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Voith Schneider Propeller (VSP) - Investigations of the cavitation behaviour

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INTRODUCTION

Voith Schneider Propellers (VSP) are used primarily for ships that have to satisfy particularly demanding safety and manoeuvrability requirements. Unique to the Voith Schneider Propeller is its vertical axis of rotation. The thrust is generated by separately oscillating, balanced propeller blades. Due to its physical operating principle and its design, thrust adjustments can be done very quickly. The VSP, a controllable-pitch propeller, permits continuously variable thrust adjustments through 360°; combining steering and propulsion. Rapid step-less thrust variation according to X/Y coordinates improves ship handling. Voith Schneider Propellers operate at a comparably low rotational speed. Currently, VSPs are used primarily on Voith Water tractors (VWT), Offshore Support Vessels (OSV), Double-Ended Ferries (DEF), Mine Countermeasure Vessels (MCMV) and Buoy Layers.

A question which has been posed several times: What is the cavitation behaviour of the VSP and are there any differences when compared to the cavitation effects of screw propellers?

Cavitation tests have been carried out by Voith Turbo in its own tank from 1933-1976 [1], which had a quite small measuring section (0.75 x 0.25 m²). Further tests have also been carried out at MARIN [2] and at the HSVA [3]. Investigation into the influence of the cavitation on VSP blades with regard to the hydro-acoustic have also been done by SSPA [4] and the KRYLOV Institute [5].

In the last years, the demand on the input power of the VSP relative to the propeller sizes has increased. There is only limited knowledge available about the cavitation effects for the current propeller loads and future increases of the input power. Cavitation can, for high input power not be avoided, but what effects does the cavitation have?

Voith has gained over the years the experience that cavitation does not create damage on the VSP blades. There is no detailed insight available why the cavitation does not create erosion on the VSP blades. Nowadays a deep understanding of cavitation phenomena can be achieved by using high speed camera technology. There are no reliable measurements available of the present VSP loads as functions of the cavitation number. As yet, new developed blade profiles have not been investigated by extensively experiments.

Voith and Potsdam Model Basin (SVA) have carried out together investigations about the cavitation behaviour of Voith Schneider Propellers.

Two main questions have been in the focus of the research activities:

1. Why does the cavitation of the VSP blades not create erosion?
2. At which cavitation number does a thrust deduction occur?

Different profiles of VSP blades had been investigated in tests with single blades and in propulsion and cavitation tests with a VWT model. Selected results of these tests had been presented at the Hydrodynamic Symposium – Voith Schneider Propulsion in March 2006 [2].

The cavitation tests have been carried out in the large circulating and cavitation tunnel UT2 at the Technical University of Berlin and in the cavitation tunnel K15A of the SVA Potsdam. The aim of the bollard pull measurements at cavitation identity in the large circulating and cavitation tunnel UT2 of the TU Berlin was to study the influence of cavitation on the forces and moments of the Voith Schneider Propellers.

Investigation into cavitation behaviour of single VSP blade and of the Voith Schneider Propeller at high thrust loading coefficients have been carried out in the cavitation tunnel of the SVA Potsdam. The optical access in the SVA's medium sized cavitation tunnel (test section 850 mm x 850 mm) is better than in the test section of the UT2 (test section 5000 mm x 3000 mm). In addition high-speed video technique could be used for the cavitation observation.

THE TECHNICAL AND HYDRODYNAMICAL PRINCIPAL OF THE VSP

For a better understanding of the later presented hydrodynamical investigations, a short explanation of the technical principle of the VSP is required. A detailed description can be found in [1], [6], [7] and [8].

The thrust of a VSP can be applied very fast applying X/Y-logic. Figure 1 shows the sectional drawing of a VSP and figure 2 the installation of two VSPs in a Offshore Support Vessel.

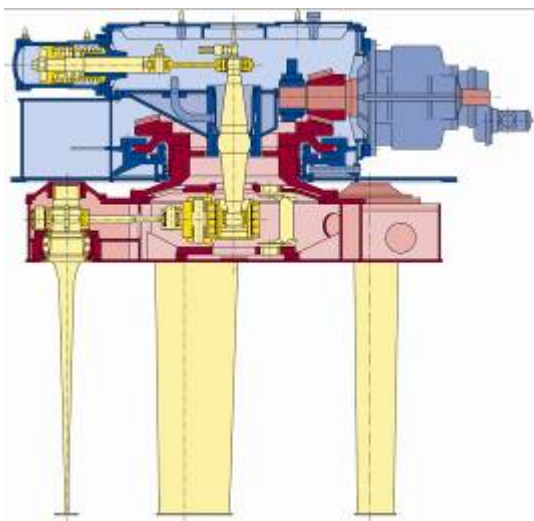


Fig.1 Sectional drawing of a VSP

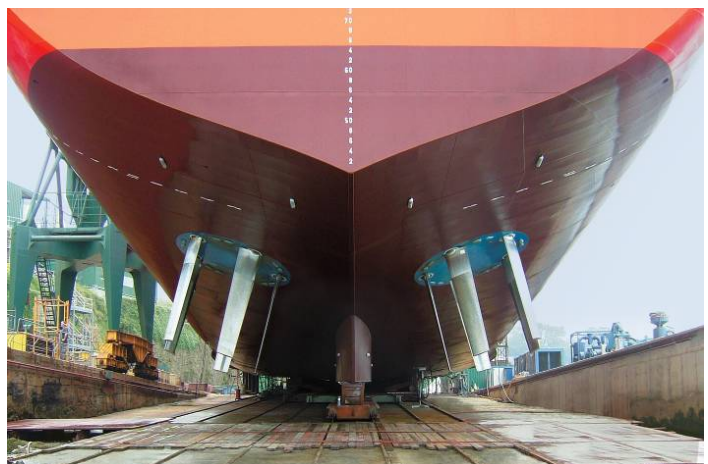


Fig. 2 Two VSP installed in a Offshore Support Vessel

The thrust is created by vertically mounted blades in a rotor casing. While the rotor casing is rotating, the blades are oscillating. The blades oscillation is steered by the law of intersecting normals. Figure 3 shows the mechanical principle of the VSP and figure 4 the corresponding hydrodynamic thrust creation. A descriptive simulation program showing the technology of the VSP and the hydrodynamics can be downloaded at www.voithturbo.com/marine.

