Aeolus

Comparison of Aerodynamic Simulations with Wind Tunnel Results for a Propeller

Technical Report CR-19-13

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Revisions

Revision	Date	Description
-	02 September 2019	Initial version

Contents

Symbols

Symbol	Description	Unit
C_T	Thrust coefficient	$[-]$
C_P	Performance coefficient	$[-]$
D	Propeller diameter	$[m]$
F_t	Propeller thrust	$[N]$
J	Advance rate	$[-]$
M_t	Propeller torque	$[Nm]$
n	Revolutions per second	$[s^{-1}]$
V_{tas}	True airspeed	$[m/s]$
η	Efficiency	$[-]$
ω	Angular velocity of the propeller	$[s^{-1}]$
ρ	Air density	$[kg/m^3]$

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1 Introduction

This report provides a comparison of the performance of a propeller as predicted through numermical simulations using *Aeolus ASP* and wind tunnel results from [1]. This comparison is done for the 2-blade propeller 4412 (Diameter 9ft), for which Fig.1.1 shows the blade geometry.
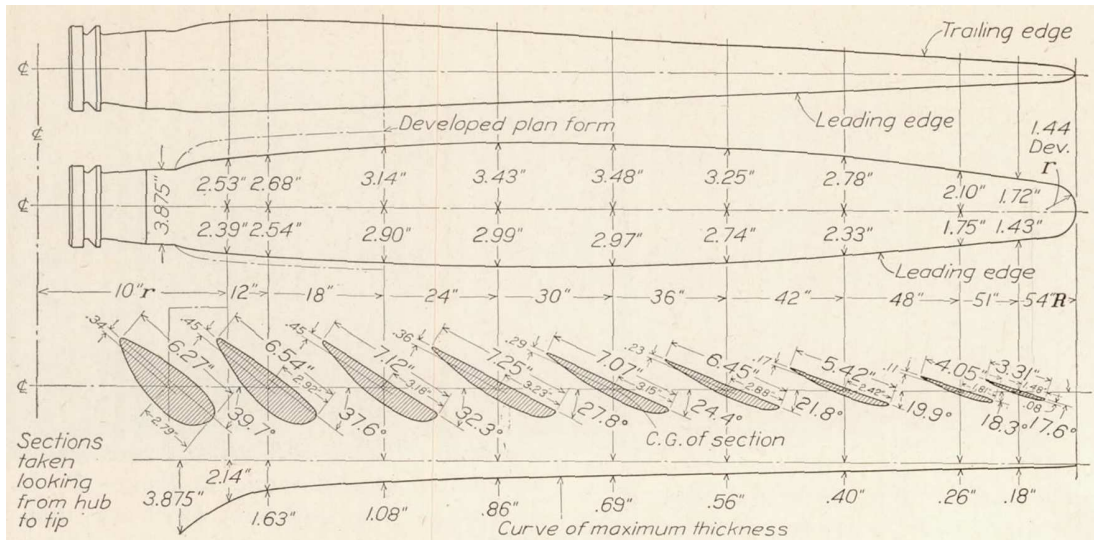

