Potsdam Propeller Test Case (PPTC)
Cavitation Test
Case 2.3

Hans-Jürgen Heinke

Potsdam Model Basin (SVA)

The Second International Symposium on Marine Propulsors 2011 – smp‘11

Model propeller VP1304

Main data of model propeller VP1304

			VP1304
Diameter	D	[m]	0.250
Pitch ratio $r/R = 0.7$	$P_{0.7}/D$	[–]	1.635
Area ratio	A_E/A_0	[–]	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

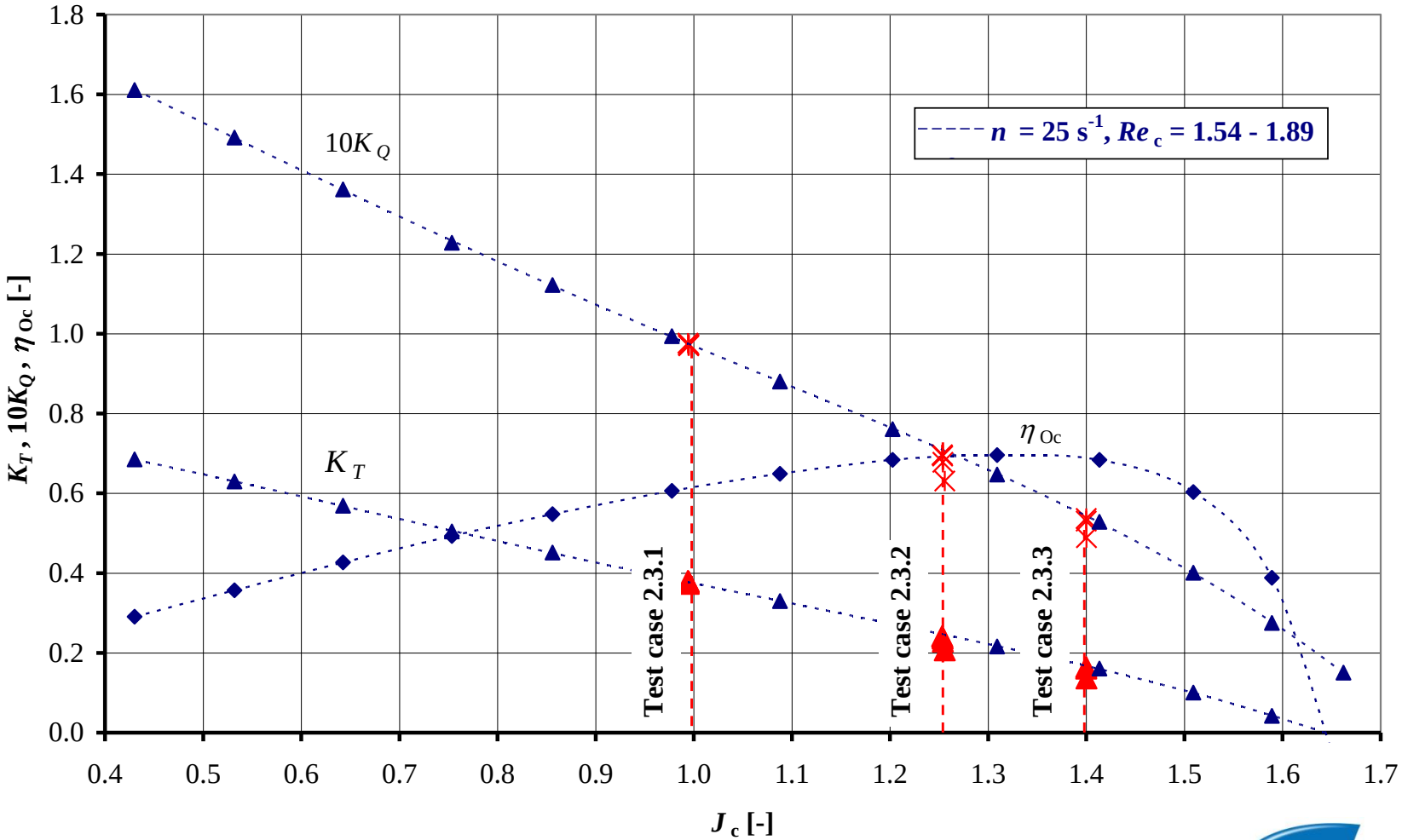
Working points

Working points for the cavitation tests

			Case 2.3.1	Case 2.3.2	Case 2.3.3
Advanced coefficient	J	[-]	1.019	1.269	1.408
Cavitation number based on n	σ_n	[-]	**2.024**	**1.424**	**2.000**
Thrust coefficient (**non-cavitating**)	K_T	[-]	**0.387**	**0.245**	**0.167**
Number of revolutions	n	[1/s]	24.987	24.986	25.014
Water density (t_w = 23.2°C)	ρ	[kg/m^3]	997.44	997.44	997.37
Kinematic viscosity water (t_w = 23.2°C)	ν	[m^2/s]	$9.337 \cdot 10^{-7}$	$9.337 \cdot 10^{-7}$	$9.272 \cdot 10^{-7}$
Vapour pressure (t_w = 23.2°C)	p_v	[Pa]	2818	2818	2869
Air content	α/α_s	[%]	53.5	53.5	58.5

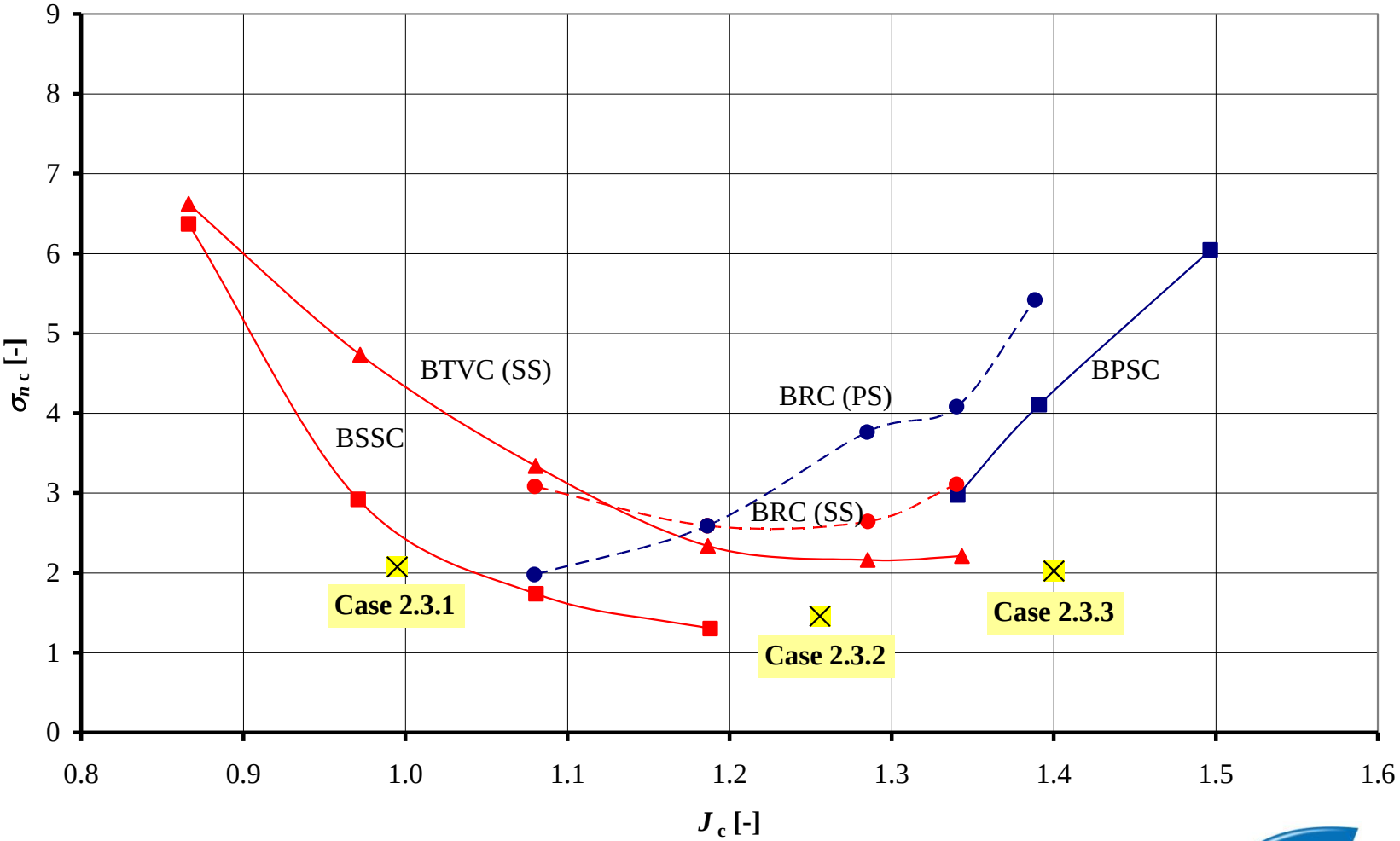
Working points

Working points for the cavitation tests



Working points

Working points for the cavitation tests



Working points

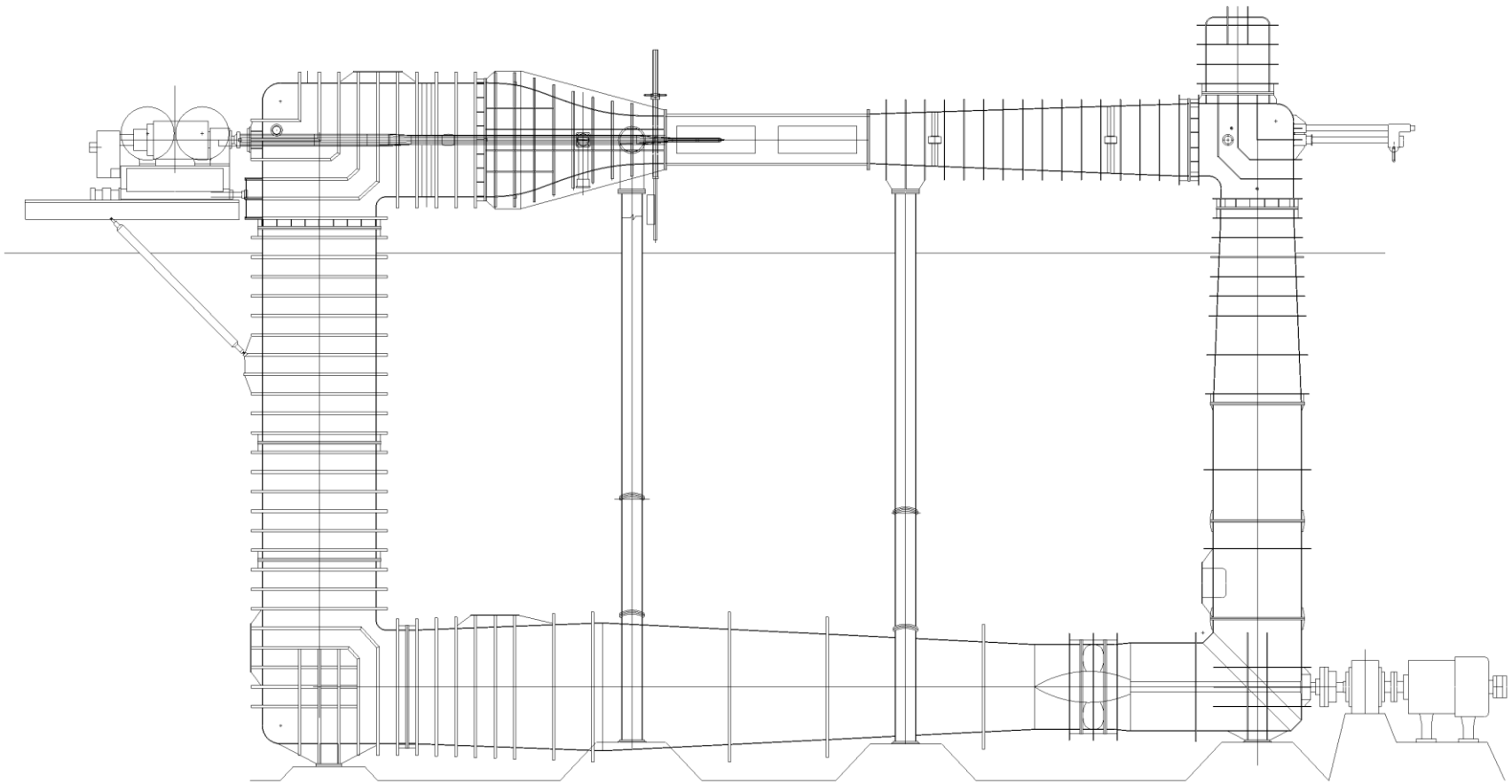
Working points for the cavitation tests

Propeller	Case 2.3.1 K_T [-]	Case 2.3.2 K_T [-]	Case 2.3.3 K_T [-]
(non-cavitating)	0.3870	0.2450	0.1670
(cavitating)	0.3725	0.2064	0.1362

The cavitating propeller works in the range of the thrust break down in each working point.

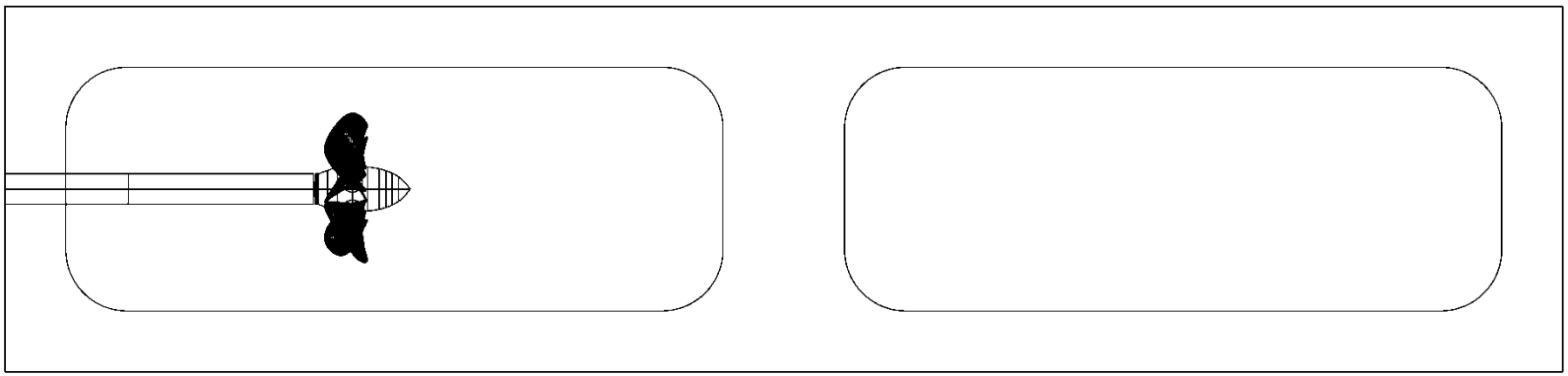
Test arrangement

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



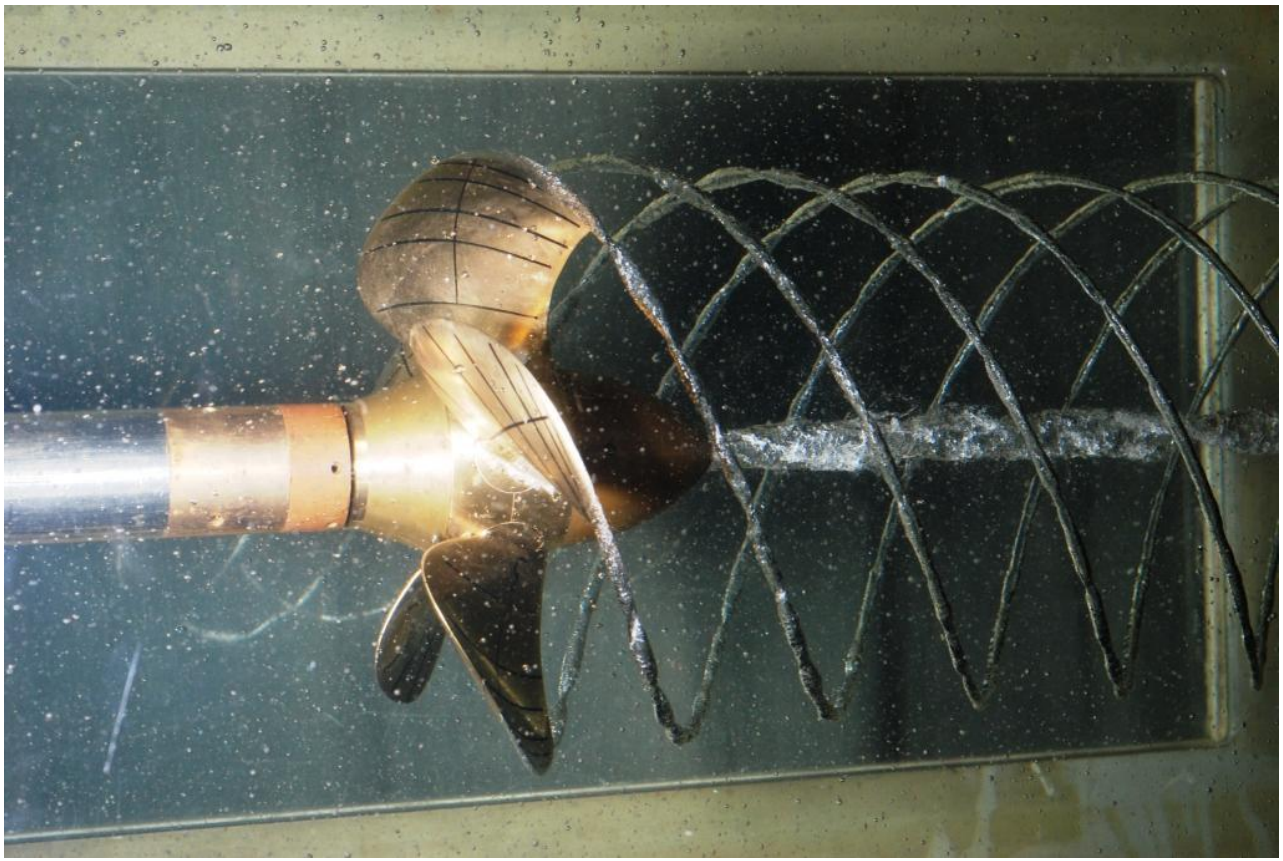
Test arrangement

Dynamometer Kempf & Remmers J25



Cavitation observation

Cavitation behaviour – Case 2.3.1 – K_T = 0.3725, σ_n = 2.024



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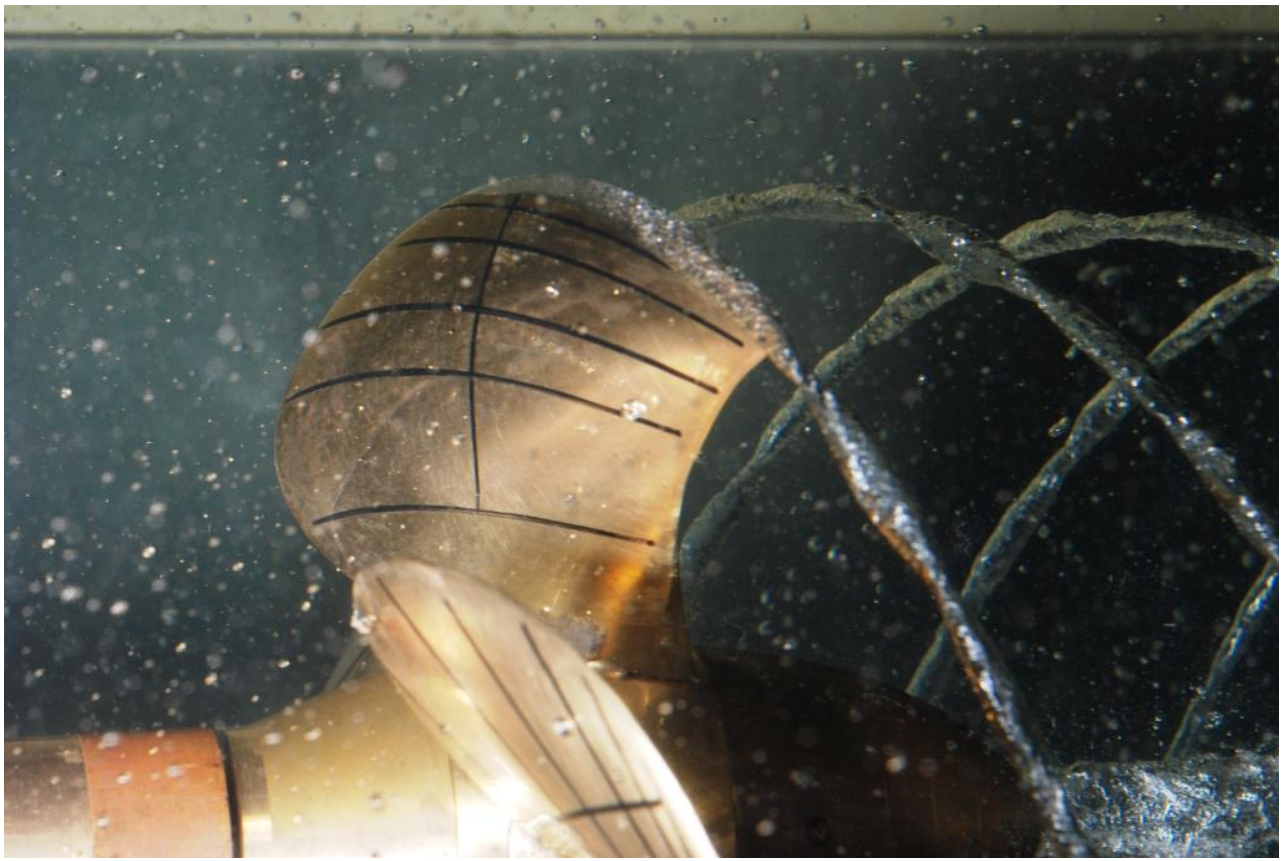

