CAVITATION CLOUD EROSION MODEL – CLOUD SAMPLE EXPERIMENTAL TESTS

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Abstract

Hydrodynamic cavitation erosion remains insufficiently understood and hardly predictable. A new innovative and promising cavitation erosion model has been tested and was so far found valid. It creates a correlation between the erosion rate and the cavitation cloud fluctuations for the case of transient cloud cavitation.

A measurement technique has been developed, which acquires time resolved images of the cavitation clouds and deduces a gauge for the cloud extension. The analysis of the cloud fluctuations for different cavitation numbers and constant velocity revealed a maximum for a certain cavitation number. This corresponds to the maximum aggressiveness of the cavitation erosion at this range of the cavitation number. Planned tests with continuous time resolved image acquisition and analysis may furthermore confirm the model approach concerning the velocity scale effect.

Introduction

The erosive effects of hydrodynamic cavitation still remain insufficiently predictable. A large variety of empirical data about erosion pattern and rates for numerous experimental setups has been gathered, but no unitary model could be deduced yet and the direct transferability of experimental results to prototype facilities is hindered by scale effects, e.g. size scale effect and velocity scale effect. Although the origin of the erosion, i.e. the dynamics and collapses of the microscopic cavitation bubbles could be clarified, it is so far impossible to combine these processes with hydrodynamic cavitation, as the calculation of the large number and the complex dynamic of the bubble regime is impossible with nowadays processing power.

A recently at the TU Darmstadt developed erosion model establishes a relation between the dynamics of the cavitation clouds and the erosive properties of the flow phenomenon. It is meant to explain the especially aggressive transient cloud cavitation and postulates coherent collapses of the clouds, which emit strong pressure waves. These waves are thought to initialize the formation of fierce micro jets in bubbles near a solid boundary. Therefore the cavitation clouds cause substantial damage to the material. This approach is thus promising to predict cavitation erosion from flow investigations or numerical simulations (Dular et al., 2006).

However it was so far just implemented on the basis of time averaged, pixel-wise greyscale fluctuations, which served to evaluate the vapour fraction variations. The actual vapour clouds were not measured directly. Furthermore the model was just validated for one flow phenomenon (shedding cloud cavitation at hydrofoils) and the velocity scale effect was just included in an empirically motivated formalism.

Content

Thanks to extensive cavitation erosion test series with mass loss and pit count techniques at the hydraulic laboratory in Obernach (VAO) the scale effects of erosion, i.e. its dependencies from hydraulic conditions are known for a number of experimental setups. The cavitation cloud erosion model should be employed for these experiments, to see if it is capable to explain the empirical data. The cavitation clouds should be observed directly instead of using time averaged, pixel-wise grayscale fluctuations. However in the first stage, presented in here, no continuously time resolved cloud observation was implemented, but the clouds were visualized at random moments and the results of these samples were analyzed statistically.

The former erosion research campaigns revealed a strong velocity scale effect (increase of damage rate with rising velocity under constant cavitation number) on the one hand side and a maximum aggressiveness for a given cavitation number (~ 1.5) at constant velocity on the other hand side (see Fig. 1) (Huber, 2004) (Geiger et al., 2009). According to the concept of the cavitation number (same cloud appearance for constant cavitation number) the first observation should not be explainable by cloud behavior without a continuous time resolved analysis of the cloud dynamics, which enables the detection of a higher shedding frequency of clouds with the same size. However the second observation may also be understandable by the investigation of random samples of the cloud size.

