Emerson Cavitation Tunnel
School of Marine Science and Technology
University of Newcastle

Multi-quadrant open water tests with an AXIOM Propeller in the Emerson Cavitation Tunnel

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MULTI-QUADRANT OPEN WATER TESTS WITH AN AXIOM PROPELLER
IN THE EMERSON CAVITATION TUNNEL

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Abstract:

Axiom Propellers Ltd. requested the School of Marine Science and Technology (MAST) of Newcastle University to conduct open water model tests on a 300mm diameter, 3 bladed, Axiom propeller to measure its performance and cavitation characteristics. Although the original work specification included only ahead motion (1st quadrant) and stopping in ahead motion (2nd quadrant) performances, the remaining data including astern motion (3rd quadrant) and stopping in astern motion (4th quadrant) data were included in the test programme as an in-kind contribution of the Emerson Cavitation Tunnel

Following the introduction in Section1, Section 2 of the report presents the description of the Emerson Cavitation Tunnel and H45/33 Kempf & Remmers dynamometer used in these tests. Section 3 presents the AXIOM propeller description and test set-up whilst Section 4 gives the results of the open water performance tests at atmospheric condition including all four quadrant performances of this propeller. In Section 5 a short review of the cavitation observations in the 1st and 2nd quadrants are included. Finally, Section 6 of the report presents a set of concluding remarks from the tests.

In Appendix-A, the contents list of a 16 min DVD comprising of the video films of the cavitation observations that form a part of this report is included, whilst Appendix-B presents the tabulated values of the multi-quadrant data.

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Contents

1. INTRODUCTION

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Following this introduction, Section 2 of the report presents the description of the Emerson Cavitation Tunnel and H45/33 Kempf & Remmers dynamometer used in these tests. Section 3 presents the AXIOM propeller description and test set-up whilst Section 4 gives the results of the open water performance tests at atmospheric condition including all four quadrant performances of this propeller. In Section 5 a short review of the cavitation observations in the 1^{st} and 2^{nd} quadrant are included. Finally, Section 6 of the report presents a set of concluding remarks from the tests.

In Appendix-A, the contents list of a 16 min DVD comprising of the video films of the cavitation observations that form a part of this report is included, whilst Appendix-B presents the tabulated values of the multi-quadrant data.

2. FACILITY DESCRIPTION

2.1 Emerson Cavitation Tunnel

ECT is a closed circuit depressurised tunnel originally part of a German facility in Pelzerhaken researching technologies in the field of underwater acoustics developed during the World War II. The tunnel was shipped to the UK and converted to a cavitation tunnel to test propellers in 1949. Since its commissioning the tunnel has gone through two major modifications in 1979 and 2008.

In 1979 almost ¾ of the tunnel conduit, which had circular sections with radius corner elbows, was renewed by modern rectangular conduit at the top limb with accompanying flow management devices and mitred corners. The old propeller drive system through the top limb was replaced by modern Z-drive dynamometer system.

In 2008 the measuring section of the tunnel was enhanced through the installation of a more modern and accessible measuring section with larger twin mono block windows to ease the use of laser based flow measurement devices. In the contraction, in order to improve the inflow quality, the measuring section's major flow management system, which used to have a mild steel honeycomb section with 100mmx100mm rectangular cell units, was replaced with a stainless steel system with 25.4mm diameter hexagonal cell units. In the downstream of the measuring section following the diffuser, old semi-circular shape flat guide vanes for flow management were replaced by modern hydrofoil shape section to avoid vibration and cavitation. In order to increase the tunnel speed at the measuring section from a maximum of 6 m/s to 10 m/s, a specially designed insert section was constructed to reduce the measuring cross-section from 1210mm x 800mm to 800mm x 800mm. The insert section has a foil shape entry with three separate pieces and is fitted at one side of the measuring section, hence blocking access from the respective side.

Complementing the modernisation of the ECT in 2008, a new degassing system and tunnel operations control system were also implemented. The new degassing system, which makes use of retractable porous membranes connected to a vacuum pump, helps to de-aerate the tunnel in few hours as opposed to conventional way of de-aeration which could take days to get the desired gas content levels.

The old manual tunnel operations control unit was also replaced with a modern control system (AUTOTEST of Cussons) which provides both manual and computerised control of the entire tunnel system including water/vacuum pumps/valves; tunnel main drive system; testing dynamometer control system; and tunnel and dynamometer data acquisition control. Although the data acquisition rate of the Autotest system is relatively low (100Hz), this can be overruled by the special protocol built in the system, which allows to collect data by other external system with much higher data rate (e.g. LabView system as currently used)

Further modernisation activities in 2008 also involved the overhauling of the almost 30 years old main drive shaft, its bearing and impeller, including the replacement of the bearing, dynamic balancing of the impeller, re-alignment of the shaft and gearbox maintenance. In order to increase the tunnel storage capacity and hence enable changing of the testing equipment in a dry measuring section environment, two 7500lt FRP tanks were installed. In finalising the modernisation activities the entire ECT laboratory environment has been improved with new floor, ceiling and access to the tunnel.

The specification of the newly improved ECT is given in Table 1 together with an overall sketch (Figure 1)

