Comparison of Aerodynamic Simulations with Wind Tunnel Results for a Propeller

Technical Report CR-19-13

Uwe Schuster

June 2, 2021

Revisions

Revision	Date	Description
-	02 September 2019	Initial version
A	02 June 2021	Updated results for improved wake model (Kernel V4.2.20210602 first in Aeolus ASP 4.15)

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	$[kg/m^3]$

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.

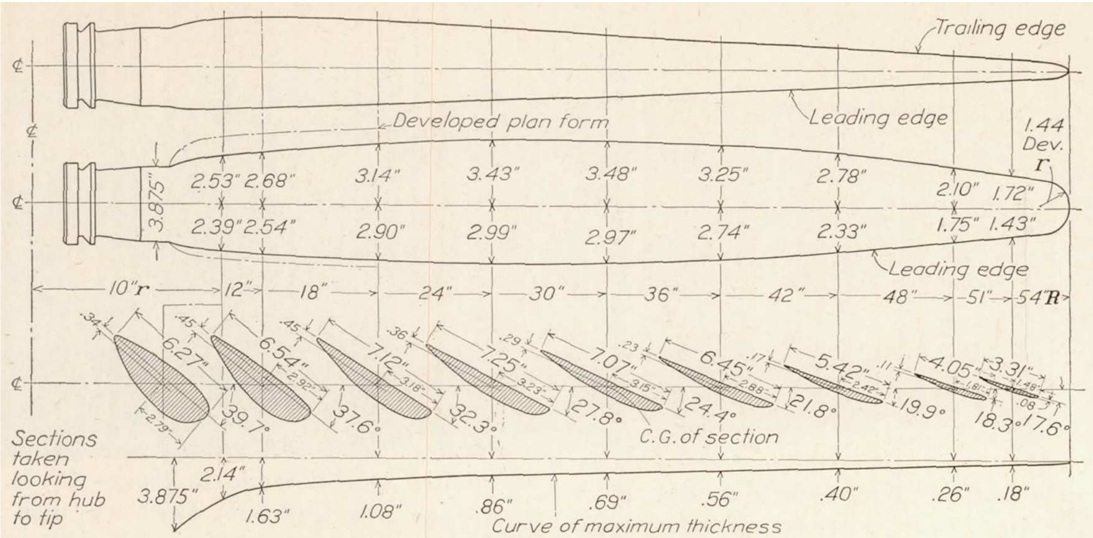

Figure 1.1: Propeller blade geometry

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

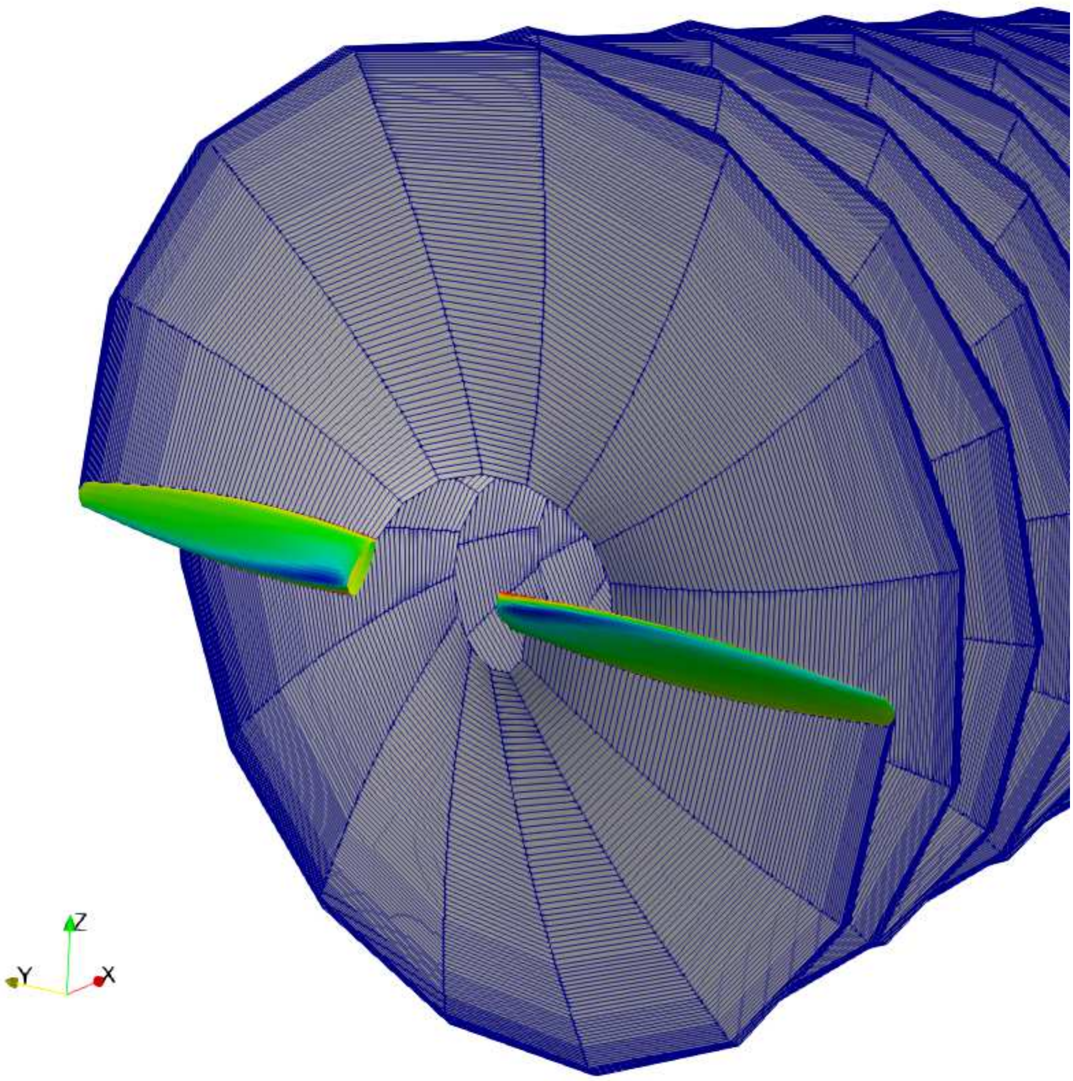

Figure 2.1: Propeller model in Aeolus ASP. The propeller has 2 blades.

3 Results

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

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

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

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

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: The error is less than $\pm 5\%$ for $0.1 \leq J \leq 0.7$ on thrust, input power, and efficiency.

