New insights into the Mechanisms of Cavitation Erosion

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Abstract. Recently simultaneous observation of both cavitation structures and cavitation damage, has pointed to the fact that the small scale structures and the topology of the cavitation clouds play a significant role in cavitation erosive potential. Although this opened some new insights to the physics of cavitation damage, many new questions appeared. In the present study we attached a thin aluminium foil to the surface of a transparent Venturi section using two sided transparent adhesive tape. The surface was very soft – prone to be severely damaged by cavitation in a very short period of time. Using high speed cameras, which captured the images at 30000 frames per second, we simultaneously recorded cavitation structures (from several perspectives) and the surface of the foil. Analysis of the images revealed that five distinctive damage mechanisms exist – spherical cavitation cloud collapse, horseshoe cavitation cloud collapse, the "twister" cavitation cloud collapse and in addition it was found that pits also appear at the moment of cavitation cloud separation and near the stagnation point at the closure of the attached cavity.

1. Introduction

Cavitation and consequently cavitation erosion is one of the most ubiquitous problems at operation of turbines, pumps, ship propellers and valves.

In the past, cavitation shedding process and its relation to the erosive potential of cavitation was frequently discussed. Reisman et al. [1] suggested that the formation, focusing and propagation of shock waves, emitted at macroscopic structures collapse play a critical role in generating the pressure pulses which lead to cavitation noise and damage. Bark et al. [2] pointed to the spherical cavitation cloud collapse, where the converging flow enables efficient focusing of the energy which increases as the collapse proceeds and is finally converted into acoustic energy in the cavity collapse, associated with the radiation of shock waves. Foeth et al. [3] have shown that the cloud cavitation that is associated with the break up of sheet cavitation is essentially an organized mixture of cavitating vortices. Van Rijsbergen et al. [4] related the structures to the acoustic emission signals and suggested that the orientation of the shock wave should be considered.

Large scale primary spanwise vortices were studied by Pereira et al. [5] and Kawanami et al. [6], who have shown that the focusing of the collapse could play a role in the aggressiveness of erosion.

The present study is a logical continuation of our previous work [7]. Here the types of macro-cavities or the origins of damage occurrence are discussed. High speed cameras were used to simultaneously record the sequences of the cavitation dynamics and the damage sustained on the surface of the solid body. It is shown that the shedding process can evolve in different ways, leading to various hydrodynamic mechanisms that eventually converge to extreme conditions that can trigger

events on a micro-scale that cause erosion. The results are valuable for future development of cavitation erosion prediction methods [8, 9].

2. Experimental set-up

Erosion was studied in a Venturi geometry, which was 10 mm wide with a converging angle of 18º and diverging angle of 8º. The throat dimensions were $10 \times 10 \text{mm}^2$.

The idea of the experiment was to simultaneously record images of cavitation structures and cavitation erosion. The upper side of the foil is covered by vapour structures that obstruct the view, hence one needs to look at the foil from the bottom side to see the damage. Consequently the whole test section had to be made of transparent material and, equally important, the foil had to be thin enough so that the cavitation damage, which occurs on the side exposed to cavitation was also visible on the other side.

For the present experiment high speed cameras were synchronized and recorded at 30000fps at a reduced (608×86 pixels) resolution. One camera was used for observation of the aluminium foil while the other one captured images of cavitation structures.

Erosion was evaluated in image pairs: image at time t+Δt was subtracted from image at time t. This way the change between times t and t+Δt could be detected and recognized as damage [7].

3. Results

In the following we present the results of extensive image analysis. In the process, first the instant of the damage occurrence was determined by comparing pairs of successive images of the foil. Then the evolution of cavitation structures during this period was analyzed and correlations between the two were investigated. Figure 1 represents the time evolution and the variants of the shedding that lead to different mechanisms of cavitation induced damage, which were observed during our study (Fig. 2).

