Propulsion Aerodynamics and Power Estimation for a Mad Rock Marine Solution Hydro Craft Using a Hoverhawk Warp Drive Propfan-No Nozzle Case

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TITLE

PROPULSION AERODYNAMICS AND POWER ESTIMATION FOR A MAD ROCK MARINE SOLUTION HYDRO CRAFT USING A HOVERHAWK WARP DRIVE PROPFAN-NO NOZZLE CASE

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SUMMARY

Propulsion aerodynamics and power estimation for a Mad Rock Marine Solution hydro craft (or airboat), using a Hoverhawk Warp Drive propfan, were performed. With a given on–the-shelf controllable pitch propeller blade of the Warp Drive Propfan, measurement of geometry data was obtained, along with the airboat resistance data. In the current work, based on the available data, a series of virtual full-scale propellers was designed and built. These virtual full-scale propellers were then tested under “open water” (open air) condition in a virtual wind tunnel, simulated by the in-house propeller software package, PROPELLA. A series of thrust coefficients KT and power coefficients KP were then obtained after a number of computational runs. These obtained coefficients from the virtual wind tunnel, as the basis, or the fundamental design charts, were then used for the design and optimization of the propulsion system of the airboat. Different from the traditional design methods that use Bp-δ diagram or charts etc., a computer-aided design method was developed. This CAD method utilizes the advantage of spreadsheet software for generation of trend-line equations and then for interpolations for optimization. The design optimization was performed in terms of efficiency (minimum required power for the given airboat speed) for 4, 6 and 8 propfan blades. Mach number correction was included. The blade root chord section’s spindle torque, in-plane and out-of-plane bending moments were also predicted by the virtual wind tunnel/cavitation tunnel, PROPELLA and a strength analysis of the blade root section was then performed based on the magnitudes of the moments, moment inertias of the section and the carbon-fiber material of the blade. Suggestions on the configuration and geometry of the propulsion system were made based on the above analysis.

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ABSTRACT

Propulsion aerodynamics and power estimation for a Mad Rock Marine Solution hydro craft (or airboat), using a Hoverhawk Warp Drive propfan, were performed. With a given on–the-shelf controllable pitch propeller blade of the Warp Drive Propfan, measurement of geometry data was obtained, along with the airboat resistance data. In the current work, based on the available data, a series of virtual full-scale propellers was designed and built. These virtual full-scale propellers were then tested under “open water” (open air) condition in a virtual wind tunnel, simulated by the in-house propeller software package, PROPELLA. A series of thrust coefficients K_T and power coefficients K_P were then obtained after a number of computational runs. These obtained coefficients from the virtual wind tunnel, as the basis, or the fundamental design charts, were then used for the design and optimization of the propulsion system of the airboat. Different from the traditional design methods that use Bp-δ diagram or charts etc., a computer-aided design method was developed. This CAD method utilizes the advantage of spreadsheet software for generation of trend-line equations and then for interpolations for optimization. The design optimization was performed in terms of efficiency (minimum required power for the given airboat speed) for 4, 6 and 8 propfan blades. Mach number correction was included. The blade root chord section’s spindle torque, in-plane and out-of-plane bending moments were also predicted by the virtual wind tunnel/cavitation tunnel, PROPELLA and a strength analysis of the blade root section was then performed based on the magnitudes of the moments, moment inertias of the section and the carbon-fiber material of the blade. Suggestions on the configuration and geometry of the propulsion system were made based on the above analysis.

1 INTRODUCTION

The task of this work is to estimate the required engine power and configuration of the propeller, in terms of number of blades and pitch angle setting, with the following given information:

1. As per the rough estimate made by the propeller vendor, Hoverhawk via Mad Rock Marine Solutions, the hydro craft should need two propellers. The hydro craft is about 3-m wide so the maximum diameter of the propeller is restricted at 58”. Therefore, the maximum allowable diameter of the propeller is 58” = 1.4732 meters.
2. The propeller blade is a Warp Drive propeller blade manufactured by Hoverhawk (see the scanned image obtained by IOT Design and Fabrication, shown in figure 1). The blade was given as is, that is, there was description for neither the geometry nor the propulsive performance prediction/measurement of the propeller.
3. The engine shaft rotational speed, according to Mad Rock Marine Solutions, is 3800 RPM = 63.3333 rps.

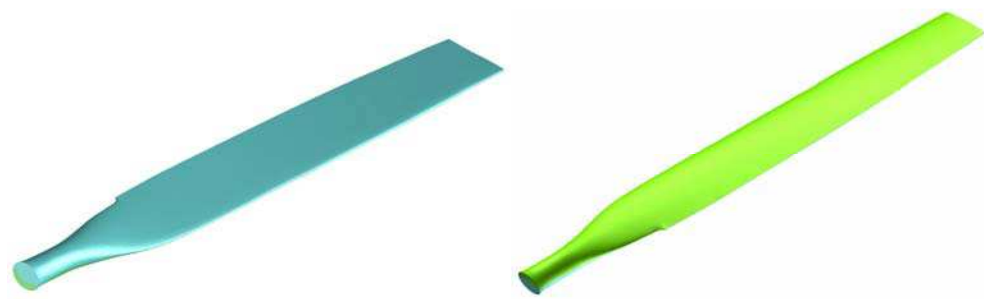

Figure 1. The scanned image of the Hoverhawk Warp Drive propeller blade produced by IOT Design and Fabrication. Left: face-up view (suction side up) and right: back-up view (pressure side up).

This was not a normal propeller design task. The design and optimization were to be performed with no given design charts/Kt-Kq curves or detailed geometry information of the propeller blade. The following tasks needed to be completed:

1. Measure the corresponding pitch angle and its distribution for the given blade at the marker point. This was performed by IOT Design and Fabrication.
2. Measure all other necessary geometry information of the propeller blade. This was performed by IOT Design and Fabrication as well.
3. Make up a set of virtual full-scale propellers based on the given propeller blades with different pitch settings and number of blades.
4. Test these virtual propellers in the virtual cavitation/wind tunnel, the in-house code PROPELLA to establish a database of propulsive performance.

5. Use the performance database along with the design criteria and navigation information to design and optimize the propeller for the particular application.

2 METHODS AND SOLUTIONS

2.1 Obtain the geometry information of the blade for PROPELLA input

The most important geometry information to the propulsive performance of the propeller is the propeller sectional pitch value and its distribution along the radial direction, and the sectional offsets of the blade sections. Measurement and image scan were performed by IOT Design and Fabrication.

The blade sectional offsets were obtained by Design and Fabrication of IOT. As the blade sectional offsets were measured based Base-line of the blade section (section bottom is treated as the abscissa, or the *x*-axis, the horizontal axis), the blade sections need to be rotated about an angle to convert the base-line section to nose-tail based, that is, to make the nose-tail line to be aligned with the horizontal axis. This is the requirement of PROPELLA input, which complies with the *NACA* format for aerofoil sectional offsets. The *NACA* format has typically offset values in terms of % local chord length, and the local chord stations are expressed as % of the local chord length.

Altogether 4 sectional offsets were measured and given by IOT Design and Fabrication. In base-line to nose-tail conversion, coordinate rotation formula is used, that is:

$$x = x\cos(\alpha) + z\sin(\alpha),$$
$$z = z\cos(\alpha) - x\sin(\alpha). \qquad (1)$$

Tables 1, 2 and 3 show the original measurement, rotation of the section and *NACA* format data, for the first section (*r=11”, r/R=0.37931*).

Table 1. Original measured data with some necessary smooth

X (%)	X (value)	Z (upper)	Z (lower)
0	0	0.126	0.126
0.625	0.021888	0.166	0.0887
1.25	0.043775	0.206	0.0767
2.5	0.08755	0.2433	0.0616
5	0.1751	0.2941	0.0415
10	0.3502	0.3633	0.0186
20	0.7004	0.4435	0.0031
30	1.0506	0.4752	0
35.6	1.2479	0.4797	0
40	1.4008	0.4774	0.0016
50	1.751	0.4573	0.0069
60	2.1012	0.4199	0.0161
70	2.4514	0.3684	0.0301

80	2.8016	0.3063	0.0509
90	3.1518	0.2377	0.0798
99.1	3.4703	0.1731	0.1097
99.3	3.4765	0.1718	0.1105
100	3.502	0.1411	0.1411

Table 2. Rotation for Base-line to Nose-tail conversion

BL to NT angle	Rad	Deg	
angle=	0.00431180	0.24704766	
x_int_up	z_int_up	x_int_lo	z_int_lo
0.00054328	0.12599883	0.00054328	0.12599883
0.02260305	0.16590408	0.02226975	0.08860480
0.04466282	0.20580934	0.04410531	0.07651054
0.08859824	0.24292024	0.08781479	0.06122193
0.17636647	0.29334227	0.17527731	0.04074462
0.35176321	0.36178664	0.35027694	0.01708984
0.70230576	0.44047591	0.70040686	0.00008000
1.05263919	0.47066562	1.05059023	-0.00452996
1.24995676	0.47431487	1.24788840	-0.00538067
1.40284542	0.47135562	1.40079388	-0.00443996
1.75295550	0.44974582	1.75101347	-0.00064999
2.10299098	0.41083618	2.10124989	0.00703993
2.45296567	0.35782667	2.45150700	0.01952982
2.80289466	0.29421726	2.80179343	0.03881964
3.15279561	0.22410792	3.15211478	0.06620938
3.47101411	0.15813521	3.47074074	0.09473580
3.47720845	0.15680849	3.47694414	0.09550906
3.50257584	0.12599883	3.50257584	0.12599883

Table 3. NACA sectional format

Station	r=	11”	r/R=	0.37931
	x_new_up	z_new_up	x_new_lo	z_new_lo
1	0.0000	0.0000	0.0000	0.0000
2	0.6299	1.1395	0.6204	-1.0678
3	1.2598	2.2790	1.2439	-1.4131
4	2.5144	3.3387	2.4920	-1.8497
5	5.0206	4.7785	4.9895	-2.4344
6	10.0290	6.7329	9.9866	-3.1099
7	20.0387	8.9798	19.9845	-3.5956
8	30.0424	9.8419	29.9839	-3.7272
9	35.6768	9.9461	35.6177	-3.7515
10	40.0425	9.8616	39.9839	-3.7247
11	50.0399	9.2445	49.9844	-3.6164
12	60.0351	8.1335	59.9854	-3.3969
13	70.0285	6.6198	69.9869	-3.0402
14	80.0207	4.8035	79.9893	-2.4894
15	90.0121	2.8015	89.9926	-1.7073
16	99.0988	0.9176	99.0910	-0.8927
17	99.2756	0.8798	99.2681	-0.8706
18	100.0000	0.0000	100.0000	0.0000

Tables A1, A2, and A3 (for *r=17", r/R=0.5862*), A4, A5, and A6 (for *r=17", r/R=0.7931*), and A7, A8, A9 (for *r=29", r/R=1.0000*) are listed for the other *3* sections and they are placed in Append A.

It can be seen that to obtain the offsets for different sections, interpolation is needed. The offsets data in the above 4 sections were used to produce the sectional offsets for *r/R=0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 0.95*, and *1.0*. As the chord-wise stations for all the sections except r/R=1.0 section, have two sections at *x/c=0.991* and *0.993*, respectively, the station at *x/c=0.993* was removed. The code does not use such accuracy for a very small interval either at the trailing edge or the leading edge.

The final sectional offsets data for PREPELLA input are tabulated in tables B1-9 and they are placed in Appendix B.

The measured pitch distribution, noting that when the black dot markers are aligned vertically, are given in the following table:

Table 4. Pitch angle measurement given by IOT Design and Fabrication

Radial location marker	Radius	r/R	Measured Pitch angle
6	11	0.37931	18.04
12	17	0.586207	13.23
18	23	0.793103	7.53
24	29	1	3.77

With the angular correction values obtained from tables 2, A2, A5, and A8, a new pitch angle distribution was obtained and listed in Table 5. Again, these angular values were obtained during the conversion from the measured data based on baseline reference to the code required format, the nose-tail reference.

Table 5. Modified pitch distribution

Location	Radius	r/R	Pitch angle	BL to NT correction	Modified
6	11	0.3793	18.04	0.2470	17.7930
12	17	0.5862	13.23	-0.7975	14.0275
18	23	0.7931	7.53	-1.4249	8.9549
24	29	1.0000	3.77	-1.0734	4.8434

To obtain the pitch angle distribution at prescribed *r/R* values, interpolation is required. Figure 2 uses the graph method with the Trend-line functionality of Microsoft Excel and shows the polynomial-fitted curve of the pitch angle versus the radial locations.

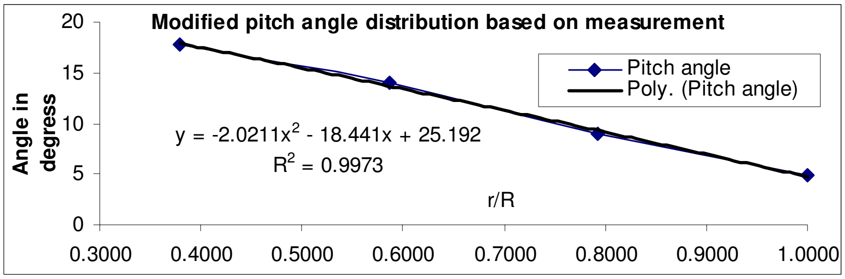

Figure 2. Pitch angle distribution when the position markers, the black dots on the blade cylindrical root section, are aligned vertically.

Based on the single-line linear regression equation in figure 2, the first set of pitch angle values when the black dots align vertically were obtained and listed in table 6. As indicated, in table 6, the pitch angles were modified by a correction value that was obtained for the rotation of the section due to Base-line to Nose-tail conversion (BL to NT). The result of the interpolation for pitch distribution in the radial direction is show in table 6.

Table 6. Interpolated pitch angle and pitch to diameter after base-line to nose-tail correction for the base pitch angle.

	Pitch with the black dots vertically aligned		
r/R	angle	angle rads	p/D
0.3	19.4778	0.3400	0.3333
0.4	17.4922	0.3053	0.3960
0.5	15.4662	0.2699	0.4346
0.6	13.3998	0.2339	0.4491
0.7	11.2930	0.1971	0.4391
0.75	10.2244	0.1784	0.4250
0.8	9.1457	0.1596	0.4046
0.9	6.9580	0.1214	0.3451
0.95	5.8490	0.1021	0.3057
1	4.7299	0.0826	0.2599

Even though the pitch angle distribution shown in figure 2 is to be kept in constant relationship for different nominal pitch values, adding or subtracting the same angle for each radial location by turning the blade principal axis with a plus or minus angular value, will result in a quite different pitch to diameter ratio distribution.

It is also noted that from the pitch to diameter ratio p/D distribution in table 2, the *p/D* values at the blade tip seem too small and at a radial location around *r/R=0.5*, the *p/D* values seem too large. This seems a rather abnormal designation of pitch distribution. This implies that the nominal pitch ratio of the given blade could be far away from the pitch angle of *10.2244°* at *r/R=0.75*. Nevertheless, with the given propeller blade, *4* nominal pitch angles were taken as *6.2244°, 10.2244°, 15.2244°,* and *20.2244°*. The pitch to diameter ratios of the newly formed propellers are obtained and listed in table 7 below:

Table 7. Newly formed propellers with different pitch to diameter ratio p/D.

		6.2244°			15.2244°			20.2244°	
r/R	angle	angle rads	p/D	angle	angle rads	p/D	angle	angle rads	p/D
0.3	15.4778	0.2701	0.2610	24.4778	0.4272	0.4291	29.4778	0.5145	0.5327
0.4	13.4922	0.2355	0.3015	22.4922	0.3926	0.5203	27.4922	0.4798	0.6539
0.5	11.4662	0.2001	0.3186	20.4662	0.3572	0.5862	25.4662	0.4445	0.7481
0.6	9.3998	0.1641	0.3120	18.3998	0.3211	0.6270	23.3998	0.4084	0.8157
0.7	7.2930	0.1273	0.2814	16.2930	0.2844	0.6428	21.2930	0.3716	0.8571
0.75	6.2244	0.1086	0.2570	15.2244	0.2657	0.6412	20.2244	0.3530	0.8680
0.8	5.1457	0.0898	0.2263	14.1457	0.2469	0.6334	19.1457	0.3342	0.8725
0.9	2.9580	0.0516	0.1461	11.9580	0.2087	0.5988	16.9580	0.2960	0.8622
0.95	1.8490	0.0323	0.0963	10.8490	0.1894	0.5720	15.8490	0.2766	0.8473
1	0.7299	0.0127	0.0400	9.7299	0.1698	0.5387	14.7299	0.2571	0.8259

To perform the design and optimization for the best possible propulsive efficiency, the thrust and torque coefficients of the propellers need to be known, that is, a propulsive performance database needs to be established. They were not available at the beginning of the work so that the first step was to build the database. This kind of database was traditionally generated by obtaining data from a cavitation tunnel/wind tunnel facility where a series of propeller models are designed, built and tested. In this case, the IOT in-house propeller code, PROPELLA was used as a numerical cavitation/wind tunnel to create this database for a series of propellers on the given Warp Drive propeller blade.

In the virtual wind tunnel tests, this series of virtual propeller models are therefore defined as:

1. Propeller models have *4, 6* and *8* blades.
2. Propeller models have 4 different pitch angles at *r/R=0.75,* such as *6.224°, 10.2244°, 15.2244°,* and *20.2244°,* respectively. See tables 6 and 7 above for the pitch distribution of each propeller.
3. The planform characteristic of the propeller is described in table 8.

