The Design of a Podded Propeller Base Model Geometry and Predictions of its Hydrodynamics

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THE DESIGN OF A PODDED PROPELLER BASE MODEL GEOMETRY AND PREDICTION OF ITS HYDRODYNAMICS

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SUMMARY

A podded propeller base model was designed using a marine propeller research and design software package, PROPELLA. This model was a base for a variation of other podded propellers for a "Synthetic Analysis of Podded Propeller" project funded by the NSERC-NRC Partnership Research Programme. This report describes the detailed geometry of the propeller, followed by a numerical prediction on hydrodynamic characteristics at the design stage, in terms of a recently co-authored paper.

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TABLE OF CONTENTS

LIST OF FIGURES

Abstract

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1. Geometry Description

1.1 General Geometry Information

- Angular Speed: 2 rps=120 rpm
- Base Geometry: 4-blade with expended area ratio of EAR=0.60, with zero skew, zero rake and constant pitch distribution of p/D=1.0
- Hub/diameter ratio: d/D=0.26, tapered hub at 15 degrees

1.2 Model Propeller:

- Propeller similitude constant was set at 10 (meter)*(rps) with design advance coefficient of J=V/(nD)=0.8. The required velocity is then V=8 m/s, within the capacity of IOT Towing Tank carriage's maximum speed of 9 m/s. Model was designed for tests in both two tank (for very low J and comparison) and cavitation tunnel (for cavitation condition).

- Diameter D=0.270 meters (10.63")
- Angular speed n=10/0.270= 37.03703 rps= 2222.2222 rpm.
- Hub diameter d=0.27×0.26=0.0702m (2.7638")
- This gives a Reynolds Number of about 2.3 x 10^6 at 0.7R.

1.3 Blade Section Geometry:

- NACA 66 (DTMB Modified)
- A=0.8 Meanline

The blade profile was modified from a DTMB P4119 propeller [ITTC 1998]. A proportional reduction of the expanded area ratio was made. The geometry component of PROPELLA was run for a number of times to obtain the designed expanded area ratio, EAR, as follows:

r/R	cd	p/D	60% cd	75% cd	80% cd	100% cd	120%
0.3000	0.3625	1.1020	0.2175	0.2719	0.2900	0.3625	0.4350
0.4000	0.4048	1.0980	0.2429	0.3036	0.3238	0.4048	0.4858
0.5000	0.4392	1.0930	0.2635	0.3294	0.3514	0.4392	0.5270
0.6000	0.4610	1.0880	0.2766	0.3458	0.3688	0.4610	0.5532
0.7000	0.4622	1.0840	0.2773	0.3467	0.3698	0.4622	0.5546
0.8000	0.4347	1.0810	0.2608	0.3260	0.3478	0.4347	0.5216
0.9000	0.3613	1.0790	0.2168	0.2710	0.2890	0.3613	0.4336
0.9500	0.2775	1.0770	0.1665	0.2081	0.2220	0.2775	0.3330
1.0000	0.1600	1.0750	0.0960	0.1200	0.1280	0.1600	0.1920

Geometry 2 planform, 60%cd yields EAR=0.457

0.3000	0.2175	1.0000	0.0000	0.0000	1.0000	1.0000	0.0000
0.4000	0.2429	1.0000	0.0000	0.0000	1.0000	1.0000	0.0000
0.5000	0.2635	1.0000	0.0000	0.0000	1.0000	1.0000	0.0000
0.6000	0.2766	1.0000	0.0000	0.0000	1.0000	1.0000	0.0000
0.7000	0.2773	1.0000	0.0000	0.0000	1.0000	1.0000	0.0000
0.8000	0.2608	1.0000	0.0000	0.0000	1.0000	1.0000	0.0000
0.9000	0.2168	1.0000	0.0000	0.0000	1.0000	1.0000	0.0000
0.9500	0.1665	1.0000	0.0000	0.0000	1.0000	1.0000	0.0000
1.0000	0.0960	1.0000	0.0000	0.0000	1.0000	1.0000	0.0000

Trial planform, 75%cd yields EAR=0.571286

0.3000	0.2719	1.0000	0.0000	0.0000	1.0000	1.0000	0.0000
0.4000	0.3036	1.0000	0.0000	0.0000	1.0000	1.0000	0.0000
0.5000	0.3294	1.0000	0.0000	0.0000	1.0000	1.0000	0.0000
0.6000	0.3458	1.0000	0.0000	0.0000	1.0000	1.0000	0.0000
0.7000	0.3467	1.0000	0.0000	0.0000	1.0000	1.0000	0.0000
0.8000	0.3260	1.0000	0.0000	0.0000	1.0000	1.0000	0.0000
0.9000	0.2710	1.0000	0.0000	0.0000	1.0000	1.0000	0.0000
0.9500	0.2081	1.0000	0.0000	0.0000	1.0000	1.0000	0.0000
1.0000	0.1200	1.0000	0.0000	0.0000	1.0000	1.0000	0.0000

