Full-Scale Total Wake Field PIV-Measurements for an Enhanced Cavitation Prediction

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Abstract: Propeller and rudder cavitation can impair vessel efficiency due to vibrations, noise and erosion. Hence in the propeller design process it is mandatory to predict the cavitation behavior. The mean wake field determines the overall design dimensions of the propeller. A precise velocity field is therefore crucial for the propeller blade section design and pitch. As a consequence the prognosis of cavitation inception and extent is as good as the wake field determinations.

Currently the full scale nominal wake field is either calculated by numeric simulations or measured at model scale and corrected by an upscaling process. The obtained wake fields are a good approximation for the real world. The actual cavitation behavior in some cases varies however. Thus there is a big demand to improve the cavitation prediction by validating the calculated full scale wake fields against a reliable data set, measured at full-scale.

For previous full-scale measurements Laser Doppler Velocimetry was the favored technology. In the presented project, however, the Particle Imaging Velocimetry technique could be adapted and applied. It proved to be robust and powerful. In order to allow a precise offset estimation by adaptive cross correlation algorithms, a calibration strategy was designed for the equalization of the flow images. The design of the optics, the alignment of the measuring system and the triggering of measurements on propeller’s angular position to identify its strong effect on the wake were further challenges. In addition, the validation of the measurement system in the towing tank of the Potsdam Model Basin (SVA) was a milestone, in order to deliver a reliable full-scale total wake field data set, which hopefully will contribute to a better evaluation of cavitation prognosis and to a deeper understanding of scaling effects between model and ship scale.

A first step was taken already by comparing the measured velocities with RANS simulation data for the full scale wake. Systematic deviations were revealed, which indicate possible inaccuracies in current calculations.

1. Introduction and purpose

Cavitation is a general fluid mechanics phenomenon and occur when a moving object induce pressure and velocity fluctuations in a fluid, like a propeller in sea water. When the vapor pressure is reached at local flow regions, gas bubbles arise and implode afterwards at regions of higher pressure.

With respect to the ship and propeller design process the cavitation behavior of the propeller in the wake field influences the propulsion efficiency and the vibration level in the aft ship. The displacement of the water volume by cavitation is much higher and more unsteady than the pressure fluctuations caused by the propeller blades itself. Hence there is an increasing demand to enhance the cavitation prediction methods to reduce the propeller induced pressure fluctuations as well as the underwater noise and to improve the propulsive efficiency at the same time.

The mean wake field determines, along with other parameters, the overall design dimensions of the propeller and variability of the wake field influences the propeller blade section design and pitch. As a consequence the prognosis of cavitation inception and extent is as good as the wake field determinations [SWF].

The wake field can be simulated for full scale with several approaches. Figure 1 shows a RANS simulation of the nominal wake field (ship without propeller) in model and full scale within ANSYS CFX for the target ConRo-Vessel “Amandine”, calculated by SVA. Due to the continuous
development of CFD methods it is possible to carry out qualified calculations of the model- and full-scale wake field. Since most of the wake field calculations are validated against a set of model scale data, a lack of available and reliable full scale data however is responsible for low evaluation rates of ship-scale simulations [CMP].

The second approach, which has become routine during the design phase of ships, is based on vessel investigations at model scale. Measurements of the three dimensional wake field components have to be scaled up, since the Reynolds numbers for model tests (between 10-10) strongly differ to ship scale (about 10). But it’s also indispensable to have reliable full-scale data to validate the upscaling and correction methods.

Unfortunately the number of well documented and reliable full-scale measurements is still extremely small. The reason for that is the huge technical effort that is necessary to measure the flow speed behind a real ship [SWF]. The most promising technique was Laser Doppler Velocimetry (LDV), e.g. presented in [Kux (1985)] or [Kui]. High distances between the measuring points of interest and ship’s hull, high flow velocities, the limited technical backup facilities and the harsh environmental conditions (vibration, noise, dust, high humidity, grease, salty air, restricted space) are the biggest problems an optical measurement system is faced with [Nor].