Table 8. Planform characteristics (with zero rake and skew)

	For all pitch angles				PA_6.2244	PA_10.2244	PA_15.2244	PA_20.2244
r/R	t_max/c	t_max/D	20t_max/D	c/D	p/D	p/D	p/D	p/D
0.3000	0.1493	0.0088	0.1762	0.0586	0.2610	0.3333	0.4291	0.5327
0.4000	0.1347	0.0082	0.1636	0.0608	0.3015	0.3960	0.5203	0.6539
0.5000	0.1273	0.0079	0.1580	0.0622	0.3186	0.4346	0.5862	0.7481
0.6000	0.1244	0.0078	0.1560	0.0628	0.3120	0.4491	0.6270	0.8157
0.7000	0.1235	0.0077	0.1546	0.0626	0.2814	0.4391	0.6428	0.8571
0.7500	0.1229	0.0077	0.1532	0.0623	0.2570	0.4250	0.6412	0.8680
0.8000	0.1218	0.0075	0.1506	0.0617	0.2263	0.4046	0.6334	0.8725
0.9000	0.1168	0.0070	0.1407	0.0600	0.1461	0.3451	0.5988	0.8622

0.9500	0.1122	0.0066	0.1325	0.0589	0.0963	0.3057	0.5720	0.8473
1.0000	0.1057	0.0061	0.1217	0.0576	0.0400	0.2599	0.5387	0.8259

Figure 3 summarizes the processed propeller planform geometry data.

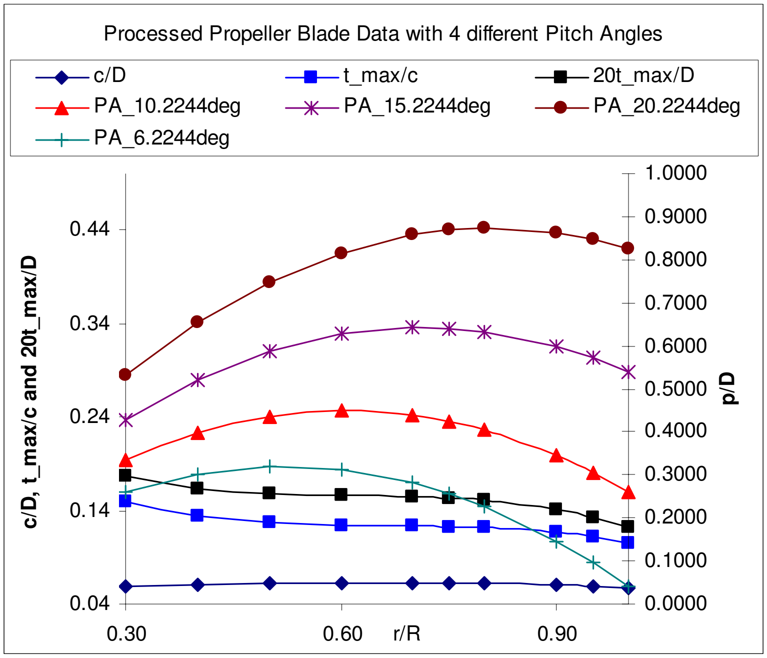

Figure 3. Finalized planform geometry data for propellers of 4 different pitch values.

For PROPELLA input, the maximum thickness at *r/R=1.0, 0.95* and *0.0* is also needed. After interpolation, these values were obtained as: *t_max/D = 0.006058, 0.006626 and 0.014360*, respectively.

With the above geometry data preparation, the propeller geometry was then defined and the INPUT file for PROPELLA was created. The hub diameter ratio was assumed to be *0.3*. For number of blades, PROPELLA can automatically output the desired geometry when the number of blades is modified in the INPUT file. Changes to various geometry and motion parameters can either be done by editing the ASCI INPUT file or creating a new one by using the PROPELLA software GUI dialogue boxes. For details, see PROPELLA Manuel.

Once the INPUT file is created, the first step is to generate the geometry for a visual inspection. A detailed check up can be performed by using its output files with DXF extension, that could be loaded from within AutoCAD.

Figure 4, 5 and 6 show the geometry of the virtual propeller models.

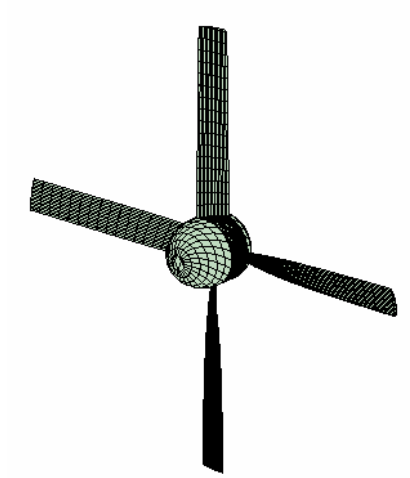

Figure 4. Meshed 4-blade virtual propeller

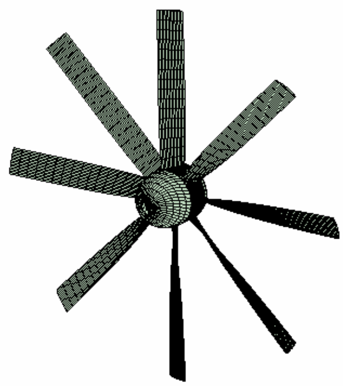

Figure 5. Meshed 8-blade virtual propeller

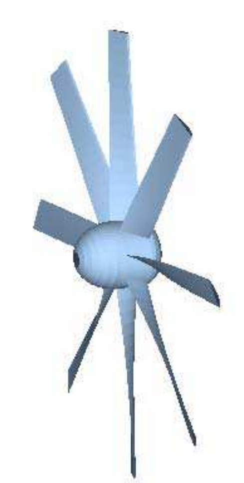

Figure 6. Solid model of the 8-blade virtual propeller

2.2 Propulsive Performance Curves from the Numerical Wind Tunnel Runs

With *4* different pitch values and *3* different blades, a total of *12* virtual full-scale propellers were built. For each propeller, test runs were performed for each of the advance coefficients with an interval of *0.1* from *J=0.0 to J/[p/D]=1.0*. When *J/[p/D] =0.0*, propellers usually give zero or negative thrust. Therefore, the range of advance coefficient is determined. A total of about *90* virtual wind tunnel test runs were performed on a Dual Core *64*-bit PC with *4*GB of memory. A sample INPUT file is listed in Appendix D. These runs were performed by *4* different batch files that run the corresponding executables, rename and store the output files. The total time for all the runs on the *4* simultaneous batch processes is for a full week. K_T and K_Q curves were obtained. To normalize the numbers, the following equations were used:

$$J = \frac{V_{prop}}{nD}, \tag{2}$$

which is advance coefficient, where V_{prop} is the effective propeller disk speed after the axial wake correction, i.e., the ship speed or propeller shaft speed minus the wake fraction factor, n is shaft rotational speed in rps and D is the diameter of the propeller.

$$K_T = \frac{T}{\rho n^2 D^4}, \tag{3}$$

which is thrust coefficient and T is the thrust in Newtons and ρ is the density of air taken as $1.225\ kg/m^3$.

$$K_Q = \frac{Q}{\rho n^2 D^5}, \tag{4}$$

which is shaft torque coefficient and Q is the shaft torque in $N\text{-}m$.

$$K_P = \frac{P}{\rho n^3 D^5}, \tag{5}$$

which C_p is power coefficient and it can be also expressed as:

$$K_P = \frac{Q\omega}{\rho n^3 D^5} = \frac{K_Q \rho n^2 D^5 2\pi n}{\rho n^3 D^5} = 2\pi K_Q \tag{6}$$

$$\eta_0 = \frac{K_T J}{2\pi K_Q}, \tag{7}$$

which is the propeller hydrodynamic efficiency.

$$K_s = \sqrt[5]{\frac{\rho V_{prop}^5}{P n^2}} = \frac{J}{\sqrt[5]{2\pi K_Q}}, \tag{8}$$

which is called thruster power factor that was used extensively in air propeller literature.

$$F_{TP} = T/P = \frac{K_T \rho n^2 D^4}{2\pi n Q} = \frac{K_T \rho n^2 D^4}{2\pi n K_Q \rho n^2 D^5} = \frac{K_T}{2\pi n D K_Q} \quad , \tag{9}$$

which is propeller hydrodynamic thrust to power ratio factor, in *Newton/Watt* or *kN/kW*.

The results produced from these virtual wind tunnel runs are presented in Appendix C, and they are listed in tables C1-C12 and figures C1-C12.

2.3 Propeller Design and Optimization: Computer-Aided Design Approach

In the design and optimization, the following formulation/equations were used:

- Wake fraction w to correct the propeller inflow speed, $V_{prop} = (1-w)V_{shaft}$ (10)
- Thrust deduction fraction factor t to correct thrust requirement, $T = \frac{R_T}{(1-t)}$ (11)
- Engine breaking power P_B
- Delivered power P_D
- Effective thrust power on shaft to propel the vehicle, P_E
- Propeller shaft power after transmission and gearbox, $\eta_s = \frac{P_D}{P_B} \approx 98\%$ (12)
- Relative rotational efficiency due to induced wake, scale factor, etc, $\eta_R \approx 1.0$
- Open water efficiency η_o
- Propeller hydrodynamic efficiency $\eta_P = \eta_O \eta_R$ (13)
- Hull efficiency $\eta_H = \frac{1-t}{1-w}$ (14)
- Total efficiency:

$$\eta_T = \frac{P_E}{P_B} = \eta_S \frac{P_E}{P_D} = \eta_S \frac{R_T V_{shaft}}{2\pi n Q} = \eta_S \frac{TV_{prop}}{2\pi n Q} \frac{R_T V_{shaft}}{TV_{prop}} = \eta_S \eta_P \frac{R_T V_{shaft}}{TV_{prop}} = \eta_S \eta_P \eta_H = \eta_S \eta_O \eta_R \eta_H \tag{15}$$

Power or Resistance versus speed data of the airboat is given by Mad Rock Marine Solutions and listed in table 9:

Table 9. Power and resistance versus speed curve provided by Mad Rock Marine Solutions for the 7meter Polar MPV Catamaran

Speed		Resistance			Power		
(m/sec)	(knots)	Residual	Total Resistance (kN)	Half resistance for one propeller in kN	Required one-shaft thrust power HP	Required thrust power HP	Required thrust power kW

0.01	0.02	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.66	1.28	0.0040	0.0193	0.0096	0.0086	0.0173	0.0063
1.31	2.55	0.1271	0.1800	0.0900	0.1603	0.3206	0.1178
1.96	3.81	0.4026	0.5129	0.2564	0.6833	1.3666	0.5022
2.61	5.07	0.9359	1.1221	0.5610	1.9907	3.9814	1.4632
3.26	6.34	1.7193	1.9990	0.9995	4.4297	8.8594	3.2558
3.91	7.60	2.4080	2.7983	1.3991	7.4373	14.8746	5.4664
4.56	8.86	2.6950	3.2125	1.6062	9.9576	19.9153	7.3189
5.21	10.13	2.9187	3.5798	1.7899	12.6779	25.3558	9.3183
5.86	11.39	3.1217	3.9424	1.9712	15.7037	31.4074	11.5422
6.51	12.66	3.3407	4.3367	2.1684	19.1907	38.3815	14.1052
7.15	13.92	3.5665	4.7534	2.3767	23.1346	46.2692	17.0039
7.80	15.18	3.6733	5.0662	2.5331	26.8959	53.7918	19.7685
8.45	16.45	3.6716	5.2857	2.6429	30.3966	60.7933	22.3415
9.10	17.71	3.7109	5.5613	2.7806	34.4382	68.8764	25.3121
9.75	18.97	3.7161	5.8175	2.9087	38.5951	77.1902	28.3674
10.40	20.24	3.7015	6.0684	3.0342	42.9414	85.8828	31.5619
11.05	21.50	3.7163	6.3635	3.1817	47.8409	95.6818	35.1631
11.70	22.76	3.7002	6.6420	3.3210	52.8697	105.7394	38.8592
12.35	24.03	3.7655	7.0162	3.5081	58.9480	117.8961	43.3268
13.00	25.29	3.7655	7.2775	3.6388	64.3590	128.7181	47.3039
13.38	26.00	3.7655	7.4360	3.7180	67.6676	135.3352	49.7357
13.89	27.00	3.7655	7.6410	3.8205	72.2075	144.4149	53.0725
14.41	28.00	3.7655	7.8400	3.9200	76.8320	153.6640	56.4715

In table 9, the original data range was from *0* to *25.29* knots. The speed range was extrapolated to *28* knots to be used for optimization process.

Some main given motion parameters are:

- Design speed is *25* knots, which is *15.8625 m/s.*
- Engine constant speed is *3800 rpm (63.3333 rps)*.
- Diameter of the propeller is *58" (1.4732 m)*.
- Number of propellers is *2*.
- Density of air is $1.225\ kg/m^3$.
- Thrust deduction fraction factor *t=0.0*.
- Wake fraction factor *w=0.0*.
- The propeller tip speed is then *293.401 m/s*, with a Mach number of *0.8629*. The efficiency due to Mach number was taken as $\eta_M \approx 0.9$.
- Relative rotational efficiency is taken at $\eta_R \approx 1.0$.
- Hull efficiency as *t= 0.0* and *w=0.0*, it is then $\eta_H = \dfrac{1-t}{1-w} = 1.0$.
- Engine transmission efficiency was taken as $\eta_s = \dfrac{P_D}{P_B} \approx 98\%=0.98$.

- Total propulsion system efficiency is then:

$$\eta_{total} = \eta_M \eta_R \eta_H \eta_s \eta_0 = 0.9 \times 1.0 \times 1.0 \times 0.98 \times \eta_0 = 0.882\eta_0 .$$

This design and optimization is reduced to within given propeller diameter *D*, shaft rotation speed *n* and desired service speed of *25* knots, look for lowest engine power, i.e., the highest possible propeller efficiency.

For the *4*-blade propeller configuration, calculations were listed step by step in table 10. Instead of using the classical Bp-δ diagram for design and optimization, a computer-aided design procedure was established and employed, that utilizes spreadsheet and trend-line interpolation. In this case, the spreadsheet program used is Microsoft Office Excel.

Table 10. Propeller design and optimization for the 4-blade propfan

1	Vprop in knots	23.0000	24.0000	25.0000	26.0000	27.0000	28.0000	
2	Vprop in m/s	11.8335	12.3480	12.8625	13.3770	13.8915	14.4060	p/D
3	J	0.1268	0.1323	0.1379	0.1434	0.1489	0.1544	
4	eta_4B_POD02570	0.1782	0.1811	0.1837	0.1859	0.1878	0.1892	0.2570
5	eta_4B_POD04250	0.2568	0.2645	0.2719	0.2790	0.2859	0.2926	0.4250
6	eta_4B_POD06412	0.2633	0.2715	0.2796	0.2876	0.2954	0.3030	0.6412
7	eta_4B_POD08680	0.2227	0.2308	0.2389	0.2469	0.2548	0.2627	0.8680
8	Kt_4B_POD02570	0.0544	0.0529	0.0514	0.0499	0.0484	0.0469	0.2570
9	Kt_4B_POD04250	0.1063	0.1046	0.1030	0.1013	0.0997	0.0980	0.4250
10	Kt_4B_POD06412	0.1723	0.1706	0.1689	0.1671	0.1654	0.1637	0.6412
11	Kt_4B_POD08680	0.2338	0.2321	0.2304	0.2287	0.2270	0.2253	0.8680
12	Thrust_Power_4B_POD02570	14.8858	15.1089	**15.2963**	15.4479	15.5639	15.6441	0.2570
13	Thrust_Power_4B_POD04250	29.1154	29.9055	**30.6561**	31.3672	32.0388	32.6708	0.4250
14	Thrust_Power_4B_POD06412	47.1986	48.7555	**50.2710**	51.7454	53.1784	54.5702	0.6412
15	Thrust_Power_4B_POD08680	64.0412	66.3404	**68.5991**	70.8173	72.9950	75.1321	0.8680
16	Required thrust power at 25 knots = Vshaft x R/(1-t) in KW			46.3275				
17	Pitch values	0.2570	0.4250	0.6412	0.8680			
18	Produced thrust power for 4 pitch values at 25knots	**15.2963**	**30.6561**	**50.2710**	**68.5991**			
19	Optimum pitch found			0.6230				
20	Efficiency at 4 different pitch values	0.1837	0.2719	0.2796	0.2389			
21	Efficiency of optimum pitch at 25 knots			0.2818				0.6230
22	Required Shaft Power			164.3819				0.6230
23	Power after deduction of Mach No. effect eta_Mach=0.90			182.6466				0.6230
24	Shaft power requirement (relative rotational and hull efficiency =1.0)			182.6466				0.6230
25	Required engine power in kW (transmission efficiency=0.98)			186.3741				0.6230
26	Required engine power in HP (conversion factor =0.735)			253.5702				0.6230
27	Ftp_4B_POD02570	0.0155	0.0151	0.0148	0.0144	0.0140	0.0136	0.2570
28	Ftp_4B_POD04250	0.0223	0.0221	0.0218	0.0215	0.0213	0.0210	0.4250
29	Ftp_4B_POD06412	0.0213	0.0212	0.0210	0.0209	0.0208	0.0206	0.6412
30	Ftp_4B_POD08680	0.0191	0.0190	0.0189	0.0188	0.0187	0.0186	0.8680
31	Ftp at Optimum pitch	0.0216	0.0214	0.0213	0.0212	0.0210	0.0208	0.6230

The following describes the details of each row in table 10:

- Row 1 and 2 store propeller speed in knots and meters per second. This is a result from the equation: $V_{prop} = (1-w)V_{shaft}$, where $w = 0.0$.
- Row 3 lists corresponding advance coefficient by equation (2)
- For rows 4-7, efficiency η_0 of each pitch value versus advance coefficient J is plotted (see figure 7) along with a trend line fitted polynomial equation. The efficiencies in rows 4-7 for the 4 different pitch values are obtained by using the trend-line equations for 5 different speeds (advance ratio Js) in figure 7.

