e-03
-12.00	-1.02733e+00	3.29051e-02	-7.52779e-03
-10.00	-8.77970e-01	2.27010e-02	-2.35500e-02
-8.00	-6.67080e-01	1.50770e-02	-5.41760e-02
-6.00	-4.17450e-01	9.91950e-03	-7.14870e-02
-4.00	-1.50950e-01	7.08850e-03	-8.09610e-02
-2.00	1.10030e-01	6.42300e-03	-8.91590e-02
-1.00	2.37690e-01	6.72130e-03	-9.29260e-02
0.00	3.64250e-01	7.30380e-03	-9.64180e-02
1.00	4.89910e-01	8.09090e-03	-9.96550e-02
2.00	6.15320e-01	8.93580e-03	-1.02650e-01
3.00	7.41170e-01	9.73350e-03	-1.05400e-01

Angle (deg)	Cl (-)	Cd (-)	Cm (-)
4.00	8.68300e-01	1.03800e-02	-1.07910e-01
5.00	9.95620e-01	1.08080e-02	-1.10180e-01
6.00	1.12210e+00	1.10970e-02	-1.12160e-01
7.00	1.24580e+00	1.13680e-02	-1.13790e-01
8.00	1.36500e+00	1.17370e-02	-1.15000e-01
9.00	1.47770e+00	1.23270e-02	-1.15740e-01
10.00	1.58200e+00	1.32550e-02	-1.15910e-01
11.00	1.67636e+00	1.46214e-02	-1.15414e-01
12.00	1.75935e+00	1.65585e-02	-1.14166e-01
13.00	1.82837e+00	1.93153e-02	-1.11984e-01
14.00	1.87574e+00	2.34454e-02	-1.08362e-01
15.00	1.89386e+00	2.96680e-02	-1.03202e-01
16.00	1.88215e+00	3.87065e-02	-9.83769e-02
18.00	1.78716e+00	6.61541e-02	-9.58939e-02
20.00	1.65237e+00	1.03402e-01	-1.02042e-01
24.00	1.45144e+00	1.93736e-01	-1.27719e-01
28.00	1.30859e+00	2.89635e-01	-1.55906e-01
32.00	1.20040e+00	3.86777e-01	-1.83235e-01
36.14	1.11383e+00	4.91566e-01	-2.10688e-01
40.29	1.04704e+00	5.98977e-01	-2.36596e-01
44.43	9.92439e-01	7.07796e-01	-2.60314e-01
48.57	9.42145e-01	8.16471e-01	-2.82201e-01
52.71	8.87405e-01	9.23104e-01	-3.02804e-01
56.86	8.25565e-01	1.02581e+00	-3.22670e-01
61.00	7.47077e-01	1.12275e+00	-3.42226e-01
65.14	6.54122e-01	1.21213e+00	-3.61409e-01
69.29	5.50604e-01	1.29219e+00	-3.80033e-01
73.43	4.40413e-01	1.36113e+00	-3.97913e-01
77.57	3.27430e-01	1.41717e+00	-4.14865e-01
81.71	2.15537e-01	1.45852e+00	-4.30713e-01
85.86	1.08573e-01	1.48338e+00	-4.45279e-01
90.00	1.01399e-02	1.49045e+00	-4.57675e-01
94.14	-8.09702e-02	1.48039e+00	-4.65716e-01
98.29	-1.64570e-01	1.45437e+00	-4.71714e-01
102.43	-2.41785e-01	1.41354e+00	-4.75428e-01
106.57	-3.13441e-01	1.35908e+00	-4.75933e-01
110.71	-3.80356e-01	1.29214e+00	-4.73702e-01
114.86	-4.43340e-01	1.21388e+00	-4.69554e-01
119.00	-5.03184e-01	1.12546e+00	-4.64309e-01
123.14	-5.60512e-01	1.02825e+00	-4.58735e-01
127.29	-6.15950e-01	9.24428e-01	-4.53393e-01
131.43	-6.69204e-01	8.16395e-01	-4.48790e-01
135.57	-7.21047e-01	7.06545e-01	-4.45425e-01
139.71	-7.67198e-01	5.97276e-01	-4.44185e-01
143.86	-7.93764e-01	4.90986e-01	-4.45608e-01
148.00	-7.83059e-01	3.90062e-01	-4.49148e-01
150.29	-7.55749e-01	3.37510e-01	-4.47777e-01
152.57	-7.14630e-01	2.87521e-01	-4.30384e-01
154.86	-6.62650e-01	2.40308e-01	-4.13063e-01
157.14	-6.02803e-01	1.96092e-01	-3.95236e-01
159.43	-5.38144e-01	1.55106e-01	-3.78595e-01
161.71	-4.71806e-01	1.17611e-01	-3.95282e-01
164.00	-4.07015e-01	8.34460e-02	-4.24260e-01
166.29	-3.46268e-01	5.34635e-02	-4.53199e-01
168.57	-2.88684e-01	3.19026e-02	-4.82322e-01
170.86	-2.32219e-01	2.16461e-02	-4.56288e-01
173.14	-1.76846e-01	1.76935e-02	-3.43916e-01
175.43	-1.20159e-01	1.51647e-02	-2.27768e-01
177.71	-6.06774e-02	1.29301e-02	-1.14641e-01
180.00	3.07792e-03	1.19277e-02	4.91830e-03

Table C.14: Aerodynamic properties of Airfoil14.