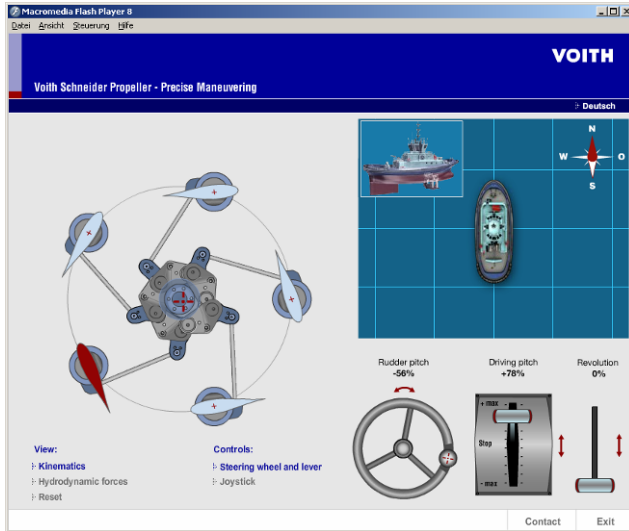


Fig. 3 Mechanical principle of the VSP

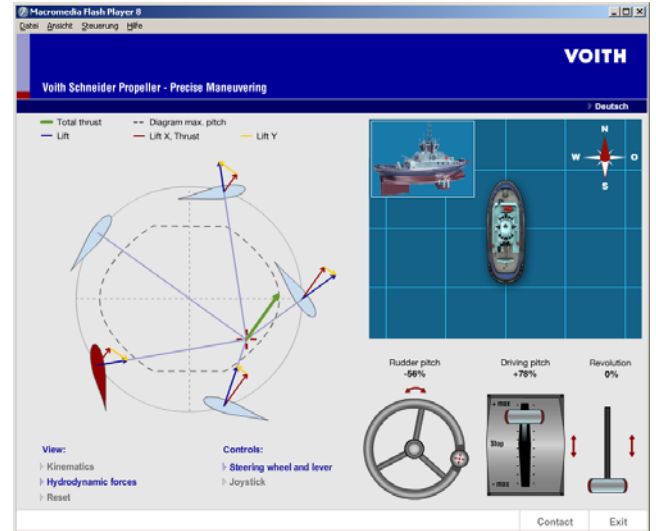


Fig. 4 Hydrodynamic principle of the VSP

Figure 5 shows the forces acting at the propeller for selected blade positions. Lift changes during revolution due to the nonstationary flow at the propeller blades. The forces acting across the desired direction of thrust cancel each other, whereas the forces acting in thrust direction are added over the propeller circumference. Figure 6 shows the lift as a function of the cycloid path for a stationary observer.

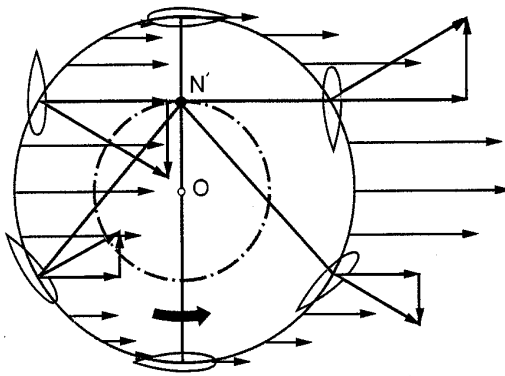


Fig. 5 Blades forces for different blade position

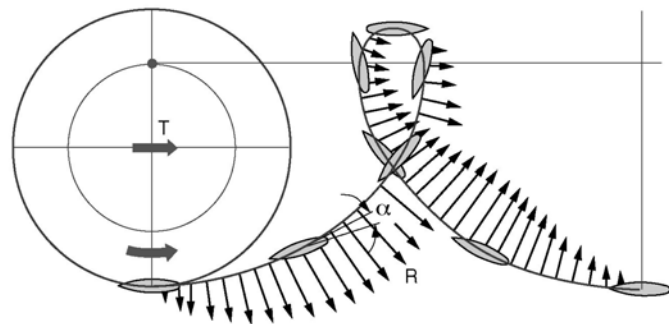


Fig. 6 Lift generation on a blade as a function of the cycloidal blade path

CAVITATION TESTS WITH SINGLE VSP BLADES

The inflow of the VSP blades is complex. The inflow speed as a function of the chord length consist in a vectorial addition of the advanced speed, the rotational speed and the inflow velocity due to the oscillation of the blades around the shaft axis. Firstly the blades had been tested in a parallel flow and stationary angles of attack to get a better understanding of the complex situation

The profiles of VSP for VWT are high lift profiles. The profiles are based on the DVL profile Series and HSVA profiles, but they have a modified leading and trailing edge. Voith Turbo Marine has varied the profile shape systematically. Five profiles (Figure 7) have been investigated in model tests for different angles of attack and cavitation numbers [9]. The main parameters of the profiles are:

Profile length	L	[mm]	: 390.00
Chord length	c	[mm]	: 150.00
Relative thickness	t/c	[-]	: 0.16

