FOCUS ON IMAGING

In Application

Underwater PIV in High Velocity Towing Tanks

Introduction

Beside stationary PIV experiments with a wide range of individually configurable FlowMaster systems, LaVision adapts the non-intrusive measurement technique into moving environments like towing tanks.

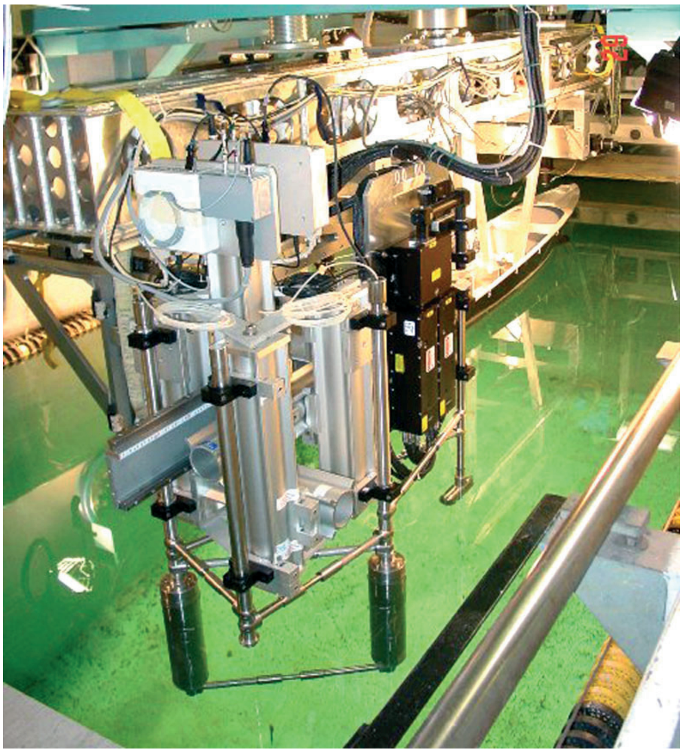

Figure 1: *Underwater PIV system in a towing tank*

The Underwater PIV (UW-PIV) system is a solution to cover the need for validation of numerical simulation of the flow field around ship hulls and similar marine applications. All involved system components like cameras, laser, optics etc. are protected in special torpedo shaped watertight streamlined housings which can be used in the wake flow of the ship model but also for maneuvering or seakeeping related applications. The PIV system is mounted to the carriage and towed with the ship model through the water tank. In many experiments our customers benefit from the proven mechanical rigidity and compact system size which lead to accurate measurement as LaVision customers in other application fields are used to.

Taking experimental data during tests for high-speed vessels is even more challenging as measurements at lower towing velocities. Operating the towing tank carriage at higher speeds increases significantly the structural vibrations and forces applied to the mechanical structure of the Underwater PIV system.

Therefore, LaVision developed a new rigid, wing-shaped vertical support tube which minimizes the hydrodynamical interaction with the ship model. Compared to the cylindrical shaped support tubes, lift and drag forces and therefore the deformation of the system is reduced to a minimum too. In combination with the high stiffness of the rectangular cross section main tube, the Underwater PIV system is capable to be used at high towing velocities and increased depth at the same time.

In this study, we present the development of the new Underwater PIV support tube for high-speed towing tanks and the verification at the towing tank no. 1 of the Department of Maritime and Transport Technology at the Delft University of Technology, The Netherlands.

Simulation of expected forces

The input targets for the new designed hydrofoil support tube were mainly described by the maximum immersion depth of the Underwater PIV mechanics (1.5 m from water surface) and a towing velocity of 7 m/s at the defined depth.
The main objectives during the design of the hydrofoiled shape for the support tube to decrease negative influence to the PIV measurements were:

- **lift force**: force acting perpendicular to the towing direction
- **drag force**: force parallel to the towing direction
- '**ventilation**': effect that air enters from the atmosphere to low pressure areas of the strut during movement

Especially **lift forces** are depending on the angle of attack, so the relative angle of the hydrofoil support tube to the towing direction. Too high lift forces would introduce a displacement of the relative position of the PIV system to the AOI (Area of Interest = measurement area) and are therefore a source of systematical measurement errors.