A typical LDV-setup is depicted in Figure 2. However, the LDV technique has some disadvantages. Firstly, the optical components are vibration and shock sensitive. As a consequence the adjustment under ship conditions is hard to achieve. Second, the technique can only be used for narrow angles [KUX (1982)]. At wider angles 2C-measurements may become impossible because the two measurement volumes may no longer be coincident and for 1C-systems the data rate may be significantly reduced, due to a decreasing effective aperture of the receiving lens [ALB]. The last big disadvantage is the low data rate. At large distances only the bigger particles scatter enough light energy to contribute to the velocity determination. Furthermore the measurement volume is very small (several mm). Consequently the measuring time increases dramatically in order to gain statistical secure data.

The Particle Imaging Velocimetry (PIV) on the other hand promised to overcome those disadvantages. It is currently one of the most applied optical techniques in flow investigations even at all model basins. The PIV technique was further applied already for a number of large-
scale measurements, but not for flow investigations on ships [BOS (2006), BOS (2009), DIE, KAN, RAF (1998), SUN]. Consequently, the first use of the PIV technique for velocity measurements at ship scale is a logical step.

This paper describes the development, validation and application of PIV, in order to deliver a reliable full-scale wake field data set, which hopefully will contribute to a better evaluation of cavitation prognosis methods and to a deeper understanding of scaling effects between model and ship scale. The full-scale measurements represent the total wake with a strong influence of both ship’s hull and the propeller action on the flow, because the vessel was driven by its own propeller.

Supported by the Federal Ministry of Economics and Technology (BMWI) the joint project KonKav started in 2009. Along with Hamburg Ship Model Basin (HSVA), Potsdam Model Basin (SVA), Technical University of Hamburg Harburg (TUHH) and Flensburger Schiffbau-Gesellschaft (FSG) the University of Rostock was involved.

The focus of KonKavI was to investigate the impact of water quality and gas content on cavitation with comparative measurements at several cavitation tunnels - K15a (SVA), HYKAT & K22 (HSVA), K27 (TU Berlin) and K21 (UniHRO). Laser Doppler, Phase Doppler [Alb], Time Shift technique and Shadow Imaging were adopted and applied [BOR, HOE].

KonKavII started in June 2011 and was dedicated to evaluate the scale effects between model- and ship-scale. For this reason data of the main cavitation influencing parameters were measured at full-scale - the spatial resolved flow velocities and the nuclei concentration and distribution in the wake field. For the classification of nuclei and determination of particle size and concentration Interferometric Particle Imaging Technique (IPI) [Dam] was adopted and applied.

In parallel new wake field calculation algorithms and cavitation prediction methods have been developed by TUHH. Further foci of KonKavII were the conduction of thrust and torque fluctuations of the propeller shaft (FSG) and comparing model scale investigations - nominal wake field measurements and cavitation observations were executed by SVA & HSVA.

The full-scale investigations took place on the freight ferry “Amandine” (ConRo), shipping twice a month between Rotterdam and Dublin, as depicted in Figure 3. The propulsion has one counterclockwise turning four blade pitch propeller at a constant number of revolutions.

2. Measurement principle / Conception
The PIV measurement principle is based on a double illumination and imaging of the flow to be observed at defined time intervals and a subsequent velocity calculation based on an offset estimation of the captured particles [Raf (2007)]. For lighting usually pulse lasers, e.g. Nd: YAG, are used.

To gain an optical access to observe the wake field, the Con-Ro vessel was equipped with four portholes. Normally, the flow area to be examined is completely illuminated and there are stationary cameras. Due to the large measuring distances of more than 4 m below ship’s hull, the large flow field of about 3x3 m and the limited light energy transmission only local flow areas are illuminated and imaged by a High-Speed camera and a wide aperture lens.

In order to characterize the entire measuring area spatially resolved, both the observation and illumination setup must be pivoted. Precise and vibration-resistant motorized linear and rotation stages provide for an automatic definition of each single measurement volume.

To convert the particle displacement in a flow rate, a calibration of the PIV-system is required. For naval engineering considerations, the data are then transformed from image into ship’s coordinates. Since no calibration panels can be positioned in the measurement area, image equalization is done via two laser beams with a variable but defined distance. A similar approach, but with a structured laser light sheet has already been demonstrated by Willert [RAF (1998)].