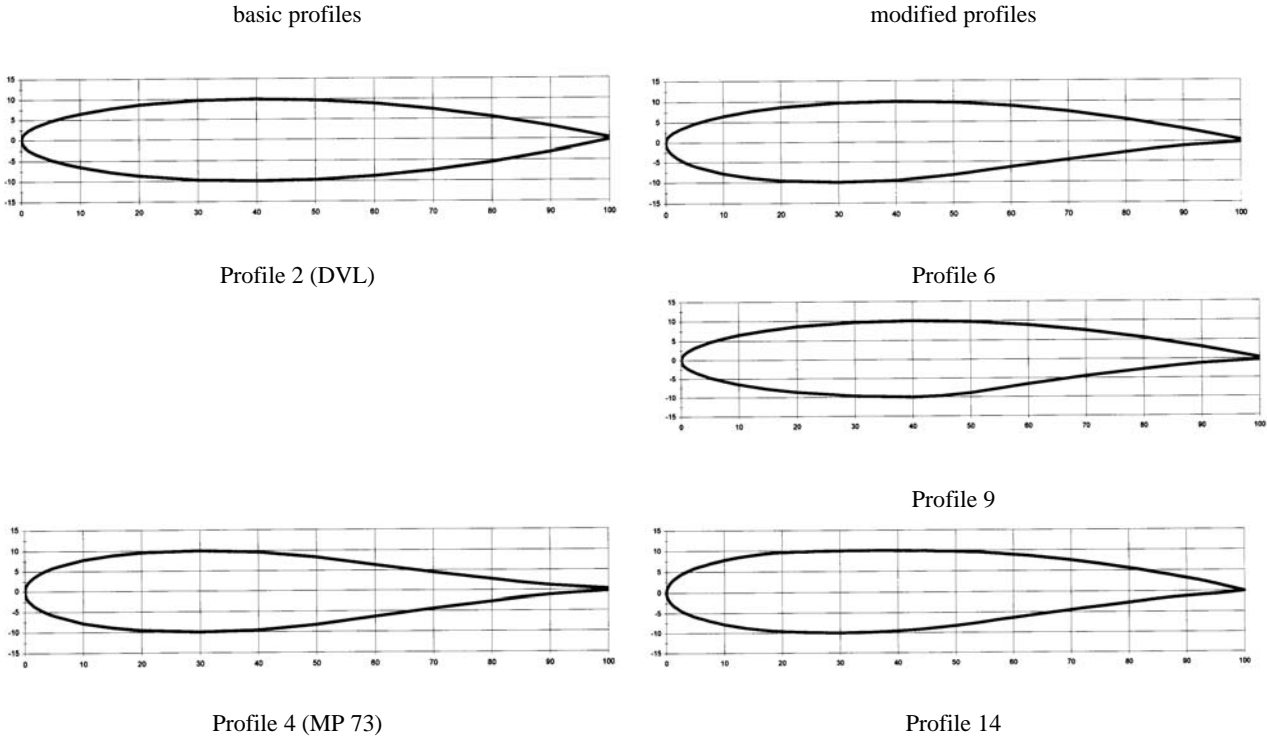


Fig. 7 Profiles for single VSP blade tests

The cavitation behaviour of the profiles was analysed with high-speed videos. A comparison of the cavitation inception at similar lift coefficients shows a better cavitation behaviour of the MP 73 profile at higher lift coefficients compared to the DVL Profile.

The figures 8 and 9 present video prints of the cavitating MP 73 profile at the angles of attack 12 and 19 degrees. Sheet cavitation appears at the leading edge on the suction side of the profile during the test with an angle of attack of 12 degrees. The cavitation separates from the profile surface after a chord length of about 25%. Two cavitating vortices appear at the profile sole.

At the angle of attack of 19 degrees the flow separates at the suction side. Cavitating vortices can be observed in the separated flow. A cavitating vortex appears on the profile sole.

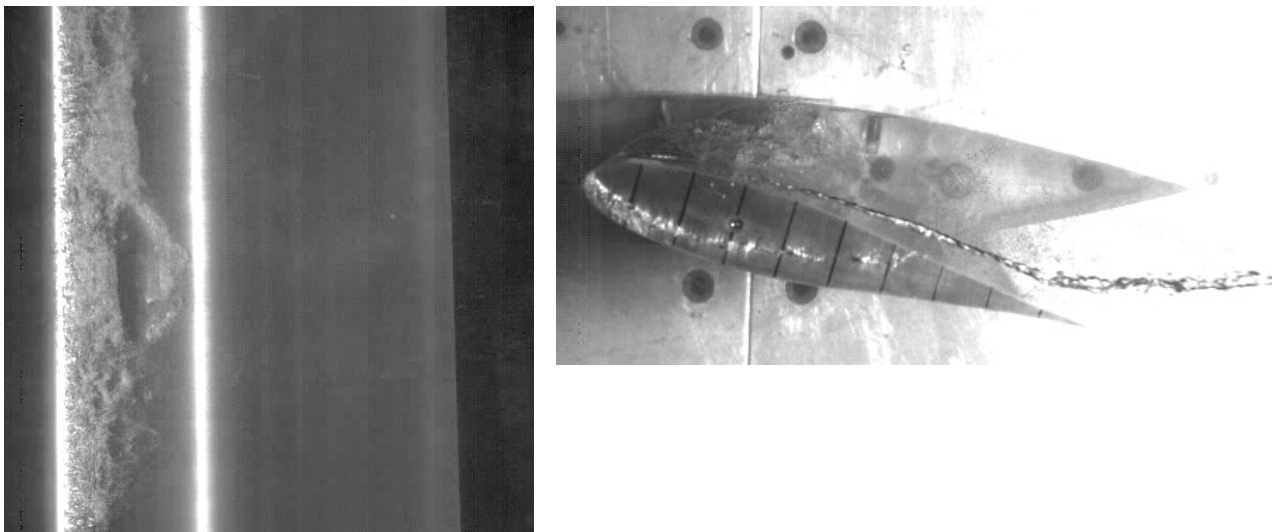


Fig. 8 Cavitation observation, angle of attack = 12° , $V_M = 4.00$ m/s, $\sigma_V = 2.40$



Fig. 9 Cavitation observation, angle of attack = 19° , $V_M = 4.00$ m/s, $\sigma_V = 2.40$

CAVITATION TESTS WITH A VSP MODEL

Measuring device, test arrangement

SVA Potsdam has developed a special thrust measuring system (3-component balance) for VSP model drives (Figure 10 & 11) [8], [10]. The VSP-balance allows the measurement of the longitudinal and transverse forces of the VSP during open water and propulsion tests.

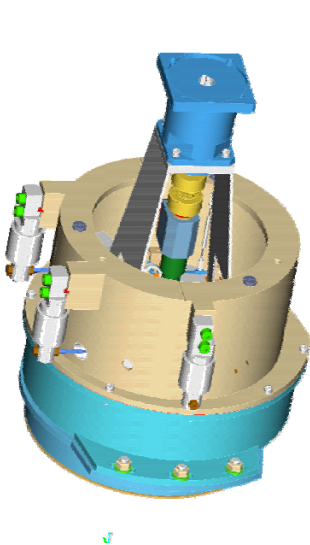


Fig. 10 VSP-balance of the SVA Potsdam for open water and propulsion tests in the towing tank

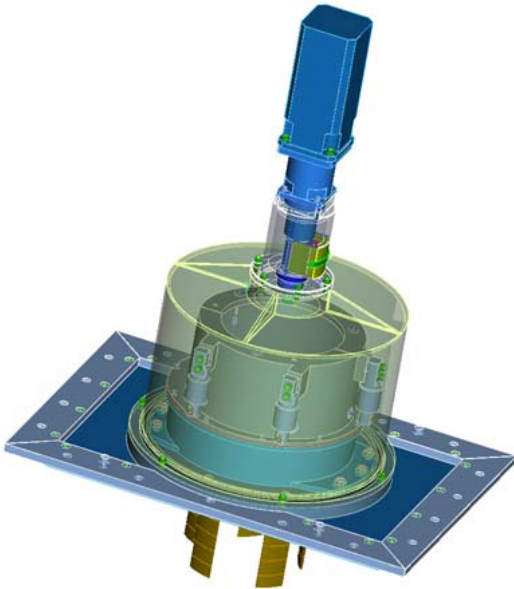


Fig. 11 VSP-balance of the SVA Potsdam for cavitation tests

The VSP-balance was also used for the test set-up in the cavitation tunnel type K15A from Kempf & Remmers. The VSP-balance is arranged on a plate by a test section window. A pod surrounds the balance. The driving motor and a torque measurement device are arranged on the top of the pod (Figures 11 and 12).