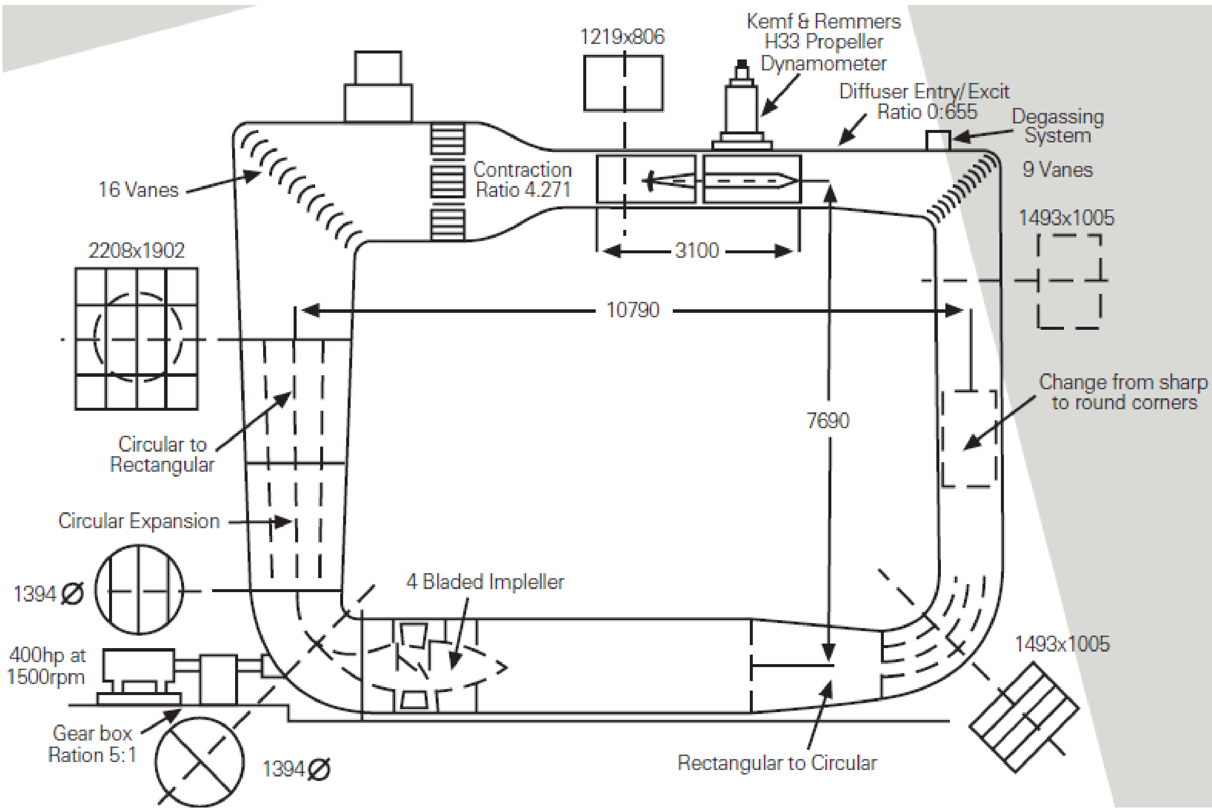


Figure 1- Emerson Cavitation Tunnel

Table -1 Main particulars of Emerson Cavitation Tunnel and main equipment

Maximum velocity	10 m/s with insert (0.81m x 0.81m measuring cross-section) 6 m/s without insert (0.8m x 1.21m measuring cross-section)
Absolute pressure range	7.6 kN/m^2 (min) to 106 kN/m^2 (max)
Cavitation number range	0.5 (min) to 23 (max) – without insert
MODEL PROPELLER SIZE	150 mm to 400 mm depending on the type of test
DYNAMOMETER TYPE 1	Kempf & Remmers H33/45 propeller dynamometer with height, pitch and tilt adjustable
Maximum thrust ±	2943 N
Maximum torque ±	147 Nm
Maximum rpm	4000
DYNAMOMETER TYPE 2	Kempf & Remmers R45 with vertically adjustable drive system and suitable for placement inside of hull models
Maximum thrust ±	687 N
Maximum torque ±	39 Nm
Maximum rpm	4000
DYNAMOMETER TYPE 3	Kempf & Remmers H101; Pod drive testing with height, pitch and tilt adjustment
Maximum thrust ±	700 N
Maximum torque ±	15 Nm
Maximum rpm	2000
3-COMPONENT BALANCE	Cussons R102 Multi-component balance with height, pitch and tilt adjustment
Fx	4.33 kN
Fy	5.0 kN
Mz	750 Nm
ABSORPTION DYNAMOMETER	Cussons ventilated regenerative loading system for water turbine testing
Control type	Speed (RPM) or torque
Max torque absorbed	40 Nm
Max speed	3000 rpm
LDA/PDA FLOW MEASURING SYSTEM	3-D Dantec Dynamics with probe submersibility capability
Electronics	Multi-PDA Signal Processor
Laser type and power	Spectra Physics, water cooled Argon-Ion and 3W
Probe details	60mm diameter 3-D submersible type with 500mm working distance
Traversing system	3-D computer driven with a range of 590 mm x 690 mm
PIV FLOW MEASURING SYSTEM	3-D Time resolved Dantec Dynamics System with a submersible capability
Acquisition & Control Unit	Dynamics Studio
Cameras	• NanoSense MkIII 2kHz, (1280 x 1024) with Nikon 50mm f/1.2 lens with submersible housing unit. • Also available NanoSense MkII+ 10kHz (512x512), 4Gb, Nikon 60mm lens camera for high-speed filming
Double Frame Rate	1 KHz
Laser type & power	New Wave (Pegasus TR), 10mJ at 1kHz
ACOUSTICS	Bruel & Kjaer Pulse 3560 System
Hydrophones	B&K 8103 miniature type

2.2 Open water propeller dynamometer & data acquisition

The H33/45 Kempf & Remmers Dynamometer measures shaft thrust and torque with the shaft speed obtained from a Hohner encoder at a resolution of 1800 pulses / min. The specifications of H33/45 dynamometer are given in Table 1 whilst a general view of the dynamometer and its interfacing with the tunnel lid is shown in Figure 2. The data acquisition system (DAQ) used in ECT is Labview 7.1. Data signals from the dynamometer and encoder are amplified using HBM MCG Plus system fitted with ML-30B amplifiers. The data signals are passed to Labview and acquired on a 2 GHz Pentium PC. Custom built virtual instrument (vi) object oriented software is used for the data acquisition.

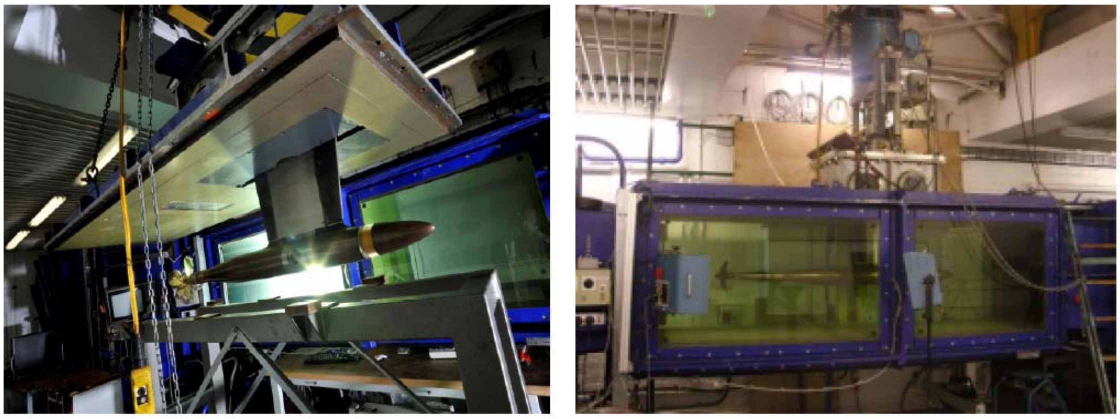


Figure 2 – H33 K&R open water dynamometer attached to the tunnel lid (Left) outside the measuring section and inside the measuring section (Right)

3. PROPELLER DESCRIPTION

The model propeller, which actually represents a typical AXIOM propeller in full-scale, is a symmetric 3 bladed propeller made from bronze by AXIOM and delivered to ECT for testing. The principle dimensions of the propeller are included in Table 2. Figure 3 shows the photograph of the propeller whilst Figure 4 presents the Axiom propeller attached to the H33/45 dynamometer shaft.