In summary the technical challenges for adapting PIV to the harsh measurement environment directly above ship’s hull concern three areas: illumination of the measurement volumes, calibration of the optical distance estimation and the traversal, which includes the mounting, aligning and tilting of the measurement system. Furthermore, the identification of the positioning and velocity error is mandatory. Inside the propeller design process the determination of the axial flow component u is most important to specify the axial wake fraction (1). It depends on the measurement volume position in the plane, defined by the normalized radius r/R and the propeller angle $\theta$. V is the axial ship velocity.

$$w(r/R, \theta) = 1 - \frac{u(r/R, \theta)}{v}$$

(1)

The uncertainty of u in ship coordinates after the transformation of the two component picture data is below one percent, since the tilting angle of the measurement area in front of the propeller (rotation about ship’s transversal axis Y) is below 15°. That is one reason, why the velocity determination initially was planned in two components ($0D2C$). Another reason is the limited measurement time, which depends directly on the water quality respectively the visibility in the Irish Sea and the English Channel. Through an exchange of observation and illumination setup over the two portholes however, a second observation direction and thus a determination of the third component of the velocity can be reached ($0D3C$).

In order to validate the developed measurement technique, two test voyages took place on the target ship. In addition, the measurement inaccuracies were determined by means of several tow rides of an original ship section in the towing tank of SVA.

3. Challenges of applying and validating the PIV-technique

A schematic configuration of the main setup components to conduct PIV – measurements is shown in Figure 5. The portholes were arranged almost at the same vertical level as the propeller to observe the wake field in front and the cavitation on both the suction and the pressure side of the propeller.
The most interesting area is spanned between 0 and 90°, as the propeller has the biggest affinity to suction side cavitation. A rotation of the illumination and the observation setup define single measurement volumes in the measurement sector. Additionally the measurement plane has to be tilted (rotation about Y), in order to measure the flow velocities in front of the propeller.

**Liquid prisms as an optical access**

Since the portholes were arranged at nearly the same vertical level as the propeller, a tilt angle (rotation around Y) has to be adjusted for both measurement setups to characterize flow velocities in front of the propeller. Both setups were finally tilted by 13.3°. For different measurement volumes in the tilted sector a second degree of freedom (rotation around X) became necessary. To serve those requirements liquid prisms were used (Figure 4).

They consist of a flexible bellow, which was filled with a fluid [ALB]. Since the camera or the laser respectively was firmly assembled perpendicular to the upper acrylic glass pane, a first refraction within the optical path can be avoided, regardless of the variable angle, necessary to define a measurement volume in the measurement sector. Refractive index matched oil (adapted for acrylic glass) implicates a single refraction at the lower pane, respectively the porthole, at the boundary layer to sea water. Compared with a water filling a wider angle, referred to the perpendicular, can be reached in order to observe the most interesting area around $\theta = 0$; $r/R = 1$. Whereas water lead to a parallel optical path and therefore to a better imaging quality.
Observation

The measurement target parameters are flow velocities of up to 10 m/s (vessel speed 19 kn). To obtain a particle offset of 1/10 of picture’s Y-dimension, corresponding to the main flow direction (see Figure 25), the time between both laser illuminations, respectively both PIV-pictures, was adjusted to 1400 µs. The vertical picture dimension for this consideration is ca. 14 cm using a lens with a focal length of 200 mm at a distance of the closest measurement volume of about 2 m. A bigger offset would deliver weaker correlation peaks, since the out of plane loss rise. An offset of few pixels however would reduce the precision of velocity determination. A large distance of 1/10 of the pictures vertical dimension can be defined, since the flow was not expected to be turbulent over this distance.