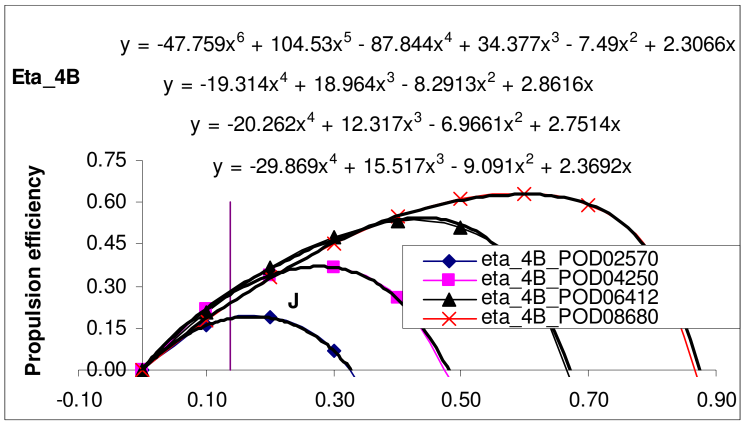

Figure 7. Efficiency interpolation trend-line based on the propulsive performance data for the 4-blade propfan listed in tables C1, C4 and C7.

- Similar to rows 4-7, numbers in rows 8-11 were obtained also from the polynomial-fitted equations for the thrust coefficient K_T data for the 4-bladed propfan listed in tables C1, C4, and C7:

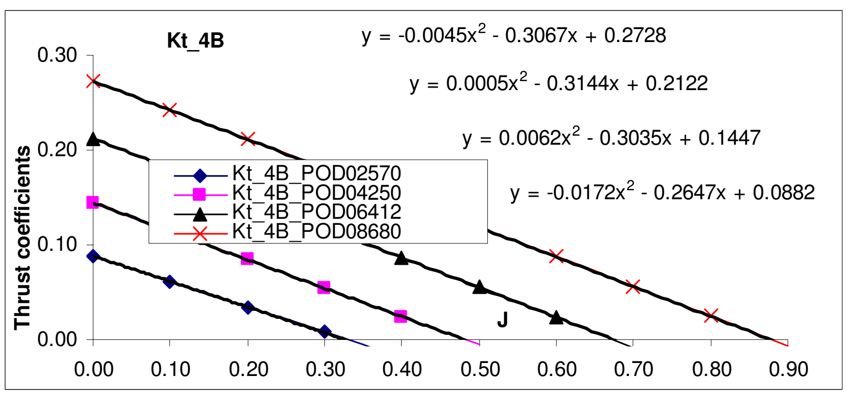

Figure 8. Thrust coefficients for interpolation. Trend-lines are based on the propulsive performance data for the 4-blade propfan listed in tables C1, C4 and C7.

- Rows 12-15 are for thrust power that the propfan can produce for each pitch value at each speed. These numbers in these rows were obtained by using the K_T values in rows 8-11 and $P_E = T \times V_{prop} \times \eta_R = \rho n^2 D^4 K_T V_{prop} \eta_R$. In this case, $\eta_R \approx 1.0$.
- Row 16 is for the required thrust power for one *4*-balde propfan at *25* knots. The required thrust power can be calculated by: $P_{E\_Required} = V_{shaft} R/(1-t)$, where V_{shaft} is the design service speed and R is the half resistance (for one of the two propellers)

and *t* the thrust deduction fraction factor. A thrust power requirement curve is plotted in the following figure along with the created trend-line equation. Plugging in the speed of *25* knots into the equation, the required thrust power was then obtained.

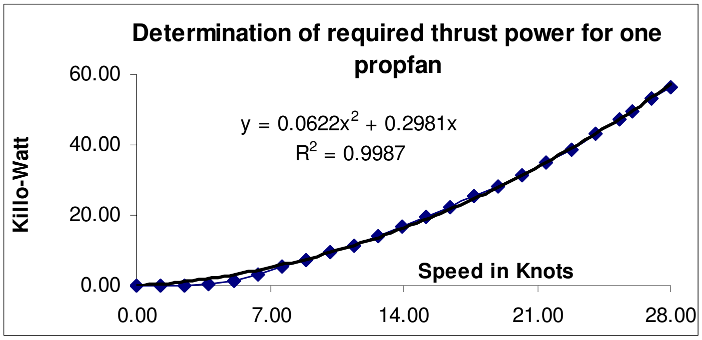

Figure 9. Required thrust power in kW for one of the two propfans based the given speed-resistance data in table 9.

- Rows 17-26 perform optimization to determine the optimum pitch of 4-blade propeller for the maximum achievable efficiency. Row 17 lists *4* pitch values.
- Row 18 stores the required thrust power at *25* knots for each of the above pitch values. These numbers in row 18 are the transpose of the numbers in the *25*-knot column from row 12 to 15 (see the shaded cells).
- Row 19 is the cell to store the optimum pitch obtained. The following figure was created using the data in row 18. Plugging in the required thrust power *46.3275 kW* into the trend-line equation in the following figure, the optimum pitch is determined at *p/D=0.6230*.

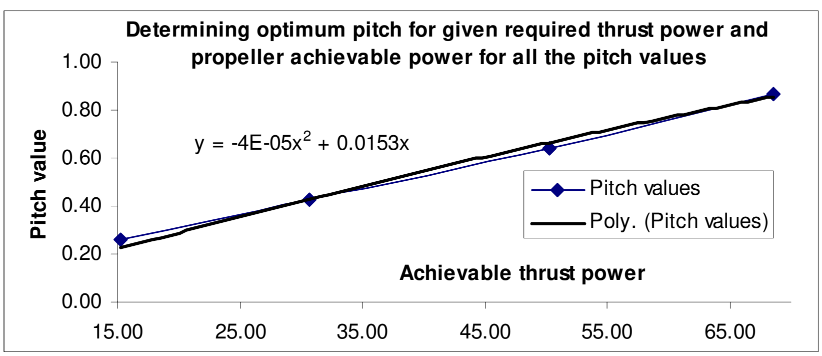

Figure 10. Determination of optimum pitch at 25 knots.

- Row 20 is the transpose of the *25*-knot column from row 4-7, which stores the efficiency for each pitch value at *25* knots. The data is plotted in the following figure along with the generated trend-line equation. Plugging the optimum pitch values into the trend-line equation, the maximum achievable efficiency is obtained.

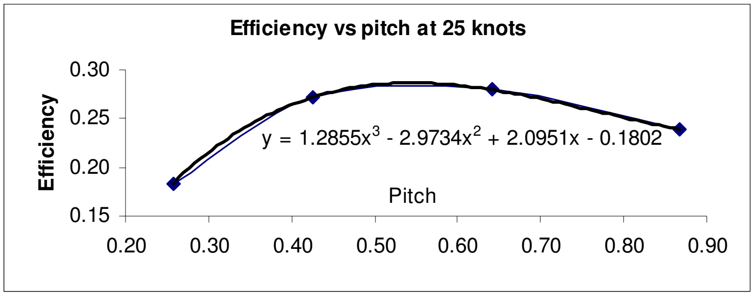

Figure 11. Determination of the maximum achievable efficiency at 25 knots.

- Rows 22-25 are for engine power estimation. These calculations are performed by following the equations (12)-(15). The required of the one of the twin engines power is *187 kW*, about *254 HP*.

The nominal pitch angle corresponding to the optimum p/D value can be calculated by:

$$p / D = 2\pi\, r \tan(\alpha) / [2R] = \pi \tan(\alpha)[r / R]. \qquad (16)$$

Therefore, $\alpha = \tan^{-1}(\frac{p}{D} / \pi / [r / R]) = \tan^{-1}(0.6230 / \pi / 0.75) = 14.8097°$. This means that the pitch adjustment is needed to increase the base angle (10.2244°) at 4.5853°.

For propfan with 6 and 8 blades, calculations were performed similarly. Summary of the design and optimization will be given later in this report.

2.4 The thrust to power ratio factor

In the early design stage, a thrust to power ratio factor, F_{TP} is often useful. This section describes how to find this factor. Using the propulsion performance data in tables C1, C4, C7 and C10, thrust to power factors are plotted in the following figure, along with the trend-line of each curve.

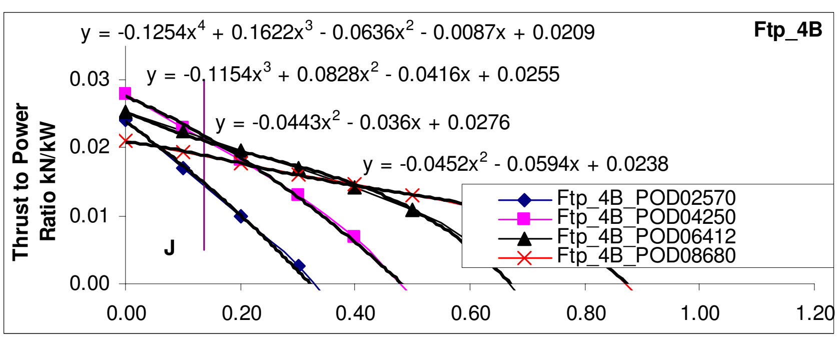

Figure 11. Plotting and creation of the thrust to power factor for the 4 pitch values at different advance coefficient J.

Table 11 lists the thrust to power factors for each pitch value at each given speed. Values in rows 3-6 in table are obtained by plugging the advance coefficient values to these trend-line equations.

Table 11. Determination of thrust to power factor of the 4-blade propfan with the optimum pitch p/D of 0.6230

1	V knots	23.00	24.00	25.00	26.00	27.00	28.00	p/D
2	J	0.1268	0.1323	0.1379	0.1434	0.1489	0.1544	
3	Ftp_4B_POD02570	0.0155	0.0151	0.0148	0.0144	0.0140	0.0136	0.2570
4	Ftp_4B_POD04250	0.0223	0.0221	0.0218	0.0215	0.0213	0.0210	0.4250
5	Ftp_4B_POD06412	0.0213	0.0212	0.0210	0.0209	0.0208	0.0206	0.6412
6	Ftp_4B_POD08680	0.0191	0.0190	0.0189	0.0188	0.0187	0.0186	0.8680
7	Ftp at Optimum pitch	0.0216	0.0214	0.0214	0.0212	0.0210	0.0209	0.6230

For each speed column, there are *4* factors corresponding to *4* different pitch values. The thrust to power factor with the optimum pitch of p/D=0.6230 for the 4-blade propeller at *23* knots is obtained, as an example, by using the trend-line equation in the following figure:

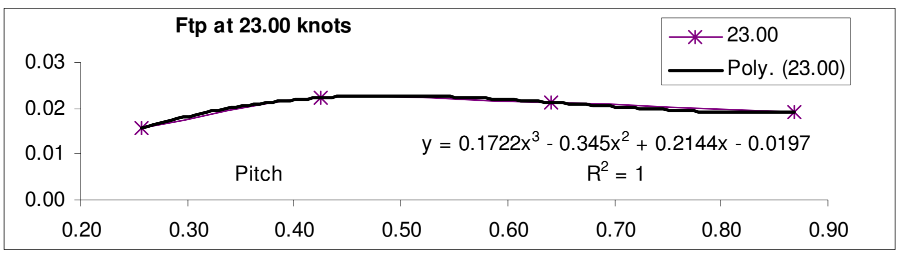

Figure 12. Thrust to power factor for different pitch values at 23 knots.

Plugging the optimum pitch value of *p/D=0.6230* into the equation, the thrust to power factor F_{TP} at 23 knots for the optimum pitch is obtained which is *0.0216*.

The thrust to power factor for other speeds is obtained similarly. These plots and trend-line equations are then used to obtain the thrust to power factor F_{TP} at other speeds (see the last row of table 11).

To estimate the required power for the 4-blade propfan with the optimum pitch at 25 knots, there needs:

1. The thrust to power factor F_{TP} at *25* knots and from table 11, it is *0.0214*.
2. The thrust requirement at *25* knots, $T=R/(1-t)$ and from the trend-line equation in figure 9, it is *3.6017 kN*.

Therefore, the required power is $T/F_{TP}=3.6017kN/0.0214\ kN/kW=168\ kW$. With the consideration of Mach number and shaft transmission efficiency, the required engine power is then *168/0.9/0.98=190 kW*. This is close to the value in row 25 of table 10, which is *186 kW*.

2.5 Propeller blade strength estimation

Strength estimation is based on the following assumptions:

- The material is carbon fiber composite.
- The maximum stresses occur at the blade root section, which is assumed at *r/R = 0.3*. This is true as this was verified for all the output files for all *J* values of all propellers.
- The blade root section in the propfan helical surface is assumed to be the blade expanded plane on which the centroid and moment inertias were obtained.

The sectional offsets for the *r/R=0.3* section is list in table 12.

Table 12. Sectional offsets for the root section at r/R=0.3

Chord length at r/R=0.3 is 0.0863 meters

Localized chord length and ordinates in cm:

x_up	y_up	x_low	y_low
0.0000	0.0000	0.0000	0.0000
0.0551	0.0946	0.0529	-0.0947
0.1099	0.2100	0.1064	-0.1133
0.2188	0.3034	0.2140	-0.1630
0.4361	0.4219	0.4293	-0.2181
0.8698	0.5822	0.8604	-0.2879
1.7352	0.7755	1.7234	-0.3426
2.5992	0.8543	2.5865	-0.3617
3.2313	0.8659	3.2186	-0.3650
3.4623	0.8591	3.4498	-0.3658
4.3249	0.8060	4.3131	-0.3575
5.1871	0.7090	5.1765	-0.3379
6.0489	0.5752	6.0400	-0.3027
6.9103	0.4150	6.9037	-0.2462
7.7716	0.2410	7.7674	-0.1638
8.5504	0.0815	8.5487	-0.0778
8.6321	0.0000	8.6321	0.0000

Figure 12 shows the plotted sectional shape for r/R=0.3.

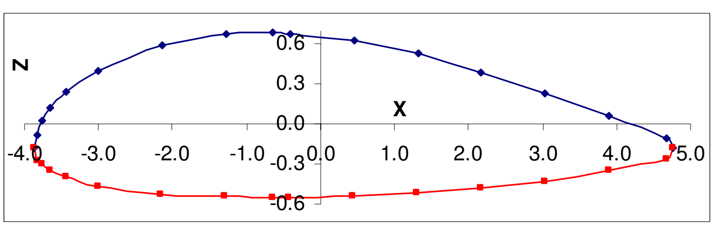

Figure 12. Blade root sectional shape with the origin coincides with the centroid.

For this section, moments of inertia along with other geometry parameters were obtained from with AutoCAD by using the *MassProp* command for a polyline-drawn and Region-ized sectional offsets. The sectional properties are listed in the following table:

Table 13. The sectional properties obtained from AutoCAD

Sectional Area at r/R=0.3		**7.5963**	**is**	**0.00076**	**m^2**
Perimeter:	**18.6891**				
Bounding box:		**X: -3.8756 -- 4.7565**			
Y: -0.2596 -- 0.8520					
Centroid: X=	**0**	**y=**	**0**		
Moments of inertia about x-axis (out-of-plane)		**0.7002**	**cm^4**	**7E-09**	**m^4**
Moments of inertia about y-axis (in-plane)		**32.6014**	**cm^4**	**3.26E-07**	**m^4**
Product of inertia: XY=		**-0.4859**	**cm^2**		
Radii of gyration: X=		**0.3036**	**cm**		
Y=		**2.0717**	**cm**		
Principal moments and X-Y directions about centroid:					
I: 0.6928 along [0.9999 -0.0152]				**cm^4**	
J: 32.6088 along [0.0152 0.9999]				**cm^4**	

The following table lists the values needed for stress calculation.

Table 14. Values needed for stress calculation

Out-of-plane bending about x-axis:				
Cy_compress=	0.6831	cm	0.00683100	meters
Cy_tensile	-0.5486	cm	-0.00548600	meters
Moment of inertia about x-axis I_x=			0.00000001	
Out-of-plane bending moment coefficient			-0.00749400	N-m
In-plane bending about y-axis:				
Compressive stress = moment*Cx_compress/I_y				
Tensile stress = moment*Cx_tensile/I_y				
Cx_compress=	4.7565	cm	0.04756500	meters
Cx_tensile	-3.8756	cm	-0.03875600	meters
Moment of inertia about y-axis I_y=			0.00000033	
In-plane bending moment: coefficient, in N-m and safety factor			0.00133100	N-m
Spindle torque about the centroid				
Tortional shear stress = torque*Cr/I_r				
Cr= 0.061355169	meters			
I_r= 3.260892E-07	m^4			
Spindle torque: coefficient			0.00042700	N-m

With the values in table 14 and the formulae for stress calculation, and some propfan motion information, stresses and safety factors are ready to be obtained. The information is:

- Diameter of the propeller $D = 1.4732\ m$
- Revolution speed $n = 63.3333\ rps$

- Air density ρ = *1.225 kg/m*^{3}
- The moment and torque factor = $\rho n^2 D^5$ = *34092.8741*
- Assumed carbon fibre composite ultimate tensile stress in bending: *4.47E+08 N/m*^{2}
- Assumed ultimate compressive stress in bending: *4.78E+08 N/m*^{2}
- Assumed ultimate tortional shear stress in tortional deformation: *9.28E+07 N/m*^{2}

With the information above, stresses due to bending moments (blade root section in-plane and out-of-plane) and the tortional stress due to blade root section spindle torque, along with the safety factors, are listed in the following table.