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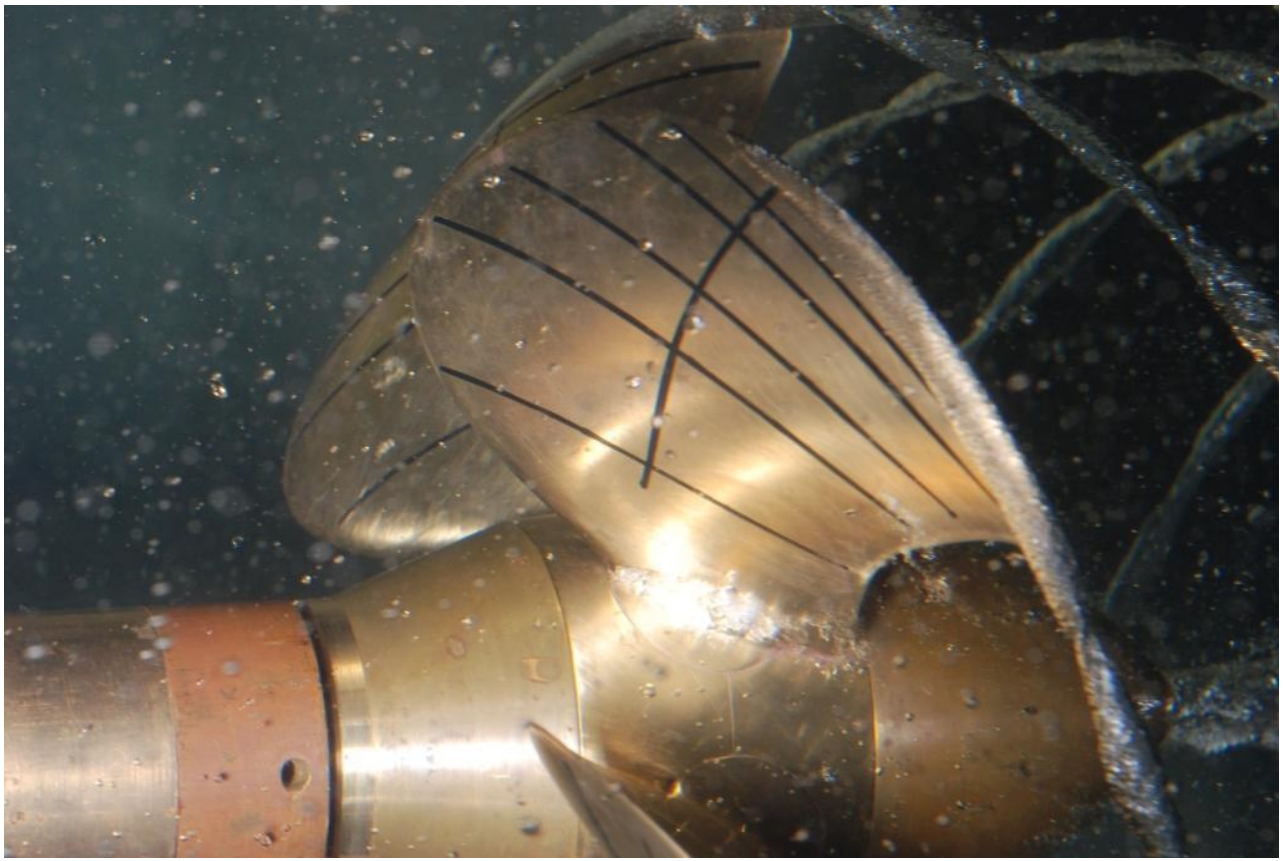
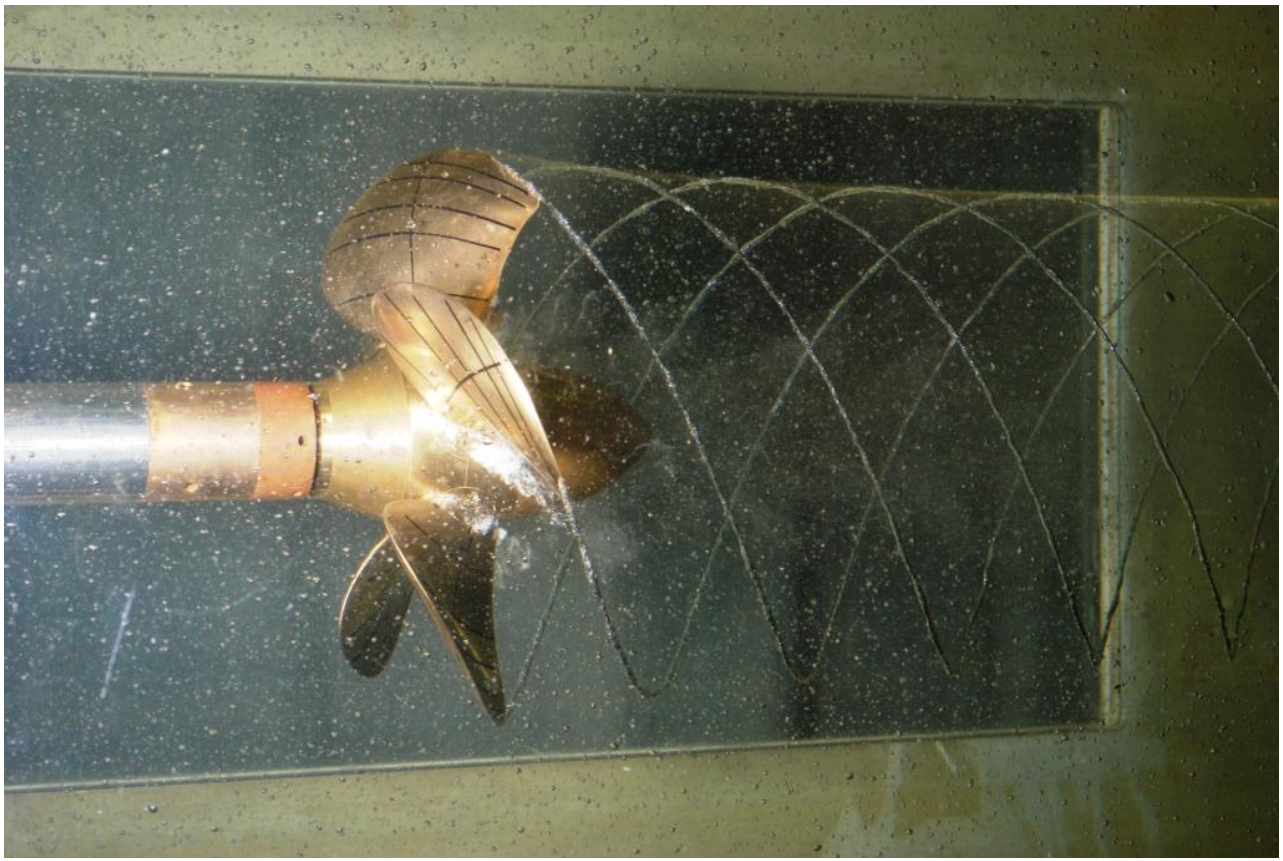


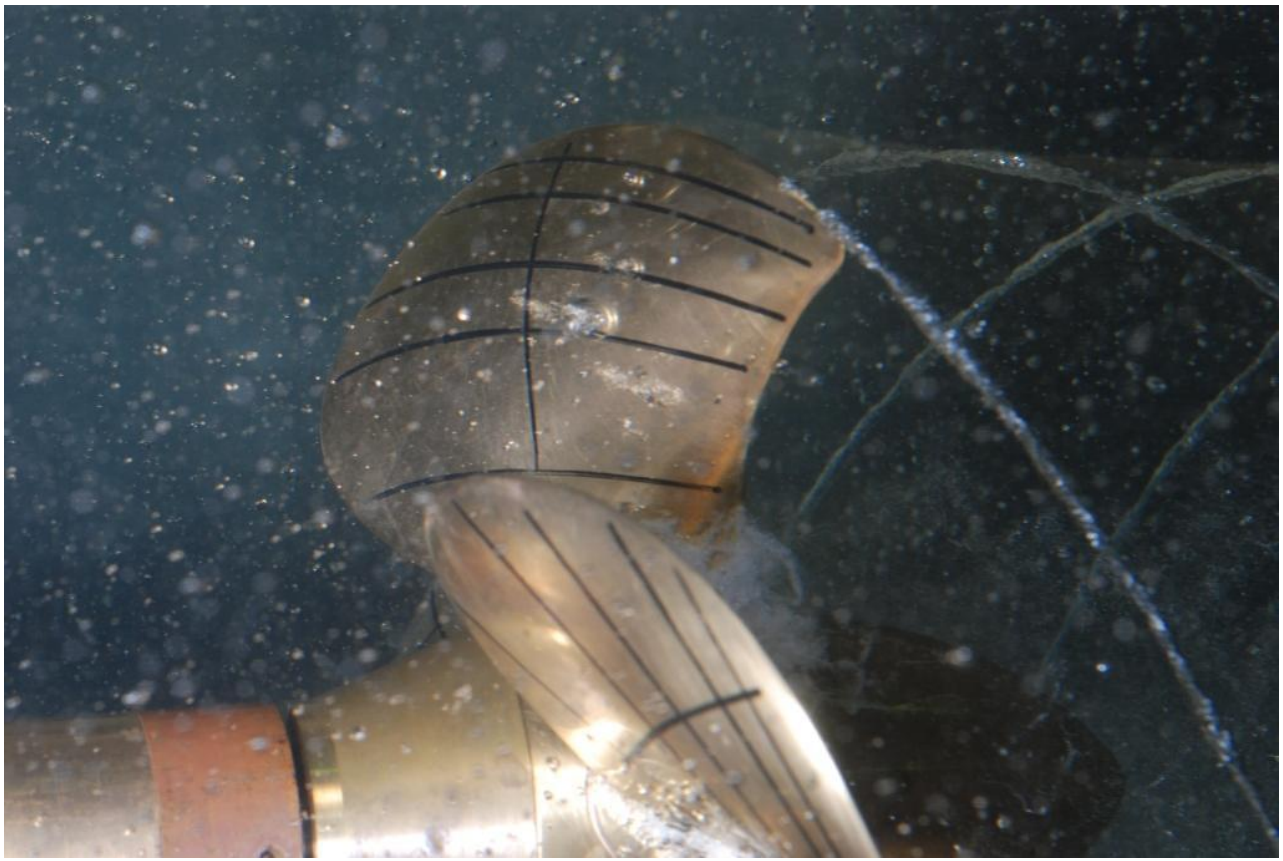
Cavitation observation

Cavitation behaviour – Case 2.3.2 – K_T = 0.2064, σ_n = 1.424



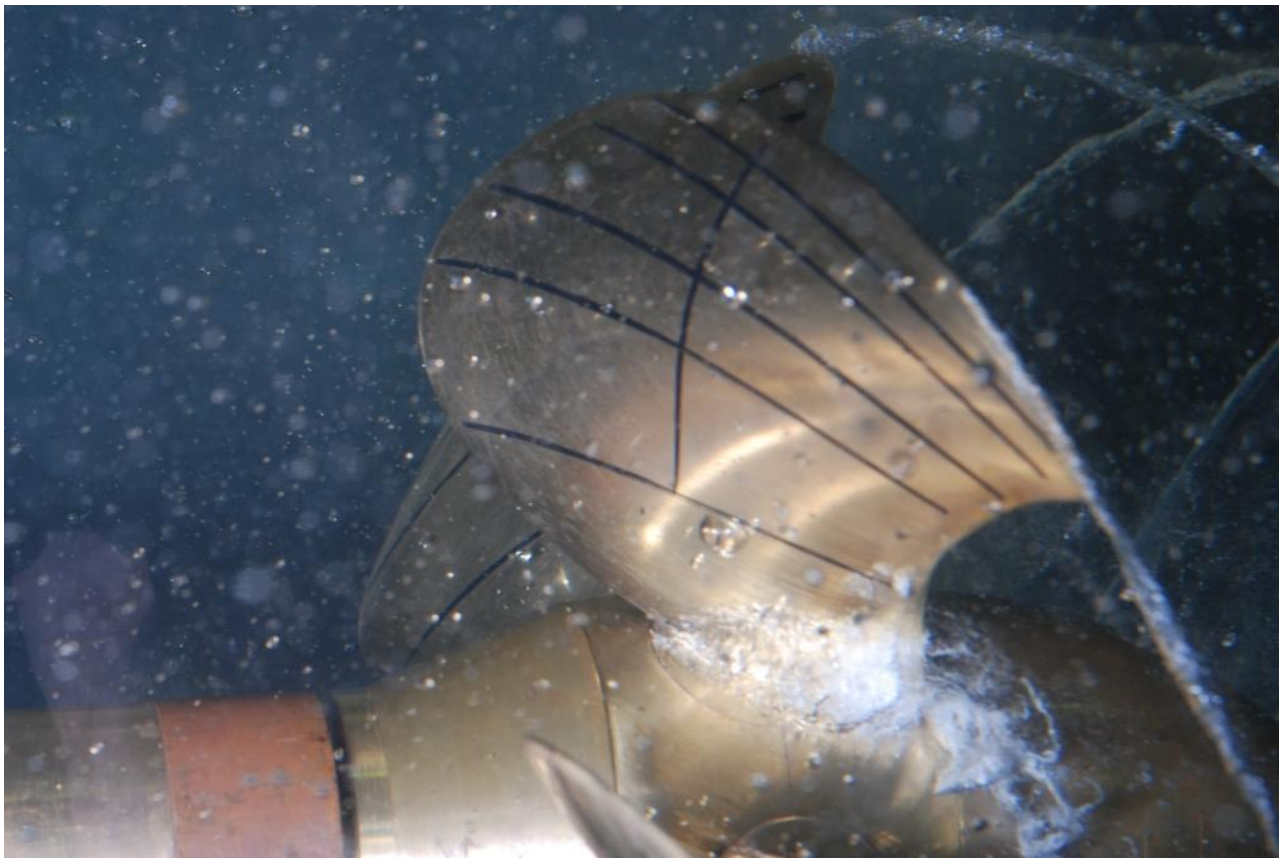
Cavitation observation

Cavitation behaviour – Case 2.3.2 – K_T = 0.2064, σ_n = 1.424



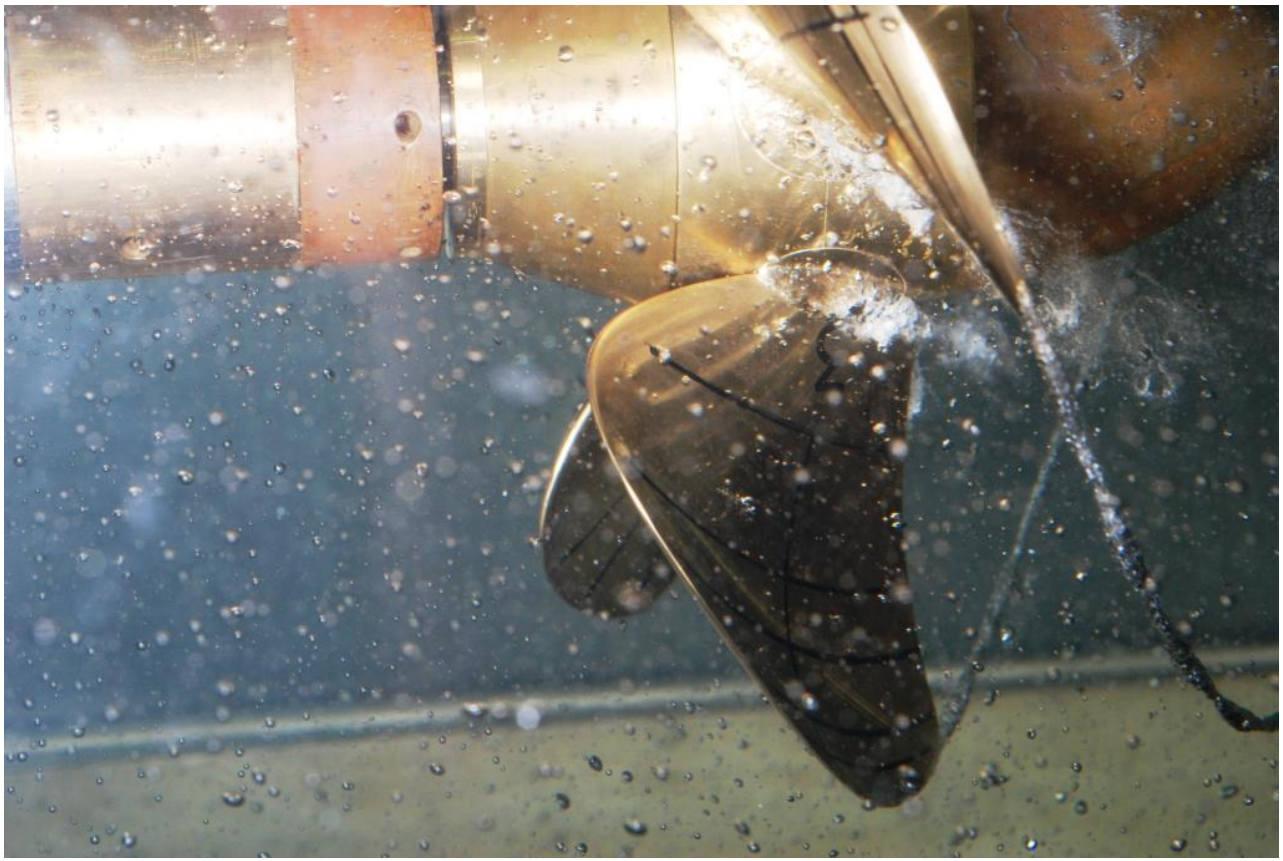
Cavitation observation

Cavitation behaviour – Case 2.3.2 – K_T = 0.2064, σ_n = 1.424



Cavitation observation

Cavitation behaviour – Case 2.3.2 – K_T = 0.2064, σ_n = 1.424

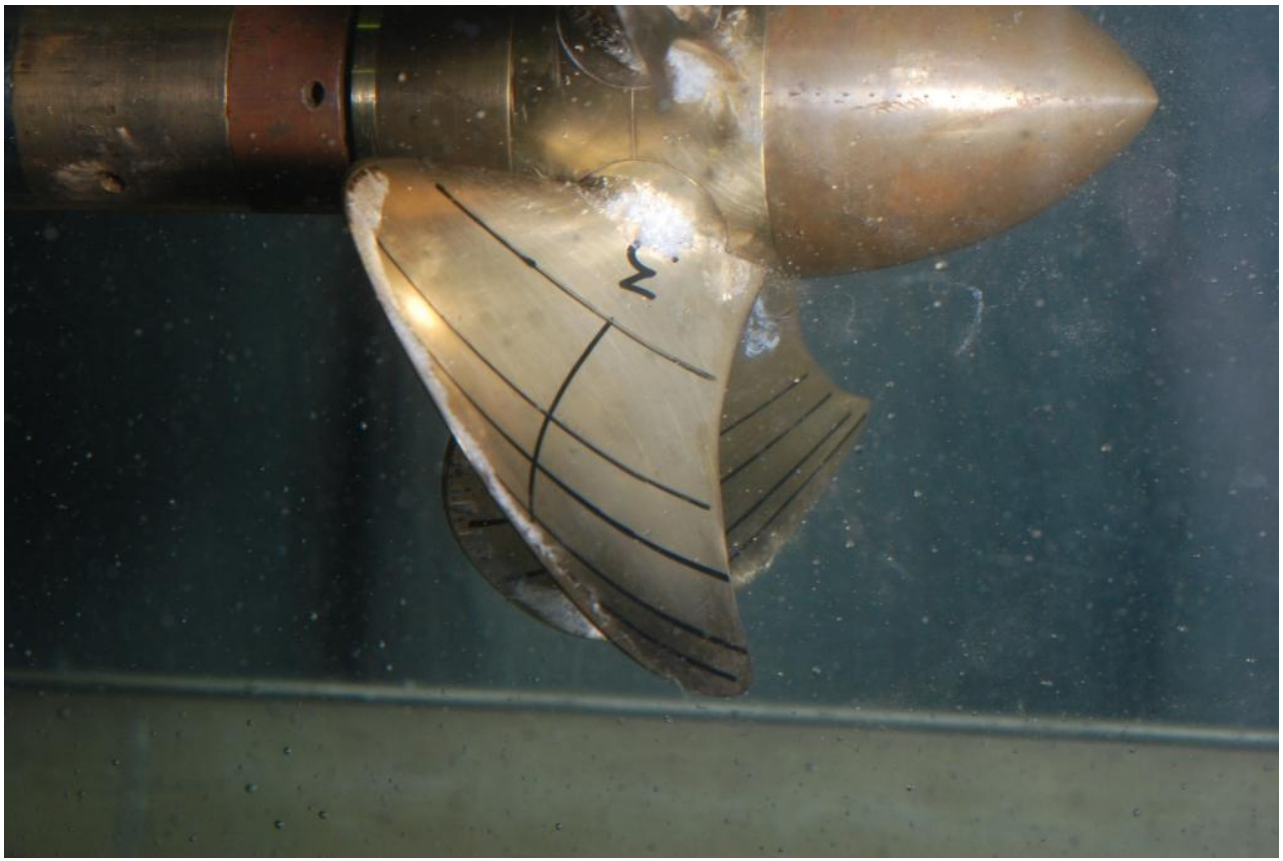


Cavitation observation

Cavitation behaviour – Case 2.3.3 – K_T = 0.1362, σ_n = 2.000

Cavitation observation

Cavitation behaviour – Case 2.3.3 – K_T = 0.1362, σ_n = 2.000



Participants

11 groups, 12 solvers, 15 calculations

Group	Solver	Acronym
Berg-Propulsion	Procal	Berg-Procal
Cradle	SC/Tetra	Cradle-SC/Tetra
CSSRC	ANSYS Fluent	CSSRC-Fluent
HSVA	QCM	HSVA-QCM
	PPB	HSVA-PPB
INSEAN	PFC	INSEAN-PFC
SSPA	ANSYS Fluent	SSPA-Fluent
TUHH	FreSCO+	TUHH-FreSCO
University of Genua	Panel	UniGenua-Panel
	StarCCM+	UniGenua-StarCCM
University of Triest	ANSYS CFX(FCM)	UniTriest-CFX(FCM)
	ANSYS CFX(Kunz)	UniTriest-CFX(Kunz)
	ANSYS CFX(Zwart)	UniTriest-CFX(Zwart)
VOITH	Comet	VOITH-Comet
VTT	FinFlo	VTT-FinFlo

Thrust coefficient

Thrust coefficients of cavitating propeller

	Case 2.3.1 K_T [-]	Case 2.3.2 K_T [-]	Case 2.3.3 K_T [-]
Exp. (non-cavitating)	**0.3870**	**0.2450**	**0.1670**
Exp. (cavitating)	**0.3725**	**0.2064**	**0.1362**
Berg-Procal	0.3760		
Cradle-SC/Tetra	0.3750	0.1990	0.1380
CSSRC-Fluent	0.3740	0.1940	0.1320
INSEAN-PFC	0.3570	0.2330	0.1610
SSPA-Fluent	0.3880	0.2050	0.1440
TUHH-FreSCO+	0.3830		0.1440
UniGenua-Panel	0.3922	0.2369	0.1378
UniGenua-StarCCM	0.3782	0.2035	0.1306
UniTriest-CFX(FCM)	0.3740	0.2030	0.1300
UniTriest-CFX(Kunz)	0.3750	0.2100	0.1330
UniTriest-CFX(Zwart)	0.3730	0.1960	0.1330
VOITH-Comet	0.3852	0.2101	0.1513
VTT-FinFlo	0.3860	0.2020	0.1420

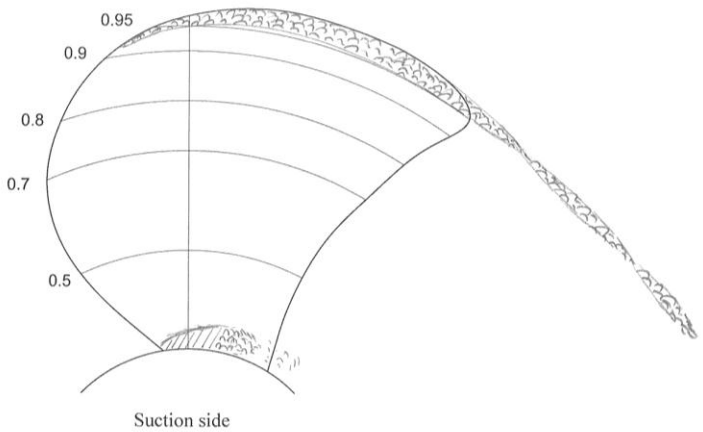
Thrust coefficient

Difference between computed and measured thrust of cavitating propeller

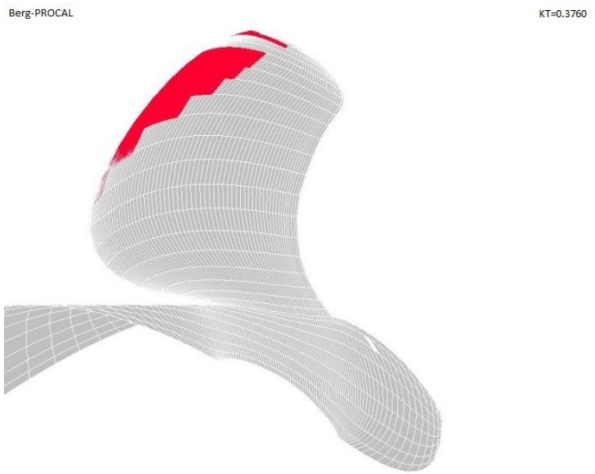
	Case 2.3.1	Case 2.3.2	Case 2.3.3
	ΔK_T [%]	ΔK_T [%]	ΔK_T [%]
Berg-Procal	0.94		
Cradle-SC/Tetra	0.67	-3.59	1.32
CSSRC-Fluent	0.40	-6.01	-3.08
INSEAN-PFC	-4.16	12.89	18.21
SSPA-Fluent	4.16	-0.68	5.73
TUHH-FreSCO+	2.82		5.73
UniGenua-Panel	5.29	14.78	1.17
UniGenua-StarCCM	1.53	-1.41	-4.11
UniTriest-CFX(FCM)	0.40	-1.65	-4.55
UniTriest-CFX(Kunz)	0.67	1.74	-2.35
UniTriest-CFX(Zwart)	0.13	-5.04	-2.35
VOITH-Comet	3.41	1.79	11.09
VTT-FinFlo	3.62	-2.13	4.26