LaVisionUK Ltd
2 Minton Place / Victoria Road
Bicester, Oxon / OX26 6QB / United Kingdom
E-Mail: sales@lavision.com / www.lavisionuk.com
Phone: +44-(0)-870-997-6532 / Fax: +44-(0)-870-762-6252

LaVision GmbH
Anna-Vandenhoeck-Ring 19
D-37081 Göttingen / Germany
E-Mail: info@lavision.com / www.lavision.com
Tel. +49-(0)551-9004-0 / Fax +49-(0)551-9004-100

LaVision Inc.
211 W. Michigan Ave. / Suite 100
Ypsilanti, MI 48197 / USA
E-mail: sales@lavisioninc.com / www.lavisioninc.com
Phone: (734) 485 - 0913 / Fax: (240) 465 - 4306

LaVision
FOCUS ON IMAGING

Underwater PIV in High Velocity Towing Tanks

Comparing different shapes of the hydrofoil support tube the best tradeoff between reasonable flow around the support tube and low lift force were found in the 'Eppler E 838' profile, where a chord length (length in x-direction, i.e. in towing direction) of 0.32 m was chosen.

Figure 2 shows the compared profiles:

- **NACA 16-021** (maximum thickness of 21% at 50% chord length)
- **Eppler E 838** (maximum thickness of 18.4% at 37.2% chord length)

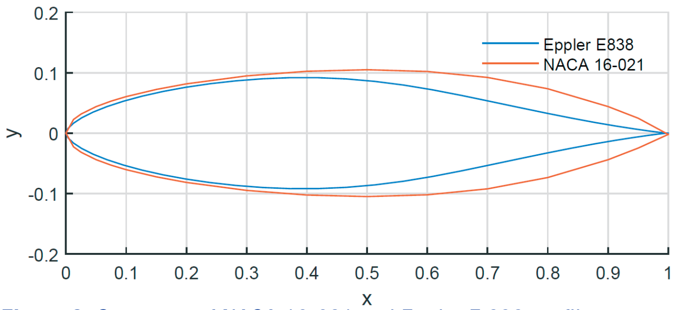

Figure 2: *Geometry of NACA 16-021 and Eppler E 838 profiles*

The plot in Figure 3 represents the calculated lift forces at different angles of attack on the Eppler E 838 profile, 1.5 m submerged.

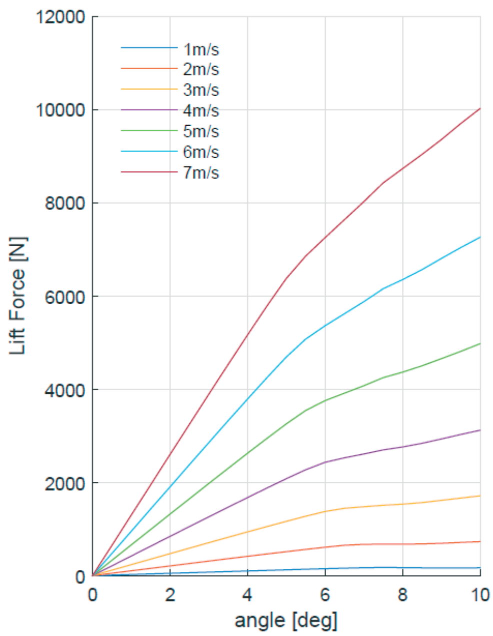

Figure 3: *Lift forces for Eppler E 838 profile*

The strong influence of the relative angle of attack lead to the conclusion that a strong rectangular cross section main support tube is necessary.

Drag forces under these conditions are at least two orders of magnitude lower than the lift forces and lead to the conclusion that these forces are not critical for the overall stability of the system.

