Potsdam Propeller Test Case (PPTC)

Cavitation Tests
with the Model Propeller VP1304

Report 3753

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This report includes	8 pages text 15 pages tables 20 pages diagrams/drawings 14 pages photographs 9 pages annex

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1 Summary

For the SMP’11 workshop the SVA provided the controllable pitch propeller VP1304 as a test case. Several investigations were conducted with this propeller: open water tests [5], cavitation tests and LDV measurements [6].

The open water characteristic and the cavitation behaviour of the model propeller VP1304 had been investigated in the cavitation tunnel K15A of the Potsdam Model Basin (SVA).
The influence of the number of revolutions (Reynolds number) on the open water characteristics is small in the tested range.

The cavitation buckets were determined for two blades of the model propeller VP1304. There are differences in the curves for the inception and the end of the tip vortex cavitation. The reason is the intermitting character of the tip vortex cavitation.
The development of cavitation was observed at three working conditions. Photos and videos document the cavitation behaviour in the working points at different cavitation numbers.

2 Introduction

The prediction of the cavitation behaviour of a propeller is important to analyse the propeller in design and off-design conditions [1]. The propeller VP1304 was designed to generate a tip vortex. Extensive model tests had been carried out to get data for the validation of potential and viscous flow propeller analysis programs [2], [3], [4], [5], [6].

The open water and cavitation tests had been repeated in preparation for the workshop of the SMP’11 in Hamburg. This report presents the open water characteristics and cavitation behaviour of the model propeller VP1304, measured in the small test section (data on page 2.1) of the cavitation tunnel K15A.

3 Tasks

The model propeller VP1304 was tested in the cavitation tunnel of the Potsdam Model Basin in homogeneous flow.

The characteristics of the model propeller VP1304 in the cavitation tunnel were measured at three different numbers of revolutions.

The cavitation buckets of two propeller blades were determined. The cavitation behaviour of the blades at the cavitation inception points should be documented as hand sketches.

The cavitation behaviour of the propeller was observed at different thrust coefficients and cavitation numbers. The cavitation behaviour of the propeller in the working point is shown in photos and videos.

4 Description of the model propeller VP1304

The propeller was designed by the SVA in 1998. For the manufacture of the propeller cold-rolled brass was used as raw material. The blades were manufactured on a CNC-based milling machine with HSC (high speed cutting) technology.

The propeller main properties are shown in table 1 and in the drawing on page 3.1. Photos of the propeller are shown on page 4.1.

The propeller is a controllable pitch propeller. This affects the propeller blade design near the hub and results in a 0.3 mm gap between hub and propeller blade near the leading and trailing edge of the propeller.

Table 1: Main data of model propeller

			VP1304
Diameter	D	[m]	0.250
Design pitch ratio r/R = 0.7	$P_{0.7C}/D$	[–]	1.635
Area ratio	A_E/A_0	[m]	0.77896
Chord length r/R = 0.7	$c_{0.7}$	[m]	0.10417
Skew	θ_{EXT}	[°]	18.837
Hub ratio	d_h/D	[–]	0.300
Number of blades	Z	[–]	5
Sense of rotation		[–]	right
Type			controllable pitch propeller

5 Test arrangement

The tests were carried out in the small test section of the cavitation tunnel K15A from Kempf & Remmers. The dynamometer J25 from Kempf & Remmers was used for the tests. The dynamometer was arranged in front of the propeller model (drawings on page 3.2, photos on page 4.1). The shaft inclination was zero degrees.

6 Test procedure

Apart from the calibration of the measuring device, runs had been made in order to measure the idle torque with a dummy hub, having the same shape as the real propeller hub.

The open water tests had been carried out at over pressure to avoid cavitation. The number of revolutions had been varied between n = 15, 20 and 25 s^{-1}.

The cavitation bucket had been measured with the number of revolutions n = 25 s^{-1}. Two blades had been selected for the cavitation tests.

The cavitation behaviour of the propeller had been observed in three working points, given in table 2.

Table 2: Cavitation observations

Test case 2.3.1			
Advanced coefficient	J	[-]	1.019
Thrust coefficient (non-cavitating)	K_T	[-]	0.387
Cavitation number	σ_n	[-]	2.024
Number of revolutions	n	[s^{-1}]	24.987
Test case 2.3.2			
Advanced coefficient	J	[-]	1.269
Thrust coefficient (non-cavitating)	K_T	[-]	0.245
Cavitation number	σ_n	[-]	1.424
Number of revolutions	n	[s^{-1}]	24.986
Test case 2.3.3			
Advanced coefficient	J	[-]	1.408
Thrust coefficient (non-cavitating)	K_T	[-]	0.167
Cavitation number	σ_n	[-]	2.000
Number of revolutions	n	[s^{-1}]	25.014

On page 2.2 an overview of all tests and test parameters is given.

7 Test results

The tables on the pages 2.3 to 2.15 contain mainly the measured values and the calculated characteristics of the model propeller in model scale. The influence of the test section on the propeller coefficients was corrected with the method from Glauert.

The diagrams, cavitation sketches and photos contain the propeller coefficients, corrected for the wall effect with the method from Glauert.

7.1 Open water characteristics

The open water characteristics are presented in the tables on the pages 2.3 to 2.8. The diagram on page 3.3 shows the open water characteristics measured in the cavitation free condition.

7.2 Cavitation behaviour

The results of the cavitation observation tests are given in the tables on pages 2.9 to 2.15.

On pages 3.4 and 3.5 the cavitation bucket diagrams are shown for the blades 1 and 3 of the model propeller VP1304. The diagrams on pages 3.6 to 3.11 show the comparison of the cavitation inception and cavitation end curves, observed on both blades. The tip vortex cavitation begins behind the propeller blade tip. By decreasing the cavitation number the cavitating tip vortex comes closer to the blade tip. Begin and end of the tip vortex cavitation are characterised by intermitting tip vortex cavitation. The begin of the tip vortex cavitation on the blade was defined as the point, where the cavitating tip vortex appears about 5% of the observation time.

The pages 3.13 to 3.20 show cavitation sketches of the observed cavitation.

The diagram on page 3.12 shows the working points of the cavitation observation in relation to the open water characteristics. The photographs of the cavitation are presented on the pages 4.2 to 4.14.

In addition high-speed videos give an impression of the cavitation dynamic.

8 References

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[6] Mach, K.-P.
Potsdam Propeller Test Case (PPTC) - LDV Velocity Measurements with the Model Propeller VP1304
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Details of model tests

VP1304

Cavitation tunnel	K15A (Kempf & Remmers)
Dimensions of the small test section	0.600 m · 0.600 m with rounded edges
Propeller	VP1304
Material of the propeller	brass
Type of propeller	controllable pitch propeller
Diameter of propeller	0.250 m
Measuring equipment in cavitation tunnel for:	
Number of revolutions, thrust and torque	Dynamometer J25 with:
	T_{max} = 3000 N
	Q_{max} = 150 Nm
Inflow velocity	manometer (principle of venturi nozzle)
Maximum inflow velocity	V_{max} = 14 m/s

Overview of model tests with the VP1304

Open water tests in the cavitation tunnel

Test No.	Date	Test	Test parameters	Table	Diagram
10PH0544	09/11/10	Open water test	V_V = 1.76 – 6.25 m/s, n = 15 s^{-1}	2.3 – 2.4	3.3
10PH0545	09/11/10	Open water test	V_V = 2.36 – 8.45 m/s, n = 20 s^{-1}	2.5 – 2.6	3.3
10PH0546	09/11/10	Open water test	V_V = 2.97 - 10.38 m/s, n = 25 s^{-1}	2.7 – 2.8	3.3, 3.12

Cavitation observation tests in the cavitation tunnel

Test No.	Date	Test	Test parameters	Table	Diagram Photo
10KM0547 10KM0549	09/11/10 11/11/10	Cavitation bucket	J_c = 0.865 – 1.50 n = 25 s^{-1}	2.9 – 2.12	3.4 - 3.11 3.13 - 3.20
10KM0548 10KM0550	10/09/10 11/11/10	Cavitation observation	J_c = 0.995; 1.254; 1.400 n = 25 s^{-1}	2.13– 2.15	3.12 4.2 - 4.14

Open water test in the cavitation tunnel, n = 15 s^{-1}

Test		**10PH0544**				Date		09.11.2010
Type of test		**OWT, n = 15 s^{-1}**						

Particulars of the propulsor

Propeller		**VP1304**	D	[m]	**0.25000**	$P_{0.7}/D$	[-]	**1.63500**
Sense of rotation		right-handed	$c_{0.7}$	[m]	0.10417	d_h/D	[-]	0.30000

Environmental data

t_W	[°C]	22.1	ν	[m²/s]	9.581e-7	ρ	[kg/m³]	997.71
Air content	[%]	46.70	p_A	[kPa]	98.237	p_V	[kPa]	2.687
Test section		600 x 600	w_a	[-]	0.000	t_A	[°C]	21.9

Measured values

No.	V [m/s]	n [rps]	T [N]	Q [Nm]	D_{H2} [kPa]
1	1.762	14.980	596.83	35.465	86.51
2	2.170	14.978	541.50	32.467	86.51
3	2.594	14.976	486.69	29.586	86.51
4	2.995	14.958	429.92	26.683	86.51
5	3.418	14.958	380.50	24.019	86.51
6	3.890	15.000	325.14	21.249	86.51
7	4.359	14.999	268.02	18.326	86.51
8	4.725	14.976	217.82	15.722	86.51
9	5.207	14.999	161.11	12.701	86.51
10	5.603	14.998	104.03	9.801	86.51
11	5.903	14.998	55.48	7.290	86.51
12	6.254	14.998	-8.79	3.737	86.51

Characteristic of propeller (model scale)

No.	J	K_T	$10K_Q$	η_O	σ_V	σ_n	$\sigma_{0.7}$	Re $[10^{-6}]$	C_{Th}
1	0.4705	0.6824	1.6220	0.315	117.424	25.998	5.141	0.916	7.85
2	0.5794	0.6194	1.4854	0.385	77.463	26.006	5.028	0.926	4.70
3	0.6928	0.5568	1.3539	0.453	54.196	26.012	4.893	0.939	2.95
4	0.8009	0.4930	1.2240	0.513	40.647	26.075	4.760	0.952	1.96
5	0.9140	0.4363	1.1018	0.576	31.214	26.075	4.598	0.969	1.33
6	1.0374	0.3708	0.9693	0.632	24.097	25.931	4.386	0.992	0.88
7	1.1625	0.3057	0.8361	0.676	19.190	25.932	4.191	1.014	0.58
8	1.2621	0.2492	0.7194	0.696	16.330	26.012	4.046	1.032	0.40
9	1.3885	0.1837	0.5795	0.701	13.450	25.933	3.834	1.061	0.24
10	1.4944	0.1187	0.4472	0.631	11.613	25.936	3.669	1.084	0.14
11	1.5744	0.0633	0.3326	0.477	10.464	25.936	3.546	1.103	0.07
12	1.6680	-0.0100	0.1705	-0.156	9.323	25.937	3.405	1.125	-0.01

Open water test in the cavitation tunnel, n = 15 s^{-1}

Test	**10PH0544**				Date		09.11.2010
Type of test	**OWT, n = 15 s^{-1}**						

Particulars of the propulsor

Propeller	**VP1304**	D	[m]	**0.25000**	$P_{0.7}/D$	[-]	**1.63500**
Sense of rotation	right-handed	$c_{0.7}$	[m]	0.10417	d_h/D	[-]	0.30000

Environmental data

t_W	[°C]	22.1	ν	[m²/s]	9.581e-7	ρ	[kg/m³]	997.71
Air content	[%]	46.70	p_A	[kPa]	98.237	p_V	[kPa]	2.687
Test section		600 x 600	w_a	[-]	0.000	t_A	[°C]	21.9

Characteristic of propeller (model scale), velocity correction by Glauert

No.	J_c	K_T	$10K_Q$	η_{Oc}	σ_{Vc}	σ_{nc}	$\sigma_{0.7c}$	Re_c [10^{-6}]	C_{Thc}
1	0.4255	0.6824	1.6220	0.285	143.841	26.039	5.190	0.912	9.60
2	0.5379	0.6194	1.4854	0.357	90.047	26.053	5.083	0.922	5.45
3	0.6553	0.5568	1.3539	0.429	60.689	26.063	4.950	0.934	3.30
4	0.7676	0.4930	1.2240	0.492	44.337	26.127	4.816	0.947	2.13
5	0.8851	0.4363	1.1018	0.558	33.350	26.127	4.649	0.964	1.42
6	1.0132	0.3708	0.9693	0.617	25.309	25.980	4.432	0.987	0.92
7	1.1432	0.3057	0.8361	0.665	19.877	25.977	4.229	1.011	0.60
8	1.2467	0.2492	0.7194	0.687	16.759	26.050	4.076	1.029	0.41
9	1.3776	0.1837	0.5795	0.695	13.681	25.963	3.856	1.058	0.25
10	1.4875	0.1187	0.4472	0.628	11.731	25.956	3.682	1.083	0.14
11	1.5708	0.0633	0.3326	0.476	10.517	25.948	3.553	1.102	0.07
12	1.6680	-0.0100	0.1705	-0.156	9.323	25.937	3.405	1.125	-0.01

Open water test in the cavitation tunnel, n = 20 s^{-1}

Test		**10PH0545**				Date		09.11.2010
Type of test		**OWT, n = 20 s^{-1}**						

Particulars of the propulsor

Propeller		**VP1304**	D	[m]	**0.25000**	$P_{0.7}/D$	[-]	**1.63500**
Sense of rotation		right-handed	$c_{0.7}$	[m]	0.10417	d_h/D	[-]	0.30000

Environmental data

t_W	[°C]	23.6	ν	[m²/s]	9.251e-7	ρ	[kg/m³]	997.34
Air content	[%]	47.90	p_A	[kPa]	98.264	p_V	[kPa]	2.944
Test section		600 x 600	w_a	[-]	0.000	t_A	[°C]	22.2

Measured values

No.	V [m/s]	n [rps]	T [N]	Q [Nm]	D_{H2} [kPa]	comment
1	2.360	19.987	1058.07	62.391	98.87	TVC
2	2.710	19.965	997.83	58.772	98.87	
3	3.267	19.963	898.61	53.555	98.87	
4	3.804	19.962	801.10	48.926	92.69	
5	4.325	19.960	714.35	44.528	92.69	
6	4.940	19.960	608.96	39.212	92.69	
7	5.533	19.960	511.79	34.143	86.51	
8	6.090	19.959	423.47	29.708	86.51	
9	6.620	19.960	335.58	25.233	86.51	
10	7.179	19.960	240.32	20.285	86.51	
11	7.664	19.962	137.44	14.708	86.51	
12	8.049	19.960	48.93	9.887	86.51	
13	8.453	19.960	-55.01	4.170	86.51	

Characteristic of propeller (model scale)

No.	J	K_T	$10K_Q$	η_O	σ_V	σ_n	$\sigma_{0.7}$	Re [10^{-6}]	C_{Th}	comment
1	0.4723	0.6798	1.6035	0.319	69.859	15.584	3.080	1.266	7.76	TVC
2	0.5430	0.6426	1.5139	0.367	52.980	15.619	3.044	1.274	5.55	
3	0.6546	0.5788	1.3798	0.437	36.462	15.622	2.967	1.290	3.44	
4	0.7621	0.5160	1.2606	0.497	26.039	15.126	2.792	1.308	2.26	
5	0.8667	0.4603	1.1476	0.553	20.139	15.129	2.708	1.329	1.56	
6	0.9899	0.3923	1.0105	0.612	15.440	15.129	2.601	1.356	1.02	
7	1.1087	0.3297	0.8799	0.661	11.902	14.631	2.412	1.384	0.68	
8	1.2205	0.2729	0.7657	0.692	9.822	14.632	2.313	1.414	0.47	
9	1.3266	0.2162	0.6503	0.702	8.314	14.631	2.218	1.444	0.31	
10	1.4386	0.1548	0.5228	0.678	7.069	14.631	2.119	1.477	0.19	
11	1.5356	0.0885	0.3790	0.571	6.203	14.628	2.033	1.508	0.10	
12	1.6131	0.0315	0.2548	0.318	5.623	14.631	1.967	1.533	0.03	
13	1.6939	-0.0354	0.1075	-0.889	5.099	14.631	1.899	1.560	-0.03	

Open water test in the cavitation tunnel, n = 20 s^{-1}

Test		**10PH0545**				Date		09.11.2010
Type of test		**OWT, n = 20 s^{-1}**						

Particulars of the propulsor

Propeller	**VP1304**	D	[m]	**0.25000**	$P_{0.7}/D$	[-]	**1.63500**
Sense of rotation	right-handed	$c_{0.7}$	[m]	0.10417	d_h/D	[-]	0.30000

Environmental data

t_W	[°C]	23.6	ν	[m²/s]	9.251e-7	ρ	[kg/m³]	997.34
Air content	[%]	47.90	p_A	[kPa]	98.264	p_V	[kPa]	2.944
Test section		600 x 600	w_a	[-]	0.000	t_A	[°C]	22.2

Characteristic of propeller (model scale), velocity correction by Glauert

No.	J_c	K_T	$10K_Q$	η_{Oc}	σ_{Vc}	σ_{nc}	$\sigma_{0.7c}$	Re_c [10^{-6}]	C_{Thc}	comment
1	0.4274	0.6798	1.6035	0.288	85.542	15.624	3.113	1.261	9.48	TVC
2	0.4999	0.6426	1.5139	0.338	62.670	15.664	3.080	1.268	6.55	
3	0.6155	0.5788	1.3798	0.411	41.365	15.672	3.005	1.284	3.89	
4	0.7273	0.5160	1.2606	0.474	28.694	15.178	2.829	1.302	2.48	
5	0.8361	0.4603	1.1476	0.534	21.718	15.181	2.743	1.322	1.68	
6	0.9641	0.3923	1.0105	0.596	16.330	15.179	2.633	1.350	1.07	
7	1.0876	0.3297	0.8799	0.649	12.409	14.677	2.439	1.379	0.71	
8	1.2035	0.2729	0.7657	0.683	10.131	14.673	2.335	1.409	0.48	
9	1.3135	0.2162	0.6503	0.695	8.500	14.665	2.235	1.440	0.32	
10	1.4295	0.1548	0.5228	0.674	7.173	14.657	2.131	1.474	0.19	
11	1.5305	0.0885	0.3790	0.569	6.251	14.643	2.040	1.506	0.10	
12	1.6112	0.0315	0.2548	0.317	5.638	14.637	1.969	1.532	0.03	
13	1.6939	-0.0354	0.1075	-0.889	5.099	14.631	1.899	1.560	-0.03	

Open water test in the cavitation tunnel, n = 25 s^{-1}

Test		**10PH0546**				Date		09.11.2010
Type of test		**OWT, n = 25 s^{-1}**						

Particulars of the propulsor

Propeller	**VP1304**	D	[m]	**0.25000**	$P_{0.7}/D$	[-]	**1.63500**
Sense of rotation	right-handed	$c_{0.7}$	[m]	0.10417	d_h/D	[-]	0.30000

Environmental data

t_W	[°C]	22.6	ν	[m²/s]	9.470e-7	ρ	[kg/m³]	997.59
Air content	[%]	48.20	p_A	[kPa]	98.285	p_V	[kPa]	2.771
Test section		600 x 600	w_a	[-]	0.000	t_A	[°C]	22.3

Measured values

No.	V [m/s]	n [rps]	T [N]	Q [Nm]	D_{H2} [kPa]	comment
1	2.970	25.005	1668.74	98.123	98.87	SSC
2	3.583	24.977	1530.72	90.655	98.87	SSC
3	4.250	24.976	1382.11	82.767	98.87	SSC
4	4.917	24.977	1226.86	74.618	96.40	
5	5.533	24.975	1096.89	68.183	93.93	
6	6.262	24.974	940.52	60.396	86.51	
7	6.924	24.974	801.93	53.486	86.51	
8	7.614	24.974	660.89	46.229	82.81	
9	8.253	24.973	525.44	39.313	77.86	
10	8.883	24.973	390.52	32.116	74.15	
11	9.457	24.973	244.35	24.348	70.45	
12	9.935	24.972	102.45	16.716	69.21	PSC
13	10.377	24.972	-39.66	9.139	67.97	PSC

Characteristic of propeller (model scale)

No.	J	K_T	$10K_Q$	η_O	σ_V	σ_n	$\sigma_{0.7}$	Re [10^{-6}]	C_{Th}	comment
1	0.4752	0.6849	1.6109	0.322	44.133	9.964	1.969	1.548	7.72	SSC
2	0.5739	0.6297	1.4917	0.386	30.326	9.987	1.933	1.562	4.87	SSC
3	0.6807	0.5686	1.3620	0.452	21.555	9.988	1.885	1.582	3.12	SSC
4	0.7875	0.5047	1.2278	0.515	15.901	9.860	1.807	1.605	2.07	
5	0.8861	0.4513	1.1220	0.567	12.397	9.734	1.732	1.629	1.46	
6	1.0029	0.3870	0.9940	0.621	9.298	9.353	1.601	1.661	0.98	
7	1.1089	0.3299	0.8803	0.662	7.606	9.353	1.542	1.692	0.68	
8	1.2194	0.2719	0.7608	0.694	6.162	9.163	1.449	1.728	0.47	
9	1.3220	0.2162	0.6471	0.703	5.098	8.909	1.353	1.763	0.32	
10	1.4229	0.1607	0.5286	0.688	4.306	8.718	1.271	1.799	0.20	
11	1.5148	0.1005	0.4007	0.605	3.716	8.527	1.196	1.834	0.11	
12	1.5914	0.0422	0.2752	0.388	3.342	8.465	1.149	1.865	0.04	PSC
13	1.6621	-0.0163	0.1504	-0.287	3.041	8.400	1.106	1.894	-0.02	PSC

Open water test in the cavitation tunnel, n = 25 s^{-1}

Test	**10PH0546**				Date		09.11.2010
Type of test	**OWT, n = 25 s^{-1}**						

Particulars of the propulsor

Propeller	**VP1304**	D	[m]	**0.25000**	$P_{0.7}/D$	[-]	**1.63500**
Sense of rotation	right-handed	$c_{0.7}$	[m]	0.10417	d_h/D	[-]	0.30000

Environmental data

t_W	[°C]	22.6	ν	[m²/s]	9.470e-7	ρ	[kg/m³]	997.59
Air content	[%]	48.20	p_A	[kPa]	98.285	p_V	[kPa]	2.771
Test section		600 x 600	w_a	[-]	0.000	t_A	[°C]	22.3

Characteristic of propeller (model scale), velocity correction by Glauert

No.	J_c	K_T	$10K_Q$	η_{Oc}	σ_{Vc}	σ_{nc}	$\sigma_{0.7c}$	Re_c [10^{-6}]	C_{Thc}	comment
1	0.4300	0.6849	1.6109	0.291	54.122	10.005	1.993	1.541	9.43	SSC
2	0.5320	0.6297	1.4917	0.357	35.456	10.033	1.960	1.555	5.67	SSC
3	0.6425	0.5686	1.3620	0.427	24.316	10.038	1.912	1.574	3.51	SSC
4	0.7534	0.5047	1.2278	0.493	17.461	9.912	1.834	1.597	2.26	
5	0.8560	0.4513	1.1220	0.548	13.355	9.786	1.757	1.621	1.57	
6	0.9777	0.3870	0.9940	0.606	9.837	9.403	1.624	1.653	1.03	
7	1.0877	0.3299	0.8803	0.649	7.944	9.400	1.562	1.686	0.71	
8	1.2026	0.2719	0.7608	0.684	6.363	9.203	1.465	1.722	0.48	
9	1.3090	0.2162	0.6471	0.696	5.219	8.943	1.365	1.758	0.32	
10	1.4134	0.1607	0.5286	0.684	4.378	8.745	1.280	1.796	0.20	
11	1.5090	0.1005	0.4007	0.603	3.752	8.545	1.201	1.832	0.11	
12	1.5891	0.0422	0.2752	0.388	3.355	8.472	1.151	1.864	0.04	PSC
13	1.6621	-0.0163	0.1504	-0.287	3.041	8.400	1.106	1.894	-0.02	PSC

Cavitation observation, blade 1, n = 25 s^{-1}

Test	**10KM0547**	Date	09.11.2010
Test	**10KM0549**	Date	11.11.2010
Type of test	**Cavitation observation, blade 1**		

Particulars of the propulsor

Propeller	**VP1304**	D	[m]	**0.25000**	$P_{0.7}/D$	[-]	**1.63500**
Sense of rotation	right-handed	$c_{0.7}$	[m]	0.10417	d_h/D	[-]	0.30000