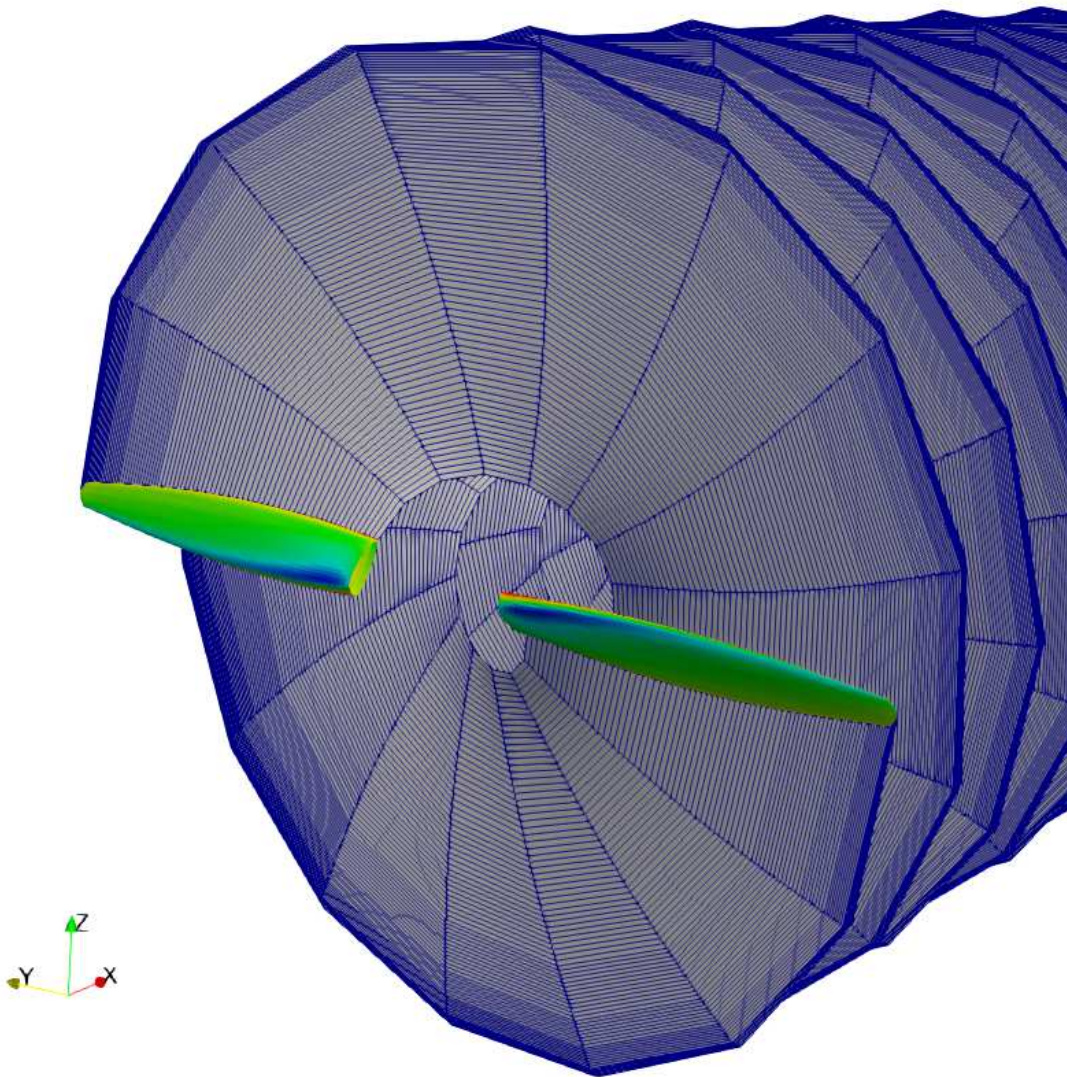*Figure 1.1:* Propeller blade geometry

2 Methodology

The flow solver *Aeolus ASP* is used for the numerical simulations. It is based on potential flow and has been developed to predict the aerodynamic performance of lifting bodies, such as fixed wings and propellers. The model is based on the 9 sections shown in fig.1.1 plus 2 sections at the tip to approximate the tip radius. Table 2.1 summarizes the geometric parameters of the 9+2 sections. Note, that the propeller blades for the wind tunnel test have been set to a blade angle of 15.5° at 75% of the blade radius. The blade angle of the reference blade shown in fig.1.1, interpolated at 75% radius, is 20.375°. That is, each blade has been mounted with an additional −4.875° pitch angle for the wind tunnel test.

The airfoil coordinates have been extracted from [1, Figure 1] and normalized. The coordinates can be found in Appendix A. Based on these normalized airfoils and the parameters from Table 2.1 the propeller blade can be modeled in *Aeolus ASP*. Figure 2.1 shows the propeller consisting of 2 blades which are shedding a wake from the respective trailing edge according to aircraft and propeller speed. The propeller rotates clockwise when looking in flight direction.