The formulae for calculating the stresses are bending moment about x and y axis and tortional stress about the normal vector to the section pass though the centroid:

$$\sigma_x = \frac{M_x C_x}{I_x}, \tag{17}$$

$$\sigma_y = \frac{M_y C_y}{I_y}, \tag{18}$$

$$\sigma_\tau = \frac{\tau\, C_r}{I_x + I_y}, \tag{19}$$

and safety factor

$$S.F. = \frac{Ultimate \quad Stress}{Allowable \quad Stress}. \tag{20}$$

Table 16. Stresses and safety factor calculation

4-blade			6-blade			8-blade		
Out-of-plane N-m	-255.492	Safety factor	Out-of-plane N-m	-219.15	Safety factor	Out-of-plane N-m	-193.4	Safety factor
Compress	-2.49E+08	1.9177	Compress	-2E+08	2.2358	Compress	-2E+08	2.5329
Tensile	2.00E+08	2.2330	Tensile	171701141	2.6034	Tensile	1.52E+08	2.9493
In-plane N-m	45.377616	Safety factor	In-plane N-m	33.0701	Safety factor	In-plane N-m	25.638	Safety factor
Compress	6.62E+06	72.199	Compress	4824881	99.07	Compress	4E+06	127.79
Tensile	-5.39E+06	82.8634	Tensile	-4E+06	113.7	Tensile	-3E+06	146.66
Spindle N-m	14.557657	Safety factor	Spindle N-m	11.3529	Safety factor	Spindle N-m	9.2733	Safety factor
Tortional shear	2.74E+06	33.8798	Tortional shear	2136105	43.444	Tortional shear	2E+06	53.186

The data in table 16 is divided into 9 blocks. They are for blade number of 4, 6 and 8 with the stresses and safety factors for out-of-plane, in-plane moments and spindle torque.

2.6 Summery of the propeller geometry and configuration

A summary is listed in table 11.

Table 11. Summary of the propfan and configuration for the 4-bale propfan

Summary of Design and Optimization

Number of propfans		2	
Ship speed (knots)		25.0000	
Ship speed (m/s)		12.8625	
Advance coefficient J		0.1379	
Number of blades	4	6	8
Nominal p/D at r/R=0.75	0.6230	0.4926	0.4213
Pitch angle (rad)	0.2585	0.2061	0.1769
Pitch angle (deg)	14.8097	11.8089	10.1376
Pitch angle adjustment (reference to the aligned dots)	4.5853	1.5845	-0.0868
Achievable efficiency	0.2818	0.2621	0.2294
Required engine power kW	187	201	230
Required engine power HP	254	273	312
Safety factor for compressive stress (on the blade suction side) due to out-of-plane bending moment	1.92	2.24	2.53

3 CONCLUDING REMARKS

3.1 Uncertainty remarks

There are a number of items that could affect uncertainty, such as the following:

- The accuracy of the geometry data measurement. The geometry data was obtained by a laser scanning machine performed by IOT Design and Fabrication. Machine precision and human related conversion/reading errors could cause some degree of uncertainty, though these should be small enough to be neglected.
- The accuracy of the code. Though PROPELLA has been verified and validated for many propellers in many cases, there still exists uncertainty but it is deemed that the predicted propulsion performance is accurate enough for this kind of design and optimization.
- Estimated hub to diameter ratio is *0.3*. This could be hydrodynamically conservative which means that a smaller hub diameter in practice could give a higher efficiency and hence lower required engine power. However, the safety factor of the blade would be reduced.
- Compressibility also has an effect on the performance and the prediction was also corrected.
- The ship hull efficiency is calculated based on a zero wake fraction factor and a zero thrust deduction factor. These two factors are difficult to determine as the ship travels in different terrains (on snow, ice, water, swamp, etc), it would have a different values of each.
- The rotational speed has been assumed at *3800 RPM*. This should be much lower at the bollard-pull condition when the ship speed is zero. Assuming a higher value of *RPM* at the bollard-pull condition, this would give a more conservative estimate of the blade root section bending moment and spindle torque, and hence a conservative estimate of blade strength.

3.2 Remarks on this design and optimization

The on-the-shell Warp Drive propeller blade has been extensively studied for its aerodynamic propulsion performance. Design and optimization were performed based on *3* types of propeller configuration of *4, 6* and *8* blades. For each propeller type, the optimum pitch was found for the maximum achievable efficiency and hence the minimum required engine power. With a little sacrifice on strength allowance, the *4*-blade propfan gives the best efficiency and lowest cost (fewer number blades needed to be purchased).

It is important to make sure a correct pitch value can be obtained when adjusting the pitch angle. The pitch angles referred to in this work have been based on the two marker dots around the blade root section to align vertically.

With a little more work similar to the current study, a series of new propfans can be developed specially for airboat propulsion. This current optimization and design has been based on the given on-the-shelf Warp Drive propfan blade. This blade is primarily designed and developed for much higher speeds in applications of hovercrafts or Wing-in-ground ships. These speeds are usually over 100 mp/h (approximately over 160 km/h, or about 70 m/s). The airboat in this work travels typically a lot less, at about 13 m/s. This means that a very lightly loaded propeller blade and configuration have been used for a very heavily loaded condition. There should be substantial room to improve the propulsion performance by developing a series of propellers/propfans especially for airboat.

The current Warp Drive propeller has a nearly constant maximum sectional thickness and shape across the span. Therefore, the allowable strength of the propeller blade could reach a substantially higher level by increasing the thickness and area of the blade root section.

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4 APPENDIX A: PREPARATION OF SECTIONAL OFFSETS DATA

Table A1. Original measured data with some necessary smooth

X (%)	X (value)	Z (Upper)	Z (Lower)
0.000	0	0.107	0.107
0.625	0.02271875	0.1522	0.0706
1.250	0.0454375	0.1746	0.0454
2.500	0.090875	0.2104	0.0421
5.000	0.18175	0.2678	0.0247
10.000	0.3635	0.3456	0.0103
20.000	0.727	0.423	0.0016
30.000	1.0905	0.4444	0.0002
31.200	1.1352	0.4447	0
40.000	1.454	0.4367	0
50.000	1.8175	0.409	0
60.000	2.181	0.3648	0.0022
70.000	2.5445	0.3081	0.0053
80.000	2.908	0.2408	0.0104
90.000	3.2715	0.1642	0.0174
99.200	3.6069	0.0876	0.0252
99.300	3.6102	0.0868	0.0259
100.000	3.635	0.0564	0.0564

Table A2. Rotation for Base-line to Nose-tail conversion

	rad	deg	
angle=	-0.01391932	-0.79751835	
x_int_up	z_int_up	x_int_lo	z_int_lo
-0.00148932	0.10698963	-0.00148932	0.10698963
0.0205981	0.15250148	0.02173388	0.07090938
0.04300286	0.17521552	0.04480118	0.04602804
0.08793767	0.2116445	0.09028021	0.0433608
0.17800492	0.27030381	0.1813886	0.02722736
0.35865442	0.35062603	0.36332142	0.01535851
0.72104189	0.43307804	0.7269073	0.01171886
1.08420881	0.45953548	1.09039158	0.01537851
1.12890031	0.46045762	1.13509003	0.0158007
1.44778078	0.45689574	1.45385915	0.02023804
1.81163112	0.43425793	1.81732393	0.02529755
2.17571112	0.39512172	2.1807581	0.03255685
2.5399651	0.34348672	2.54417974	0.04071606
2.90436663	0.28125275	2.90757354	0.05087507
3.2688976	0.20971968	3.27094089	0.0629339
3.6053313	0.13779549	3.60619984	0.07540154
3.60864211	0.1370415	3.60948977	0.0761474
3.63386285	0.10698963	3.63386285	0.10698963

Table A3. NACA sectional format

r=	17"	r/R=	0.5862069
x_new_up	z_new_up	x_new_lo	z_new_lo
0.0000	0.0000	0.0000	0.0000
0.6076	1.2519	0.6388	-0.9925
1.2239	1.8767	1.2733	-1.6769
2.4599	2.8788	2.5244	-1.7503
4.9375	4.4924	5.0305	-2.1941
9.9067	6.7019	10.0351	-2.5206
19.8751	8.9699	20.0365	-2.6207
29.8650	9.6977	30.0351	-2.5200

31.0944	9.7231	31.2646	-2.5084
39.8660	9.6251	40.0332	-2.3863
49.8747	9.0024	50.0313	-2.2472
59.8897	7.9258	60.0285	-2.0475
69.9094	6.5055	70.0254	-1.8230
79.9333	4.7936	80.0215	-1.5436
89.9607	2.8259	90.0169	-1.2119
99.2152	0.8474	99.2391	-0.8689
99.3062	0.8267	99.3296	-0.8484
100.0000	0.0000	100.0000	0.0000

Table A4. Original measured data with some necessary smooth

X (%)	X (value)	Z (Upper)	Z (Lower)
0	0	0.1205	0.1205
0.625	0.0224375	0.1605	0.0838
1.25	0.044875	0.1824	0.0673
2.5	0.08975	0.2183	0.0455
5	0.1795	0.2708	0.0225
10	0.359	0.3408	0.0082
20	0.718	0.4128	0.001
30	1.077	0.4374	0
32.3	1.1617	0.4383	0
40	1.436	0.4312	0
50	1.795	0.4043	0
60	2.154	0.3607	0
70	2.513	0.3036	0
80	2.872	0.2408	0
90	3.231	0.1505	0
99.1	3.5588	0.0637	0
99.4	3.567	0.0614	0.0011
100	3.59	0.0312	0.0312

Table A5. Rotation for Base-line to Nose-tail conversion

	rad	deg	
angle=	-0.02486952	-1.42491873	
x_int_up	z_int_up	x_int_lo	z_int_lo
-0.00299647	0.12046274	-0.00299647	0.12046274
0.01843941	0.16100832	0.02034671	0.08433204
0.04032539	0.1834595	0.04318758	0.06839509
0.08429379	0.2204643	0.0885908	0.04771774
0.17271052	0.27517988	0.17888499	0.02695666
0.35041433	0.34962185	0.35868508	0.0171247
0.70751289	0.43052683	0.71775311	0.01885417
1.06579015	0.46404646	1.07666696	0.02678172
1.15044158	0.46705241	1.16134077	0.02888795
1.42483331	0.46677561	1.43555594	0.03570895
1.78439122	0.44881117	1.79444493	0.04463619
2.1443644	0.41415189	2.15333392	0.05356343
2.50467329	0.36599679	2.5122229	0.06249067
2.86512393	0.31214345	2.87111189	0.07141791
3.2262584	0.23079861	3.23000088	0.08034515
3.55611548	0.15217684	3.55769951	0.08849654
3.56437014	0.15008146	3.56586962	0.08980011
3.58811401	0.12046274	3.58811401	0.12046274

Table A6. NACA sectional format

r=	23”	r/R=	0.79310345
x_new_up	z_new_up	x_new_lo	z_new_lo
0.0000	0.0000	0.0000	0.0000
0.5969	1.1291	0.6500	-1.0061
1.2064	1.7542	1.2861	-1.4499

2.4307	2.7847	2.5504	-2.0257
4.8928	4.3083	5.0648	-2.6038
9.8413	6.3813	10.0716	-2.8776
19.7852	8.6342	20.0704	-2.8294
29.7620	9.5676	30.0649	-2.6087
32.1193	9.6513	32.4228	-2.5500
39.7601	9.6436	40.0587	-2.3601
49.7726	9.1434	50.0525	-2.1115
59.7966	8.1782	60.0463	-1.8629
69.8299	6.8373	70.0402	-1.6143
79.8672	5.3376	80.0340	-1.3657
89.9236	3.0725	90.0278	-1.1171
99.1090	0.8831	99.1531	-0.8901
99.3388	0.8248	99.3806	-0.8538
100.0000	0.0000	100.0000	0.0000

Table A7. Original measured data with some necessary smooth

X (%)	X (value)	Z (upper)	Z (lower)
0	0	0.0626	0.0626
0.625	0.02088125	0.1016	0.0288
1.25	0.0417625	0.1217	0.0175
2.5	0.083525	0.1512	0.0066
5	0.16705	0.1975	0
10	0.3341	0.2617	0
20	0.6682	0.3281	0
30	1.0023	0.3509	0
34.3	1.1463	0.3531	0
40	1.3364	0.3493	0
50	1.6705	0.3244	0
60	2.0046	0.2816	0
70	2.3387	0.2301	0
80	2.6728	0.1692	0
90	3.0069	0.0961	0
99.2	3.315	0.0308	0
100	3.341	0	0

Table A8. Rotation for Base-line to Nose-tail conversion

	rad	deg	
angle=	-0.01873471	-1.07341998	
x_int_up	z_int_up	x_int_lo	z_int_lo
-0.00117272	0.06258901	-0.00117272	0.06258901
0.01897425	0.10197335	0.02033806	0.02918613
0.03947529	0.12246101	0.04142733	0.01827929
0.08067782	0.15273819	0.0833867	0.00816357
0.1633208	0.20059479	0.16702068	0.00312945
0.32913878	0.26791298	0.33404137	0.0062589
0.66193624	0.34056022	0.66808274	0.0125178
0.99555048	0.36961513	1.00212411	0.0187767
1.139484	0.37451238	1.14609884	0.02147435
1.32962182	0.37427431	1.33616548	0.02503561
1.66412966	0.35563758	1.67020684	0.03129451
1.99897283	0.31910399	2.00424821	0.03755341
2.33397898	0.27387193	2.33828958	0.04381231
2.66916122	0.21924152	2.67233095	0.05007121
3.00457202	0.15241325	3.00637232	0.05633011
3.31384126	0.09289654	3.31441825	0.06210194
3.34041369	0.06258901	3.34041369	0.06258901

Table A9. NACA sectional format

r=	**29**	**r/R=**	**1**

x_new_up	z_new_up	x_new_lo	z_new_lo
0.0000	0.0000	0.0000	0.0000
0.6029	1.1786	0.6437	-0.9996
1.2164	1.7917	1.2748	-1.3260
2.4495	2.6978	2.5305	-1.6287
4.9226	4.1299	5.0333	-1.7794
9.8849	6.1445	10.0316	-1.6857
19.8441	8.3185	20.0281	-1.4984
29.8278	9.1880	30.0246	-1.3111
34.1352	9.3346	34.3331	-1.2304
39.8252	9.3275	40.0211	-1.1238
49.8357	8.7697	50.0175	-0.9365
59.8562	7.6764	60.0140	-0.7492
69.8815	6.3228	70.0105	-0.5619
79.9122	4.6880	80.0070	-0.3746
89.9496	2.6881	90.0035	-0.1873
99.2048	0.9070	99.2221	-0.0146
100.0000	0.0000	100.0000	0.0000

5 APPENDIX B: FINAL SECTIONAL OFFSETS FOR PROPELLA INPUT

Table B1. Sectional Offsets at r/R=0.3

r=	8.7000”	r/R=	0.3000
x_new_up	Z_new_up	x_new_lo	z_new_lo
0.0000	0.0000	0.0000	0.0000
0.6385	1.0964	0.6133	-1.0966
1.2736	2.4331	1.2326	-1.3120
2.5353	3.5149	2.4796	-1.8878
5.0525	4.8881	4.9738	-2.5265
10.0759	6.7448	9.9680	-3.3358
20.1014	8.9836	19.9646	-3.9693
30.1104	9.8972	29.9643	-4.1899
37.4332	10.0316	37.2862	-4.2280
40.1102	9.9523	39.9651	-4.2376
50.1032	9.3374	49.9664	-4.1413
60.0908	8.2131	59.9688	-3.9140
70.0742	6.6636	69.9721	-3.5067
80.0542	4.8072	79.9769	-2.8519
90.0318	2.7921	89.9834	-1.8972
99.0541	0.9446	99.0342	-0.9018
100.0000	0.0000	100.0000	0.0000

Table B2. Sectional Offsets at r/R=0.4

r=	11.6000”	r/R=	0.4000
x_new_up	Z_new_up	x_new_lo	z_new_lo
0.0000	0.0000	0.0000	0.0000
0.6277	1.1507	0.6222	-1.0602
1.2562	2.2387	1.2469	-1.4395
2.5089	3.2927	2.4953	-1.8397
5.0123	4.7498	4.9936	-2.4104
10.0168	6.7298	9.9914	-3.0509
20.0224	8.9789	19.9897	-3.4981
30.0247	9.8275	29.9890	-3.6064
35.2183	9.9238	35.1822	-3.6271
40.0249	9.8379	39.9889	-3.5908
50.0233	9.2203	49.9891	-3.4794
60.0205	8.1127	59.9897	-3.2618
70.0166	6.6084	69.9907	-2.9184
80.0120	4.8025	79.9925	-2.3948
90.0069	2.8039	89.9951	-1.6577
99.1104	0.9106	99.1058	-0.8903
100.0000	0.0000	100.0000	0.0000