Trial planform, 80%cd yields EAR=0.609372

0.3000	0.2900	1.0000	0.0000	0.0000	1.0000	1.0000	0.0000
0.4000	0.3238	1.0000	0.0000	0.0000	1.0000	1.0000	0.0000
0.5000	0.3514	1.0000	0.0000	0.0000	1.0000	1.0000	0.0000
0.6000	0.3688	1.0000	0.0000	0.0000	1.0000	1.0000	0.0000
0.7000	0.3698	1.0000	0.0000	0.0000	1.0000	1.0000	0.0000
0.8000	0.3478	1.0000	0.0000	0.0000	1.0000	1.0000	0.0000
0.9000	0.2890	1.0000	0.0000	0.0000	1.0000	1.0000	0.0000
0.9500	0.2220	1.0000	0.0000	0.0000	1.0000	1.0000	0.0000
1.0000	0.1280	1.0000	0.0000	0.0000	1.0000	1.0000	0.0000

Trial planform, 100%cd yields EAR=0.761715

0.3000	0.3625	1.0000	0.0000	0.0000	1.0000	1.0000	0.0000
0.4000	0.4048	1.0000	0.0000	0.0000	1.0000	1.0000	0.0000
0.5000	0.4392	1.0000	0.0000	0.0000	1.0000	1.0000	0.0000
0.6000	0.4610	1.0000	0.0000	0.0000	1.0000	1.0000	0.0000
0.7000	0.4622	1.0000	0.0000	0.0000	1.0000	1.0000	0.0000
0.8000	0.4347	1.0000	0.0000	0.0000	1.0000	1.0000	0.0000
0.9000	0.3613	1.0000	0.0000	0.0000	1.0000	1.0000	0.0000
0.9500	0.2775	1.0000	0.0000	0.0000	1.0000	1.0000	0.0000
1.0000	0.1600	1.0000	0.0000	0.0000	1.0000	1.0000	0.0000

Trial planform, 120%cd yields EAR=0.914058

0.3000	0.4350	1.0000	0.0000	0.0000	1.0000	1.0000	0.0000
0.4000	0.4858	1.0000	0.0000	0.0000	1.0000	1.0000	0.0000
0.5000	0.5270	1.0000	0.0000	0.0000	1.0000	1.0000	0.0000
0.6000	0.5532	1.0000	0.0000	0.0000	1.0000	1.0000	0.0000
0.7000	0.5546	1.0000	0.0000	0.0000	1.0000	1.0000	0.0000
0.8000	0.5216	1.0000	0.0000	0.0000	1.0000	1.0000	0.0000
0.9000	0.4336	1.0000	0.0000	0.0000	1.0000	1.0000	0.0000
0.9500	0.3330	1.0000	0.0000	0.0000	1.0000	1.0000	0.0000
1.0000	0.1920	1.0000	0.0000	0.0000	1.0000	1.0000	0.0000

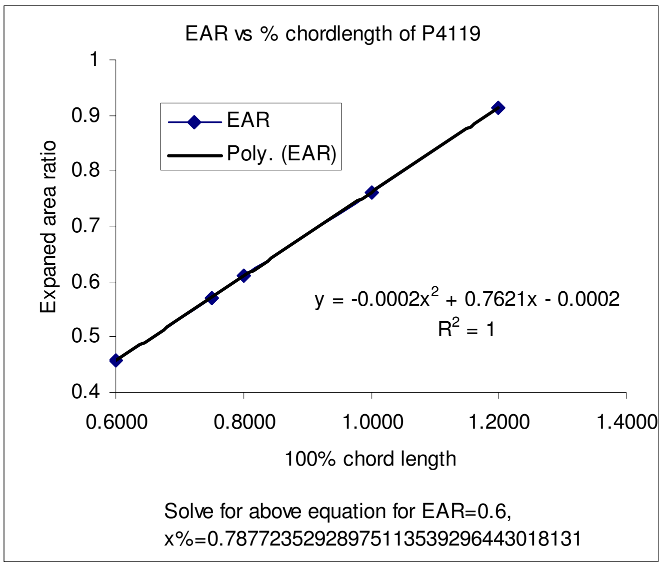
Trial planform, 78.77236%cd yields EAR=0.600021

0.3000	0.2855	1.0000	0.0000	0.0000	1.0000	1.0000	0.0000
0.4000	0.3189	1.0000	0.0000	0.0000	1.0000	1.0000	0.0000
0.5000	0.3460	1.0000	0.0000	0.0000	1.0000	1.0000	0.0000
0.6000	0.3631	1.0000	0.0000	0.0000	1.0000	1.0000	0.0000
0.7000	0.3641	1.0000	0.0000	0.0000	1.0000	1.0000	0.0000
0.8000	0.3424	1.0000	0.0000	0.0000	1.0000	1.0000	0.0000

0.9000	0.2846	1.0000	0.0000	0.0000	1.0000	1.0000	0.0000
0.9500	0.2186	1.0000	0.0000	0.0000	1.0000	1.0000	0.0000
1.0000	0.1260	1.0000	0.0000	0.0000	1.0000	1.0000	0.0000

%cd	EAR
0.6000	0.457
0.7500	0.5713
0.8000	0.6094
1.0000	0.7617
1.2000	0.9141

The reduction factor was determined by the following plot:



1.4 Base Propeller Sectional Geometry Offsets:

r	cd	pd	tc	fc
0.30	0.285550	1.0000	0.15530	0.02318
0.40	0.318870	1.0000	0.11800	0.02303
0.50	0.345968	1.0000	0.09160	0.02182
0.60	0.363141	1.0000	0.06960	0.02072
0.70	0.364086	1.0000	0.05418	0.02003
0.80	0.342423	1.0000	0.04206	0.01967
0.90	0.284605	1.0000	0.03321	0.01817
0.95	0.218593	1.0000	0.03228	0.01631
1.00	0.126036	1.0000	0.03160	0.01175

1.5 Sectional Maximum Thickness and Camber Distribution are then:

xc	tc	fc
0.0000	0.0000	0.0000
0.0125	0.2088	0.0907
0.0250	0.2932	0.1586
0.0500	0.4132	0.2712
0.0750	0.5050	0.3657
0.1000	0.5814	0.4482
0.1500	0.7042	0.5869
0.2000	0.8000	0.6993
0.3000	0.9274	0.8635
0.4000	0.9904	0.9615
0.4500	1.0000	0.9881
0.5000	0.9924	1.0000
0.6000	0.9306	0.9786
0.7000	0.8070	0.8892
0.8000	0.6220	0.7027
0.9000	0.3754	0.3586
0.9500	0.2286	0.1713
1.0000	0.0666	0.0000

1.6 Hub geometry

- Diameter D=0.270 meters (10.63”)
- Hub diameter d=0.27*0.26=0.0702m (2.7638”)
- d/D=0.26
- L_{hub}=0.0434m (1.70866”)
- Angle of taper 15 degrees
- This gives $Delta_r$=5.8114497476 mm (0.228917223”)
- D_{front}=81.8229 mm (3.221374”)
- D_{rear}=58.5771 mm (2.306185”)

1.7 Propeller name legend (all are 4-bladed propellers):

PP00+00C0 with
P for podded,
P for propeller,
00 for zero degree of skew,
+00 for positive zero rake,
C/V for Constant/Variable pitch, and
0/1/… for NACA 66 Modified/critical cavitation number based/…

Therefore, the name for the base propeller is PP00+00C0.

1.8 Geometry Details (Part of the Input for PROPELLA)

The following lists a section of the input file for PROPELLA. The blade sectional offsets were described using two sets of x-y coordinates for blade back and face, respectively.

```
------------------------ Blade Outline Geometry Input------------------
Number of radii *N_Radius* are available for given offset (integer):
9
Diameter of the propeller *DIAMETER* in meters (real number):
0.270
Ratio of the hub diameter to the propeller diameter *H_to_D* (real):
0.26
Pitch at 0.7R based on DIAMETER *Pitch07R* (real number):
1.0
Setting the wake angle factor or not? *S_W_Ang* (AUTO/MANUAL/NO)
AUTO
PITCH at RootChord *RtPitch* is (real number)
1.0
---------------------------------------------------------------------------
RADIUS   CHRDLNG PITCH    SKEW     RAKE  ThickUp  ThickLo  SWAngOffst
                   *Blade Outline Marker*
0.300000  0.285550  1.000000  0.000000  0.000000  1.000000  1.000000  0.000000
0.400000  0.318870  1.000000  0.000000  0.000000  1.000000  1.000000  0.000000
0.500000  0.345968  1.000000  0.000000  0.000000  1.000000  1.000000  0.000000
0.600000  0.363141  1.000000  0.000000  0.000000  1.000000  1.000000  0.000000
0.700000  0.364086  1.000000  0.000000  0.000000  1.000000  1.000000  0.000000
0.800000  0.342423  1.000000  0.000000  0.000000  1.000000  1.000000  0.000000
0.900000  0.284605  1.000000  0.000000  0.000000  1.000000  1.000000  0.000000
0.950000  0.218593  1.000000  0.000000  0.000000  1.000000  1.000000  0.000000
1.000000  0.126036  1.000000  0.000000  0.000000  1.000000  1.000000  0.000000

---------------------- Blade Sectional Data Input-----------------
Max. thick. at shaft centre based on DIAMETER *Thick_0* (real number):
0.08468
Max. thick. at 90% Radius based on DIAMETER *Thick_09* (real number):
0.012
Blade tip thickness *Thick_Tip* at r=1.0R based on DIAMETER (Real):
0.0048
       *BLADE SECTIONS*
Number of given sectional offsets *NC_Statn* (integer):
18
  *Statn_Up*   *Thick_Up*  *Statn_Lo*   *Thick_Lo*
    0.000000    0.000000    0.000000    0.000000
    1.250000    1.831575    1.250000   -1.411090
    2.500000    2.644333    2.500000   -1.909063
    5.000000    3.837140    5.000000   -2.579856
    7.500000    4.769018    7.500000   -3.073632
   10.000000    5.553498   10.000000   -3.475643
   15.000001    6.828548   15.000001   -4.107679
   20.000000    7.832978   20.000000   -4.591023
   30.000002    9.202854   30.000002   -5.199668
   40.000000    9.919213   40.000000   -5.461699
   45.000000   10.055416   45.000000   -5.474585
   50.000000   10.023987   50.000000   -5.387986
   60.000004    9.494504   60.000004   -4.957714
   70.000000    8.327520   70.000000   -4.205190
   80.000000    6.458689   80.000000   -3.200971
   90.000000    3.746216   90.000000   -2.083746
   95.000000    2.172153   95.000000   -1.378006
  100.000000    0.000000  100.000000    0.000000

    0.000000    0.000000    0.000000    0.000000
    1.250000    1.440802    1.250000   -1.023038
    2.500000    2.095136    2.500000   -1.364624
    5.000000    3.062454    5.000000   -1.813306
    7.500000    3.821707    7.500000   -2.137293
   10.000000    4.462464   10.000000   -2.398055
```