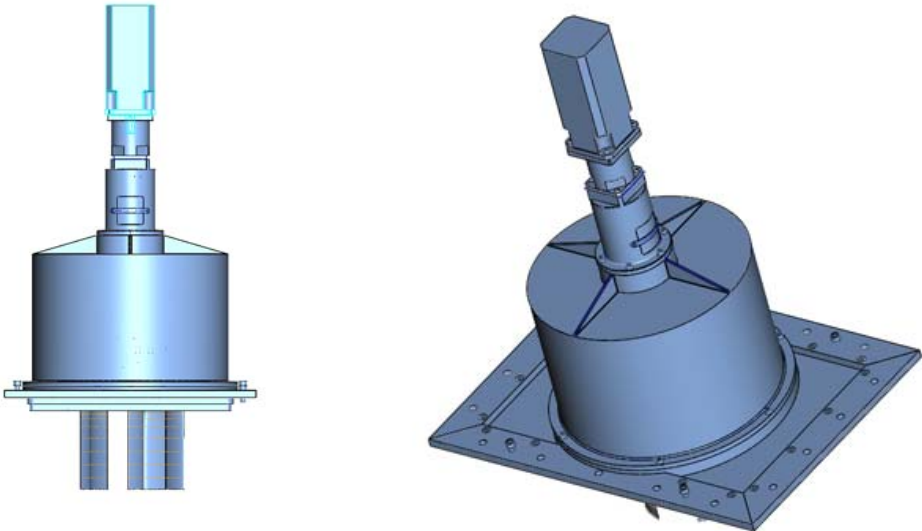


Fig. 12 Views of the VSP-balance for cavitation tests

The driving shaft was designed in a way that no forces will be transmitted on the measuring system. The pod with the balance is filled with water during the measurements. This is necessary to minimise the take of air in the gap between rotor casing and the plate.

The test set-up for the cavitation tests has been tested successfully. The measurement of the forces was possible at overpressure and low pressure. The measurement of the torque was more complicated due to the influence of the water in the rotor casing on the idle torque. Idle torque measurements in the water with the VSP without blades is necessary.

The cavitation tests have been carried out with the VSP model P9659 from Voith Turbo Marine. The main data of the model VSP P9659 are:

Diameter	D	[mm]	: 200.00
Blade length	L	[mm]	: 166.50
Chord length	c	[mm]	: 40.00
Number of blades	Z	[-]	: 5

The blades are characterised by an asymmetrical profile, as shown in figure 13. This profile was developed by Voith Turbo Marine using a numerical optimisation strategy [11], [12] based on CFD calculation.

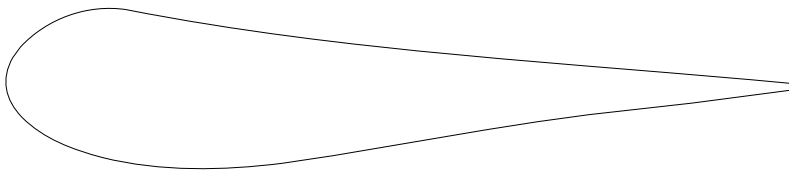


Fig. 13 Profile of the VSP blades, model P9659

Tests in the cavitation tunnel

The tests have been carried out in the SVA's cavitation tunnel in the test section No. 2 with 850 mm x 850 mm. The arrangement of the VSP model P9659 in the cavitation tunnel is shown in figure 14. Rotation is clockwise.



Fig. 14 Rotor casing with VSP blades P9659_R in the cavitation tunnel

The rotor speed of the VSP models is limited to $n_{\max} \approx 6$ rps. The cavitation tests have been carried out at rotor speeds in the range between $n = 5$ to 5.5 rps. Due to the work of the VSP model a minimum water speed of $V_{\min} = 0.473$ m/s appears in the test section.

The following coefficients have been calculated on the base of measured values in the cavitation tests:

Circumferential velocity	$U = \pi \cdot n \cdot D$
Advance coefficient	$\lambda = V_A / U$
Longitudinal force coefficient	$K_{SX} = T_X / (\rho / 2 \cdot D \cdot L \cdot U^2)$
Transverse force coefficient	$K_{SY} = T_Y / (\rho / 2 \cdot D \cdot L \cdot U^2)$
Torque coefficient	$K_D = 2Q / (\rho / 2 \cdot D^2 \cdot L \cdot U^2)$
Cavitation number	$\sigma_n = (p - p_v + \rho \cdot g \cdot h) / (\rho / 2 \cdot \pi^2 \cdot n^2 \cdot D^2)$
Reynolds number	$Re = c / \nu \cdot U$

Force measurements

The cavitation tests have been done at the advance coefficient $\lambda = 0.15$ at pressures between atmospheric pressure and the pressure corresponding to the full size cavitation numbers. The full-scale cavitation numbers of the VSP for a VWT are in the range between $\sigma_n = 2.2$ (water depth rotor casing) and $\sigma_n = 2.6$ (water depth blade end).

The Figure 15 shows the measured longitudinal, transverse and torque coefficients during the cavitation number variation in the cavitation tunnel. The change of the longitudinal force and torque coefficients of the VSP model P9659_R due to the influence of cavitation is small.

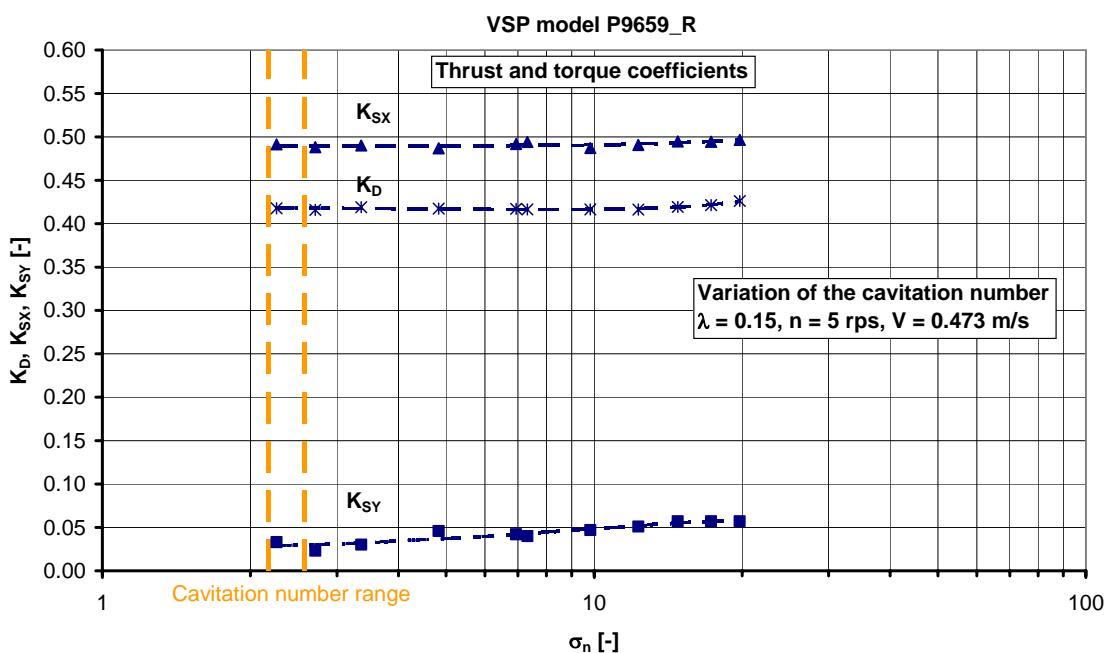


Fig. 15 Influence of the cavitation on the VSP coefficients, model P9659_R, at mode Reynoldsnumber

Cavitation observation

The Figure 16 shows a calculated pressure distribution of a VSP with symmetrical blade profiles acting at a VWT with guard plate [12]. It can be seen, that a low pressure and consequently a large cavitation danger will occur in the angle range 300 to 360 degrees. The CFD calculation with a cavitation model shows that cavitation will appear at the outside and inside of the blades (Figure 17).