Table B3. Sectional Offsets at r/R=0.5

r=	14.5000”	r/R=	0.5000
x_new_up	Z_new_up	x_new_lo	z_new_lo
0.0000	0.0000	0.0000	0.0000
0.6169	1.2051	0.6311	-1.0239
1.2389	2.0443	1.2611	-1.5670
2.4826	3.0704	2.5109	-1.7917
4.9721	4.6116	5.0134	-2.2942
9.9577	6.7148	10.0149	-2.7661
19.9433	8.9741	20.0148	-3.0269
29.9389	9.7578	30.0138	-3.0230
33.0035	9.8160	33.0783	-3.0263
39.9396	9.7236	40.0127	-2.9439

49.9435	9.1033	50.0118	-2.8176
59.9502	8.0123	60.0105	-2.6097
69.9591	6.5531	70.0093	-2.3301
79.9697	4.7977	80.0081	-1.9376
89.9821	2.8157	90.0068	-1.4183
99.1667	0.8767	99.1774	-0.8788
100.0000	0.0000	100.0000	0.0000

Table B4. Sectional Offsets at r/R=0.6

r=	17.4000"	r/R=	0.6000
x_new_up	Z_new_up	x_new_lo	z_new_lo
0.0000	0.0000	0.0000	0.0000
0.6069	1.2437	0.6396	-0.9934
1.2227	1.8686	1.2742	-1.6618
2.4580	2.8725	2.5261	-1.7686
4.9345	4.4801	5.0328	-2.2214
9.9023	6.6805	10.0375	-2.5444
19.8691	8.9475	20.0387	-2.6346
29.8581	9.6890	30.0371	-2.5259
31.1627	9.7183	31.3419	-2.5112
39.8590	9.6263	40.0349	-2.3846
49.8679	9.0118	50.0327	-2.2381
59.8835	7.9427	60.0297	-2.0352
69.9041	6.5276	70.0264	-1.8091
79.9289	4.8299	80.0223	-1.5317
89.9582	2.8423	90.0176	-1.2056
99.2081	0.8498	99.2333	-0.8703
100.0000	0.0000	100.0000	0.0000

Table B5. Sectional Offsets at r/R=0.7

r=	20.3000"	r/R=	0.7000
x_new_up	Z_new_up	x_new_lo	z_new_lo
0.0000	0.0000	0.0000	0.0000
0.6017	1.1843	0.6450	-1.0000
1.2142	1.8094	1.2803	-1.5521
2.4439	2.8270	2.5387	-1.9018
4.9129	4.3912	5.0494	-2.4194
9.8707	6.5255	10.0552	-2.7169
19.8257	8.7853	20.0551	-2.7355
29.8084	9.6262	30.0515	-2.5688
31.6581	9.6836	31.9016	-2.5313
39.8078	9.6353	40.0472	-2.3719
49.8185	9.0799	50.0430	-2.1725
59.8385	8.0647	60.0383	-1.9460
69.8657	6.6880	70.0335	-1.7082
79.8969	5.0928	80.0284	-1.4458
89.9403	2.9615	90.0229	-1.1598
99.1567	0.8670	99.1918	-0.8806
100.0000	0.0000	100.0000	0.0000

Table B6. Sectional Offsets at r/R=0.8

r=	23.2000"	r/R=	0.8000
x_new_up	Z_new_up	x_new_lo	z_new_lo
0.0000	0.0000	0.0000	0.0000
0.5971	1.1307	0.6498	-1.0059
1.2067	1.7555	1.2857	-1.4458
2.4314	2.7818	2.5497	-2.0125
4.8938	4.3024	5.0637	-2.5763
9.8427	6.3734	10.0702	-2.8379
19.7872	8.6237	20.0690	-2.7851
29.7642	9.5550	30.0635	-2.5654
32.1865	9.6408	32.4865	-2.5060

39.7623	9.6331	40.0575	-2.3189
49.7747	9.1309	50.0514	-2.0723
59.7986	8.1615	60.0453	-1.8258
69.8316	6.8201	70.0392	-1.5792
79.8687	5.3160	80.0331	-1.3327
89.9244	3.0597	90.0270	-1.0861
99.1121	0.8839	99.1554	-0.8609
100.0000	0.0000	100.0000	0.0000

Table B7. Sectional Offsets at r/R=0.9

r=	26.1000"	r/R=	0.9000
x_new_up	Z_new_up	x_new_lo	z_new_lo
0.0000	0.0000	0.0000	0.0000
0.6000	1.1547	0.6468	-1.0028
1.2116	1.7736	1.2803	-1.3859
2.4404	2.7398	2.5401	-1.8206
4.9082	4.2162	5.0485	-2.1779
9.8638	6.2589	10.0509	-2.2618
19.8157	8.4711	20.0485	-2.1417
29.7960	9.3715	30.0441	-1.9383
33.1608	9.4877	33.4098	-1.8682
39.7938	9.4803	40.0393	-1.7213
49.8052	8.9503	50.0345	-1.5044
59.8274	7.9190	60.0297	-1.2875
69.8566	6.5715	70.0248	-1.0706
79.8904	5.0020	80.0200	-0.8536
89.9370	2.8739	90.0152	-0.6367
99.1585	0.8955	99.1887	-0.4378
100.0000	0.0000	100.0000	0.0000

Table B8. Sectional Offsets at r/R=0.95

r=	27.5500"	r/R=	0.9500
x_new_up	Z_new_up	x_new_lo	z_new_lo
0.0000	0.0000	0.0000	0.0000
0.6015	1.1666	0.6453	-1.0012
1.2140	1.7827	1.2776	-1.3559
2.4449	2.7188	2.5353	-1.7247
4.9154	4.1731	5.0409	-1.9786
9.8743	6.2017	10.0413	-1.9738
19.8299	8.3948	20.0383	-1.8201
29.8119	9.2798	30.0343	-1.6247
33.6480	9.4111	33.8715	-1.5493
39.8095	9.4039	40.0302	-1.4226
49.8204	8.8600	50.0260	-1.2205
59.8418	7.7977	60.0218	-1.0184
69.8691	6.4472	70.0177	-0.8162
79.9013	4.8450	80.0135	-0.6141
89.9433	2.7810	90.0094	-0.4120
99.1816	0.9012	99.2054	-0.2262
100.0000	0.0000	100.0000	0.0000

Table B9. Sectional Offsets at r/R=1.0

r=	29.0000"	r/R=	1.0000
x_new_up	z_new_up	x_new_lo	z_new_lo
0.0000	0.0000	0.0000	0.0000
0.6029	1.1786	0.6437	-0.9996
1.2164	1.7917	1.2748	-1.3260
2.4495	2.6978	2.5305	-1.6287
4.9226	4.1299	5.0333	-1.7794
9.8849	6.1445	10.0316	-1.6857
19.8441	8.3185	20.0281	-1.4984
29.8278	9.1880	30.0246	-1.3111

34.1352	9.3346	34.3331	-1.2304
39.8252	9.3275	40.0211	-1.1238
49.8357	8.7697	50.0175	-0.9365
59.8562	7.6764	60.0140	-0.7492
69.8815	6.3228	70.0105	-0.5619
79.9122	4.6880	80.0070	-0.3746
89.9496	2.6881	90.0035	-0.1873
99.2048	0.9070	99.2221	-0.0146
100.0000	0.0000	100.0000	0.0000

6 APPENDIX C: PROPULSION PERFORMANCE DATA FOR THE SERIES OF 12 PROPELLERS

Tables C1-C12 and figures C1-C12 show the *4, 6* and *8* blade propellers with a nominal pitch angle at *r/R=0.75 of 6.2244°*.

In the following, the prefix of the data titles *J*, K_t, *Kq*, *eta*, K_p, K_s, F_{tp}, etc, stands for advance coefficient, thrust coefficient, torque coefficient, propeller open water/air efficiency, thrust power coefficient and thrust to power ratio, that were defined in equations (2) to (9). Term "4B" stands for a 4-bladed propeller and "POD02570" stands for a nominal pitch to diameter ratio at 0.75R being 0.2570.

Table C1. Propulsive characteristics: 6.2244 deg., p/D=0.2570 for 4-blade

J_4B_PO D02570	Kt_4B_PO D02570	Kq_4B_P OD02570	eta_4B_P OD02570	Kp_4B_P OD02570	Ks_4B_PO D02570	Ftp_4B_P OD02570	20Ftp_4B_ POD02570
0.00	0.0884	0.0063	0.0000	0.0394	0.0000	0.0240	0.4807
0.10	0.0612	0.0061	0.1585	0.0386	0.1917	0.0170	0.3398
0.20	0.0343	0.0059	0.1865	0.0368	0.3871	0.0100	0.1999
0.30	0.0079	0.0054	0.0696	0.0340	0.5899	0.0025	0.0497
0.40	-0.0207	0.0047	-0.2784	0.0298	0.8078	-0.0075	-0.1492

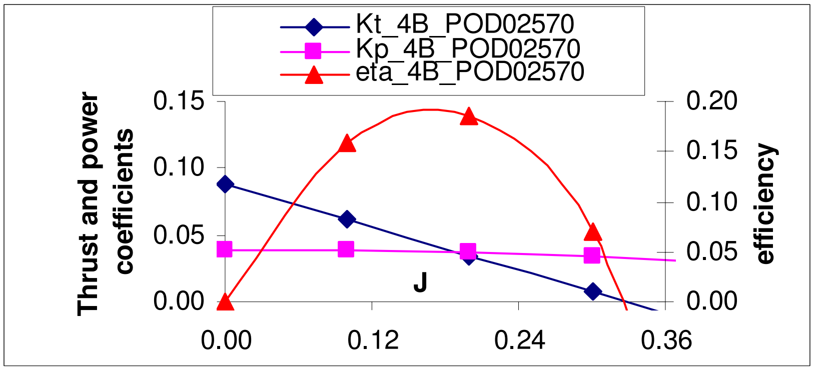

Figure C1. Thrust and power coefficients and efficiency versus advance coefficient at nominal pitch angle of *6.2244°* for the 4-blade propeller.

Table C2. Propulsive characteristics: 6.2244 deg., p/D=0.2570 for 6-blade

J_6B_POD 02570	Kt_6B_PO D02570	Kq_6B_PO D02570	eta_6B_PO D02570	Kp_6B_PO D02570	Ks_6B_PO D02570	Ftp_6B_PO D02570	20Ftp_6B_ POD02570
0.00	0.1133	0.0094	0.0000	0.0589	0.0000	0.0206	0.4124
0.10	0.0770	0.0090	0.1355	0.0568	0.1775	0.0145	0.2905
0.20	0.0420	0.0086	0.1556	0.0540	0.3586	0.0083	0.1667
0.30	0.0083	0.0080	0.0494	0.0503	0.5455	0.0018	0.0353

0.40	-0.0281	0.0072	-0.2487	0.0452	0.7431	-0.0067	-0.1333

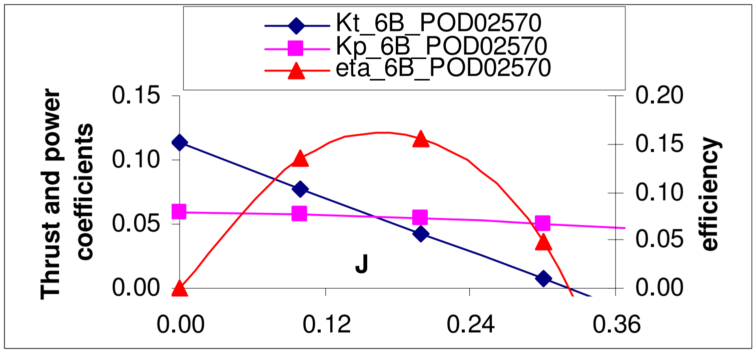

Figure C2. Thrust and power coefficients and efficiency versus advance coefficient at nominal pitch angle of *6.2244°* for the *6*-blade propeller.

Table C3. Propulsive characteristics: 6.2244 deg., p/D=0.2570 for 8-blade

J_8B_PO D02570	Kt_8B_PO D02570	Kq_8B_PO D02570	eta_8B_PO D02570	Kp_8B_PO D02570	Ks_8B_PO D02570	Ftp_8B_PO D02570	20Ftp_8B_P OD02570
0.00	0.1352	0.0125	0.0000	0.0785	0.0000	0.0185	0.3693
0.10	0.0904	0.0119	0.1208	0.0748	0.1680	0.0130	0.2590
0.20	0.0481	0.0113	0.1358	0.0708	0.3396	0.0073	0.1455
0.30	0.0082	0.0106	0.0370	0.0665	0.5159	0.0013	0.0265
0.40	-0.0345	0.0097	-0.2387	0.0503	0.7275	-0.0064	-0.1279

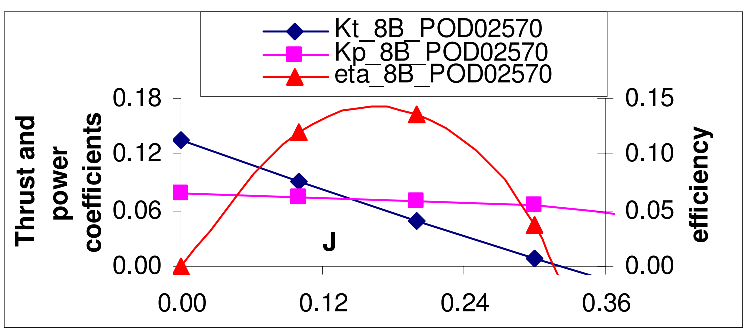

Figure C3. Thrust and power coefficients and efficiency versus advance coefficient at nominal pitch angle of *6.2244°* for the *8*-blade propeller.

Table C4. Propulsive characteristics: Pitch angle 10.2244 deg. p/D=0.4250 for 4-blade

J_4B_PO D04250	Kt_4B_PO D04250	Kq_4B_PO D04250	eta_4B_PO D04250	Kp_4B_PO D04250	Ks_4B_PO D04250	Ftp_4B_PO D04250	20Ftp_4B_P OD04250
0.00	0.1447	0.0088	0.0000	0.0554	0.0000	0.0280	0.5600
0.10	0.1143	0.0085	0.2149	0.0532	0.1798	0.0230	0.4607
0.20	0.0842	0.0079	0.3395	0.0496	0.3647	0.0182	0.3638

0.30	0.0542	0.0071	0.3652	0.0446	0.5589	0.0130	0.2609
0.40	0.0244	0.0061	0.2564	0.0381	0.7689	0.0069	0.1374
0.50	-0.0056	0.0048	-0.0928	0.0301	1.0078	-0.0020	-0.0398

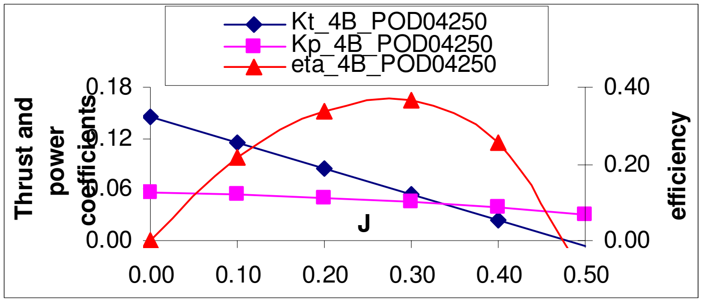

Figure C4. Thrust and power coefficients and efficiency versus advance coefficient at nominal pitch angle of *10.2244°* for the *4*-blade propeller.

Table C5. Propulsive characteristics: Pitch angle 10.2244 deg. p/D=0.4250 for 6-blade

J_6B_PO D04250	Kt_6B_PO D04250	Kq_6B_PO D04250	eta_6B_PO D04250	Kp_6B_PO D04250	Ks_6B_PO D04250	Ftp_6B_PO D04250	20Ftp_6B_P OD04250
0.00	0.1903	0.0128	0.0000	0.0807	0.0000	0.0253	0.5056
0.10	0.1491	0.0122	0.1947	0.0766	0.1672	0.0209	0.4173
0.20	0.1088	0.0113	0.3064	0.0710	0.3394	0.0164	0.3284
0.30	0.0693	0.0102	0.3250	0.0639	0.5200	0.0116	0.2322
0.40	0.0302	0.0088	0.2190	0.0552	0.7139	0.0059	0.1173
0.50	-0.0086	0.0071	-0.0964	0.0448	0.9305	-0.0021	-0.0413

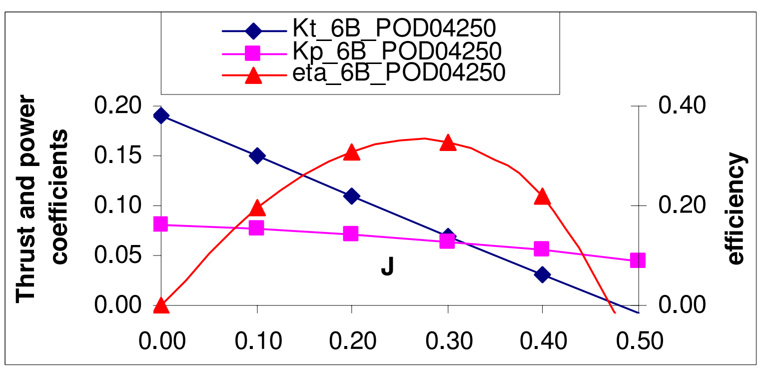

Figure C5. Thrust and power coefficients and efficiency versus advance coefficient at nominal pitch angle of *10.2244°* for the *6*-blade propeller.