Table 2. Main particulars of the propeller

Number of Blades	3
Propeller Diameter (m)	0.3
Pitch Ratio	0.846
Direction of rotation	Right handed
Material made	Bronze

Figure 3 – Axiom propeller suction side view

Figure 4 – Axiom propeller attached to the H33/45 K&R open water dynamometer

4. TESTS

4.1 Open water performance tests (1st Quadrant)

In order to assess the efficiency performance of the propeller, open water tests at atmospheric condition were conducted using the Emerson Cavitation Tunnel's H33/45 Kempf & Remmers dynamometer. The tests were performed to cover a practical range of advance coefficient (J) varying between 0.15 – 0.55 under the atmospheric condition. As a standard procedure of the ECT open water tests, the tunnel water speeds were kept at 2.2m/s, 2.6m/s, 3.0m/s and 4.0m/s whilst the rate of shaft rotation was varied to to cover the above range.

Figure 5, 6 and 7 display the thrust coefficient (K_T), torque coefficient (K_Q) and open water efficiency (η_O) of the propeller against the advance coefficient (J), respectively. The averaged open water test results of 2.6m/s and 3.0m/s are displayed in Figure 8 and plotted values are tabulated in Table 3. Based on the analysed results one can note the maximum efficiency of the propeller varied between 33% and 35% depending on the tunnel speed.

The legends used in the tables and figures for propeller advance coefficient, J, thrust coefficient, K_T, torque coefficient, K_Q, and open water efficiency, η_O, are defined as follows:

$$J = \frac{V}{nD}$$

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

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

$$\eta_O = \frac{J}{2\pi}\frac{K_T}{K_Q}$$

Where, V is the tunnel free stream water velocity (m/s), n is the rotational speed of the propeller (rps), T is thrust (N) of the propeller, Q is the torque (N-m) of the propeller and ρ is the density of the tunnel solution (kg/m^3).