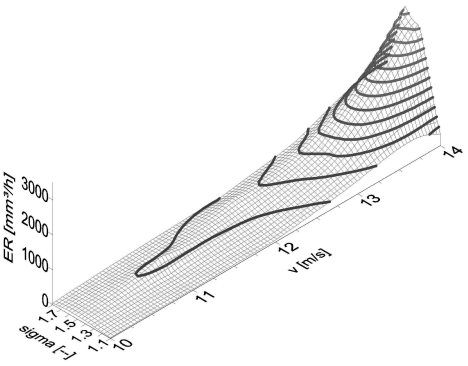

Figure 1: Dependency of erosion rate (ER) on flow velocity v and cavitation number σ (Huber. 2004)

Experimental Setup

Tests were conducted in the cavitation rig K26 at the VAO. A rectangular prism (height 97.5 mm) with an equilateral triangle base (side length 75 mm) was mounted in the middle of the square shaped test section (side length 300 mm) with one corner pointing in opposition to the flow direction. For cavitation numbers σ of about 1.5 ± 0.5 transient cavitation clouds appear in the triangle wake's shear layer vortices. This represents one of the experiments, for which detailed erosion tests were already completed and analyzed.

So far a simple and not continuously time resolved approach with a standard CMOS digital camera (Edmund Optics, 1280 x 1024 black and white) and stroboscopic illumination (DrellScop 2008, up to 25000 flash/min.) was implemented. Optical access to the experiment was provided by acrylic glass in top view of the prism. The manual adjustment of frame rate, exposure time and stroboscope frequency could achieve series of time resolved cavitation cloud images. They were processed subsequently to deduce the cloud surface in the projection plane of the camera perspective. Figure 2 shows the setup.

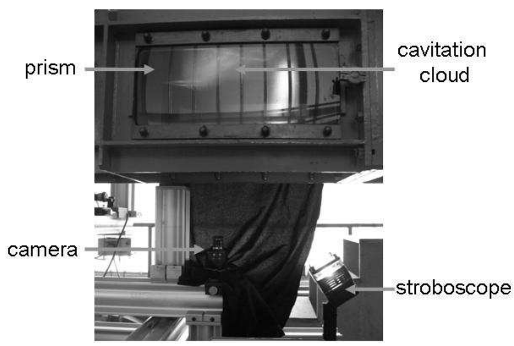

Figure 2: Experimental Setup, flow direction from left to right

Image acquisition and processing was done successively by a LabVIEW based program. The acquired images were filtered (noise reduction), binarized, conditioned and the resulting primary objects measured (number of pixels). Whereas the cavitation clouds were brightly illuminated, the background remained dark, which enabled the separation of the clouds. Due to the stroboscopic illumination and the darkening from other light sources each image provided a time resolved cloud shape. Original images and binarized ones could be compared directly on the interface to confirm the correctness and to adjust parameters if necessary. In each series 1000 to 5000 images where taken, processed and the final results stored (cloud size per image in number of pixels for each image). Of course the size of the cavitation cloud with regard to the camera perspective does in general not enable the calculation of the total cloud volume, because of the complex vapor structure. However for the given type of cavitation clouds (known from high-speed imaging in (Huber, 2004)) it's a monotonous function of the volume and provides thus an appropriate measure.

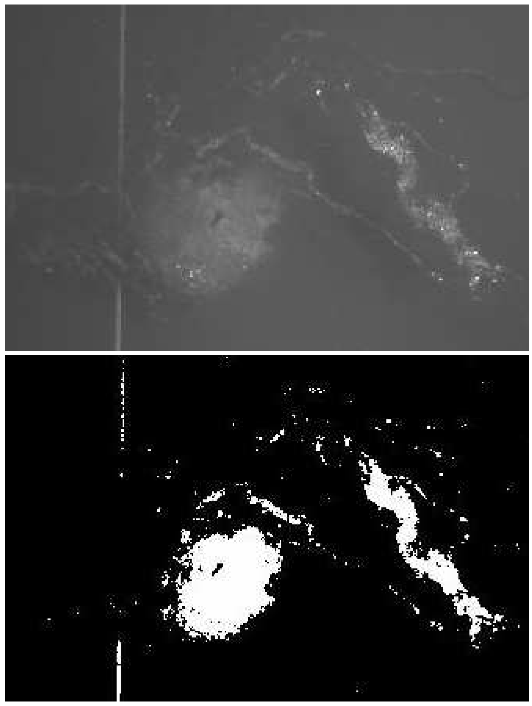

Figure 3: Exemplary original (top) and binarized (bottom) images of cavitation cloud, flow direction from left to right

The variation of hydraulic conditions included so far test section inflow velocities of 9.2 m/s and 10 m/s and cavitation numbers from 0.85 to 1.92.