Environmental data

t_W	[°C]	22.8	ν	[m²/s]	9.425e-7	ρ	[kg/m³]	997.54
Air content	[%]	48.70	p_A	[kPa]	98.384	p_V	[kPa]	2.805
Test section		600 x 600	w_a	[-]	0.000	t_A	[°C]	22.6

Propeller coefficients (model scale), velocity correction by Glauert, cavitation observation on blade 1

No.	J_c	K_T	$10K_Q$	η_{Oc}	σ_{Vc}	σ_{nc}	$\sigma_{0.7c}$	Re_c [10^{-6}]	C_{Thc}	comment
3	0.8649	0.4473	1.1102	0.555	8.847	6.619	1.185	1.634	1.52	BTVC
4	0.8649	0.4463	1.1123	0.552	10.507	7.859	1.407	1.634	1.52	ETVC
7	0.8663	0.4447	1.1087	0.553	7.979	5.988	1.072	1.632	1.51	BSSC
8	0.8663	0.4435	1.1070	0.552	8.663	6.502	1.164	1.632	1.50	ESSC
13	0.9725	0.3870	0.9947	0.602	4.468	4.225	0.731	1.661	1.04	BTVC
14	0.9726	0.3872	0.9943	0.603	6.644	6.285	1.087	1.661	1.04	ETVC
17	0.9709	0.3880	0.9933	0.604	3.052	2.877	0.498	1.663	1.05	BSSC
18	0.9709	0.3882	0.9932	0.604	3.542	3.339	0.578	1.663	1.05	ESSC
23	1.0805	0.3291	0.8794	0.644	2.646	3.089	0.515	1.693	0.72	BTVC
24	1.0808	0.3281	0.8753	0.645	4.247	4.961	0.826	1.693	0.72	ETVC
28	1.0807	0.3158	0.8577	0.633	1.650	1.927	0.321	1.694	0.69	BSSC
27	1.0803	0.3239	0.8735	0.638	1.865	2.177	0.363	1.694	0.71	ESSC
34	1.1877	0.2628	0.7525	0.660	1.411	1.991	0.319	1.726	0.47	BTVC
35	1.1871	0.2760	0.7651	0.681	3.317	4.674	0.748	1.725	0.50	ETVC
40	1.1880	0.2454	0.7089	0.654	1.059	1.495	0.239	1.726	0.44	BSSC
41	1.1871	0.2628	0.7501	0.662	1.414	1.992	0.319	1.726	0.47	ESSC
3	1.2850	0.2227	0.6638	0.686	1.764	2.912	0.449	1.790	0.34	BTVC
4	1.2851	0.2223	0.6628	0.686	2.234	3.690	0.569	1.789	0.34	ETVC
12	1.3433	0.1869	0.5961	0.670	1.296	2.338	0.352	1.808	0.26	BTVC
11	1.3428	0.1925	0.5997	0.686	1.645	2.966	0.447	1.808	0.27	ETVC
14	1.3402	0.1945	0.6032	0.688	1.630	2.927	0.441	1.811	0.28	BPSC
13	1.3402	0.1946	0.6032	0.688	1.818	3.266	0.492	1.811	0.28	EPSC
19	1.3884	0.1724	0.5554	0.686	2.015	3.884	0.574	1.827	0.23	BPSC
20	1.3887	0.1709	0.5508	0.686	2.376	4.582	0.677	1.827	0.23	EPSC
25	1.4966	0.1067	0.4154	0.612	3.724	8.340	1.179	1.869	0.12	BPSC
24	1.4966	0.1056	0.4074	0.618	3.748	8.394	1.186	1.869	0.12	EPSC

Cavitation observation, blade 3, n = 25 s^{-1}

Test	**10KM0547**	Date	09.11.2010
Test	**10KM0549**	Date	11.11.2010
Type of test	**Cavitation observation, blade 3**		

Particulars of the propulsor

Propeller	**VP1304**	D	[m]	**0.25000**	$P_{0.7}/D$	[-]	**1.63500**
Sense of rotation	right-handed	$c_{0.7}$	[m]	0.10417	d_h/D	[-]	0.30000

Environmental data

t_W	[°C]	22.8	ν	[m²/s]	9.425e-7	ρ	[kg/m³]	997.54
Air content	[%]	48.70	p_A	[kPa]	98.384	p_V	[kPa]	2.805
Test section		600 x 600	w_a	[-]	0.000	t_A	[°C]	22.6

Propeller coefficients (model scale), velocity correction by Glauert, cavitation observation on blade 3

No.	J_c	K_T	$10K_Q$	η_{Oc}	σ_{Vc}	σ_{nc}	$\sigma_{0.7c}$	Re_c [10^{-6}]	C_{Thc}	comment
2	0.8662	0.4478	1.1091	0.557	8.825	6.622	1.185	1.632	1.52	BTVC
1	0.8659	0.4456	1.1067	0.555	9.963	7.470	1.337	1.633	1.51	ETVC
5	0.8663	0.4439	1.1036	0.555	8.486	6.369	1.140	1.633	1.51	BSSC
6	0.8663	0.4440	1.1067	0.553	10.130	7.602	1.361	1.633	1.51	ESSC
10	0.8656	0.4504	1.1133	0.557	4.950	3.709	0.664	1.633	1.53	BRC
11	0.9722	0.3877	0.9913	0.605	5.005	4.731	0.818	1.661	1.04	BTVC
12	0.9725	0.3868	0.9929	0.603	6.493	6.141	1.062	1.661	1.04	ETVC
15	0.9709	0.3899	0.9953	0.605	3.098	2.921	0.505	1.663	1.05	BSSC
16	0.9709	0.3877	0.9908	0.605	3.204	3.020	0.523	1.663	1.05	ESSC
19	0.9709	0.3871	0.9918	0.603	3.644	3.436	0.595	1.663	1.05	BRC
21	1.0804	0.3309	0.8793	0.647	2.858	3.337	0.556	1.693	0.72	BTVC
22	1.0805	0.3303	0.8765	0.648	3.992	4.661	0.776	1.693	0.72	ETVC
26	1.0807	0.3122	0.8466	0.634	1.487	1.737	0.289	1.694	0.68	BSSC
25	1.0805	0.3181	0.8608	0.636	1.648	1.923	0.320	1.694	0.69	ESSC
29	1.0799	0.3318	0.8770	0.650	2.643	3.082	0.514	1.694	0.72	BRC (SS)
30	1.0802	0.3111	0.8456	0.633	1.440	1.680	0.280	1.695	0.68	FC
31	1.0796	0.3199	0.8678	0.633	1.697	1.978	0.330	1.695	0.70	BRC (PS)
32	1.1867	0.2736	0.7721	0.669	1.659	2.336	0.374	1.726	0.49	BTVC
33	1.1869	0.2748	0.7644	0.679	2.617	3.686	0.590	1.725	0.50	ETVC
36	1.1866	0.2706	0.7659	0.667	1.518	2.138	0.342	1.726	0.49	FC
37	1.1863	0.2752	0.7681	0.676	1.840	2.589	0.415	1.726	0.50	BRC (SS), BRC (PS)
38	1.1882	0.2387	0.6944	0.650	0.921	1.300	0.208	1.727	0.43	BSSC
39	1.1875	0.2543	0.7288	0.659	1.235	1.742	0.279	1.726	0.46	ESSC

Cavitation observation, blade 3, n = 25 s^{-1}

Test	**10KM0547**	Date	09.11.2010
Test	**10KM0549**	Date	11.11.2010
Type of test	**Cavitation observation, blade 3**		

Particulars of the propulsor

Propeller	**VP1304**	D	[m]	**0.25000**	$P_{0.7}/D$	[-]	**1.63500**
Sense of rotation	right-handed	$c_{0.7}$	[m]	0.10417	d_h/D	[-]	0.30000

Environmental data

t_W	[°C]	22.8	ν	[m²/s]	9.425e-7	ρ	[kg/m³]	997.54
Air content	[%]	48.70	p_A	[kPa]	98.384	p_V	[kPa]	2.805
Test section		600 x 600	w_a	[-]	0.000	t_A	[°C]	22.6

Propeller coefficients (model scale), velocity correction by Glauert, cavitation observation on blade 3

No.	J_c	K_T	$10K_Q$	η_{Oc}	σ_{Vc}	σ_{nc}	$\sigma_{0.7c}$	Re_c [10-6]	C_{Thc}	comment
1	1.2852	0.2137	0.6527	0.670	1.309	2.162	0.333	1.790	0.33	BTVC
2	1.2848	0.2241	0.6648	0.689	2.554	4.216	0.650	1.790	0.35	ETVC
5	1.2850	0.2239	0.6644	0.689	2.278	3.762	0.580	1.790	0.35	BRC (PS)
6	1.2854	0.2210	0.6608	0.684	1.599	2.642	0.407	1.789	0.34	BRC (SS)
8	1.3409	0.1966	0.6088	0.689	1.653	2.973	0.448	1.810	0.28	BPSC
7	1.3406	0.1967	0.6096	0.688	1.782	3.202	0.483	1.810	0.28	EPSC
10	1.3433	0.1841	0.5891	0.668	1.225	2.210	0.333	1.808	0.26	BTVC
9	1.3425	0.1926	0.6032	0.682	1.461	2.633	0.397	1.808	0.27	ETVC
15	1.3401	0.1954	0.6053	0.689	2.273	4.081	0.615	1.810	0.28	BRC (PS)
16	1.3401	0.1954	0.6052	0.689	1.731	3.109	0.469	1.810	0.28	BRC (SS)
18	1.3911	0.1705	0.5527	0.683	2.122	4.107	0.606	1.825	0.22	BPSC
17	1.3907	0.1703	0.5506	0.685	2.468	4.774	0.705	1.825	0.22	EPSC
21	1.3885	0.1725	0.5544	0.688	2.810	5.418	0.801	1.827	0.23	BRC (PS)
23	1.4967	0.1034	0.4098	0.601	2.698	6.043	0.854	1.869	0.12	BPSC
22	1.4964	0.1061	0.4157	0.608	2.917	6.532	0.923	1.869	0.12	EPSC

Cavitation observation, begin of thrust break down, n = 25 s^{-1}

Test	**10KM0547**	Date	09.11.2010
Test	**10KM0549**	Date	11.11.2010
Type of test	**Cavitation observation, begin of thrust break down**		

Particulars of the propulsor

Propeller	**VP1304**	D	[m]	**0.25000**	$P_{0.7}/D$	[-]	**1.63500**
Sense of rotation	right-handed	$c_{0.7}$	[m]	0.10417	d_h/D	[-]	0.30000

Environmental data

t_W	[°C]	22.8	ν	[m²/s]	9.425e-7	ρ	[kg/m³]	997.54
Air content	[%]	48.70	p_A	[kPa]	98.384	p_V	[kPa]	2.805
Test section		600 x 600	w_a	[-]	0.000	t_A	[°C]	22.6

Propeller coefficients (model scale), velocity correction by Glauert, inception of thrust break down

No.	J_c	K_T	$10K_Q$	η_{Oc}	σ_{Vc}	σ_{nc}	$\sigma_{0.7c}$	Re_c [10^{-6}]	C_{Thc}	comment
9	0.8662	0.4393	1.1045	0.548	2.534	1.901	0.340	1.633	1.49	TD
20	0.9714	0.3819	0.9904	0.596	2.142	2.021	0.350	1.663	1.03	TD
25	1.0805	0.3181	0.8608	0.636	1.648	1.923	0.320	1.694	0.69	TD
36	1.1866	0.2706	0.7659	0.667	1.518	2.138	0.342	1.726	0.49	TD
6	1.2854	0.2217	0.6608	0.686	1.522	2.515	0.388	1.789	0.34	TD
9	1.3425	0.1926	0.6032	0.682	1.461	2.633	0.397	1.808	0.27	TD

Cavitation observation, J_c = 0.9947

Test	**10KM0548**				Date		10.11.2010
Type of test	**Working points for photos and videos**						

Particulars of the propulsor

Propeller	**VP1304**	D	[m]	**0.25000**	$P_{0.7}/D$	[-]	**1.63500**
Sense of rotation	right-handed	$c_{0.7}$	[m]	0.10417	d_h/D	[-]	0.30000

Environmental data

t_W	[°C]	23.2	ν	[m²/s]	9.337e-7	ρ	[kg/m³]	997.44
Air content	[%]	53.50	p_A	[kPa]	98.878	p_V	[kPa]	2.873
Test section		600 x 600	w_a	[-]	0.000	t_A	[°C]	23.1

Measured values

No.	V [m/s]	n [rps]	T [N]	Q [Nm]	D_{H2} [kPa]
1	6.367	24.996	926.30	59.407	2.09
2	6.367	24.988	919.24	59.117	-7.65
3	6.367	24.987	919.60	59.150	-17.40
4	6.367	24.990	914.46	59.063	-36.88
5	6.367	24.987	908.70	58.980	-56.37

Characteristic of propeller (model scale)

No.	J	K_T	$10K_Q$	η_O	σ_V	σ_n	$\sigma_{0.7}$	Re [10^{-6}]	C_{Th}
1	1.0189	0.3805	0.9762	0.632	4.841	5.026	0.856	1.690	0.93
2	1.0193	0.3779	0.9720	0.631	4.359	4.529	0.771	1.690	0.93
3	1.0193	0.3780	0.9726	0.631	3.877	4.028	0.686	1.690	0.93
4	1.0192	0.3758	0.9709	0.628	2.913	3.026	0.515	1.690	0.92
5	1.0193	0.3735	0.9698	0.625	1.949	2.024	0.345	1.690	0.92

Characteristic of propeller (model scale), velocity correction by Glauert

No.	J_c	K_T	$10K_Q$	η_{Oc}	σ_{Vc}	σ_{nc}	$\sigma_{0.7c}$	Re_c [10^{-6}]	C_{Thc}
1	0.9941	0.3805	0.9762	0.617	5.136	5.076	0.871	1.683	0.98
2	0.9947	0.3779	0.9720	0.615	4.627	4.578	0.786	1.683	0.97
3	0.9947	0.3780	0.9726	0.615	4.121	4.077	0.700	1.683	0.97
4	0.9946	0.3758	0.9709	0.613	3.109	3.075	0.528	1.683	0.97
5	0.9949	0.3735	0.9698	0.610	2.095	2.074	0.356	1.683	0.96

Cavitation observation, J_c = 1.2535

Test		**10KM0548**				Date		10.11.2010
Type of test		**Working points for photos and videos**						

Particulars of the propulsor

Propeller		**VP1304**	D	[m]	**0.25000**	$P_{0.7}/D$	[-]	**1.63500**
Sense of rotation		right-handed	$c_{0.7}$	[m]	0.10417	d_h/D	[-]	0.30000

Environmental data

t_W	[°C]	23.2	ν	[m²/s]	9.337e-7	ρ	[kg/m³]	997.44
Air content	[%]	53.50	p_A	[kPa]	98.878	p_V	[kPa]	2.873
Test section		600 x 600	w_a	[-]	0.000	t_A	[°C]	23.1

Measured values

No.	V [m/s]	n [rps]	T [N]	Q [Nm]	D_{H2} [kPa]
1	7.924	24.996	589.43	42.372	-36.88
2	7.924	24.995	583.53	42.376	-46.63
3	7.924	24.999	574.39	42.233	-52.48
4	7.923	24.993	556.42	41.241	-56.37
5	7.924	24.986	502.08	38.383	-68.06

Characteristic of propeller (model scale)

No.	J	K_T	$10K_Q$	η_O	σ_V	σ_n	$\sigma_{0.7}$	Re [10^{-6}]	C_{Th}
1	1.2681	0.2421	0.6962	0.702	1.881	3.024	0.469	1.770	0.38
2	1.2681	0.2397	0.6963	0.695	1.569	2.523	0.392	1.770	0.38
3	1.2680	0.2359	0.6938	0.686	1.382	2.222	0.345	1.770	0.37
4	1.2680	0.2286	0.6778	0.681	1.258	2.023	0.314	1.770	0.36
5	1.2686	0.2064	0.6312	0.660	0.885	1.424	0.221	1.770	0.33

Characteristic of propeller (model scale), velocity correction by Glauert

No.	J_c	K_T	$10K_Q$	η_{Oc}	σ_{Vc}	σ_{nc}	$\sigma_{0.7c}$	Re_c [10^{-6}]	C_{Thc}
1	1.2531	0.2421	0.6962	0.694	1.950	3.062	0.478	1.765	0.39
2	1.2534	0.2397	0.6963	0.687	1.630	2.560	0.400	1.765	0.39
3	1.2535	0.2359	0.6938	0.678	1.438	2.259	0.353	1.765	0.38
4	1.2537	0.2286	0.6778	0.673	1.310	2.059	0.321	1.765	0.37
5	1.2557	0.2064	0.6312	0.654	0.923	1.456	0.227	1.765	0.33

Cavitation observation, J_c = 1.4000

Test		**10KM0550**				Date		11.11.2010
Type of test		**Working points for photos and videos**						

Particulars of the propulsor

Propeller		**VP1304**	D	[m]	**0.25000**	$P_{0.7}/D$	[-]	**1.63500**
Sense of rotation		right-handed	$c_{0.7}$	[m]	0.10417	d_h/D	[-]	0.30000

Environmental data

t_W	[°C]	23.5	ν	[m²/s]	9.272e-7	ρ	[kg/m³]	997.37
Air content	[%]	58.50	p_A	[kPa]	100.585	p_V	[kPa]	2.926
Test section		600 x 600	w_a	[-]	0.000	t_A	[°C]	21.9

Measured values

No.	V [m/s]	n [rps]	T [N]	Q [Nm]	D_{H2} [kPa]
1	8.807	24.993	399.27	32.667	-19.49
2	8.807	24.997	391.50	32.268	-38.97
3	8.807	25.014	331.94	29.801	-58.46

Characteristic of propeller (model scale)

No.	J	K_T	$10K_Q$	η_O	σ_V	σ_n	$\sigma_{0.7}$	Re $[10^{-6}]$	C_{Th}
1	1.4095	0.1641	0.5369	0.685	2.016	4.004	0.587	1.834	0.21
2	1.4092	0.1608	0.5302	0.680	1.512	3.003	0.440	1.834	0.21
3	1.4083	0.1362	0.4890	0.624	1.008	1.999	0.293	1.835	0.17

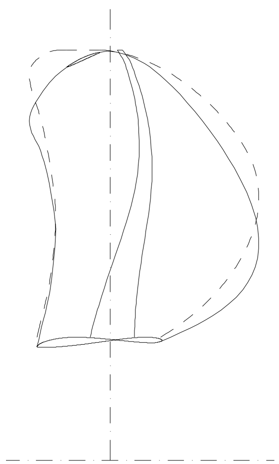
Characteristic of propeller (model scale), velocity correction by Glauert

No.	J_c	K_T	$10K_Q$	η_{Oc}	σ_{Vc}	σ_{nc}	$\sigma_{0.7c}$	Re_c $[10^{-6}]$	C_{Thc}
1	1.3998	0.1641	0.5369	0.681	2.058	4.032	0.593	1.830	0.21
2	1.3998	0.1608	0.5302	0.676	1.546	3.029	0.446	1.831	0.21
3	1.4001	0.1362	0.4890	0.621	1.031	2.022	0.298	1.832	0.18

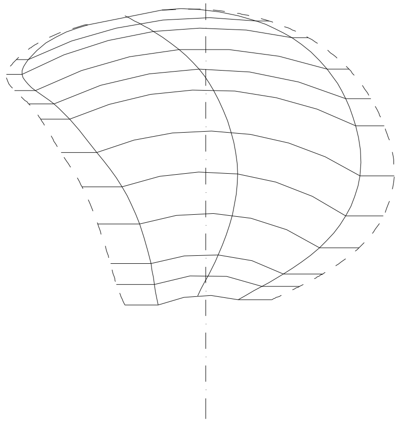
POTSDAM MODEL BASIN

Model propeller VP1304

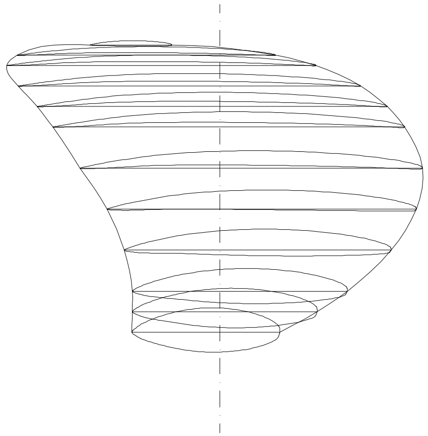
SIDE VIEW
CLEARANCE CURVE



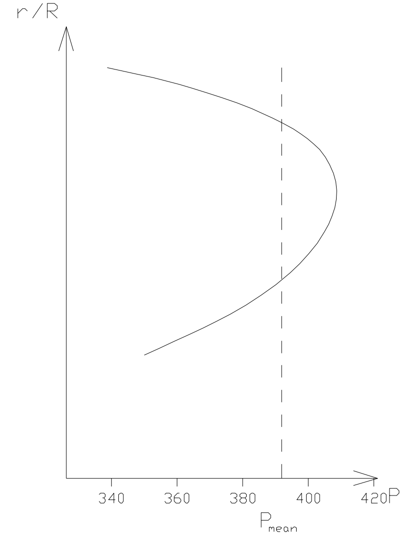
PROJECTED OUTLINE
DEVELOPED OUTLINE

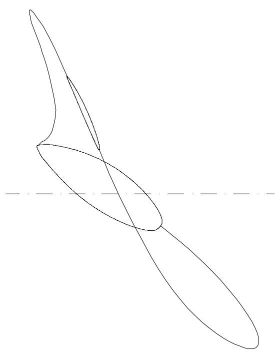


BLADE SECTIONS
EXPANDED OUTLINE



PITCH DISTRIBUTION





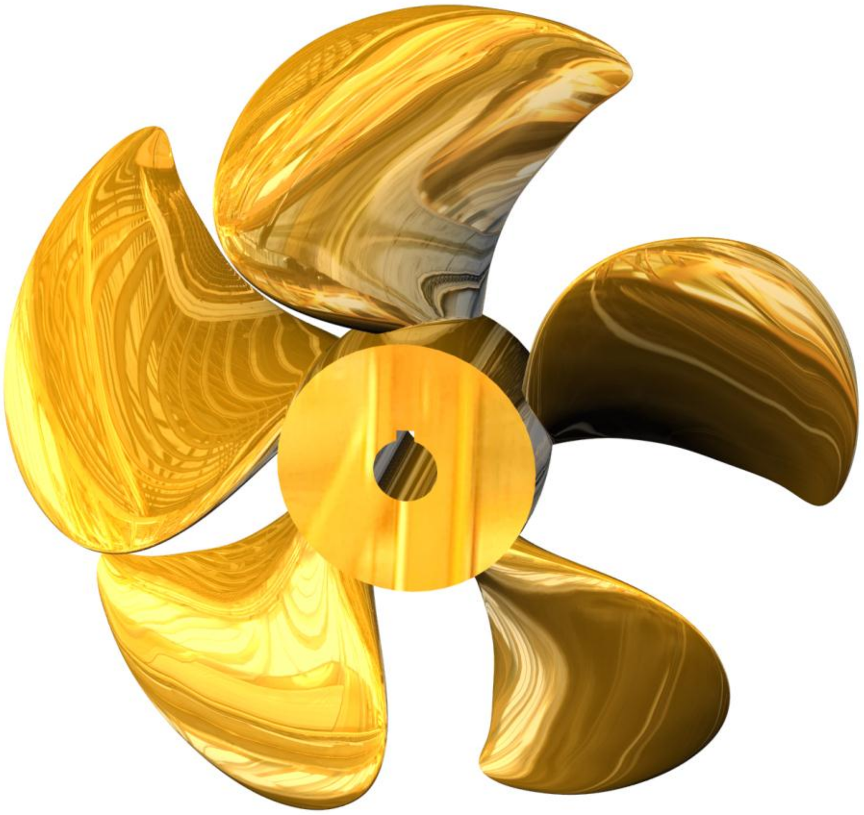
r/R	r	t	c	c_LE	f	rake	P
0.30000	37.50	13.525	45.00	18.25	0.675	0.000	350.00
0.35000	43.75	12.050	56.25	29.63	1.125	-0.500	363.75
0.40000	50.00	10.688	65.42	38.79	1.570	-1.250	376.25
0.50000	62.50	8.137	81.25	52.13	2.356	-3.350	394.50
0.60000	75.00	6.050	94.17	59.83	2.837	-5.875	405.00
0.70000	87.50	4.425	104.17	61.67	3.093	-7.500	408.75
0.80000	100.00	3.250	107.08	56.29	3.052	-7.375	403.50
0.85000	106.25	2.775	106.54	50.93	2.967	-6.625	395.50
0.90000	112.50	2.375	104.17	42.83	2.672	-5.450	382.75
0.95000	118.75	2.013	94.17	29.33	2.194	-4.033	364.50
0.97500	121.88	1.825	78.67	17.00	1.715	-3.300	352.75
1.00000	125.00	1.638	25.00	-14.58	0.500	-2.500	338.75