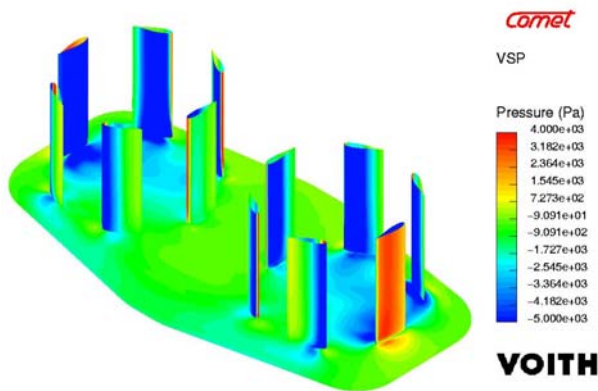


Fig. 16 Calculated pressure distribution at VSP blades

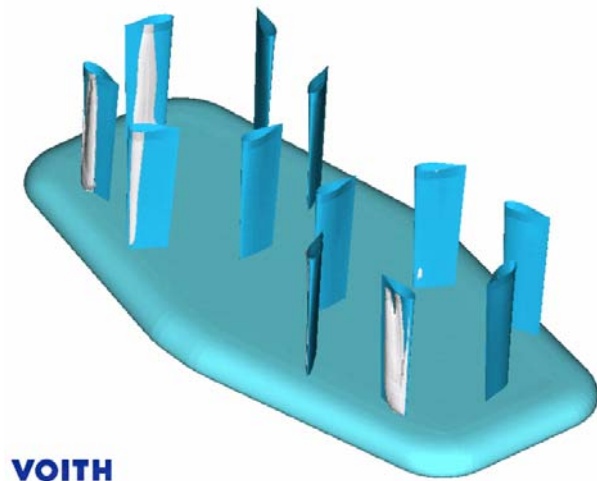


Fig. 17 Calculated cavitation behaviour at high thrust loading

In general the calculations from Voith Turbo Marine show, that the pressure distribution and cavitation danger at the blades can be calculated actually with CFD-methods. A problem is the calculation of the cavitation dynamic and connected separated cavitation. The calculated cavitation allows today no differentiation between bubble, sheet and cloud cavitation. That's why the investigation of the cavitation behaviour of Voith Schneider Propellers is still a task for model tests.

The following video prints from the high-speed camera videos show examples of cavitation patterns on the VSP model P9659 with the asymmetrical profile. The realised advance coefficient of $\lambda = 0.15$ represents the maximum possible load in the cavitation tunnel K15A with the test section 850 x 850 mm.

Due to the asymmetrical profile and the blade angle curve no cavitation at the outside of the blades was observed.

The cavitation inception for the VSP model P9659 has been observed at the cavitation number $\sigma_n = 6.94$. Blade sheet cavitation first appears at the leading edge near the rotor casing (Figure 18).

The cavitation observation at the cavitation number $\sigma_n = 3.36$ shows sheet and vortex cavitation in the angle range 270° to 360°. The cavitation separates from the blade (Figure 19).

At the design cavitation number $\sigma_n = 2.71$ for bollard pull condition sheet cavitation appears at the leading edge of the whole blade length (Figure 20). At the blade end intermittent tip vortex cavitation could be observed. The cavitation separates from the blade and hits the following blade.

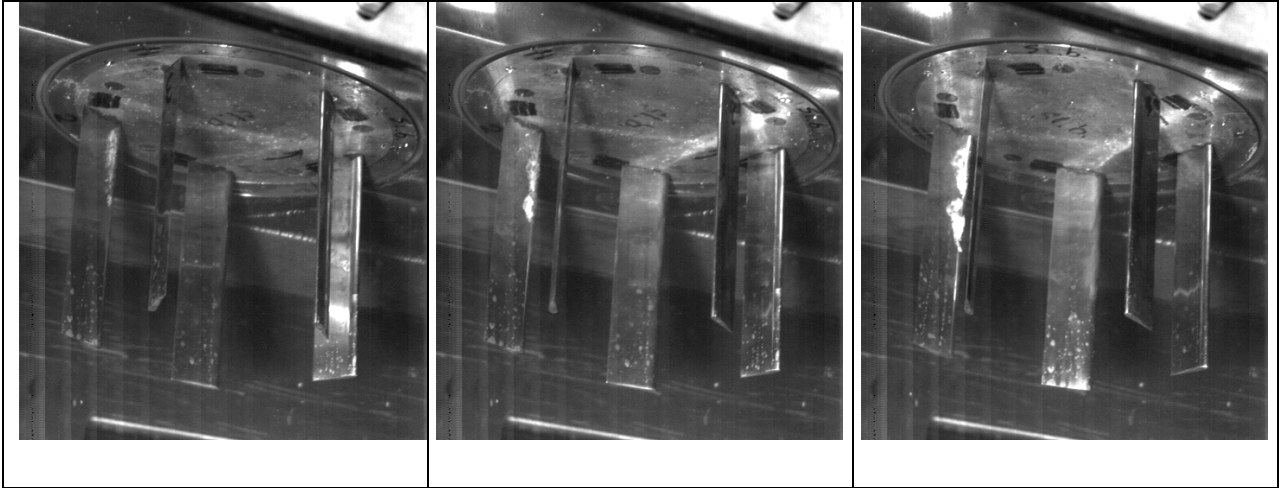


Fig. 18 Cavitation inception, $n_M = 5 \text{ s}^{-1}$, $V_M = 0.473 \text{ m/s}$,
 $\lambda = 0.15$, $K_{SX} = 0.492$, $K_D = 0.423$, $\sigma_n = 6.94$