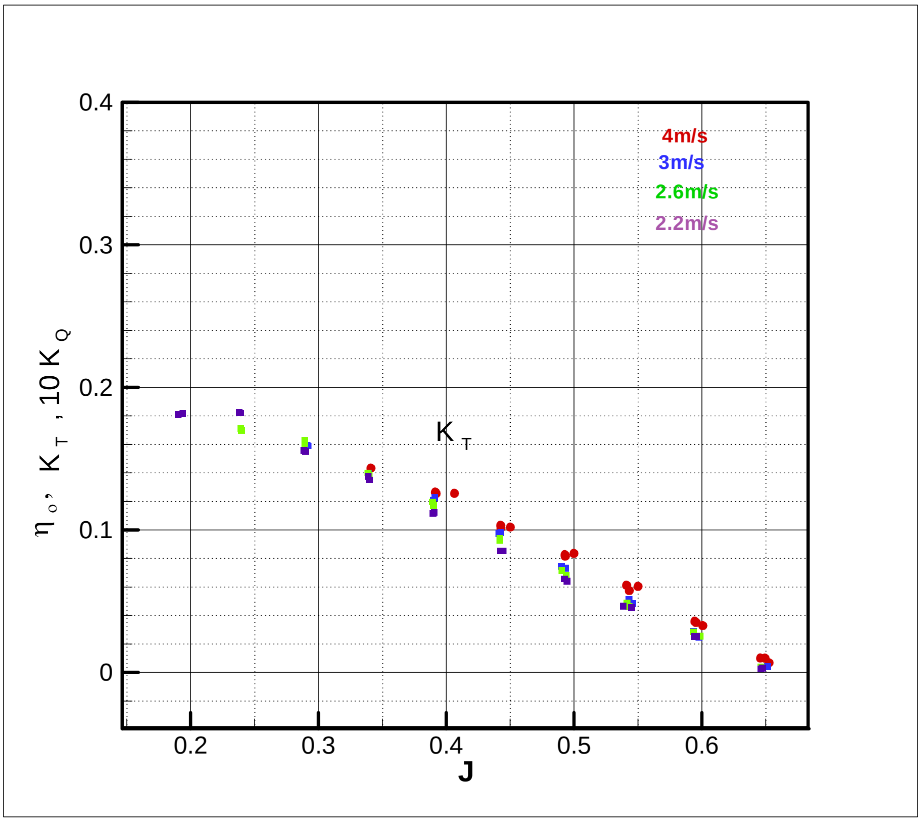


Figure 5 - Thrust coefficient (K_T) vs advance coefficient (J) curves

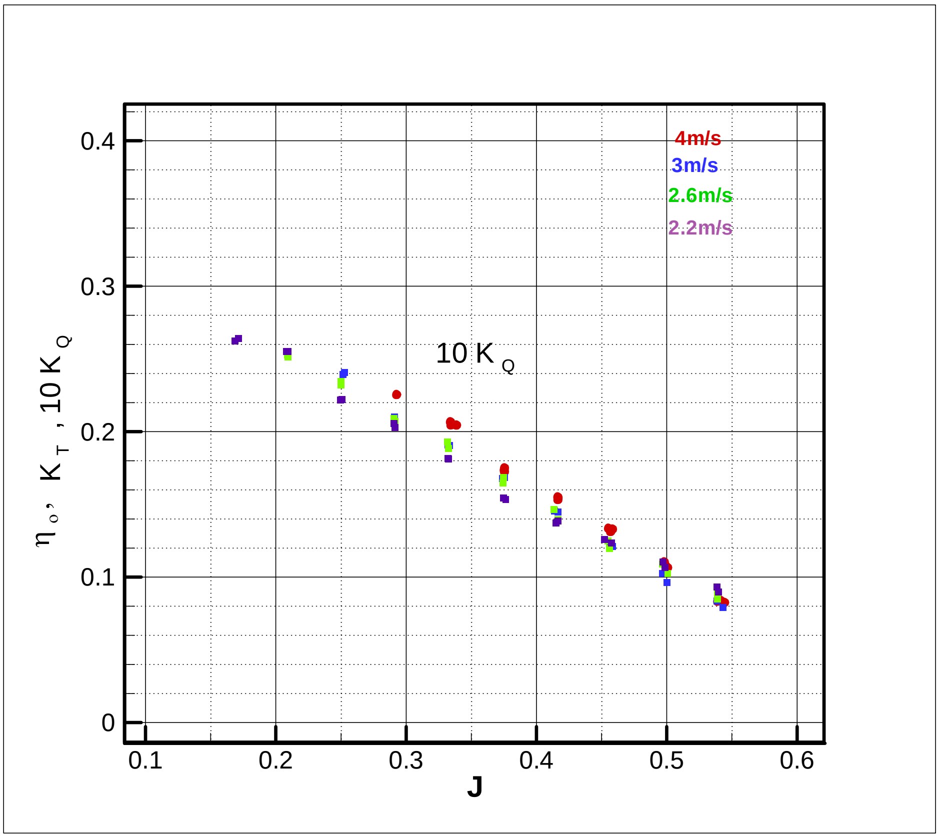


Figure 6 - Torque coefficient (K_Q) vs advance coefficient (J) curves

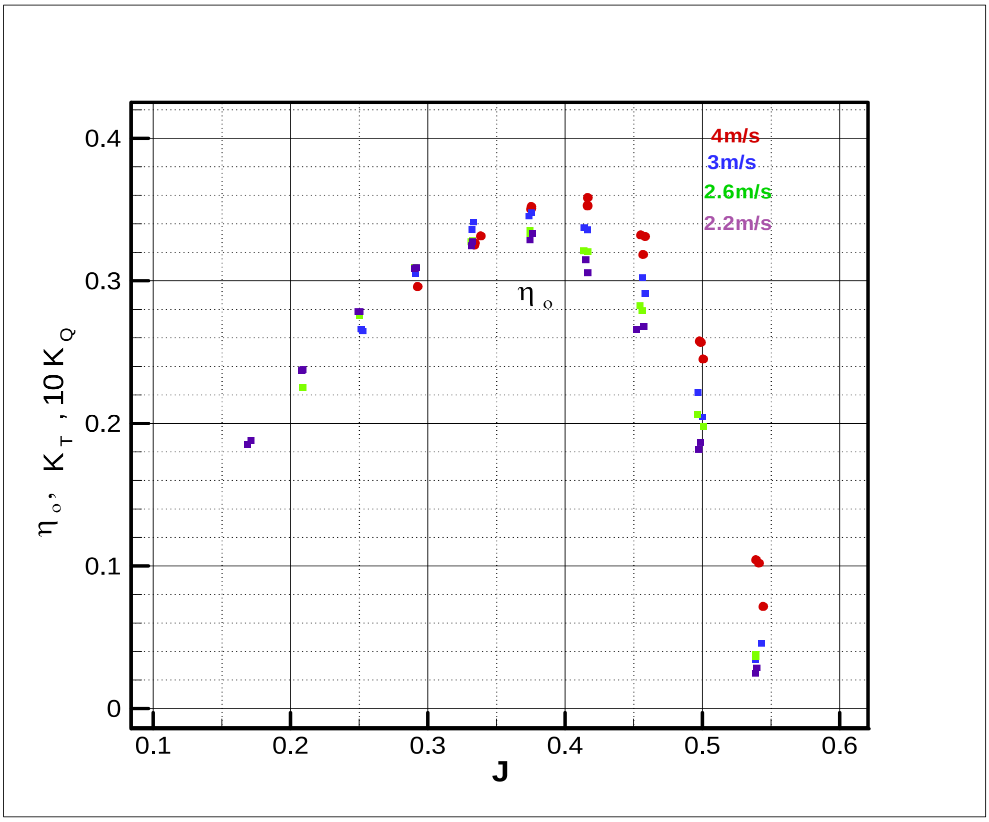


Figure 7 - Open water efficiency (η_O) vs advance coefficient (J) curves

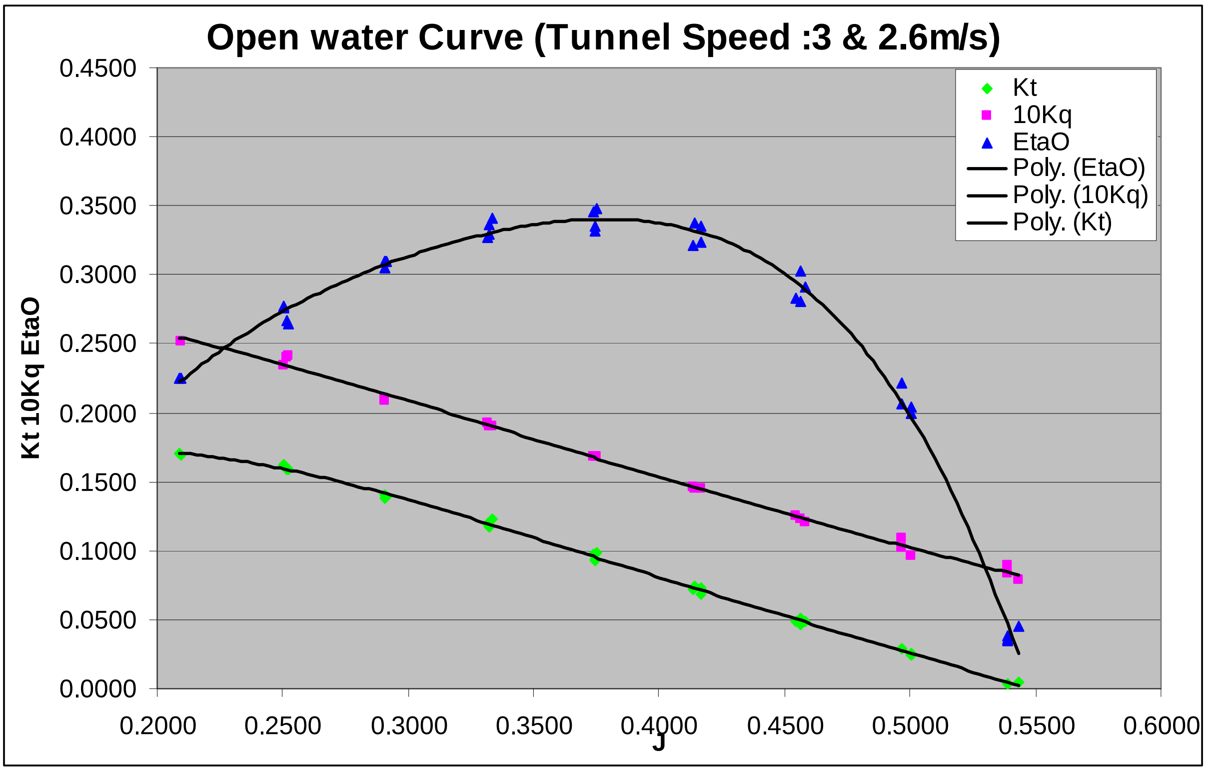


Figure 8 - Open water diagram (mean values)