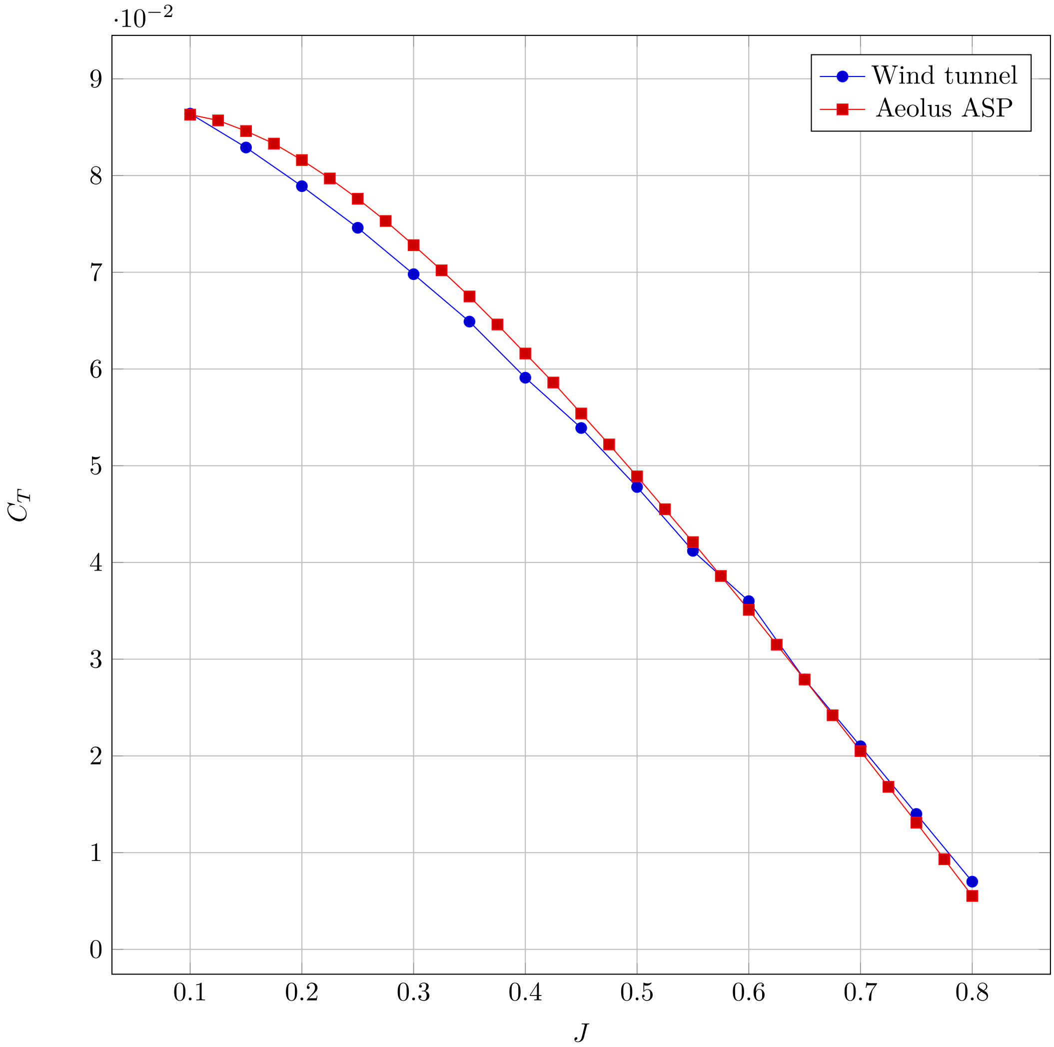

Figure 3.1: Comparison of thrust coefficient C_T

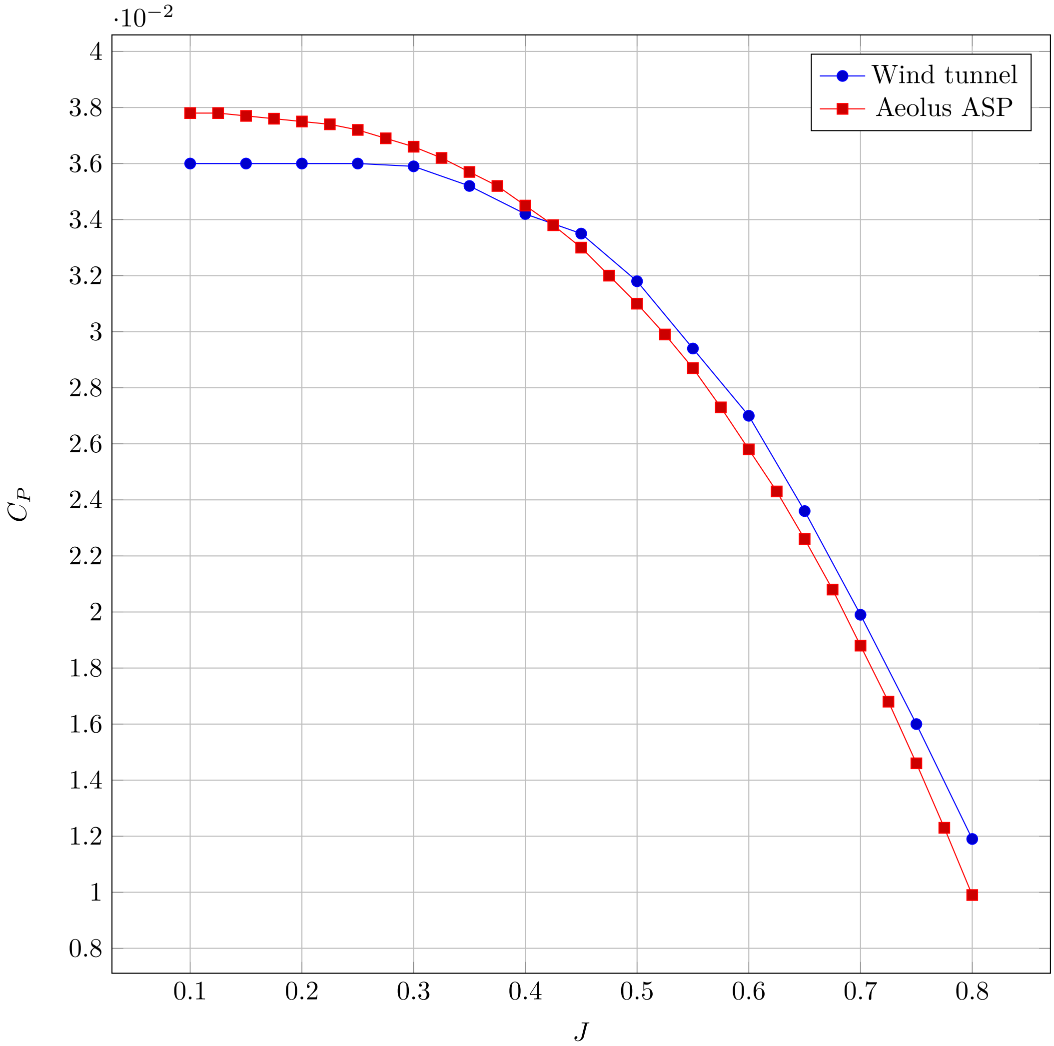

Figure 3.2: Comparison of performance coefficient C_P

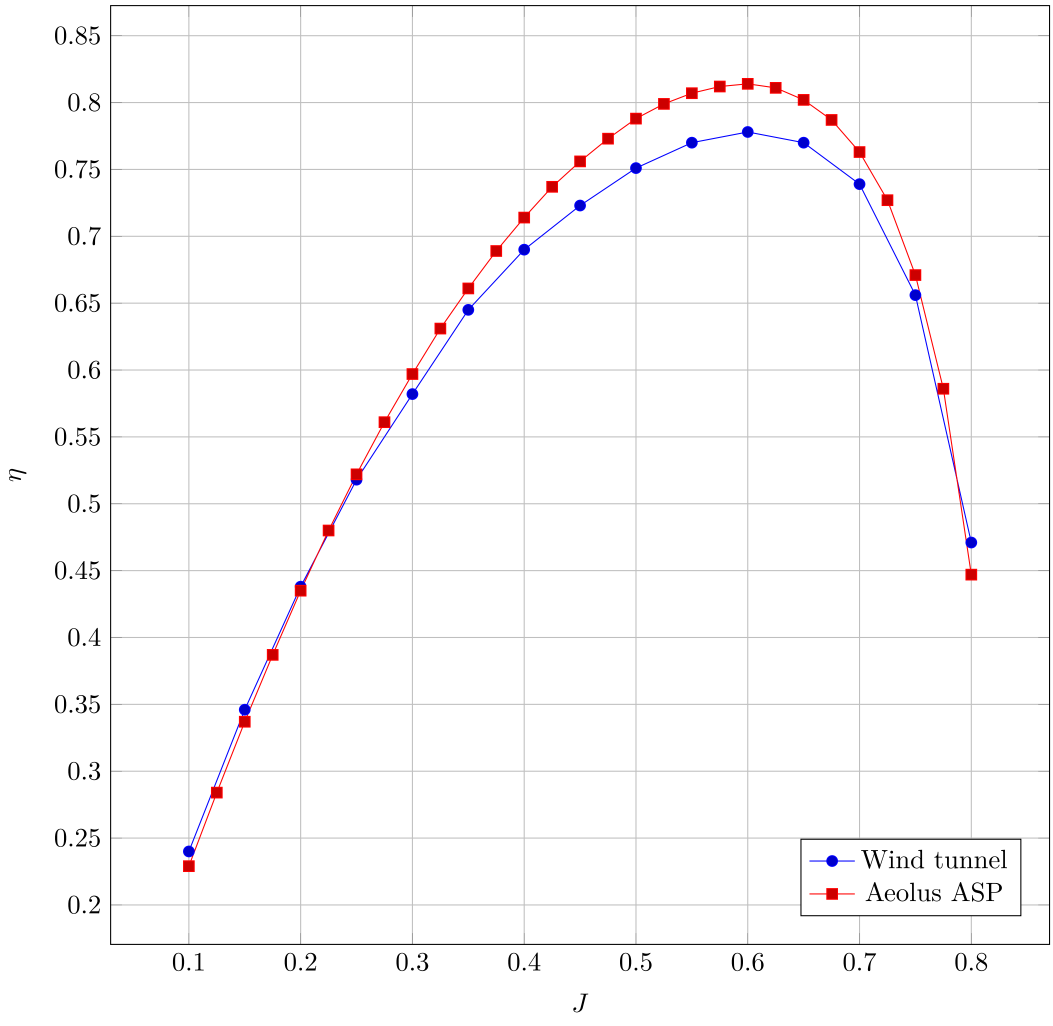

Figure 3.3: Comparison of efficiency η

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

List of Figures

List of Tables

Appendix A Airfoil coordinates

prop_NACA339_9ft_0185.dat

```
0       0
0.025   -0.03987
0.05    -0.0622
0.1     -0.08293
0.2     -0.10048
0.3     -0.10526
0.4     -0.10367
0.5     -0.10048
0.6     -0.09091
0.7     -0.07815
0.8     -0.05901
0.9     -0.03668
1       0
0       0
0.025   0.097289
0.05    0.138756
0.1     0.186603
0.2     0.22488
0.3     0.236045
0.4     0.23445
0.5     0.22488
0.6     0.205742
0.7     0.175439
0.8     0.132376
0.9     0.082935
1       0
```