PROPELLER DIAMETER	D	250.0000mm
PITCH AT r/R=0.7	$P_{0.7}$	408.7500mm
PITCH AT r/R=0.75	$P_{0.75}$	407.3804mm
MEAN PITCH	P_{mean}	391.8812mm
CORDL. AT r/R=0.75	$c_{0.75}$	106.3476mm
THICKN. AT r/R=0.75	$t_{0.75}$	3.7916mm
PITCH RATIO	$P_{0.7}/D$	1.63500
MEAN PITCH RATIO	P_{mean}/D	1.56752
AREA RATIO	A_E/A_0	0.77896
SKEW		18.837°
HUB DIAMETER RATIO	d_h/D	0.30000
NUMBER OF BLADES	z	5
DIRECTION OF ROTATION		RIGHT-HANDED

MODEL SCALE 1 : 1.000000

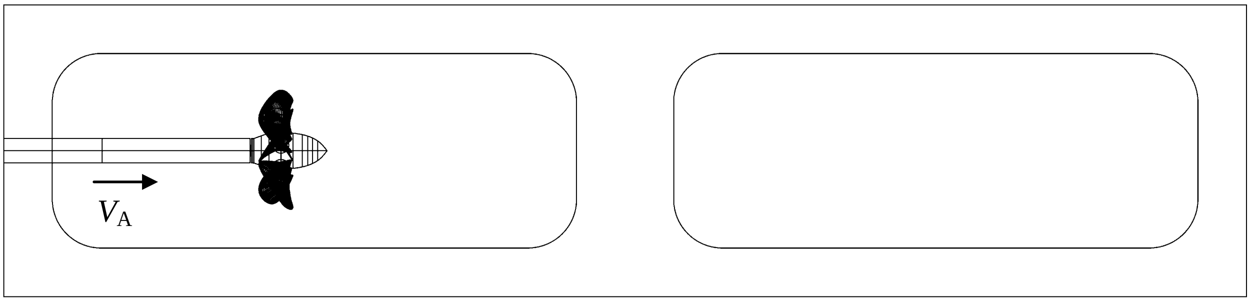
DIAGRAMS/SKETCHES

Propeller VP1304

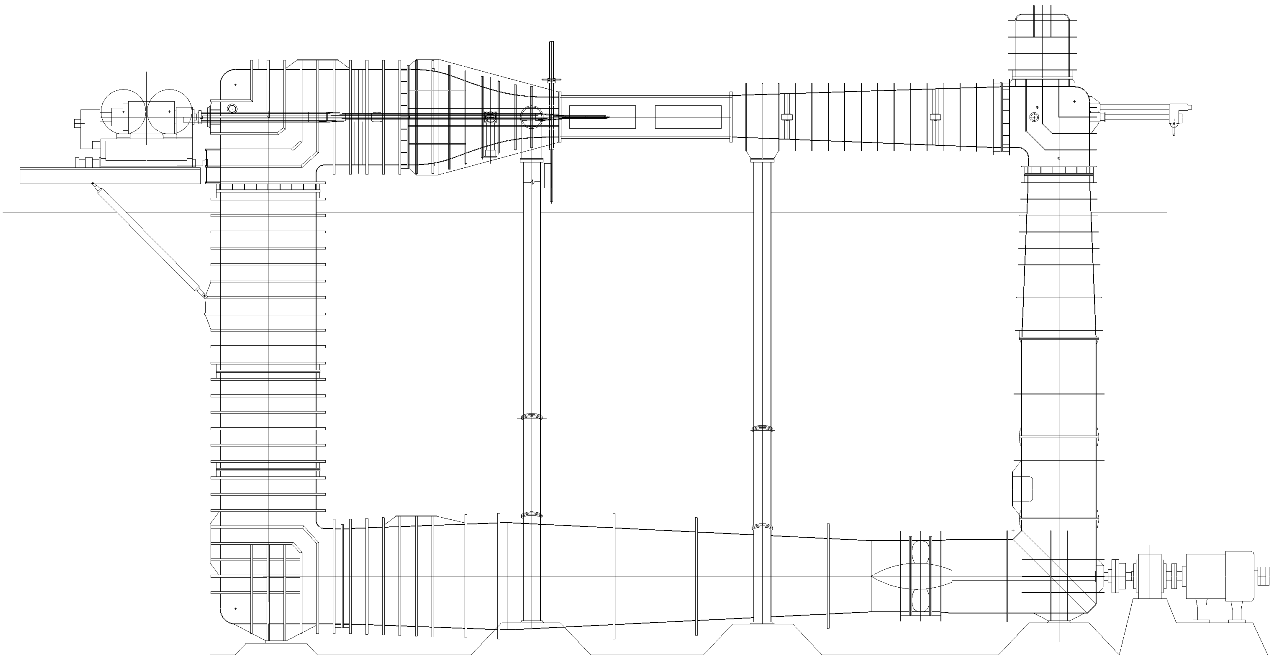


VP1304 in cavitation tunnel configuration

Test arrangement in the cavitation tunnel

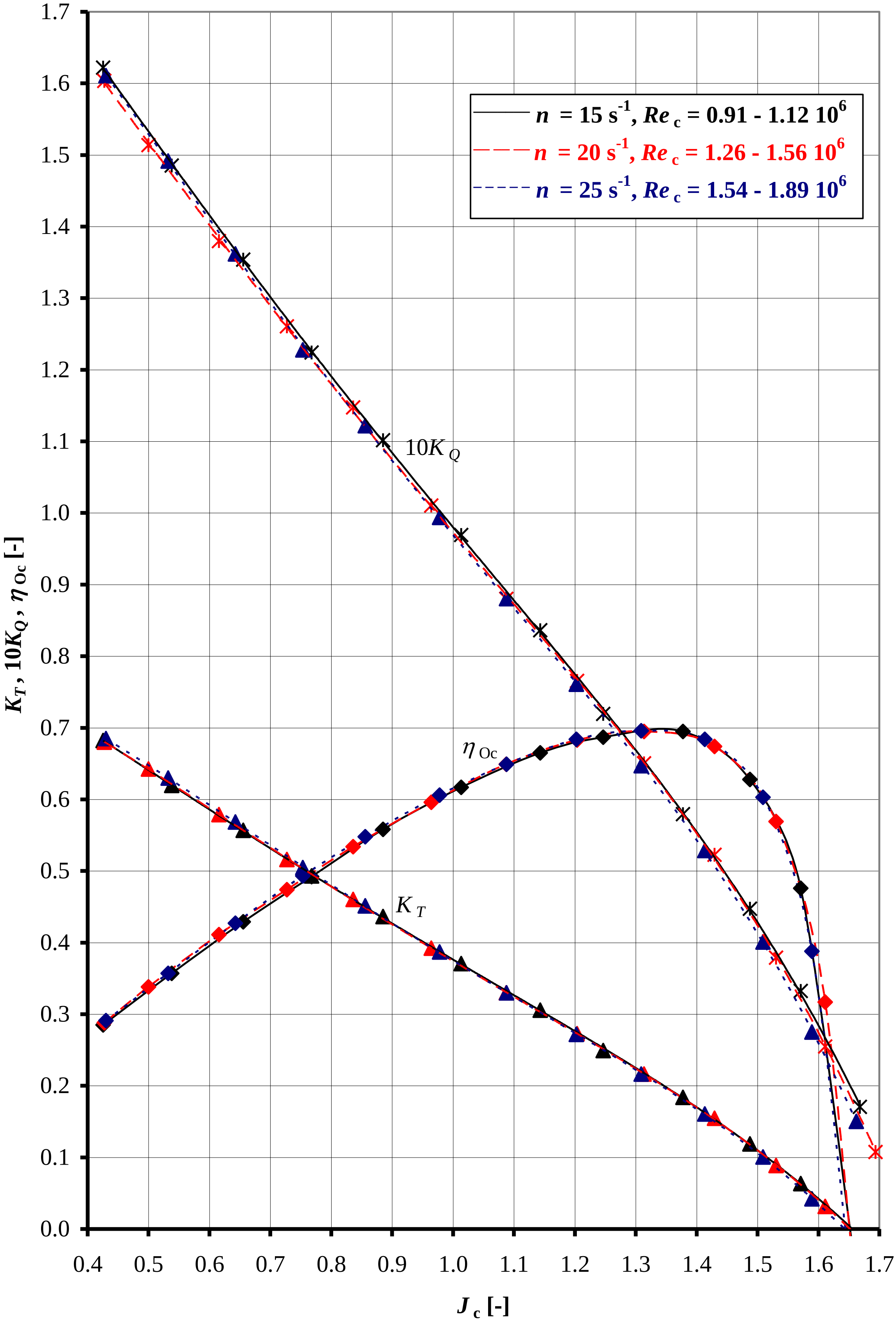


Model propeller VP1304 in the test section with dynamometer J25 (shaft diameter 50 mm)

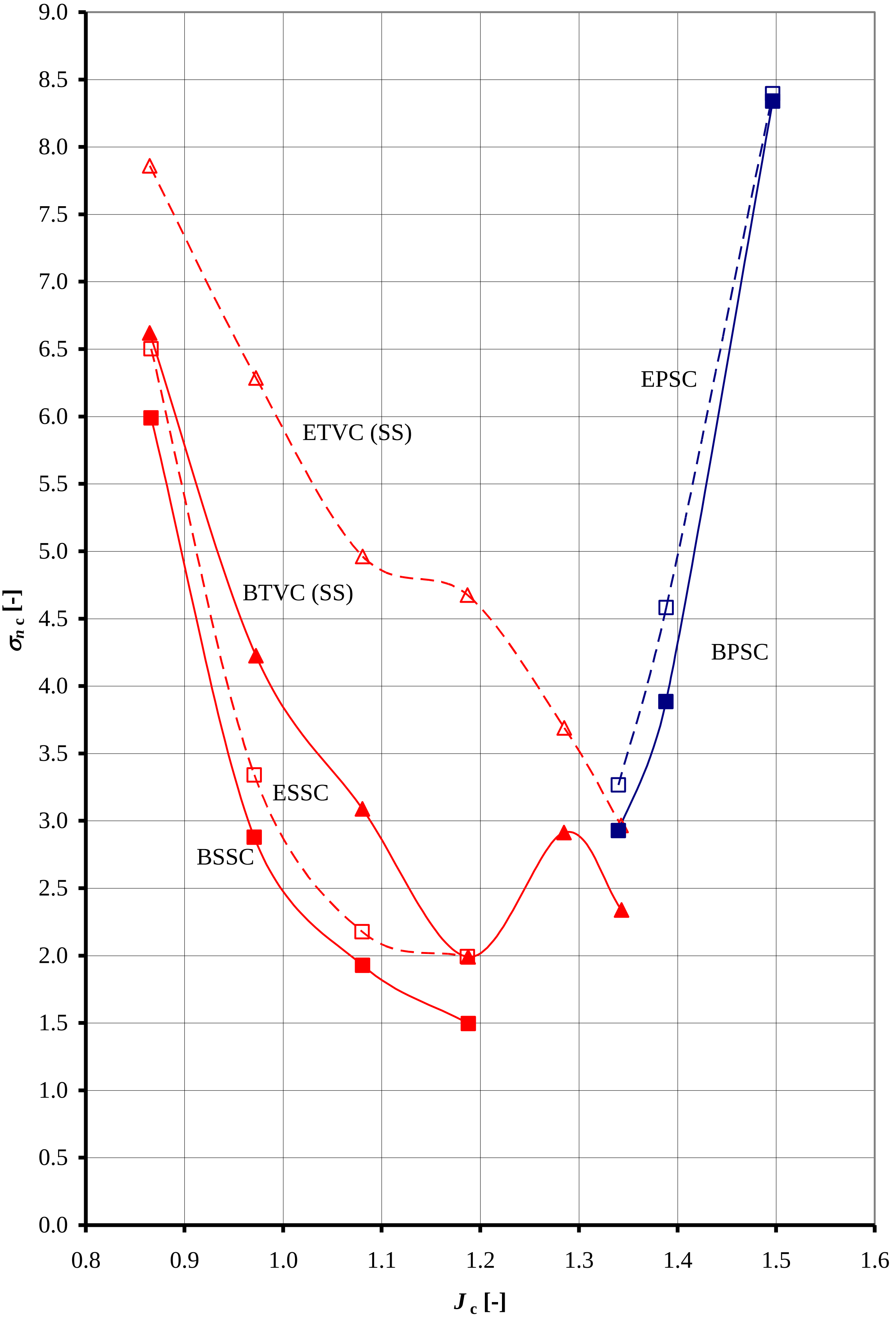


Cavitation tunnel type Kempf & Remmers K15A, test section 600 x 600 mm

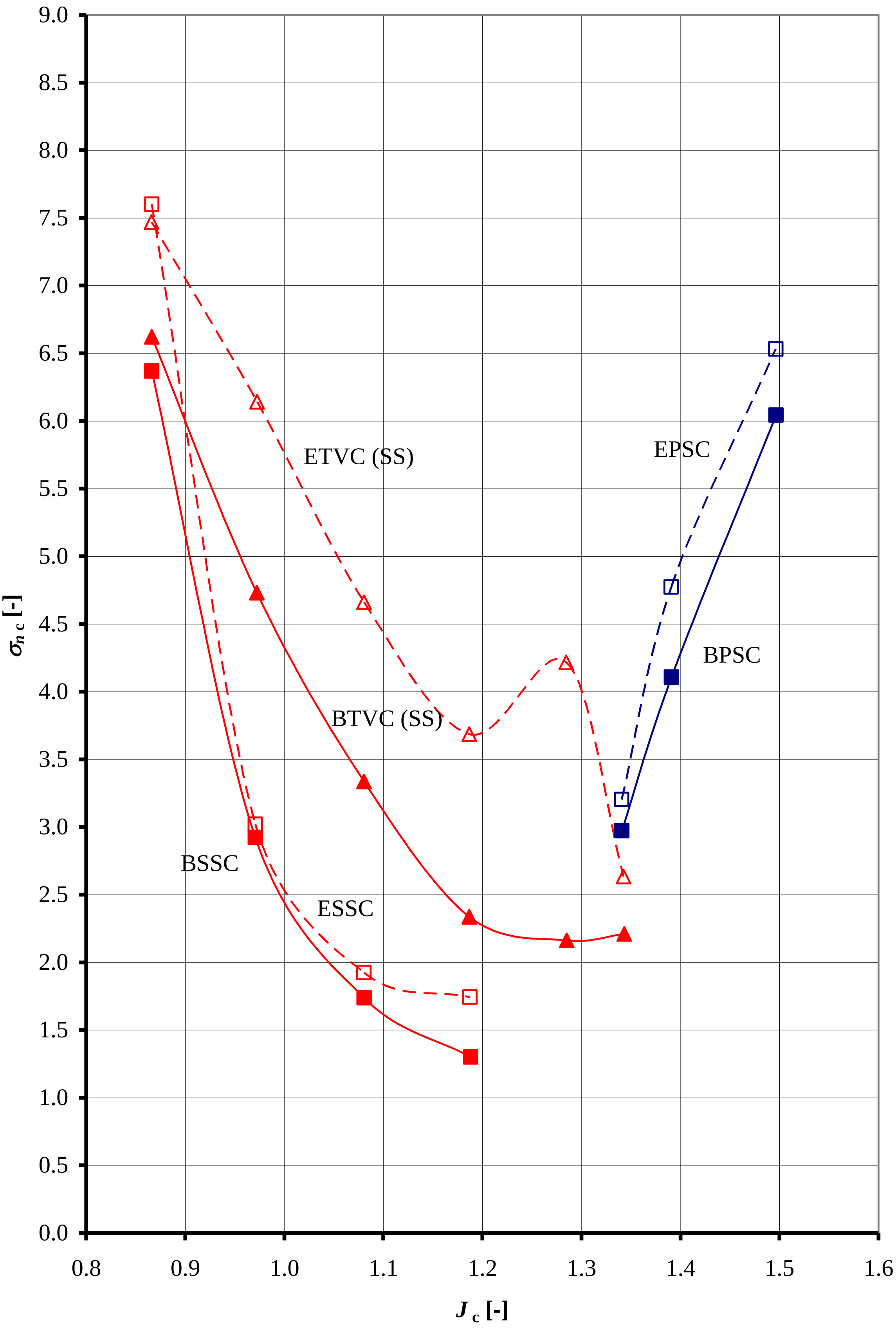
Open water characteristics, measured in the cavitation tunnel