15.000001	5.506411	15.000001	-2.803149
20.000000	6.330488	20.000000	-3.109512
30.000002	7.460300	30.000002	-3.483019
40.000000	8.057694	40.000000	-3.629026
45.000000	8.175594	45.000000	-3.624406
50.000000	8.158160	50.000000	-3.552160
60.000004	7.744256	60.000004	-3.236824
70.000000	6.809127	70.000000	-2.713472
80.000000	5.288118	80.000000	-2.051482
90.000000	3.040716	90.000000	-1.389004
95.000000	1.743244	95.000000	-0.954236
100.000000	0.000000	100.000000	0.000000

0.000000	0.000000	0.000000	0.000000
1.250000	1.154211	1.250000	-0.758397
2.500000	1.688921	2.500000	-0.996791
5.000000	2.484214	5.000000	-1.300698
7.500000	3.110857	7.500000	-1.514943
10.000000	3.640784	10.000000	-1.684840
15.000001	4.505852	15.000001	-1.944620
20.000000	5.189873	20.000000	-2.138128
30.000002	6.131649	30.000002	-2.363335
40.000000	6.634025	40.000000	-2.438039
45.000000	6.736034	45.000000	-2.423966
50.000000	6.727192	50.000000	-2.363192
60.000004	6.397453	60.000004	-2.126843
70.000000	5.636294	70.000000	-1.755826
80.000000	4.382051	80.000000	-1.315469
90.000000	2.501797	90.000000	-0.936867
95.000000	1.420765	95.000000	-0.673211
100.000000	0.000000	100.000000	0.000000

0.000000	0.000000	0.000000	0.000000
1.250000	0.914554	1.250000	-0.538694
2.500000	1.348955	2.500000	-0.691717
5.000000	1.999862	5.000000	-0.876010
7.500000	2.515131	7.500000	-0.999670
10.000000	2.951942	10.000000	-1.094602
15.000001	3.666673	15.000001	-1.234559
20.000000	4.232950	20.000000	-1.335051
30.000002	5.016524	30.000002	-1.438180
40.000000	5.438820	40.000000	-1.454364
45.000000	5.527343	45.000000	-1.432657
50.000000	5.525552	50.000000	-1.381552
60.000004	5.266147	60.000004	-1.210829
70.000000	4.650783	70.000000	-0.965938
80.000000	3.620554	80.000000	-0.708566
90.000000	2.049411	90.000000	-0.563373
95.000000	1.150462	95.000000	-0.440594
100.000000	0.000000	100.000000	0.000000

0.000000	0.000000	0.000000	0.000000
1.250000	0.747311	1.250000	-0.383967
2.500000	1.111955	2.500000	-0.476603
5.000000	1.662572	5.000000	-0.576145
7.500000	2.100542	7.500000	-0.635548
10.000000	2.472757	10.000000	-0.677268
15.000001	3.083239	15.000001	-0.732117
20.000000	3.567898	20.000000	-0.766502
30.000002	4.241917	30.000002	-0.782736
40.000000	4.608878	40.000000	-0.757109
45.000000	4.688164	45.000000	-0.729836
50.000000	4.691411	50.000000	-0.685412
60.000004	4.481131	60.000004	-0.560860
70.000000	3.967230	70.000000	-0.405095
80.000000	3.092506	80.000000	-0.277490
90.000000	1.735234	90.000000	-0.298683
95.000000	0.962391	95.000000	-0.276163
100.000000	0.000000	100.000000	0.000000

0.000000	0.000000	0.000000	0.000000
1.250000	0.617513	1.250000	-0.260699
2.500000	0.928566	2.500000	-0.304633
5.000000	1.402410	5.000000	-0.335509
7.500000	1.781347	7.500000	-0.342683
10.000000	2.104294	10.000000	-0.341075
15.000001	2.635365	15.000001	-0.326500
20.000000	3.057923	20.000000	-0.306877
30.000002	3.648827	30.000002	-0.251818
40.000000	3.974082	40.000000	-0.191541
45.000000	4.046593	45.000000	-0.159407
50.000000	4.054017	50.000000	-0.120017
60.000004	3.881958	60.000004	-0.032145
70.000000	3.446177	70.000000	0.051935
80.000000	2.690277	80.000000	0.074145
90.000000	1.494832	90.000000	-0.084100
95.000000	0.817693	95.000000	-0.143799
100.000000	0.000000	100.000000	0.000000