In a next step, the calculated lift and drag forces were applied to a 3D CAD model, where the influence of the forces to the deformation of a typical horizontal Underwater PIV system was calculated (Fig. 4). The dimension and wall thickness of the stainless-steel support tube were chosen accordingly to the calculated results so the mechanics can be operated up to 1.5 m immersion depth, 7 m/s towing speed and 10° angle of attack. The rigid and stiff main support tube ensures a limited deformation at angles of attack up to 10° and high stability for the PIV measurements at high towing velocities.

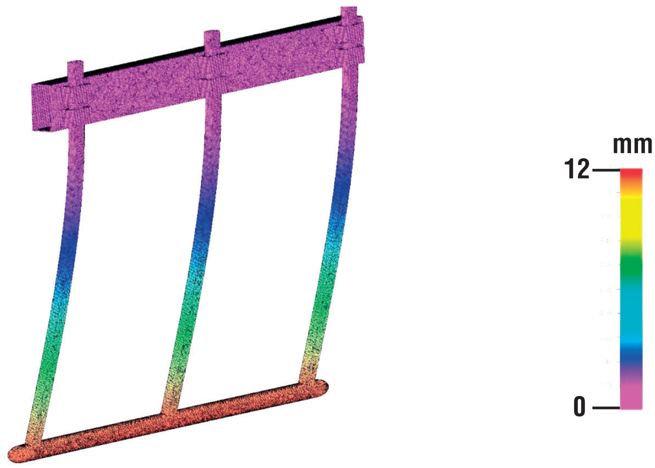

Figure 4: *Simulated deformation of an UW-PIV structure*

Compared to cylindrical shaped support tubes, the Eppler E 838 shape leads to much lower **ventilation effect**, even at high velocities up to 7 m/s. Ventilation would lead to disturbing effects in the recorded images. The ventilation was verified in the towing tank measurements too.

LaVisionUK Ltd
2 Minton Place / Victoria Road
Bicester, Oxon / OX26 6QB / United Kingdom
E-Mail: sales@lavision.com / www.lavisionuk.com
Phone: +44-(0)-870-997-6532 / Fax: +44-(0)-870-762-6252

LaVision GmbH
Anna-Vandenhoeck-Ring 19
D-37081 Göttingen / Germany
E-Mail: info@lavision.com / www.lavision.com
Tel. +49-(0)551-9004-0 / Fax +49-(0)551-9004-100

LaVision Inc.
211 W. Michigan Ave. / Suite 100
Ypsilanti, MI 48197 / USA
E-mail: sales@lavisioninc.com / www.lavisioninc.com
Phone: (734) 485 - 0913 / Fax: (240) 465 - 4306

Underwater PIV in High Velocity Towing Tanks

Simulation of expected forces

The simulated results were verified during measurements in towing tank no. 1 at the TU Delft in spring 2016 under extreme conditions: the experimental setup was chosen that way, that the Stereo-PIV cameras were separated in two single torpedo shaped housings, on the left and right hand side of the ship model (Fig. 5).