Cavitation bucket, VP1304, blade 1

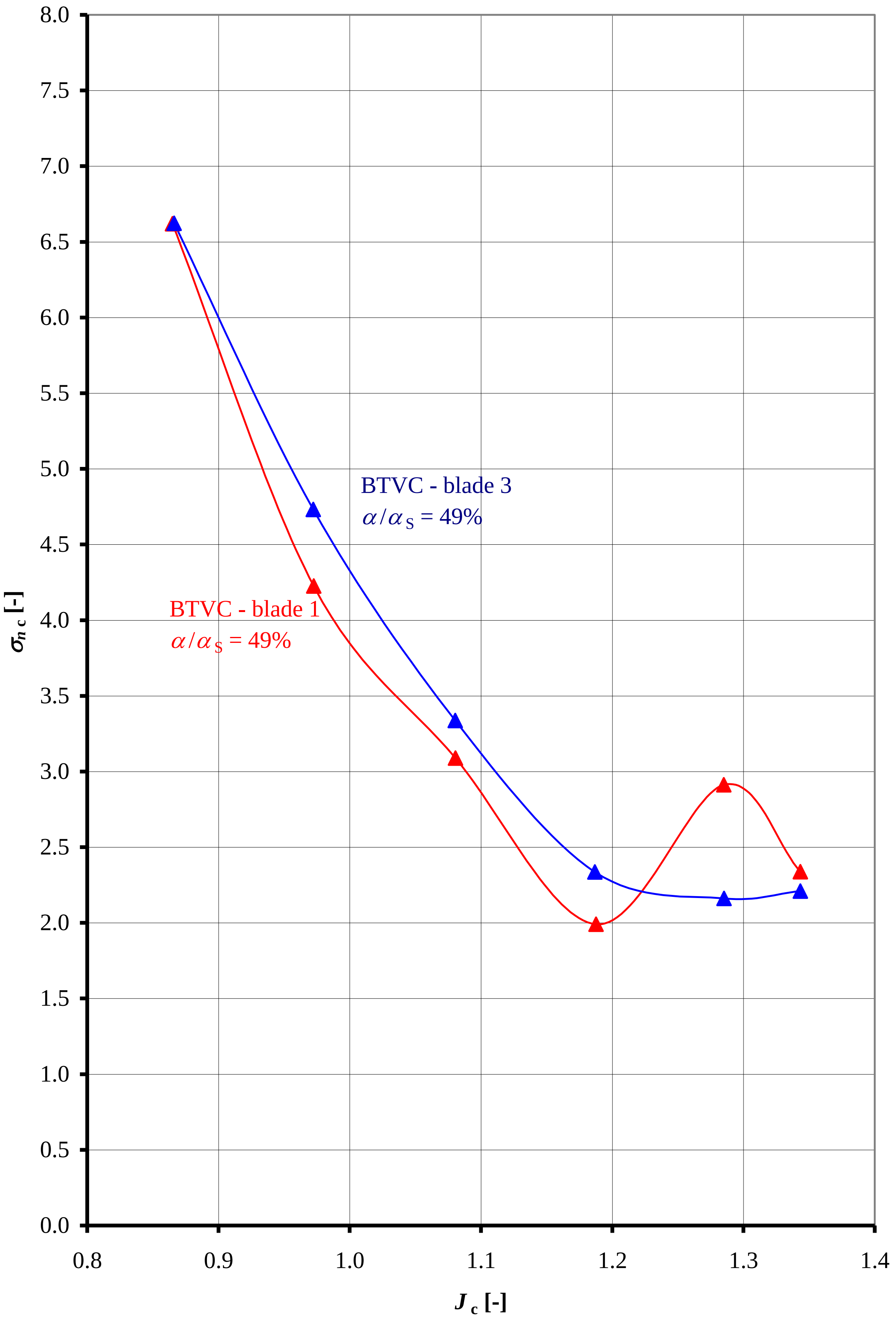


Cavitation bucket, VP1304, blade 3



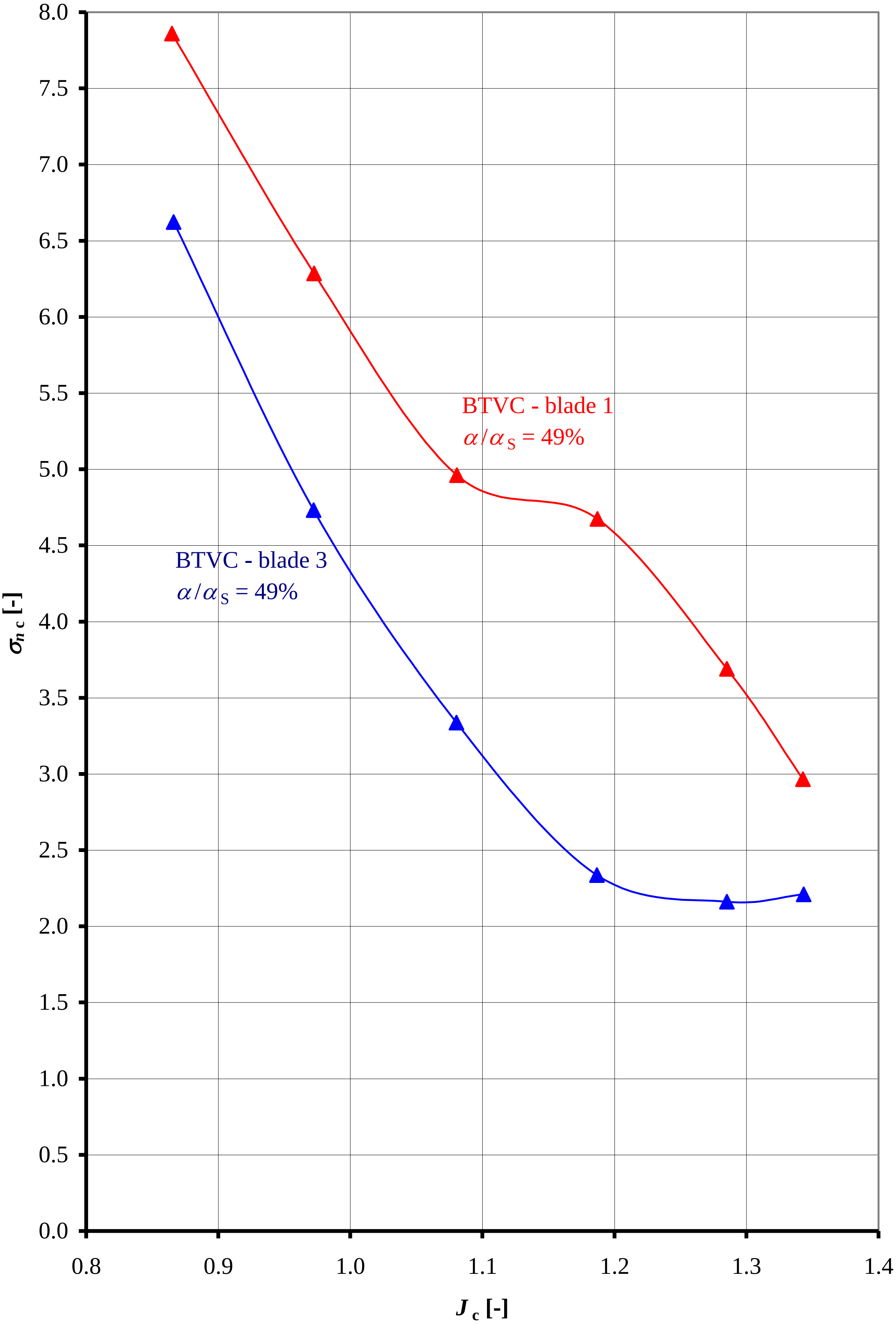
POTSDAM MODEL BASIN

Begin of tip vortex cavitation, VP1304, blades 1 and 3



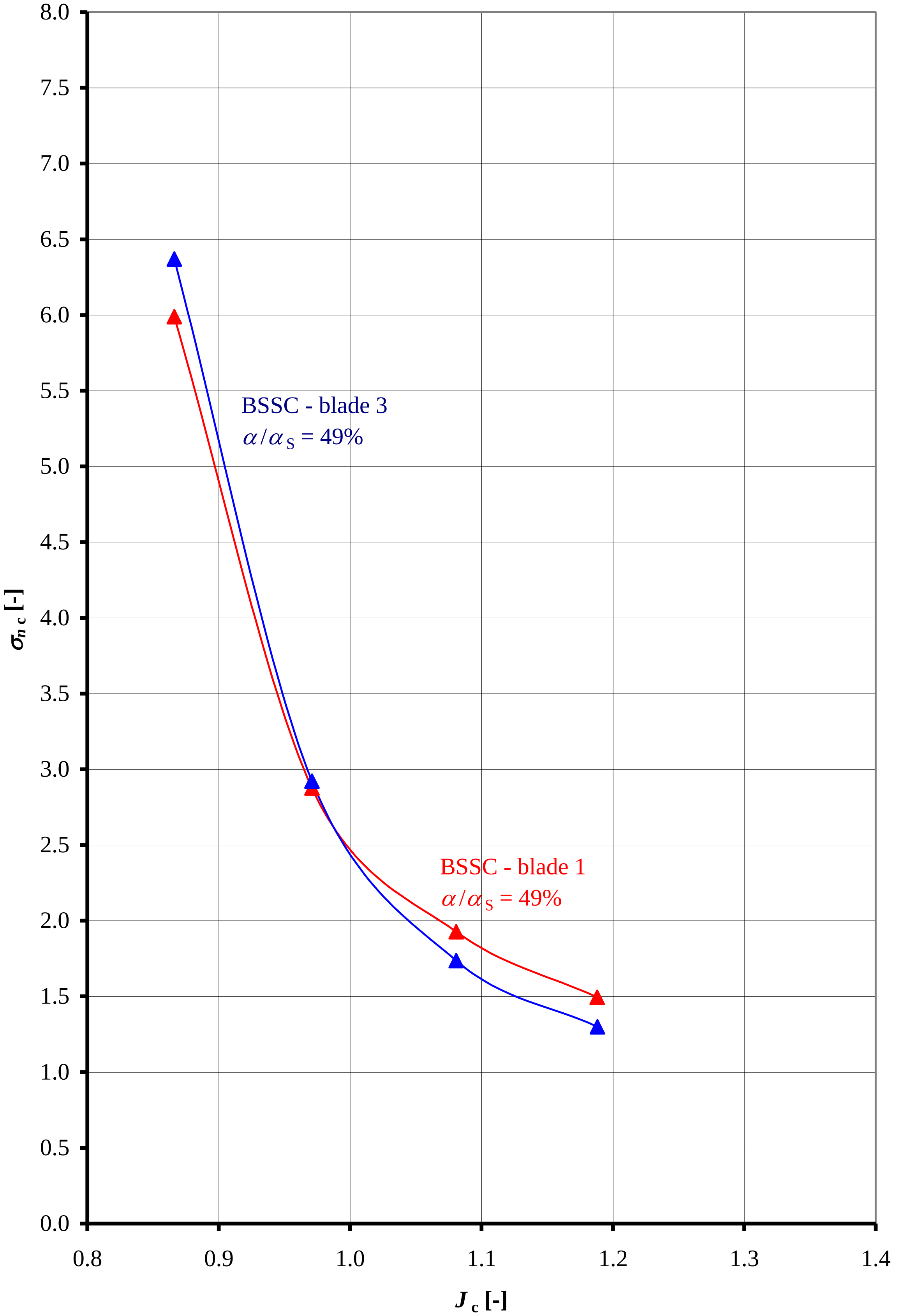
DIAGRAMS/SKETCHES

End of tip vortex cavitation, VP1304, blades 1 and 3

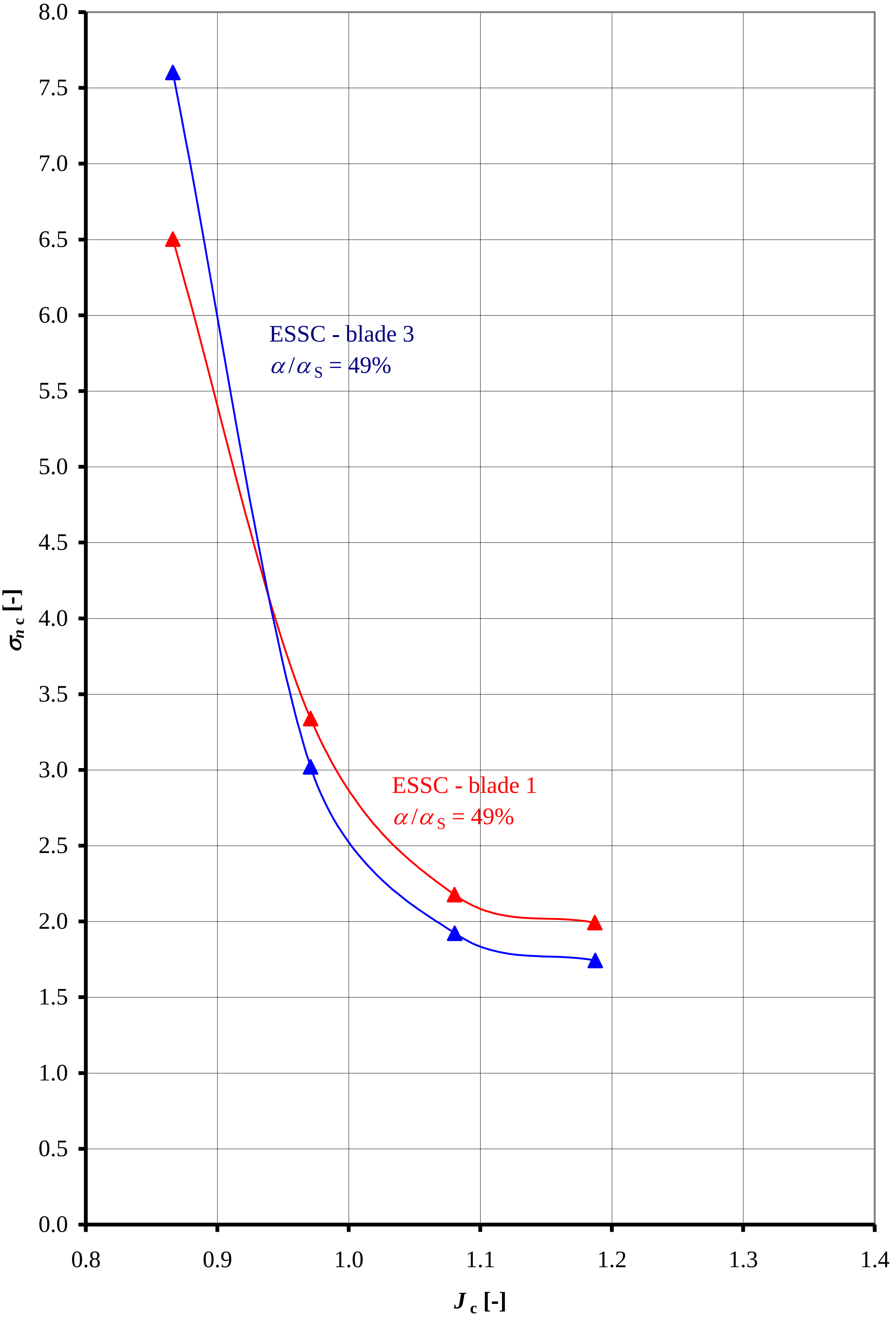


DIAGRAMS/SKETCHES

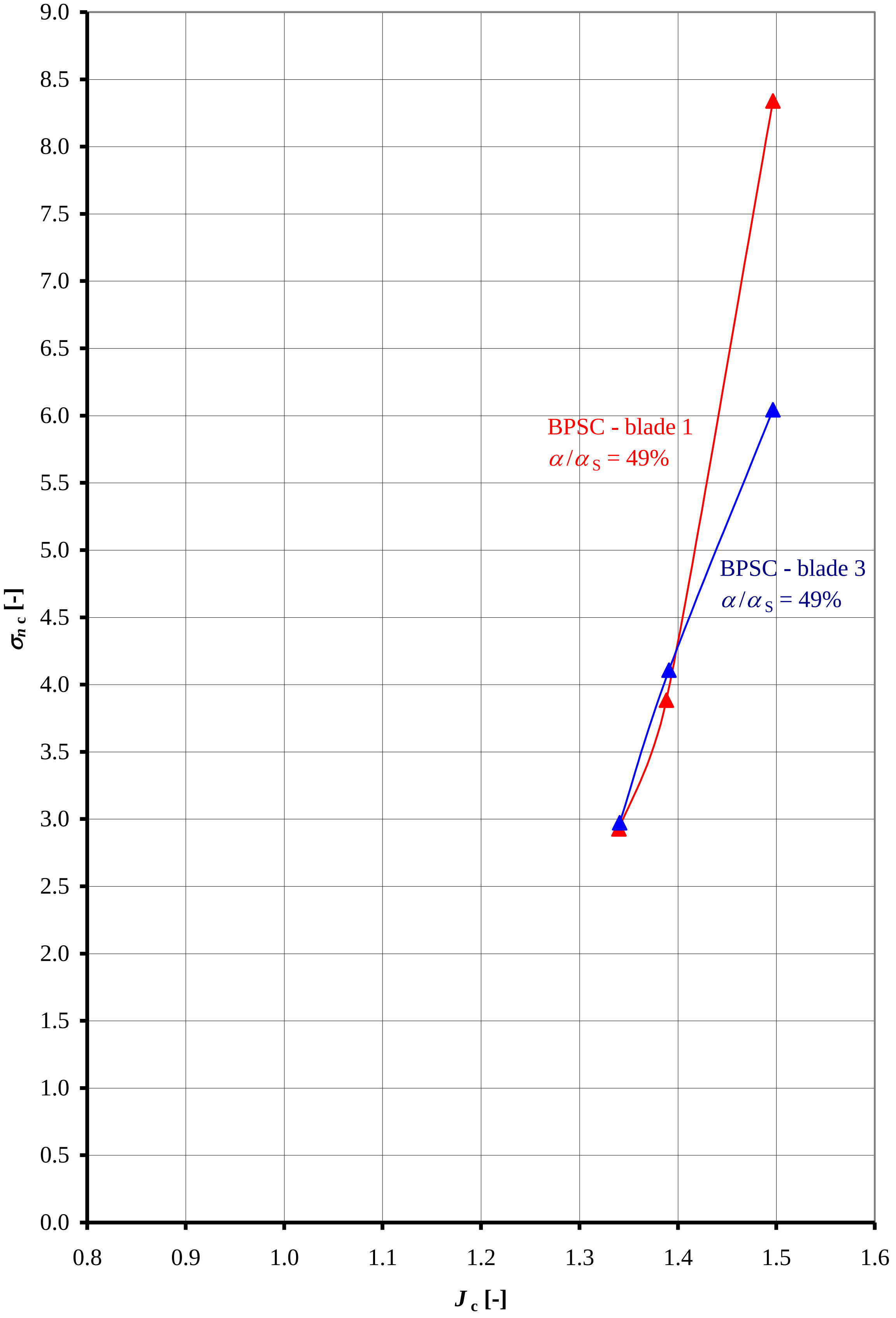
Begin of suction side cavitation, VP1304, blades 1 and 3



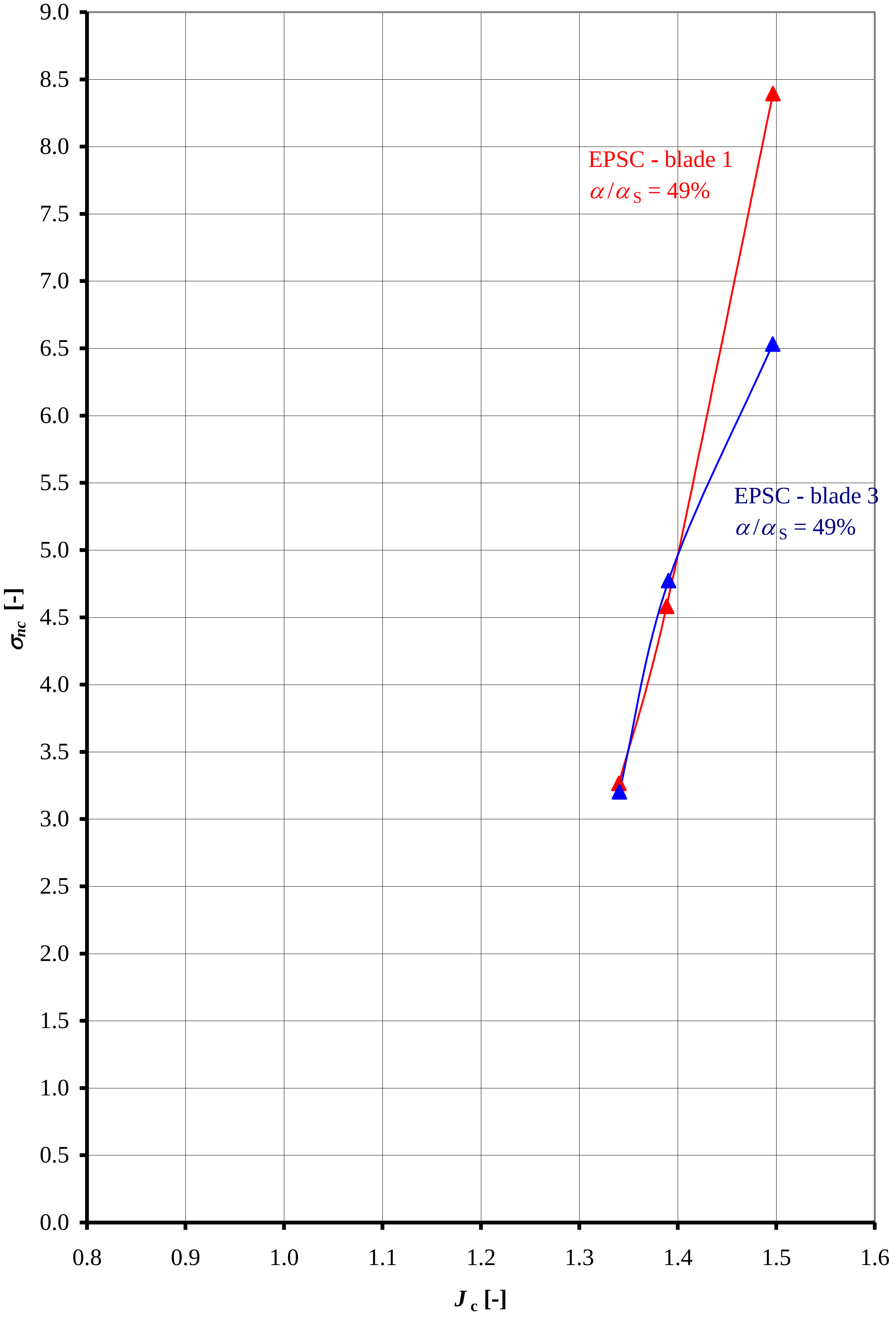
End of suction side cavitation, VP1304, blades 1 and 3



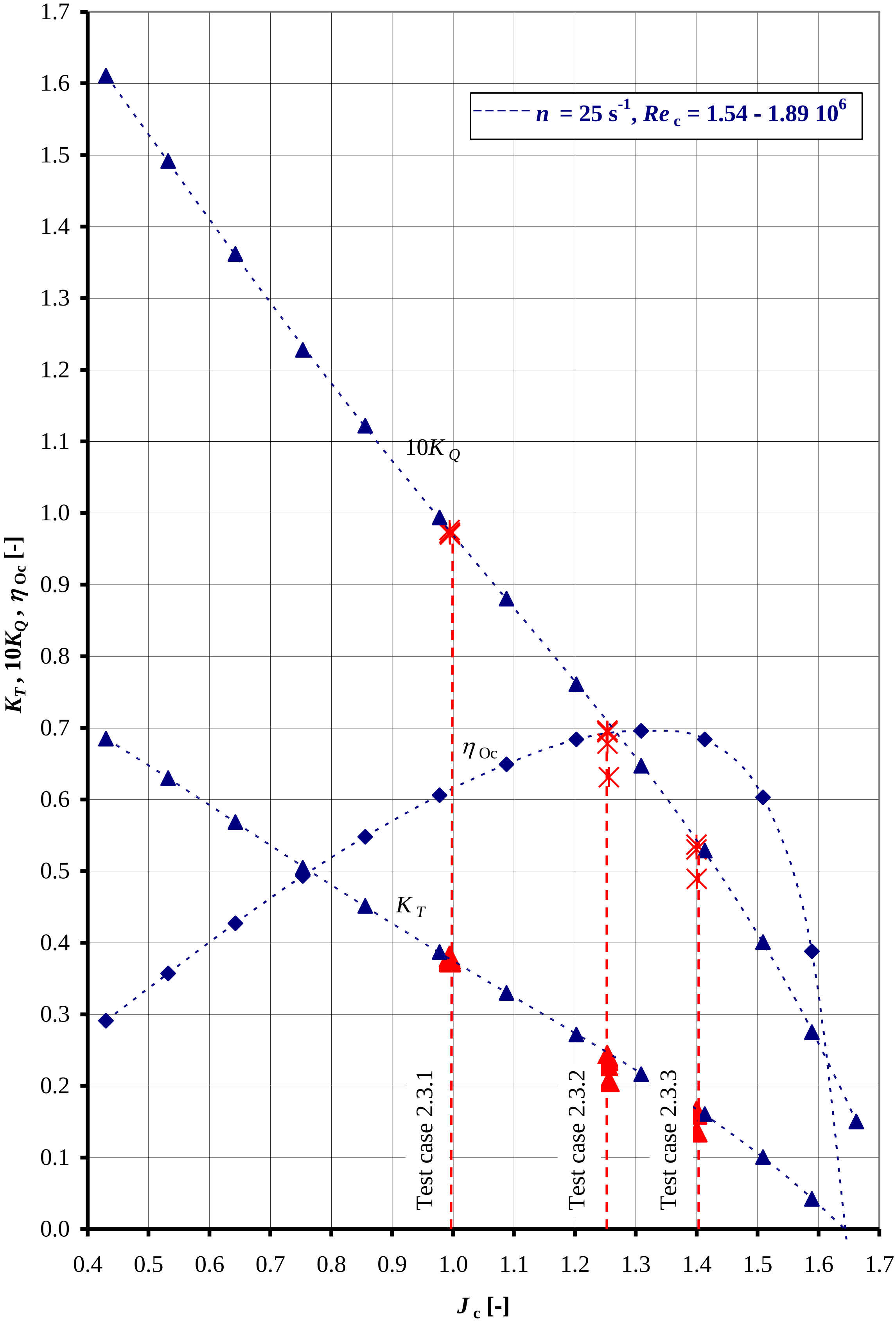
Begin of pressure side cavitation, VP1304, blades 1 and 3



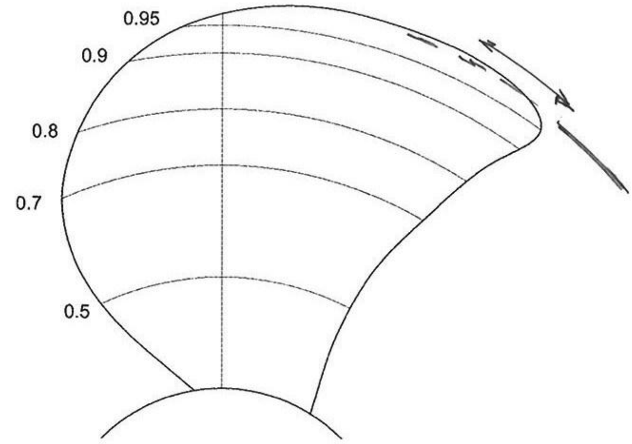
End of pressure side cavitation, VP1304, blades 1 and 3



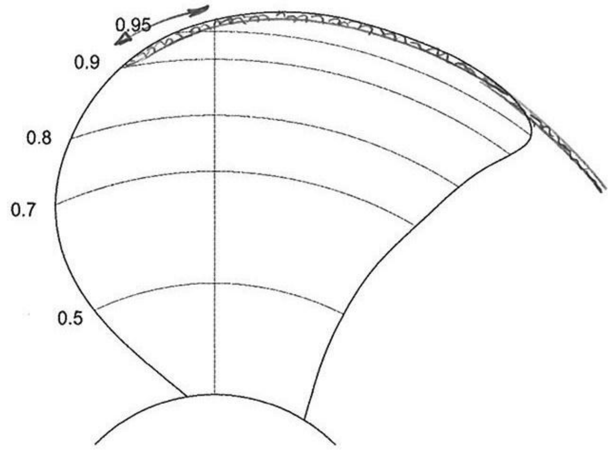
Working points for the cavitation observations



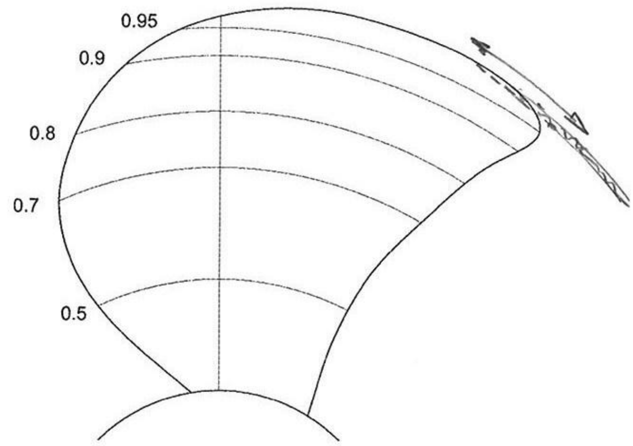
Cavitation sketches, suction side, blade 1



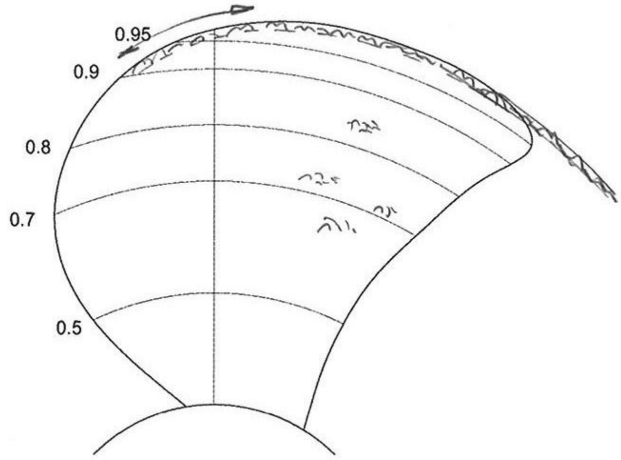
BTVC - $J_c = 0.8649$, $K_T = 0.4473$, $\sigma_{nc} = 6.619$



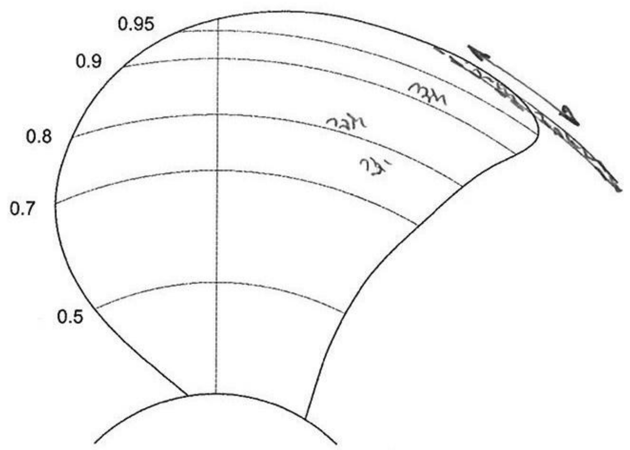
BSSC - $J_c = 0.8663$, $K_T = 0.4447$, $\sigma_{nc} = 5.988$



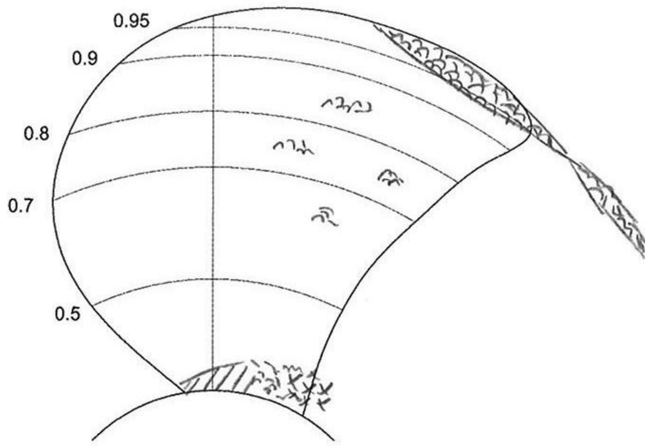
BTVC - $J_c = 0.9725$, $K_T = 0.3870$, $\sigma_{nc} = 4.225$