0.000000	0.000000	0.000000	0.000000
1.250000	0.511514	1.250000	-0.181910
2.500000	0.775035	2.500000	-0.198682
5.000000	1.178889	5.000000	-0.193348
7.500000	1.503029	7.500000	-0.174076
10.000000	1.779794	10.000000	-0.151035
15.000001	2.235721	15.000001	-0.102927
20.000000	2.599028	20.000000	-0.057772
30.000002	3.108927	30.000002	0.029032
40.000000	3.391604	40.000000	0.102486
45.000000	3.455878	45.000000	0.134878
50.000000	3.464880	50.000000	0.169120
60.000004	3.323377	60.000004	0.232855
70.000000	2.955700	70.000000	0.275653
80.000000	2.309637	80.000000	0.243975
90.000000	1.274928	90.000000	0.028224
95.000000	0.690842	95.000000	-0.068338
100.000000	0.000000	100.000000	0.000000

0.000000	0.000000	0.000000	0.000000
1.250000	0.484935	1.250000	-0.189072
2.500000	0.731901	2.500000	-0.214548
5.000000	1.109232	5.000000	-0.224578
7.500000	1.411527	7.500000	-0.218613
10.000000	1.669394	10.000000	-0.207365
15.000001	2.093813	15.000001	-0.179345
20.000000	2.431758	20.000000	-0.150642
30.000002	2.905192	30.000002	-0.088455
40.000000	3.166713	40.000000	-0.030299
45.000000	3.225591	45.000000	-0.002409
50.000000	3.232734	50.000000	0.029266
60.000004	3.098085	60.000004	0.094108
70.000000	2.752783	70.000000	0.147787
80.000000	2.150012	80.000000	0.142196
90.000000	1.190772	90.000000	-0.021019
95.000000	0.648351	95.000000	-0.089570
100.000000	0.000000	100.000000	0.000000

0.000000	0.000000	0.000000	0.000000
1.250000	0.436476	1.250000	-0.223331
2.500000	0.649611	2.500000	-0.276901
5.000000	0.971516	5.000000	-0.334196
7.500000	1.227597	7.500000	-0.368202
10.000000	1.445247	10.000000	-0.391977
15.000001	1.802243	15.000001	-0.423028
20.000000	2.085677	20.000000	-0.442322
30.000002	2.479904	30.000002	-0.450679
40.000000	2.694594	40.000000	-0.435069
45.000000	2.741017	45.000000	-0.418982
50.000000	2.742992	50.000000	-0.392992
60.000004	2.620203	60.000004	-0.320493

70.000000	2.319870	70.000000	-0.230250
80.000000	1.808432	80.000000	-0.157087
90.000000	1.014487	90.000000	-0.171777
95.000000	0.562465	95.000000	-0.159910
100.000000	0.000000	100.000000	0.000000
100.000000	0.000000	100.000000	0.000000

1.9 Graphical descriptions of the Propeller Geometry

The following are a few plots generated from the PROPELLA code. The view was created by its visualization component as well.