Angle (deg)	Cl (-)	Cd (-)	Cm (-)
-180.00	5.82410e-03	1.29268e-02	4.91760e-03
-177.71	6.11381e-02	1.62115e-02	9.15404e-02
-175.43	1.22989e-01	1.61890e-02	1.82507e-01
-173.14	1.78173e-01	1.64749e-02	2.74934e-01
-170.86	2.29400e-01	2.17023e-02	3.64966e-01
-168.57	2.79373e-01	3.54956e-02	3.95134e-01
-166.29	3.30807e-01	5.74565e-02	3.86724e-01
-164.00	3.86389e-01	8.61699e-02	3.77180e-01
-161.71	4.48820e-01	1.20631e-01	3.70044e-01
-159.43	5.19058e-01	1.59374e-01	3.67620e-01
-157.14	5.90907e-01	2.01701e-01	3.84801e-01
-154.86	6.56447e-01	2.47299e-01	4.02422e-01
-152.57	7.07746e-01	2.95862e-01	4.19907e-01
-150.29	7.39004e-01	3.47066e-01	4.36589e-01
-148.00	7.53061e-01	4.00606e-01	4.40498e-01
-143.86	7.50856e-01	5.02625e-01	4.39810e-01
-139.71	7.33405e-01	6.09469e-01	4.41002e-01
-135.57	7.06371e-01	7.19005e-01	4.43955e-01
-131.43	6.70679e-01	8.29020e-01	4.48270e-01
-127.29	6.25989e-01	9.37033e-01	4.53798e-01
-123.14	5.73709e-01	1.04102e+00	4.59901e-01
-119.00	5.15154e-01	1.13881e+00	4.65943e-01
-114.86	4.51139e-01	1.22819e+00	4.71239e-01
-110.71	3.82481e-01	1.30692e+00	4.75169e-01
-106.57	3.09994e-01	1.37305e+00	4.77196e-01
-102.43	2.34405e-01	1.42573e+00	4.76919e-01
-98.29	1.56659e-01	1.46440e+00	4.73988e-01
-94.14	7.77946e-02	1.48851e+00	4.68052e-01
-90.00	-1.76861e-03	1.49751e+00	4.58784e-01
-85.86	-8.12988e-02	1.49084e+00	4.45943e-01
-81.71	-1.59619e-01	1.46794e+00	4.29644e-01
-77.57	-2.36069e-01	1.42861e+00	4.11077e-01
-73.43	-3.09987e-01	1.37414e+00	3.90834e-01
-69.29	-3.80815e-01	1.30620e+00	3.69273e-01
-65.14	-4.47873e-01	1.22650e+00	3.46756e-01
-61.00	-5.10491e-01	1.13685e+00	3.23608e-01
-56.86	-5.68067e-01	1.03933e+00	3.00024e-01
-52.71	-6.19970e-01	9.36095e-01	2.76162e-01
-48.57	-6.65568e-01	8.29133e-01	2.52184e-01
-44.43	-7.02481e-01	7.20073e-01	2.30287e-01
-40.29	-7.30568e-01	6.10982e-01	2.06774e-01
-36.14	-7.60820e-01	5.05791e-01	1.47654e-01
-32.00	-8.42129e-01	3.94100e-01	8.54033e-02
-28.00	-1.00966e+00	2.36462e-01	4.84309e-02
-24.00	-1.14410e+00	1.45888e-01	1.82390e-02
-20.00	-1.14388e+00	9.49648e-02	1.96310e-05
-18.00	-1.15173e+00	7.51688e-02	-4.79427e-03
-16.00	-1.15301e+00	5.78403e-02	-6.79237e-03
-14.00	-1.11731e+00	4.30581e-02	-6.77023e-03
-12.00	-1.02667e+00	3.08672e-02	-1.00479e-02
-10.00	-8.71310e-01	2.12610e-02	-2.48120e-02
-8.00	-6.57000e-01	1.41230e-02	-5.60110e-02
-6.00	-4.05540e-01	9.33070e-03	-7.18740e-02
-4.00	-1.45040e-01	6.82940e-03	-8.06980e-02
-2.00	1.11900e-01	6.34670e-03	-8.77670e-02
-1.00	2.38930e-01	6.62820e-03	-9.09380e-02
0.00	3.64930e-01	7.13620e-03	-9.39610e-02
1.00	4.90230e-01	7.71070e-03	-9.68020e-02
2.00	6.15150e-01	8.37560e-03	-9.94490e-02
3.00	7.39960e-01	9.03450e-03	-1.01900e-01
4.00	8.63640e-01	9.58710e-03	-1.04130e-01
5.00	9.88320e-01	9.97630e-03	-1.06150e-01
6.00	1.11210e+00	1.02800e-02	-1.07890e-01
7.00	1.23340e+00	1.06100e-02	-1.09290e-01
8.00	1.35080e+00	1.10760e-02	-1.10280e-01
9.00	1.46310e+00	1.17890e-02	-1.10810e-01
10.00	1.56800e+00	1.28610e-02	-1.10810e-01
11.00	1.66312e+00	1.44289e-02	-1.10258e-01
12.00	1.74545e+00	1.65808e-02	-1.09093e-01
13.00	1.81172e+00	1.94618e-02	-1.07199e-01
14.00	1.85701e+00	2.36759e-02	-1.04105e-01
15.00	1.87769e+00	2.98547e-02	-9.97093e-02
16.00	1.87268e+00	3.86295e-02	-9.57487e-02
18.00	1.78730e+00	6.51529e-02	-9.41963e-02
20.00	1.66197e+00	1.01597e-01	-9.96548e-02
24.00	1.45535e+00	1.91036e-01	-1.24040e-01
28.00	1.29979e+00	2.89127e-01	-1.53380e-01
32.00	1.17851e+00	3.96213e-01	-1.82555e-01
36.14	1.08813e+00	5.02977e-01	-2.10758e-01
40.29	1.02241e+00	6.10676e-01	-2.36711e-01
44.43	9.72214e-01	7.20359e-01	-2.60577e-01
48.57	9.28845e-01	8.29922e-01	-2.82727e-01
52.71	8.84700e-01	9.37128e-01	-3.03560e-01
56.86	8.25638e-01	1.04008e+00	-3.23647e-01
61.00	7.49034e-01	1.13685e+00	-3.43385e-01
65.14	6.56904e-01	1.22567e+00	-3.62715e-01
69.29	5.53359e-01	1.30490e+00	-3.81460e-01
73.43	4.42600e-01	1.37286e+00	-3.99446e-01
77.57	3.28696e-01	1.42793e+00	-4.16498e-01
81.71	2.15801e-01	1.46844e+00	-4.32440e-01
85.86	1.08051e-01	1.49277e+00	-4.47098e-01
90.00	8.36042e-03	1.49974e+00	-4.59536e-01
94.14	-8.20795e-02	1.48996e+00	-4.67472e-01
98.29	-1.65663e-01	1.46449e+00	-4.73472e-01
102.43	-2.42562e-01	1.42442e+00	-4.77237e-01
106.57	-3.13797e-01	1.37079e+00	-4.77708e-01
110.71	-3.80272e-01	1.30467e+00	-4.75355e-01
114.86	-4.42891e-01	1.22714e+00	-4.71027e-01
119.00	-5.02557e-01	1.13925e+00	-4.65521e-01
123.14	-5.59965e-01	1.04230e+00	-4.59573e-01
127.29	-6.14600e-01	9.38500e-01	-4.53763e-01
131.43	-6.66645e-01	8.30115e-01	-4.48551e-01
135.57	-7.14383e-01	7.19507e-01	-4.44395e-01
139.71	-7.55861e-01	6.09298e-01	-4.41204e-01
143.86	-7.77429e-01	5.01908e-01	-4.39229e-01
148.00	-7.62220e-01	3.99767e-01	-4.39919e-01
150.29	-7.33113e-01	3.46514e-01	-4.37291e-01
152.57	-6.91129e-01	2.95784e-01	-4.19702e-01
154.86	-6.39493e-01	2.47748e-01	-4.02581e-01
157.14	-5.81295e-01	2.02564e-01	-3.84566e-01
159.43	-5.19427e-01	1.60373e-01	-3.68028e-01
161.71	-4.56539e-01	1.21278e-01	-3.86496e-01
164.00	-3.95200e-01	8.59943e-02	-4.17907e-01
166.29	-3.36812e-01	5.55989e-02	-4.49262e-01
168.57	-2.82032e-01	3.36938e-02	-4.80801e-01
170.86	-2.30236e-01	2.31537e-02	-4.56299e-01
173.14	-1.76038e-01	1.94390e-02	-3.43903e-01
175.43	-1.19781e-01	1.60859e-02	-2.27777e-01
177.71	-5.97359e-02	1.37076e-02	-1.14637e-01
180.00	5.82410e-03	1.29268e-02	4.91760e-03

Table C.15: Aerodynamic properties of Airfoil15.