BSSC - $J_c = 0.9709$, $K_T = 0.3880$, $\sigma_{nc} = 2.877$

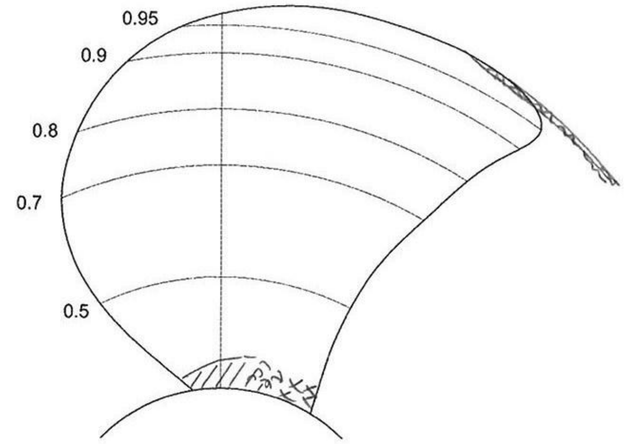


BTVC - $J_c = 1.0805$, $K_T = 0.3291$, $\sigma_{nc} = 3.089$

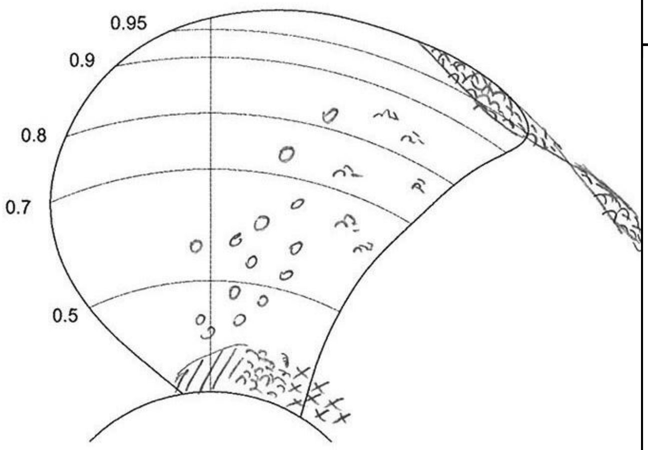


BSSC - $J_c = 1.0807$, $K_T = 0.3158$, $\sigma_{nc} = 1.927$

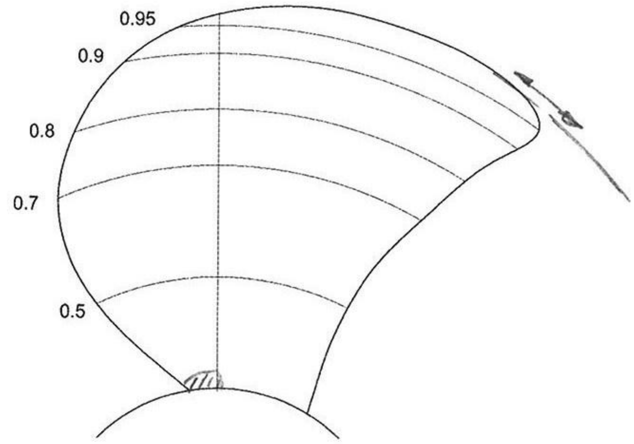
Cavitation sketches, suction side, blade 1



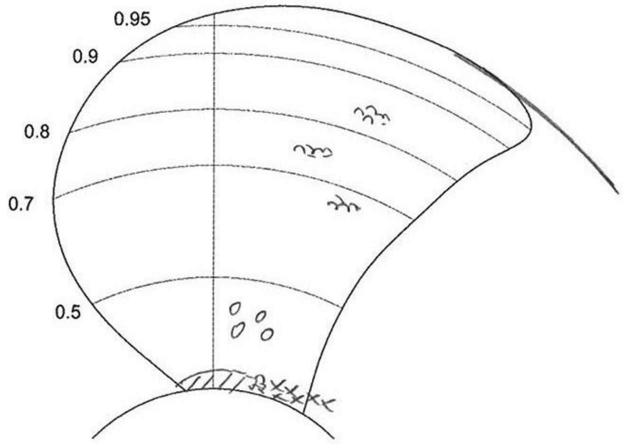
BTVC - $J_c = 1.1877$, $K_T = 0.2628$, $\sigma_{nc} = 1.991$



BSSC - $J_c = 1.1880$, $K_T = 0.2454$, $\sigma_{nc} = 1.495$

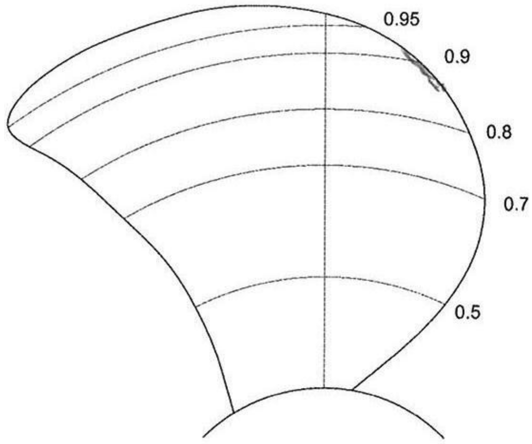


BTVC - $J_c = 1.2850$, $K_T = 0.2227$, $\sigma_{nc} = 2.912$

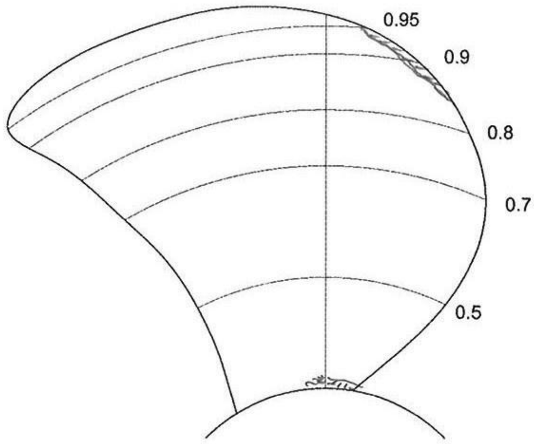


BTVC - $J_c = 1.3433$, $K_T = 0.1869$, $\sigma_{nc} = 2.338$

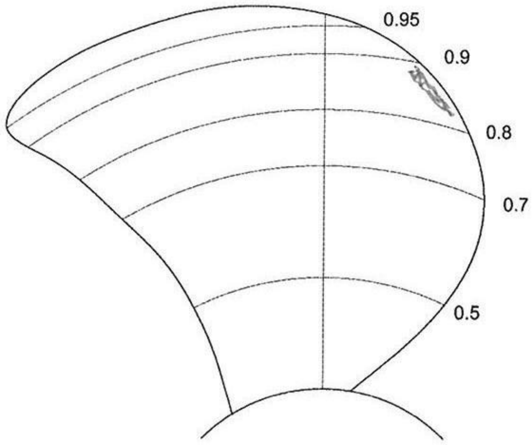
Cavitation sketches, pressure side, blade 1



BPSC - $J_c = 1.3402$, $K_T = 0.1945$, $\sigma_{nc} = 2.927$

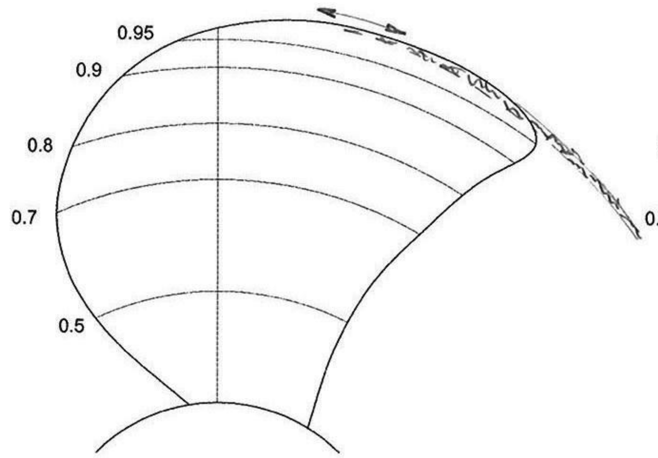


BPSC - $J_c = 1.3884$, $K_T = 0.1724$, $\sigma_{nc} = 3.884$

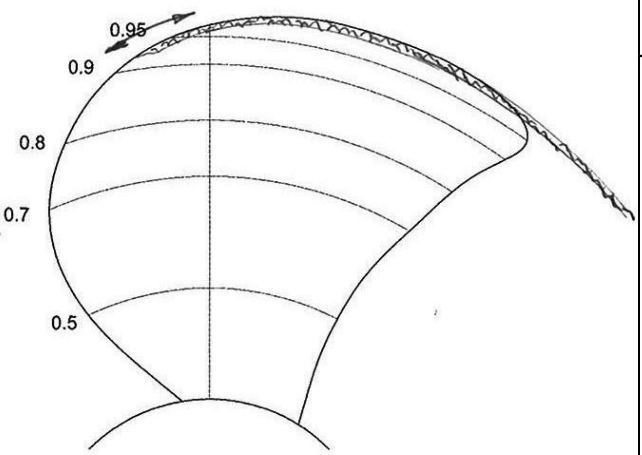


BPSC - $J_c = 1.4966$, $K_T = 0.1067$, $\sigma_{nc} = 8.340$

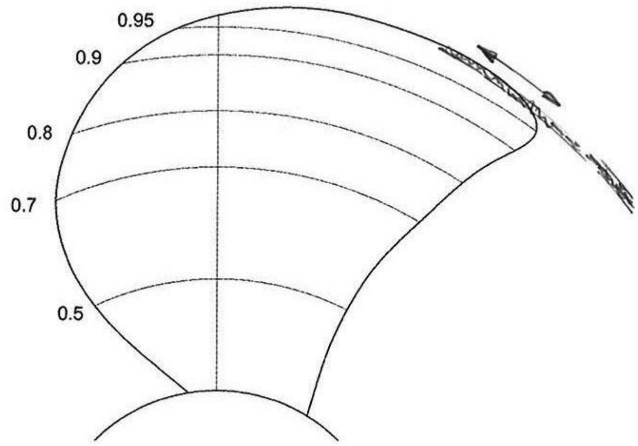
Cavitation sketches, suction side, blade 3



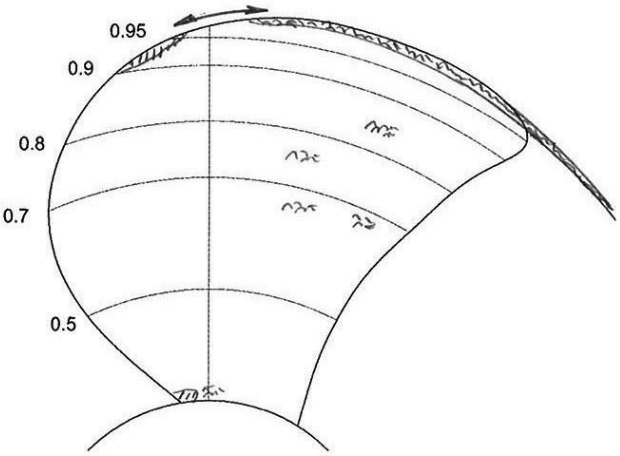
BTVC - $J_c = 0.8662$, $K_T = 0.4478$, $\sigma_{nc} = 6.622$



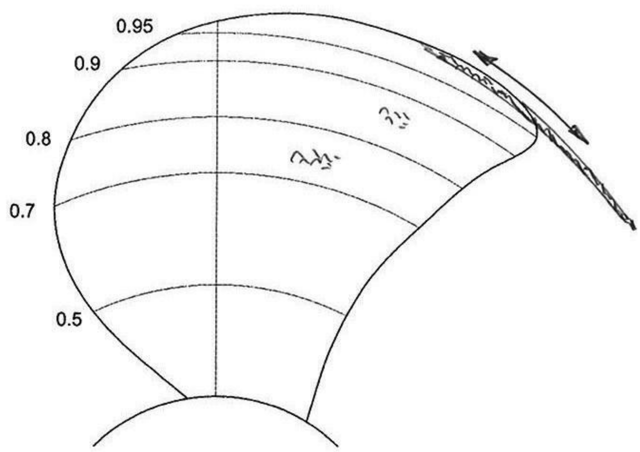
BSSC - $J_c = 0.8663$, $K_T = 0.4439$, $\sigma_{nc} = 6.369$



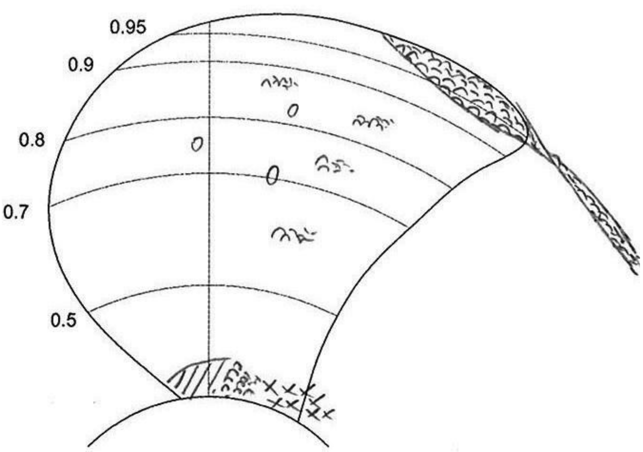
BTVC - $J_c = 0.9722$, $K_T = 0.3877$, $\sigma_{nc} = 4.731$



BSSC - $J_c = 0.9709$, $K_T = 0.3899$, $\sigma_{nc} = 2.921$

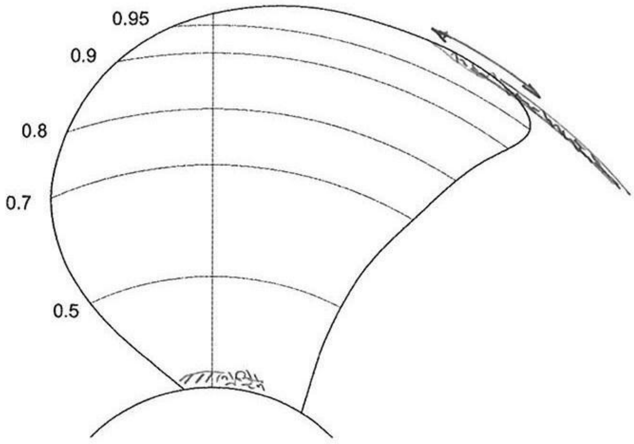


BTVC - $J_c = 1.0804$, $K_T = 0.3309$, $\sigma_{nc} = 3.337$

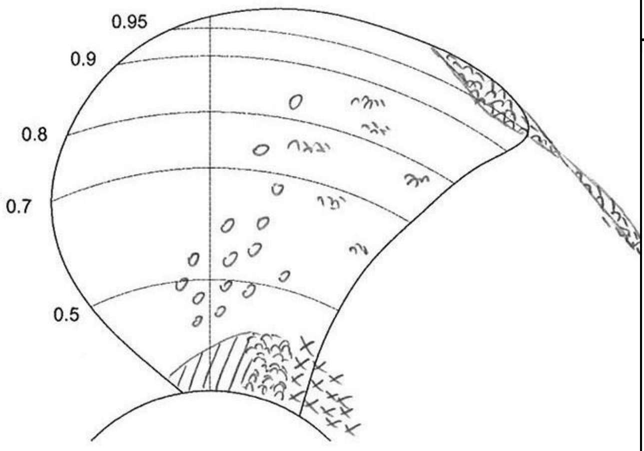


BSSC - $J_c = 1.0807$, $K_T = 0.3122$, $\sigma_{nc} = 1.737$

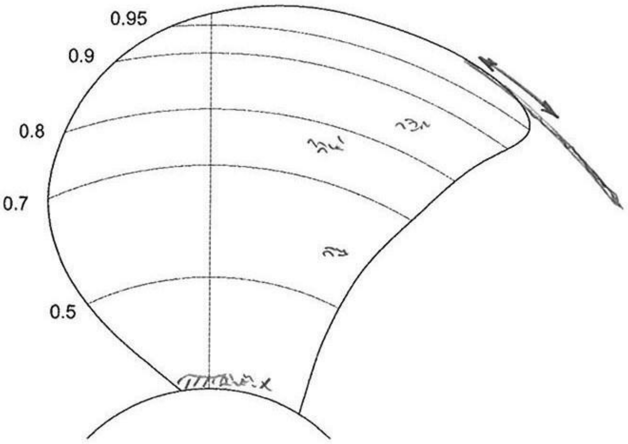
Cavitation sketches, suction side, blade 3



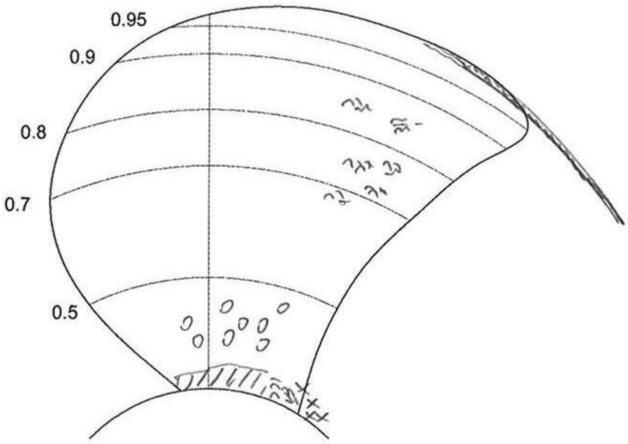
BTVC - $J_c = 1.1867$, $K_T = 0.2736$, $\sigma_{nc} = 2.336$



BSSC - $J_c = 1.1882$, $K_T = 0.2387$, $\sigma_{nc} = 1.300$



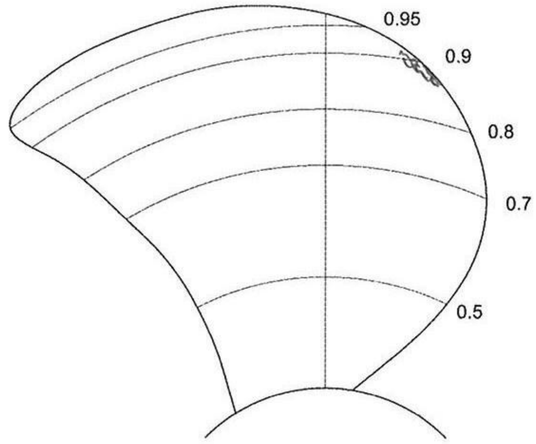
BTVC - $J_c = 1.2852$, $K_T = 0.2137$, $\sigma_{nc} = 2.162$



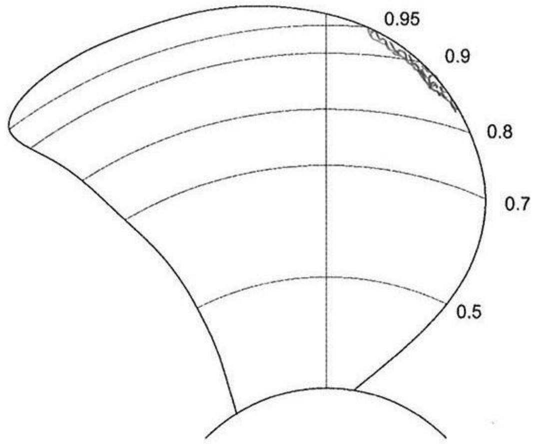
BTVC - $J_c = 1.3433$, $K_T = 0.1841$, $\sigma_{nc} = 2.210$

DIAGRAMS/SKETCHES

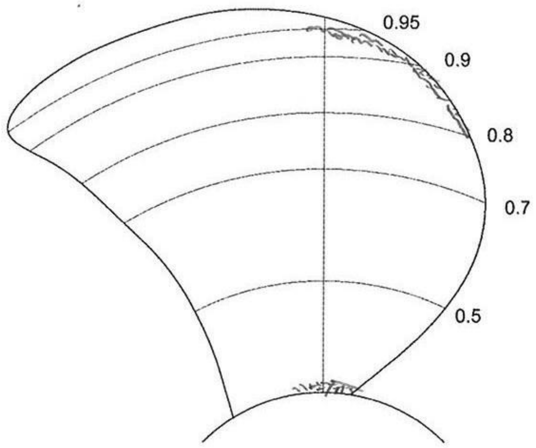
Cavitation sketches, pressure side, blade 3



BPSC - $J_c = 1.3409$, $K_T = 0.1966$, $\sigma_{nc} = 2.973$

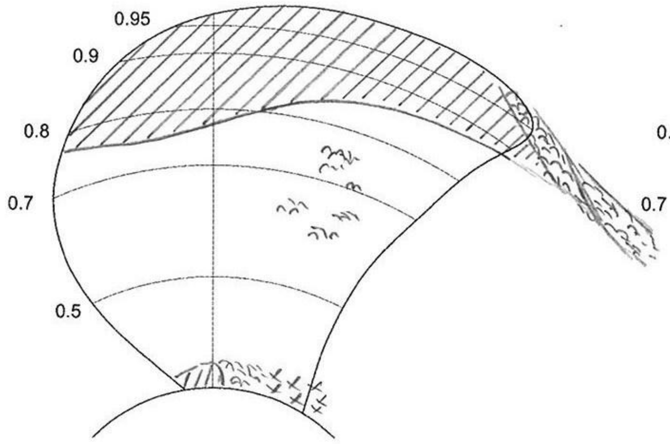


BPSC - $J_c = 1.3911$, $K_T = 0.1705$, $\sigma_{nc} = 4.107$

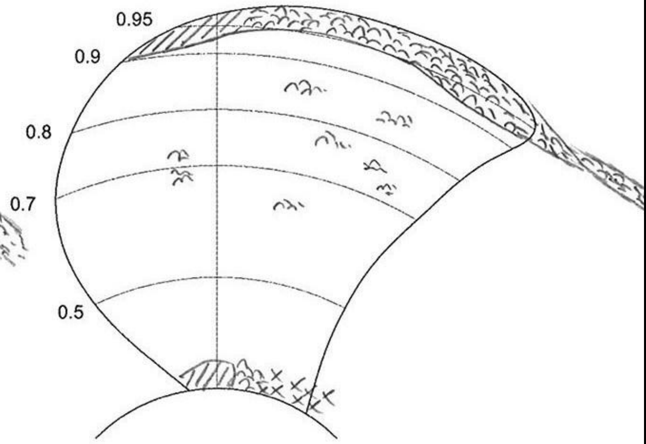


BPSC - $J_c = 1.4967$, $K_T = 0.1034$, $\sigma_{nc} = 6.043$

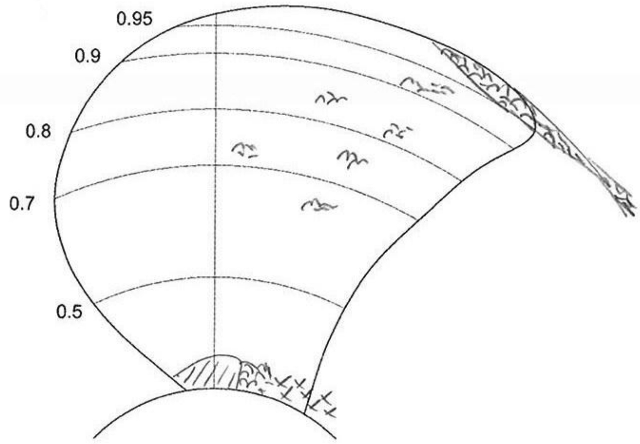
Cavitation sketches, begin of thrust deduction, blade 3



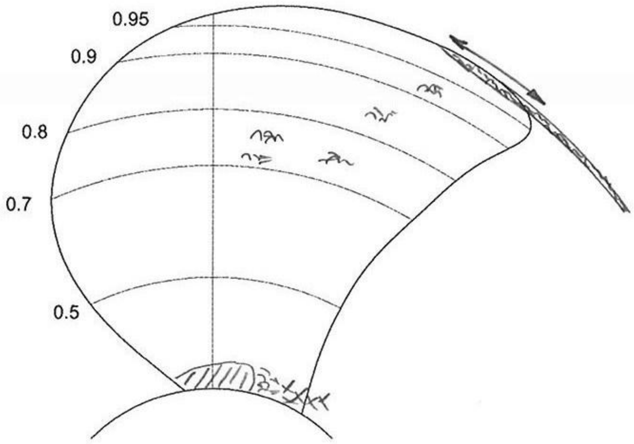
TD - $J_c = 0.8662$, $K_T = 0.4393$, $\sigma_{nc} = 1.901$