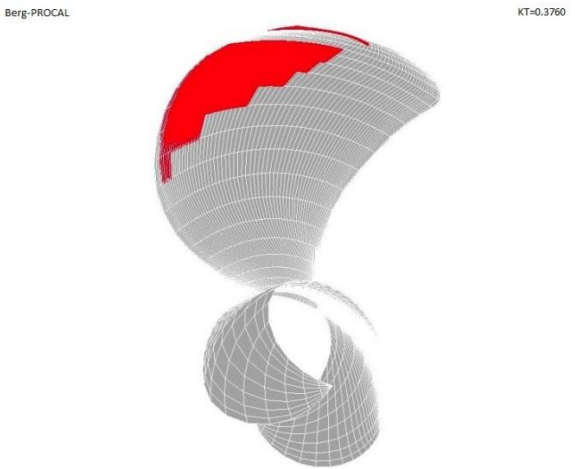
Cavitation prognosis

Berg-Procal



Test Case 2.3.1

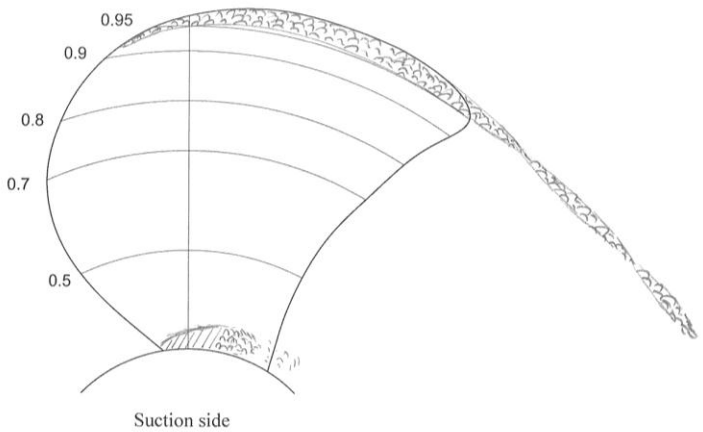


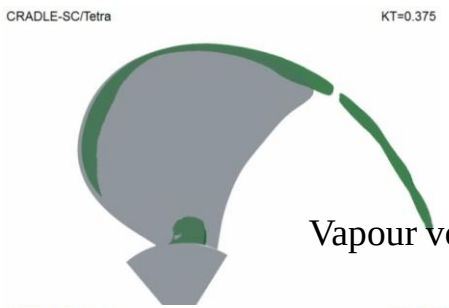


Vapour volume fraction 50%

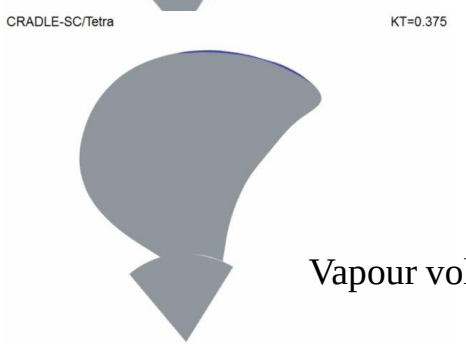
Cavitation prognosis

Cradle-SC/Tetra



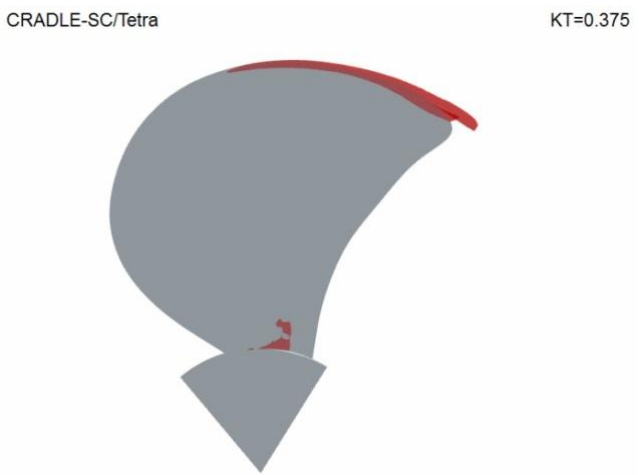


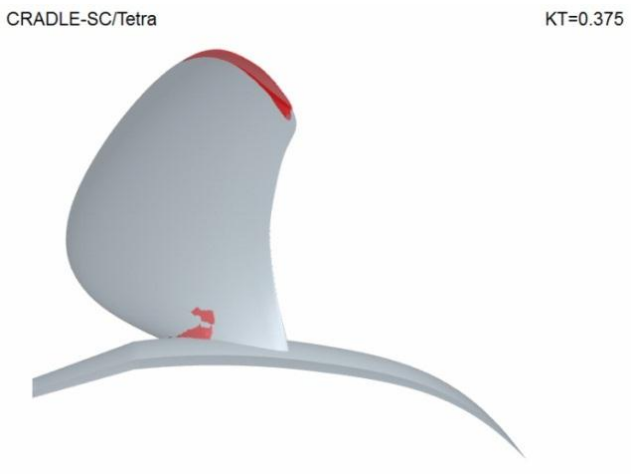
Vapour volume fraction 20%



Vapour volume fraction 80%

Test Case 2.3.1

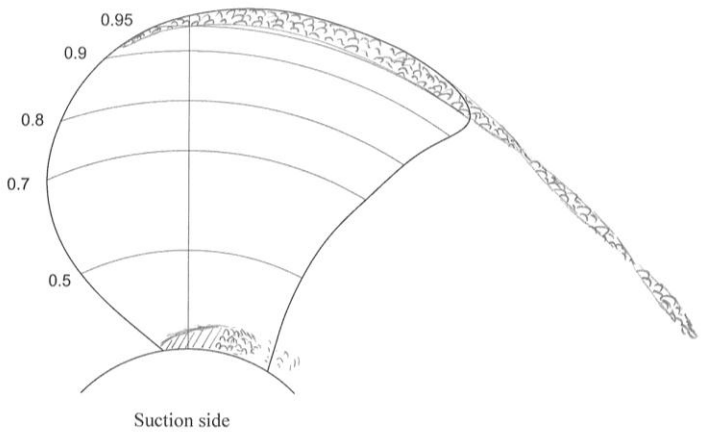


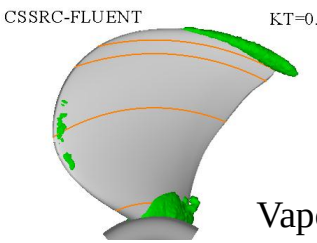


Vapour volume fraction 50%

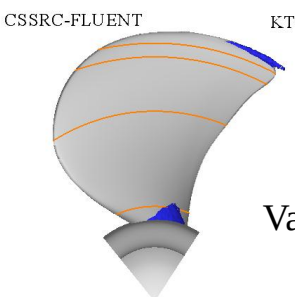
Cavitation prognosis

CSSRC-Fluent





Vapour volume fraction 20%



Vapour volume fraction 80%

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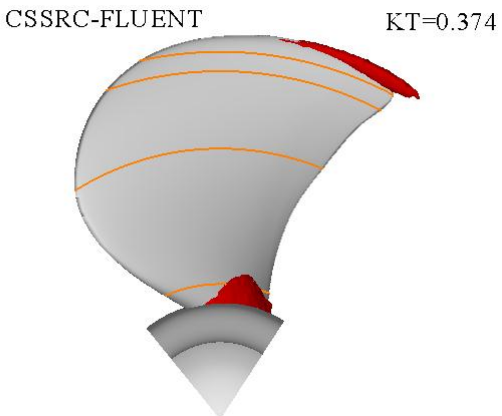
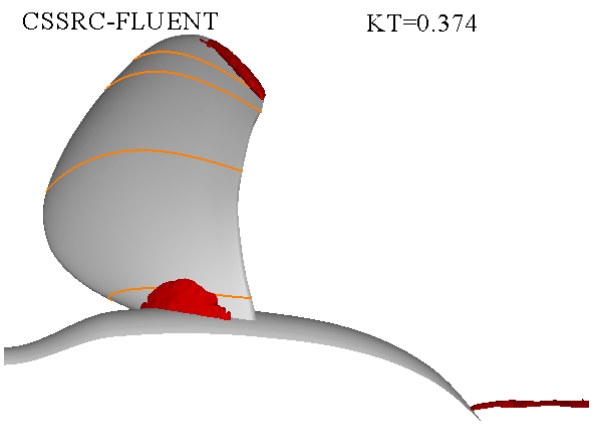
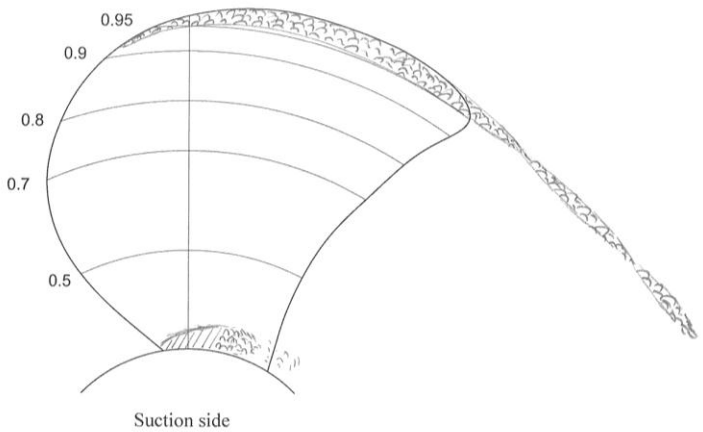




Vapour volume fraction 50%

Cavitation prognosis

HSVA-QCM



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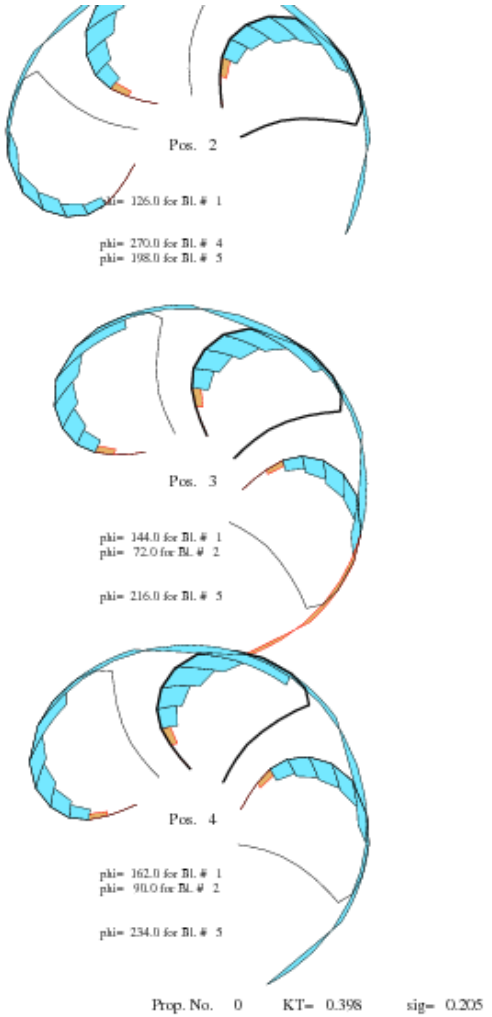
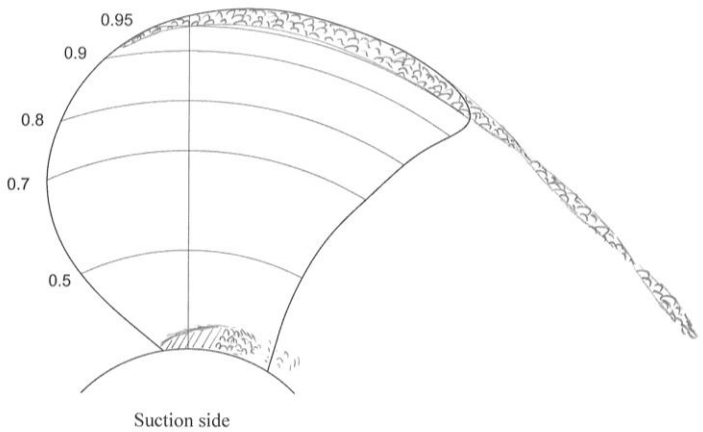
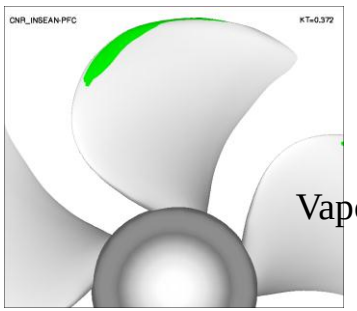


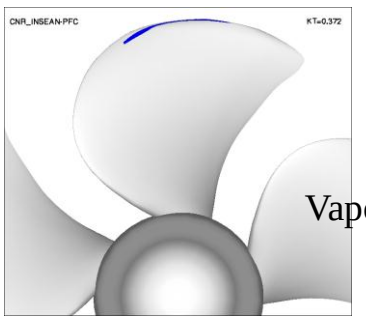
Cavitation prognosis

INSEAN-PFC





Vapour volume fraction 20%



Vapour volume fraction 80%

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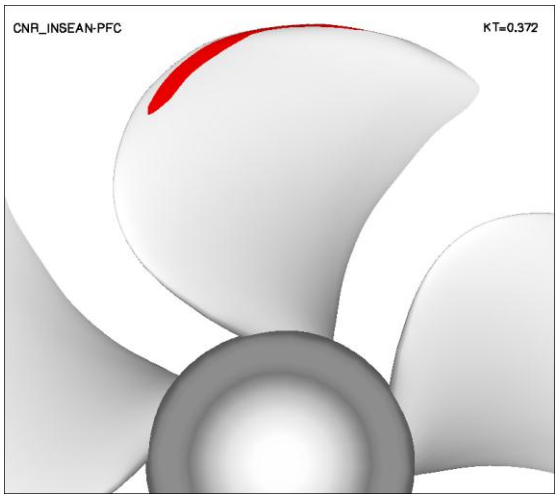
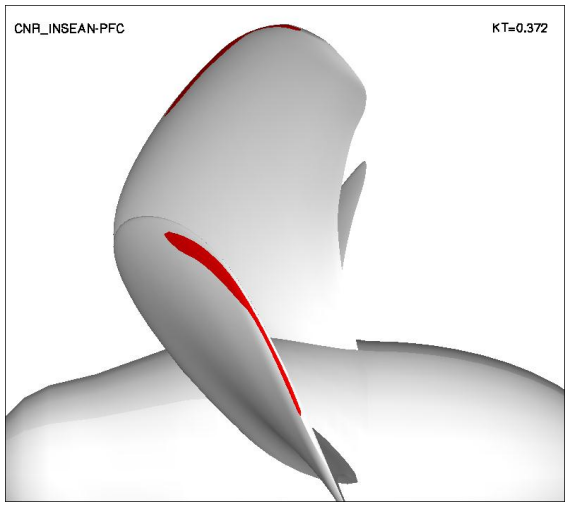
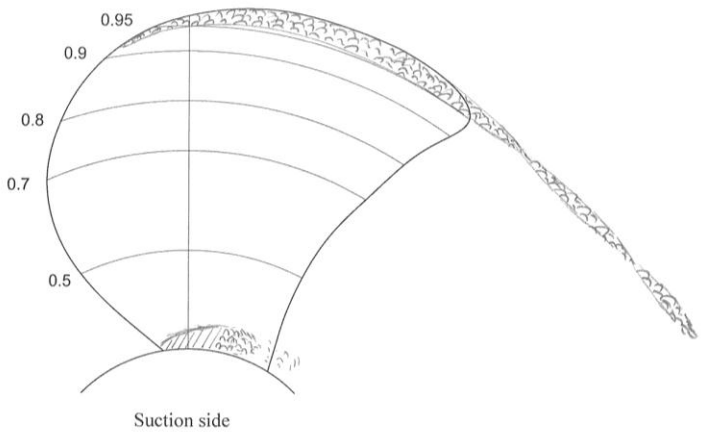


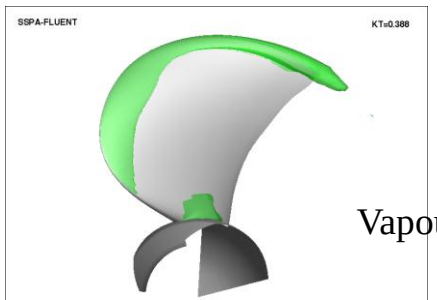


Vapour volume fraction 50%

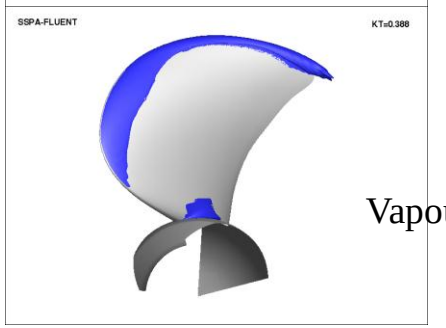
Cavitation prognosis

SSPA-Fluent



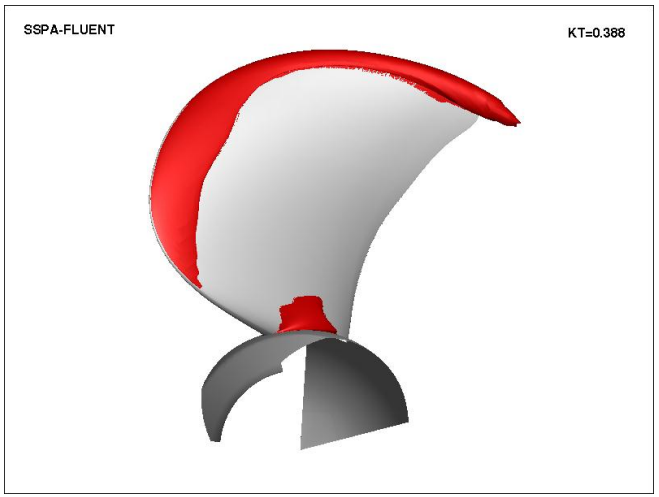


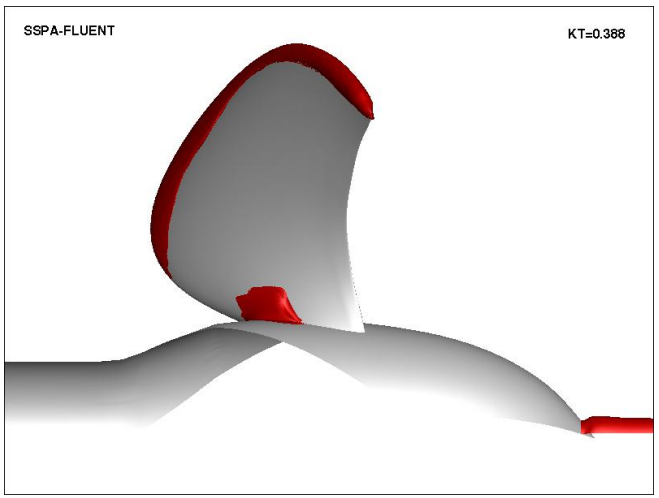
Vapour volume fraction 20%



Vapour volume fraction 80%

Test Case 2.3.1

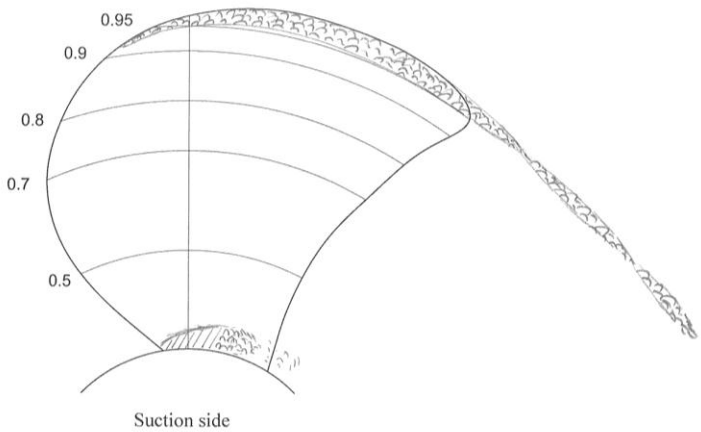


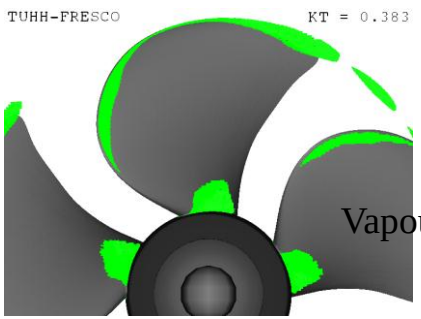


Vapour volume fraction 50%

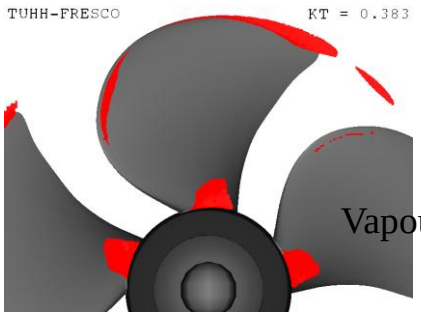
Cavitation prognosis

TUHH-FreSCO+



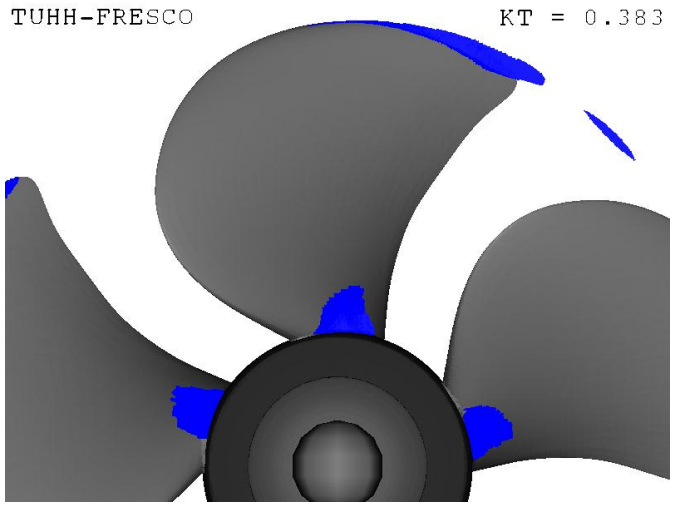


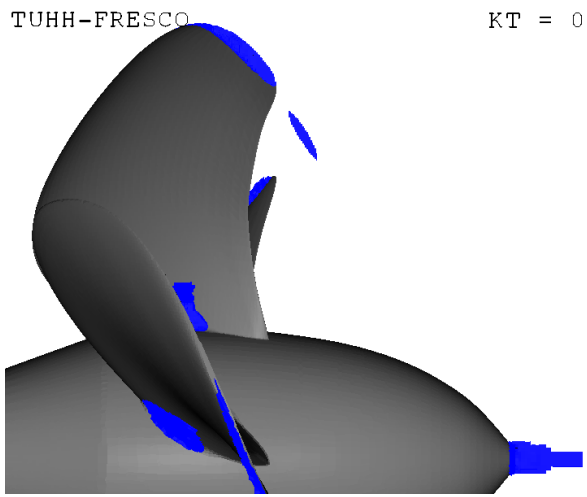
Vapour volume fraction 20%



Vapour volume fraction 50%

Test Case 2.3.1

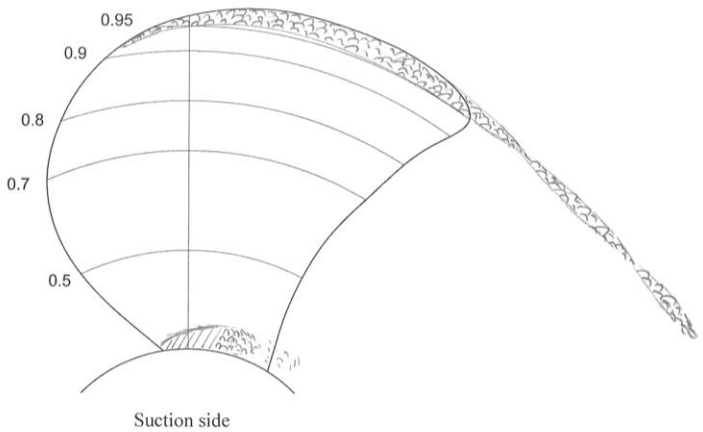




Vapour volume fraction 80%

Cavitation prognosis

UniGenua-Panel



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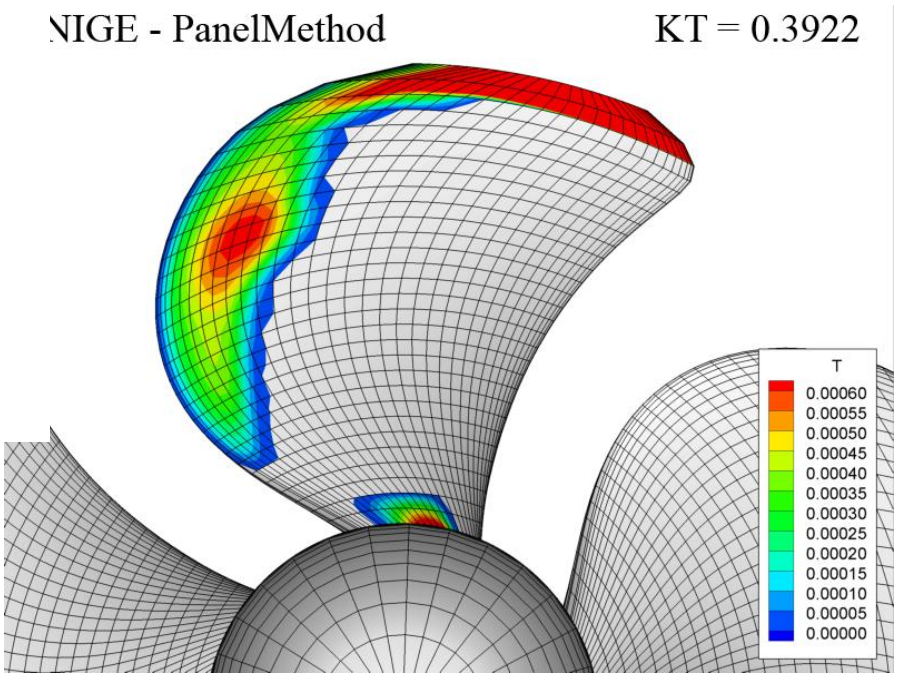
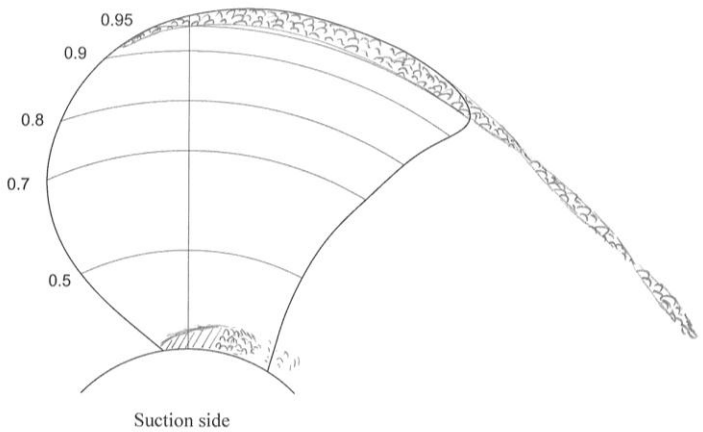
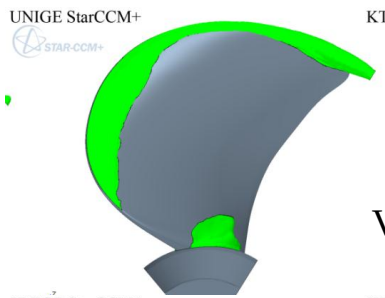