Table 3. Open water data (mean values)

J	K_T	10 K_Q	η_O
0.60	-0.031	0.057	-0.512
0.55	-0.001	0.079	-0.017
0.50	0.025	0.102	0.198
0.45	0.052	0.127	0.296
0.40	0.080	0.153	0.334
0.35	0.109	0.181	0.336
0.30	0.137	0.209	0.313
0.25	0.159	0.235	0.270
0.20	0.173	0.258	0.213

4.2 Multi quadrant tests

Test results described in Section 4.2 represent the first quadrant performance of the propeller. That is for the propeller working with positive rotational speed and positive advance velocity. In order to study the manoeuvring, stopping and astern performance of a vessel's propeller, an additional three more quadrant tests and associated data are required. Three additional sets of open water tests were conducted to complete the four quadrant tests. During these tests the propeller was rotated in the ahead (clockwise) and astern (anti clockwise) directions while the direction of the tunnel flow was kept in the same (ahead) direction but the relative position of the propeller was changed back to front to simulate the appropriate quadrant according to the notation described in the following.

In the case of a fixed pitch propeller it is conventional to define the four quadrants based on an advance angle (β) defined as:

$$\beta = \tan^{-1}\left(\frac{V_a}{0.7\pi nD}\right)$$

and takes the following values at each quadrant:

2nd quadrant: *(Stopping in ahead)*	Advance speed – ahead Rotational speed – astern *advance angle* $90 < \beta \le 180$	***1st quadrant:*** *(Going ahead)*	Advance speed – ahead Rotational speed – ahead *advance angle* $0 \le \beta \le 90$
3rd quadrant: *(Reversing)*	Advance speed – astern Rotational speed – astern *advance angle* $180 < \beta \le 270$	***4th quadrant:*** *(Stopping in astern)*	Advance speed – ahead Rotational speed – ahead *advance angle* $270 < \beta \le 360$

Within the above context it should be noted that when β=0 or 360 then this defines the ahead bollard pull condition and when β =180 this corresponds to the astern bollard pull situation. For β =90 and 270, these positions relate to the condition when the propeller is not rotating and is being dragged ahead or astern through the water respectively.

Figure 9 assists in clarifying this notation for fixed pitch propellers while the. thrust coefficient (C_T) and torque coefficient (C_Q) can be represented using this notation by the following expressions

$$C_T = \frac{T}{(\pi/8)\rho[V_a^2 + (0.7\pi nD)^2]D^2}$$

$$C_T = \frac{T}{(\pi/8)\rho[V_a^2 + (0.7\pi nD)^2]D^3}$$

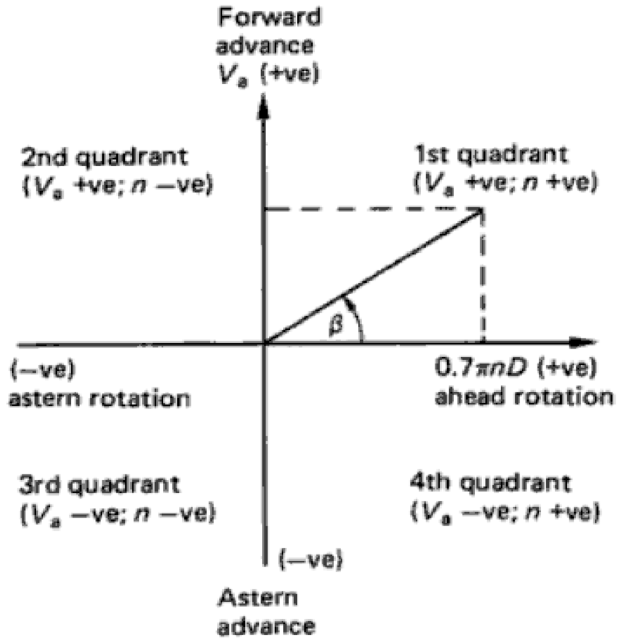


Figure 9 – Four quadrant notation

The four sets of open water tests were conducted by appropriately varying the tunnel flow speed (V), propeller shaft speed (n), direction of shaft speed (clockwise and anti-clockwise) and direction of tunnel flow (ahead and astern) via the relative position of the propeller with respect to flow. By this way the entire four quadrant data (i.e. thrust and torque) was collected and presented in the classical four quadrant notation, as C_T, $10C_Q$ values against to β, as shown in Figure 10.

The associated data for Figure 10 as collected from the runs is tabulated in Appendix B for further information.

As it can be seen in Figure 10 there are small discontinuities in the plotted data around β = 0, 90, 180, 270 and 360 deg due to the physical limitations of the facility. However these values can be obtained from the values around their vicinity by simple interpolation..

Perhaps the most striking nature of the presented data in Figure 10 is the symmetric nature of the AXIOM propeller performance for almost in all quadrants, i.e. 1^{st} quadrant vs 2^{nd} quadrant and 2^{nd} vs 3^{rd} as well as the skew symmetry of C_T and C_Q curves whilst this will not be the case for the conventional propellers which are usually optimised for the forward motion only. Obviously this is a favourable attribute for the AXIOM propeller for stopping and reversing as well as controlling the course keeping in both directions, ahead and astern, with almost similar performance.