Angle (deg)	Cl (-)	Cd (-)	Cm (-)
-180.00	2.54199e-03	1.67723e-02	4.91158e-03
-177.71	5.95492e-02	1.93529e-02	9.15235e-02
-175.43	1.19827e-01	1.96557e-02	1.82562e-01
-173.14	1.73758e-01	2.11407e-02	2.74828e-01
-170.86	2.23916e-01	2.77777e-02	3.65091e-01
-168.57	2.72872e-01	4.26538e-02	3.93865e-01
-166.29	3.23209e-01	6.53369e-02	3.83412e-01
-164.00	3.77483e-01	9.45037e-02	3.72283e-01
-161.71	4.38264e-01	1.29132e-01	3.62784e-01
-159.43	5.06463e-01	1.67901e-01	3.59090e-01
-157.14	5.76199e-01	2.10190e-01	3.76072e-01
-154.86	6.39955e-01	2.55704e-01	3.93699e-01
-152.57	6.90200e-01	3.04147e-01	4.10927e-01
-150.29	7.21419e-01	3.55212e-01	4.27640e-01
-148.00	7.36246e-01	4.08605e-01	4.32161e-01
-143.86	7.36449e-01	5.10369e-01	4.32986e-01
-139.71	7.21395e-01	6.17012e-01	4.35453e-01
-135.57	6.96432e-01	7.26392e-01	4.39574e-01
-131.43	6.62478e-01	8.36278e-01	4.44919e-01
-127.29	6.19525e-01	9.43726e-01	4.51243e-01
-123.14	5.68844e-01	1.04702e+00	4.57944e-01
-119.00	5.11633e-01	1.14412e+00	4.64417e-01
-114.86	4.48730e-01	1.23278e+00	4.69943e-01
-110.71	3.80970e-01	1.31076e+00	4.73959e-01
-106.57	3.09190e-01	1.37610e+00	4.76050e-01
-102.43	2.33982e-01	1.42803e+00	4.75815e-01
-98.29	1.56533e-01	1.46604e+00	4.72905e-01
-94.14	7.80153e-02	1.48965e+00	4.66965e-01
-90.00	-1.28865e-03	1.49837e+00	4.57688e-01
-85.86	-8.07211e-02	1.49170e+00	4.44932e-01
-81.71	-1.59050e-01	1.46915e+00	4.28864e-01
-77.57	-2.35509e-01	1.43055e+00	4.10518e-01
-73.43	-3.09341e-01	1.37704e+00	3.90440e-01
-69.29	-3.79997e-01	1.31010e+00	3.68988e-01
-65.14	-4.46601e-01	1.23125e+00	3.46520e-01
-61.00	-5.08306e-01	1.14215e+00	3.23366e-01
-56.86	-5.64446e-01	1.04509e+00	2.99751e-01
-52.71	-6.14276e-01	9.42504e-01	2.75871e-01
-48.57	-6.57051e-01	8.36481e-01	2.51924e-01
-44.43	-6.91070e-01	7.28216e-01	2.29931e-01
-40.29	-7.17535e-01	6.19620e-01	2.06180e-01
-36.14	-7.45826e-01	5.12956e-01	1.50456e-01
-32.00	-8.11921e-01	4.01297e-01	9.17774e-02
-28.00	-9.61803e-01	2.55833e-01	5.46028e-02
-24.00	-1.14918e+00	1.43883e-01	1.74314e-02
-20.00	-1.17876e+00	8.96853e-02	-1.49143e-03
-18.00	-1.18792e+00	7.09496e-02	-5.70449e-03
-16.00	-1.18454e+00	5.41341e-02	-7.62228e-03
-14.00	-1.13953e+00	3.96259e-02	-8.62558e-03
-12.00	-1.03785e+00	2.77873e-02	-1.46495e-02
-10.00	-8.73910e-01	1.88470e-02	-3.12740e-02
-8.00	-6.54530e-01	1.25660e-02	-5.70270e-02
-6.00	-3.98500e-01	8.60480e-03	-7.08060e-02
-4.00	-1.36320e-01	6.67460e-03	-7.91810e-02
-2.00	1.20510e-01	6.39020e-03	-8.58650e-02
-1.00	2.46640e-01	6.65890e-03	-8.88090e-02
0.00	3.71290e-01	7.10220e-03	-9.15740e-02
1.00	4.94740e-01	7.52680e-03	-9.41500e-02
2.00	6.17300e-01	8.04680e-03	-9.65400e-02
3.00	7.39580e-01	8.57060e-03	-9.87530e-02
4.00	8.59830e-01	9.00130e-03	-1.00800e-01
5.00	9.80780e-01	9.29830e-03	-1.02670e-01
6.00	1.10100e+00	9.54940e-03	-1.04310e-01
7.00	1.21980e+00	9.87430e-03	-1.05640e-01
8.00	1.33660e+00	1.03920e-02	-1.06590e-01
9.00	1.45030e+00	1.12200e-02	-1.07080e-01
10.00	1.55750e+00	1.24800e-02	-1.07060e-01
11.00	1.65435e+00	1.43097e-02	-1.06485e-01
12.00	1.73637e+00	1.68116e-02	-1.05305e-01
13.00	1.79919e+00	2.01395e-02	-1.03447e-01
14.00	1.83805e+00	2.48209e-02	-1.00715e-01
15.00	1.85031e+00	3.14127e-02	-9.71802e-02
16.00	1.83917e+00	4.04720e-02	-9.41422e-02
18.00	1.76049e+00	6.70123e-02	-9.34230e-02
20.00	1.64930e+00	1.02854e-01	-9.83372e-02
24.00	1.44441e+00	1.89365e-01	-1.21072e-01
28.00	1.28388e+00	2.85348e-01	-1.51030e-01
32.00	1.16125e+00	4.04348e-01	-1.81835e-01
36.14	1.07074e+00	5.11285e-01	-2.10564e-01
40.29	1.00633e+00	6.17920e-01	-2.36270e-01
44.43	9.58453e-01	7.27523e-01	-2.60012e-01
48.57	9.17856e-01	8.37146e-01	-2.82257e-01
52.71	8.76084e-01	9.44053e-01	-3.03158e-01
56.86	8.19926e-01	1.04648e+00	-3.23332e-01
61.00	7.45263e-01	1.14251e+00	-3.43131e-01
65.14	6.54215e-01	1.23044e+00	-3.62480e-01
69.29	5.51095e-01	1.30869e+00	-3.81195e-01
73.43	4.40452e-01	1.37571e+00	-3.99093e-01
77.57	3.26485e-01	1.42992e+00	-4.15993e-01
81.71	2.13625e-01	1.46976e+00	-4.31710e-01
85.86	1.06246e-01	1.49368e+00	-4.46063e-01
90.00	7.58931e-03	1.50056e+00	-4.58252e-01
94.14	-8.15721e-02	1.49098e+00	-4.66376e-01
98.29	-1.63953e-01	1.46596e+00	-4.72435e-01
102.43	-2.39496e-01	1.42651e+00	-4.76121e-01
106.57	-3.09628e-01	1.37364e+00	-4.76545e-01
110.71	-3.75461e-01	1.30837e+00	-4.74169e-01
114.86	-4.38106e-01	1.23172e+00	-4.69794e-01
119.00	-4.98673e-01	1.14469e+00	-4.64074e-01
123.14	-5.57786e-01	1.04855e+00	-4.57624e-01
127.29	-6.13856e-01	9.45484e-01	-4.51125e-01
131.43	-6.65532e-01	8.37549e-01	-4.45061e-01
135.57	-7.09806e-01	7.27021e-01	-4.39912e-01
139.71	-7.44117e-01	6.16886e-01	-4.35723e-01
143.86	-7.57927e-01	5.09585e-01	-4.32646e-01
148.00	-7.38628e-01	4.07565e-01	-4.31669e-01
150.29	-7.10114e-01	3.54395e-01	-4.28145e-01
152.57	-6.70413e-01	3.03764e-01	-4.10708e-01
154.86	-6.22090e-01	2.55846e-01	-3.93925e-01
157.14	-5.67611e-01	2.10810e-01	-3.75809e-01
159.43	-5.09298e-01	1.68807e-01	-3.59430e-01
161.71	-4.49313e-01	1.29967e-01	-3.79421e-01
164.00	-3.90041e-01	9.48598e-02	-4.12789e-01
166.29	-3.31738e-01	6.43672e-02	-4.46066e-01
168.57	-2.76232e-01	4.13913e-02	-4.79532e-01
170.86	-2.23050e-01	2.83980e-02	-4.56422e-01
173.14	-1.68602e-01	2.26455e-02	-3.43762e-01
175.43	-1.13471e-01	1.96040e-02	-2.27870e-01
177.71	-5.67311e-02	1.81600e-02	-1.14602e-01
180.00	2.54199e-03	1.67723e-02	4.91158e-03

Table C.16: Aerodynamic properties of Airfoil16.