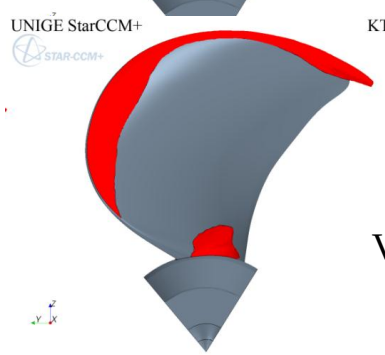
Cavitation prognosis

UniGenua-StarCCM+



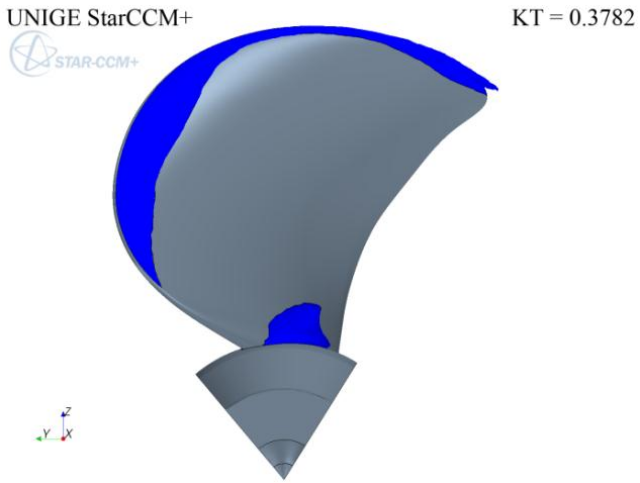


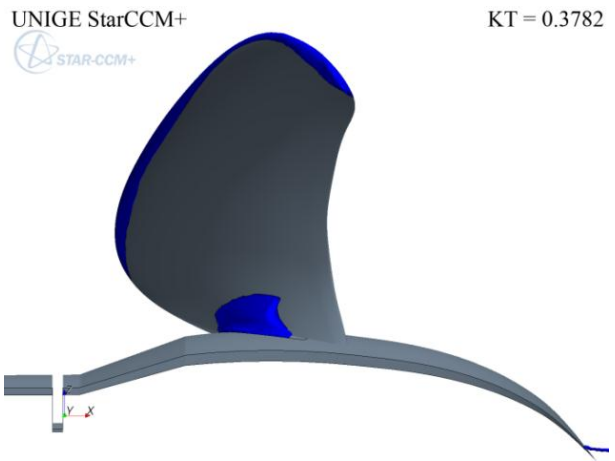
Vapour volume fraction 20%



Vapour volume fraction 50%

Test Case 2.3.1

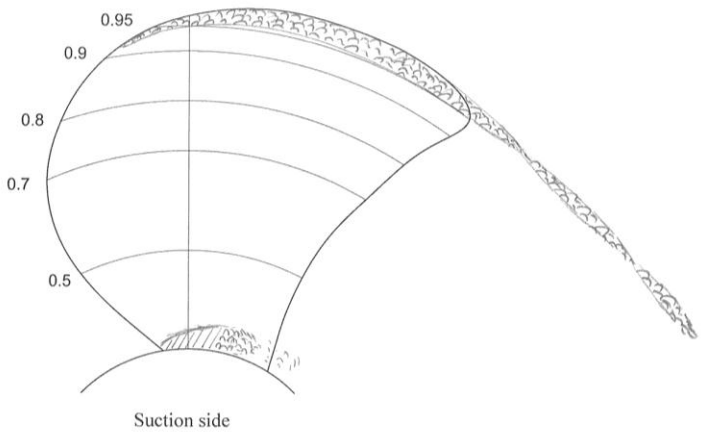


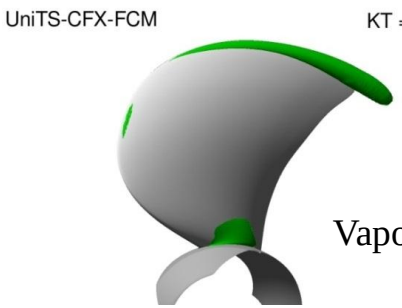


Vapour volume fraction 80%

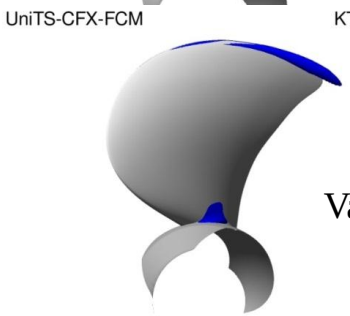
Cavitation prognosis

UniTriest-CFX(FCM)



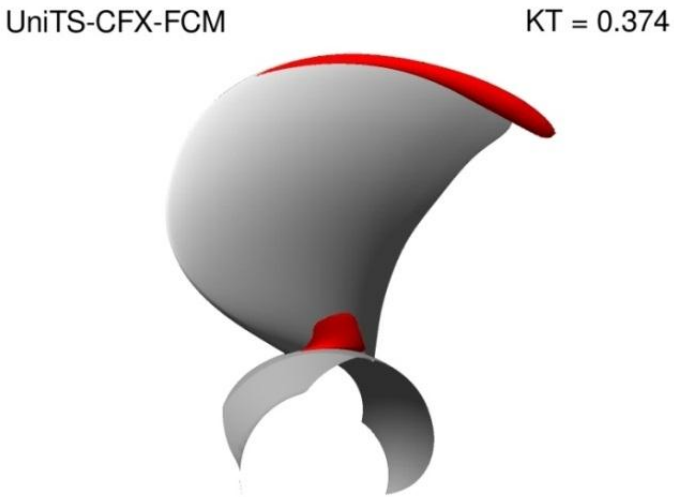


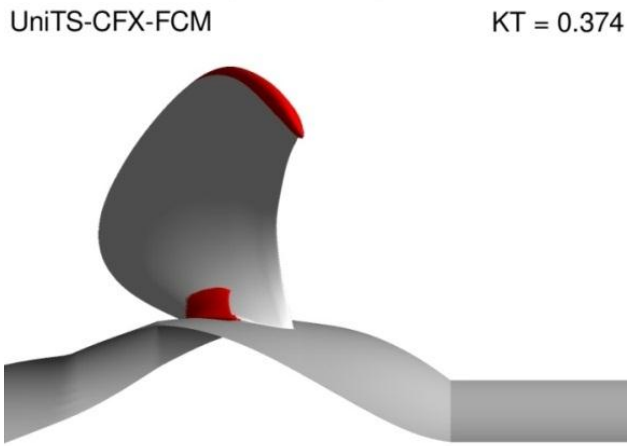
Vapour volume fraction 20%



Vapour volume fraction 80%

Test Case 2.3.1

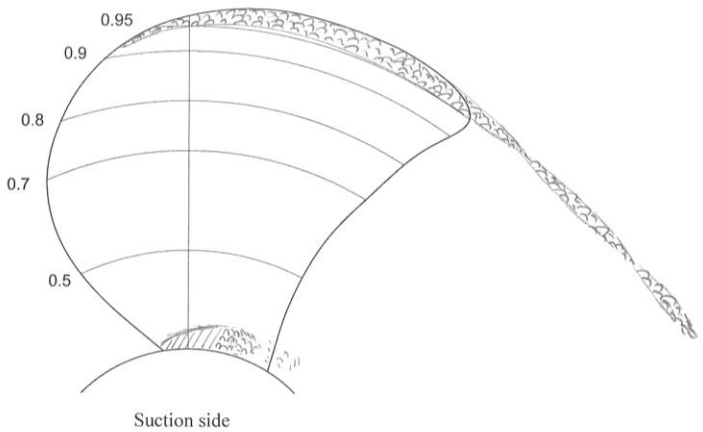




Vapour volume fraction 50%

Cavitation prognosis

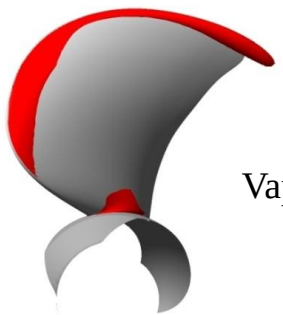
UniTriest-CFX(Kunz)



UniTS-CFX-Kunz KT = 0.375

Vapour volume fraction 20%

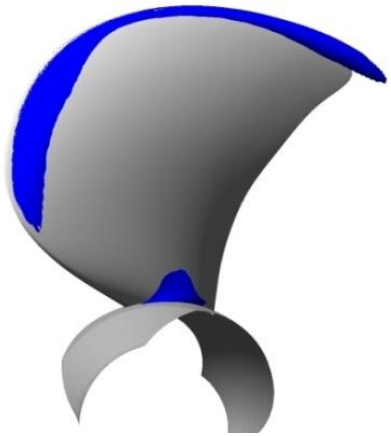
UniTS-CFX-Kunz KT = 0.375



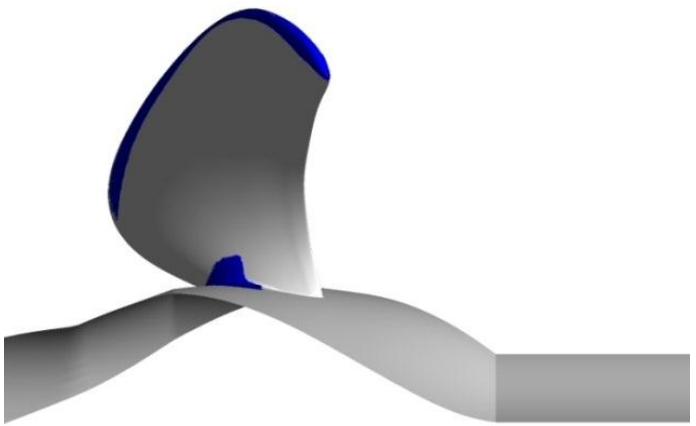
Vapour volume fraction 50%

Test Case 2.3.1

UniTS-CFX-Kunz KT = 0.375



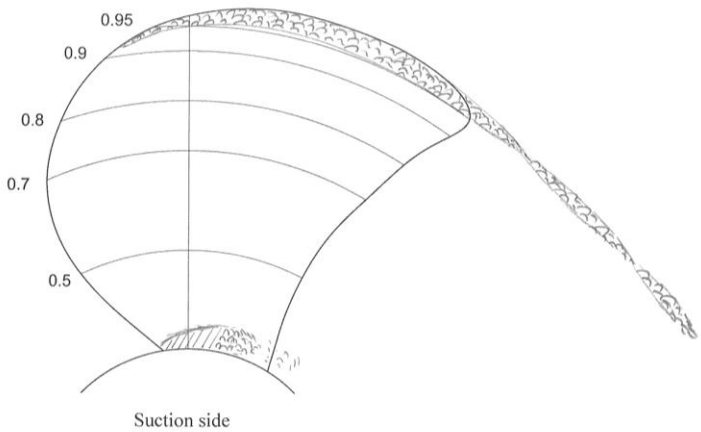
UniTS-CFX-Kunz KT = 0.375

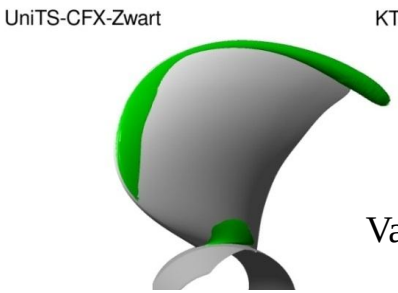


Vapour volume fraction 80%

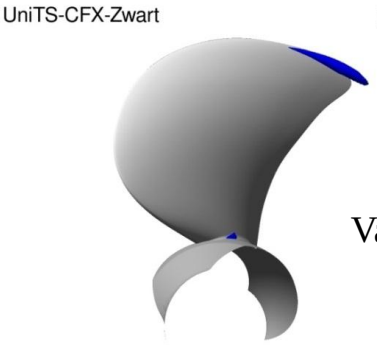
Cavitation prognosis

UniTriest-CFX(Zwart)



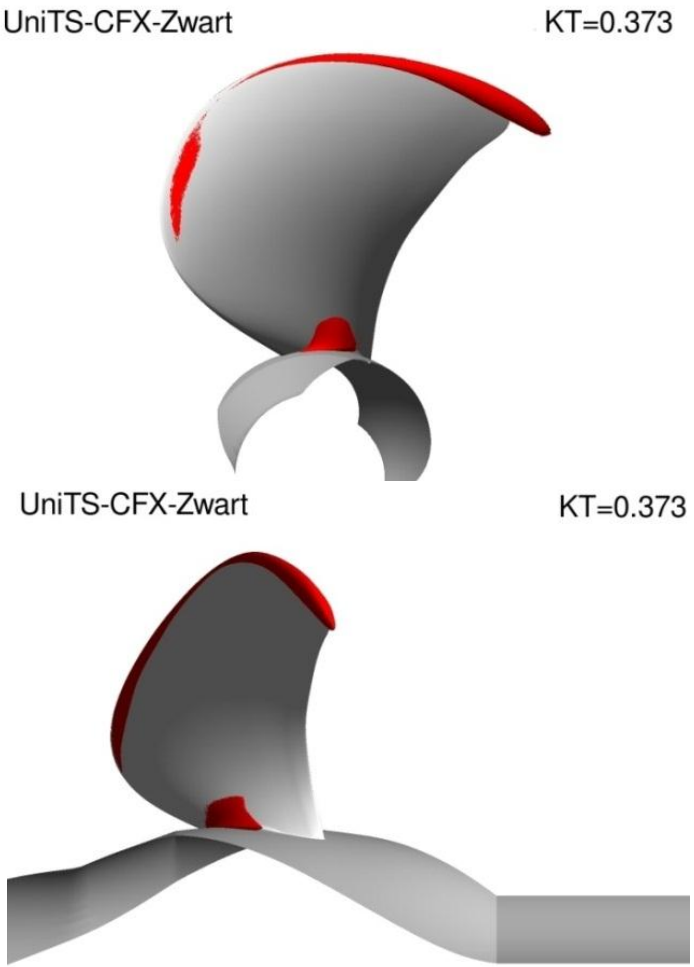


Vapour volume fraction 20%



Vapour volume fraction 80%

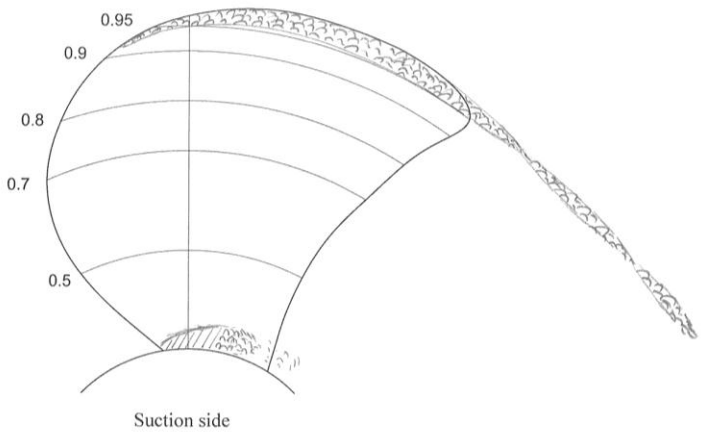
Test Case 2.3.1

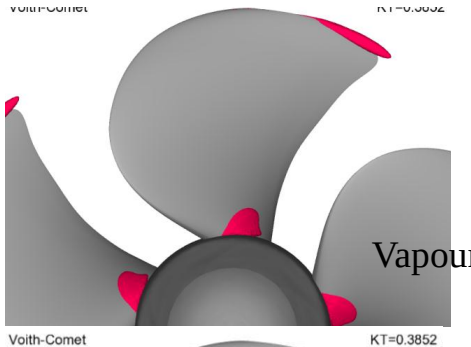


Vapour volume fraction 50%

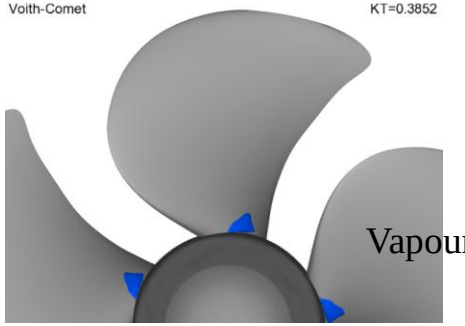
Cavitation prognosis

VOITH-Comet



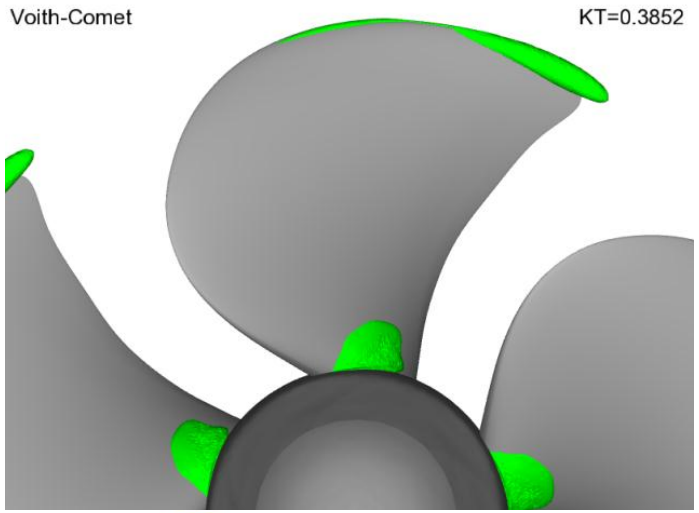


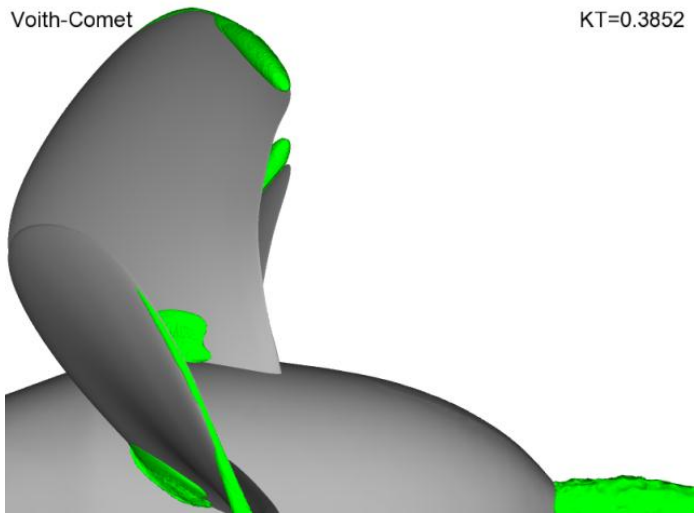
Vapour volume fraction 50%



Vapour volume fraction 80%

Test Case 2.3.1

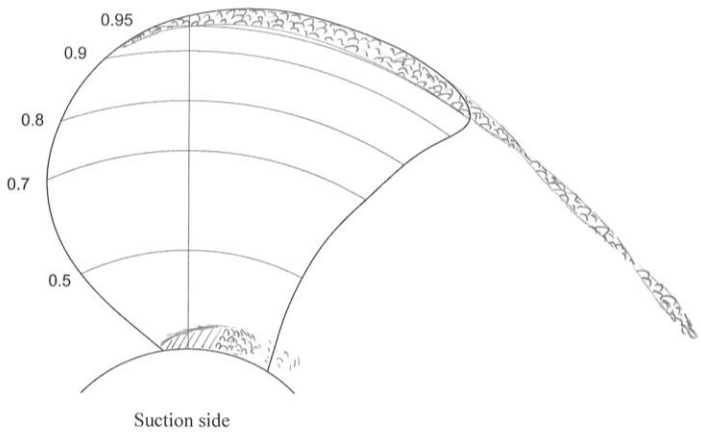


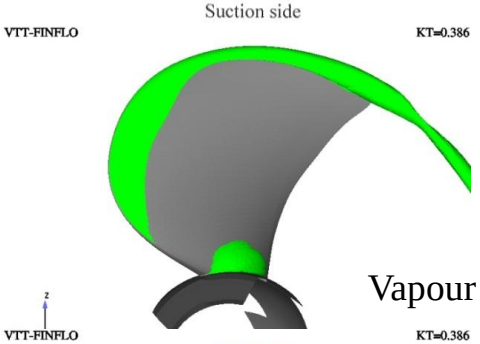


Vapour volume fraction 20%

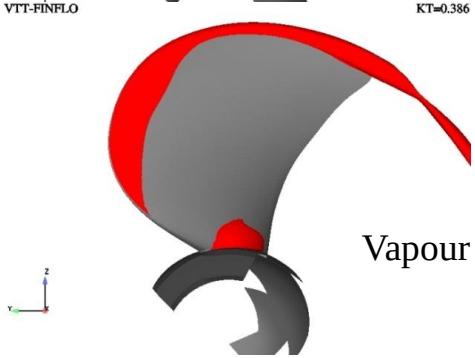
Cavitation prognosis

VTT-FinFlo



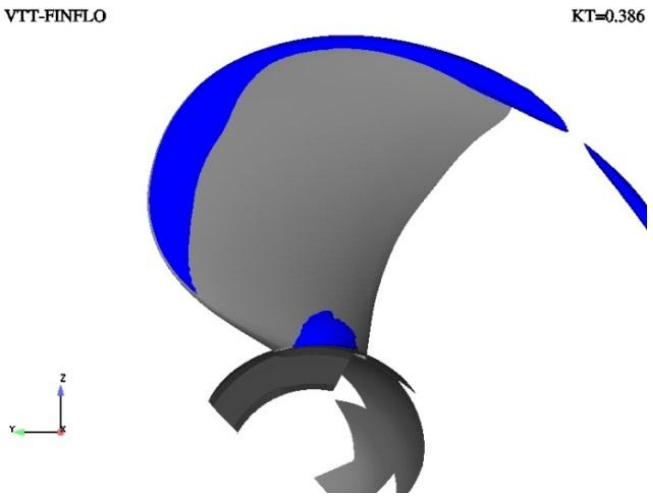


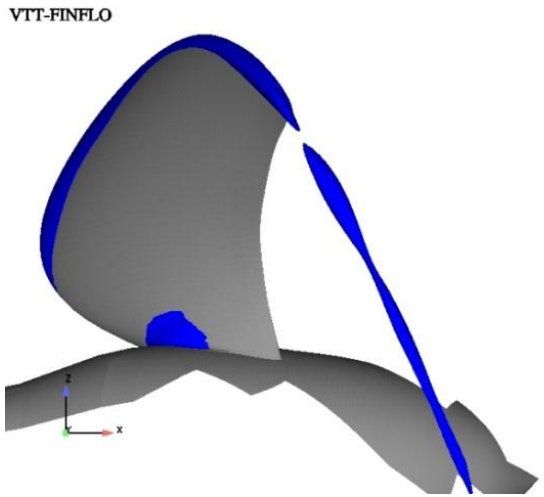
Vapour volume fraction 20%



Vapour volume fraction 50%

Test Case 2.3.1





Vapour volume fraction 80%

Cavitation prognosis

Summary - Test Case 2.3.1

J = 1.0193, K_T = 0.3735, $10K_Q$ = 0.9698, σ_n = 2.024

Cavitation test

Inception of thrust break down (K_T = 0.387 (non-cavitating) → K_T = 0.3735 (σ_n = 2.024)).

Tip vortex and suction side cavitation appear in the radius range $r/R > 0.90$. Near the hub root cavitation appears on the suction side. Hub vortex cavitation is strongly developed.

Calculation

There is in general an **over determination of the risk of suction side sheet cavitation**.

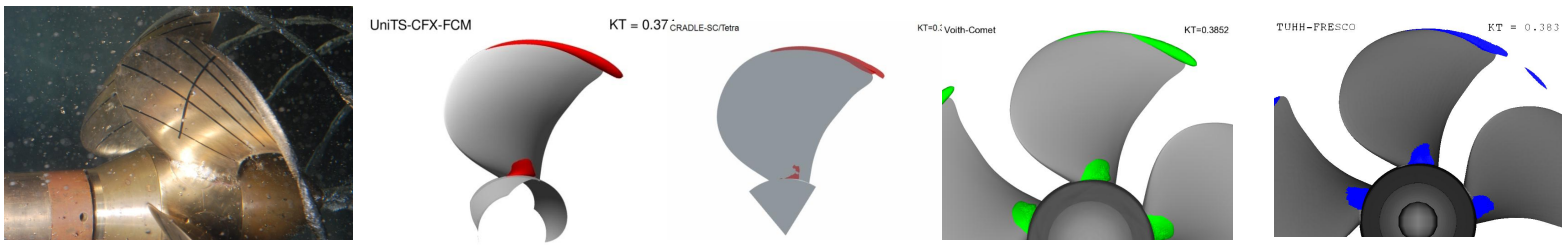
In general the calculations with VOF 20% over determine the suction side sheet cavitation, especially on the leading edge.

The best agreement between the calculated and observed cavitation is found for a volume fraction of VOF 50%.