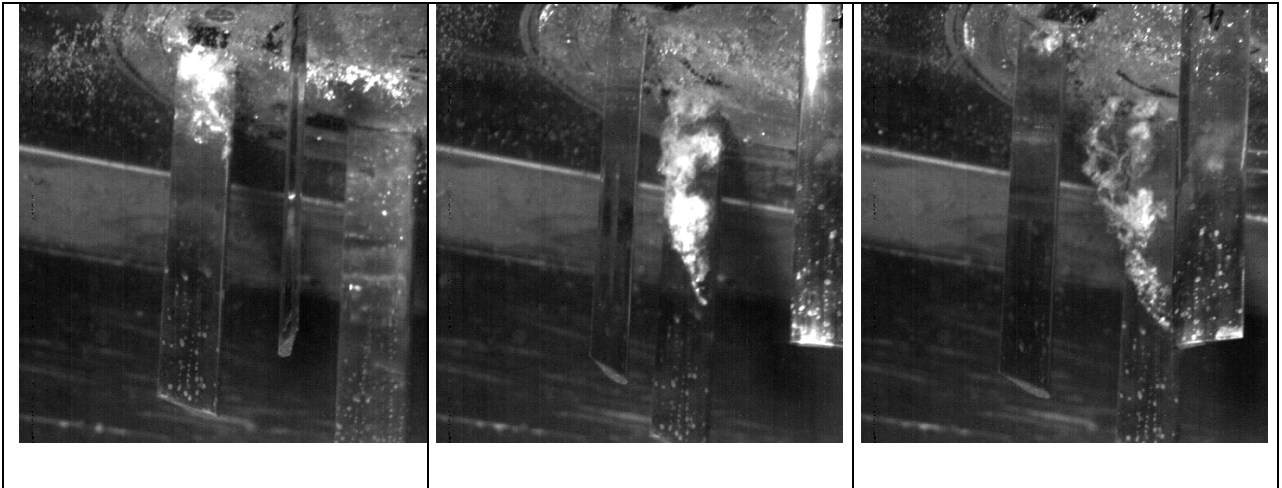
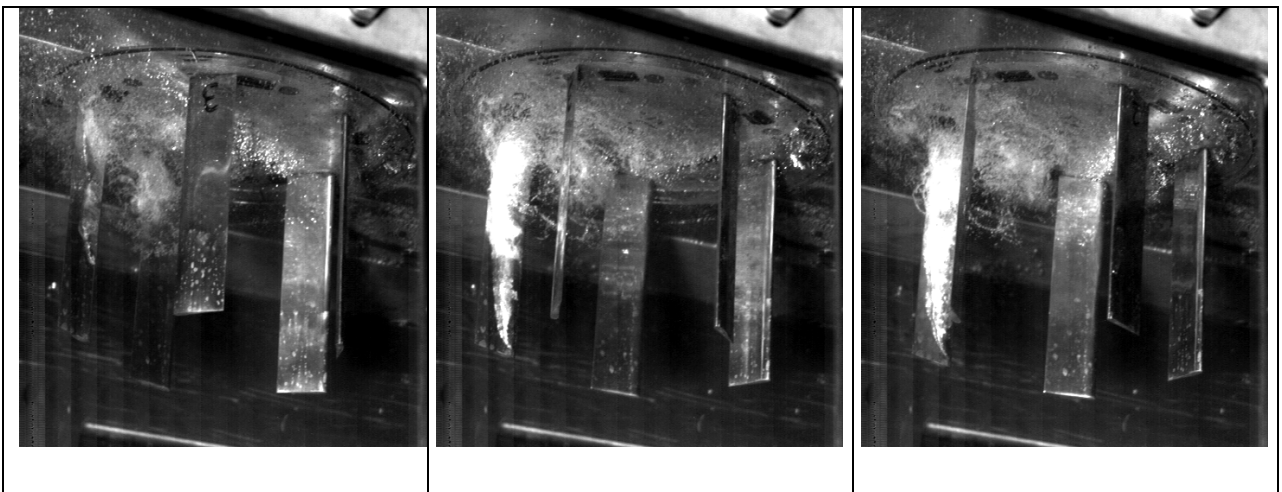


Fig. 19 Cavitation observation, $n_M = 5 \text{ s}^{-1}$, $V_M = 0.473 \text{ m/s}$,
 $\lambda = 0.15$, $K_{SX} = 0.490$, $K_D = 0.426$, $\sigma_n = 3.36$



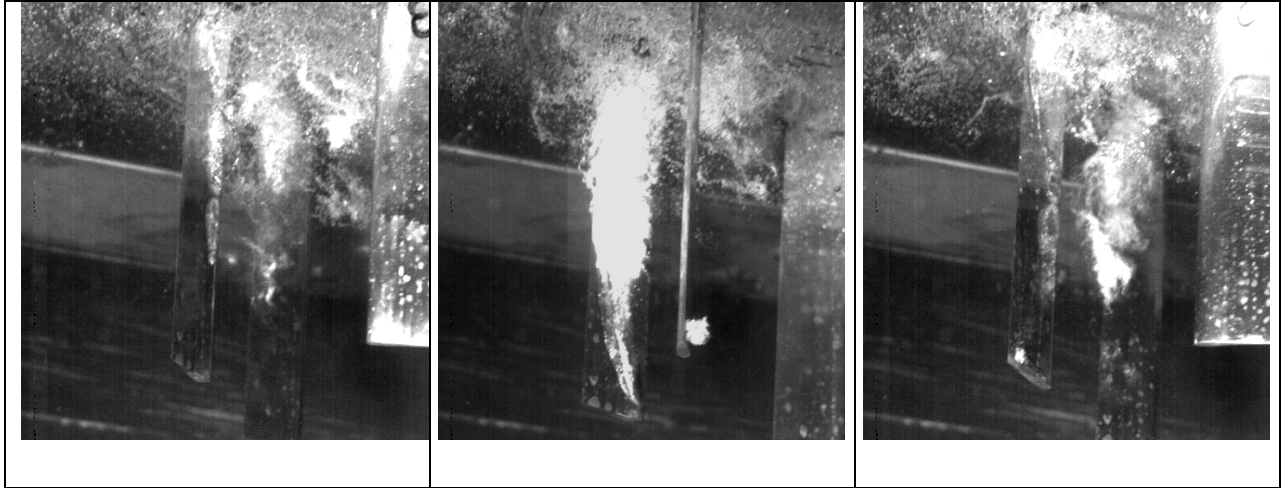


Fig. 20 Cavitation observation, $n_M = 5 \text{ s}^{-1}$, $V_M = 0.473 \text{ m/s}$,
 $\lambda = 0.15$, $K_{SX} = 0.488$, $K_D = 0.416$, $\sigma_n = 2.71$

Bollard pull measurements at cavitation similarity in the large circulating and cavitation tunnel UT2

Bollard pull measurements have been carried out in the large circulating and cavitation tunnel UT2 of the TU Berlin, to study the influence of cavitation on the forces and moments [9]. The test section of this tunnel has a length of 11.0 m, a width of 5.0 m and a depth of 3.0 m which allows tests at bollard pull conditions. The photos in Figure 21 shows a VWT model during the installation in the UT2. Measurements in the UT2 have been done at a water velocity $V_S = 0$ and different rotor speeds in the range from $n_M = 1$ to 5.5 rps at atmospheric pressure and at pressures corresponding to the model and full size cavitation numbers.