Angle (deg)	Cl (-)	Cd (-)	Cm (-)
-180.00	-2.79208e-03	2.09851e-02	4.90465e-03
-177.71	5.83922e-02	2.28479e-02	9.15035e-02
-175.43	1.17527e-01	2.34990e-02	1.82628e-01
-173.14	1.70496e-01	2.62709e-02	2.74699e-01
-170.86	2.19795e-01	3.44015e-02	3.65248e-01
-168.57	2.67916e-01	5.03849e-02	3.92838e-01
-166.29	3.17368e-01	7.37541e-02	3.80742e-01
-164.00	3.70631e-01	1.03290e-01	3.68543e-01
-161.71	4.30200e-01	1.37844e-01	3.56983e-01
-159.43	4.96962e-01	1.76329e-01	3.52383e-01
-157.14	5.65226e-01	2.18257e-01	3.69134e-01
-154.86	6.27720e-01	2.63355e-01	3.86736e-01
-152.57	6.77164e-01	3.11349e-01	4.03682e-01
-150.29	7.08213e-01	3.61946e-01	4.20399e-01
-148.00	7.23378e-01	4.14868e-01	4.25213e-01
-143.86	7.24837e-01	5.15812e-01	4.26848e-01
-139.71	7.11067e-01	6.21715e-01	4.29888e-01
-135.57	6.87208e-01	7.30427e-01	4.34729e-01
-131.43	6.54127e-01	8.39697e-01	4.40843e-01
-127.29	6.12476e-01	9.46711e-01	4.47741e-01
-123.14	5.63200e-01	1.04964e+00	4.54855e-01
-119.00	5.07230e-01	1.14638e+00	4.61615e-01
-114.86	4.45412e-01	1.23469e+00	4.67357e-01
-110.71	3.78592e-01	1.31232e+00	4.71546e-01
-106.57	3.07617e-01	1.37733e+00	4.73763e-01
-102.43	2.33138e-01	1.42894e+00	4.73614e-01
-98.29	1.56282e-01	1.46668e+00	4.70744e-01
-94.14	7.81068e-02	1.49009e+00	4.64797e-01
-90.00	-8.74592e-04	1.49870e+00	4.55502e-01
-85.86	-7.99493e-02	1.49203e+00	4.42914e-01
-81.71	-1.58076e-01	1.46962e+00	4.27306e-01
-77.57	-2.34393e-01	1.43131e+00	4.09402e-01
-73.43	-3.08054e-01	1.37820e+00	3.89655e-01
-69.29	-3.78367e-01	1.31170e+00	3.68419e-01
-65.14	-4.44378e-01	1.23323e+00	3.46048e-01
-61.00	-5.05156e-01	1.14440e+00	3.22883e-01
-56.86	-5.59916e-01	1.04759e+00	2.99207e-01
-52.71	-6.07810e-01	9.45350e-01	2.75290e-01
-48.57	-6.47988e-01	8.40002e-01	2.51404e-01
-44.43	-6.80047e-01	7.32959e-01	2.29289e-01
-40.29	-7.06922e-01	6.25341e-01	2.05385e-01
-36.14	-7.35727e-01	5.17786e-01	1.52749e-01
-32.00	-7.86237e-01	4.06864e-01	9.73398e-02
-28.00	-9.10916e-01	2.75459e-01	6.08262e-02
-24.00	-1.15142e+00	1.42738e-01	1.68510e-02
-20.00	-1.21171e+00	8.51778e-02	-2.71866e-03
-18.00	-1.21898e+00	6.72817e-02	-6.34223e-03
-16.00	-1.20941e+00	5.07938e-02	-8.20637e-03
-14.00	-1.15921e+00	3.64082e-02	-1.02353e-02
-12.00	-1.05169e+00	2.48132e-02	-1.92254e-02
-10.00	-8.79100e-01	1.64830e-02	-3.84430e-02
-8.00	-6.53520e-01	1.10500e-02	-5.75470e-02
-6.00	-3.94040e-01	7.94140e-03	-6.92240e-02
-4.00	-1.28000e-01	6.59320e-03	-7.74410e-02
-2.00	1.29980e-01	6.47700e-03	-8.40640e-02
-1.00	2.55340e-01	6.72020e-03	-8.69210e-02
0.00	3.78620e-01	7.08880e-03	-8.95330e-02
1.00	5.00120e-01	7.44510e-03	-9.19240e-02
2.00	6.20170e-01	7.85780e-03	-9.41240e-02
3.00	7.39430e-01	8.25570e-03	-9.61630e-02
4.00	8.56880e-01	8.56450e-03	-9.80710e-02
5.00	9.74270e-01	8.76030e-03	-9.98590e-02
6.00	1.09120e+00	8.94300e-03	-1.01460e-01
7.00	1.20790e+00	9.24340e-03	-1.02790e-01
8.00	1.32440e+00	9.79210e-03	-1.03760e-01
9.00	1.43990e+00	1.07200e-02	-1.04280e-01
10.00	1.54980e+00	1.21570e-02	-1.04290e-01
11.00	1.64855e+00	1.42399e-02	-1.03717e-01
12.00	1.73041e+00	1.70944e-02	-1.02489e-01
13.00	1.78984e+00	2.09039e-02	-1.00579e-01
14.00	1.82165e+00	2.61151e-02	-9.81104e-02
15.00	1.82352e+00	3.32259e-02	-9.53782e-02
16.00	1.80345e+00	4.27343e-02	-9.32133e-02
18.00	1.72805e+00	6.97569e-02	-9.30865e-02
20.00	1.62921e+00	1.05272e-01	-9.76623e-02
24.00	1.42926e+00	1.88229e-01	-1.18720e-01
28.00	1.26817e+00	2.80903e-01	-1.49046e-01
32.00	1.14791e+00	4.10951e-01	-1.81203e-01
36.14	1.05857e+00	5.17351e-01	-2.10291e-01
40.29	9.95289e-01	6.22390e-01	-2.35633e-01
44.43	9.48540e-01	7.31386e-01	-2.59114e-01
48.57	9.08877e-01	8.40544e-01	-2.81319e-01
52.71	8.67036e-01	9.47151e-01	-3.02356e-01
56.86	8.12657e-01	1.04928e+00	-3.22704e-01
61.00	7.39278e-01	1.14493e+00	-3.42625e-01
65.14	6.49094e-01	1.23243e+00	-3.62011e-01
69.29	5.46578e-01	1.31024e+00	-3.80665e-01
73.43	4.36392e-01	1.37685e+00	-3.98389e-01
77.57	3.22915e-01	1.43070e+00	-4.14984e-01
81.71	2.10715e-01	1.47027e+00	-4.30254e-01
85.86	1.04310e-01	1.49403e+00	-4.43999e-01
90.00	7.24531e-03	1.50087e+00	-4.55692e-01
94.14	-8.05602e-02	1.49137e+00	-4.64190e-01
98.29	-1.61199e-01	1.46652e+00	-4.70367e-01
102.43	-2.35226e-01	1.42733e+00	-4.73896e-01
106.57	-3.04213e-01	1.37478e+00	-4.74225e-01
110.71	-3.69480e-01	1.30988e+00	-4.71805e-01
114.86	-4.32345e-01	1.23363e+00	-4.67336e-01
119.00	-4.94129e-01	1.14701e+00	-4.61401e-01
123.14	-5.55369e-01	1.05128e+00	-4.54567e-01
127.29	-6.13408e-01	9.48615e-01	-4.47518e-01
131.43	-6.65033e-01	8.41159e-01	-4.40790e-01
135.57	-7.06431e-01	7.31225e-01	-4.34920e-01
139.71	-7.33872e-01	6.21697e-01	-4.30261e-01
143.86	-7.40202e-01	5.15018e-01	-4.26847e-01
148.00	-7.17503e-01	4.13633e-01	-4.24822e-01
150.29	-6.90207e-01	3.60820e-01	-4.20651e-01
152.57	-6.53440e-01	3.10557e-01	-4.03462e-01
154.86	-6.08939e-01	2.63041e-01	-3.87024e-01
157.14	-5.58418e-01	2.18462e-01	-3.68851e-01
159.43	-5.03560e-01	1.77008e-01	-3.52634e-01
161.71	-4.46022e-01	1.38862e-01	-3.73860e-01
164.00	-3.87736e-01	1.04309e-01	-4.08764e-01
166.29	-3.28995e-01	7.39560e-02	-4.43544e-01
168.57	-2.71540e-01	4.98873e-02	-4.78516e-01
170.86	-2.15366e-01	3.40252e-02	-4.56566e-01
173.14	-1.60030e-01	2.58404e-02	-3.43598e-01
175.43	-1.06043e-01	2.34546e-02	-2.27979e-01
177.71	-5.35751e-02	2.32748e-02	-1.14561e-01
180.00	-2.79208e-03	2.09851e-02	4.90465e-03

Table C.17: Aerodynamic properties of Airfoil17.