Cavitation prognosis

Summary - Test Case 2.3.1

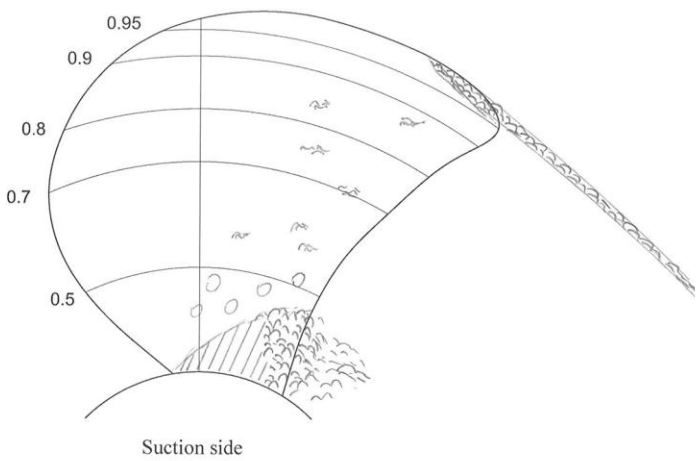
$J = 1.0193$, $K_T = 0.3735$, $10K_Q = 0.9698$, $\sigma_n = 2.024$



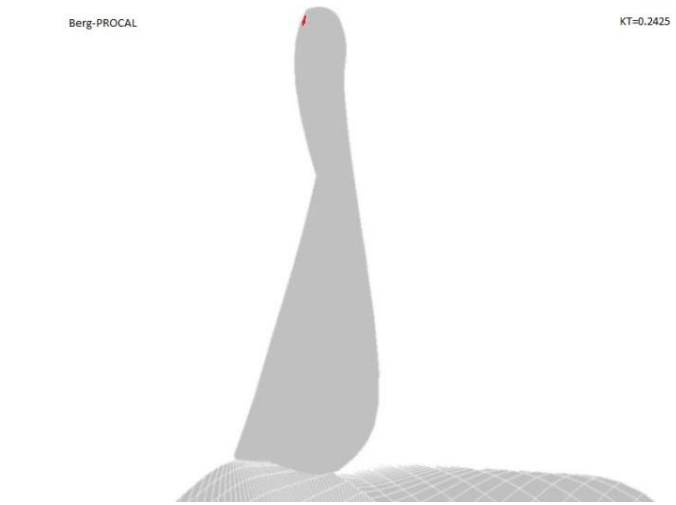
Calc.	1	2	3	4	5	6	7	8	9	10	11	12
TVC												
SSC r/R>0.90												
SSC r/R<0.90		20	20			20-50		20	20-50			
RC												