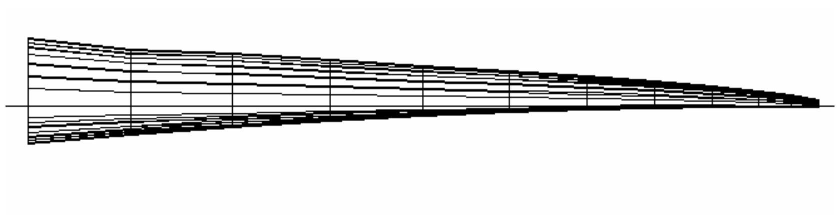


Figure 1. Blade Maximum Thickness Profile

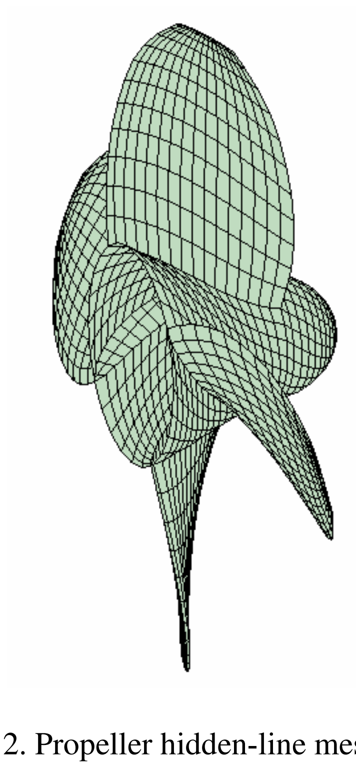


Figure 2. Propeller hidden-line mesh view

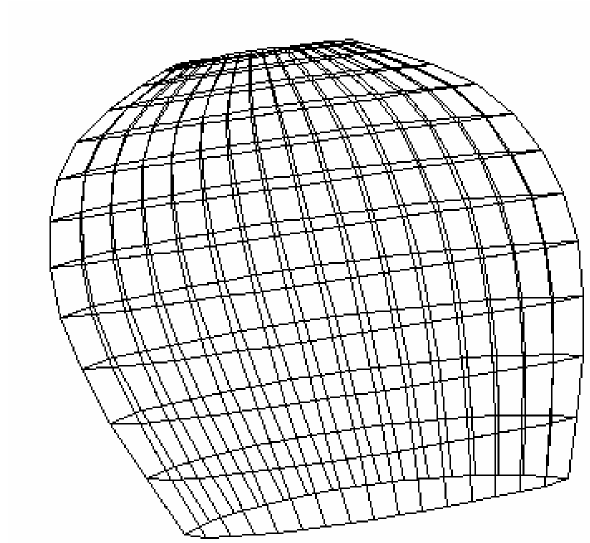


Figure 3. Propeller Blade Expended Planform Profile

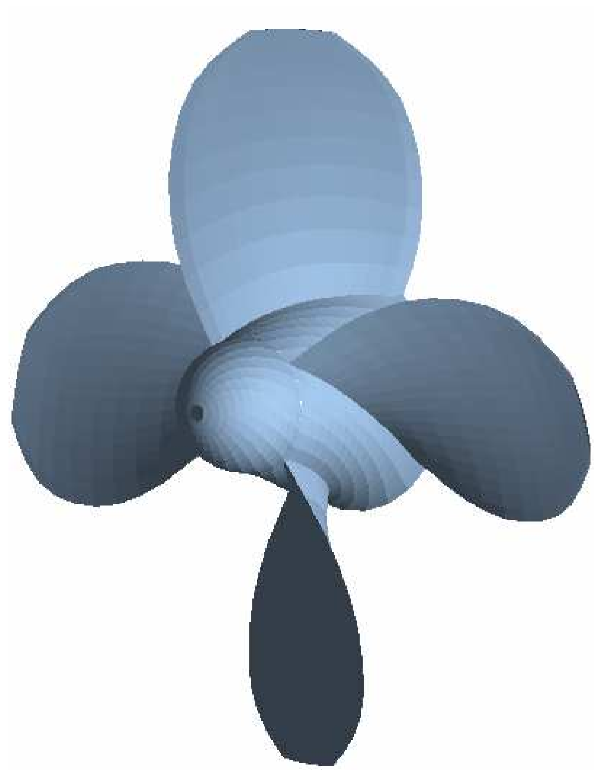


Figure 4. Solid Modeling View of the Propeller

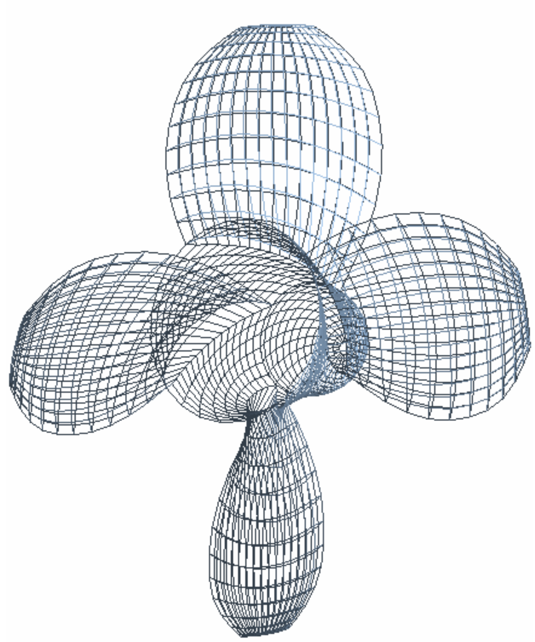


Figure 5. Wire-frame View of the Propeller

Figure 6 shows the thickness and camber distribution of the blades.

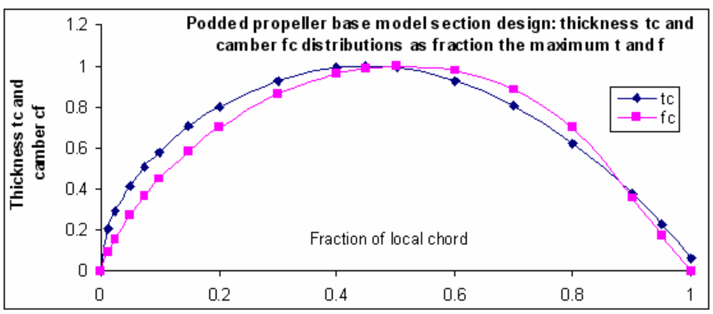


Figure 6. Thickness and Camber Distribution

Figure 7. shows planform shape (chord width), maximum thickness, maximum camber and pitch ratio distribution of the blade.

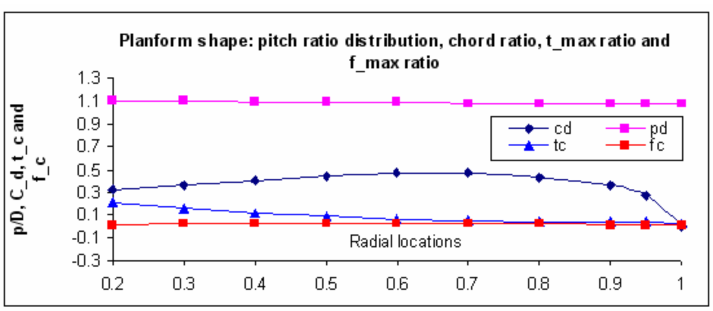


Figure 7. Blade Planform Shape, Radial Pitch Distribution and Maximum Thickness and Camber ratios

2. Hydrodynamic Prediction and Comparison

The code PROPELLA was then used to make the prediction before the model was manufactured.

1.10 Numerical and experimental comparison on propulsive characteristics

Figures 8 and 9 show the thrust, torque coefficients and efficiency of the model propeller with a hub of zero taper angle, and the propeller outlook, respectively.