Table C6. Propulsive characteristics: Pitch angle 10.2244 deg. p/D=0.4250 for 8-blade

J_8B_PO D04250	Kt_8B_PO D04250	Kq_8B_PO D04250	eta_8B_PO D04250	Kp_8B_PO D04250	Ks_8B_PO D04250	Ftp_8B_PO D04250	20Ftp_8B_P OD04250
0.00	0.2319	0.0166	0.0000	0.1040	0.0000	0.0239	0.4777
0.10	0.1797	0.0157	0.1827	0.0984	0.1590	0.0196	0.3917

0.20	0.1296	0.0145	0.2844	0.0911	0.3229	0.0152	0.3049
0.30	0.0813	0.0131	0.2964	0.0823	0.4943	0.0106	0.2118
0.40	0.0345	0.0114	0.1922	0.0718	0.6773	0.0051	0.1030
0.50	-0.0114	0.0095	-0.0959	0.0594	0.8793	-0.0021	-0.0411

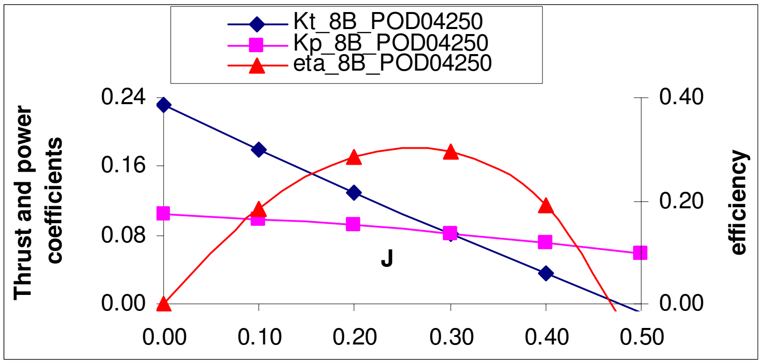

Figure C6. Thrust and power coefficients and efficiency versus advance coefficient at nominal pitch angle of *10.2244°* for the *8*-blade propeller.

Table C7. Propulsive characteristics: Pitch angle 15.2244 deg. p/D=0.6412 for 4-blade

J_4B_POD06412	Kt_4B_POD06412	Kq_4B_POD06412	eta_4B_POD06412	Kp_4B_POD06412	Ks_4B_POD06412	Ftp_4B_POD06412	20Ftp_4B_POD06412
0.00	0.2123	0.0144	0.0000	0.0903	0.0000	0.0252	0.5043
0.10	0.1807	0.0138	0.2089	0.0865	0.1631	0.0224	0.4477
0.20	0.1492	0.0129	0.3680	0.0811	0.3305	0.0197	0.3944
0.30	0.1178	0.0118	0.4779	0.0740	0.5050	0.0171	0.3415
0.40	0.0866	0.0104	0.5316	0.0651	0.6907	0.0142	0.2849
0.50	0.0553	0.0087	0.5070	0.0546	0.8945	0.0109	0.2174
0.60	0.0240	0.0067	0.3411	0.0422	1.1301	0.0061	0.1219
0.70	-0.0078	0.0044	-0.1967	0.0278	1.4331	-0.0030	-0.0602

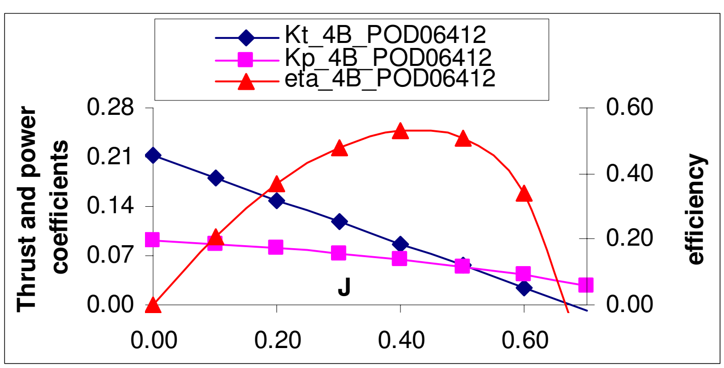

Figure C7. Thrust and power coefficients and efficiency versus advance coefficient at nominal pitch angle of *15.2244°* for the *4*-blade propeller.

Table C8. Propulsive characteristics: Pitch angle 15.2244 deg. p/D=0.6412 for 6-blade

J_6B_POD06412	Kt_6B_POD06412	Kq_6B_POD06412	eta_6B_POD06412	Kp_6B_POD06412	Ks_6B_POD06412	Ftp_6B_POD06412	20Ftp_6B_POD06412
0.00	0.2836	0.0209	0.0000	0.1313	0.0000	0.0231	0.4628
0.10	0.2409	0.0198	0.1936	0.1245	0.1517	0.0207	0.4149
0.20	0.1985	0.0184	0.3433	0.1156	0.3079	0.0184	0.3679
0.30	0.1564	0.0167	0.4472	0.1049	0.4710	0.0160	0.3196
0.40	0.1144	0.0147	0.4966	0.0922	0.6444	0.0133	0.2661
0.50	0.0727	0.0123	0.4689	0.0775	0.8340	0.0101	0.2010
0.60	0.0308	0.0097	0.3044	0.0607	1.0509	0.0054	0.1087
0.70	-0.0117	0.0066	-0.1973	0.0415	1.3229	-0.0030	-0.0604

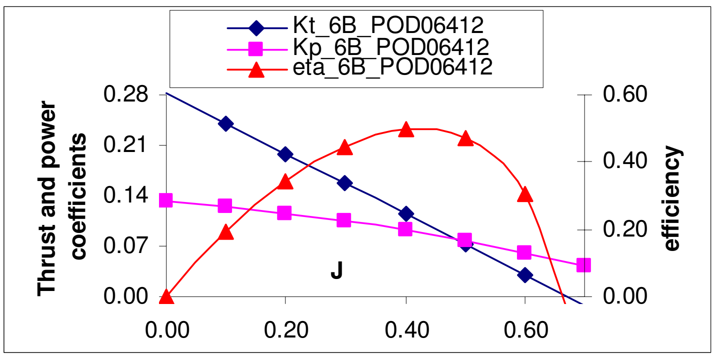

Figure C8. Thrust and power coefficients and efficiency versus advance coefficient at nominal pitch angle of *15.2244°* for the *6*-blade propeller.

Table C9. Propulsive characteristics: Pitch angle 15.2244 deg. p/D=0.6412 for 8-blade

J_8B_POD06412	Kt_8B_POD06412	Kq_8B_POD06412	eta_8B_POD06412	Kp_8B_POD06412	Ks_8B_POD06412	Ftp_8B_POD06412	20Ftp_8B_POD06412
0.00	0.3489	0.0268	0.0000	0.1683	0.0000	0.0222	0.4444
0.10	0.2947	0.0252	0.1858	0.1586	0.1445	0.0199	0.3984
0.20	0.2414	0.0234	0.3289	0.1468	0.2936	0.0176	0.3526
0.30	0.1889	0.0211	0.4266	0.1329	0.4492	0.0152	0.3048
0.40	0.1373	0.0186	0.4700	0.1168	0.6145	0.0126	0.2519
0.50	0.0863	0.0157	0.4376	0.0986	0.7947	0.0094	0.1876
0.60	0.0357	0.0124	0.2746	0.0781	0.9991	0.0049	0.0981
0.70	-0.0152	0.0087	-0.2026	0.0553	1.2490	-0.0031	-0.0620

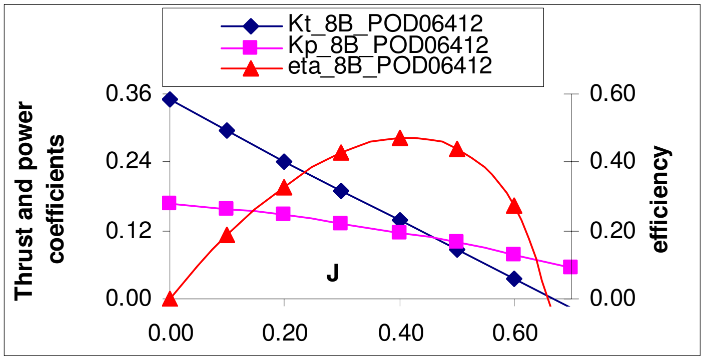

Figure C9. Thrust and power coefficients and efficiency versus advance coefficient at nominal pitch angle of *15.2244°* for the *8*-blade propeller.

Table C10. Propulsive characteristics: Pitch angle 20.2244 deg. p/D=0.8680 for 4-blade

J_4B_PO D08680	Kt_4B_PO D08680	Kq_4B_PO D08680	eta_4B_PO D08680	Kp_4B_PO D08680	Ks_4B_PO D08680	Ftp_4B_PO D08680	20Ftp_4B_P OD08680
0.00	0.2730	0.0221	0.0000	0.1390	0.0000	0.0211	0.4210
0.10	0.2421	0.0214	0.1802	0.1344	0.1494	0.0193	0.3862
0.20	0.2112	0.0204	0.3303	0.1279	0.3018	0.0177	0.3540
0.30	0.1803	0.0190	0.4526	0.1195	0.4588	0.0162	0.3234
0.40	0.1494	0.0174	0.5470	0.1092	0.6229	0.0147	0.2931
0.50	0.1184	0.0154	0.6100	0.0970	0.7972	0.0131	0.2615
0.60	0.0874	0.0132	0.6320	0.0830	0.9872	0.0113	0.2258
0.70	0.0562	0.0106	0.5883	0.0669	1.2023	0.0090	0.1802
0.80	0.0248	0.0078	0.4069	0.0488	1.4635	0.0055	0.1090
0.90	-0.0071	0.0045	-0.2229	0.0285	1.8335	-0.0027	-0.0531

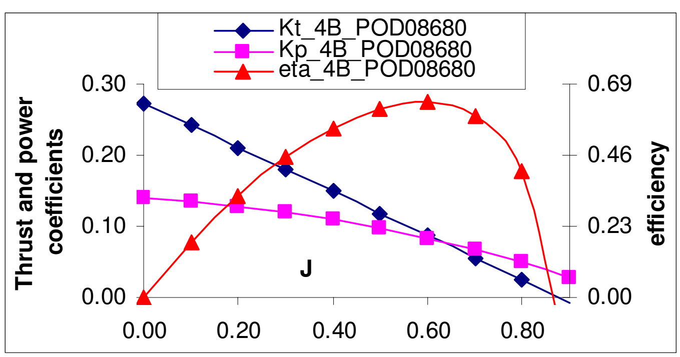

Figure C10. Thrust and power coefficients and efficiency versus advance coefficient at nominal pitch angle of *20.2244°* for the *4*-blade propeller.

Table C11. Propulsive characteristics: Pitch angle 20.2244 deg. p/D=0.8680 for 6-blade

J_6B_POD08680	Kt_6B_POD08680	Kq_6B_POD08680	eta_6B_POD08680	Kp_6B_POD08680	Ks_6B_POD08680	Ftp_6B_POD08680	20Ftp_6B_POD08680
0.00	0.3702	0.0323	0.0000	0.2028	0.0000	0.0196	0.3912
0.10	0.3282	0.0309	0.1689	0.1943	0.1388	0.0181	0.3621
0.20	0.2862	0.0292	0.3121	0.1835	0.2808	0.0167	0.3345
0.30	0.2443	0.0271	0.4301	0.1704	0.4274	0.0154	0.3073
0.40	0.2022	0.0247	0.5220	0.1550	0.5808	0.0140	0.2797
0.50	0.1602	0.0219	0.5833	0.1373	0.7438	0.0125	0.2501
0.60	0.1180	0.0187	0.6035	0.1173	0.9211	0.0108	0.2156
0.70	0.0756	0.0151	0.5574	0.0949	1.1211	0.0085	0.1707
0.80	0.0328	0.0111	0.3746	0.0700	1.3616	0.0050	0.1004
0.90	-0.0107	0.0067	-0.2278	0.0424	1.6937	-0.0027	-0.0543

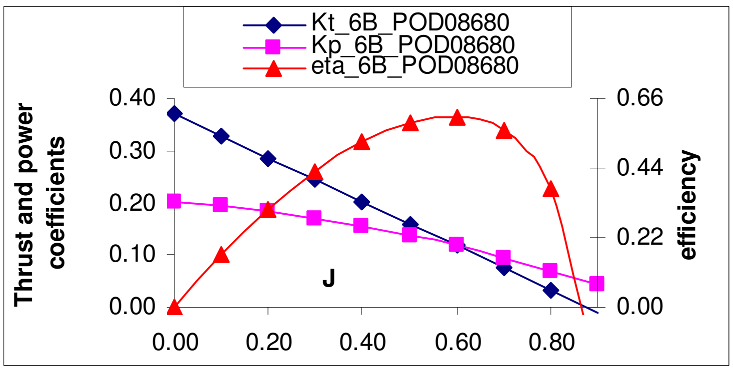

Figure C11. Thrust and power coefficients and efficiency versus advance coefficient at nominal pitch angle of *20.2244*° for the *6*-blade propeller.

Table C12. Propulsive characteristics: Pitch angle 20.2244 deg. p/D=0.8680 for 8-blade

J_8B_POD08680	Kt_8B_POD08680	Kq_8B_POD08680	eta_8B_POD08680	Kp_8B_POD08680	Ks_8B_POD08680	Ftp_8B_POD08680	20Ftp_8B_POD08680
0.00	0.4534	0.0416	0.0000	0.2617	0.0000	0.0186	0.3714
0.10	0.4015	0.0396	0.1612	0.2490	0.1321	0.0173	0.3456
0.20	0.3497	0.0372	0.2991	0.2338	0.2675	0.0160	0.3206
0.30	0.2980	0.0344	0.4135	0.2162	0.4075	0.0148	0.2954
0.40	0.2463	0.0312	0.4929	0.1948	0.5548	0.0132	0.2641
0.50	0.1946	0.0276	0.5400	0.1759	0.7078	0.0116	0.2315
0.60	0.1429	0.0236	0.5348	0.1571	0.8688	0.0096	0.1910
0.70	0.0909	0.0191	0.5013	0.1257	1.0599	0.0077	0.1535
0.80	0.0385	0.0143	0.3183	0.1005	1.2666	0.0043	0.0853
0.90	-0.0147	0.0089	-0.2149	0.0628	1.5653	-0.0026	-0.0512

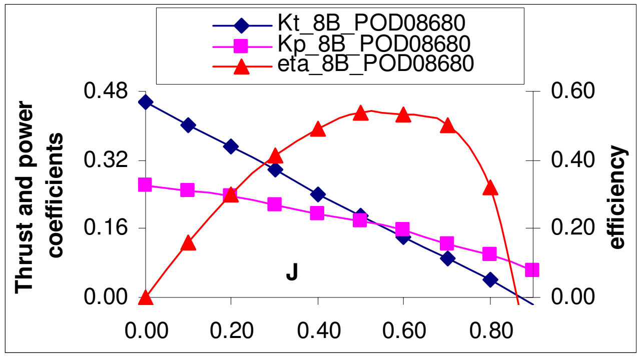

Figure C12. Thrust and power coefficients and efficiency versus advance coefficient at nominal pitch angle of *20.2244*° for the *8*-blade propeller.