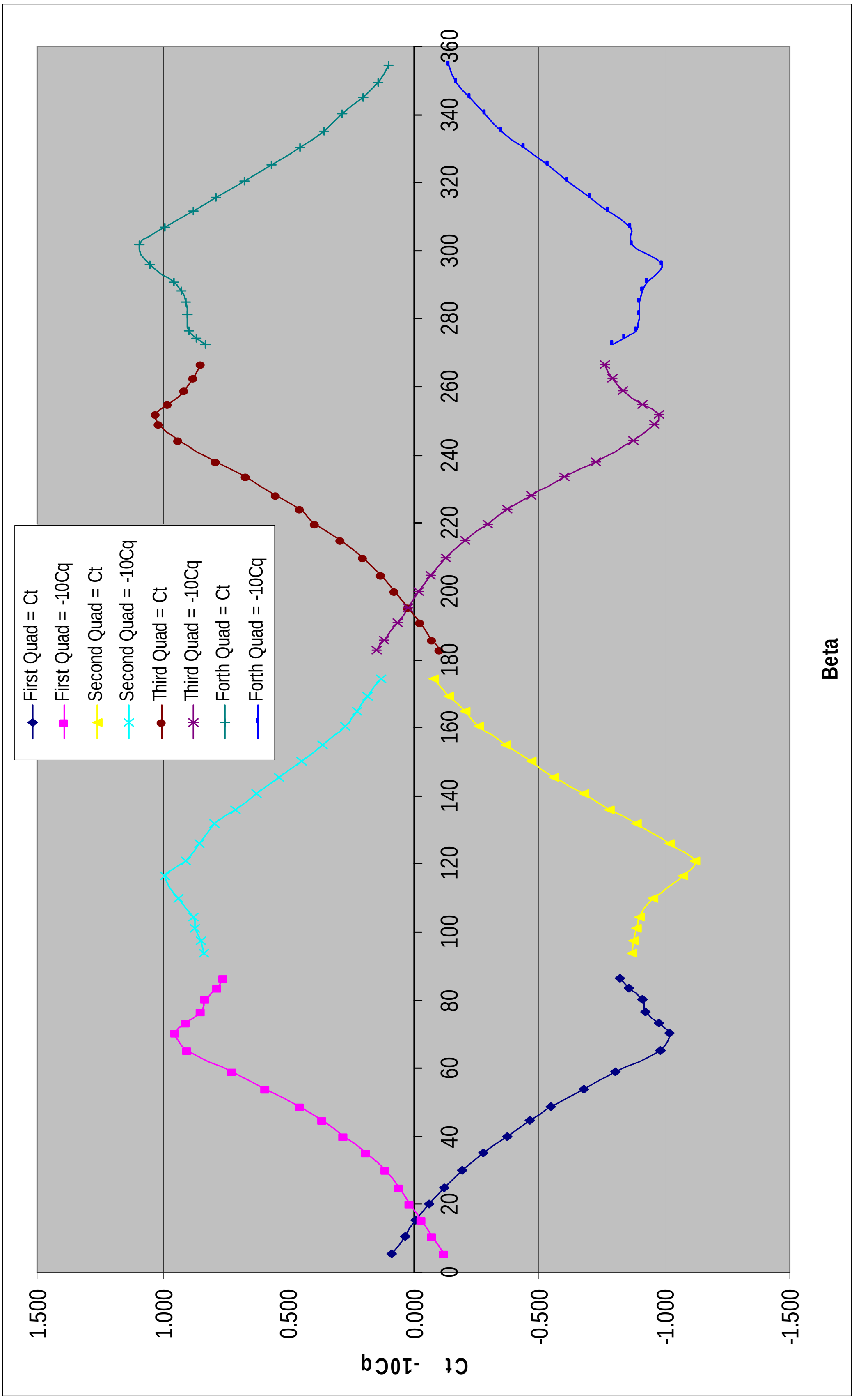


Figure 10 - Four quadrant data for the AXIOM propeller

5. CAVITATION OBSERVATIONS

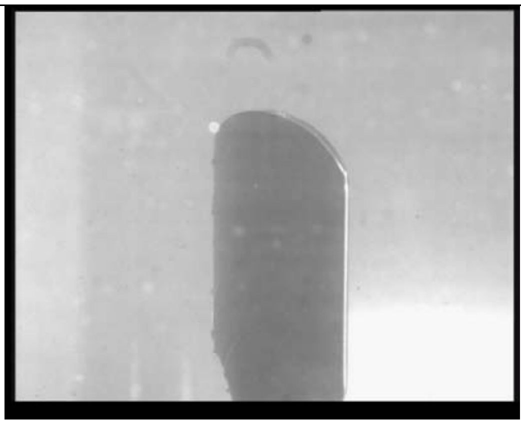
Cavitation observations were made with the propeller mainly in the 1st and 2nd quadrant runs at atmospheric condition. The observations were made visually by naked eye and recorded using a FlashCam black & white CCD video camera with a fast electronic shutter. In these tests the tunnel was open to atmosphere and the tunnel water was kept constant speed whilst the shaft rpm was varied to cover the range of operational conditions (i.e. different advance coefficients J).

The full details of the cavitation recording can be found in the video film accompanying this report and the contents list of the video is given in Appendix A. The pictures in Figure 11, which were captured from the video film taken, illustrate typical cavitation patterns observed.

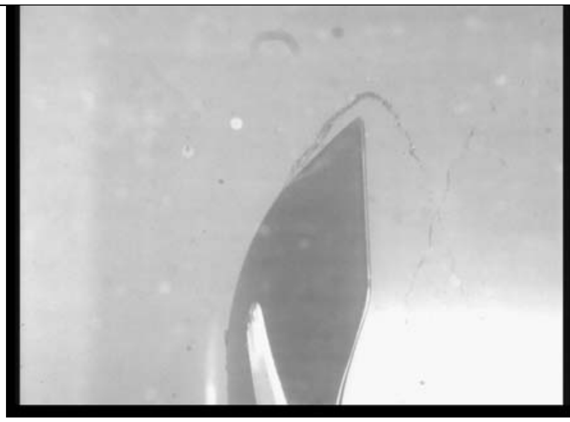
During the tests cavitation inception and developed cavitation patterns (mainly tip vortex combined with sheet cavitation) were observed and recorded. As can be observed in more detail in the attached video film, a visual appearance of the tip vortex cavitation inception was detected around J=0.508 (at 3 m/s runs) as shown in the first picture of Figure 11. It is noted that the inception kicks off in the mid chord region of the blade section at the tip, where the turn of the typical "S" section takes place on the suction side.