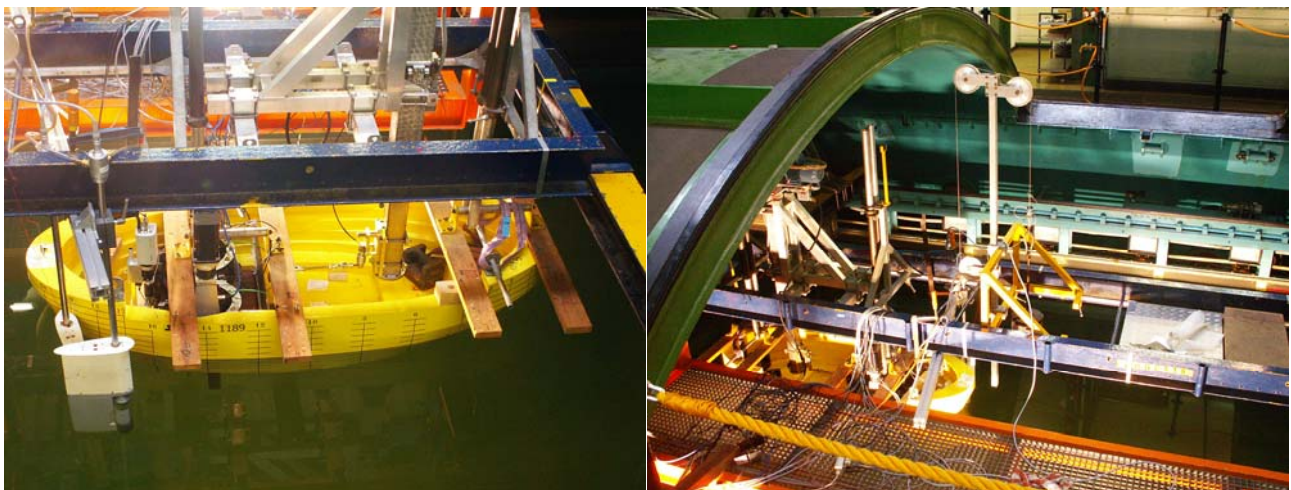


Fig. 21 VWT model in the test section of the UT2

The cavitation numbers of the VSP for the VWT are in the range between $\sigma_n = 2.176$ (water depth rotor casing) and $\sigma_n = 2.573$ (water depth blade end).

The bollard pull investigations with the VWT model have been carried out with different profiles, presented in Figure 7, on the VSP models. The measurements show, that in general the changes in the forces of the VSP due to the influence of cavitation are small. But it could be seen in the bollard pull measurements at cavitation similarity, that the blade profiles influence the cavitation behaviour and also the tendencies in changing of the VSP characteristic.

The Figures 22 and 23 show results of bollard pull measurements for the VSP with profile 4 and with profile 9. All data are at model Reynolds number. There is a very strong effect of the very low Reynolds number.

The cavitation at the VSP with the profile 4 leads to a slight increasing of torque coefficients (Figure 22). The thrust of the VSP with cavitation is a little bit smaller than without cavitation. The result is also a slight decreasing of the bollard pull at the design cavitation number.

The Figures 23 shows results of bollard pull measurements for the VSP with profile 9. The cavitation at the VSP blades with the profile 9 hasn't an influence at the thrust and torque coefficients as well as at the bollard pull.

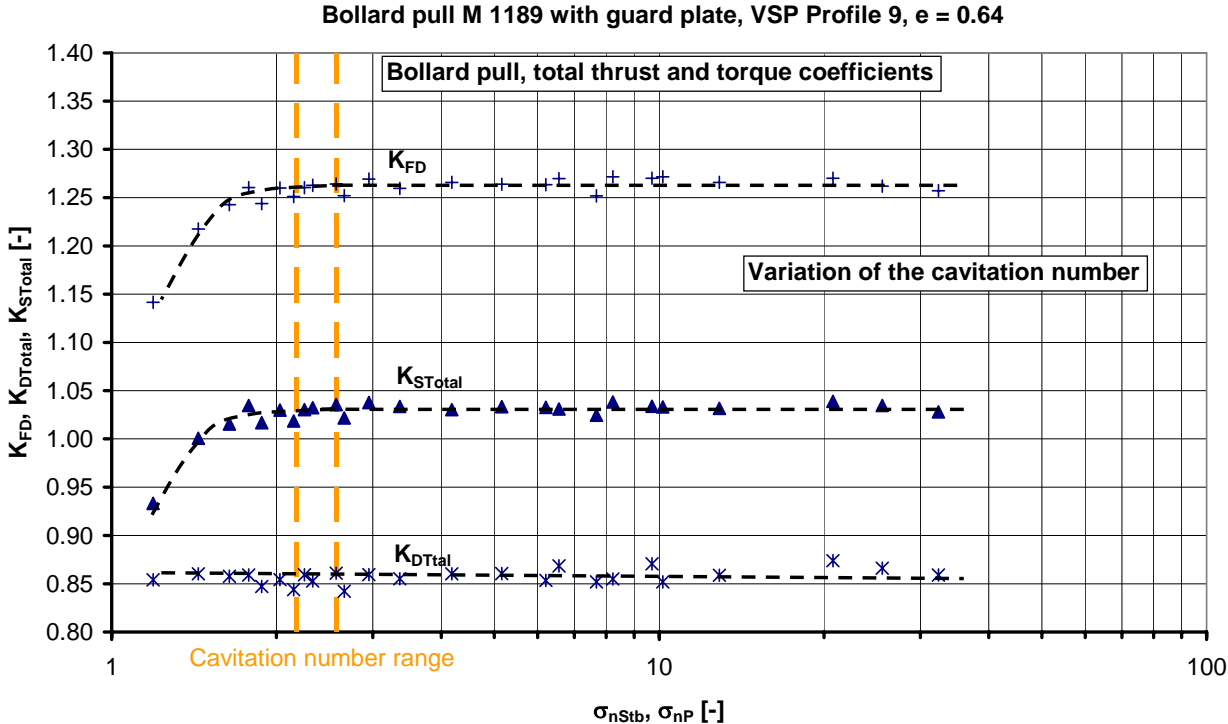


Fig. 22 Bollard pull, total thrust and torque coefficients at different cavitation numbers, VSP with profile 4, data at model Reynolds number