Table 2.1: Overview of blade sections

Section	Airfoil	Radial position [m]	Chord [m]	Blade angle [deg]
1	prop_NACA339_9ft_0185.dat	0.2540	0.1593	34.825
2	prop_NACA339_9ft_0222.dat	0.3048	0.1661	32.725
3	prop_NACA339_9ft_0333.dat	0.4572	0.1808	27.425
4	prop_NACA339_9ft_0444.dat	0.6096	0.1842	22.925
5	prop_NACA339_9ft_0556.dat	0.7620	0.1796	19.525
6	prop_NACA339_9ft_0667.dat	0.9144	0.1638	16.925
7	prop_NACA339_9ft_0778.dat	1.0668	0.1377	15.025
8	prop_NACA339_9ft_0889.dat	1.2192	0.1029	13.425
9	prop_NACA339_9ft_0944.dat	1.2954	0.0841	12.725
10	prop_NACA339_9ft_0944.dat	1.3520	0.0710	12.225
11	prop_NACA339_9ft_0944.dat	1.3716	0.0210	12.025

Figure 2.1: Propeller model in Aeolus ASP. The propeller has 2 blades.

3   Results

The results are expressed as coefficient of thrust, coefficient of input power, and efficiency.

$$C_T \quad = \frac{F_T}{\rho n^2 D^4} \tag{1}$$

$$C_P \quad = \frac{M_t \omega}{\rho n^3 D^5} \tag{2}$$

$$\eta \quad = \frac{F_T V_{tas}}{M_t \omega} \tag{3}$$

where V_{tas} is the true airspeed of the aircraft, n is the rotational frequency, and D is the propeller diameter. Figures 3.1,3.2, and 3.3 show the comparison of these parameters for different advance ratios

$$J = \frac{V_{tas}}{n \cdot D}. \tag{4}$$

The simulation results obtained with Aeolus ASP show a good agreement with the wind tunnel results. At low advance ratios ($J < 0.3$) the thrust is underestimated, as shown in Figure 3.2. For other operating conditions ($J > 3$) the error of thrust and performance is in the order of $\pm 5\%$.