A HS-Camera became necessary to observe the particle flow in front of the propeller. For a short distance to the measurement sector it was mounted over porthole 2. Imaging quality tests were performed in an indoor swimming hall. Over an acrylic glass window from the side of a high diving water basin two air outlets were observed. The whole target construction, displayed in Figure 6, was positioned at distances and angles similar to the desired measurement volumes at full scale beneath the vessel (Figure 7). The ceramic air outlet generates bubbles with a mean diameter of 50 µm. If structures of those bubbles can be captured with a sufficient imaging quality, the expected bigger particles in vessels slip stream should be as well. The tests have confirmed that the imaging quality is better using a prism filled with water (Figure 8). Especially for higher refraction angles, e.g. to reach MP1 at $\theta = 0^\circ$; $r/R = 1$, the distortions (astigmatism and aberrations) using an oil prism prevent nuclei observation. A higher light absorption is a further disadvantage.

To choose a suitable objective the high-performance lenses Sigma 200-500 mm f/2.8 EX DG, Canon EF 400 mm f/2.8L IS II and Canon EF 200 mm f/2.8L II USM were verified. To control the lens parameters focal length and focus the high-speed camera was equipped with a Canon lens mount.
A high imaging quality and a wide aperture combined with a small closest focusing distance were the main criteria in the lens selection. Furthermore small lens dimensions are important for the usability in a very narrow measurement area. The weight has to allow for a traversing of the observation setup. A next circumstance is a rising minimum focusing distance, when the focal length became increased. In addition, observations in water cause a further increase by a factor of 1.33 compared with air.

All lenses have a small aperture value of 2.8 to catch as much light intensity as. The Sigma zoom lens promised to regulate the minimum focus distance by adjusting the focal length. At smaller distances the focal length can be decreased and the minimum focus distance decreases as well and the measurement volume can be observed. A main shortcoming is however, that focal lengths greater than 400 mm are only available from measuring distances in water at about 4 m. In addition the focus cannot be controlled by the high-speed camera. A third major disadvantage is the size (length = 700 mm/weight of 15 kg), which prevent accurate and reproducible traversing of the observation setup.

As a consequence, two lenses with a fixed focal length have been utilized. The Canon EF 400 mm f/2.8L IS II combined with a close-up ring delivers sufficient resolved pictures from 2.5 m and the Canon EF 200 mm f/2.8L II USM up to this radius. A partial automation by controlling the focus was possible, since both lenses can be controlled remotely via the canon lens mount.

**Illumination**

A monochromatic laser illumination (532 nm, Nd:YAG) offers efficient energy transmission and prevent chromatic aberrations. Not only the illumination of the measuring volume but also the calibration strategy were realized with one laser through the same optical access over porthole 3. Signal noise ratio has been improved by using an interference filter. Dimensions of the measurement volume are determined by the dimensions of the laser light sheet. A plano-concave cylindrical lens with \( f = -145 \) was used to widen the laser beam (\( \varnothing \approx 6 \) mm).

In order to characterize the axial component best, the laser light sheet was turned into the main flow direction for each measurement volume. The out of plane loss in the adaptive cross correlation for the axial component became reduced to a minimum.

The laser pulses and picture capturing were synchronized and triggered by the shaft signal. Due to a close average distance between each single measurement volume and the propeller, a high propeller influence on the wake field was expected which had to be characterized. To specify the propeller position for each measurement volume, the absolute \( 0^\circ \)-position had to be identified initially. For this purpose the propeller was illuminated stroboscopically over porthole 1. The flash lamp has been triggered by the shaft signal. The delay time between shafts signal and stroboscopic flash for \( 0^\circ \)-position (identified by a mounting hole on the stern tube) was determined and used to position the propeller for the measurements.

**Calibration of the velocity determination**

For the calibration of the recorded PIV double frame pictures two parallel laser beams have been projected into each measurement volume. By imaging the straight light beams the spherical and perspective aberrations became obvious. Based on those calibration images a matrix was generated for each measurement volume to equalize the double frame pictures. In order to avoid additional uncertainties the calibration pictures were taken by the same pulsed laser instead of assembling a second continuous laser. In order to recognize the single back-scattered photons as a ray, the 682 captured picture of a whole calibration video were summed up.

The known distance of both parallel rays defines the spatial length dimensions in the calibration pictures respectively the PIV double frame pictures for the velocity calculation.
Set-up and Alignment of the measurement equipment
The traversing of the measurement equipment was based on an X95 profile system. It was stiffly clamped on vessel’s H-profiles. The alignment of the complete setup was accomplished by a cross line leveling instrument, which defines a Cartesian coordinate system. The waterlines inside the vessel were used as reference edges. Hence the measurement sector is rigidly associated with the vessel regardless any ship movement.