Angle (deg)	Cl (-)	Cd (-)	Cm (-)
-180.00	-6.71315e-03	2.33902e-02	4.90052e-03
-177.71	5.78231e-02	2.48701e-02	9.14914e-02
-175.43	1.16396e-01	2.57160e-02	1.82668e-01
-173.14	1.68875e-01	2.92092e-02	2.74620e-01
-170.86	2.17722e-01	3.81669e-02	3.65347e-01
-168.57	2.65401e-01	5.47429e-02	3.92298e-01
-166.29	3.14386e-01	7.84508e-02	3.79344e-01
-164.00	3.67132e-01	1.08132e-01	3.66642e-01
-161.71	4.26100e-01	1.42638e-01	3.53958e-01
-159.43	4.92170e-01	1.80971e-01	3.48916e-01
-157.14	5.59732e-01	2.22690e-01	3.65527e-01
-154.86	6.21619e-01	2.67533e-01	3.83107e-01
-152.57	6.70656e-01	3.15235e-01	3.99885e-01
-150.29	7.01573e-01	3.65513e-01	4.16601e-01
-148.00	7.16828e-01	4.18100e-01	4.21520e-01
-143.86	7.18755e-01	5.18415e-01	4.23505e-01
-139.71	7.05513e-01	6.23695e-01	4.26823e-01
-135.57	6.82156e-01	7.31796e-01	4.31941e-01
-131.43	6.49531e-01	8.40467e-01	4.38311e-01
-127.29	6.08467e-01	9.47289e-01	4.45387e-01
-123.14	5.59820e-01	1.05014e+00	4.52616e-01
-119.00	5.04441e-01	1.14681e+00	4.59445e-01
-114.86	4.43176e-01	1.23505e+00	4.65294e-01
-110.71	3.76871e-01	1.31262e+00	4.69621e-01
-106.57	3.06372e-01	1.37755e+00	4.71939e-01
-102.43	2.32465e-01	1.42910e+00	4.71857e-01
-98.29	1.56081e-01	1.46680e+00	4.69019e-01
-94.14	7.81239e-02	1.49017e+00	4.63067e-01
-90.00	-6.51705e-04	1.49875e+00	4.53758e-01
-85.86	-7.94386e-02	1.49209e+00	4.41303e-01
-81.71	-1.57343e-01	1.46970e+00	4.26064e-01
-77.57	-2.33502e-01	1.43145e+00	4.08512e-01
-73.43	-3.07027e-01	1.37841e+00	3.89028e-01
-69.29	-3.77066e-01	1.31200e+00	3.67965e-01
-65.14	-4.42689e-01	1.23360e+00	3.45672e-01
-61.00	-5.02976e-01	1.14483e+00	3.22497e-01
-56.86	-5.57047e-01	1.04807e+00	2.98773e-01
-52.71	-6.04003e-01	9.45901e-01	2.74827e-01
-48.57	-6.42948e-01	8.40845e-01	2.50990e-01
-44.43	-6.73982e-01	7.34769e-01	2.28794e-01
-40.29	-7.01336e-01	6.27926e-01	2.04858e-01
-36.14	-7.31085e-01	5.20007e-01	1.53959e-01
-32.00	-7.72480e-01	4.09716e-01	1.00345e-01
-28.00	-8.82643e-01	2.86265e-01	6.42535e-02
-24.00	-1.15185e+00	1.42315e-01	1.65684e-02
-20.00	-1.22981e+00	8.27598e-02	-3.36369e-03
-18.00	-1.23567e+00	6.53025e-02	-6.64629e-03
-16.00	-1.22229e+00	4.89741e-02	-8.48594e-03
-14.00	-1.16988e+00	3.46428e-02	-1.11034e-02
-12.00	-1.06039e+00	2.31767e-02	-2.17460e-02
-10.00	-8.83240e-01	1.51820e-02	-4.25810e-02
-8.00	-6.53330e-01	1.02160e-02	-5.76980e-02
-6.00	-3.92120e-01	7.57890e-03	-6.81120e-02
-4.00	-1.23430e-01	6.56780e-03	-7.64090e-02
-2.00	1.35400e-01	6.54630e-03	-8.30750e-02
-1.00	2.60430e-01	6.76910e-03	-8.58970e-02
0.00	3.82990e-01	7.08640e-03	-8.84370e-02
1.00	5.03420e-01	7.42930e-03	-9.07380e-02
2.00	6.22070e-01	7.78720e-03	-9.28420e-02
3.00	7.39400e-01	8.10990e-03	-9.47930e-02
4.00	8.55380e-01	8.34600e-03	-9.66330e-02
5.00	9.70770e-01	8.48090e-03	-9.83830e-02
6.00	1.08600e+00	8.62130e-03	-9.99740e-02
7.00	1.20150e+00	8.90460e-03	-1.01310e-01
8.00	1.31780e+00	9.46800e-03	-1.02310e-01
9.00	1.43450e+00	1.04490e-02	-1.02870e-01
10.00	1.54600e+00	1.19850e-02	-1.02910e-01
11.00	1.64594e+00	1.42131e-02	-1.02347e-01
12.00	1.72775e+00	1.72710e-02	-1.01084e-01
13.00	1.78516e+00	2.13513e-02	-9.91205e-02
14.00	1.81282e+00	2.68740e-02	-9.67817e-02
15.00	1.80877e+00	3.43147e-02	-9.45068e-02
16.00	1.78356e+00	4.41488e-02	-9.28631e-02
18.00	1.70799e+00	7.16803e-02	-9.30221e-02
20.00	1.61462e+00	1.07178e-01	-9.74648e-02
24.00	1.41901e+00	1.87702e-01	-1.17499e-01
28.00	1.25952e+00	2.78211e-01	-1.47986e-01
32.00	1.14108e+00	4.14421e-01	-1.80862e-01
36.14	1.05278e+00	5.20341e-01	-2.10105e-01
40.29	9.90116e-01	6.24247e-01	-2.35193e-01
44.43	9.43703e-01	7.32663e-01	-2.58461e-01
48.57	9.04146e-01	8.41305e-01	-2.80570e-01
52.71	8.62067e-01	9.47753e-01	-3.01716e-01
56.86	8.07998e-01	1.04982e+00	-3.22204e-01
61.00	7.34926e-01	1.14539e+00	-3.42221e-01
65.14	6.45074e-01	1.23280e+00	-3.61637e-01
69.29	5.42974e-01	1.31053e+00	-3.80242e-01
73.43	4.33215e-01	1.37705e+00	-3.97827e-01
77.57	3.20299e-01	1.43084e+00	-4.14180e-01
81.71	2.08788e-01	1.47036e+00	-4.29091e-01
85.86	1.03226e-01	1.49409e+00	-4.42352e-01
90.00	7.17867e-03	1.50093e+00	-4.53648e-01
94.14	-7.97528e-02	1.49144e+00	-4.62446e-01
98.29	-1.59184e-01	1.46663e+00	-4.68717e-01
102.43	-2.32329e-01	1.42748e+00	-4.72120e-01
106.57	-3.00694e-01	1.37499e+00	-4.72374e-01
110.71	-3.65706e-01	1.31016e+00	-4.69918e-01
114.86	-4.28796e-01	1.23398e+00	-4.65374e-01
119.00	-4.91390e-01	1.14745e+00	-4.59326e-01
123.14	-5.53972e-01	1.05180e+00	-4.52359e-01
127.29	-6.13229e-01	9.49223e-01	-4.45097e-01
131.43	-6.64936e-01	8.42064e-01	-4.38126e-01
135.57	-7.04755e-01	7.32722e-01	-4.32030e-01
139.71	-7.28337e-01	6.23765e-01	-4.27252e-01
143.86	-7.30528e-01	5.17630e-01	-4.23706e-01
148.00	-7.06011e-01	4.16753e-01	-4.21188e-01
150.29	-6.79480e-01	3.64202e-01	-4.16696e-01
152.57	-6.44483e-01	3.14198e-01	-3.99668e-01
154.86	-6.02299e-01	2.66948e-01	-3.83429e-01
157.14	-5.54204e-01	2.22654e-01	-3.65234e-01
159.43	-5.01471e-01	1.81523e-01	-3.49109e-01
161.71	-4.45378e-01	1.43757e-01	-3.70985e-01
164.00	-3.87289e-01	1.09571e-01	-4.06683e-01
166.29	-3.28084e-01	7.94216e-02	-4.42237e-01
168.57	-2.69079e-01	5.47696e-02	-4.77986e-01
170.86	-2.11076e-01	3.71783e-02	-4.56652e-01
173.14	-1.54922e-01	2.76002e-02	-3.43500e-01
175.43	-1.01544e-01	2.56511e-02	-2.28043e-01
177.71	-5.18417e-02	2.63143e-02	-1.14536e-01
180.00	-6.71315e-03	2.33902e-02	4.90052e-03

Table C.18: Aerodynamic properties of Airfoil18.