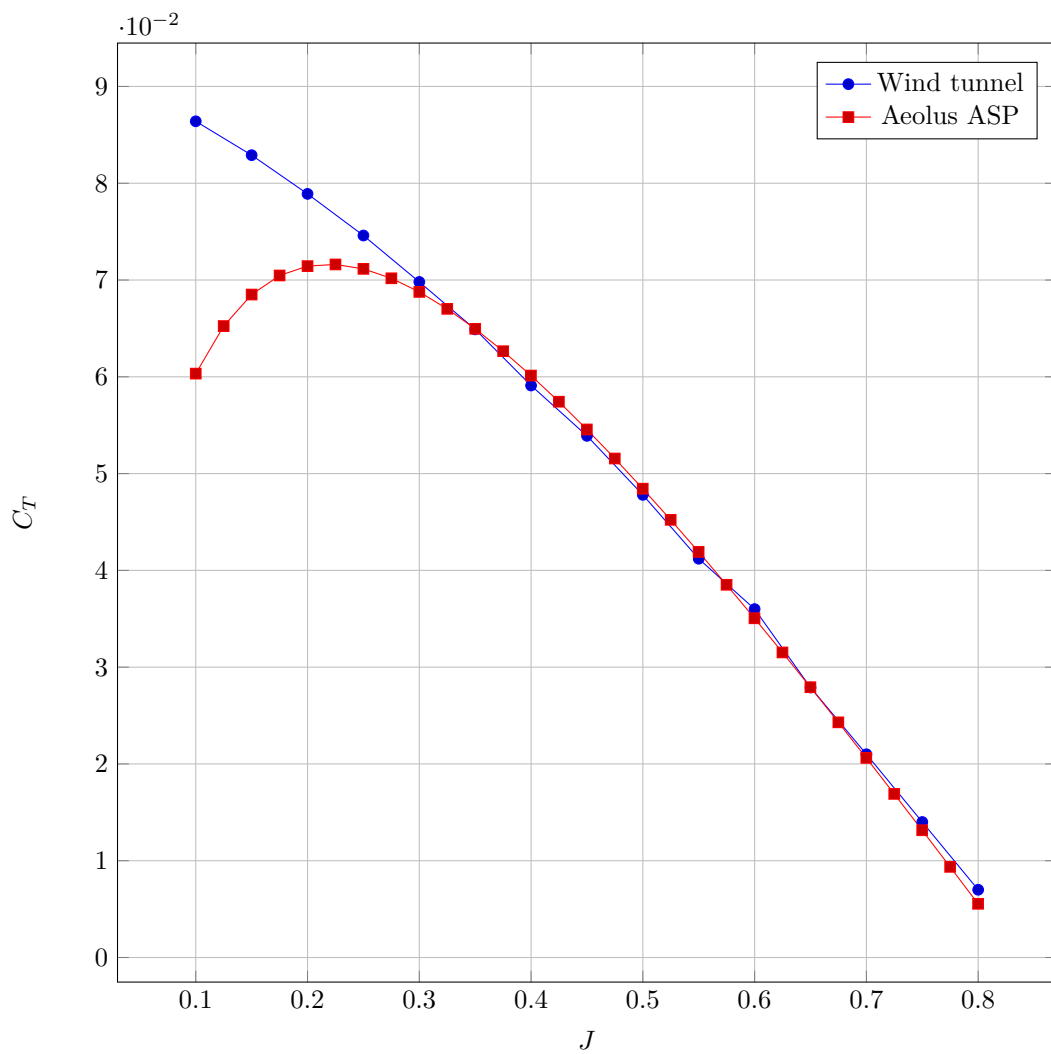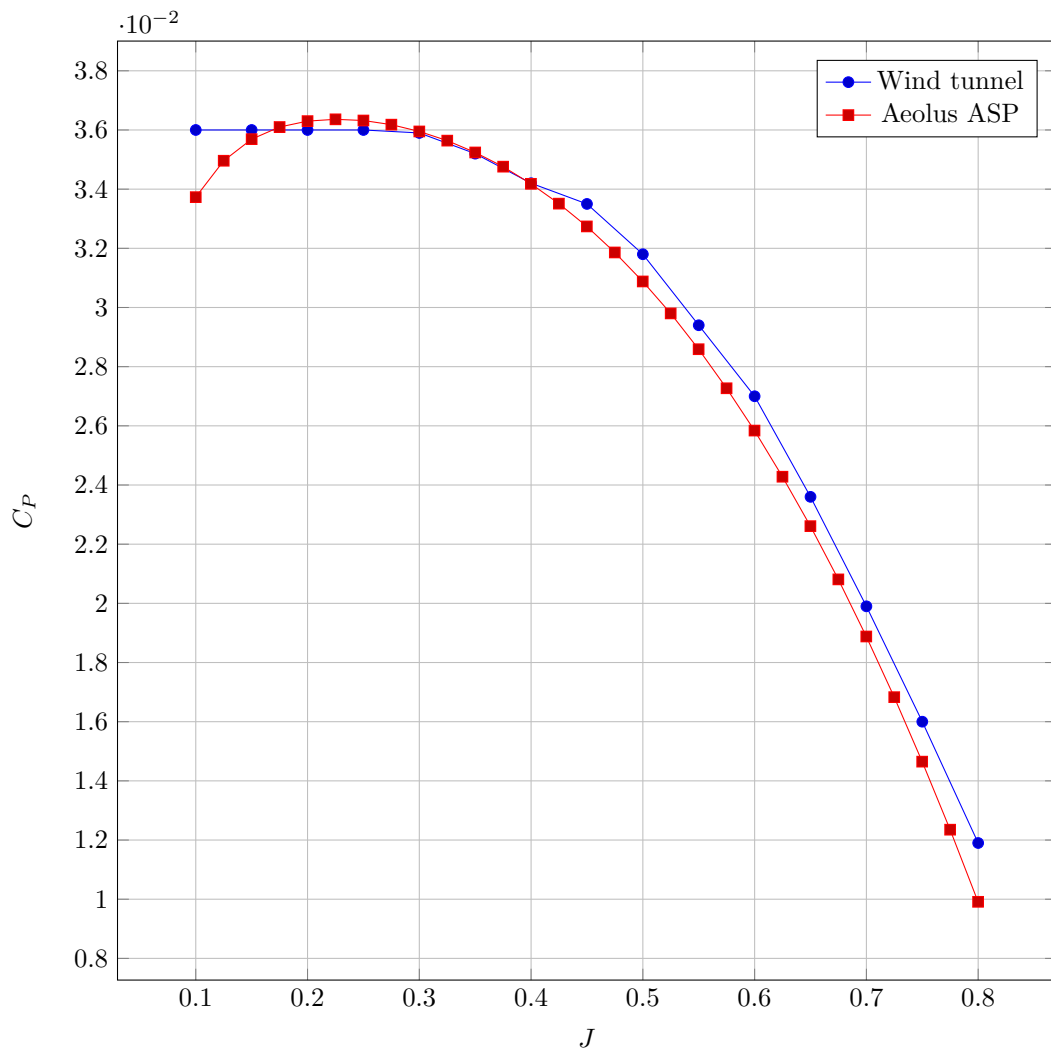*Figure 3.1:* Comparison of thrust coefficient C_T