Cavitation prognosis

Berg-Procal



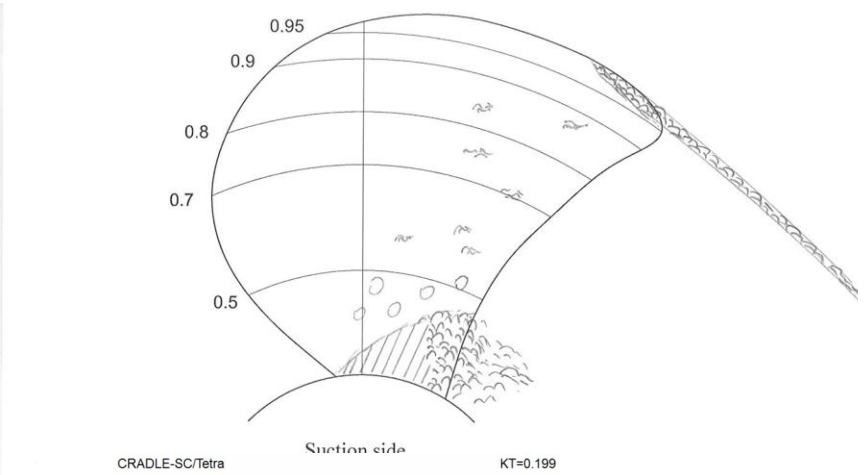
Test Case 2.3.2

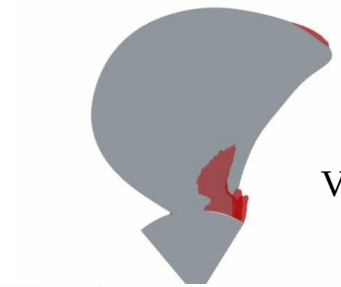


Vapour volume fraction 50%

Cavitation prognosis

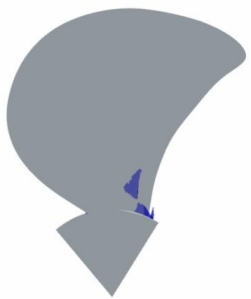
Cradle-SC/Tetra





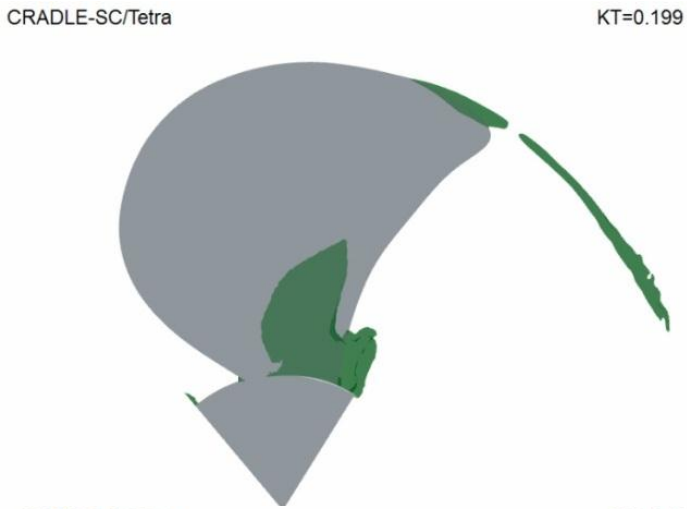
Vapour volume fraction 50%

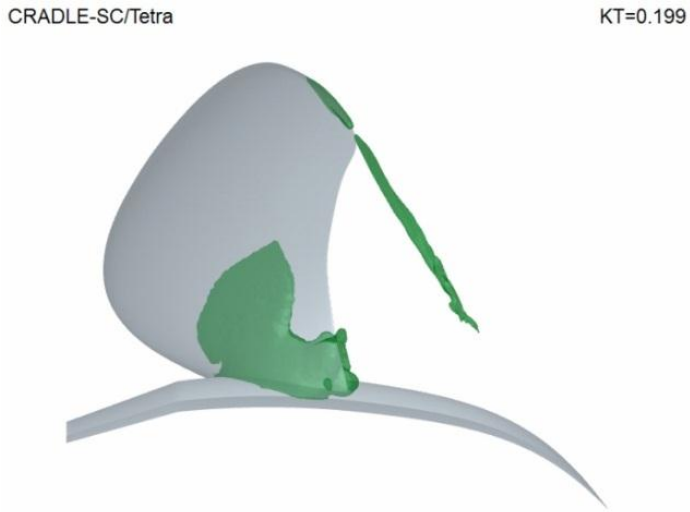
CRADLE-SC/Tetra KT=0.199



Vapour volume fraction 80%

Test Case 2.3.2

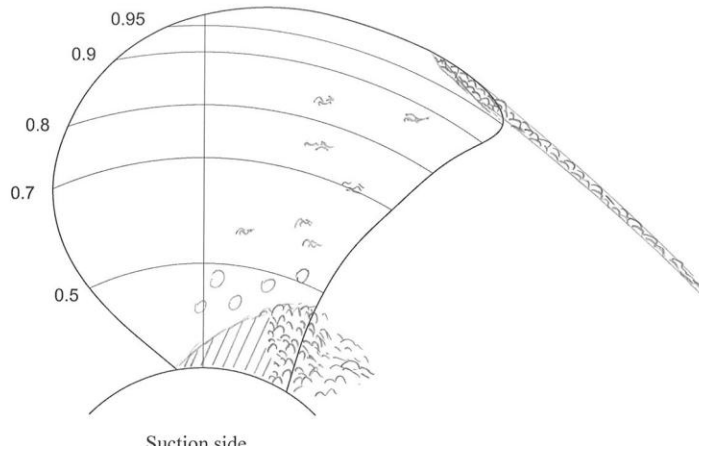


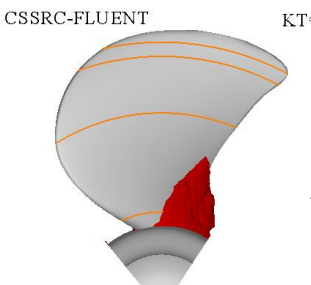


Vapour volume fraction 20%

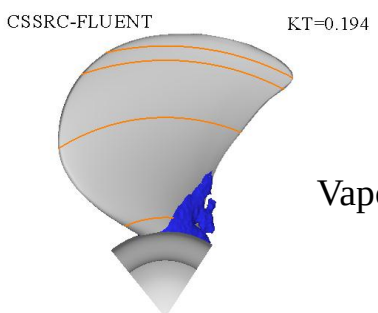
Cavitation prognosis

CSSRC-Fluent



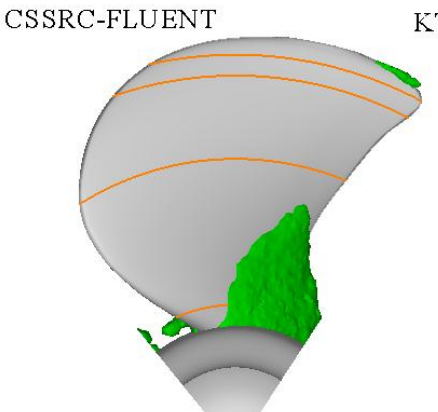


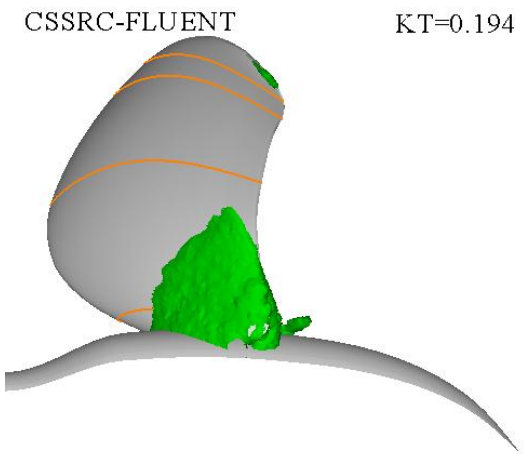
Vapour volume fraction 50%



Vapour volume fraction 80%

Test Case 2.3.2

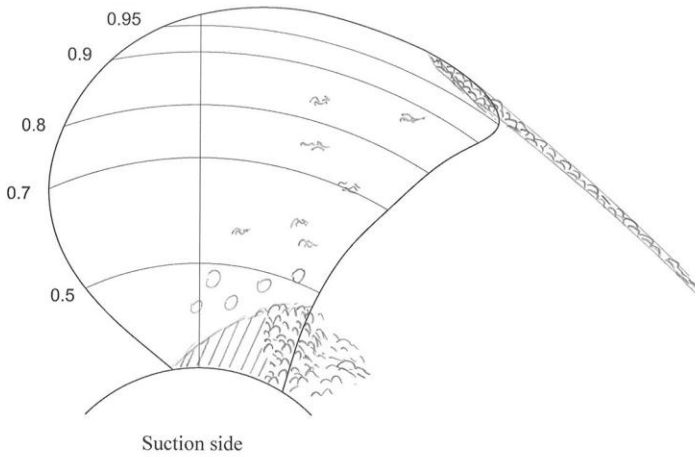




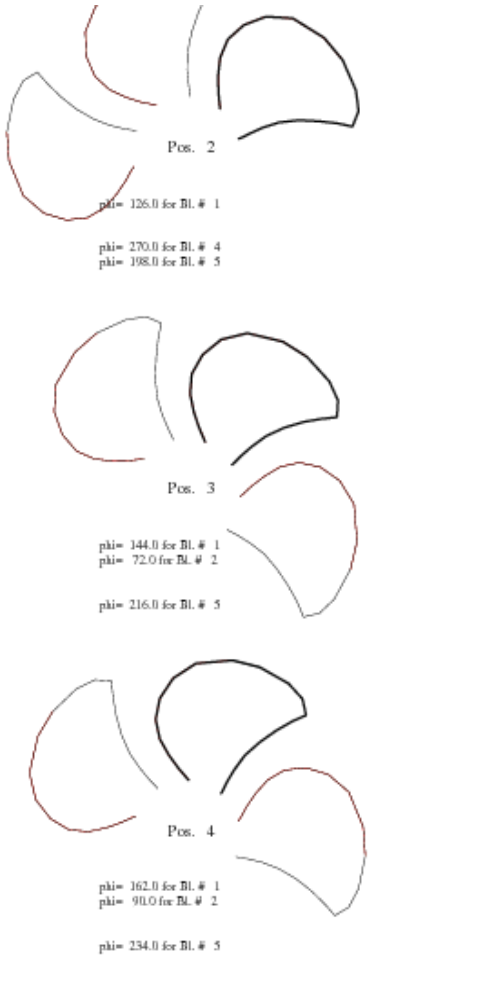
Vapour volume fraction 20%

Cavitation prognosis

HSVA-QCM

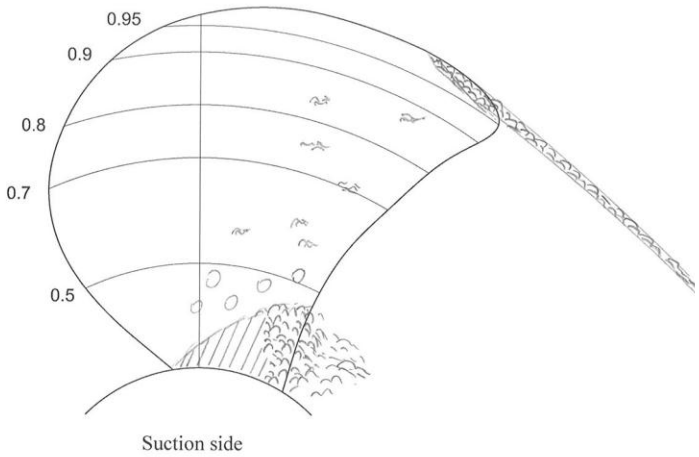


Test Case 2.3.2

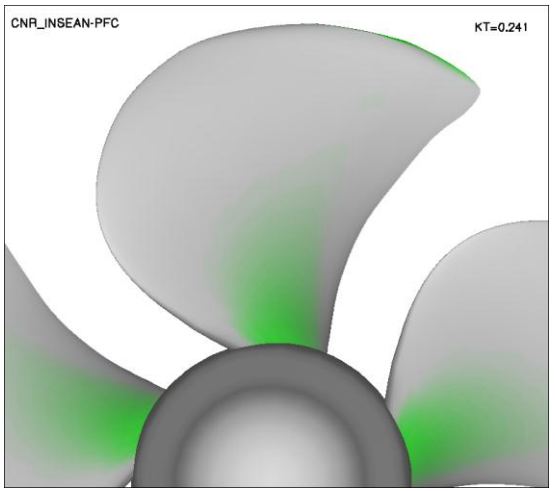


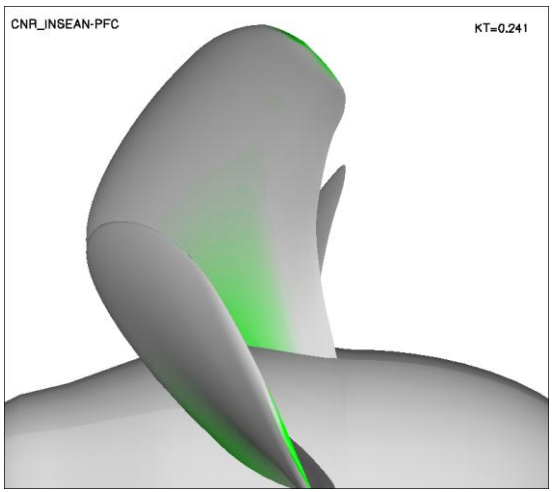
Cavitation prognosis

INSEAN-PFC



Test Case 2.3.2

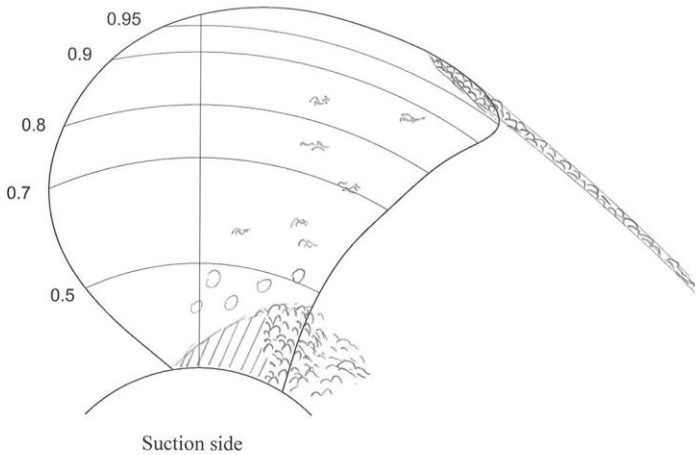


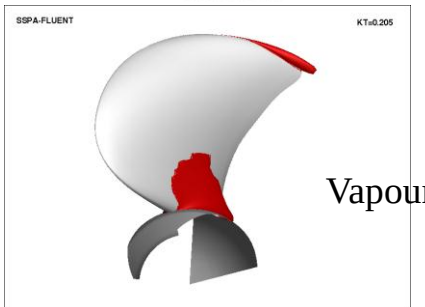


Blade surface region $p \leq p_V$

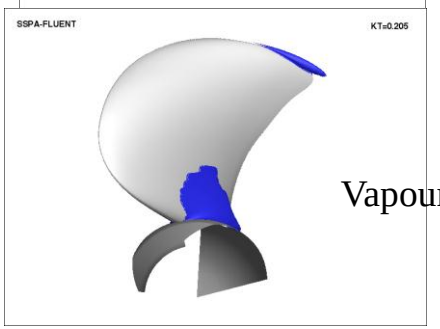
Cavitation prognosis

SSPA-Fluent



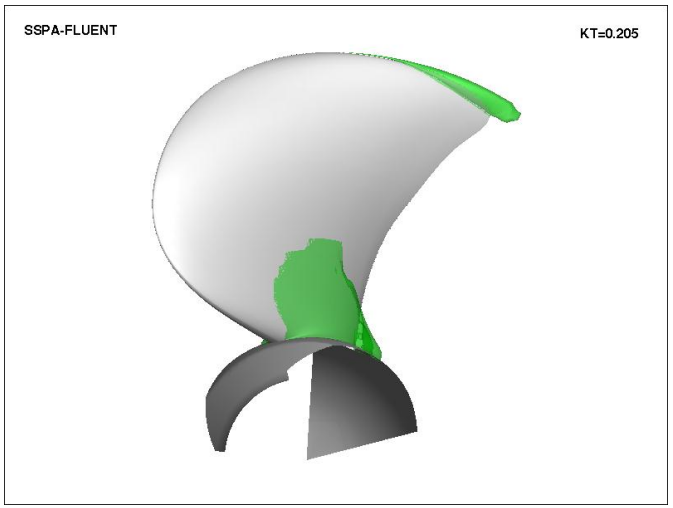


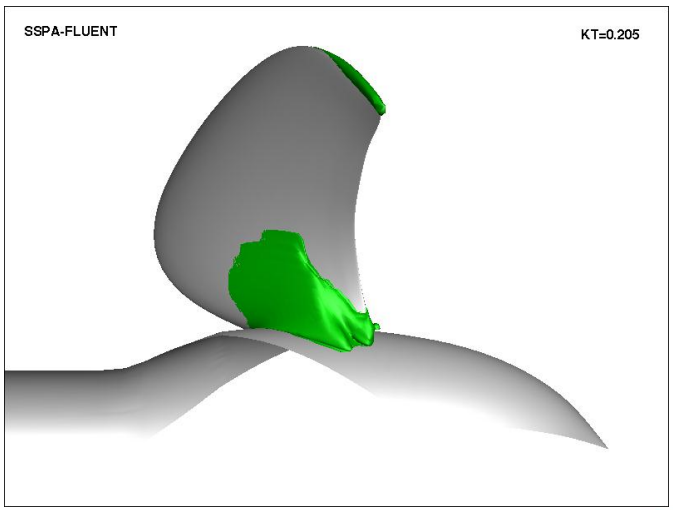
Vapour volume fraction 50%



Vapour volume fraction 80%

Test Case 2.3.2

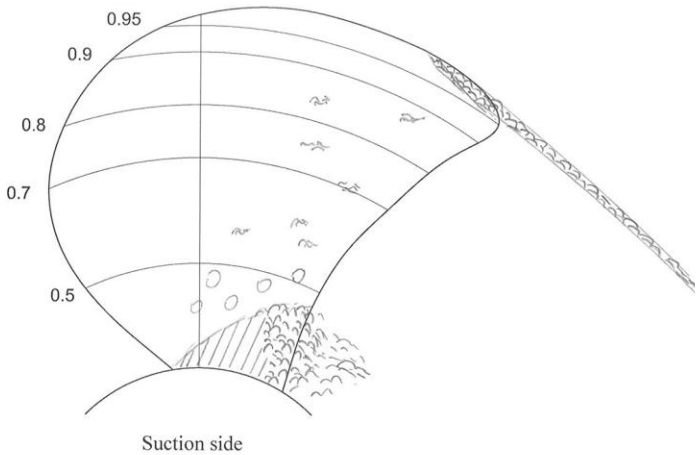




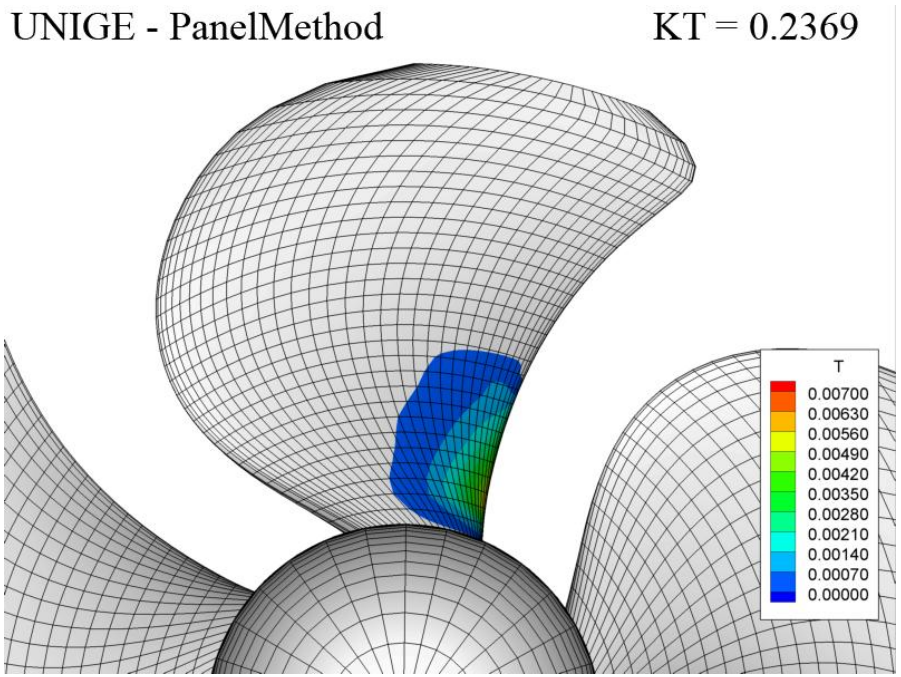
Vapour volume fraction 20%

Cavitation prognosis

UniGenua-Panel

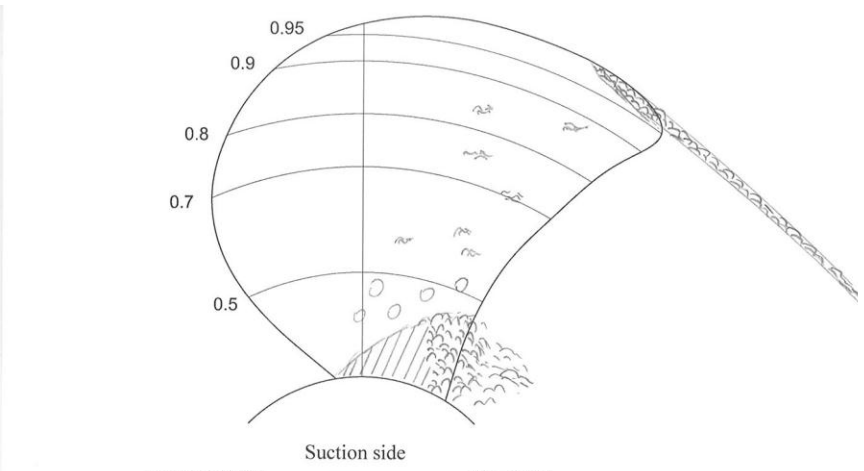


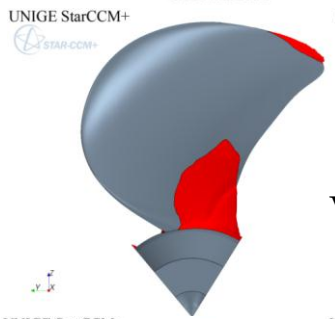
Test Case 2.3.2



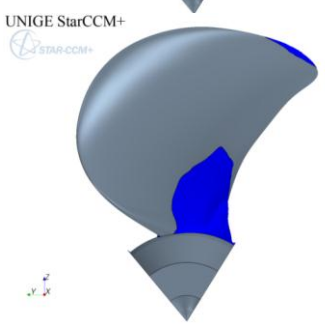
Cavitation prognosis

UniGenua-StarCCM+



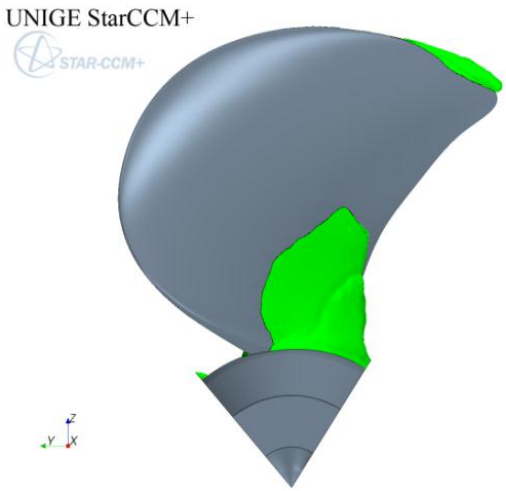


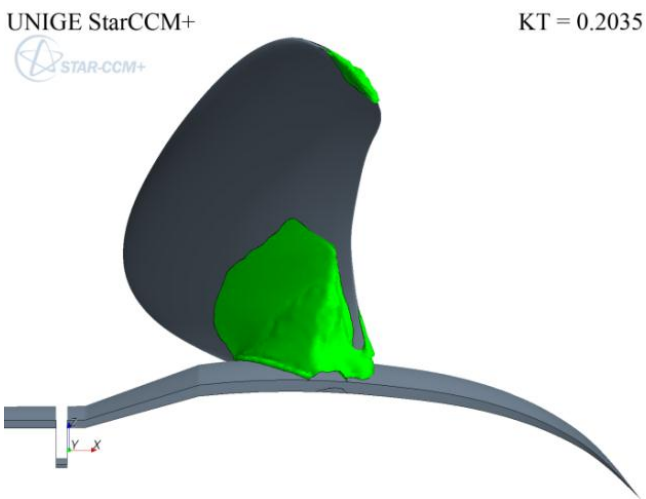
Vapour volume fraction 50%



Vapour volume fraction 80%

Test Case 2.3.2

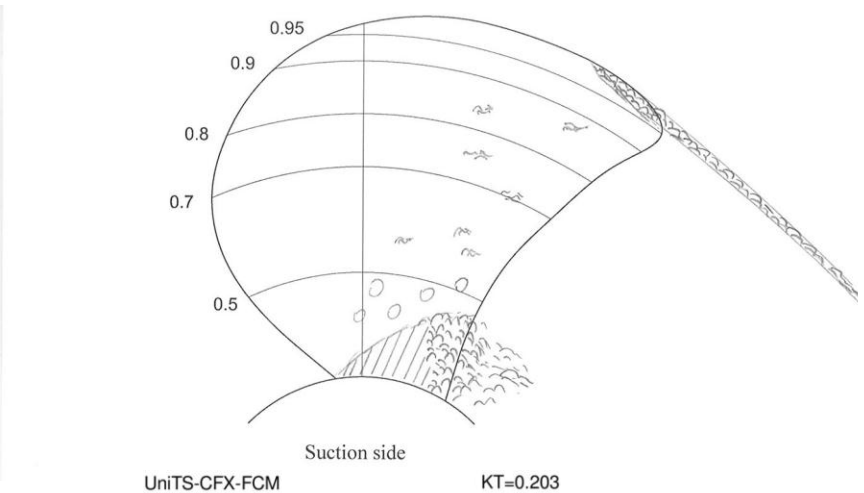


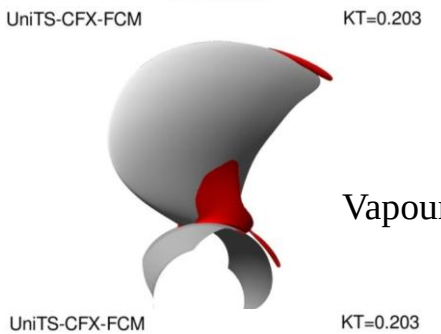


Vapour volume fraction 20%

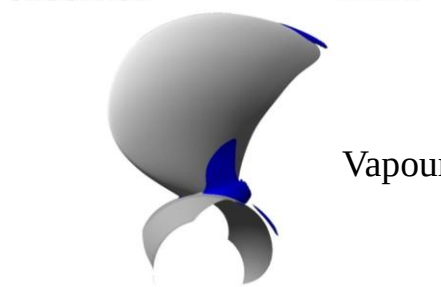
Cavitation prognosis

UniTriest-CFX(FCM)



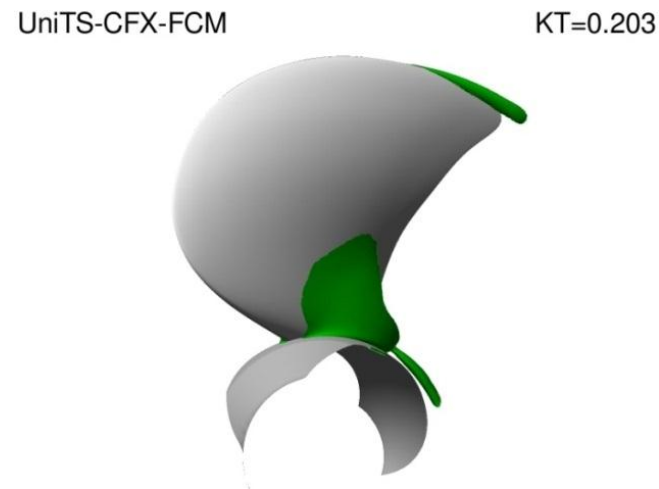


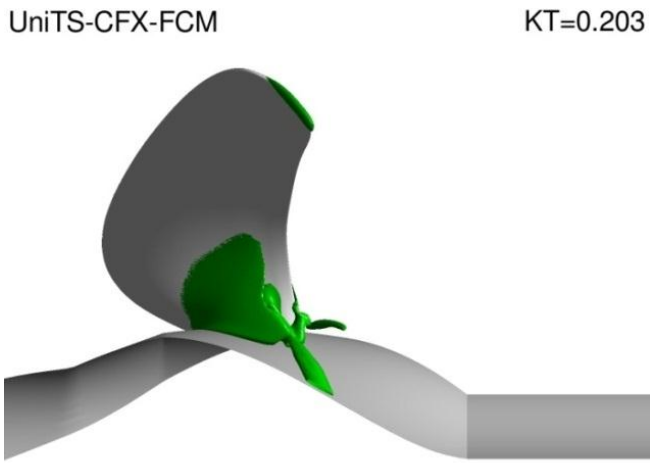
Vapour volume fraction 50%



Vapour volume fraction 80%

Test Case 2.3.2

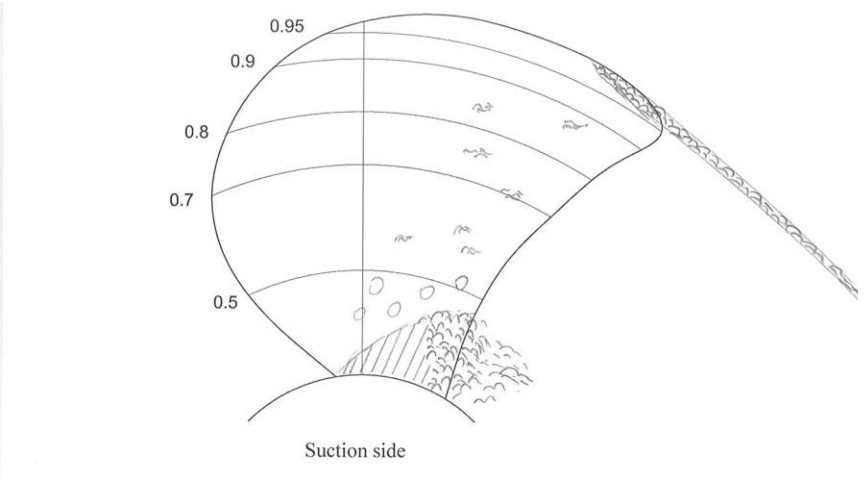


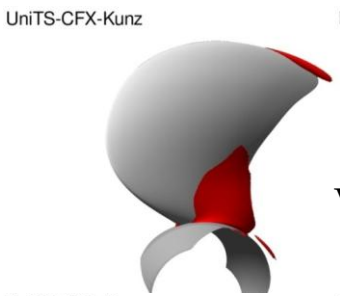


Vapour volume fraction 20%

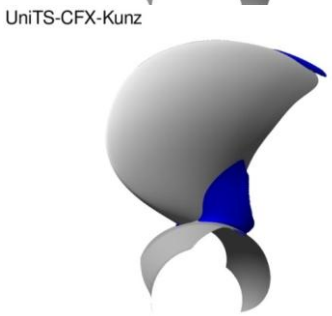
Cavitation prognosis

UniTriest-CFX(Kunz)



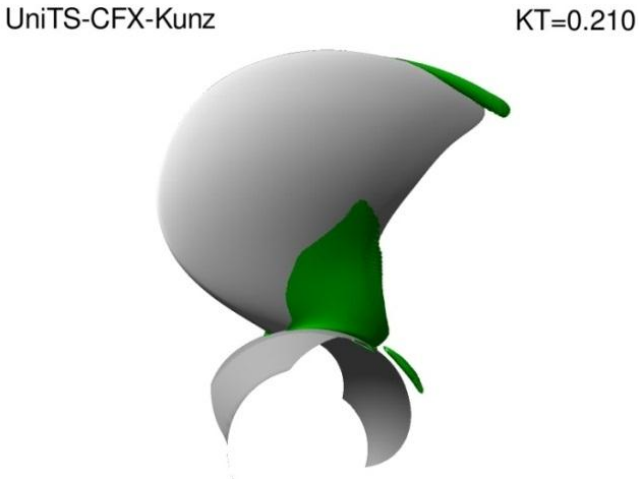


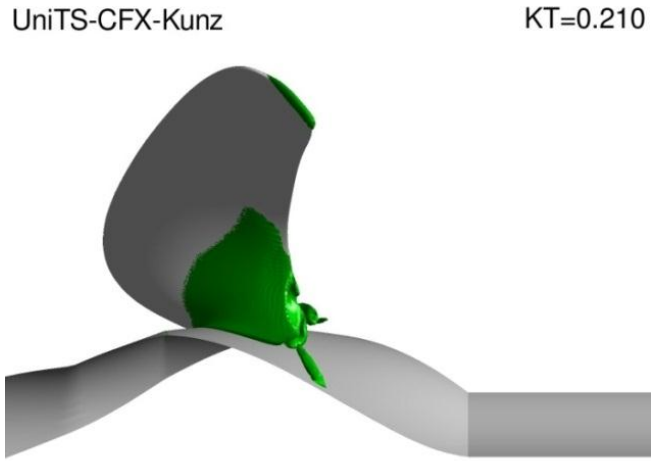
Vapour volume fraction 50%



Vapour volume fraction 80%

Test Case 2.3.2

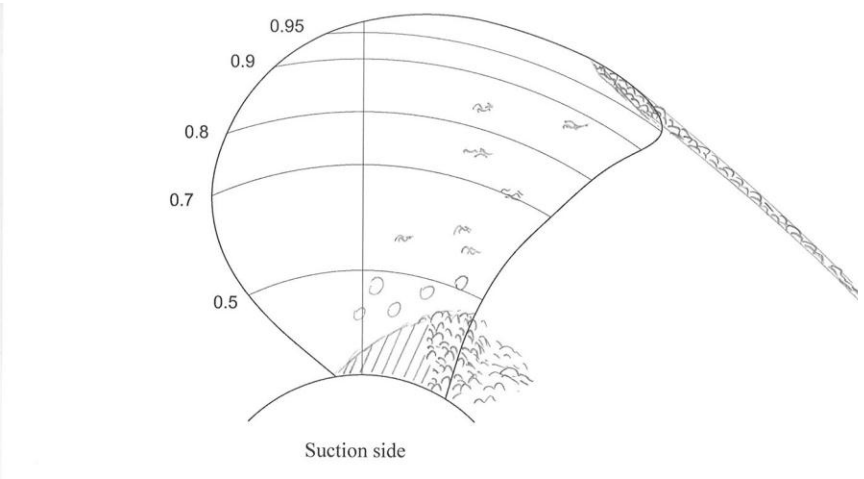


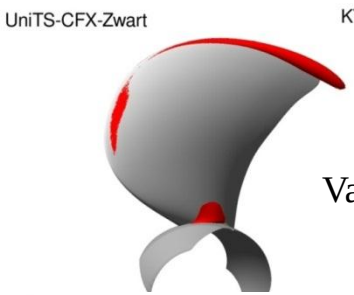


Vapour volume fraction 20%

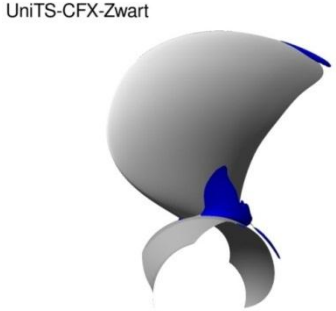
Cavitation prognosis

UniTriest-CFX(Zwart)



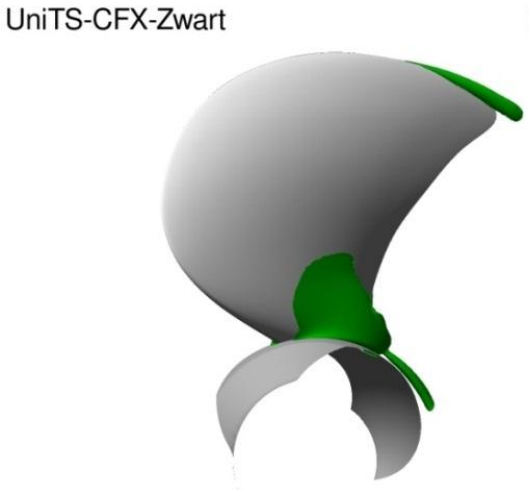


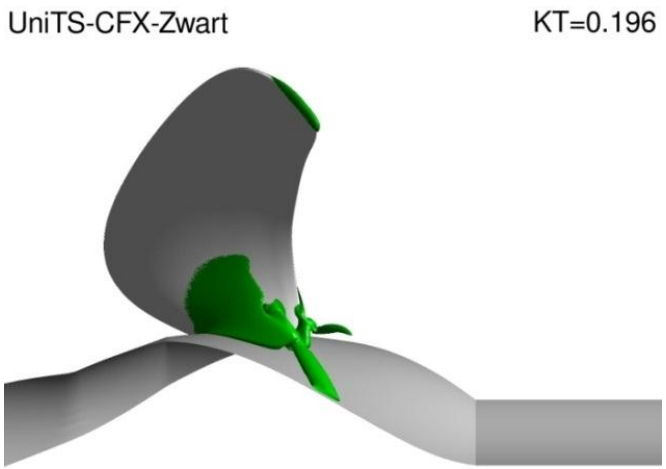
Vapour volume fraction 50%



Vapour volume fraction 80%

Test Case 2.3.2

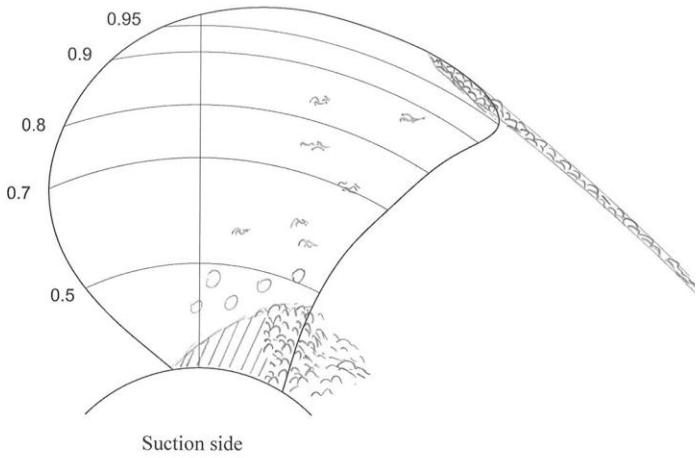


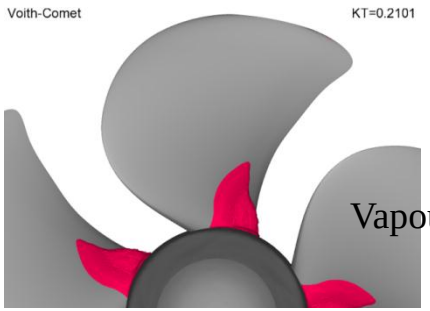


Vapour volume fraction 20%

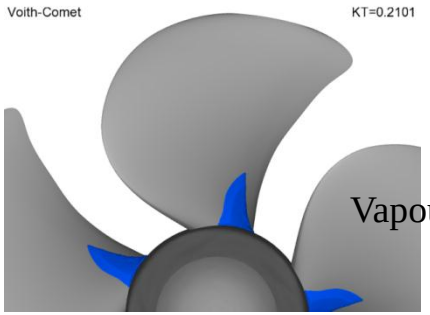
Cavitation prognosis

VOITH-Comet



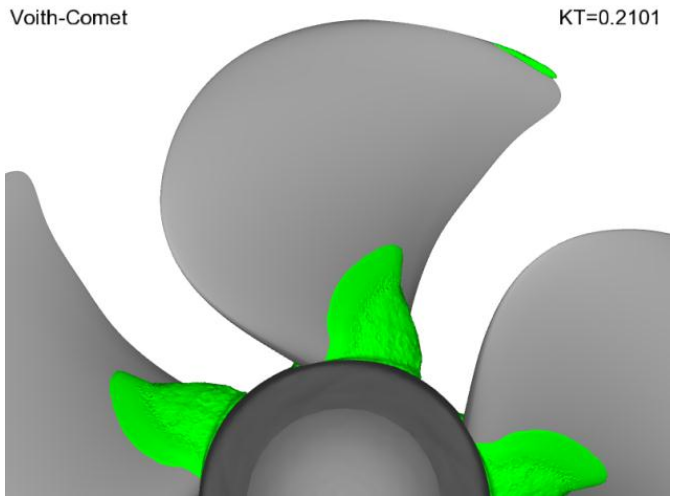


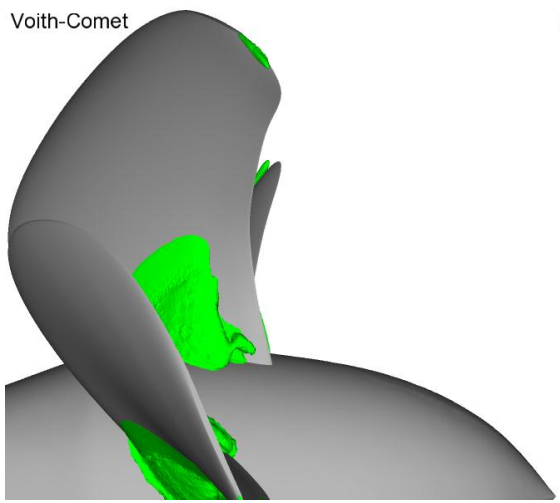
Vapour volume fraction 50%



Vapour volume fraction 80%

Test Case 2.3.2

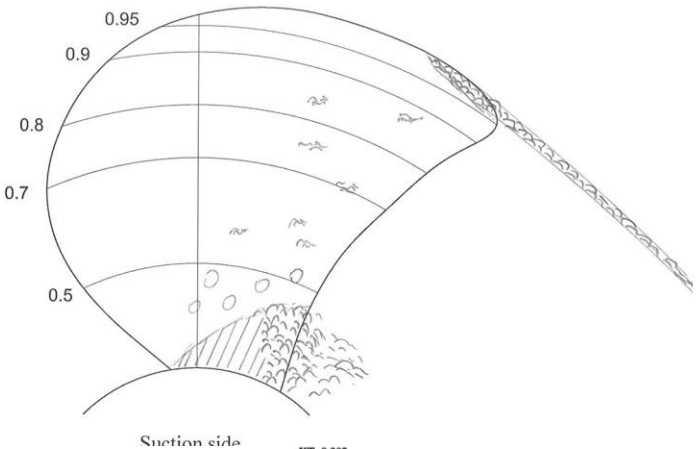


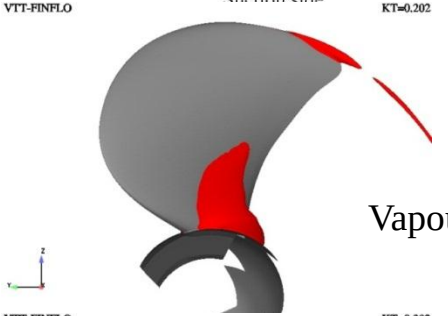


Vapour volume fraction 20%

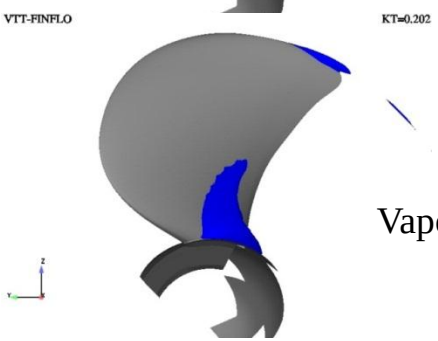
Cavitation prognosis

VTT-FinFlo



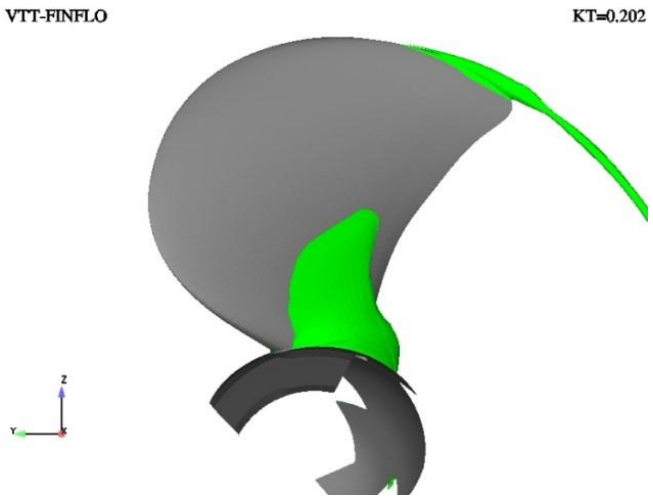


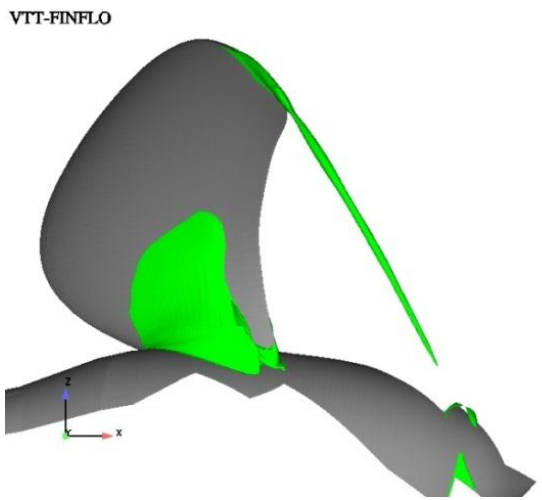
Vapour volume fraction 50%



Vapour volume fraction 80%

Test Case 2.3.2





Vapour volume fraction 20%

Cavitation prognosis

Summary - Test Case 2.3.2
$J = 1.2686$, $K_T = 0.2064$, $10K_Q = 0.6312$, $\sigma_n = 1.424$

Cavitation test

Strong thrust break down ($K_T = 0.245$ (non-cavitating) → $K_T = 0.2064$ ($\sigma_n = 1.424$)).

Tip vortex cavitation appears on the blade tip.. Strong developed root cavitation appears on the suction side in the radial range from the hub to the radius $r/R < 0.45$.
Intermittent foam cavitation appears on the suction side.

Calculation

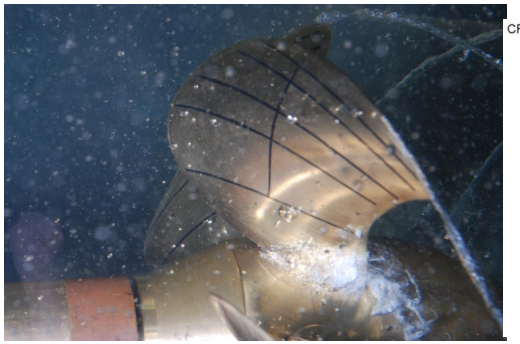
The calculations show in general a good prediction of the regions with cavitation danger.
The influence of VOF on the cavitation prediction is small.

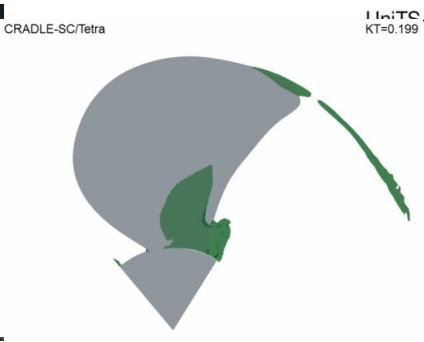
The best agreement between the calculated and observed cavitation is obtained for a volume fraction of VOF 20%.