As can be seen in the captured pictures in Figure 11, having reached inception with increasing shaft speed (i.e. reducing J from 0.5 to 0.15), the cavitation develops into a full vortex type by further contribution from a sheet cavitation at the blade leading in the form of a wedge shape at the suction side of the blades. The thickness of the tip vortex increases with increasing loading as well as the spread and thickness of the sheet cavitation from the tip to mid chord region. At the maximum loading tested the entire cavitation pattern appears almost like "super cavitation", covering entire blade chord with a spread almost half (about 40-45%) of the blade area. With the increasing loading a thin vortex development at the trailing edge was also noticed and this was later taken up by the growing main tip vortex emanating from the mid-chord and leading edge. During the entire 1st quadrant tests no erosive "face" cavitation was observed and the developed tip vortex and sheet cavitations were rather steady leaving the blade chord at almost the mid-chord region initially and gradually attaching to the blade with increasing blade loading.

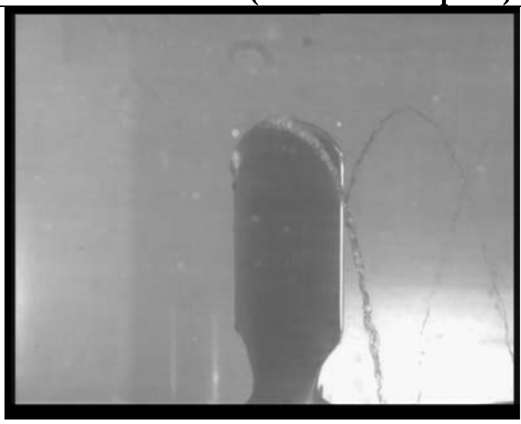
Limited recordings of the cavitation pattern were also included in the 2nd quadrant (i.e. simulating the stopping of vessel while advancing ahead). In this condition it was observed that the main tip vortex emanated from the leading edge of the blades at the face and in rather an unsteady state. With increased propeller loading this vortex developed into a strong vortex cavitation in combination with a flashing and equally unsteady sheet cavitation at the leading edge. However it was noted that as soon as it developed, the tip vortex did not wrap up around the entire tip as opposed to the pattern observed in the 1st quadrant case, but separated from the



J=0.508 V=3m/s (Cavitation inception)

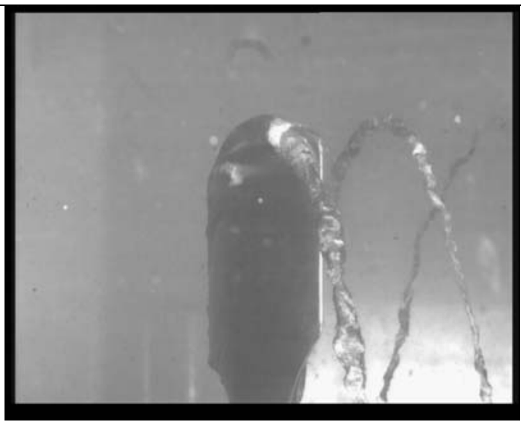


J=0.45 V=3m/s



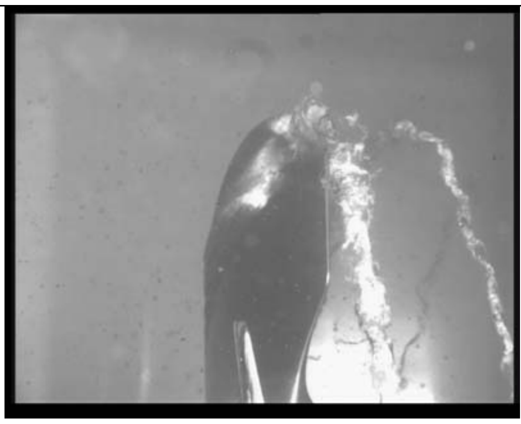
J=0.40 V=3m/s

J=0.35 V=3m/s



J=0.30 V=3m/s

J=0.25 V=3m/s



J=0.20 V=2m/s

J=0.15 V=2m/s

Figure 11 - Developed cavitation patterns in open water (1^{st} Quadrant) condition

blade being in contact at the leading edge region only. However both the tip vortex and flashing leading edge face cavitation were rather unsteady.

Although the above observations were conducted in atmospheric condition without any particular full-scale condition, these observations still will provide invaluable information on the cavitation behaviour of a typical AXIOM propeller.

6. CONCLUDING REMARKS

This report presented the cavitation tunnel tests for a 300mm diameter, 3 bladed Axiom propeller provided by Axiom Propellers Ltd. These tests were conducted for the first time to verify the propeller's efficiency, multi quadrant performance and cavitation characteristics. Based on the tests it was found that:

- Maximum efficiency of the AXIOM propeller was about 35% which was obtained during the entire first quadrant measurements.

- First time generated multi-quadrant data of the AXIOM propeller reflected the symmetric feature of this propeller, as such the ahead and astern (thrust and torque) performance of the AXIOM propeller had close similarity.

- In the first quadrant the main cavitation patterns observed were the steady tip vortex and leading edge sheet cavitation at the suction (back) side of the blades, increasing with increased blade loading and becoming more attached to the blades.

  The above patterns in the second quadrant were replaced by the similar cavitations with a lesser strength but in rather unsteady form and at the pressure (face) side of the blades.

APPENDIX – A: CONTENTS OF DVD

A 16 min DVD containing the video film of the cavitation tunnel tests is part of this report. The content of the video recording as follows:

- Menu
- Title
- View of the AXIOM propeller and K&R H33/45dynamometer
- **Cavitation observations at 2 m/s tunnel water speed (in 1st quadrant)**
  - Views at J=0.35, 0.30, 0.25, 0.2, 0.15
  - Cavitation build-up; shaft speed varying between N=1100 and 2632 rpm up and down
- **Cavitation observations at 3 m/s tunnel water speed (in 1st quadrant)**
  - Cavitation inception at J=0.508
  - Views at J=0.5, 0.45, 0.40, 0.35, 0.30, 0.25
  - Cavitation build-up; shaft speed varying between N=1200 and 2400 rpm up and down
- **Cavitation observations at 1 m/s tunnel water speed (in 2nd quadrant)**
  - Cavitation build-up; shaft speed varying from N= -500 to -1500 rpm up and down