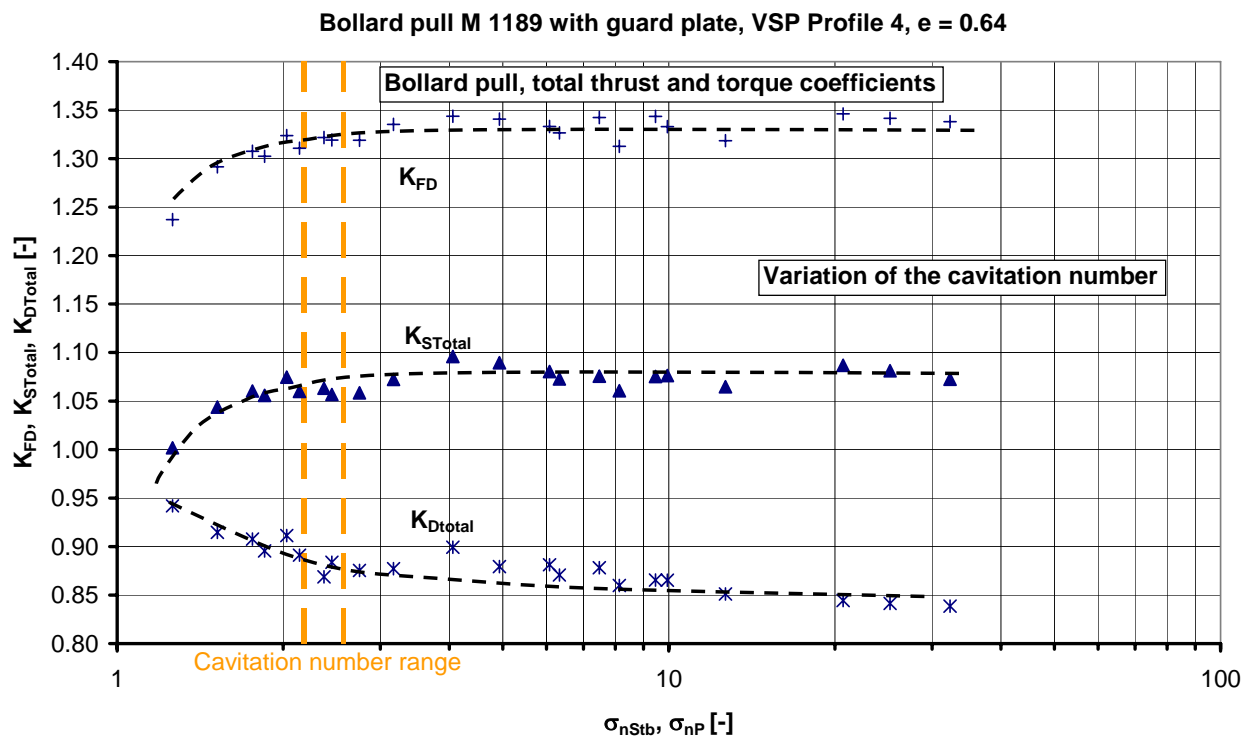


Fig. 23 Bollard pull, total thrust and torque coefficients at different cavitation numbers, VSP with profile 9, data at model Reynolds number

SUMMARY

Cavitation tests with single VSP blades and with a VSP model have been carried out in the cavitation tunnel K15A. In addition bollard pull measurements at cavitation similarity have been carried out with a VWT model in the large circulating and cavitation tunnel UT2 of the TU Berlin.

A test arrangement for cavitation tests with a VSP model was developed and tested at the SVA Potsdam. A 3-component VSP-balance was used for the measurement of the longitudinal and transverse forces.

Different VSP blade profiles have been investigated in the cavitation tests. The blades are partly characterised by asymmetrical profiles.

The force measurements showed that the danger of a thrust break down due to cavitation is small. Cavitation at the blades appears only in a limited angle range. The cavitation separates rapidly from the blade and floats with the stream in the VSP area. The cavitating flow hits the following blade and leads to an increasing of the cavitation thickness at this blade.

Sheet cavitation appears mainly at the blades. Vortex cavitation could be observed at the blade end. This kind of cavitation at the VSP is not erosive. Erosive cavitation, like bubble or cloud cavitation, has not been observed on the VSP blades during the different cavitation tests.

The forces measurements and especially the high speed videos give a deep insight into the cavitation phenomena of Voith Schneider Propellers. The nonstationary working mode is the main reason for unique effects. The cavitation separates from the blades and therefore creates neither erosion on the blade surface or thrust reduction.

The cavitation at the blades has to take in account for choose of the profiles. A variation of the high lift profiles of the VSPs can guarantee a high thrust at very low cavitation numbers.

REFERENCES

- [1] Jürgens, B.; Fork, W.: Faszination Voith-Schneider-Propeller, Geschichte und Technik [The Fascination of Voith-Schneider Propellers, History and Engineering], Hamburg 2002.
- [2] Manen van, J. D.: Ergebnisse systematischer Versuche mit Propellern mit annähernd senkrechter Achse, STG Jahrbuch 1963.
- [3] Friesch, J.: Cavitation Studies at the Hamburg Ship Model Basin (HSVA); Hydrodynamic Symposium – Voith Schneider Propulsion, Heidenheim, March 2006.
- [4] Bjarne, E., “Comparison of a Cycloidal Propeller with Azimuth Thrusters with Regard to Efficiency, Cavitation and Noise”, Proceedings of International Conference on Propulsion for Small Craft, RINA, Nov. 1982.
- [5] Poutstoshniy, A. V.; Semionicheva, B. Y.: Minehunter: Choice of Propulsor with Improved Cavitation Characteristics at Positioning Mode, NSW conferences proceedings, Section A V2, St. Petersburg 26.02.-29.02. 1996.
- [6] Bartels, J.-E.; Jürgens, D.: The Voith Schneider Propeller - Current Application and New Developments, Voith Publication; G 1849; Heidenheim 2006.
- [7] Bartels, J.-E.; Jürgens, D.: Voith-Schneider-Propeller-Gegenwärtige Anwendungen und neue Entwicklungen, Handbuch der Werften, Band XXVI, 2002.
- [8] Jürgens, D.; Grabert, R.: New Hydrodynamic Aspects of Double-ended Ferries with Voith Schneider Propeller. 2nd International conference on Double Ended Ferries, Norway, Alesund, March 2003.
- [9] Heinke, H.-J.: Model tests with Voith Schneider Propellers at high thrust coefficients Hydrodynamic Symposium – Voith Schneider Propulsion, Heidenheim, March 2006.
- [10] Jürgens, D.; Grabert, R.: New Hydrodynamic Aspects of Double Ended Ferries with Voith Schneider Propeller. SVA-Forum, Germany, Potsdam, June 2003.
- [11] Jürgens, D.; Palm, M.; Singer, S.; Urban, K.: Numerical optimization of the Voith Schneider Propeller. ZAMMZ: Angew. Math. Mech. 87, No. 10, 2007.
- [12] Palm, M.: Matching the Reality of Ship Hydrodynamics through CFD. 2nd Symposium on Voith Schneider Technology, Heidenheim, 4-6 June 2008.