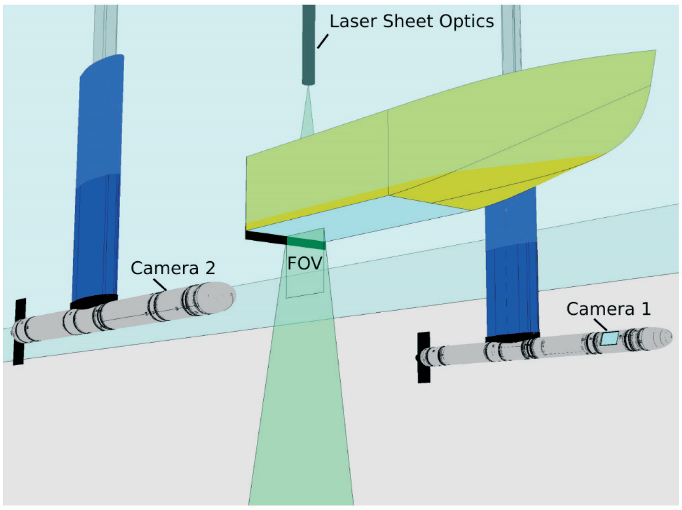

***Figure 5:** Experimental Underwater Stereo-PIV setup, courtesy of Jacobi et al., TU Delft*

The single vertical hydrofoiled support tubes were submerged 0.6 m while the maximum towing velocity was 5 m/s.

The lift and drag forces were measured during the experiments with separate strain gauges for x- and y- direction. The resonance or Eigen frequency was monitored at the same time using a built-in accelerometer to ensure that induced vibration will not increase to a critical point during the towing experiments.

The experiments confirmed the results as the simulated lift and drag forces were almost identical to the measured data. Fig. 6 shows the most critical lift (side) force during a single run at a towing velocity of 5 m/s. The peak side forces did not exceed 140 N, while the RMS was at less than 50 N.

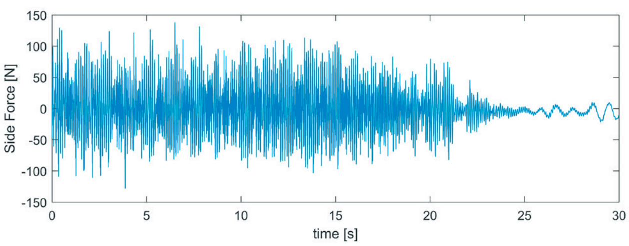

***Figure 6:** Lift forces during 5 m/s run*

During the evaluation of the vibration frequency it was found out that the system is not stimulated at a critical frequency but a vibration from the carriage is introduced to the mechanics (Fig. 7). This typical vibration in towing tank experiments lead to a displacement of the PIV camera images which can be corrected successfully with the '**Shift Correction**' and '**Stereo-PIV Self-Calibration**' functions in the **DaVis 8.3.1 software** used. So even at induced vibrations accurate Stereo-PIV results could be performed.

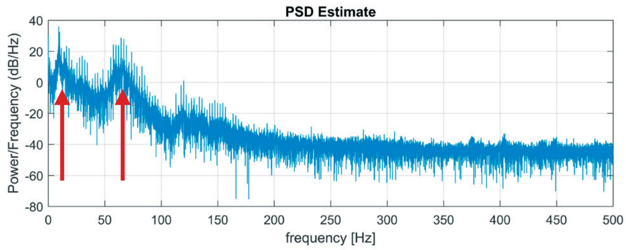

***Figure 7:** Induced vibration to PIV mechanics by towing carriage*

The important effect of ventilation was examined visually. Here it is important that the less air the better enters the area around the viewing window of the torpedo-shaped mechanics. In Fig. 8 the ventilation at 5 m/s is negligible.

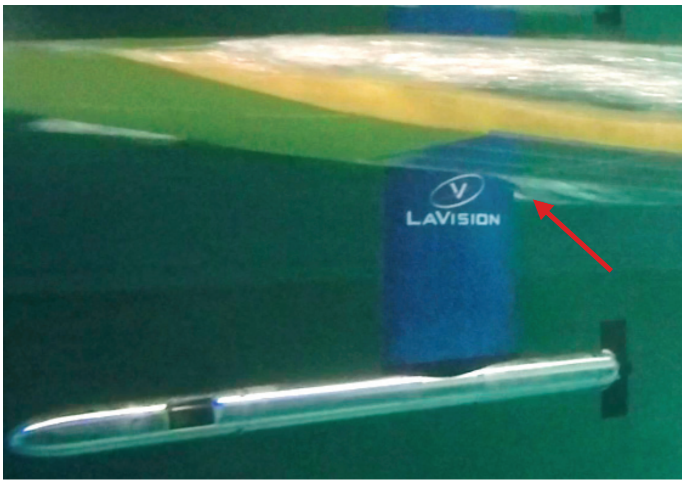

***Figure 8:** Low ventilation at high towing velocity of 5 m/s*

LaVisionUK Ltd
2 Minton Place / Victoria Road
Bicester, Oxon / OX26 6QB / United Kingdom
E-Mail: sales@lavision.com / www.lavisionuk.com
Phone: +44-(0)-870-997-6532 / Fax: +44-(0)-870-762-6252