7 APPENDIX D: SAMPLE INPUT FILE FOR PROPELLA

Job *Remarks* (prop name, job features):
Remarks:Warp_Drive
*********************** PANEL ARRANGEMENT ******************
Planform grid type (spanwise) *XYGridTp* (UNIFORM/COSINE/DOBCOS):
UNIFORM
Sectional grid type (chordwise) *XZGridTp* (UNIFORM/COSINE/SEMICOS):
UNIFORM
Choose *PITCH* based on Nose-Tail or Base-Line (NT/BL):
NT
Shaft inclination *PS_Incline* in degrees (real, negative front up):
0
Number of spanwise intervals *NSpIntK* for the Key Blade (Integer):
16
Number of chordwise intervals *NChIntK* for the Key Blade (Integer):
16
Number of spanwise intervals *NSpIntD* for the Dummy Blade (Integer):
16
Number of chordwise intervals *NChIntD* for the Dummy Blade (Integer):
16
Number of axial intervals *NFrt_Ax* in Front of the Hub (integer):
6
Number of axial intervals *NRr_Ax* at Rear of the Hub (integer):
6
Number of hub circular intervals on blade back side *NFrt_Cir* (integer):
48
Number of hub circular intervals on blade face side *NRr_Cir* (integer):
48
No. of panels between blades *N_B_Intv* (integer):
6
Number of blades *N_Blade* (integer, N_Blade on [2,10]):
8
Output DXF file option *DXF_STEP* (YES/NO):
YES
Output DXF file option *DXF_PATH* (YES/NO):
YES
Length *RrHubLng* of the rear elliptic cone based on H_to_D is: (real)
0.6
Hydrodynamic panel layout for rear elliptic hub cone *RrHydro* (Y/N):
Y
Length *FrHubLng* of the front cylinder based on H_to_D is: (real no.)
0.3
Hydrodynamic panel layout for front cylindrical hub *FrHydro* (Y/N):
Y
Front hub shape *FrHubShape* (CYLINDRICAL/CONICAL):
CONICAL
Root Hub Angle *RH_angle* (float):
0
Pod/Strut Inclusion *Pod_Strut* (Y/N):
N
Pod/Strut relative velocity to propeller *Pod_Veloc* (float/real):
1
Pod/Strut relative velocity to propeller *Strut_Veloc* (float/real):
1
Yaw (Helm) angle of Propeller in degrees *Yaw_Prop* (float/real):
0
Yaw (Helm) angle of Pod in degrees *Yaw_Pod* (float/real):
0
Yaw (Helm) angle of Strut in degrees *Yaw_Strut* (float/real):
0
Yaw (Helm) Angular velocity of Propeller+Pod+Strut degree/sec *V_Yaw* (float/real):
0
************************ MOTION PARAMETERS********************
Number of time steps *NTStep* per revolution (Integer):

```
36
Number of revolutions per minute *Turn_rpm* (real number):
3800
Number of total revolutions *T_Rev* (real number):
3
Advance ratio of the propeller *Ad_Ratio* (real number):
0.4
Fluid density *Rho* in kg/m^3 (real number):
1.225
Option of axial Wake velocity *Axial_W* (SET/AUTO) (string):
AUTO
Manual setup of wake vel. factor *Axial_V* (real number,1.0=Auto stretch=Vslip):
1
Wake contraction factor *W_Shrink* (real number 0.1->1.0):
1
Wake rollup iteration *I_WakeRollUp* (integer, if 0, then no rollup):
0
Enforce cavitation or not *EnforceCAV* (Y/N):
N
Cavitation number *Cn* (real number):
10
Propeller shaft immersion depth *DepthS* (real number in diameter of propeller):
1
Water temperature in degee C *TempFluid* (real num., 0.0 to 100 °C):
15
Spin direction *N_Direct* (CCW=-1/CW=1 viewing from stern, integer):
1
Maximum number of IPK iterations *IPK_Max* (Integer):
100
Average pressure difference for IPK *F_Epsilon* (real number):
0.05
Number of multibody interaction iterations *BWI_Iteration* (integer):
2
***** Spindle, in-plane and out-of-plane torques calculation *****
# of total strip(s) *NSpinTt* (must be integer):
2
Strip label(s) *SpLabelSp* (must be integers):
1 8
# of total points(s) *NChSpnTt* (must be integer):
2
Panel #(s) from T.E. *SpLabelCh* (must be integers):
8 9
# of total strip(s) *NInPlnTt* (must be integer):
2
Strip label(s) *InLabelSp* (must be integers):
1 8
# of total points(s) *NChInPTt* (must be integer):
2
Panel #(s) from T.E. *InLabelCh* (must be integers):
8 9
# of total strip(s) *NOutPlTt* (must be integer):
2
Strip label(s) *OutLabel* (must be integers):
1 8
************************* OUTPUT OPTIONS *********************
Number of Output Options *N_Option* (integer):
200
Option index *IO_Index* (integer, change sequence to disable)
   0   0   0   0   0   0   0   0   0   0
   0   0   0   0   0   0   0   0  19   0
   0   0   0   0   0   0   0   0   0   0
   0   0   0   0   0   0   0   0   0   0
   0   0   0   0   0   0   0  48   0   0
   0   0   0   0   0   0   0  58   0   0
  61   0   0   0   0   0  67  68  69  70
   0   0   0   0   0  76  77  78  79   0
   0  82  83  84  85  86   0  88  89  90
  91  92   0   0   0   0   0   0   0   0
   0   0   0   0   0   0   0 108   0   0
   0   0 113 114   0   0   0   0   0 120
```

```
 121    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0
   0  152    0    0    0    0    0    0    0  160
   0    0    0    0    0    0    0    0    0    0
 171  172  173    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0
   0    0    0    0    0    0    0    0    0    0
******************* Blade Outline Input ********************
----------------Troost B4-55 Blade Planform Input-----------------------
Number of radii *N_Radius* are available for given offset (integer):
9
Diameter of the propeller *DIAMETER* in meters (real number):
1.4732
Ratio of the hub diameter to the propeller diameter *H_to_D* (real):
0.3
Pitch at 0.7R based on DIAMETER *Pitch07R* (real number):
0.2814
PITCH at RootChord *RtPitch* is (real number)
0.2610
Setting the wake angle factor or not? *S_W_Ang*(AUTO/MANUAL/NO)
AUTO
Root Hub Angle *RH_angle* (float):
0.0
Front hub shape *FrHubShape* (CYLINDRICAL/CONICAL):
CONICAL
---------------------------------------------------------------------
RADIUS   CHRDLNG  PITCH     SKEW     RAKE    ThickUp  ThickLo  SWAngOffst
                 *Blade Outline Marker*
0.3000   0.0586   0.2610  0.0000    0.0000  1.00     1.00    0.0
0.4000   0.0608   0.3015  0.0000    0.0000  1.00     1.00    0.0
0.5000   0.0622   0.3186  0.0000    0.0000  1.00     1.00    0.0
0.6000   0.0628   0.3120  0.0000    0.0000  1.00     1.00    0.0
0.7000   0.0626   0.2814  0.0000    0.0000  1.00     1.00    0.0
0.8000   0.0617   0.2263  0.0000    0.0000  1.00     1.00    0.0
0.9000   0.0600   0.1461  0.0000    0.0000  1.00     1.00    0.0
0.9500   0.0589   0.0963  0.0000    0.0000  1.00     1.00    0.0
1.0000   0.0576   0.0400  0.0000    0.0000  1.00     1.00    0.0
------------------------Troost B Blade Sectional Input--------------------
Max. thick. at shaft centre based on DIAMETER *Thick_0* (real number):
0.014500
Max. thick. at 90% Radius based on DIAMETER *Thick_09* (real number):
0.007034
Blade tip thickness *Thick_Tip* at r=1.0R based on DIAMETER (real):
0.006085
                          *BLADE SECTIONS*
Number of given sectional offsets *NC_Statn* (integer):
17
*Statn_Up*   *Thick_Up*  *Statn_Lo*  *Thick_Lo*
  0.0000   0.0000    0.0000    0.0000
  0.6385   1.0964    0.6133   -1.0966
  1.2736   2.4331    1.2326   -1.3120
  2.5353   3.5149    2.4796   -1.8878
  5.0525   4.8881    4.9738   -2.5265
 10.0759   6.7448    9.9680   -3.3358
 20.1014   8.9836   19.9646   -3.9693
 30.1104   9.8972   29.9643   -4.1899
 37.4332  10.0316   37.2862   -4.2280
 40.1102   9.9523   39.9651   -4.2376
 50.1032   9.3374   49.9664   -4.1413
 60.0908   8.2131   59.9688   -3.9140
 70.0742   6.6636   69.9721   -3.5067
 80.0542   4.8072   79.9769   -2.8519
 90.0318   2.7921   89.9834   -1.8972
 99.0541   0.9446   99.0342   -0.9018
100.0000   0.0000  100.0000    0.0000

   0.0000   0.0000   0.0000   0.0000
   0.6277   1.1507   0.6222  -1.0602
   1.2562   2.2387   1.2469  -1.4395
```

2.5089	3.2927	2.4953	-1.8397
5.0123	4.7498	4.9936	-2.4104
10.0168	6.7298	9.9914	-3.0509
20.0224	8.9789	19.9897	-3.4981
30.0247	9.8275	29.9890	-3.6064
35.2183	9.9238	35.1822	-3.6271
40.0249	9.8379	39.9889	-3.5908
50.0233	9.2203	49.9891	-3.4794
60.0205	8.1127	59.9897	-3.2618
70.0166	6.6084	69.9907	-2.9184
80.0120	4.8025	79.9925	-2.3948
90.0069	2.8039	89.9951	-1.6577
99.1104	0.9106	99.1058	-0.8903
100.0000	0.0000	100.0000	0.0000

0.0000	0.0000	0.0000	0.0000
0.6169	1.2051	0.6311	-1.0239
1.2389	2.0443	1.2611	-1.5670
2.4826	3.0704	2.5109	-1.7917
4.9721	4.6116	5.0134	-2.2942
9.9577	6.7148	10.0149	-2.7661
19.9433	8.9741	20.0148	-3.0269
29.9389	9.7578	30.0138	-3.0230
33.0035	9.8160	33.0783	-3.0263
39.9396	9.7236	40.0127	-2.9439
49.9435	9.1033	50.0118	-2.8176
59.9502	8.0123	60.0105	-2.6097
69.9591	6.5531	70.0093	-2.3301
79.9697	4.7977	80.0081	-1.9376
89.9821	2.8157	90.0068	-1.4183
99.1667	0.8767	99.1774	-0.8788
100.0000	0.0000	100.0000	0.0000

0.0000	0.0000	0.0000	0.0000
0.6069	1.2437	0.6396	-0.9934
1.2227	1.8686	1.2742	-1.6618
2.4580	2.8725	2.5261	-1.7686
4.9345	4.4801	5.0328	-2.2214
9.9023	6.6805	10.0375	-2.5444
19.8691	8.9475	20.0387	-2.6346
29.8581	9.6890	30.0371	-2.5259
31.1627	9.7183	31.3419	-2.5112
39.8590	9.6263	40.0349	-2.3846
49.8679	9.0118	50.0327	-2.2381
59.8835	7.9427	60.0297	-2.0352
69.9041	6.5276	70.0264	-1.8091
79.9289	4.8299	80.0223	-1.5317
89.9582	2.8423	90.0176	-1.2056
99.2081	0.8498	99.2333	-0.8703
100.0000	0.0000	100.0000	0.0000

0.0000	0.0000	0.0000	0.0000
0.6017	1.1843	0.6450	-1.0000
1.2142	1.8094	1.2803	-1.5521
2.4439	2.8270	2.5387	-1.9018
4.9129	4.3912	5.0494	-2.4194
9.8707	6.5255	10.0552	-2.7169
19.8257	8.7853	20.0551	-2.7355
29.8084	9.6262	30.0515	-2.5688
31.6581	9.6836	31.9016	-2.5313
39.8078	9.6353	40.0472	-2.3719
49.8185	9.0799	50.0430	-2.1725
59.8385	8.0647	60.0383	-1.9460
69.8657	6.6880	70.0335	-1.7082
79.8969	5.0928	80.0284	-1.4458
89.9403	2.9615	90.0229	-1.1598
99.1567	0.8670	99.1918	-0.8806
100.0000	0.0000	100.0000	0.0000

0.0000	0.0000	0.0000	0.0000

0.5971	1.1307	0.6498	-1.0059
1.2067	1.7555	1.2857	-1.4458
2.4314	2.7818	2.5497	-2.0125
4.8938	4.3024	5.0637	-2.5763
9.8427	6.3734	10.0702	-2.8379
19.7872	8.6237	20.0690	-2.7851
29.7642	9.5550	30.0635	-2.5654
32.1865	9.6408	32.4865	-2.5060
39.7623	9.6331	40.0575	-2.3189
49.7747	9.1309	50.0514	-2.0723
59.7986	8.1615	60.0453	-1.8258
69.8316	6.8201	70.0392	-1.5792
79.8687	5.3160	80.0331	-1.3327
89.9244	3.0597	90.0270	-1.0861
99.1121	0.8839	99.1554	-0.8609
100.0000	0.0000	100.0000	0.0000

0.0000	0.0000	0.0000	0.0000
0.6000	1.1547	0.6468	-1.0028
1.2116	1.7736	1.2803	-1.3859
2.4404	2.7398	2.5401	-1.8206
4.9082	4.2162	5.0485	-2.1779
9.8638	6.2589	10.0509	-2.2618
19.8157	8.4711	20.0485	-2.1417
29.7960	9.3715	30.0441	-1.9383
33.1608	9.4877	33.4098	-1.8682
39.7938	9.4803	40.0393	-1.7213
49.8052	8.9503	50.0345	-1.5044
59.8274	7.9190	60.0297	-1.2875
69.8566	6.5715	70.0248	-1.0706
79.8904	5.0020	80.0200	-0.8536
89.9370	2.8739	90.0152	-0.6367
99.1585	0.8955	99.1887	-0.4378
100.0000	0.0000	100.0000	0.0000

0.0000	0.0000	0.0000	0.0000
0.6015	1.1666	0.6453	-1.0012
1.2140	1.7827	1.2776	-1.3559
2.4449	2.7188	2.5353	-1.7247
4.9154	4.1731	5.0409	-1.9786
9.8743	6.2017	10.0413	-1.9738
19.8299	8.3948	20.0383	-1.8201
29.8119	9.2798	30.0343	-1.6247
33.6480	9.4111	33.8715	-1.5493
39.8095	9.4039	40.0302	-1.4226
49.8204	8.8600	50.0260	-1.2205
59.8418	7.7977	60.0218	-1.0184
69.8691	6.4472	70.0177	-0.8162
79.9013	4.8450	80.0135	-0.6141
89.9433	2.7810	90.0094	-0.4120
99.1816	0.9012	99.2054	-0.2262
100.0000	0.0000	100.0000	0.0000

0.0000	0.0000	0.0000	0.0000
0.6029	1.1786	0.6437	-0.9996
1.2164	1.7917	1.2748	-1.3260
2.4495	2.6978	2.5305	-1.6287
4.9226	4.1299	5.0333	-1.7794
9.8849	6.1445	10.0316	-1.6857
19.8441	8.3185	20.0281	-1.4984
29.8278	9.1880	30.0246	-1.3111
34.1352	9.3346	34.3331	-1.2304
39.8252	9.3275	40.0211	-1.1238
49.8357	8.7697	50.0175	-0.9365
59.8562	7.6764	60.0140	-0.7492
69.8815	6.3228	70.0105	-0.5619
79.9122	4.6880	80.0070	-0.3746
89.9496	2.6881	90.0035	-0.1873
99.2048	0.9070	99.2221	-0.0146
100.0000	0.0000	100.0000	0.0000

******************* Nozzle Input ********************
Enable *NOZZLE* ? (Y/N):
N
Set Hydrodynamic pitch *NZHydro* ? (Y/N):
N
Number of chordwise panel intervals *NDuctCh* (integer):
6
Number of spanwise panel intervals *NDuctSp* (integer):
18
Normalized nozzle chordlength *Duct_Lng* (real number):
0.8
Normalized nozzle front diameter *Duct_DFr* (real number):
1.25
Normalized distance (LE to prop center) *Duct_Dis* (real number):
0.3
Nozzle open angle in degrees *Duct_Ang* (real number):
4.5198
Normalized nozzle forward speed *Duct_Vel* (real number):
1
Nozzle yaw angle *Yaw_Noz* in degrees (real number):
0
Normalized nozzle thickness multiplier *ThickMul* (real number):
1
-----------------------JD 75 Simplified Nozzle---------------------------
Number of chordwise INPUT offsets *NDuctChI* (integer):
19
Chordwise spacing manual set *Ch_Duct* (Y/N):
N
If Ch_Duct='Y', specify *X_Up and X_Lo* (0..1.0, NDuctCh+1 terms):
0.0,0.02,0.06,0.12,0.18,0.24,0.30,0.36,0.42,0.50,0.60,0.70,0.76,
0.825,0.88,0.96,1.0 !17point for NDcutCh=16

0.0,0.025,0.05,0.1,0.15,0.2,0.25,0.3,0.35,0.4,0.45,0.5,0.55,
0.6,0.65,0.7,0.75,0.825,0.9,0.95,1.0
!21 points for NDuctCh=20

0.0,0.025,0.05,0.35,0.45,0.825,0.9,0.95,1.0
!9point for NDcutCh=8

0.0,0.025,0.05,0.1,0.9,0.95,1.0
!7 points for NDuctCh=6

Note: The number of figures under the line where *X_Up and X_Lo* is located
should be equal to NDuctCh+1, where NDuctCh is specified in the GUI interface
in Nozzle Input dialog box. If they do not match, nozzle section will have
funny shape and results will be trashed. Input sectional data: no. of data
lines must be = NDuctChI and from the L.E. to the T.E. and the ordinate of
the T.E. must be 0.
X_Up_In *Y_Up_In* *X_Lo_In* *Y_Lo_In*
0.000000 0.000000 0.000000 -0.000000
0.470000 1.656900 0.470000 -1.656900
1.080000 2.363300 1.080000 -2.363300
1.830000 2.839700 1.830000 -2.839700
2.560000 3.067600 2.560000 -3.067500
3.160000 3.173200 3.160000 -3.114500
9.980000 4.378900 9.980000 -2.989900
19.959999 6.144600 19.959999 -2.807600
30.480000 8.006200 30.480000 -2.615300
39.919998 7.424900 39.919998 -2.442900
50.410000 6.778300 50.410000 -2.251200
59.880001 5.717600 59.880001 -2.078200
69.860001 4.599800 69.860001 -1.895800
79.839996 3.481900 79.839996 -1.713400
89.830002 2.364000 89.830002 -1.531100
98.650002 1.375700 98.650002 -1.369800
99.199997 1.245800 99.199997 -1.245900
99.660004 0.899100 99.660004 -0.899200
100.00000 0.000000 100.00000 -0.000000
*********************************** Stator/Rudder Data Input ********************
Enable *Stator* ? (Y/N):