The tilting of the illumination and the observation setup to define a measurement plane in front of the propeller by 13.3° was adjusted firmly over an X95 joint with a scale. The restricted space prevented a higher angle, necessary to avoid the penetration of the measurement area by the propeller in some angular positions. To define the discrete positions for each single measurement volume in the tilted sector motorized PI miCos linear and rotation stages were applied.
axis) a precise positioning of the several measurement volumes was possible. The rotation points of both beam paths remain constant in a defined spot of the porthole. Figure 11 to Figure 13 show the measurement setup, mounted in the steering gear compartment of ConRo-vessel “Amandine” over the portholes.

Tests and validation
Prior to the final measurement voyage, two round trips with Amandine were conducted. Main aims were to characterize water quality and to test the alignment and assembling of the measurement equipment under the real measurement circumstances. In order to characterize the measurement inaccuracies thoroughly a preparation measurement campaign at SVA was conducted. Two test carriers, emulating ships frame construction around porthole 2 and 3 have been manufactured by FSG, see Figure 15, and welded together on a pontoon by SVA. This construction, shown in Figure 14, was moved in the SVA towing tank with defined velocities to reference the measured PIV-velocities to the indeed speed of the tow carriage.

![Figure 14 Pontoon with two ship sections mounted on a carrier and moved in towing tank of SVA](image)

![Figure 15 Ship section around porthole 2](image)

Furthermore the calibration strategy and the axis automation to move the setups for measurement volume definition were tested and the assembling routine of the system was trained. By observing a self-luminous calibration target the positioning inaccuracies were determined. A watertight encapsulated Tablet PC (Figure 17) was moved over an XYZ-Portal in the measurement field (Figure 16). Several calibration patterns with different resolutions had been loaded remotely. The mean absolute positioning error in the SVA accounted 5 cm, whereas the inaccuracies of positioning the target of about 3 cm have to be considered.

The actual positioning inaccuracies beneath the ship were determined directly on the vessel prior to the measurements by aiming the setups at a fix spot at the vessel. A hole for mounting the rope guard on the stern tube served as a calibration mark (Figure 18). After a calibration process, based on this hole, the absolute positioning inaccuracy for measurement volumes at high distances are 3 cm. For closer volumes the error is even smaller. The offset in X in Figure 18 is explainable over the different Z-positions of porthole two and three. An offset correction could be achieved over different angles around Y for both setups. Unfortunately that needs to be done for every measurement volume. Since the lens aperture was wide enough in order to catch the slightly shifted laser the constant parallel shift of both planes is no relevant issue. The precise definition of the measurement plane is done by the illumination.
The identification of the inaccuracies in velocity determination was conducted at two measurement points MP1 and MP2 for 1.0, 1.5 and 2.0 m/s (see Figure 19). The towing tank velocity accuracy is 1 mm/s. After transforming the one component reference vector $V_s$ into picture coordinates $V$, over two rotations around $y$ (2) and $x$ (3) and comparing it with the measured vectors the relative error in $X$ was less than 5 %. In the depicted vector statistics (Figure 20) the error for the axial component is 3.88 %. Tilting angles around $X$ and $Y$ were 36° and 15° respectively.

$$\mathbf{V}_Y = \mathbf{R}_y \cdot \mathbf{V}_S \quad \text{mit} \quad \mathbf{R}_y = \begin{pmatrix} \cos \alpha & 0 & -\sin \alpha \\ 0 & 1 & 0 \\ \sin \alpha & 0 & \cos \alpha \end{pmatrix} \quad \text{with} \quad \mathbf{V}_S = \begin{pmatrix} -2 \\ 0 \\ 0 \end{pmatrix} \quad (2)$$

$$\mathbf{V}_B = \mathbf{R}_x \cdot \mathbf{V}_Y \quad \text{mit} \quad \mathbf{R}_x = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos \alpha & \sin \alpha \\ 0 & -\sin \alpha & \cos \alpha \end{pmatrix} \quad (3)$$
Since the water is assumed as motionless, the standard deviation is a measure of the inaccuracies in the whole measurement system. It was always less than 0.05 m/s. The value is needed to rate the turbulence beneath the vessel. The data rate wasn’t as good as at full scale due to a lower particle count. Seeding was necessary. Furthermore the standard deviation may be better, since the calming time of the water after one run may have been to short due to a limited measurement time in the tank.