Angle (deg)	Cl (-)	Cd (-)	Cm (-)
-180.00	-7.78041e-03	2.39866e-02	4.89948e-03
-177.71	5.76873e-02	2.53745e-02	9.14883e-02
-175.43	1.16127e-01	2.62682e-02	1.82678e-01
-173.14	1.68486e-01	2.99389e-02	2.74599e-01
-170.86	2.17224e-01	3.90990e-02	3.65372e-01
-168.57	2.64793e-01	5.58176e-02	3.92167e-01
-166.29	3.13665e-01	7.96038e-02	3.79003e-01
-164.00	3.66285e-01	1.09314e-01	3.66183e-01
-161.71	4.25110e-01	1.43810e-01	3.53221e-01
-159.43	4.91016e-01	1.82110e-01	3.48074e-01
-157.14	5.58413e-01	2.23780e-01	3.64649e-01
-154.86	6.20156e-01	2.68561e-01	3.82223e-01
-152.57	6.69095e-01	3.16190e-01	3.98959e-01
-150.29	6.99976e-01	3.66386e-01	4.15674e-01
-148.00	7.15246e-01	4.18884e-01	4.20615e-01
-143.86	7.17272e-01	5.19029e-01	4.22682e-01
-139.71	7.04149e-01	6.24134e-01	4.26072e-01
-135.57	6.80912e-01	7.32059e-01	4.31247e-01
-131.43	6.48406e-01	8.40554e-01	4.37661e-01
-127.29	6.07475e-01	9.47334e-01	4.44765e-01
-123.14	5.58964e-01	1.05018e+00	4.52009e-01
-119.00	5.03719e-01	1.14684e+00	4.58845e-01
-114.86	4.42584e-01	1.23508e+00	4.64719e-01
-110.71	3.76405e-01	1.31264e+00	4.69084e-01
-106.57	3.06025e-01	1.37757e+00	4.71430e-01
-102.43	2.32278e-01	1.42911e+00	4.71367e-01
-98.29	1.56025e-01	1.46680e+00	4.68538e-01
-94.14	7.81252e-02	1.49017e+00	4.62585e-01
-90.00	-5.96940e-04	1.49876e+00	4.53272e-01
-85.86	-7.93043e-02	1.49209e+00	4.40854e-01
-81.71	-1.57143e-01	1.46971e+00	4.25717e-01
-77.57	-2.33254e-01	1.43146e+00	4.08263e-01
-73.43	-3.06740e-01	1.37843e+00	3.88854e-01
-69.29	-3.76703e-01	1.31202e+00	3.67839e-01
-65.14	-4.42225e-01	1.23363e+00	3.45568e-01
-61.00	-5.02394e-01	1.14486e+00	3.22390e-01
-56.86	-5.56304e-01	1.04810e+00	2.98651e-01
-52.71	-6.03047e-01	9.45943e-01	2.74698e-01
-48.57	-6.41712e-01	8.40952e-01	2.50874e-01
-44.43	-6.72490e-01	7.35147e-01	2.28658e-01
-40.29	-6.99972e-01	6.28520e-01	2.04720e-01
-36.14	-7.30010e-01	5.20522e-01	1.54255e-01
-32.00	-7.69103e-01	4.10406e-01	1.01084e-01
-28.00	-8.75716e-01	2.88911e-01	6.50930e-02
-24.00	-1.15188e+00	1.42228e-01	1.65013e-02
-20.00	-1.23426e+00	8.21662e-02	-3.52120e-03
-18.00	-1.23977e+00	6.48160e-02	-6.71789e-03
-16.00	-1.22543e+00	4.85261e-02	-8.55188e-03
-14.00	-1.17251e+00	3.42083e-02	-1.13167e-02
-12.00	-1.06263e+00	2.27743e-02	-2.23642e-02
-10.00	-8.84390e-01	1.48620e-02	-4.36120e-02
-8.00	-6.53320e-01	1.00110e-02	-5.77240e-02
-6.00	-3.91690e-01	7.48970e-03	-6.78130e-02
-4.00	-1.22310e-01	6.56330e-03	-7.61490e-02
-2.00	1.36740e-01	6.56570e-03	-8.28310e-02
-1.00	2.61700e-01	6.78270e-03	-8.56450e-02
0.00	3.84090e-01	7.08620e-03	-8.81680e-02
1.00	5.04260e-01	7.42810e-03	-9.04470e-02
2.00	6.22570e-01	7.77270e-03	-9.25280e-02
3.00	7.39400e-01	8.07600e-03	-9.44580e-02
4.00	8.55010e-01	8.29360e-03	-9.62810e-02
5.00	9.69910e-01	8.41290e-03	-9.80230e-02
6.00	1.08460e+00	8.54250e-03	-9.96120e-02
7.00	1.19990e+00	8.82130e-03	-1.00960e-01
8.00	1.31620e+00	9.38830e-03	-1.01960e-01
9.00	1.43320e+00	1.03820e-02	-1.02530e-01
10.00	1.54510e+00	1.19420e-02	-1.02580e-01
11.00	1.64535e+00	1.42075e-02	-1.02020e-01
12.00	1.72715e+00	1.73164e-02	-1.00747e-01
13.00	1.78403e+00	2.14634e-02	-9.87682e-02
14.00	1.81065e+00	2.70644e-02	-9.64604e-02
15.00	1.80515e+00	3.45905e-02	-9.43003e-02
16.00	1.77868e+00	4.45128e-02	-9.27905e-02
18.00	1.70285e+00	7.21959e-02	-9.30171e-02
20.00	1.61066e+00	1.07707e-01	-9.74317e-02
24.00	1.41629e+00	1.87579e-01	-1.17202e-01
28.00	1.25739e+00	2.77527e-01	-1.47726e-01
32.00	1.13943e+00	4.15268e-01	-1.80778e-01
36.14	1.05141e+00	5.21055e-01	-2.10055e-01
40.29	9.88907e-01	6.24656e-01	-2.35075e-01
44.43	9.42553e-01	7.32903e-01	-2.58284e-01
48.57	9.02989e-01	8.41390e-01	-2.80362e-01
52.71	8.60856e-01	9.47800e-01	-3.01538e-01
56.86	8.06788e-01	1.04986e+00	-3.22064e-01
61.00	7.33746e-01	1.14542e+00	-3.42108e-01
65.14	6.43959e-01	1.23283e+00	-3.61533e-01
69.29	5.41970e-01	1.31055e+00	-3.80125e-01
73.43	4.32334e-01	1.37707e+00	-3.97670e-01
77.57	3.19588e-01	1.43085e+00	-4.13955e-01
81.71	2.08281e-01	1.47037e+00	-4.28767e-01
85.86	1.02960e-01	1.49410e+00	-4.41892e-01
90.00	7.17347e-03	1.50093e+00	-4.53079e-01
94.14	-7.95277e-02	1.49145e+00	-4.61960e-01
98.29	-1.58636e-01	1.46663e+00	-4.68256e-01
102.43	-2.31561e-01	1.42749e+00	-4.71625e-01
106.57	-2.99775e-01	1.37501e+00	-4.71858e-01
110.71	-3.64732e-01	1.31018e+00	-4.69392e-01
114.86	-4.27887e-01	1.23401e+00	-4.64827e-01
119.00	-4.90695e-01	1.14749e+00	-4.58752e-01
123.14	-5.53624e-01	1.05184e+00	-4.51761e-01
127.29	-6.13190e-01	9.49270e-01	-4.44458e-01
131.43	-6.64929e-01	8.42188e-01	-4.37441e-01
135.57	-7.04354e-01	7.33020e-01	-4.31309e-01
139.71	-7.26977e-01	6.24228e-01	-4.26514e-01
143.86	-7.28146e-01	5.18247e-01	-4.22933e-01
148.00	-7.03182e-01	4.17510e-01	-4.20299e-01
150.29	-6.76844e-01	3.65028e-01	-4.15729e-01
152.57	-6.42294e-01	3.15092e-01	-3.98743e-01
154.86	-6.00700e-01	2.67909e-01	-3.82553e-01
157.14	-5.53229e-01	2.23686e-01	-3.64353e-01
159.43	-5.01049e-01	1.82632e-01	-3.48253e-01
161.71	-4.45328e-01	1.44954e-01	-3.70287e-01
164.00	-3.87254e-01	1.10861e-01	-4.06178e-01
166.29	-3.27911e-01	8.07761e-02	-4.41919e-01
168.57	-2.68478e-01	5.59838e-02	-4.77857e-01
170.86	-2.10022e-01	3.79538e-02	-4.56674e-01
173.14	-1.53632e-01	2.80319e-02	-3.43475e-01
175.43	-1.00400e-01	2.61957e-02	-2.28060e-01
177.71	-5.14192e-02	2.70810e-02	-1.14530e-01
180.00	-7.78041e-03	2.39866e-02	4.89948e-03

D Controller input parameters for the WINDMOOR 12 MW base case FWT

The input parameters for the ROSCO controller must be given the *DISCON.IN* file. The parameters used for the functionalities adopted in the WINDMOOR 12 MW base case FWT are provided below. Note that the input file has two more entries than the original ROSCO controller, for the power error feedback gains. Other functionalities available in the controller include floating feedback control; individual pitch control (IPC); effective wind speed (EWS) estimation; and an alternative strategy at below rated, based on tracking of optimal tip-speed ratio. These features have not been tuned for the WINDMOOR 12 MW turbine, so the corresponding values in the input file shall be assumed as dummy.

D.1 Controller flags

Parameter	Value	Description
F_LPFType	1	LP filter type for generator/pitch control signals, currently set as 1st-order.
F_NotchType	0	Switch for notch filter on rotor speed, currently not used.
IPC_ControlMode	0	Switch for individual pitch control (IPC), currently not used.
VS_ControlMode	1	Switch for generator torque control mode above rated, currently set as constant power.
PC_ControlMode	1	Switch for blade pitch torque control mode, currently set as active PI controller.
Y_ControlMode	0	Switch for yaw control mode, currently not active.
SS_Mode	0	Switch for setpoint smoother mode, currently not active.
WE_Mode	0	Switch for wind speed estimator mode, currently not used.
PS_Mode	1	Switch for pitch saturation mode, currently set as active.
SD_Mode	0	Switch for shutdown mode, not used.
Fl_Mode	0	Switch for floating specific feedback module, currently not used.
Flp_Mode	0	Flap control module, currently not used.