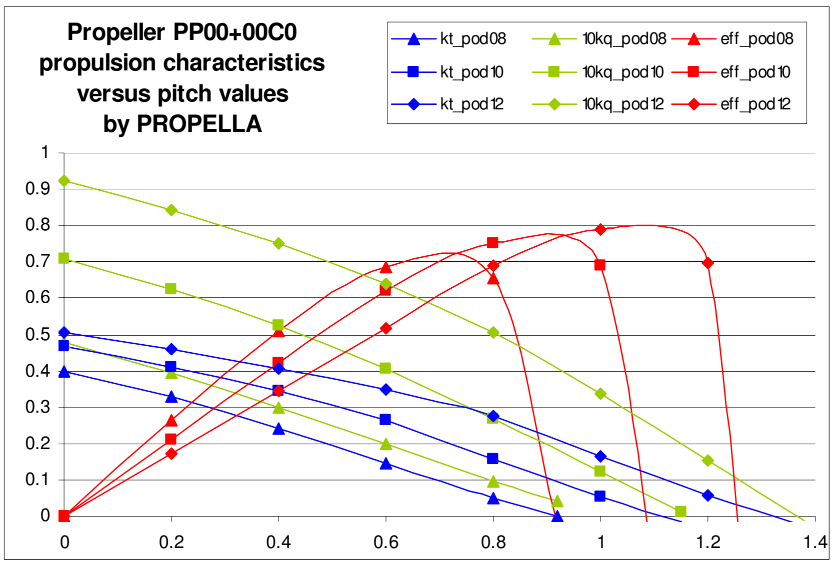


Figure 8. Propulsive characteristics of the model propeller with p/D of 0.8, 0.9 and 1.0 by PROPELLA.

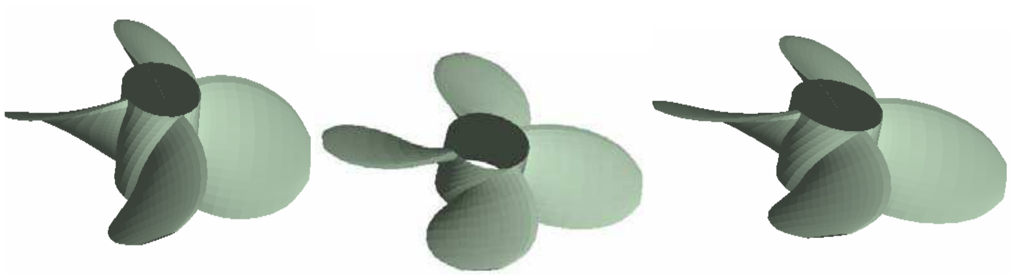


Figure 9. Outlook of the model propeller with no tapered hub and p/D of 0.8, 0.9 and 1.0.

The following comparison plots were made after the experimental tests were completed later (Islam et. al. 2005).

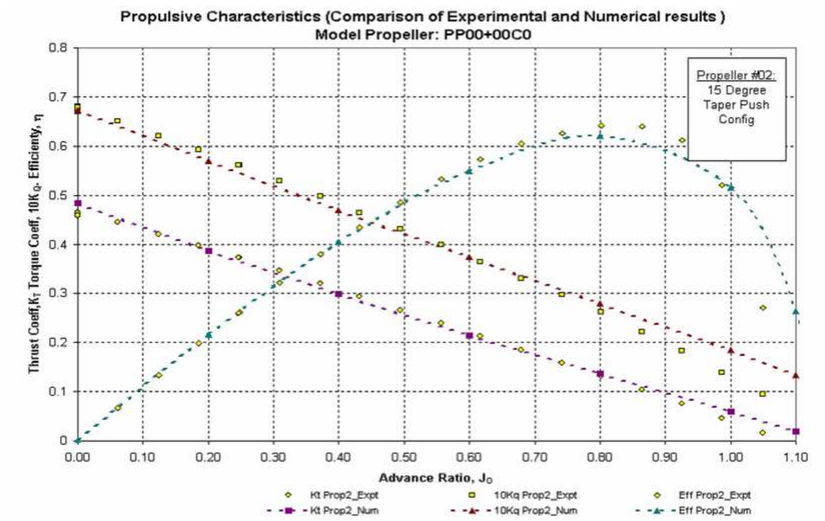


Figure 10. Experimental and numerical prediction of propulsive characteristics of the model prop at taper angle of 15° (pushing configuration).

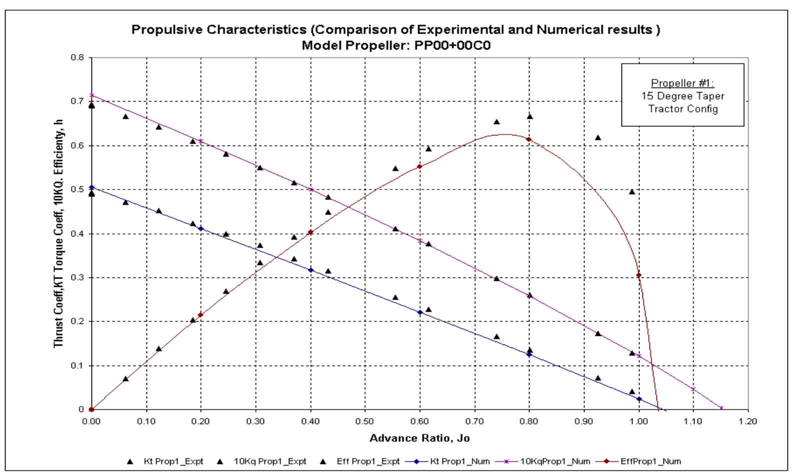


Figure 11. Experimental and numerical prediction of propulsive characteristics of the model prop at taper angle of -15° (tractor type).