prop_NACA339_9ft_0222.dat

```
0       0
0.025   -0.01682
0.05    -0.02446
0.1     -0.03211
0.2     -0.03976
0.3     -0.04128
0.4     -0.04128
0.5     -0.03976
0.6     -0.0367
0.7     -0.03058
0.8     -0.02294
0.9     -0.01376
1       0
0       0
0.025   0.085627
0.05    0.122324
0.1     0.163609
0.2     0.197248
0.3     0.207951
0.4     0.206422
0.5     0.197248
0.6     0.180428
0.7     0.154434
0.8     0.116208
0.9     0.073394
1       0
```

prop_NACA339_9ft_0333.dat

```
0       0
0.025   0
0.05    0
0.1     0
0.2     0
0.3     0
0.4     0
0.5     0
0.6     0
0.7     0
0.8     0
0.9     0
1       0
0       0
0.025   0.061798
0.05    0.089888
0.1     0.119382
0.2     0.144663
```

```
0.3      0.151685
0.4      0.150281
0.5      0.144663
0.6      0.132022
0.7      0.11236
0.8      0.085674
0.9      0.053371
1        0
```

prop_NACA339_9ft_0444.dat

```
0        0
0.025    0
0.05     0
0.1      0
0.2      0
0.3      0
0.4      0
0.5      0
0.6      0
0.7      0
0.8      0
0.9      0
1        0
0        0
0.025    0.048276
0.05     0.070345
0.1      0.093793
0.2      0.113103
0.3      0.118621
0.4      0.117241
0.5      0.113103
0.6      0.103448
0.7      0.088276
0.8      0.066207
0.9      0.041379
1        0
```

prop_NACA339_9ft_0556.dat

```
0        0
0.025    0
0.05     0
0.1      0
0.2      0
0.3      0
0.4      0
0.5      0
0.6      0
0.7      0
0.8      0
0.9      0
1        0
0        0
0.025    0.039604
0.05     0.057992
0.1      0.077793
0.2      0.093352
0.3      0.097595
0.4      0.096181
0.5      0.093352
0.6      0.084866
0.7      0.072136
0.8      0.055163
0.9      0.033946
1        0
```

prop_NACA339_9ft_0667.dat

```
0        0
0.025    0
0.05     0
0.1      0
0.2      0
0.3      0
0.4      0
0.5      0
0.6      0
0.7      0
0.8      0
```

```
0.9     0
1       0
0       0
0.025   0.035659
0.05    0.051163
0.1     0.068217
0.2     0.082171
0.3     0.086822
0.4     0.086822
0.5     0.082171
0.6     0.075969
0.7     0.065116
0.8     0.048062
0.9     0.031008
1       0
```

prop_NACA339_9ft_0778.dat

```
0       0
0.025   0
0.05    0
0.1     0
0.2     0
0.3     0
0.4     0
0.5     0
0.6     0
0.7     0
0.8     0
0.9     0
1       0
0       0
0.025   0.02952
0.05    0.04428
0.1     0.059041
0.2     0.070111
0.3     0.073801
0.4     0.073801
0.5     0.070111
0.6     0.064576
0.7     0.055351
0.8     0.04059
0.9     0.02583
1       0
```

prop_NACA339_9ft_0889.dat

```
0       0
0.025   0
0.05    0
0.1     0
0.2     0
0.3     0
0.4     0
0.5     0
0.6     0
0.7     0
0.8     0
0.9     0
1       0
0       0
0.025   0.02716
0.05    0.037037
0.1     0.051852
0.2     0.061728
0.3     0.064198
0.4     0.064198
0.5     0.061728
0.6     0.05679
0.7     0.046914
0.8     0.037037
0.9     0.022222
1       0
```

prop_NACA339_9ft_0944.dat

```
0       0
0.025   0
0.05    0
0.1     0
```

```
0.2     0
0.3     0
0.4     0
0.5     0
0.6     0
0.7     0
0.8     0
0.9     0
1       0
0       0
0.025   0.021148
0.05    0.033233
0.1     0.042296
0.2     0.05136
0.3     0.054381
0.4     0.054381
0.5     0.05136
0.6     0.048338
0.7     0.039275
0.8     0.030211
0.9     0.018127
1       0
```