D.2 Filters

Parameter	Value	Description
F_LPFCornerFreq	1.2566	Corner frequency of the LP filter on generator/pitch control signals (Hz).
F_LPFDamping	0.0000	Damping coefficient for 2^{nd}-order filter), currently dummy (-).
F_NotchCornerFreq	0.0000	Natural frequency of the notch filter, currently dummy (rad/s).
F_NotchBetaNumDen	0.0000 0.2500	Notch filter numerator and denominator, currently dummy (-).
F_SSCornerFreq	0.6283	Corner frequency for the low pass filter for the setpoint smoother (rad/s).
F_FlCornerFreq	0.0000 1.0000	Natural frequency and damping for the 2^{nd}-order LP filter on nacelle velocity for floating feedback control, currently dummy (rad/s,-).
F_FlpCornerFreq	0.0000 1.0000	Natural frequency and damping for the 2^{nd}-order LP filter on blade root bending moment, currently dummy (rad/s,-).

D.3 Blade pitch control

The values for PC_GS_angles, PC_GS_KP, PC_GS_KI, PC_GS_KD, and PC_GS_TF are given in Table D.1.

Parameter	Value	Description
PC_GS_n	16	Amount of gain-scheduling table entries (-).
PC_GS_angles	<PC_GS_n entries>	Gain-schedule table: pitch angles (rad).
PC_GS_KP	<PC_GS_n entries>	Gain-schedule table: pitch controller Kp gains (s).
PC_GS_KI	<PC_GS_n entries>	Gain-schedule table: pitch controller Ki gains (-).

PC_GS_KD	<PC_GS_n entries>	Gain-schedule table: pitch controller derivative gains, not used.
PC_GS_TF	<PC_GS_n entries>	Gain-schedule table: pitch controller tf gains, not used.
PC_PC_Pow_KP	0.0000	Power error proportional gain (rad/W).
PC_PC_Pow_KI	9.0×10^{-9}	Power error integral gain (rad/(Ws)).
PC_MaxPit	1.5708	Maximum physical pitch limit (rad).
PC_MinPit	0.0000	Minimum physical pitch limit (rad).
PC_MaxRat	0.1745	Maximum pitch rate in pitch controller (rad/s).
PC_MinRat	-0.1745	Minimum pitch rate in pitch controller (rad/s).
PC_RefSpd	0.8168	Desired (reference) HSS speed for pitch controller (rad/s).
PC_FinePit	0.0000	Below-rated pitch angle set-point (rad).
PC_Switch	0.0541	Angle above lowest minimum pitch angle for switch (rad).

D.4 Individual pitch control

Individual pitch control is not used in the current version of the turbine, so all the parameters in this section are dummy.

IPC_IntSat	0.0	Integrator saturation, currently dummy (rad).
IPC_KI	0.0 0.0	Integral gains for the individual pitch controller, currently dummy (rad).
IPC_aziOffset	0.0 0.0	Phase offset added to the azimuth angle for the individual pitch controller, currently dummy (rad).
IPC_CornerFreqAct	0.0	Corner frequency of the first-order actuators model, to induce a phase lag in the IPC signal, currently dummy (rad/s).

D.5 VS torque control

VS_GenEff	94.4	Generator efficiency (%).
VS_ArSatTq	1.46×10^7	Above rated generator torque PI control saturation, currently dummy (Nm).
VS_MaxRat	3.25×10^6	Maximum torque rate (Nm/s).
VS_MaxTq	3.25×10^6	Maximum generator torque in Region 3 (Nm).
VS_MinTq	0.0	Minimum generator torque (Nm).
VS_MinOMSpd	0.574	Cut-in speed towards optimal mode gain path (rad/s).
VS_Rgn2K	1.48×10^7	Generator torque constant in Region 2 (Nm/(rad/s)^2).
VS_RtPwr	1.2711×10^7	Wind turbine rated power (W).
VS_RtTq	1.5562×10^7	Rated torque (Nm).
VS_RefSpd	0.8168	Rated generator speed (rad/s).
VS_n	1	Number of generator PI torque controller gains (-).
VS_KP	-5.25×10^7	Proportional gain for generator PI torque controller (s/rad Nm).
VS_KI	-4.80×10^6	Integral gain for generator PI torque controller (s/rad Nm).
VS_TSRopt	9.0	Region 2 power-maximizing tip-speed-ratio, dummy (-).

D.6 Setpoint smoother

SS_VSGain	1.0000	Variable speed torque controller setpoint smoother gain (-).
SS_PCGain	0.0010	Collective pitch controller setpoint smoother gain (-).

D.7 Wind speed estimator

The wind speed is currently only used for peak shaving. It is assumed that the LP-filtered wind speed measured at hub height is enough for this purpose, so all the parameters in this section are currently dummy.

WE_BladeRadius	108.45	Rotor radius (m).
WE_CP_n	1	Amount of parameters in the Cp array, currently not used (-).
WE_CP	0.0 0.0 0.0 0.0	Parameters that define the parameterized Cp(λ) function, currently not used.
WE_Gamma	0.0	Adaption gain of the wind speed estimator algorithm, currently not used (m/rad).
WE_GearboxRatio	1.0	Gearbox ratio (-).
WE_Jtot	3.33×10^8	Total rotor + generator inertia casted to LSS (kg m^2).
WE_RhoAir	1.225	Air density (kg/m^3).
PerFileName	”dummy.txt”	File containing rotor performance tables (Cp,Ct,Cq), currently not used.
PerfTableSize	104 48	Size of rotor performance tables, currently not used.
WE_FOPoles_N	42	Number of first-order system poles used in EKF.
WE_FOPoles_v	<WE_FOPoles_N entries>	Wind speeds corresponding to first-order system poles, currently dummy (m/s).
WE_FOPoles	<WE_FOPoles_N entries>	First order system poles, currently dummy.

D.8 Yaw control

SIMA has an independent nacelle yaw control implementation. In addition, yaw-by-IPC is not used. All the parameters in this section are thus dummy.

Y_ErrThresh	0.0	Yaw error threshold, dummy (rad^{2}s).

Y_IPC_IntSat	0.0	Integrator saturation (yaw-by-IPC), dummy (rad).
Y_IPC_n	1	Number of controller gains (yaw-by-IPC), dummy.
Y_IPC_KP	0.0	Yaw-by-IPC proportional controller gain Kp, dummy.
Y_IPC_KI	0.0	Yaw-by-IPC integral controller gain Ki, dummy.
Y_IPC_omegaLP	0.0	LP filter corner frequency for the yaw alignment error (yaw-by-IPC), dummy (rad/s).
Y_IPC_zetaLP	0.0	LP filter damping factor for the yaw alignment error (yaw-by-IPC), dummy (-).
Y_IPC_MErrSet	0.0	Yaw alignment error set point, dummy (rad).
Y_omegaLPFast	0.0	Corner frequency for fast low pass filter, dummy (Hz).
Y_omegaLPSlow	0.0	Corner frequency for slow low pass filter, dummy (Hz).
Y_Rate	0.0	Yaw rate, dummy (rad/s).

D.9 Tower fore-aft damping

This functionality is not used, so all the parameters in this section are dummy.

FA_KI	-1	Integral gain for the fore-aft tower damper controller (-1 = off).
FA_HPF_CornerFreq	0.0	Corner frequency (-3dB point) in the high-pass filter on the fore-aft acceleration signal, dummy (rad/s).
FA_IntSat	0.0	Integrator saturation (rad).

D.10 Minimum pitch saturation

The values for PS_WindSpeeds and PS_BldPitchMin are given in Table D.2.

PS_BldPitchMin_N	19	Number of values in minimum blade pitch lookup table.
PS_WindSpeeds	<PS_BldPitchMin_N entries>	Wind speeds corresponding to minimum blade pitch angles (m/s).
PS_BldPitchMin	<PS_BldPitchMin_N entries>	Minimum blade pitch angles (rad).

D.11 Shutdown

Wind turbine in SIMA is configured outside the controller interface. It is thus deactivated, so all the parameters in this section are dummy.

SD_MaxPit	1.5708	Maximum blade pitch angle to initiate shutdown, dummy (rad).
SD_CornerFreq	0.42	Cutoff Frequency for first order low-pass filter for blade pitch angle, dummy (rad/s).

D.12 Floating

Nacelle feedback has not been tuned, so the parameter is dummy. See Lenfest [17] for details on this functionality.

Fl_Kp	0.0	Nacelle velocity proportional feedback gain, currently not used (s).