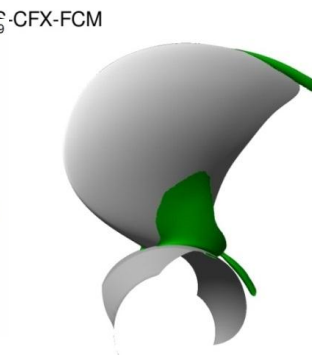
Cavitation prognosis

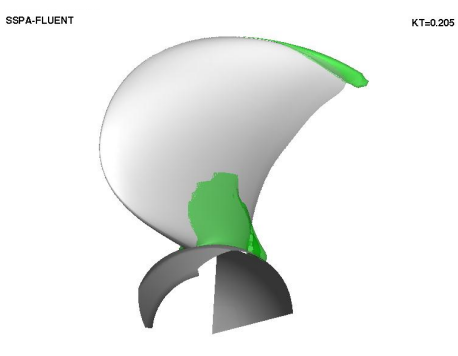
Summary - Test Case 2.3.2

$J = 1.2686$, $K_T = 0.2064$, $10K_Q = 0.6312$, $\sigma_n = 1.424$





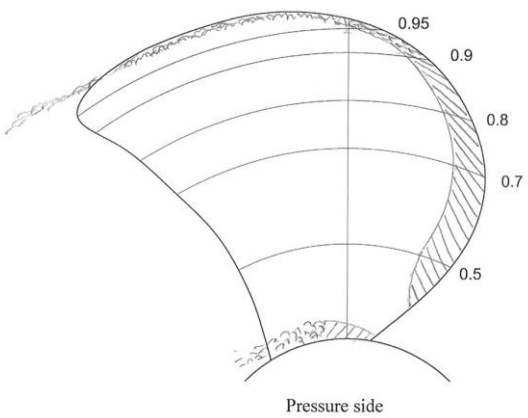


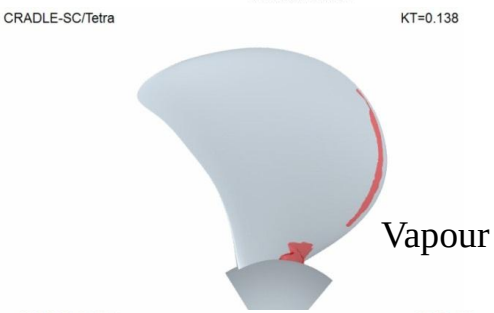


Calc.	1	2	3	4	5	6	7	8	9	10	11	12
TVC		20	20								20	
RC												
Foam cavitation												