TD - $J_c = 0.9714$, $K_T = 0.3819$, $\sigma_{nc} = 2.021$

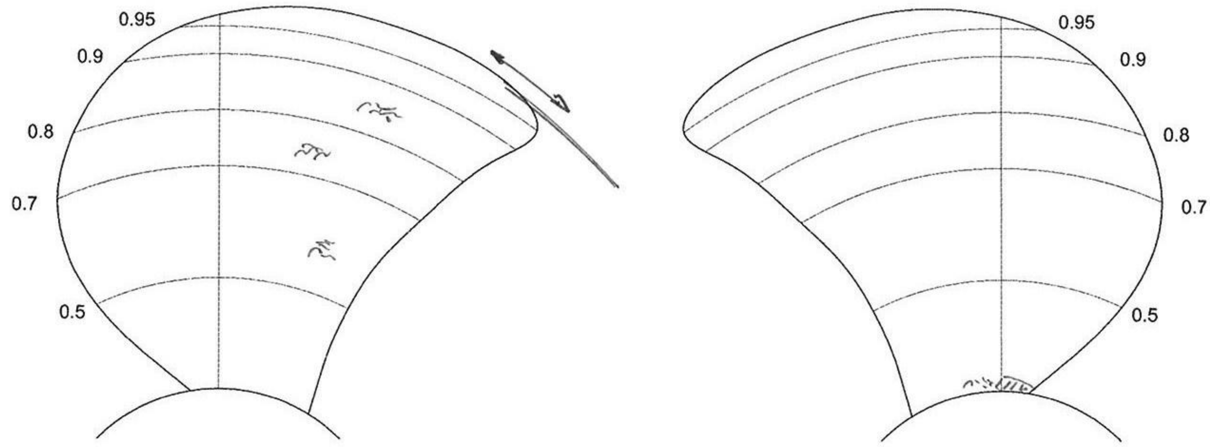


TD - $J_c = 1.0805$, $K_T = 0.3181$, $\sigma_{nc} = 1.923$

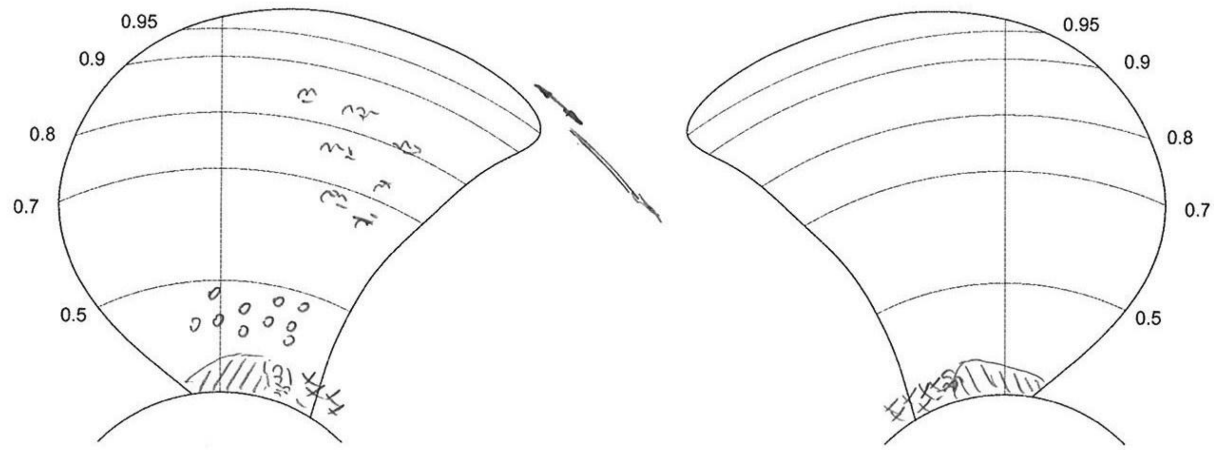


TD - $J_c = 1.1866$, $K_T = 0.2706$, $\sigma_{nc} = 2.138$

Cavitation sketches, begin of thrust deduction, blade 3



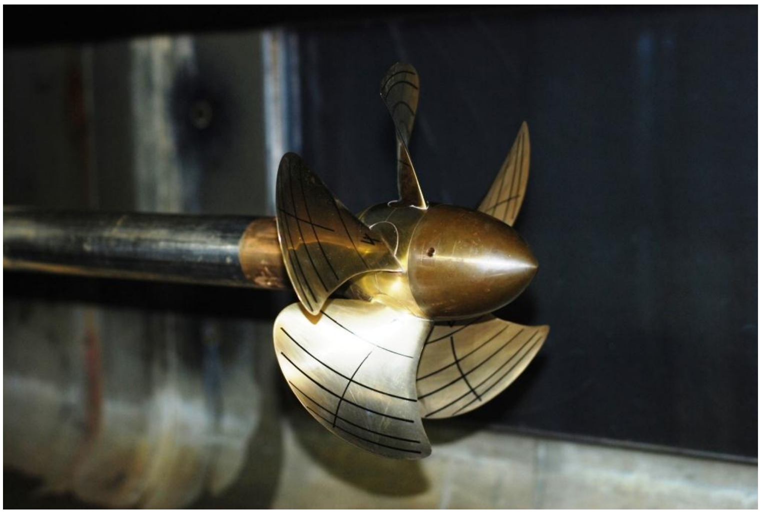
TD - $J_c = 1.2854$, $K_T = 0.2217$, $\sigma_{nc} = 2.515$



TD - $J_c = 1.3425$, $K_T = 0.1926$, $\sigma_{nc} = 2.633$

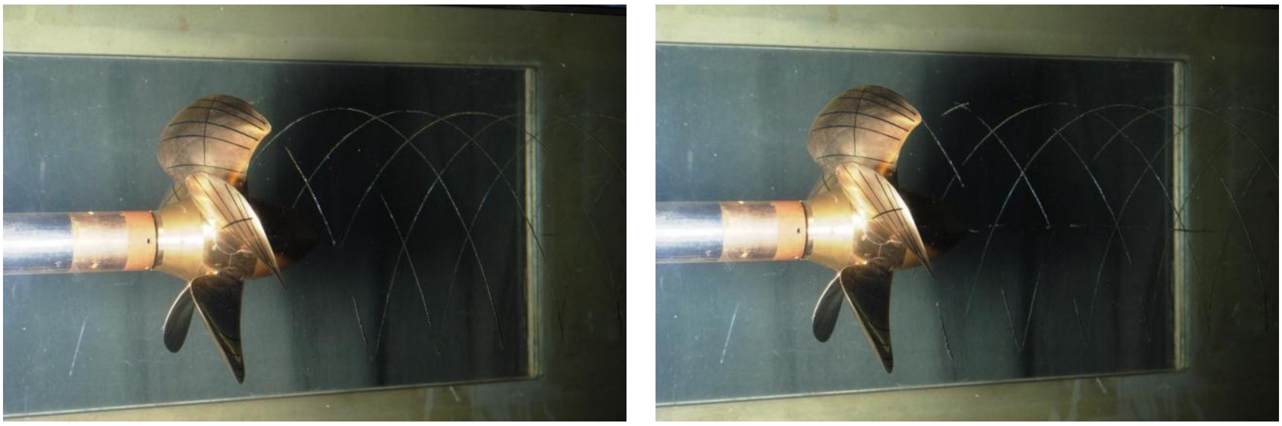
Test arrangement in the cavitation tunnel

Measurement of idle torque with a dummy hub

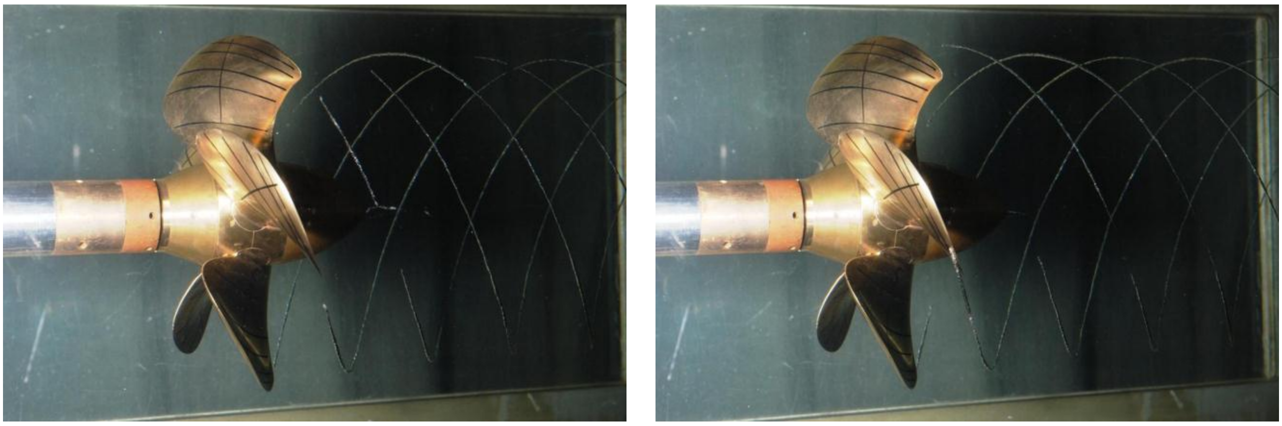


Model propeller VP1304

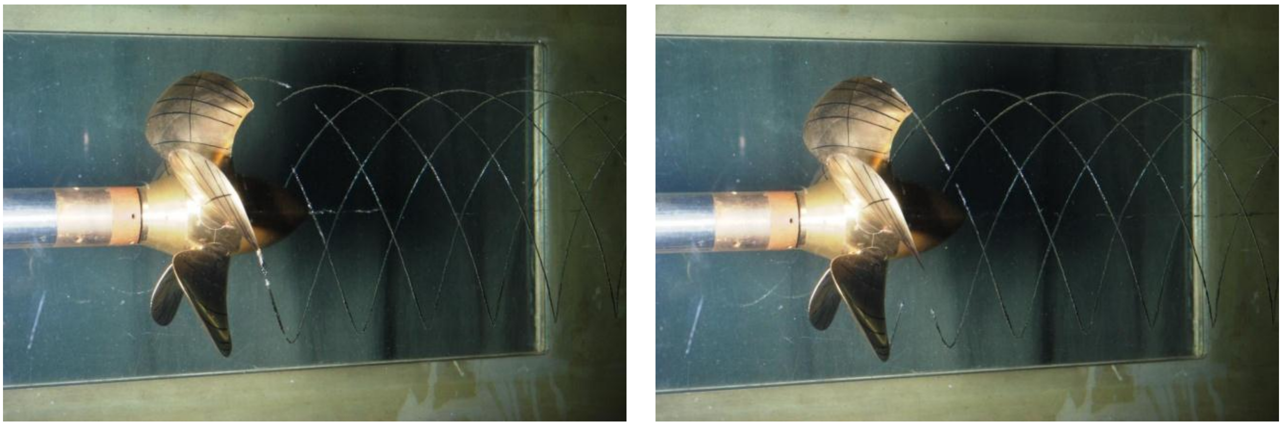
Cavitation observation, variation of the cavitation number, $J_c = 0.9945$



$K_T = 0.3805$, $10K_Q = 0.9762$, $\sigma_{nc} = 5.076$

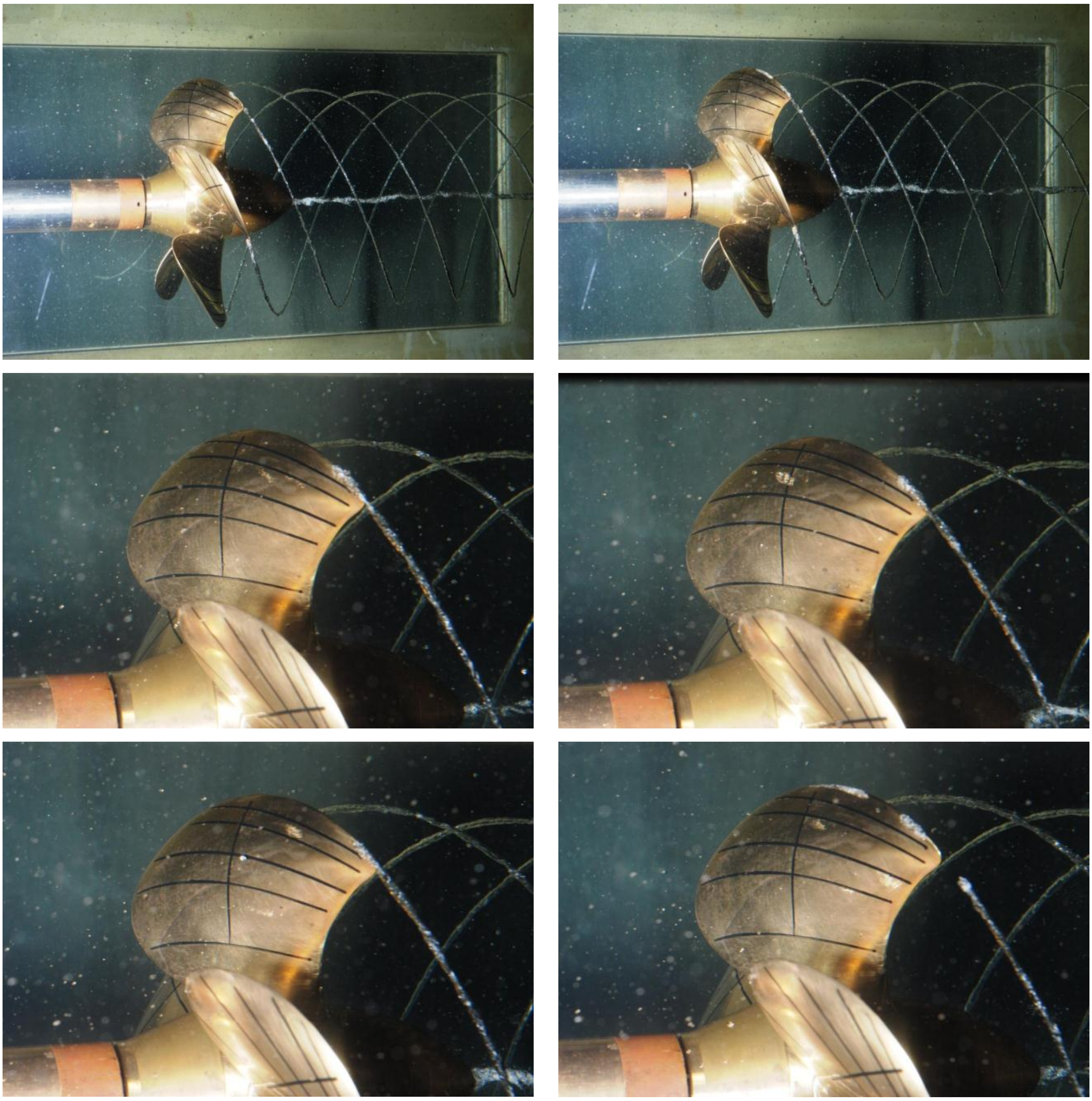


$K_T = 0.3779$, $10K_Q = 0.9720$, $\sigma_{nc} = 4.578$



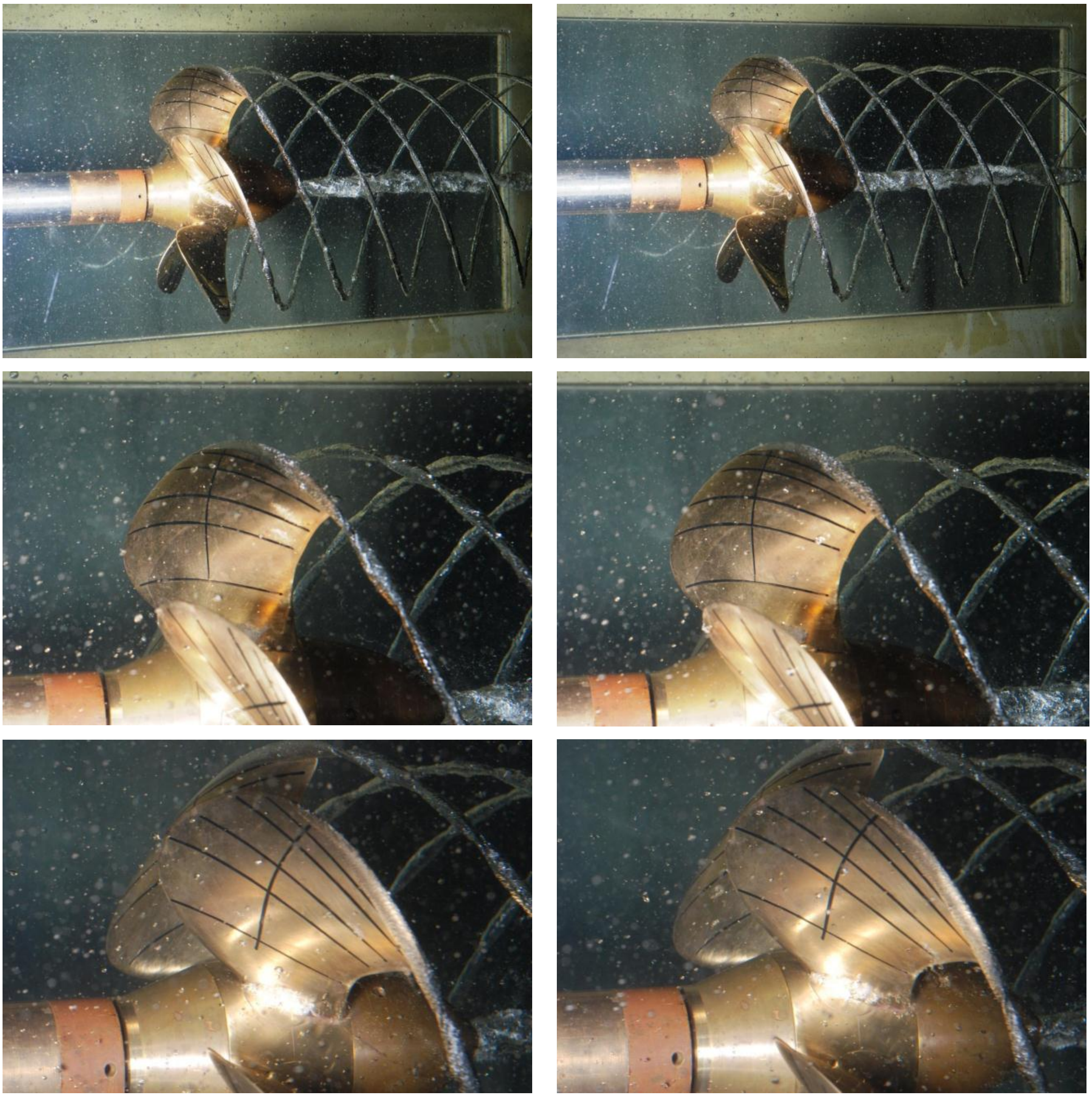
$K_T = 0.3780$, $10K_Q = 0.9726$, $\sigma_{nc} = 4.077$

Cavitation observation, variation of the cavitation number, $J_c = 0.9945$



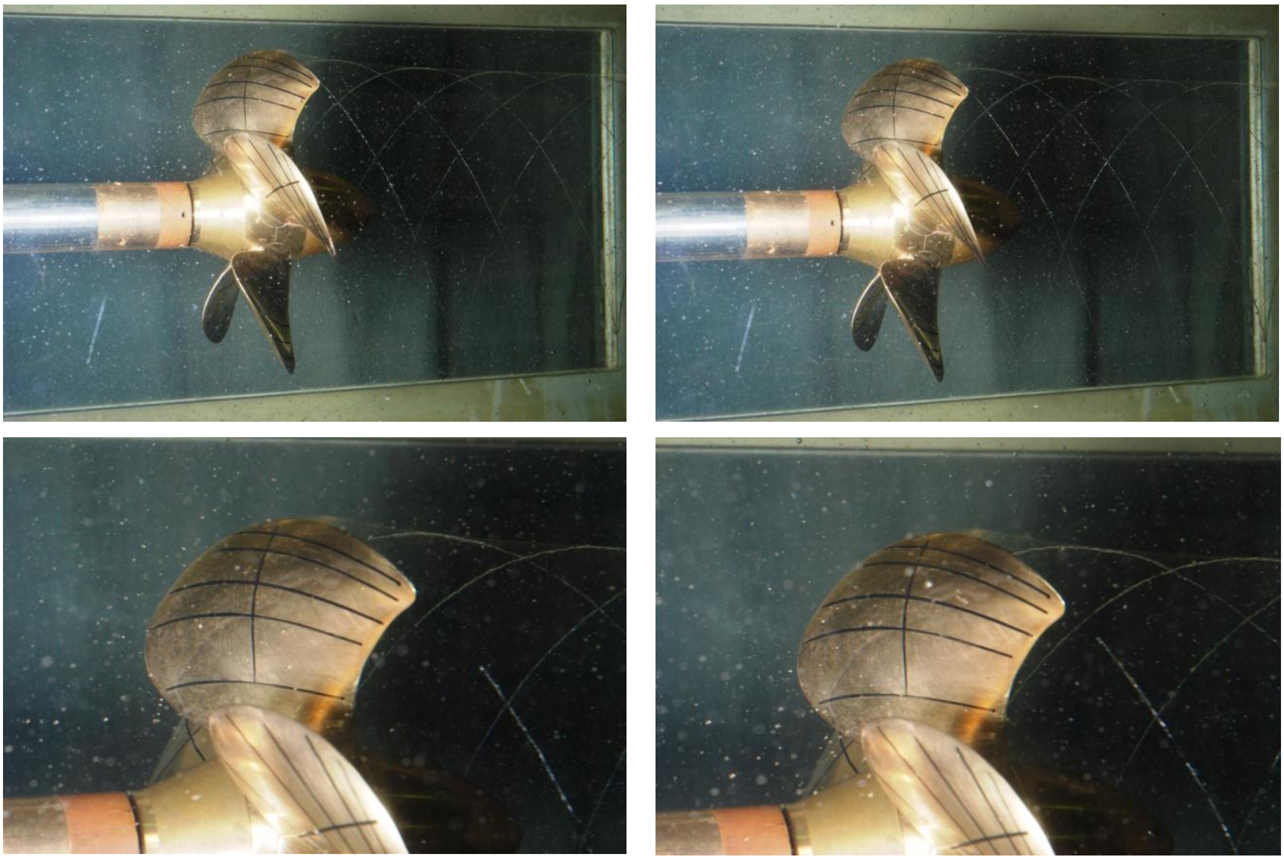
$K_T = 0.3758$, $10K_Q = 0.9709$, $\sigma_{nc} = 3.075$

Cavitation observation, variation of the cavitation number, $J_c = 0.9945$



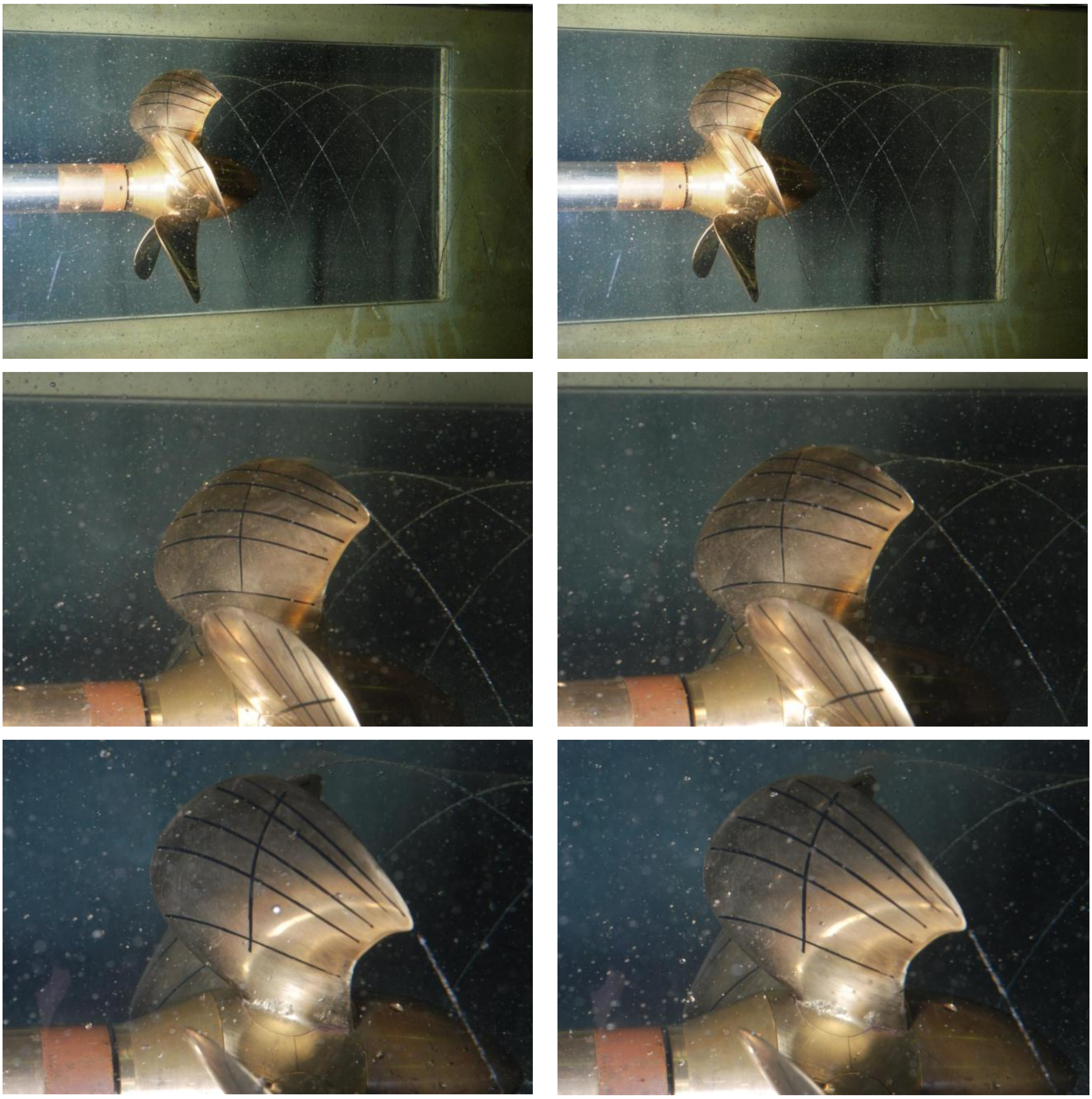
$K_T = 0.3735$, $10K_Q = 0.9698$, $\sigma_{nc} = 2.074$