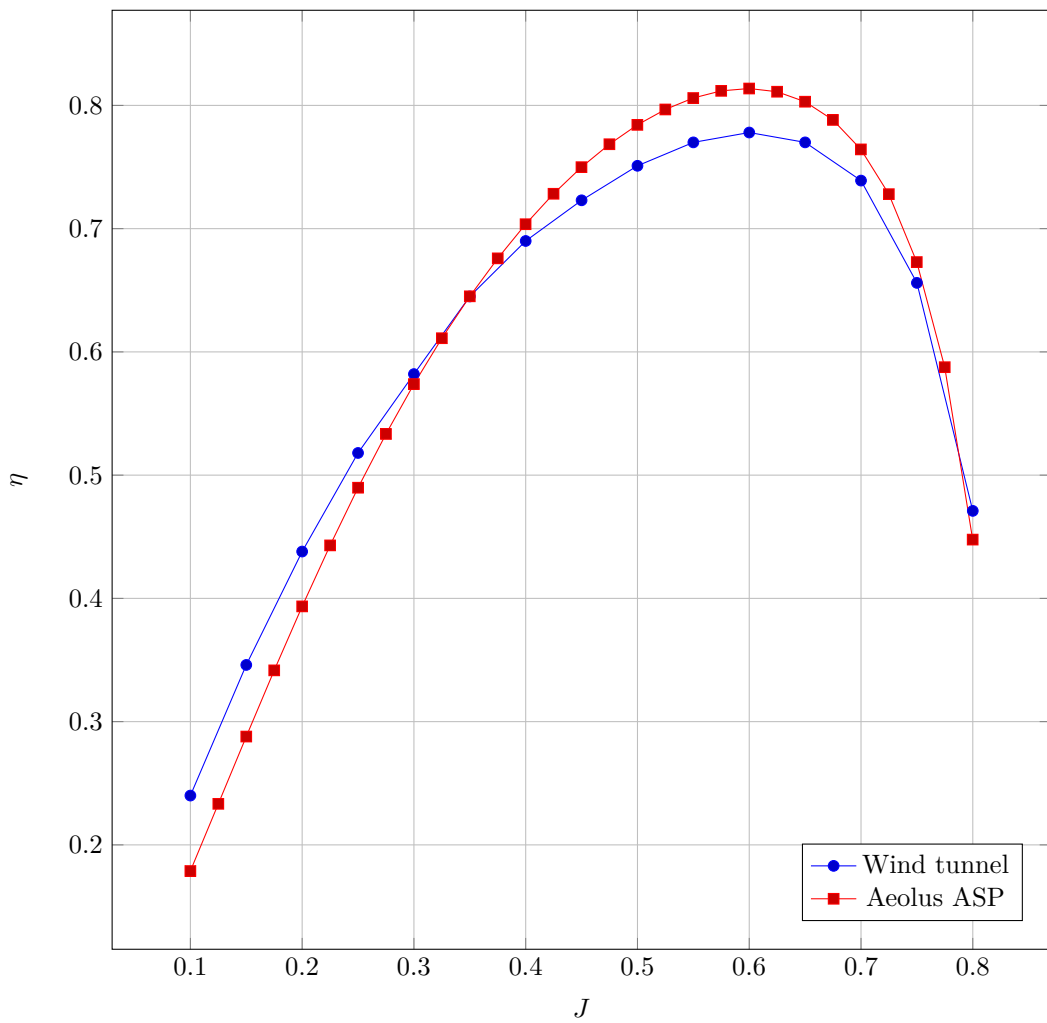*Figure 3.2:* Comparison of performance coefficient C_P