D.13 Flap actuation

Flap control is not used, so all the parameters in this section are dummy.

Flp_Angle	0.0	Initial or steady state flap angle, dummy (rad).
Flp_Kp	0.0	Blade root bending moment proportional gain for flap control, dummy (s).
Flp_Ki	0.0	Flap displacement integral gain for flap control, dummy (s).
Flp_MaxPit	0.0	Maximum (and minimum) flap pitch angle, dummy (rad).

Table D.1: Blade pitch controller gain scheduling.

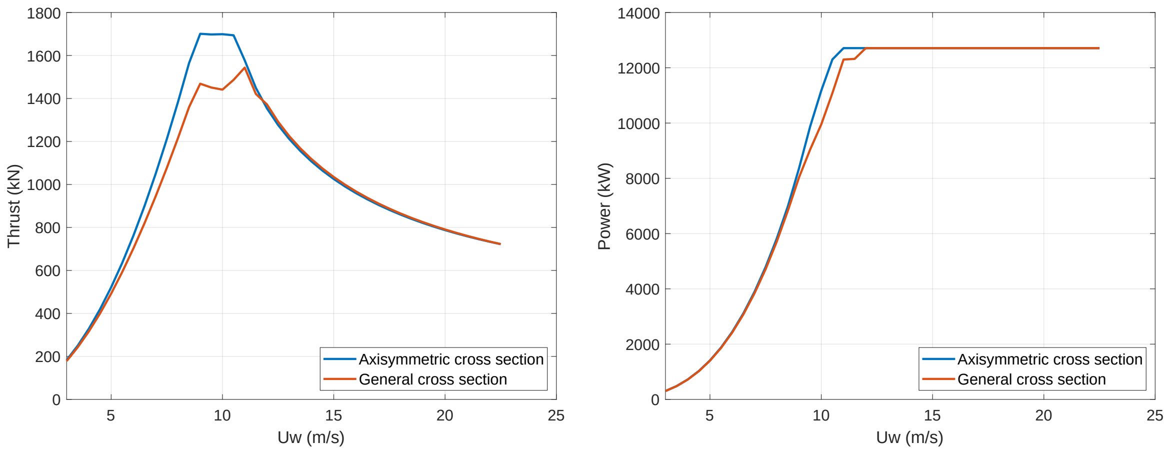
PC_GS_angles (rad)	PC_GS_KP (s)	PC_GS_KI (-)	PC_GS_KD (s^2)	PC_GS_TF
0.00524	-1.0825	-0.06802	0.00000	0.00000
0.05760	-0.8566	-0.05382	0.00000	0.00000
0.11694	-0.6779	-0.04260	0.00000	0.00000
0.15882	-0.5880	-0.03694	0.00000	0.00000
0.19199	-0.5267	-0.03310	0.00000	0.00000
0.22340	-0.4790	-0.03010	0.00000	0.00000
0.24958	-0.4415	-0.02774	0.00000	0.00000
0.27576	-0.4077	-0.02562	0.00000	0.00000
0.29845	-0.3818	-0.02399	0.00000	0.00000
0.32114	-0.3578	-0.02248	0.00000	0.00000
0.34383	-0.3367	-0.02116	0.00000	0.00000
0.36477	-0.3171	-0.01992	0.00000	0.00000
0.38397	-0.3008	-0.01890	0.00000	0.00000
0.40317	-0.2858	-0.01796	0.00000	0.00000
0.42237	-0.2711	-0.01703	0.00000	0.00000
0.44157	-0.2576	-0.01619	0.00000	0.00000

Table D.2: Relation between incoming hub wind speed and minimum blade pitch for peak shaving.

PS_WindSpeeds (m/s)	PS_BldPitchMin (deg)
8.8	0.0
8.9	0.1
9.0	0.3
9.1	0.4
9.2	0.6
9.3	0.7
9.4	0.9
9.5	1.0
9.6	1.2
9.7	1.3
9.8	1.4
9.9	1.6
10.0	1.7
10.1	1.9
10.2	2.1
10.3	2.3
10.4	2.7
10.5	3.0
10.6	3.0

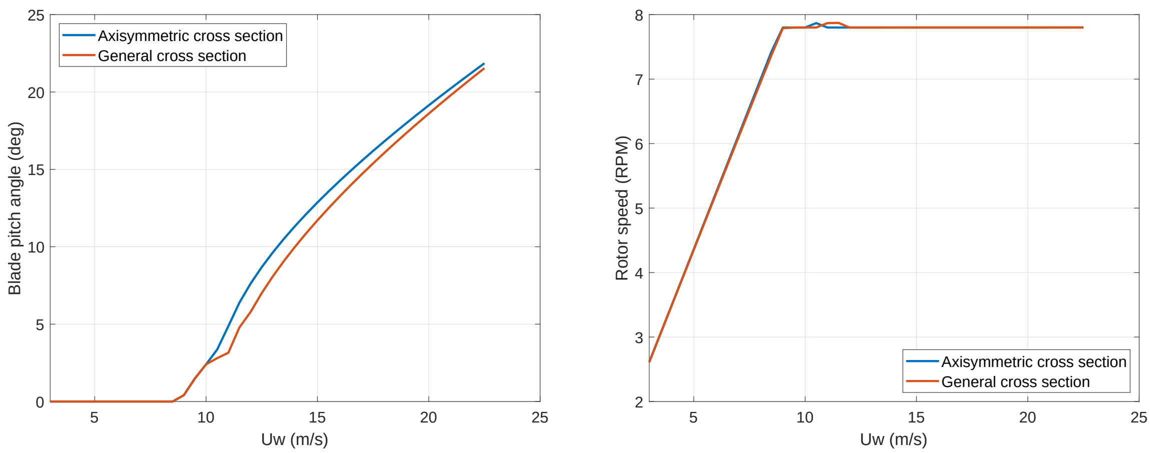
E WINDMOOR 12 MW turbine performance curve with general cross section

The performance curves shown in Appendix D is based on the axisymmetric cross section, i.e. that the area center, mass center and shear center is set to zero. The figures presented below are the comparison with the axisymmetric cross section and a general axis cross section with an offset of the mass center, area center and shear center. The blade pitch angle is reduced for the higher wind speeds when using the general axis cross section, see Figure E.2. Similar differences were also seen by Rinker et al [27] when comparing the IEA 15 MW using ElastoDyn and BeamDyn from OpenFAST.



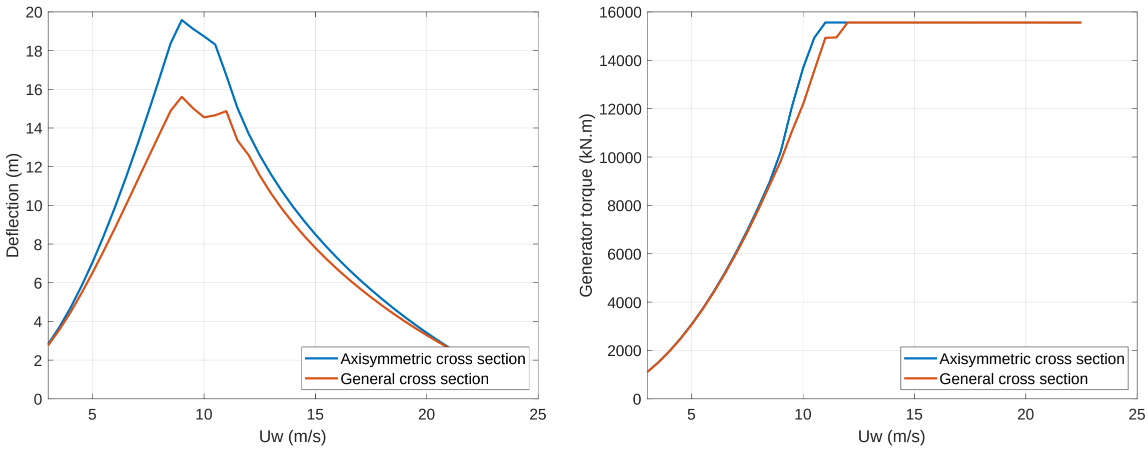
(a) Thrust. (b) Generator power.

Figure E.1: Thrust and generator power curves comparing the general cross section and axisymmetric cross section.



(a) Blade pitch. (b) Rotor speed.

Figure E.2: Blade pitch and rotor speed curves comparing the general cross section with the axisymmetric cross section.



(a) Blade tip deflection.

(b) Torque.

Figure E.3: Blade pitch and rotor speed curves comparing the general cross section with the axisymmetric cross section.

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