A big error probability is the incorrect equalization of the PIV-pictures and the imprecise determination of the pixel scale factor in µm/Px. The distance between the calibration beams should be as large as possible. The whole porthole aperture should be used. The distance failure by only 5 Px result in an scale factor error around a few 10 µm. Over 80 pixels (1/10 of the picture) the error becomes crucial however. Even more important is the imaging quality to minimize the inaccuracies in the adaptive cross correlation algorithms. An inaccuracy of only one pixel in the offset estimation between two frames results in a mean velocity error of \( \Delta V_{\text{px}} \approx 0.15 \text{ m/s} \) at the different measurement volumes in the wake of the ship. An estimation (4-6) is outlined for the measurement volume 20.

\[
D(\text{mm}) = D(\text{Steps}) \times AR = 80.9625 \text{ mm} \tag{4}
\]

\[
\text{scale factor} = \frac{D(\text{mm})}{D(\text{Px})} = 0.1811242 \text{ mm/Px} \tag{5}
\]

\[
\Delta V_{\text{px}} = \frac{\text{scale factor} \times \text{pixel count}}{\Delta t} = 0.1294 \text{ m/s} \tag{6}
\]

- \( D(\text{Steps}) \) - distance of parallel beams in steps of a linear axis: 1700000 Steps
- \( AR \) - axis resolution: 0.047625 µm/Step
- \( D(\text{mm}) \) - distance of parallel beams in mm
- \( D(\text{Px}) \) - distance of parallel beams out of the calibration pictures
  (beam recognition): 447 Px
- \( \Delta t \) - time interval between two successive frames: 1400 µs

A camera with a higher resolution or a bigger time span between the double frames would increase the accuracy of the measurement system.

The vibrations onboard could be neglected due to their ten times lower frequencies compared with the double pulse rate of image acquisition. Nevertheless vessel acceleration and tilt data were recorded.

Discussing the constraints of the measurement system the necessity for good visibility in sea water has to be named first. The spots for the measurement campaigns in Mai 2013 for example were only defined by the water conditions (Figure 21). At good visibility measurements down to 6 m beneath ship’s hull are possible. Referring to the narrow observation angles of LDV, the developed PIV-setup can be tilted very easily. Angles of 75° for the illumination and 53° for the observation setup are close to the limit, considering optical challenges. Whereas the dimensions of the porthole prevent higher angles for the illumination, the narrow aperture and the therefore reduced light intensity is the restriction for the observation at angles higher than 55°. In the case of Amandine the most interesting area around \( \theta = 0^\circ; r/R = 1 \) couldn’t be observed because the frame construction around the portholes limited the tilt angles. The red circles in Figure 22 depict the collision points.

Another constraint is the restricted time on a measurement voyage. A compromise between several parameters has to be found. Those parameters are data rate respectively the measurement time on each volume, the amount of measurement volumes and the amount of discrete propeller angles if a non-continuous measurement is necessary, as it was in the case of “Amandine”.

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The equipment transport insight the vessel and the erection of the system, which take approximately 10 h for two persons, the equipment exchange for 0D3C (2 h) and the time for saving the recorded video files have to be kept in mind while planning the campaigns.

**Data analysis**

Since the measurement sector was penetrated in some angular positions (Figure 24), the influence of the propeller on the wake field had to be identified. Instead of continuous measurements four discrete propeller positions (0°, 22.5°, 45° and 67.5°) were observed at each measurement volume. To quadruple the raw data a PIV double frame was recorded after each propeller blade was passing (~146 ms) instead of after each propeller revolution. That means a data rate of about 7 Hz, determined by the process.