1.11 Other Numerical Predictions

The followings are a few other predictions. Figure 12 shows Blade root section pressure coefficient distribution of the model propeller with a taper angle of 15° (pusher type).

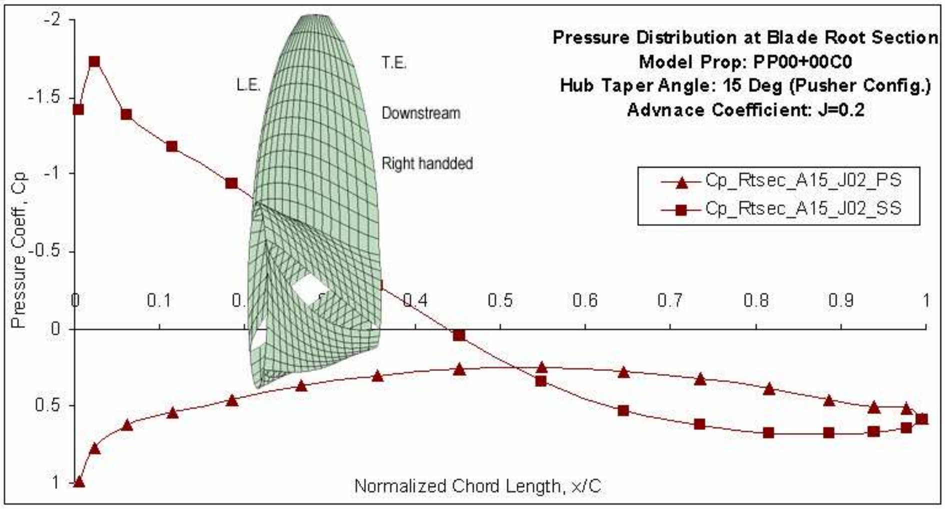


Figure 12. Blade root section pressure coefficient distribution of the model propeller with a taper angle of 15° (pusher type).

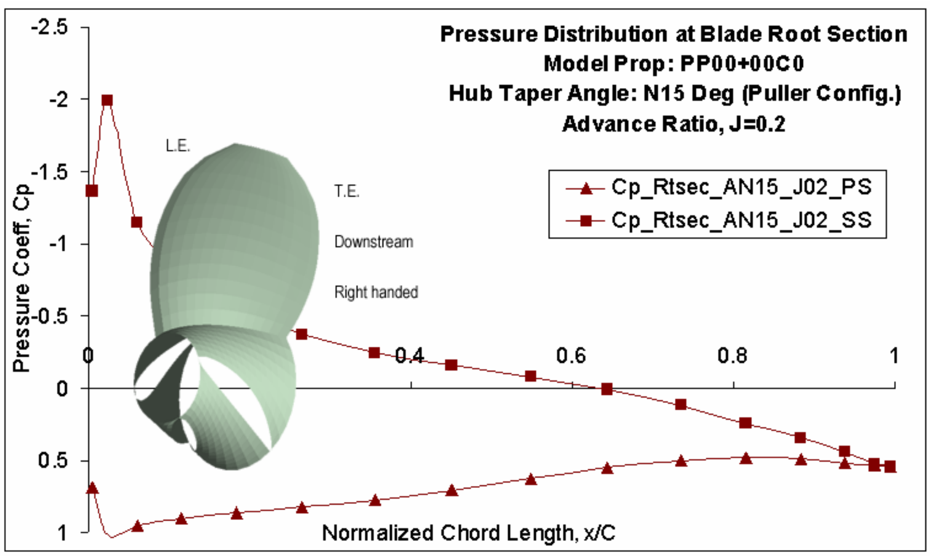


Figure 13. Blade root section pressure coefficient distribution of the model propeller with a taper angle of -15° (tractor type).

In figure 12, due to the geometrical intersection of the blade root section and the tapered hub, the camber of the blade root section was changed to produce a poor hydrodynamic characteristic, i.e., two undesired pressure curves that would cancel the total pressure on the blade root section. However, in figure 13, the intersection of the blade root section and the hub produced a more hydrodynamic shape that produced a better pressure distribution. This geometrical difference was part of the reasons for the puller type propeller having a higher efficiency at the designed load condition (design speed).

3. Conclusion

A base podded propeller model was designed and a propeller software package, PROPELLA, was used as a tool in the design process. Comparison between the numerical prediction that was generated by PROPELLA and the experimental measurements afterward was given. The change of the blade root sectional shape due to the intersection of the blade root section and the tapered hub could be one of the reasons that the tractor type propeller has a higher efficiency than the puller type at the design speed (J=0.8 for the model under examination).

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