Cavitation observation, variation of the cavitation number, $J_c = 1.2535$



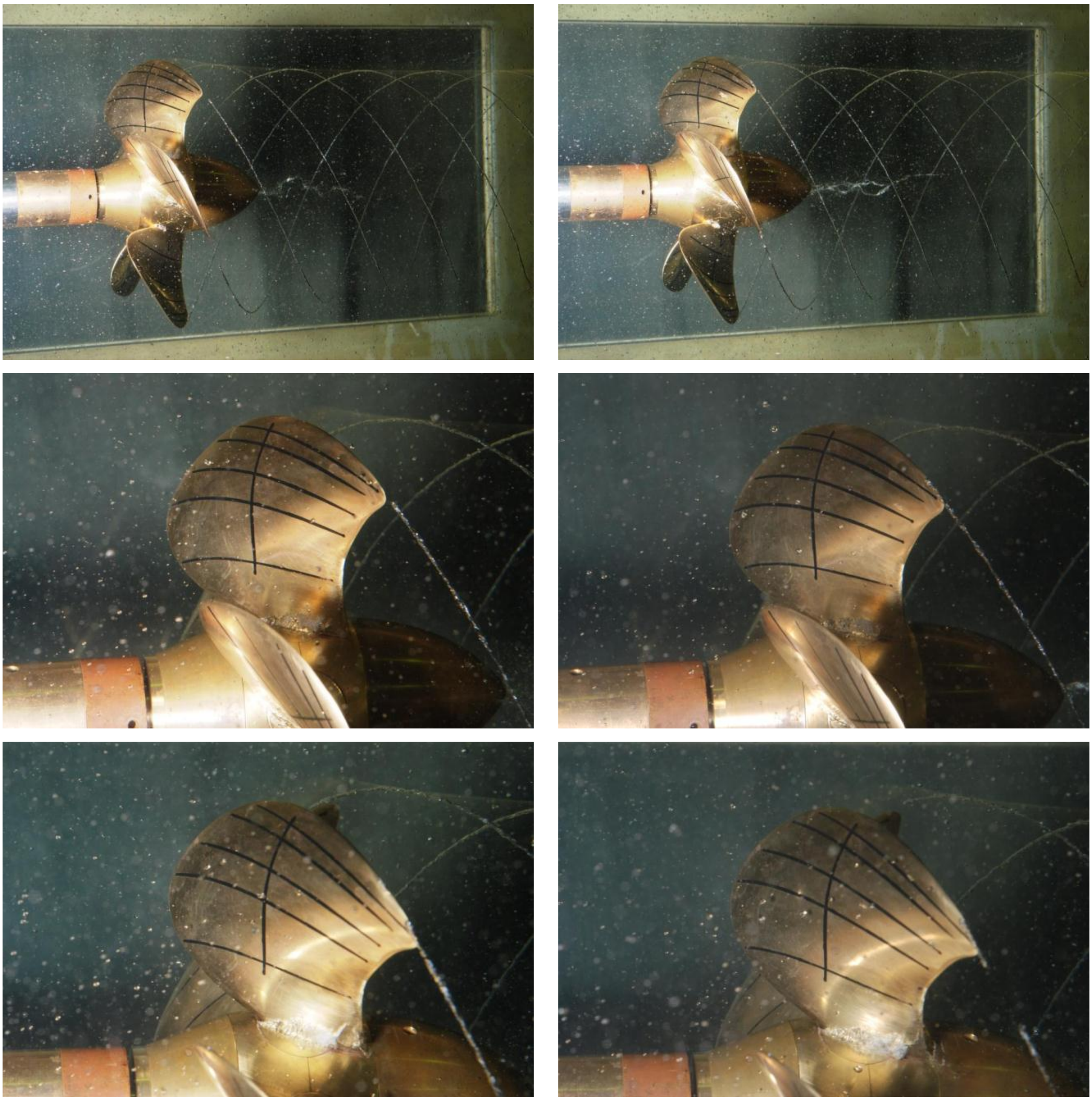
$K_T = 0.2421$, $10K_Q = 0.6962$, $\sigma_{nc} = 3.062$

Cavitation observation, variation of the cavitation number, $J_c = 1.2535$



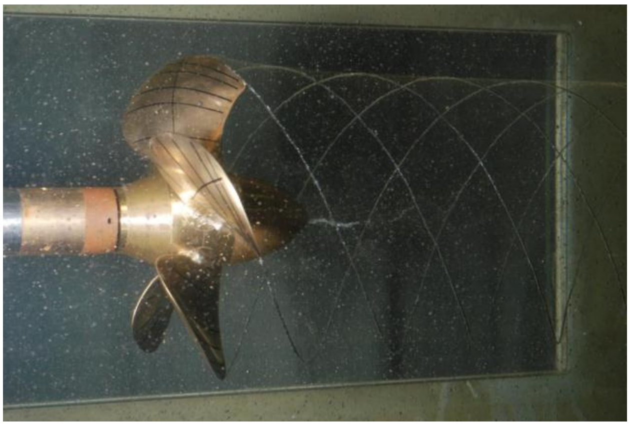
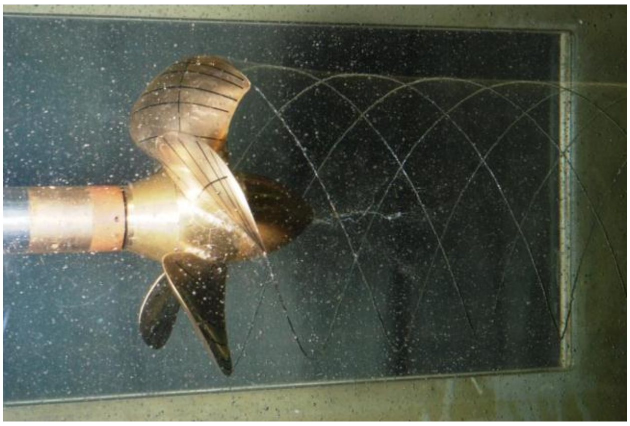
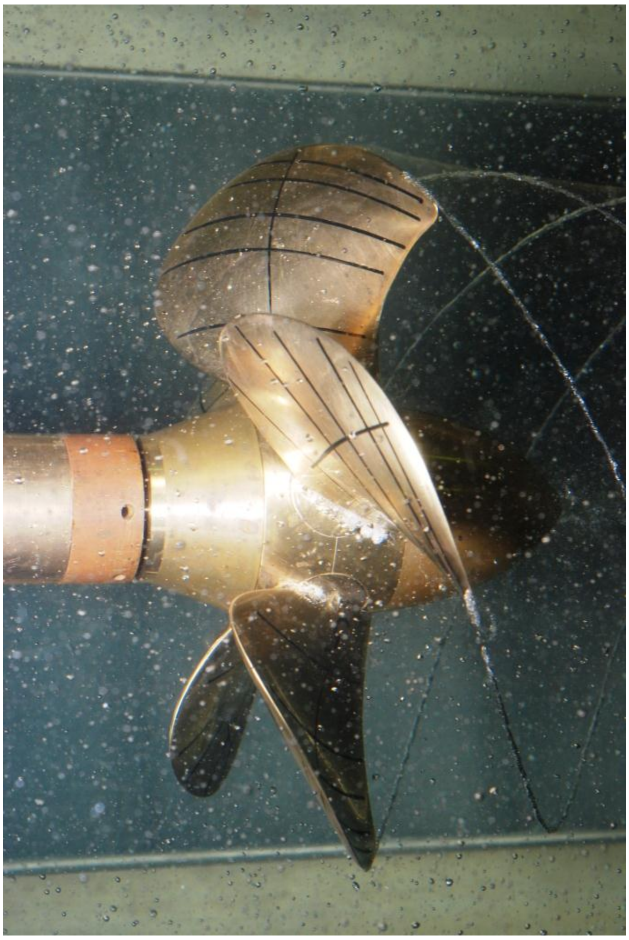
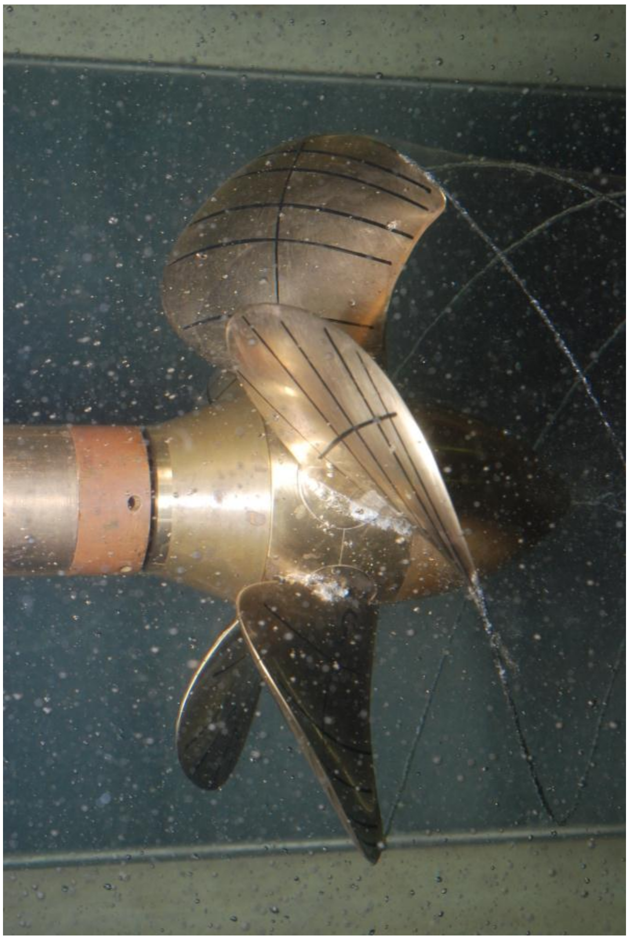
$K_T = 0.2397$, $10K_Q = 0.6963$, $\sigma_{nc} = 2.560$

Cavitation observation, variation of the cavitation number, $J_c = 1.2535$



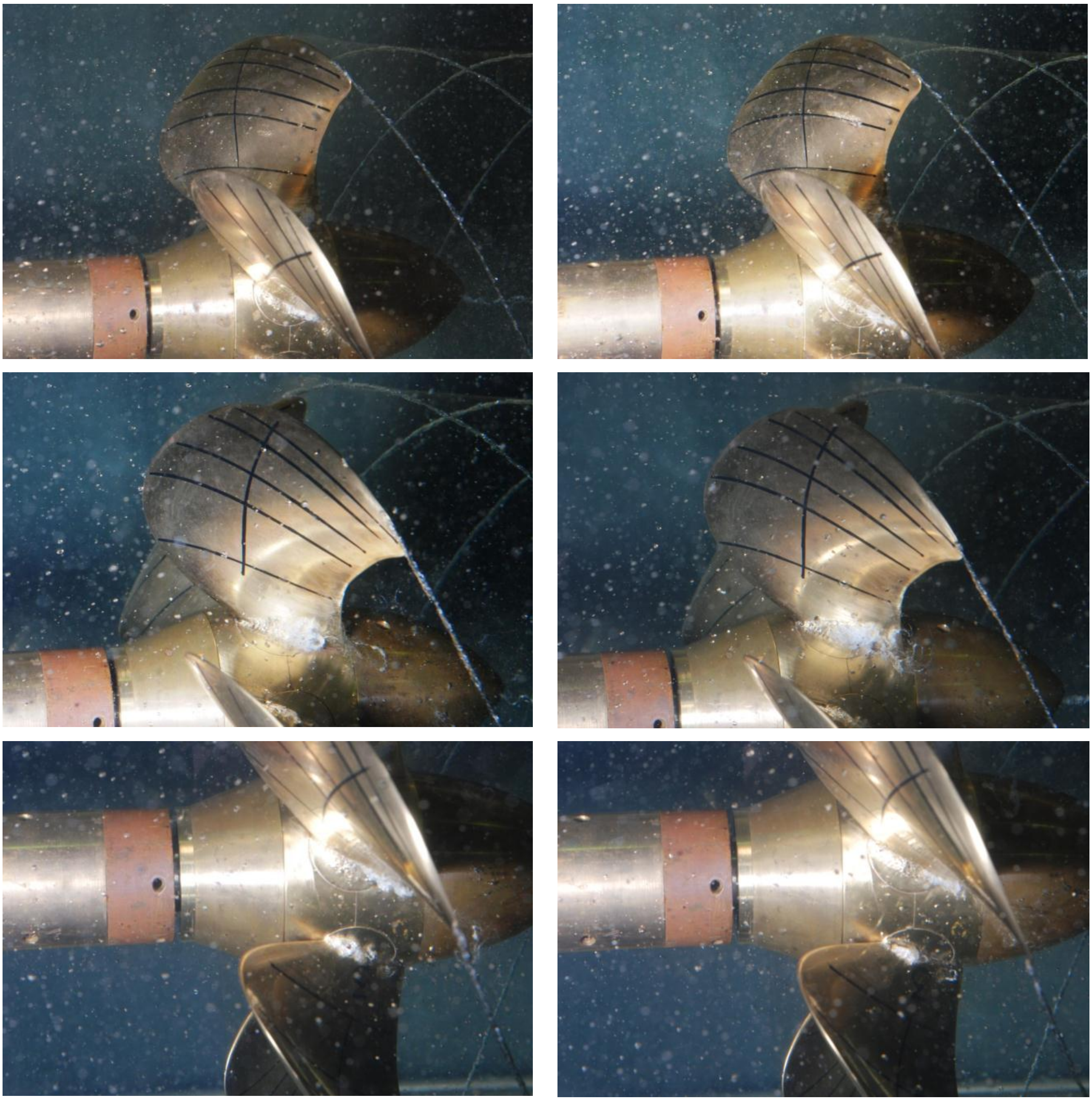
$K_T = 0.2359$, $10K_Q = 0.6938$, $\sigma_{nc} = 2.259$

Cavitation observation, variation of the cavitation number, J_c = 1.2535

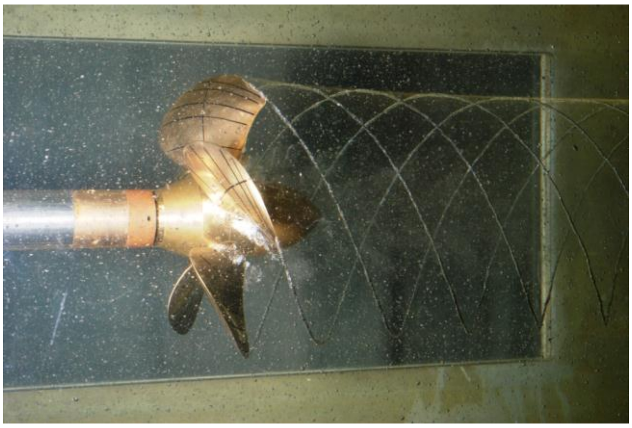
K_T = 0.2286, $10K_Q$ = 0.6778, σ_{nc} = 2.059

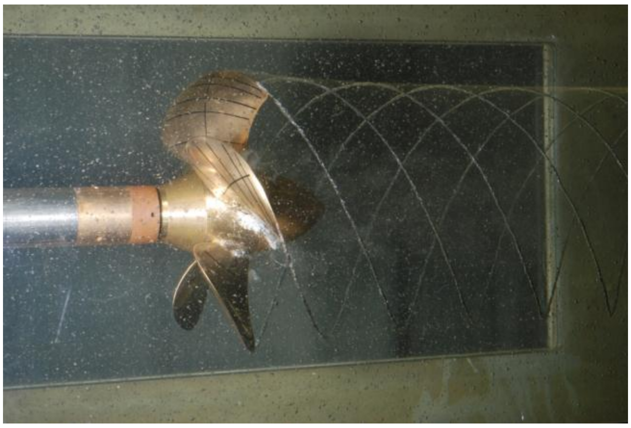
Cavitation observation, variation of the cavitation number, J_c = 1.2535

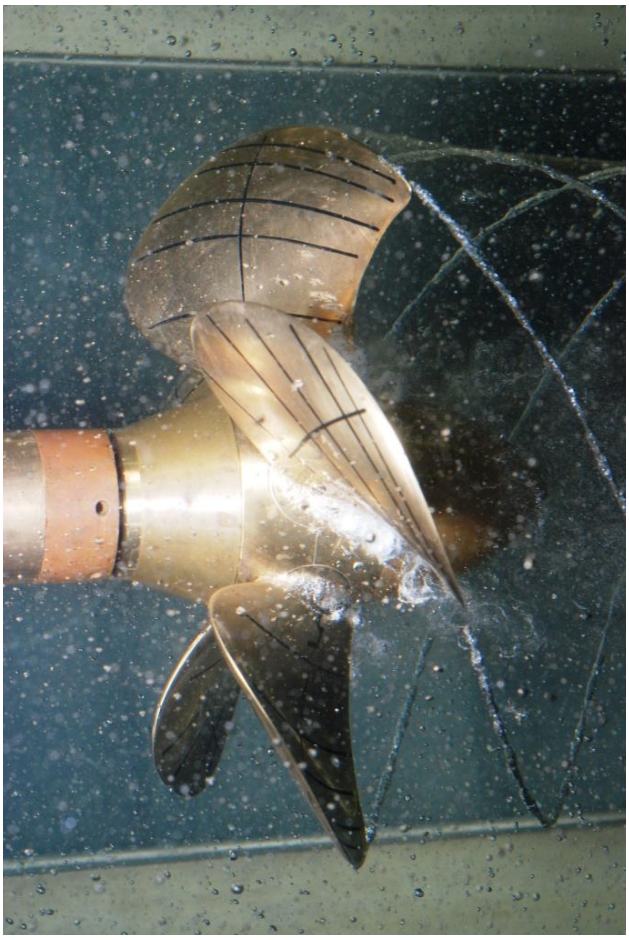


K_T = 0.2286, $10K_Q$ = 0.6778, σ_{nc} = 2.059

Cavitation observation, variation of the cavitation number, J_c = 1.2535

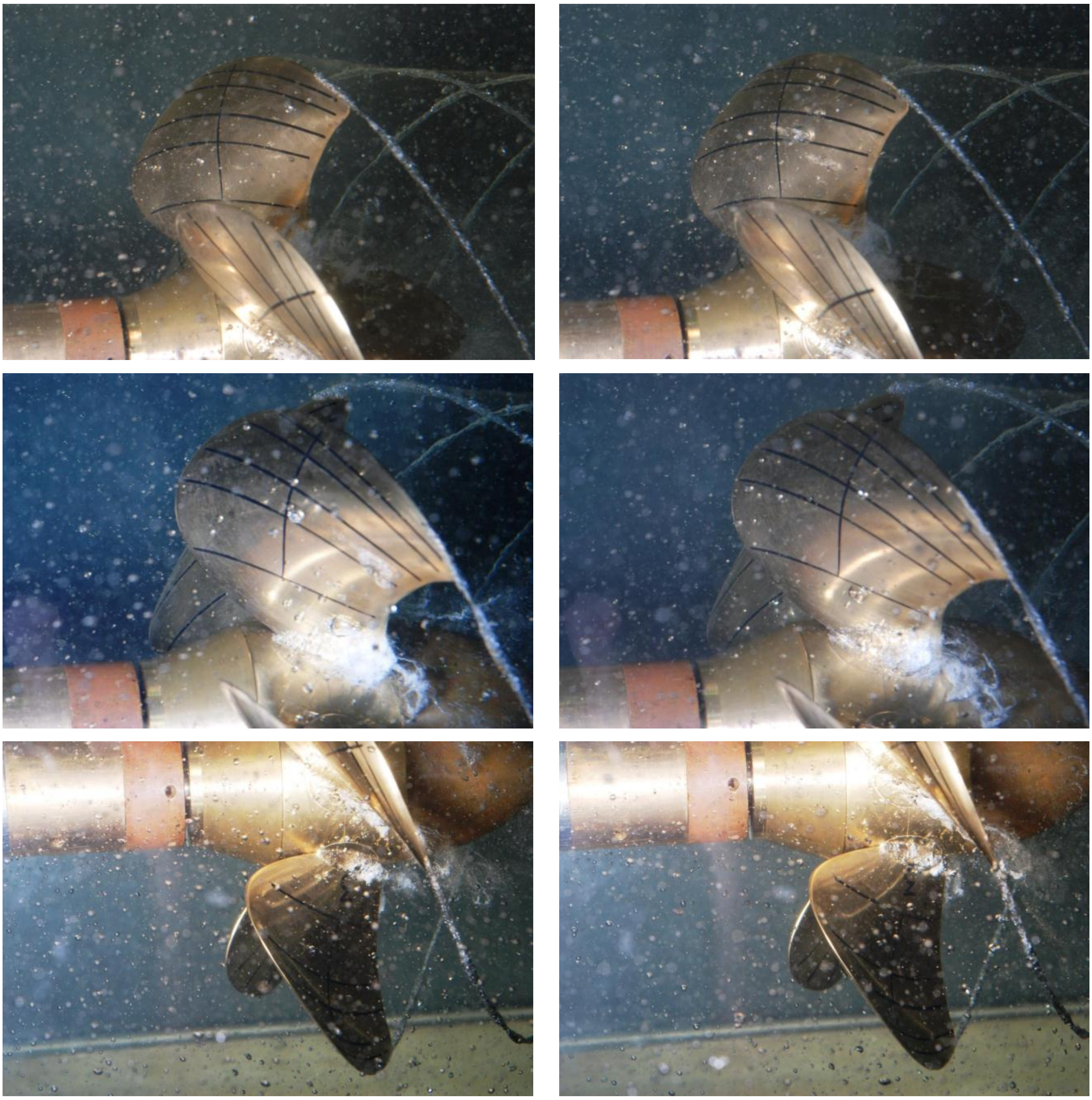






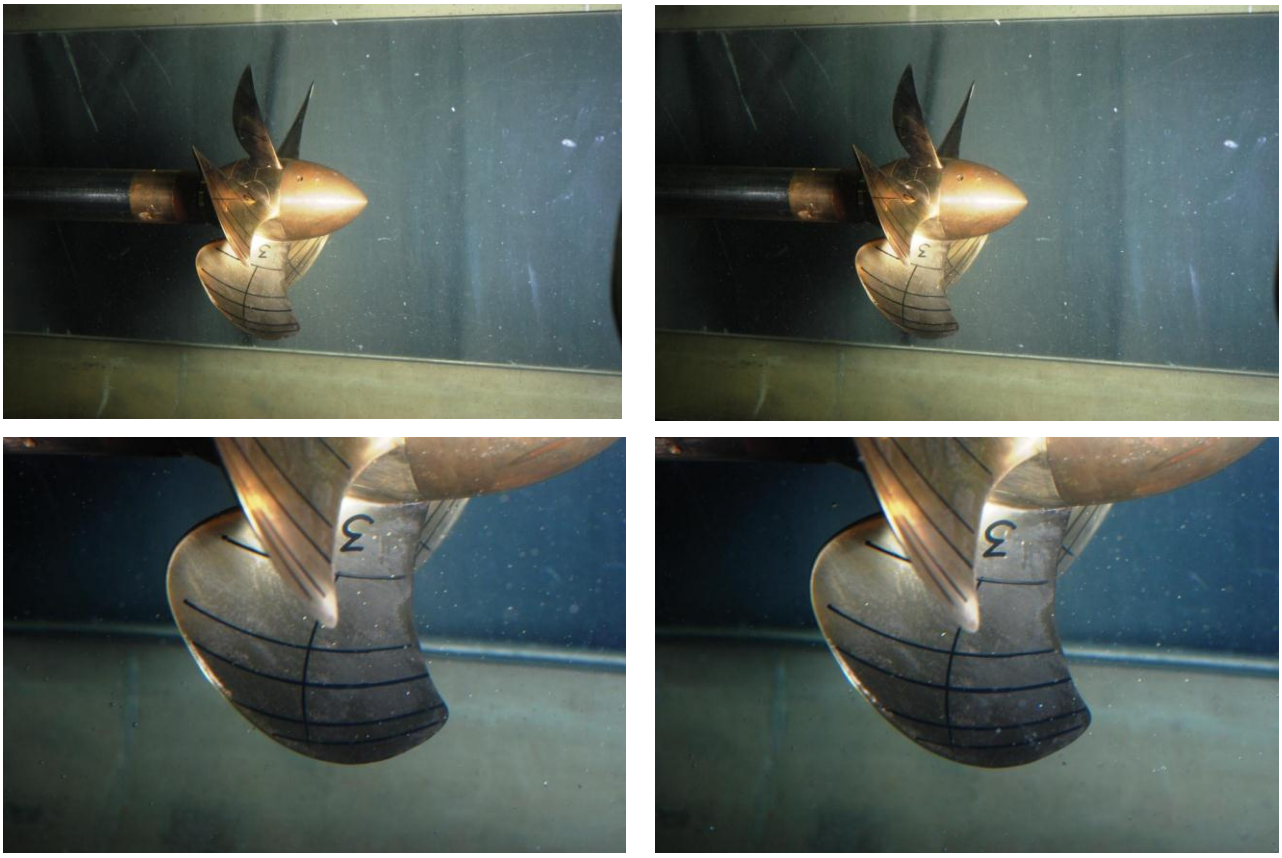
K_T = 0.2064, $10K_Q$ = 0.6312, σ_{nc} = 1.456