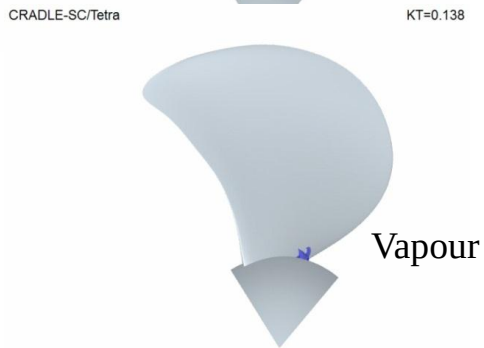
Cavitation prognosis

Cradle-SC/Tetra



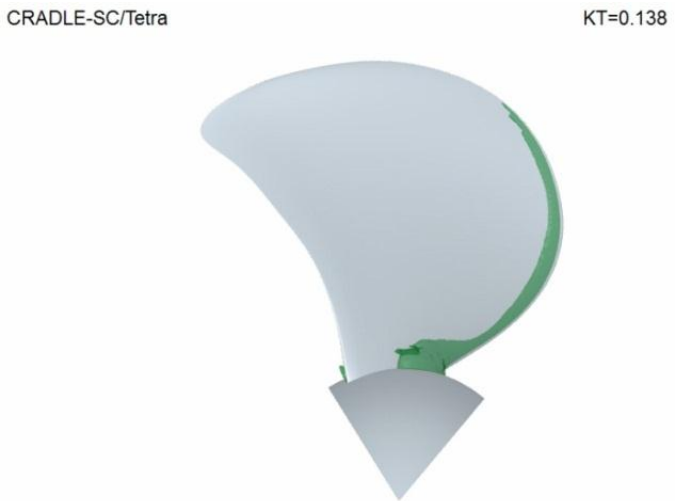


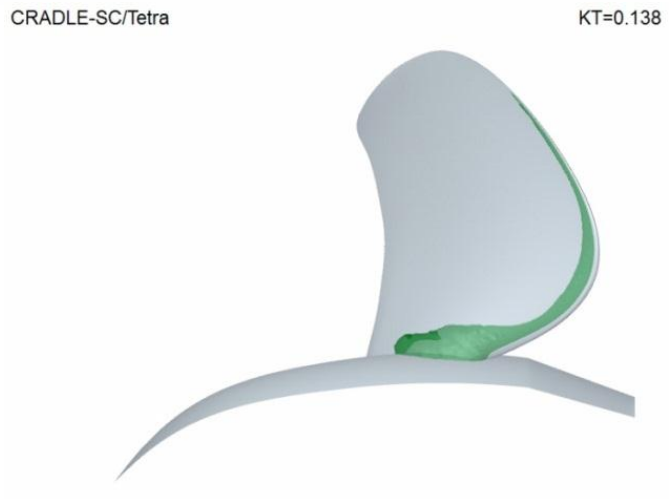
Vapour volume fraction 50%



Vapour volume fraction 80%

Test Case 2.3.3

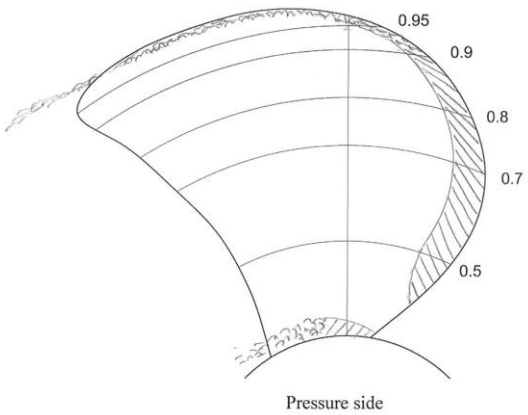


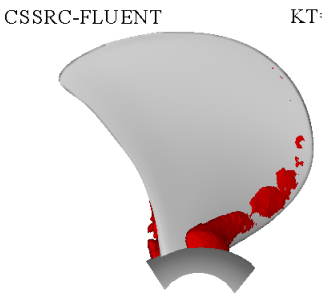


Vapour volume fraction 20%

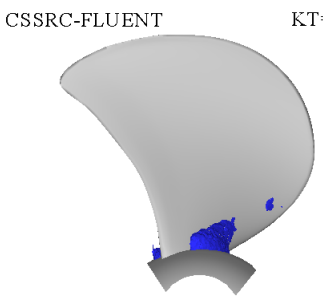
Cavitation prognosis

CSSRC-Fluent



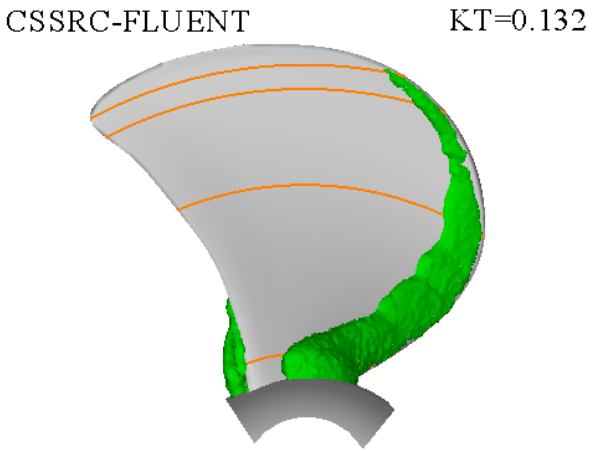


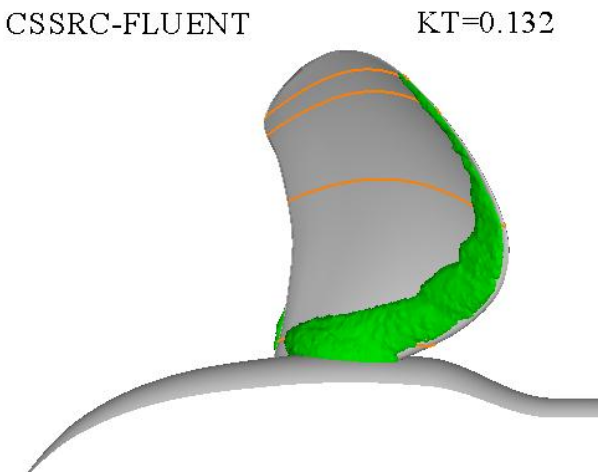
Vapour volume fraction 50%



Vapour volume fraction 80%

Test Case 2.3.3

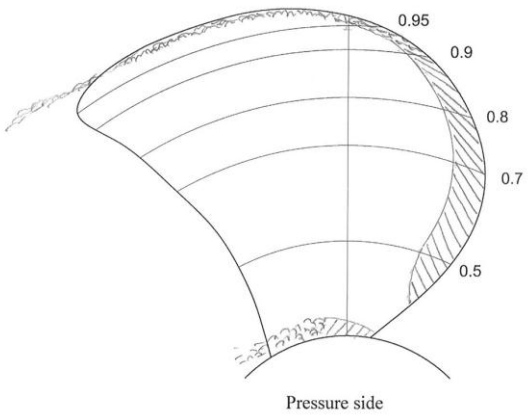




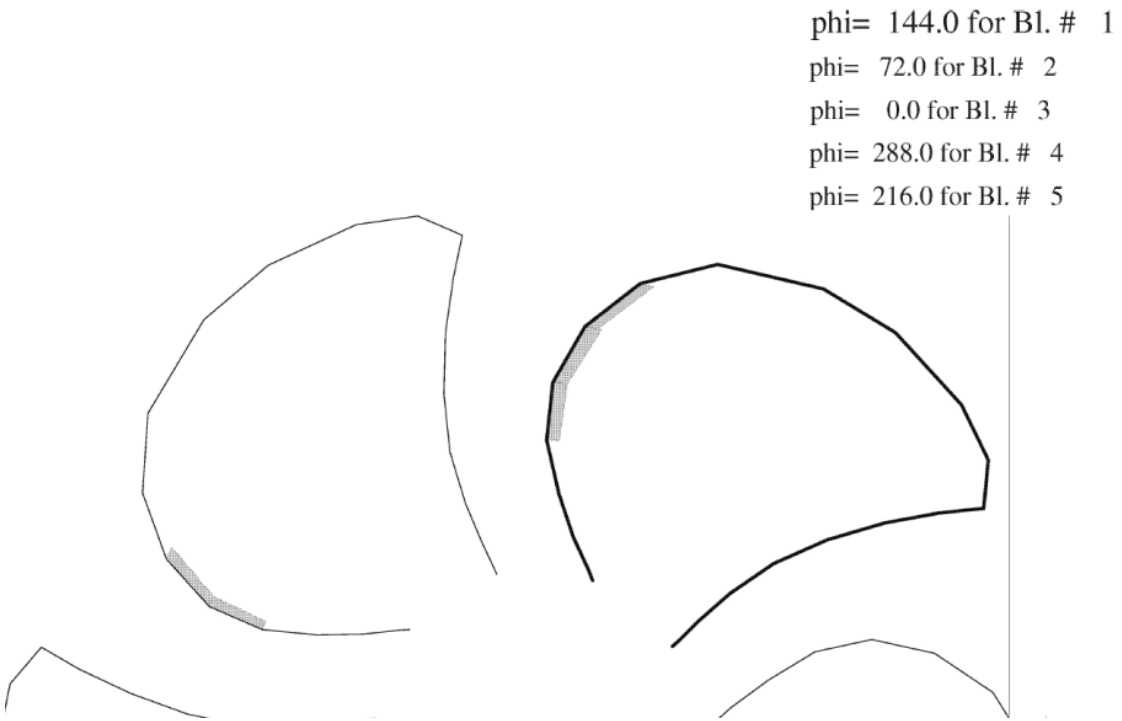
Vapour volume fraction 20%

Cavitation prognosis

HSVA-QCM/PPB

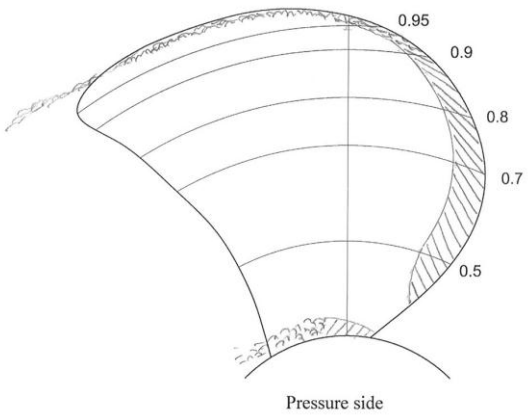


Test Case 2.3.3

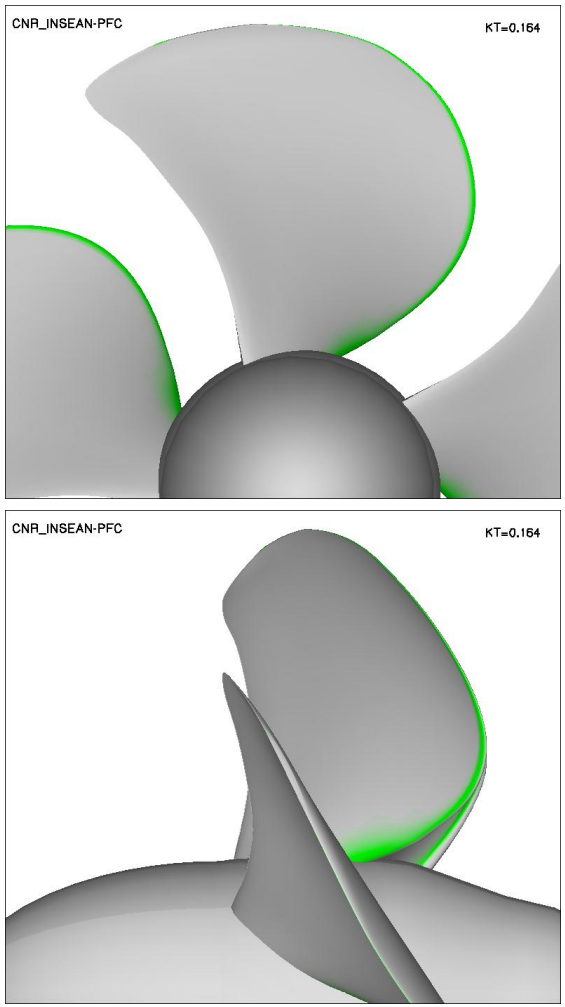


Cavitation prognosis

INSEAN-PFC



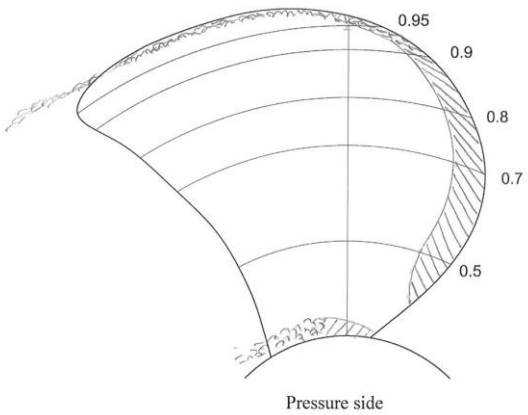
Test Case 2.3.3

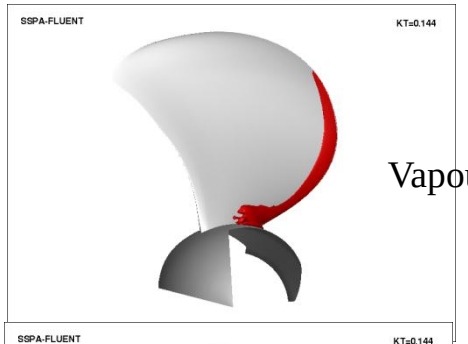


Blade surface region $p \leq p_V$

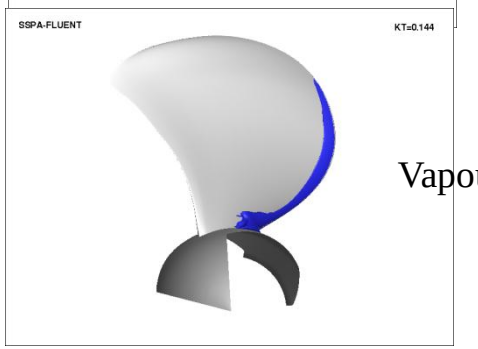
Cavitation prognosis

SSPA-Fluent



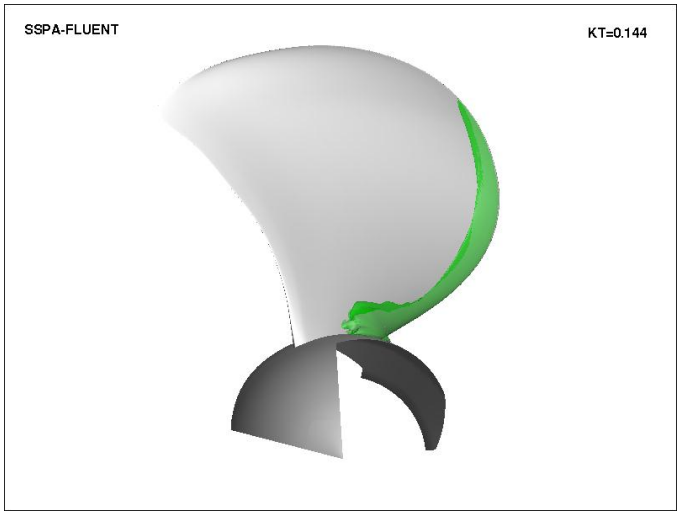


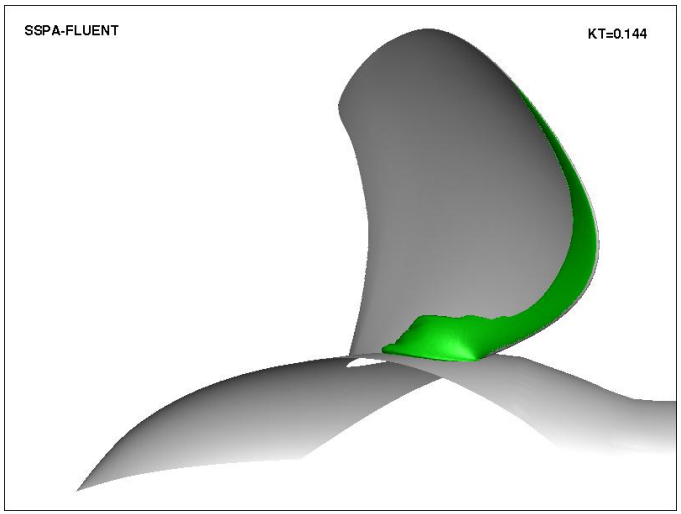
Vapour volume fraction 50%



Vapour volume fraction 80%

Test Case 2.3.3

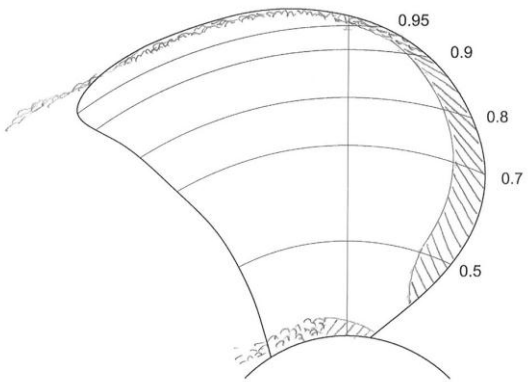


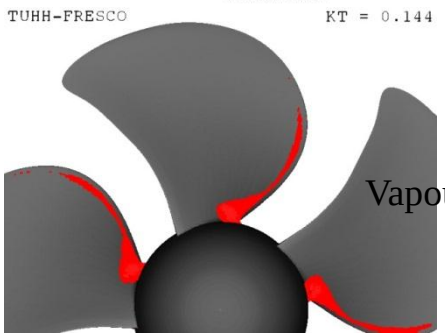


Vapour volume fraction 20%

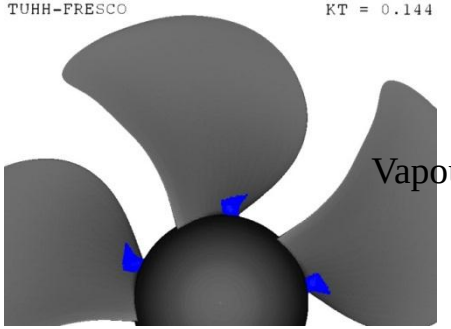
Cavitation prognosis

TUHH-FreSCO+



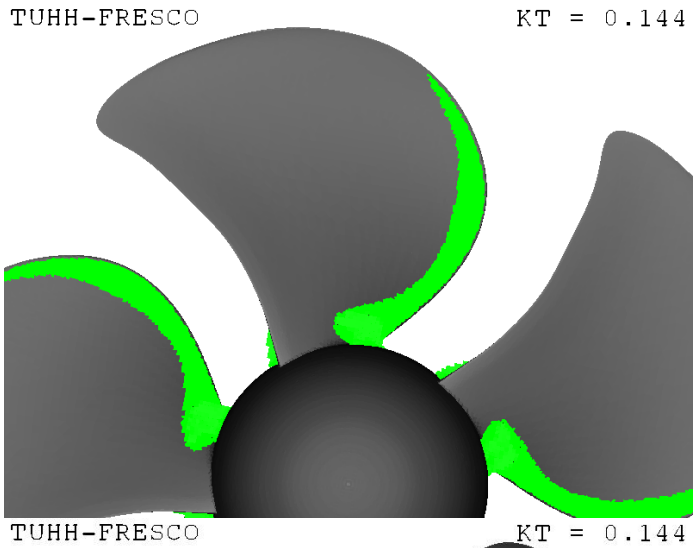


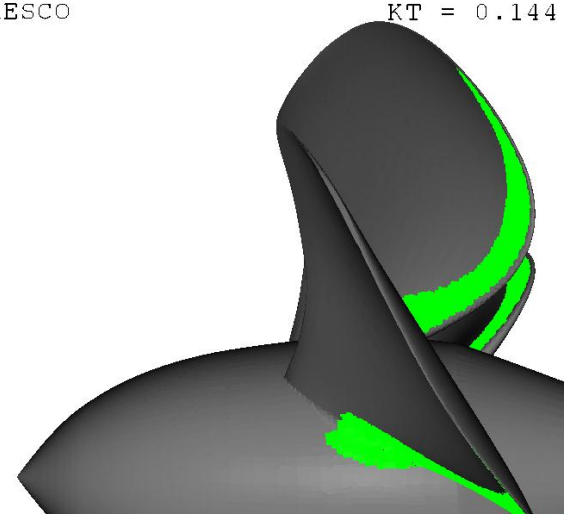
Vapour volume fraction 50%



Vapour volume fraction 80%

Test Case 2.3.3

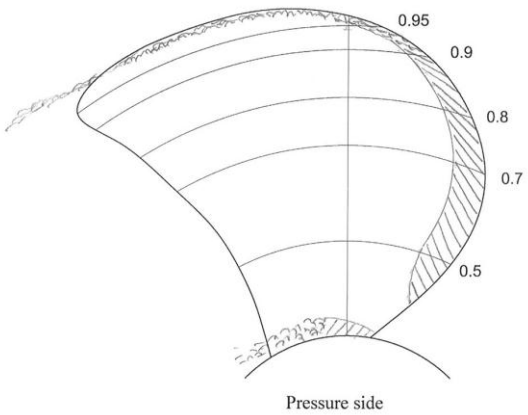




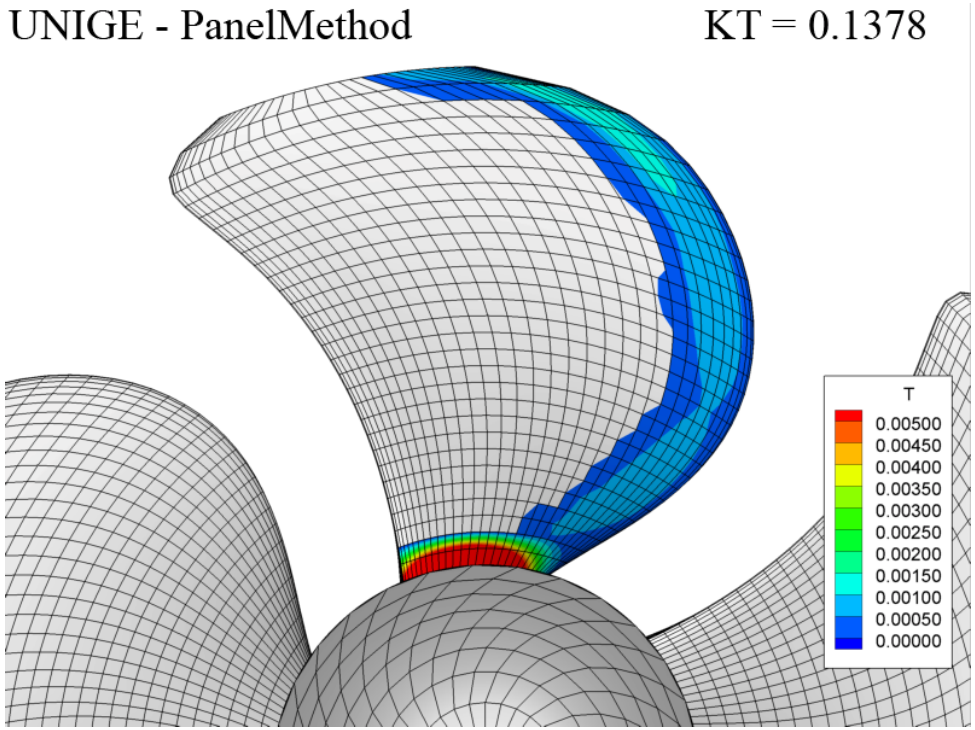
Vapour volume fraction 20%

Cavitation prognosis

UniGenua-Panel

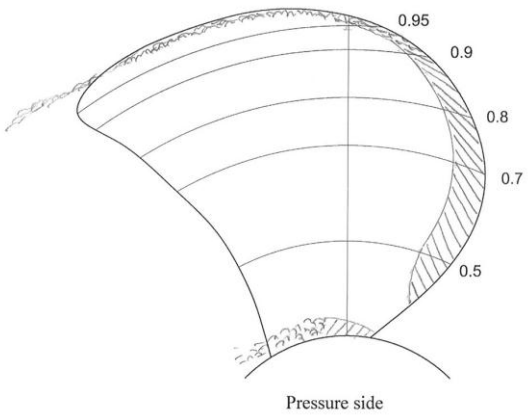


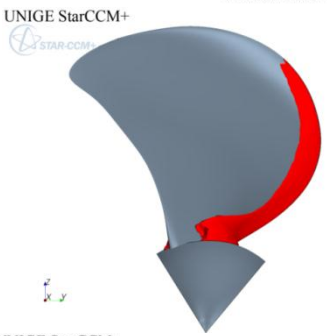
Test Case 2.3.3



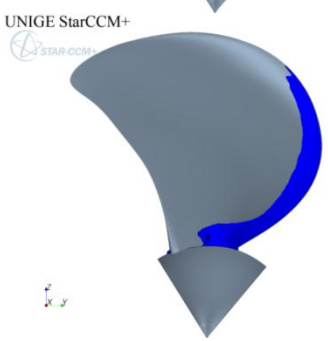
Cavitation prognosis

UniGenua-StarCCM+



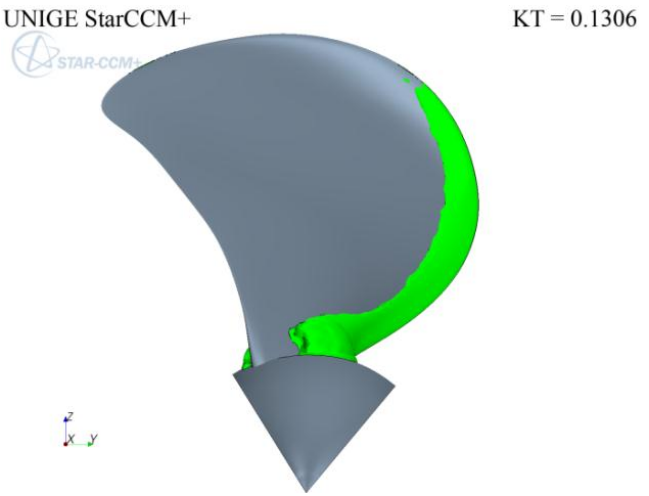


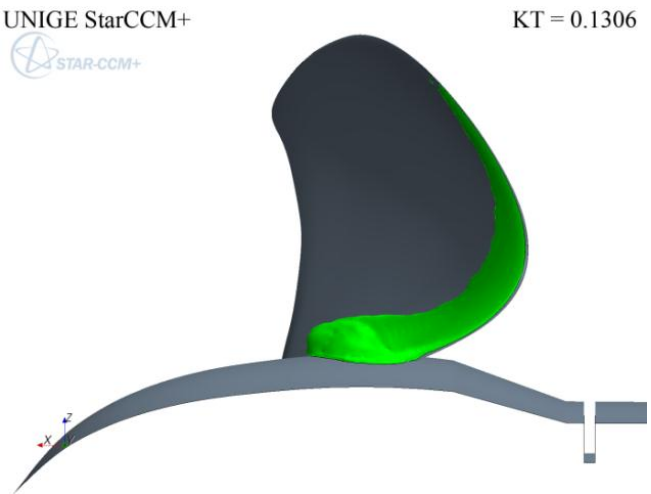
Vapour volume fraction 50%



Vapour volume fraction 80%

Test Case 2.3.3

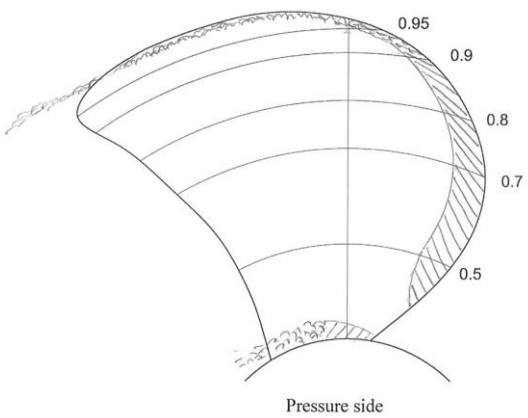




Vapour volume fraction 20%

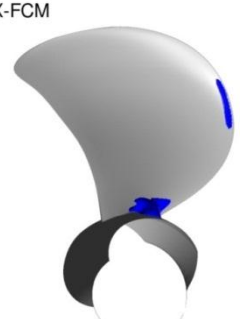
Cavitation prognosis

UniTriest-CFX(FCM)



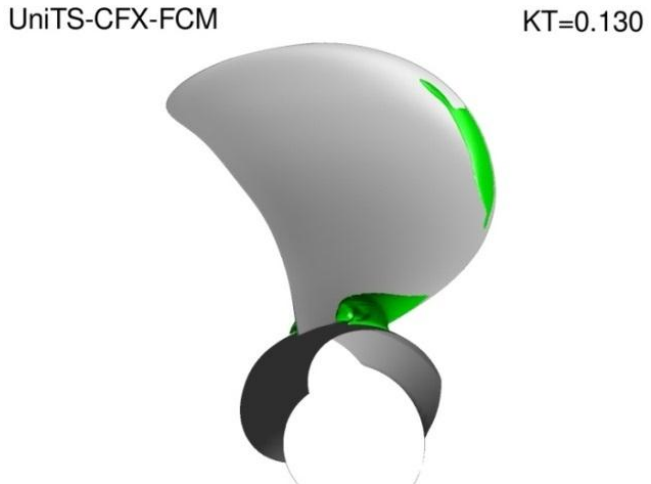
Vapour volume fraction 50%

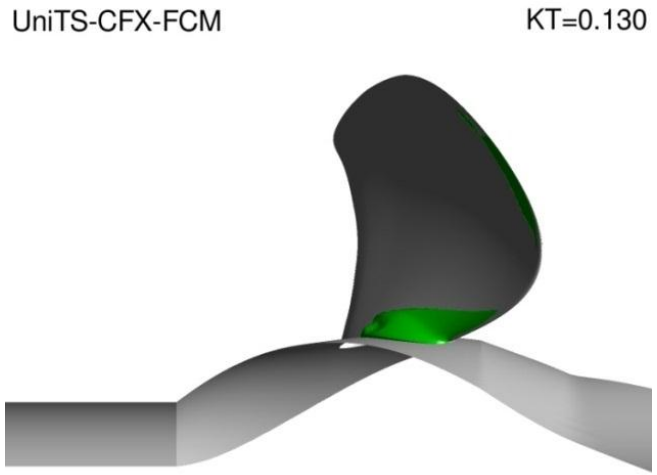
UniTS-CFX-FCM KT=0.130



Vapour volume fraction 80%

Test Case 2.3.3

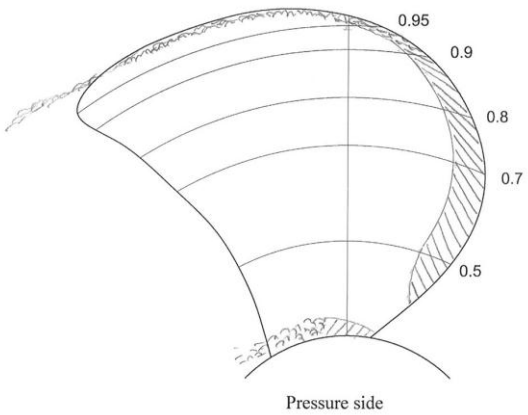


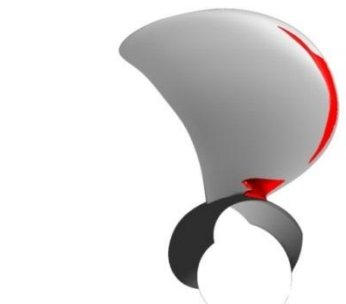


Vapour volume fraction 20%

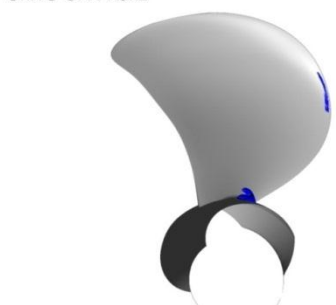
Cavitation prognosis

UniTriest-CFX(Kunz)



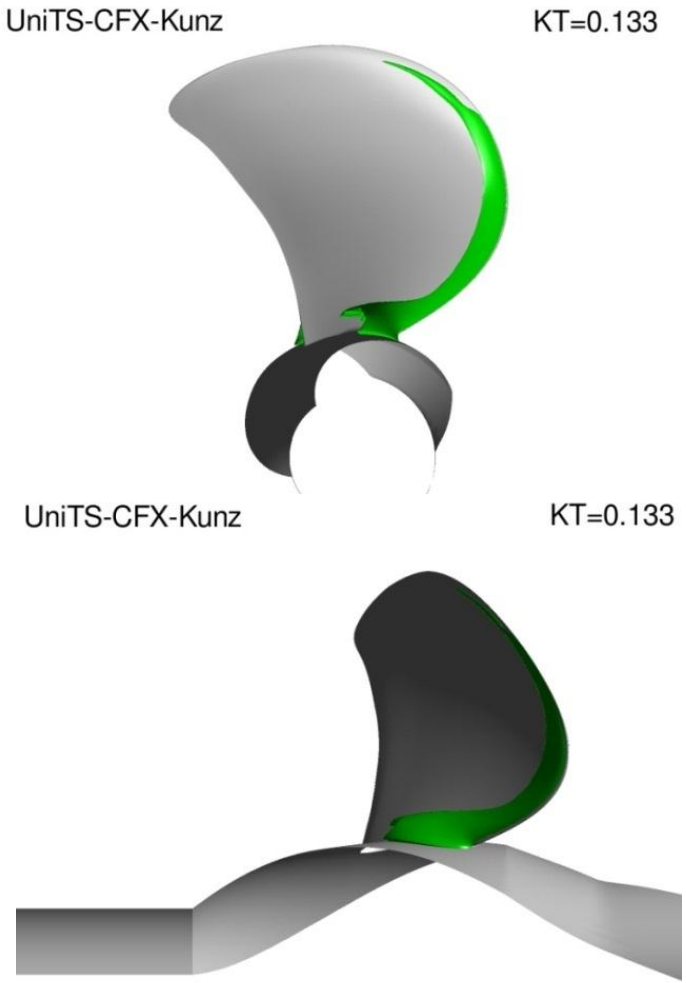


Vapour volume fraction 50%



Vapour volume fraction 80%

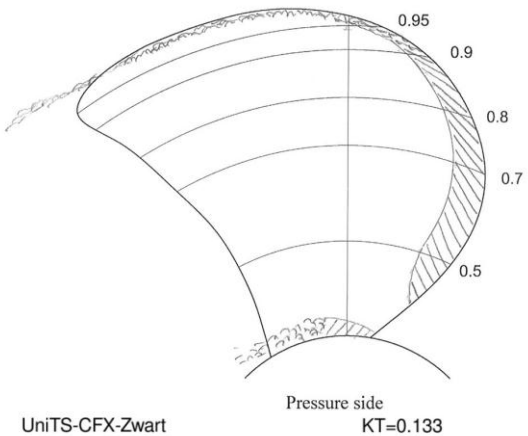
Test Case 2.3.3



Vapour volume fraction 20%

Cavitation prognosis

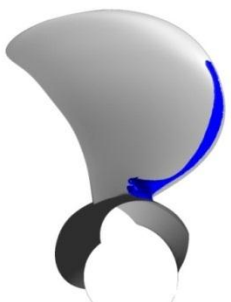
UniTriest-CFX(Zwart)



UniTS-CFX-Zwart KT=0.133

Vapour volume fraction 50%

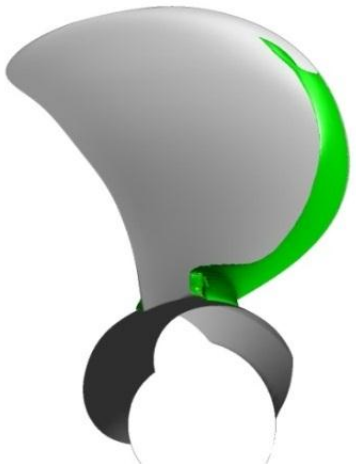
UniTS-CFX-Zwart KT=0.133



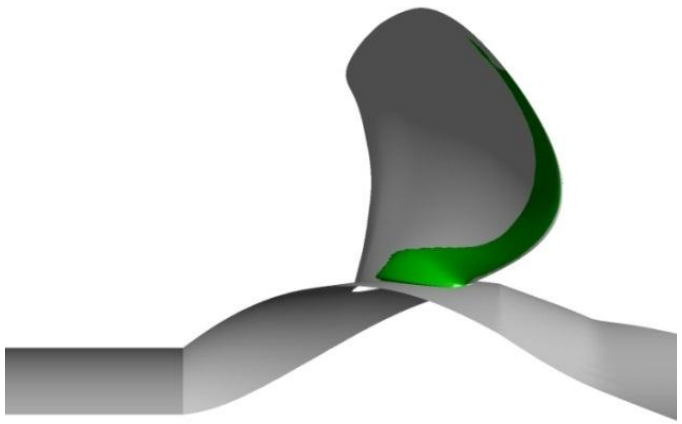
Vapour volume fraction 80%

Test Case 2.3.3

UniTS-CFX-Zwart KT=0.133



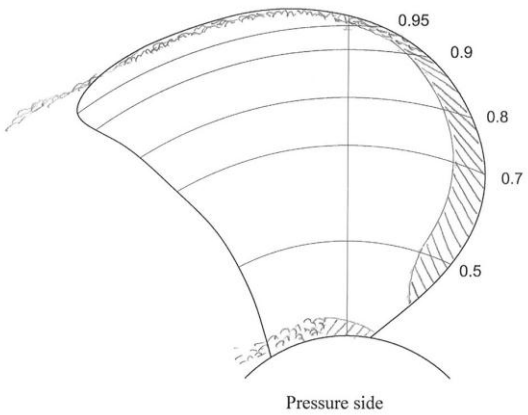
UniTS-CFX-Zwart KT=0.133

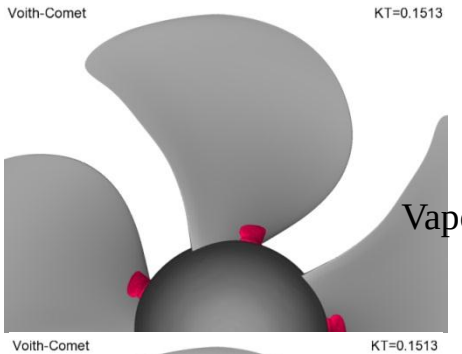


Vapour volume fraction 20%

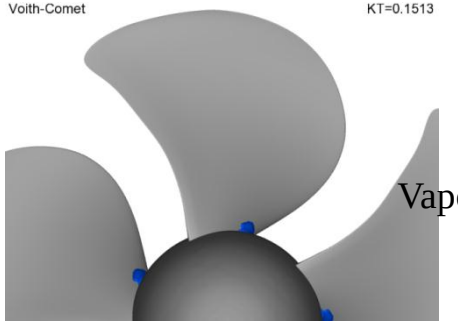
Cavitation prognosis

VOITH-Comet



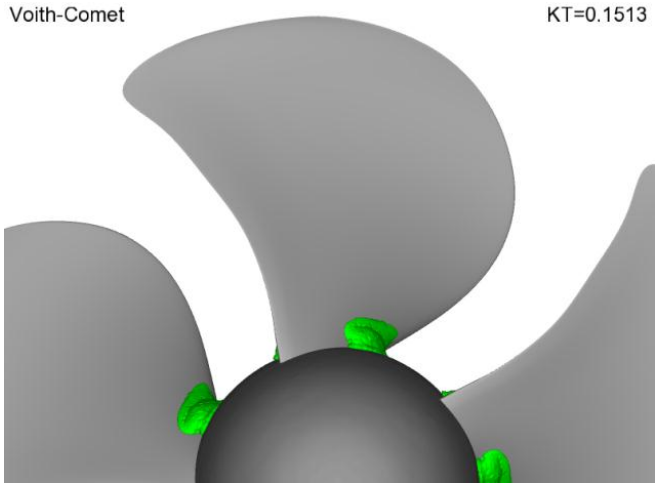


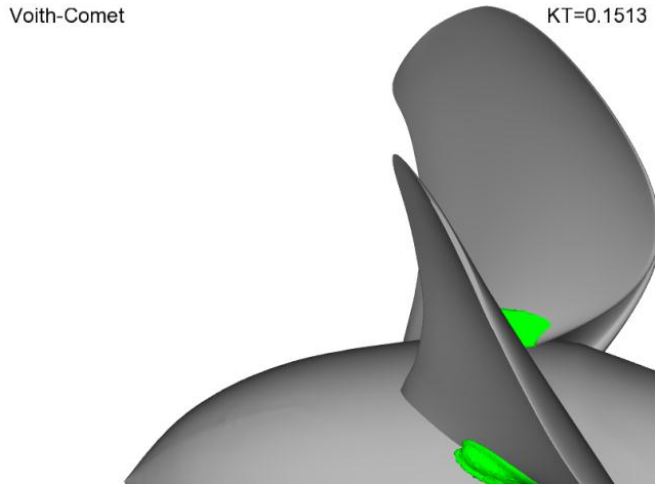
Vapour volume fraction 50%



Vapour volume fraction 80%

Test Case 2.3.3

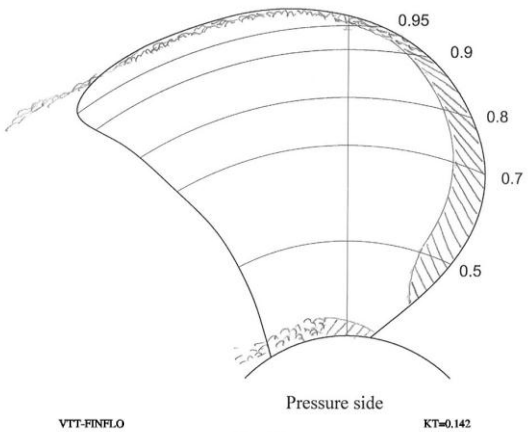


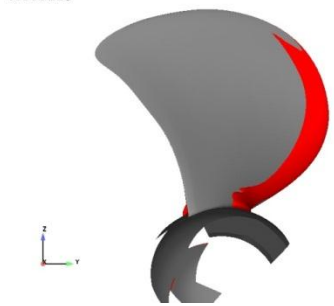


Vapour volume fraction 20%

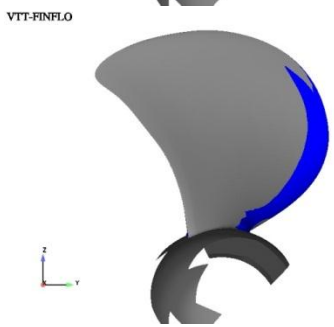
Cavitation prognosis

VTT-FinFlo



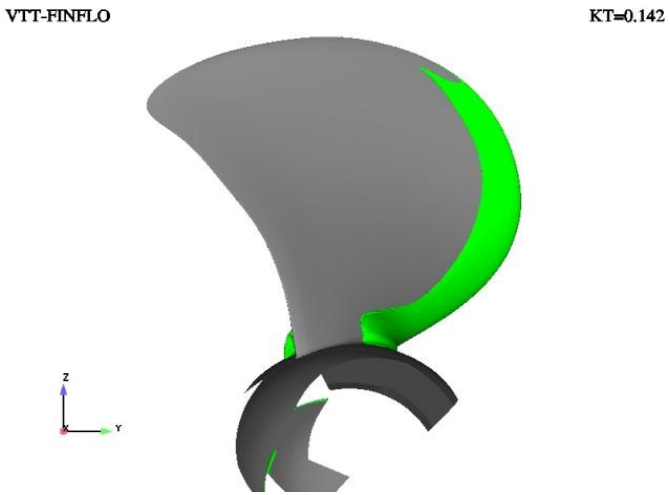


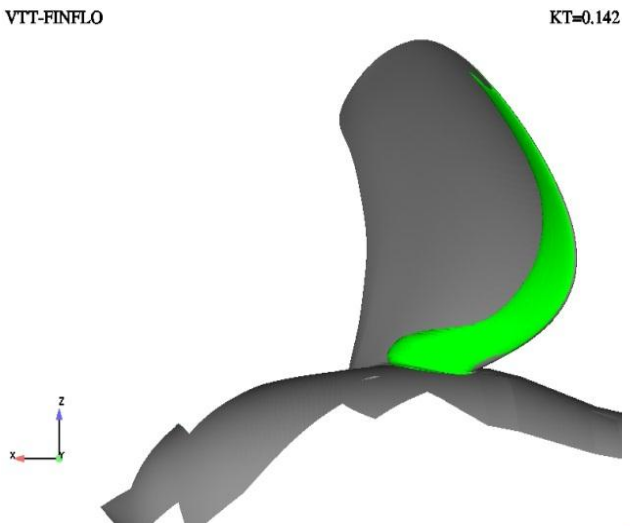
Vapour volume fraction 50%



Vapour volume fraction 80%

Test Case 2.3.3





Vapour volume fraction 20%

Cavitation prognosis

Summary - Test Case 2.3.3

$J = 1.4083$, $K_T = 0.1362$, $10K_Q = 0.4890$, $\sigma_n = 1.999$

Measurements

Thrust break down ($K_T = 0.167$ (non-cavitating) $\rightarrow$ $K_T = 0.1362$ ($\sigma_n = 1.999$)).

Pressure side sheet cavitation appears on the leading edge between darius $0.4 < r/R < 0.95$. Tip vortex cavitation is observed in the range $r/R > 0.95$.

Root cavitation appears on the pressure side near the hub and on the suction side in the range from the hub to the radius $r/R < 0.40$.

Calculations

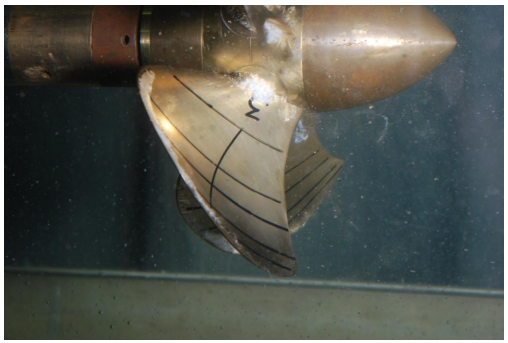
The calculations show in general a good prediction of the regions with cavitation danger (sheet and root cavitation). **No prediction of the tip vortex cavitation.**

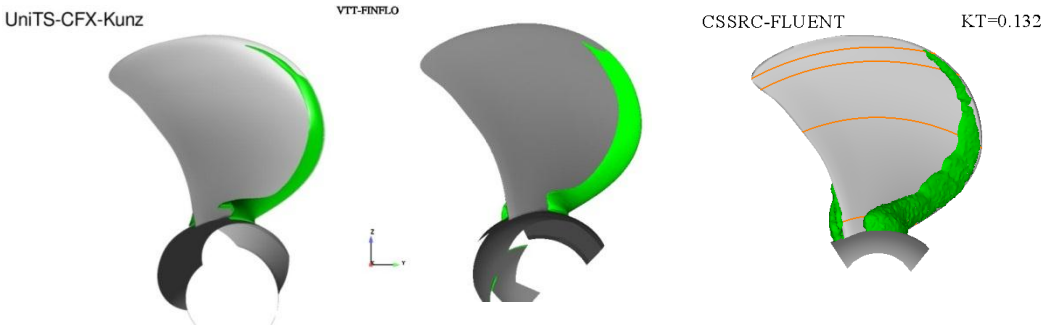
In general the best agreement between predicted and measured cavitation pattern is obtained for a volume fraction of VOF = 20%.

Cavitation prognosis

Summary - Test Case 2.3.3

$J = 1.4083$, $K_T = 0.1362$, $10K_Q = 0.4890$, $\sigma_n = 1.999$





Calc.	1	2	3	4	5	6	7	8	9	10	11
PSC		20			50						
RC											
TVC								?	?		?

Acknowledgements

The PPTC working group wishes to acknowledge the support for the Propeller Performance Workshop given by the organisation team of the smp'11.

Special thanks also to the participants; without whom the workshop could not have taken place.