N
Enable Stator/Rudder LE Alignment *StAlign* ? (Y/N):
N
Normalized lower edge if no alignment with nozzle *Height_Ali*:
-0.5
Normalized height of lower part *Height_Lo*:
0.5
Normalized height of upper part *Height_Up*:
0.4
Normalized total height *H_Stator*:
1
Nozzle/Rudder yaw angle *Yaw_Rud*:
0
Normalized distance (LE to directrix) *StatorLE*:
0.5
Normalized chordlength *StatorLng*:
1
Number of overlapping panels with nozzle *IStAlign*:
2
Number of chordwise panels *NStatorCh*:
10
Number of spanwise panels *NSpSt*:
10
Number of spanwise strips above nozzle *NSpADuct*:
0
Number of spanwise strips below nozzle *NSpBDuct*:
0
Number of spanwise strips inside nozzle *NSpIDuct*:
4
------------Stator/Rudder Sectional Shape Input------------------------------
Number of stator's chordwise offset data for input *NStChI*:
10
Stator data sectional shape:

X_St_In	*Y_St_Up_In*	*Y_St_Lo_In*
0.0	0.0	0.0
2.5	2.51	-2.51
5.0	3.39	-3.39
10.0	4.47	-4.47
20.0	5.57	-5.57
30.0	5.95	-5.95
40.0	5.98	-5.98
60.0	4.85	-4.85
80.0	2.88	-2.88
100.0	0.0	0.0

****
****
******************* Non-uniform Inflow Wake Data Input ********************
Add a non-uniform flow velocity *InflowWake* to propeller plane (Y/N)?
N
----------------------Non-uniform inflow velocity input-----------------

NR_aw	*NR_tw*	*NR_rw*
6	6	6
NTheta_aw	*NTheta_aw*	*NTheta_aw*
37	37	37

---------------------Radial locations of axial wake *r_aw*----------------
0.1972 0.3000 0.5000 0.7000 0.9000 1.1000
-----------------Radial locations of tangential wake *r_tw*----------------
0.1972 0.3000 0.5000 0.7000 0.9000 1.1000
---------------------Radial locations of radial wake *r_rw*----------------
0.1972 0.3000 0.5000 0.7000 0.9000 1.1000
---------------------Polar locations of axial wake *theta_aw*---------------
0.0 10. 20. 30. 40. 50. 60. 70. 80. 90. 100. 110. 120. 130. 140. 150.
160. 170. 180. 190. 200. 210. 220. 230. 240. 250. 260. 270. 280. 290.
300. 310. 320. 330. 340. 350. 360.
----------------Polar locations of tangential wake *theta_tw*---------------
0.0 10. 20. 30. 40. 50. 60. 70. 80. 90. 100. 110. 120. 130. 140. 150.
160. 170. 180. 190. 200. 210. 220. 230. 240. 250. 260. 270. 280. 290.
300. 310. 320. 330. 340. 350. 360.
--------------------Polar locations of radial wake *theta_rw*---------------
0.0 10. 20. 30. 40. 50. 60. 70. 80. 90. 100. 110. 120. 130. 140. 150.

160. 170. 180. 190. 200. 210. 220. 230. 240. 250. 260. 270. 280. 290.
300. 310. 320. 330. 340. 350. 360.
-------------Axial wake velocity *V_aw* is V_aw(NTheta_aw,NR_aw)-----------
0.8420 0.8420 0.8099 0.8090 0.8605 0.8590
0.7655 0.7655 0.6685 0.5970 0.5701 0.6073
0.6457 0.6457 0.4839 0.3977 0.3856 0.3906
0.5247 0.5247 0.3564 0.2725 0.2532 0.2516
0.4304 0.4304 0.2517 0.1847 0.1864 0.1805
0.3385 0.3385 0.1757 0.1313 0.1407 0.1387
0.2664 0.2664 0.1175 0.0872 0.0955 0.0894
0.2098 0.2098 0.0873 0.0766 0.0807 0.0618
0.1753 0.1753 0.0761 0.0696 0.0574 0.0456
0.1512 0.1512 0.0592 0.0552 0.0398 0.0325
0.1409 0.1409 0.0505 0.0482 0.0328 0.0269
0.1352 0.1352 0.0457 0.0444 0.0288 0.0236
0.1371 0.1371 0.0453 0.0415 0.0263 0.0314
0.1497 0.1497 0.0473 0.0400 0.0278 0.0254
0.1738 0.1738 0.0543 0.0401 0.0321 0.0183
0.2155 0.2155 0.0690 0.0410 0.0396 0.0192
0.2884 0.2884 0.1029 0.0496 0.0518 0.0206
0.4185 0.4185 0.1960 0.0937 0.0772 0.0525
0.5935 0.5935 0.4295 0.3141 0.2473 0.2289
0.4185 0.4185 0.1960 0.0937 0.0772 0.0525
0.2884 0.2884 0.1029 0.0496 0.0518 0.0206
0.2155 0.2155 0.0690 0.0410 0.0396 0.0192
0.1738 0.1738 0.0543 0.0401 0.0321 0.0183
0.1497 0.1497 0.0473 0.0400 0.0278 0.0254
0.1371 0.1371 0.0453 0.0415 0.0263 0.0314
0.1352 0.1352 0.0457 0.0444 0.0288 0.0236
0.1409 0.1409 0.0505 0.0482 0.0328 0.0269
0.1512 0.1512 0.0592 0.0552 0.0398 0.0325
0.1753 0.1753 0.0761 0.0696 0.0574 0.0456
0.2098 0.2098 0.0873 0.0766 0.0807 0.0618
0.2664 0.2664 0.1175 0.0872 0.0955 0.0894
0.3385 0.3385 0.1757 0.1313 0.1407 0.1387
0.4304 0.4304 0.2517 0.1847 0.1864 0.1805
0.5247 0.5247 0.3564 0.2725 0.2532 0.2516
0.6457 0.6457 0.4839 0.3977 0.3856 0.3906
0.7655 0.7655 0.6685 0.5970 0.5701 0.6073
0.8420 0.8420 0.8099 0.8090 0.8605 0.8590
--------Tangential wake velocity *V_tw* is V_tw(NTheta_tw,NR_tw)-----------
0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
-0.039 -0.039 -0.075 -0.079 -0.103 -0.116
-0.044 -0.044 -0.063 -0.075 -0.089 -0.104
-0.044 -0.044 -0.063 -0.098 -0.108 -0.125
-0.048 -0.048 -0.082 -0.123 -0.129 -0.140
-0.056 -0.056 -0.106 -0.139 -0.140 -0.147
-0.066 -0.066 -0.129 -0.142 -0.141 -0.146
-0.070 -0.070 -0.137 -0.139 -0.137 -0.139
-0.069 -0.069 -0.132 -0.132 -0.130 -0.129
-0.067 -0.067 -0.124 -0.122 -0.121 -0.116
-0.066 -0.066 -0.112 -0.110 -0.108 -0.105
-0.063 -0.063 -0.098 -0.096 -0.094 -0.093
-0.055 -0.055 -0.079 -0.081 -0.079 -0.079
-0.039 -0.039 -0.053 -0.063 -0.066 -0.059
-0.016 -0.016 -0.024 -0.044 -0.050 -0.037
0.0114 0.0114 0.0005 -0.023 -0.028 -0.021
0.0489 0.0489 0.0044 -0.003 0.0015 -0.020
0.0534 0.0534 0.0726 0.0637 0.0993 -0.004
0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
0.0534 0.0534 0.0726 0.0637 0.0993 -0.004
0.0489 0.0489 0.0044 -0.003 0.0015 -0.020
0.0114 0.0114 0.0005 -0.023 -0.028 -0.021
-0.016 -0.016 -0.024 -0.044 -0.050 -0.037
-0.039 -0.039 -0.053 -0.063 -0.066 -0.059
-0.055 -0.055 -0.079 -0.081 -0.079 -0.079
-0.063 -0.063 -0.098 -0.096 -0.094 -0.093
-0.066 -0.066 -0.112 -0.110 -0.108 -0.105
-0.067 -0.067 -0.124 -0.122 -0.121 -0.116
-0.069 -0.069 -0.132 -0.132 -0.130 -0.129

-0.070 -0.070 -0.137 -0.139 -0.137 -0.139
-0.066 -0.066 -0.129 -0.142 -0.141 -0.146
-0.056 -0.056 -0.106 -0.139 -0.140 -0.147
-0.048 -0.048 -0.082 -0.123 -0.129 -0.140
-0.044 -0.044 -0.063 -0.098 -0.108 -0.125
-0.044 -0.044 -0.063 -0.075 -0.089 -0.104
-0.039 -0.039 -0.075 -0.079 -0.103 -0.116
0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
------------Radial wake velocity *V_rw* is V_rw(NTheta_rw,NR_rw)-----------
0.0000 0.0000 -0.072 -0.056 -0.027 -0.022
-0.045 -0.045 -0.052 -0.041 -0.025 -0.014
-0.059 -0.059 0.0025 0.0025 0.0257 0.0054
-0.045 -0.045 0.0005 0.0163 0.0287 0.0346
-0.038 -0.038 0.0049 0.0331 0.0375 0.0445
-0.035 -0.035 0.0079 0.0366 0.0385 0.0390
-0.036 -0.036 0.0084 0.0247 0.0287 0.0208
-0.046 -0.046 -0.002 0.0059 0.0084 -0.002
-0.064 -0.064 -0.021 -0.018 -0.019 -0.026
-0.082 -0.082 -0.041 -0.042 -0.046 -0.048
-0.096 -0.096 -0.060 -0.062 -0.065 -0.066
-0.108 -0.108 -0.079 -0.079 -0.079 -0.080
-0.119 -0.119 -0.097 -0.094 -0.093 -0.093
-0.133 -0.133 -0.117 -0.106 -0.111 -0.104
-0.144 -0.144 -0.134 -0.115 -0.128 -0.113
-0.139 -0.139 -0.143 -0.121 -0.123 -0.121
-0.105 -0.105 -0.138 -0.125 -0.071 -0.123
-0.072 -0.072 -0.136 -0.134 -0.125 -0.157
-0.041 -0.041 -0.019 -0.033 -0.053 -0.156
-0.072 -0.072 -0.136 -0.134 -0.125 -0.157
-0.105 -0.105 -0.138 -0.125 -0.071 -0.123
-0.139 -0.139 -0.143 -0.121 -0.123 -0.121
-0.144 -0.144 -0.134 -0.115 -0.128 -0.113
-0.133 -0.133 -0.117 -0.106 -0.111 -0.104
-0.119 -0.119 -0.097 -0.094 -0.093 -0.093
-0.108 -0.108 -0.079 -0.079 -0.079 -0.080
-0.096 -0.096 -0.060 -0.062 -0.065 -0.066
-0.082 -0.082 -0.041 -0.042 -0.046 -0.048
-0.064 -0.064 -0.021 -0.018 -0.019 -0.026
-0.046 -0.046 -0.002 0.0059 0.0084 -0.002
-0.036 -0.036 0.0084 0.0247 0.0287 0.0208
-0.035 -0.035 0.0079 0.0366 0.0385 0.0390
-0.038 -0.038 0.0049 0.0331 0.0375 0.0445
-0.045 -0.045 0.0005 0.0163 0.0287 0.0346
-0.059 -0.059 0.0025 0.0025 0.0257 0.0054
-0.045 -0.045 -0.052 -0.041 -0.025 -0.014
0.0000 0.0000 -0.072 -0.056 -0.027 -0.022
****
******************** Ice Blockage Input *********************
ICE BLOCK OPTION (WALL/SLICE/SPHERE/NONE):
NONE
Relative velocity to propeller *V_Ice* (real):
1
ICE WALL
Normalized *THIN WALL* width and height (real):
1.05 0.25
Number of vertical intervals *N_Z* (integer):
6
Number of transversal intervals *N_Y* (integer):
6
Normalized wall distance to directrix *Dist_FP* (real):
0.0716
Normalized wall height *Hite_FP* above blade tip (real):
0
Wake shedding from the edge of the wall *W_WAKE* (YES/NO)?:
1
SLICE BLOCK
Normalized length *Slice_L* (real):
1.2
Normalized height *Slice_H* (real):
0.28875

Normalized diameter *Slice_D* (real):
1.05
Normalized axial location *Slice_X* (real):
0.1296
Normalized transversal location *Slice_Y* (real):
0
Normalized vertical location *Slice_Z* (real):
0.525
Number of axial intervals *N_SAxial* (integer):
5
Number of vertical intervals *N_SVerti* (integer):
4
SPHERE BLOCK
Normalized diameter *D_Sphere* (real):
0.25
Longitudinal (West to East) intervals *N_Longit* (integer):
8
Latitudinal (South to North) intervals *N_Latitu*
4
Normalized center location *S_Centre* (3 real):
-0.5 0 0.25
******************** Induced velocity Data Input ********************
Do you want to find the induced velocity *InducedVel* (Y/N)?
N
If yes, then the number of radial locations *N_RadialP* (integer),
11
and these radial locations in r/R to assign the values to *RadialP*
0.22 0.30 0.40 0.50 0.60 0.70 0.80 0.90 0.95 1.00 1.10
and the number of circomferential locations *N_CirP* (integer),
120
and prescribe these circomferential locations *CirP* in degree (real number)
0. 3. 6. 9. 12. 15. 18. 21. 24. 27.
30. 33. 36. 39. 42. 45. 48. 51. 54. 57.
60. 63. 66. 69. 72. 75. 78. 81. 84. 87.
90. 93. 96. 99. 102. 105. 108. 111. 114. 117.
120. 123. 126. 129. 132. 135. 138. 141. 144. 147.
150. 153. 156. 159. 162. 165. 168. 171. 174. 177.
180. 183. 186. 189. 192. 195. 198. 201. 204. 207.
210. 213. 216. 219. 222. 225. 228. 231. 234. 237.
240. 243. 246. 249. 252. 255. 258. 261. 264. 267.
270. 273. 276. 279. 282. 285. 288. 291. 294. 297.
300. 303. 306. 309. 312. 315. 318. 321. 324. 327.
330. 333. 336. 339. 342. 345. 348. 351. 354. 357.

1. 2. 3. 4. 5. 6. 7. 8. 9. 10.
11. 12. 13. 14. 15. 16. 17. 18. 19. 20.
21. 22. 23. 24. 25. 26. 27. 28. 29. 30.
31. 32. 33. 34. 35. 36. 37. 38. 39. 40.
41. 42. 43. 44. 45. 46. 47. 48. 49. 50.
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61. 62. 63. 64. 65. 66. 67. 68. 69. 70.
71. 72. 73. 74. 75. 76. 77. 78. 79. 80.
81. 82. 83. 84. 85. 86. 87. 88. 89. 90.
91. 92. 93. 94. 95. 96. 97. 98. 99. 100.
101. 102. 103. 104. 105. 106. 107. 108. 109. 110.
111. 112. 113. 114. 115. 116. 117. 118. 119. 120.
121. 122. 123. 124. 125. 126. 127. 128. 129. 130.
131. 132. 133. 134. 135. 136. 137. 138. 139. 140.
141. 142. 143. 144. 145. 146. 147. 148. 149. 150.
151. 152. 153. 154. 155. 156. 157. 158. 159. 160.
161. 162. 163. 164. 165. 166. 167. 168. 169. 170.
171. 172. 173. 174. 175. 176. 177. 178. 179. 180.
181. 182. 183. 184. 185. 186. 187. 188. 189. 190.
191. 192. 193. 194. 195. 196. 197. 198. 199. 200.
201. 202. 203. 204. 205. 206. 207. 208. 209. 210.
211. 212. 213. 214. 215. 216. 217. 218. 219. 220.
221. 222. 223. 224. 225. 226. 227. 228. 229. 230.
231. 232. 233. 234. 235. 236. 237. 238. 239. 240.
241. 242. 243. 244. 245. 246. 247. 248. 249. 250.
251. 252. 253. 254. 255. 256. 257. 258. 259. 260.

261. 262. 263. 264. 265. 266. 267. 268. 269. 270.
271. 272. 273. 274. 275. 276. 277. 278. 279. 280.
281. 282. 283. 284. 285. 286. 287. 288. 289. 290.
291. 292. 293. 294. 295. 296. 297. 298. 299. 300.
301. 302. 303. 304. 305. 306. 307. 308. 309. 310.
311. 312. 313. 314. 315. 316. 307. 318. 319. 320.
321. 322. 323. 324. 325. 326. 327. 328. 329. 330.
331. 332. 333. 334. 335. 336. 337. 338. 339. 340.
341. 342. 343. 344. 345. 346. 347. 348. 349. 350.
351. 352. 353. 354. 355. 356. 357. 358. 359. 360.

0.0 10.0 20.0 30.0 40.0 50.0 60.0 70.0 80.0 90.0 100.0
110. 120. 130. 140. 150. 160. 170. 180. 190. 200.
210. 220. 230. 240. 250. 260. 270. 280. 290. 300.
310. 320. 330. 340. 350.

0.0 90.0 180.0 270.0

0.0 10.0 20.0 30.0 40.0 50.0 60.0 70.0 80.0 90.0 100.0
110. 120. 130. 140. 150. 160. 170. 180. 190. 200.
210. 220. 230. 240. 250. 260. 270. 280. 290. 300.
310. 320. 330. 340. 350.

-------the order of these numbers above is in CW, i.e., 0=East,
--------viewing from downstream.
and number of planes *N_XPlane* that intersect the x-axis (integer)
1
and the distance to propeller *XPlane*/DIAMETER:
0.16405

-0.15 0.16405 0.5 1.0 2.0 4.0