Results

According to the erosion model the damage rate DR is a monotonic inclining function of the cloud volume change per time dV/dt. The implemented stepwise cloud volume observation does not allow a direct conclusion on this parameter. However it enables an assessment of the absolute cloud volume fluctuation ΔV, regardless of the frequency of the coherent collapses, which can be expected to be rather constant for constant velocity anyway. The standard deviation was employed to quantify the cloud fluctuations.

Figure 2 shows the average cloud size and the respective standard deviation for several cavitation numbers at a test section inflow velocity of 9.2 m/s. The cloud volume does understandably rise with decreasing cavitation number. The standard deviation shows a maximum for a cavitation number of about 1.4. This peak corresponds to the maximum erosion rate for a cavitation number of about 1.5 for a given velocity (Huber, 2004). The shift of the cavitation numbers may simply be caused by measurement inaccuracy or could be explained by an interference of the fluctuation function with the total size of the clouds. For lower cavitation numbers the clouds which remain after the coherent collapse are relatively larger and may thus buffer more collapse energy. So the maximum of erosion aggressiveness would be shifted towards higher cavitation numbers.

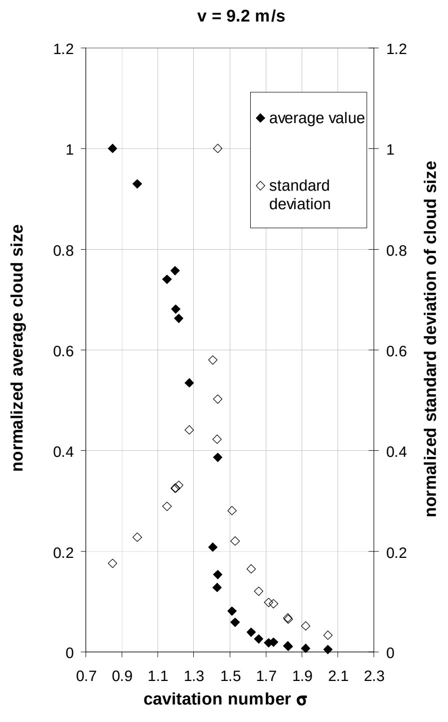

Figure 3: Dependency of cloud size and its fluctuations from the cavitation number for a test section inflow velocity of 9.2 m/s

Detailed tests series concerning the sensitivity of different parameters (camera attributes and image processing variables) revealed an influence of the binarization threshold. The cavitation number value of the cloud size standard deviation maximum could be altered. There remains a certain range for the choice of the threshold value, where the determination seems adequate (direct comparison of original and binarized images) and the maximum of the cavitation number varies of about 0.05. An automized determination of the binarization threshold could serve to avoid such a rather arbitrary choice of the parameter. However the available algorithms were developed with regard to technically motivated problems, e.g. machine vision and it remains so far unclear whether they are adequate for the detection of cavitation clouds. Investigations to clarify this point are going on at the moment.

Conclusion

The developed technique could successfully assess the size of the cavitation cloud and acquire a large number of measurement data for statistical purpose. Although it remains a certain inaccuracy due to a lack of objective calibration of image processing parameters, the general idea of the cavitation erosion cloud model could be confirmed so far. Both, the cavitation erosion rate and the fluctuations of the cavitation cloud size show a maximum for a cavitation number of about 1.45 at a given velocity.

The statements should still be confirmed for a larger variety of velocities and an imperial approach for determining the binarization threshold has to be developed. Furthermore a continuously time resolved observation and analysis of the cavitation clouds has to be implemented to clarify whether the velocity scale effect can also be explained by the cavitation erosion cloud model theory.

References

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