LaVision GmbH
Anna-Vandenhoeck-Ring 19
D-37081 Göttingen / Germany
E-Mail: info@lavision.com / www.lavision.com
Tel. +49-(0)551-9004-0 / Fax +49-(0)551-9004-100

LaVision Inc.
211 W. Michigan Ave. / Suite 100
Ypsilanti, MI 48197 / USA
E-mail: sales@lavisioninc.com / www.lavisioninc.com
Phone: (734) 485 - 0913 / Fax: (240) 465 - 4306

Underwater PIV in High Velocity Towing Tanks

Conclusion

With the new hydrofoiled support tubes LaVision's Underwater PIV systems can be used even at very challenging towing tank conditions. The growing demand for high-speed vessels in coastal water and offshore applications leads to a higher experimental effort for the validation of numerical codes. This task can be fully covered with the PIV technique from LaVision.

The latest structural, mechanical and software development covered all special requirements to a measurement system used under these conditions:

- high (lift, drag) forces
- induced vibrations by carriage
- higher immersion depth
- ventilation
- influence to the ship flow field
- system setup flexibility

LaVision can provide the new hydrofoil support tubes in individual lengths along with an exact and field-proven calculation of expected forces. This ensures the best mechanical setup at the very first design stage of the Underwater PIV system. In combination with the advanced DaVis software and its unique correction functions, the Underwater PIV system will provide best experimental results.

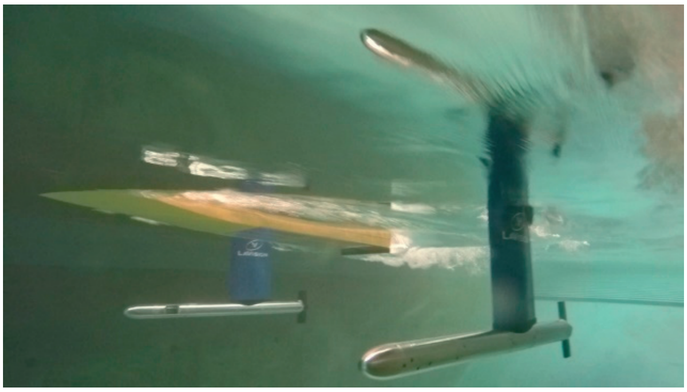

Figure 9: *Stereo-PIV measurement in the towing tank of the TU Delft*

For further information about the use of Underwater PIV at high towing velocities the reader is referred to 'The Application of Particle Image Velocimetry for the Analysis of High-Speed Craft Hydrodynamics' by Jacobi et al. (ICHD 2016).

LaVisionUK Ltd
2 Minton Place / Victoria Road
Bicester, Oxon / OX26 6QB / United Kingdom
E-Mail: sales@lavision.com / www.lavisionuk.com
Phone: +44-(0)-870-997-6532 / Fax: +44-(0)-870-762-6252

LaVision GmbH
Anna-Vandenhoeck-Ring 19
D-37081 Göttingen / Germany
E-Mail: info@lavision.com / www.lavision.com
Tel. +49-(0)551-9004-0 / Fax +49-(0)551-9004-100

LaVision Inc.
211 W. Michigan Ave. / Suite 100
Ypsilanti, MI 48197 / USA
E-mail: sales@lavisioninc.com / www.lavisioninc.com
Phone: (734) 485 - 0913 / Fax: (240) 465 - 4306