Cavitation observation, variation of the cavitation number, J_c = 1.2535



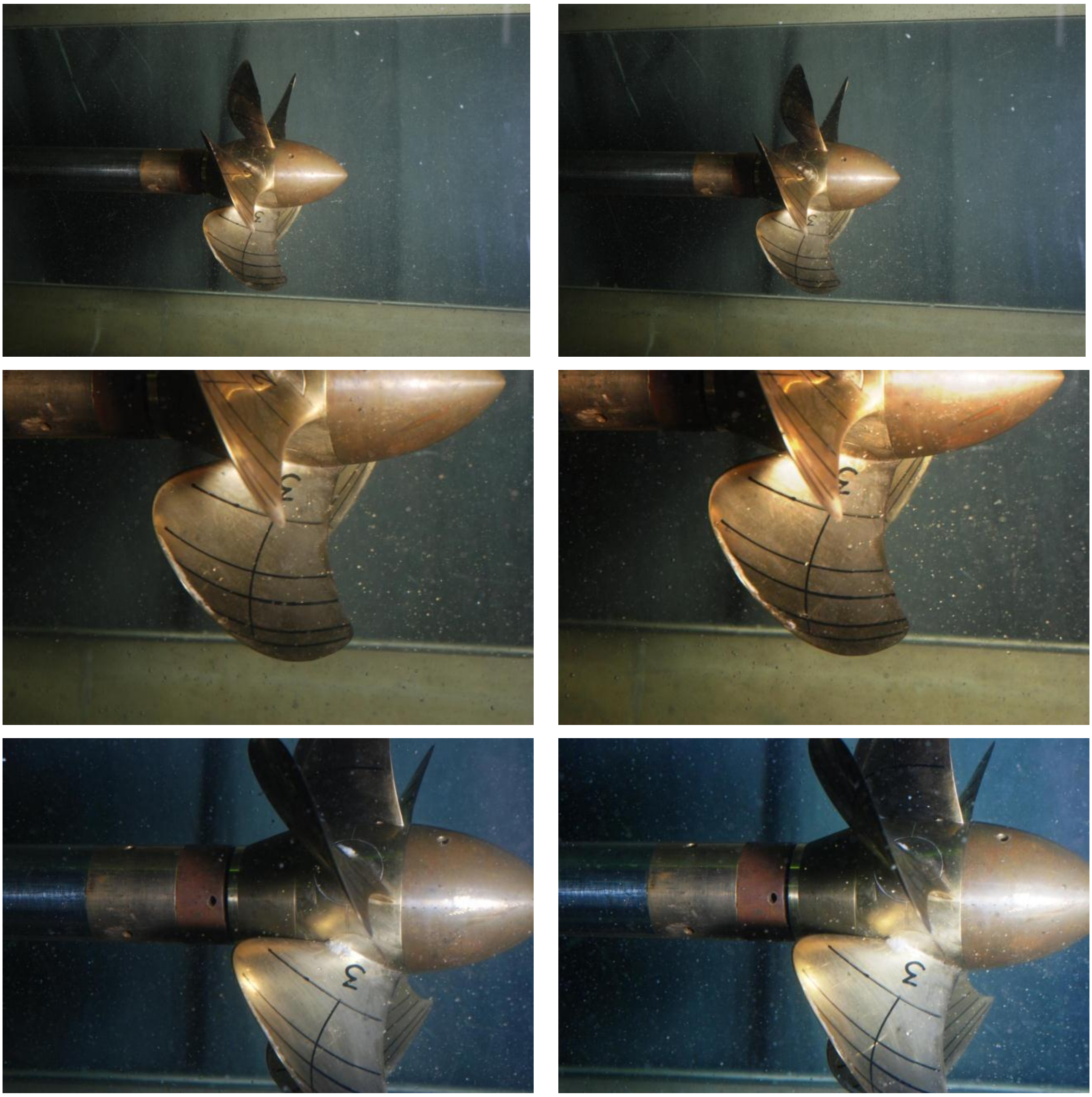
K_T = 0.2064, $10K_Q$ = 0.6312, σ_{nc} = 1.456

Cavitation observation, variation of the cavitation number, J_c = 1.4000



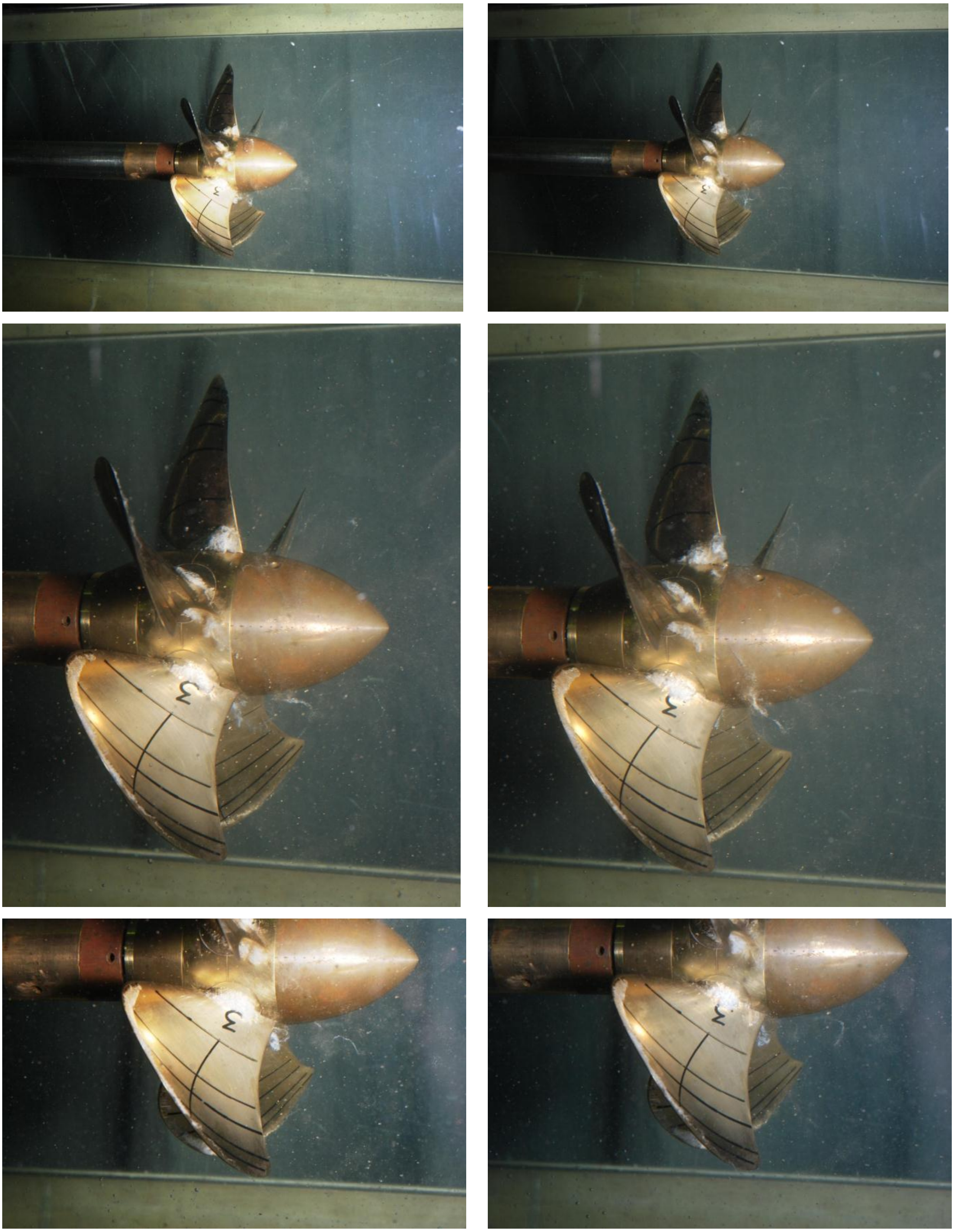
K_T = 0.1641, $10K_Q$ = 0.5369, σ_{nc} = 4.032

Cavitation observation, variation of the cavitation number, J_c = 1.4000



K_T = 0.1608, $10K_Q$ = 0.5302, σ_{nc} = 3.032

Cavitation observation, variation of the cavitation number, J_c = 1.4000



$K_T = 0.1362$, $10K_Q = 0.4890$, $\sigma_{nc} = 2.022$

Symbols

symbol	name	definition or explanation	SI - unit
A_0	Propeller disc area	$\pi D^2 / 4$	m^2
A_E	Expanded blade area	Expanded blade area of a screw propeller outside the boss or hub	m^2
c	Chord length		m
C_{Th}	Thrust loading coefficient	$T / (A_P q_A) = (T_P / A_P) / q_A$	1
D	Propeller diameter		m
d_h	Boss or hub diameter	$2 r_h$	m
D_{H2}	Pressure difference	Measured in the nozzle of the cavitation tunnel	Pa
f	Camber of a foil section		m
g	Acceleration of gravity	Weight force / mass, strength of the earth gravity field	m/s^2
h_0	Immersion	The depth of submergence of the propeller measured vertically from the propeller centre to the free surface	m
J	Propeller advance ratio	$V_A / (D n)$	1
K_Q	Torque coefficient	$Q / (\rho n^2 D^5)$	1
K_T	Thrust coefficient	$T / ((\rho n^2 D^4)$	1
l_h	Boss or hub length		m
n	Frequency or rate of revolution	Alias RPS (RPM in some propulsor applications)	s^{-1}
P	Propeller pitch in general		m
p	Pressure		Pa
p_A	Ambient pressure		Pa
p_C	Pressure within a steady or quasi-steady cavity		Pa
p_0	Ambient pressure in undisturbed flow		Pa
p_V	Vapour pressure of water	At a given temperature!	Pa
P/D	Pitch ratio of propeller		1
P_D	Delivered power, propeller power	$Q \omega$	W

Symbols

symbol	Name	definition or explanation	SI - unit
Q	Torque	P_D / ω	Nm
q	Dynamic pressure, density of kinetic flow energy,	$\rho V^2 / 2$	Pa
R	Radius		m
r	Radius		m
Re	Reynolds number	$Re = c_{0.7} / \nu \cdot \sqrt{V^2 + (0.7 D \pi n)^2}$	1
r_h	Hub radius		m
T	Propeller thrust		N
t_W	Temperature of water		°C
t_A	Temperature of air		
t	Blade section thickness		m
V	Velocity of a body, speed in general of the model or the ship		m/s
V_A	Advance speed of propeller	Equivalent propeller open water speed based on thrust or torque identity	m/s
V_S	Ship speed		m/s
w	Wake fraction in general	$w = 1 - V_A / V$	1
w_a	Wake fraction in axial direction	$w_a = 1 - V_A / V$	1
Z, z	Number of propeller blades		1
α	Solved gas content		mg/l
α_S	Solved gas content at saturation		mg/l
ε	Angle of rake		deg
η_O	Propeller efficiency in open water	$P_T / P_D = T V_A / (Q \omega)$ all quantities measured in open water tests	1
θ	Angle of propeller blade position		deg
θ_{EXT}	Skew angle extent	The difference between maximum and minimum local skew angle	deg

Symbols

symbol	name	definition or explanation	SI - unit
λ	Scale ratio, *l*inear scale of ship model	Ship (index $_S$) dimension divided by corresponding model (index $_M$) dimension $\lambda = L_S / L_M = B_S / B_M = T_S / T_M$	1
v	Kinematic viscosity	μ / ρ	m^2/s
π	Circular constant	3.1415926535	1
ρ	Mass density of fluid	dm / dV	kg/m^3
φ	Pitch angle of screw propeller	arctg (P / (2 π R))	1
σ	Cavitation number	$(p_A - p_C) / q$	1
σ_n	Cavitation number calculated with n	$(p_0 - p_V) / (\rho/2 \cdot n^2 \cdot D^2)$	1
σ_V	Cavitation number calculated with V	$(p_A + \rho \cdot g\ h_0 - p_V) / (\rho/2 \cdot V^2)$	1
$\sigma_{0.7}$	Cavitation number calculated with the resulting speed at r/R = 0.7	$(p_A + \rho \cdot g\ h_0 - p_V) / (\rho/2 \cdot (V + 0.7 \pi \cdot n \cdot D)^2)$	1
ω	Circular frequency	$2\ \pi\ f$	1/s
ω	Propeller rotational velocity	$2\ \pi\ n$	1/s

Indices

index	Name	definition or explanation
A	Air	
c	Velocity correction by Glauert method	
c	Construction, design	
M	Model	
S	Ship	
max	Maximum	
min	Minimum	
V	Venturi	
W	Water	
0.7	Related radius r/R = 0.7	

Description of the cavitation appearance

code	definition or explanation
BPSC	Begin pressure side cavitation
BRC	Begin root cavitation
BSSC	Begin suction side cavitation
BTVC	Begin tip vortex cavitation
EPSC	End of pressure side cavitation
ESSC	End of suction side cavitation
ETVC	End of tip vortex cavitation
FC	Foam cavitation
PS	Pressure side
PSC	Pressure side cavitation
SS	Suction side
SSC	Suction side cavitation
TVC	Tip vortex cavitation
TD	Thrust deduction

Methods and formulas

Open water test in the cavitation tunnel

The open water tests were carried out with the dynamometer J25 from Kempf & Remmers in the cavitation tunnel K15A. The influence of the test section on the propeller coefficients was corrected with the method from Glauert.

Measuring values: T, Q, n, V, p

with Glauert correction

Advance coefficient $$J = \frac{V}{n \cdot D} \qquad J_c = \frac{V_c}{n \cdot D}$$

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

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

Propeller efficiency $$\eta_O = \frac{J}{2\pi} \cdot \frac{K_T}{K_Q} \qquad \eta_{Oc} = \frac{J_c}{2\pi} \cdot \frac{K_T}{K_Q}$$

Reynolds number $$Re = \frac{c_{0.7}}{\nu} \cdot \sqrt{V^2 + (0.7 \cdot D \cdot \pi \cdot n)^2} \qquad Re_c = \frac{c_{0.7}}{\nu} \cdot \sqrt{V_c^2 + (0.7 \cdot D \cdot \pi \cdot n)^2}$$

Thrust loading coefficient $$C_{Th} = \frac{8}{\pi} \cdot \frac{K_T}{J^2} \qquad C_{Thc} = \frac{8}{\pi} \cdot \frac{K_T}{J_c^2}$$

Cavitation numbers $$\sigma_V = \frac{p_{stat} - p_v}{\frac{\rho}{2} \cdot V^2} \qquad \sigma_{Vc} = \frac{p_{statc} - p_v}{\frac{\rho}{2} \cdot V_c^2}$$

$$\sigma_n = \frac{p_{stat} - p_v}{\frac{\rho}{2} \cdot (n \cdot D)^2} \qquad \sigma_{nc} = \frac{p_{statc} - p_v}{\frac{\rho}{2} \cdot (n \cdot D)^2}$$

$$\sigma_{0.7} = \frac{p_{stat} - p_v}{\frac{\rho}{2} \cdot (V + 0.7\pi \cdot n \cdot D)^2} \qquad \sigma_{0.7c} = \frac{p_{statc} - p_v}{\frac{\rho}{2} \cdot (V_c + 0.7\pi \cdot n \cdot D)^2}$$

Procedure of cavitation tests in the cavitation tunnel

The conditions for cavitation tests are chosen such that the average loading of the propeller is equal on model and full-scale.

As a measure for the propeller load in homogeneous inflow the tip speed ratio of the full-scale propeller is used.

λ-identity $\qquad \lambda_M = \lambda_S \qquad$ with $\lambda = \dfrac{\pi \cdot n \cdot D}{V_A}$

J-identity $\qquad J_M = J_S \qquad$ with $J = \dfrac{n \cdot D}{V_A}$

In addition the pressure is adjusted to such a level that model and full size cavitation numbers are equal at corresponding points in the propeller disc.

σ-identity $\qquad \sigma_{VM} = \sigma_{VS}$

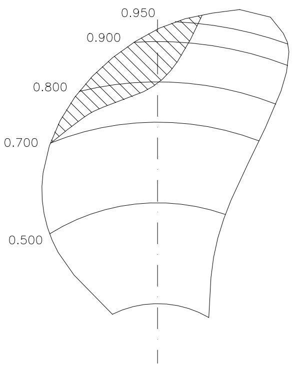
For an arbitrary point at an immersion h_0 the propeller cavitation number is:

$$\sigma_V = \frac{p_A - p_V + \rho \cdot g \cdot h_0}{0.5 \cdot \rho \cdot V^2}$$

For the cavitation tunnel the inflow speed V_M of the propeller is chosen within practical limits related to the tunnel capacity, the particular test set-up and the ranges of static pressure to be adjusted. Requiring equal cavitation numbers on model and full-scale then leads to the pressure to be adjusted in the cavitation tunnel. Obviously, at only one horizontal level the condition of equal cavitation numbers can be fulfilled.

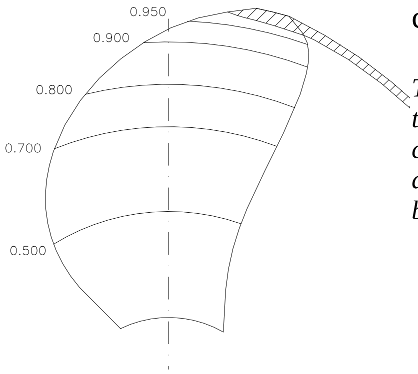
Definition of the kind of cavitation in the drawings

Sheet cavitation



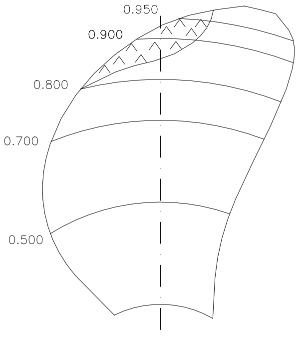
Usually thin, smooth, transparent.
Initiating near leading edge.
Often foamy in appearance.

Vortex cavitation



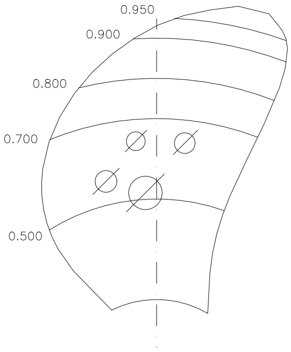
Trailing, detached tip vortex cavitation incepts downstream of the blade tip.

Foam cavitation

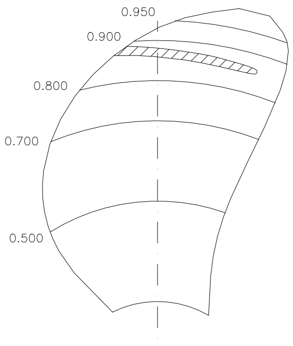


Sheet cavitation, foamy in appearance.

Spot cavitation

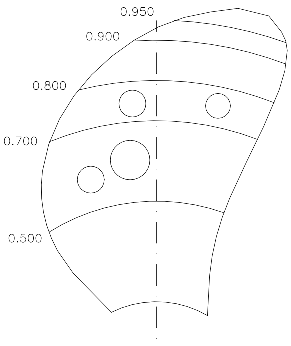


Streak cavitation



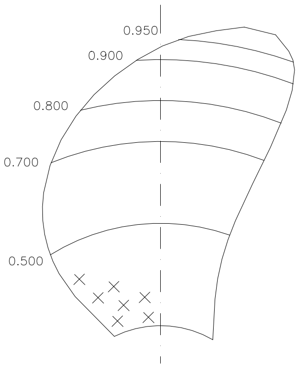
Special form of bubble cavitation, narrow, usually forms in parallel at isolated roughness spots or imperfections on the blade surface or at the leading edge.

Bubble cavitation



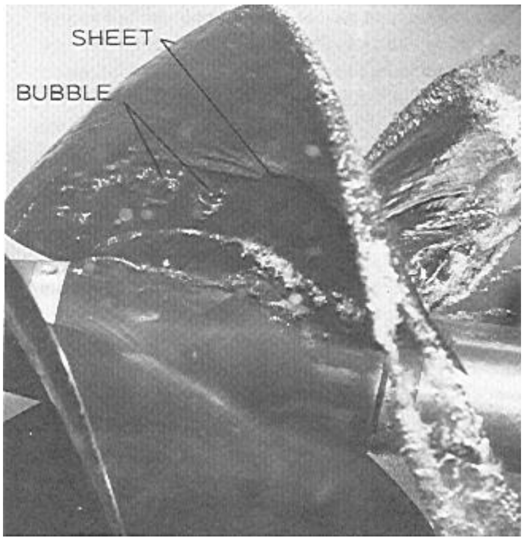
Small bubble type cavitation indicative of propellers with no suction peaks at the leading edge.

Cloud cavitation

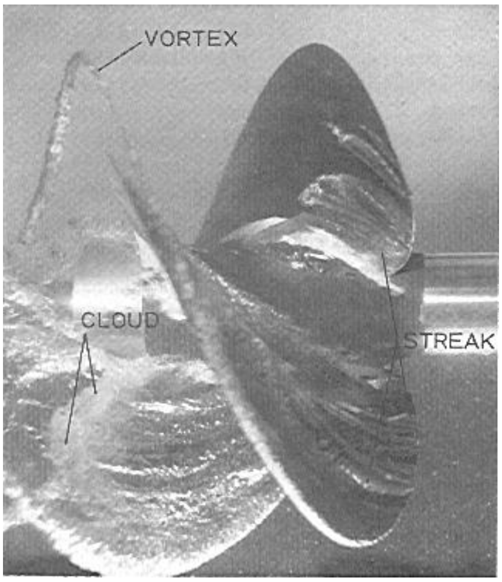


Usually develops from the break-up of unsteady sheet cavitation.

Samples of cavitation patterns, ITTC 1999



Sheet and bubble cavitation

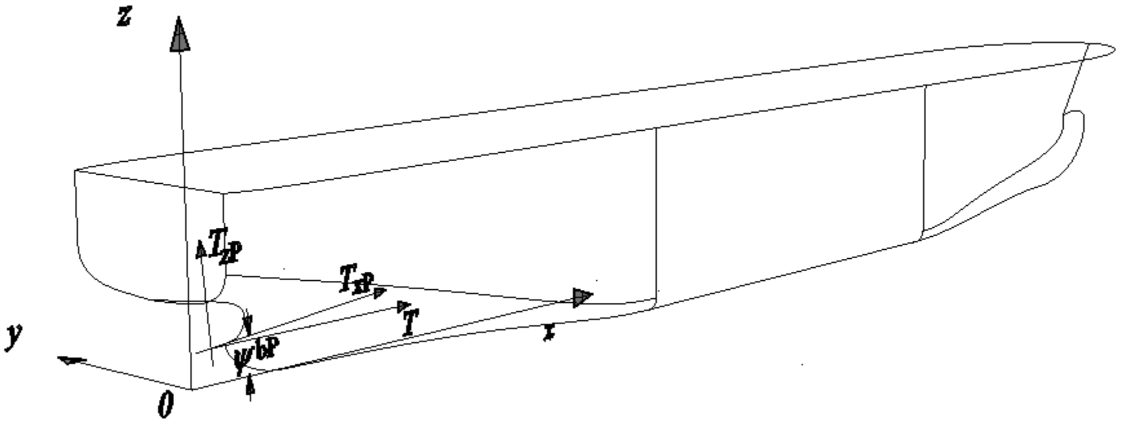


Vortex, cloud and streak cavitation

Bubble, spot and streak cavitation

Coordinate system

Cartesian coordinate system



Cylindrical propeller coordinate system looking on pressure side