Figure 3.3: Comparison of efficiency η

References

[1] WEICK, Fred E.: *Full Scale Wind Tunnel Tests with a Series of Propellers of Different Diameters on a Single Fuselage.* National Advisory Committee for Aeronautics, 1930

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Appendix A Airfoil coordinates

prop_NACA339_9ft_0185.dat

```
1   0        0
2   0.025    -0.03987
3   0.05     -0.0622
4   0.1      -0.08293
5   0.2      -0.10048
6   0.3      -0.10526
7   0.4      -0.10367
8   0.5      -0.10048
9   0.6      -0.09091
10  0.7      -0.07815
11  0.8      -0.05901
12  0.9      -0.03668
13  1        0
14  0        0
15  0.025    0.097289
16  0.05     0.138756
17  0.1      0.186603
18  0.2      0.22488
19  0.3      0.236045
20  0.4      0.23445
21  0.5      0.22488
22  0.6      0.205742
23  0.7      0.175439
24  0.8      0.132376
25  0.9      0.082935
26  1        0
```

prop_NACA339_9ft_0222.dat

```
1   0        0
2   0.025    -0.01682
3   0.05     -0.02446
4   0.1      -0.03211
5   0.2      -0.03976
6   0.3      -0.04128
7   0.4      -0.04128
8   0.5      -0.03976
9   0.6      -0.0367
10  0.7      -0.03058
11  0.8      -0.02294
12  0.9      -0.01376
13  1        0
14  0        0
15  0.025    0.085627
16  0.05     0.122324
17  0.1      0.163609
18  0.2      0.197248
19  0.3      0.207951
20  0.4      0.206422
21  0.5      0.197248
22  0.6      0.180428
23  0.7      0.154434
24  0.8      0.116208
25  0.9      0.073394
26  1        0
```

prop_NACA339_9ft_0333.dat

```
1   0        0
2   0.025    0
3   0.05     0
4   0.1      0
5   0.2      0
6   0.3      0
7   0.4      0
8   0.5      0
9   0.6      0
10  0.7      0
11  0.8      0
12  0.9      0
13  1        0
14  0        0
15  0.025    0.061798
16  0.05     0.089888
17  0.1      0.119382
18  0.2      0.144663
```

```
19   0.3       0.151685
20   0.4       0.150281
21   0.5       0.144663
22   0.6       0.132022
23   0.7       0.11236
24   0.8       0.085674
25   0.9       0.053371
26   1         0
```