A total of 230 GB video data was captured. 341 double frames for each measurement volume over a time of only 50 s were recorded. 30 valid vectors in each double frame assure good statistics for velocity determination and result in 10000 validated PIV vectors at each propeller position in every...
measurement volume.
Preprocessing of the raw video data included an image smoothing and background correction. A
double frame picture is visualized in Figure 25. Picture equalization was done next by applying the
calibration matrix. The subsequent calculations of the velocity vector fields were accomplished by
means of adaptive cross correlation techniques [ALB]. The obtained vector fields, shown in Figure
26, were then spatial averaged (2D2C => 0D2C).
In the following data transformation from picture to ship coordinates an assumption for the
missing Z-coordinate has to be made. Calculations revealed, that the transformation error is
smaller using the calculated CFD-Values instead of Z_S\(=\)0 for instance.
For final data analysis numerical calculations (RANS/ANSYS CFX) were performed in the SVA
under consideration of the dynamic floating conditions (Figure 28) for the investigated operating
point at the same measurement plane with the same discrete propeller angles for full scale. A
comparison with the measured data showed, that a large part of the measured wake field data
show very slight deviations of less than 2%. But especially in the most interesting area (small
angles for \(\theta\) and \(r/R > 0.5\); measurement volume 11, 12, 15, 16, 17 in Figure 27), where the
properness of correction algorithms is difficult to estimate due to big deviations between model
and ship scale (Figure 1) systematic deviations of almost 10% were revealed. This indicates actual
simulation inaccuracies.

Figure 27 Comparison of the measured (GA) and calculated (CFD) axial flow component of the velocity data
at the 28 discrete measurement volumes at a propeller angle of 22.5°; the data is referred to the
water inflow velocity \(V_m\)
Figure 28 Total wake field simulation: calculated isotaches (lines of equal speed) of the total axial wake
fraction for the same propeller angle of 22.5° (above); dynamic floating conditions (below)
Due to the small measurement time, the unfavorable porthole positions and the high installation and calibration expense, three-dimensional velocity information could only be obtained for measurement volume 20. However another difference to CFD-Calculations was revealed with that data, since the measured radial component was twice as high as the simulated one.

4. Results and future challenges

The project KonKavII has proved, that the PIV-technique is well suited to record wake field velocity data at full-scale on vessels like the ConRo freight ferry “Amandine”. Compared with previously executed LDV measurements, PIV convince with a higher statistical secure data rate respectively immense shorter measurement times and is much more rugged through a relatively uncomplicated modular setup. It allows furthermore for a large angular measuring range. Through a setup exchange even a velocity determination of all three components is possible. In addition, the measuring system is recommended by small systematic errors. The calibration strategy has been proven right.

The measured data correspond very well with simulation data for large parts of the measurement plane. Systematic deviations in one region however indicate possible inaccuracies in current calculations.

A lot of experiences have been collected, which should determine the preparation of further measurement campaigns:

- The ship should be equipped with at least three portholes. The positions have to be as close as possible to the interesting measurement sector in the stern flow to shorten the optical path length in water. A setup exchange should be considered to allow for three component velocity determination.
- A fixed mark on vessel’s stern tube is mandatory to calibrate the measurement positions.
- During a sequential measurement of all measurement volumes uniform flow conditions and good water quality should prevail.
- Porthole positions must furthermore allow for a position definition of one measurement volume, where the open water speed, nearly unaffected by the stern, can be measured. CFD calculations should be taken into account. This would be the best inflow reference to determine a relative wake field.

One future challenge is to streamline the erection and operation of the measurement equipment as well as the data analysis in order to provide a system, which can be used repeatedly by third parties, e.g. the model basins with less effort and shorter data processing times. Depending on the count of measurement volumes few weeks should be aspired.

A second one is the participation on a project, where an indeed nominal wake field of a two screw ship could be measured. The vessel can be driven over one propeller whilst the second one turns unloaded. This provides the unique opportunity to measure the nominal wake as a crucial basis for calculating the design of vessel’s propulsion in full-scale.

REFERENCES

investigation of aircraft trailing vortices in a catapult facility using PIV, Proceedings of 8th International Conference on Laser Anemometry, Rom, Italy