APPENDIX – B: TABULATED MULTI-QUADRANT DATA

First quadrant

Va (m/s)	Rps	B angle(Deg)	Vr (m/s)	T (N)	Q (N-m)	Ct	-10 C_Q
1.5	23.333	5.57	15.47	747.0	31.7	0.088	-0.124
2.5	20.000	10.73	13.43	230.0	14.4	0.036	-0.075
3	16.667	15.26	11.40	-54.0	4.5	-0.012	-0.033
4	16.667	19.99	11.70	-315.2	-1.9	-0.065	0.013
5	16.250	25.00	11.83	-614.3	-8.3	-0.123	0.056
5	13.167	29.92	10.02	-701.3	-12.0	-0.196	0.112
5	10.833	34.98	8.72	-760.0	-15.1	-0.281	0.186
5	9.000	40.10	7.76	-807.6	-17.8	-0.377	0.276
5	7.667	44.67	7.11	-833.0	-19.6	-0.463	0.363
5	6.667	48.66	6.66	-864.0	-21.5	-0.548	0.455
5	5.567	53.70	6.20	-927.4	-24.2	-0.678	0.589
5	4.550	59.02	5.83	-972.4	-26.2	-0.804	0.721
5	3.483	65.32	5.50	-1058.0	-29.2	-0.983	0.903
5	2.717	70.28	5.31	-1026.0	-28.6	-1.023	0.949
5	2.283	73.23	5.22	-952.0	-26.3	-0.982	0.906
5	1.817	76.52	5.14	-870.5	-23.9	-0.926	0.846
5	1.333	80.02	5.08	-836.4	-22.8	-0.913	0.829
5	0.867	83.48	5.03	-773.7	-21.0	-0.859	0.779
5	0.450	86.60	5.01	-736.0	-20.2	-0.825	0.755

Second quadrant

Va (m/s)	Rps	B angle(Deg)	Vr (m/s)	T (N)	Q (N-m)	Ct	-10 C_Q
5	-0.500	93.775	5.011	-779.0	-22.38	-0.873	0.836
5	-0.967	97.27	5.041	-793.5	-22.9	-0.878	0.845
5	-1.467	100.95	5.093	-822.5	-24.06	-0.892	0.870
5	-1.917	104.19	5.157	-849.5	-25.0	-0.898	0.879
5	-2.750	109.94	5.319	-962.0	-28.2	-0.956	0.934
5	-3.783	116.53	5.588	-1191.0	-33.1	-1.073	0.992
5	-4.500	120.70	5.815	-1349.0	-32.7	-1.122	0.906
5	-5.483	125.89	6.171	-1381.0	-34.6	-1.020	0.853
5	-6.750	131.69	6.696	-1418.0	-37.9	-0.890	0.792
5	-7.800	135.82	7.175	-1431.0	-39.1	-0.782	0.712
5	-9.250	140.67	7.889	-1505.0	-41.6	-0.680	0.626
5	-11.050	145.56	8.840	-1563.0	-44.4	-0.563	0.533
5	-13.200	150.14	10.042	-1680.0	-48.2	-0.469	0.448
5	-16.317	155.09	11.869	-1851.0	-54.6	-0.370	0.363
4	-17.067	160.44	11.949	-1851.0	-54.6	-0.370	0.363
3	-16.750	164.81	11.451	-950.0	-31.5	-0.204	0.226
2.5	-20.000	169.27	13.429	-893.0	-34.8	-0.139	0.181
1.5	-23.083	174.37	15.303	-688.0	-31.7	-0.083	0.127

Third quadrant

Va (m/s)	Rps	B angle(Deg)	Vr (m/s)	T (N)	Q (N-m)	Ct	-10 C_Q
-0.8	-26.733	182.60	17.66	-1149.0	-49.2	-0.104	0.148
-1.5	-23.417	185.55	15.52	-643.0	-29.5	-0.075	0.115
-2.5	-20.067	190.69	13.47	-158.9	-12.6	-0.025	0.065
-3	-16.817	195.13	11.49	105.0	-3.3	0.022	0.023
-4	-16.850	199.79	11.81	360.7	3.6	0.073	-0.024
-5	-16.367	204.85	11.90	650.5	10.6	0.129	-0.070
-5	-13.217	209.83	10.05	724.4	13.8	0.202	-0.128
-5	-10.883	214.85	8.75	792.0	16.9	0.291	-0.206
-5	-9.083	219.84	7.80	847.2	19.3	0.391	-0.298
-5	-7.833	224.05	7.19	835.8	20.5	0.455	-0.372
-5	-6.750	228.31	6.70	872.4	22.5	0.547	-0.472
-5	-5.600	233.54	6.22	915.7	24.7	0.666	-0.599
-5	-4.717	238.10	5.89	974.6	26.9	0.790	-0.727
-5	-3.650	244.28	5.55	1027.0	28.8	0.938	-0.877
-5	-2.917	248.95	5.36	1034.9	29.4	1.014	-0.960
-5	-2.483	251.86	5.26	1013.1	28.9	1.029	-0.977
-5	-2.041	254.93	5.18	932.7	26.2	0.978	-0.915
-5	-1.467	259.05	5.09	839.5	23.0	0.910	-0.833
-5	-1.000	262.48	5.04	792.5	21.5	0.876	-0.791
-5	-0.470	266.45	5.01	758.6	20.5	0.850	-0.764

Fourth quadrant

Va (m/s)	Rps	B angle(Deg)	Vr (m/s)	T (N)	Q (N-m)	Ct	-10 C_Q
-5	0.317	272.39	5.00	740.0	21.1	0.831	-0.791
-5	0.550	274.15	5.01	771.2	22.6	0.863	-0.843
-5	0.867	276.52	5.03	805.6	24.0	0.895	-0.888
-5	1.533	281.44	5.10	833.3	25.0	0.901	-0.900
-5	2.000	284.78	5.17	859.8	25.6	0.904	-0.898
-5	2.500	288.26	5.27	911.8	27.0	0.925	-0.914
-5	2.850	290.61	5.34	968.7	28.4	0.955	-0.934
-5	3.667	295.82	5.55	1151.8	32.6	1.050	-0.991
-5	4.683	301.71	5.88	1342.0	32.0	1.093	-0.869
-5	5.683	306.87	6.25	1378.0	36.0	0.992	-0.864
-5	6.783	311.83	6.71	1402.0	37.3	0.876	-0.777
-5	7.733	315.58	7.14	1427.4	38.2	0.787	-0.702
-5	9.133	320.31	7.83	1474.6	40.3	0.676	-0.617
-5	10.967	325.35	8.79	1559.5	44.0	0.567	-0.534
-5	13.217	330.17	10.05	1628.0	47.4	0.453	-0.440
-5	16.417	335.22	11.93	1809.5	53.3	0.358	-0.351
-4	16.800	340.16	11.78	1400.0	42.4	0.284	-0.287
-3	16.783	344.84	11.47	927.7	31.3	0.198	-0.223
-2.5	20.133	349.34	13.52	926.6	33.8	0.143	-0.173
-1.5	23.450	354.46	15.54	845.3	36.2	0.098	-0.141