prop_NACA339_9ft_0444.dat

```
1    0         0
2    0.025     0
3    0.05      0
4    0.1       0
5    0.2       0
6    0.3       0
7    0.4       0
8    0.5       0
9    0.6       0
10   0.7       0
11   0.8       0
12   0.9       0
13   1         0
14   0         0
15   0.025     0.048276
16   0.05      0.070345
17   0.1       0.093793
18   0.2       0.113103
19   0.3       0.118621
20   0.4       0.117241
21   0.5       0.113103
22   0.6       0.103448
23   0.7       0.088276
24   0.8       0.066207
25   0.9       0.041379
26   1         0
```

prop_NACA339_9ft_0556.dat

```
1    0         0
2    0.025     0
3    0.05      0
4    0.1       0
5    0.2       0
6    0.3       0
7    0.4       0
8    0.5       0
9    0.6       0
10   0.7       0
11   0.8       0
12   0.9       0
13   1         0
14   0         0
15   0.025     0.039604
16   0.05      0.057992
17   0.1       0.077793
18   0.2       0.093352
19   0.3       0.097595
20   0.4       0.096181
21   0.5       0.093352
22   0.6       0.084866
23   0.7       0.072136
24   0.8       0.055163
25   0.9       0.033946
26   1         0
```

prop_NACA339_9ft_0667.dat

```
1    0         0
2    0.025     0
3    0.05      0
4    0.1       0
5    0.2       0
6    0.3       0
7    0.4       0
8    0.5       0
9    0.6       0
10   0.7       0
11   0.8       0
```

```
12   0.9      0
13   1        0
14   0        0
15   0.025    0.035659
16   0.05     0.051163
17   0.1      0.068217
18   0.2      0.082171
19   0.3      0.086822
20   0.4      0.086822
21   0.5      0.082171
22   0.6      0.075969
23   0.7      0.065116
24   0.8      0.048062
25   0.9      0.031008
26   1        0
```

prop_NACA339_9ft_0778.dat

```
1    0        0
2    0.025    0
3    0.05     0
4    0.1      0
5    0.2      0
6    0.3      0
7    0.4      0
8    0.5      0
9    0.6      0
10   0.7      0
11   0.8      0
12   0.9      0
13   1        0
14   0        0
15   0.025    0.02952
16   0.05     0.04428
17   0.1      0.059041
18   0.2      0.070111
19   0.3      0.073801
20   0.4      0.073801
21   0.5      0.070111
22   0.6      0.064576
23   0.7      0.055351
24   0.8      0.04059
25   0.9      0.02583
26   1        0
```

prop_NACA339_9ft_0889.dat

```
1    0        0
2    0.025    0
3    0.05     0
4    0.1      0
5    0.2      0
6    0.3      0
7    0.4      0
8    0.5      0
9    0.6      0
10   0.7      0
11   0.8      0
12   0.9      0
13   1        0
14   0        0
15   0.025    0.02716
16   0.05     0.037037
17   0.1      0.051852
18   0.2      0.061728
19   0.3      0.064198
20   0.4      0.064198
21   0.5      0.061728
22   0.6      0.05679
23   0.7      0.046914
24   0.8      0.037037
25   0.9      0.022222
26   1        0
```

prop_NACA339_9ft_0944.dat

```
1    0        0
2    0.025    0
3    0.05     0
4    0.1      0
```

```
 5  | 0.2    0
 6  | 0.3    0
 7  | 0.4    0
 8  | 0.5    0
 9  | 0.6    0
10  | 0.7    0
11  | 0.8    0
12  | 0.9    0
13  | 1      0
14  | 0      0
15  | 0.025  0.021148
16  | 0.05   0.033233
17  | 0.1    0.042296
18  | 0.2    0.05136
19  | 0.3    0.054381
20  | 0.4    0.054381
21  | 0.5    0.05136
22  | 0.6    0.048338
23  | 0.7    0.039275
24  | 0.8    0.030211
25  | 0.9    0.018127
26  | 1      0
```