The instants (C, E, H, L and O) when the damage occurs are highlighted by the darker colour.
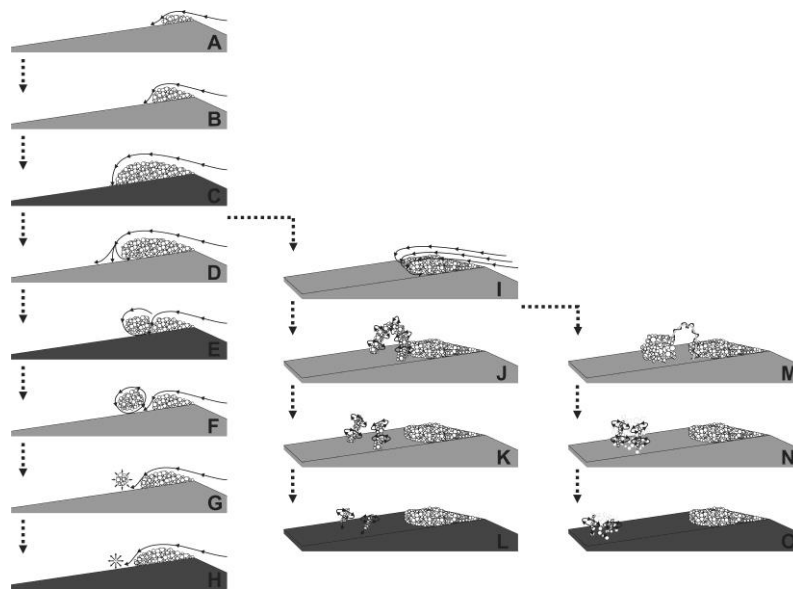

Figure 1. Representation of observed mechanisms that lead to occurrence of cavitation erosion.

Not less than 5 different mechanisms that lead to the formation of the pit were determined, although it is possible that the physical background of some is more or less the same.

The damage in Fig. 2 is enlarged (3 times) for better representation and appears smaller in reality (its position and shape are not altered). A deeper discussion of the mechanisms follows.
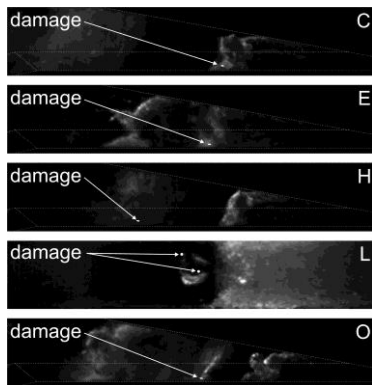
Figure 2. Cavitation structures at the moments at which the damage appeared on the foil. The position and the size of the damage were obtained from the images of the foil and were superimposed to the images of the structures.

3.1. Closure of the attached cavity (C in Figs. 1 and 2)

During the shedding process the outer flow, due to the pressure difference between cavity exterior and interior, deviates towards the solid surface and creates a stagnation point with elevated pressure. For erosion to occur small scale cavitation structures (single bubbles, which sporadically break off from the attached cavity) must enter the region of higher pressure in the vicinity of the solid surface, and violently collapse. This, however, occurs very rarely due to the fact that the developing re-entrant jet blocks the shedding of small scale structures.

3.2. Cavitation cloud separation (E in Figs. 1 and 2)

As the re-entrant jet looses momentum it turns upwards cutting the attached cavity into two parts. At this moment the gap between the cloud and the attached cavity is filled up with liquid causing an increase of the pressure. Again small scale structures that are present in the gap collapse and cause pit formations.

3.3. Spherical cavitation cloud collapse (H in Figs. 1 and 2)

Most often erosion is associated with the collapse of primarily cloud cavitation, referring to the fact that collective collapses of interacting bubbles in the cloud are shown to be very effective in focusing collapse energy into a small spot, and typically generate significantly larger collapse pulse amplitudes than singly connected cavities. According to the energy cascade approach [2] the pressure waves emitted at the cloud collapse spread and cause implosion of micro-scale single bubbles in the vicinity of solid structures – causing pitting and eventually erosion.

3.4. Horseshoe cavitation structure collapse (L in Figs. 1 and 2)

Cavitating vortices, which appear in a form of a horseshoe shaped structure, are known to be responsible for severe erosion in fluid machinery.

We could observe that the damage occurs as the vortex begins to break up. Pits appear in the region where the vortex leg touches the surface, thus implying that the breakup of the vortex "leg" and consequent focusing of acoustic energy in space and time (as postulated by van Terwisga et al. [10]) increases the aggressiveness and causes the formation of the pit.

3.5. "Twister" cavitation structure collapse (O in Figs. 1 and 2)

We believe that the origin of the "twister" type of cavitation structure is the same as for the horseshoe structure. The vortex is produced at the breakup region, but it remains liquid. As it is carried downstream by the flow it interacts with the cavitation cloud, what causes it to cavitate. This, like in the case of a breakup of a horseshoe cavitation structure, focuses the acoustic energy towards the solid material.

We can again see that the damage is concentrated in the region where the twister touches the solid surface and that it generally occurs when the vortex breaks-up.

3.6. Some statistics

The importance of individual mechanism can be defined by the product of its probability of occurrence and the damage (averaged damaged area sustained during individual events) it causes. A large ensemble of the data (over 3000 shedding periods) enables statistical evaluation of the probability of occurrence and the erosive potential of the mechanisms – Fig. 3 shows the results.
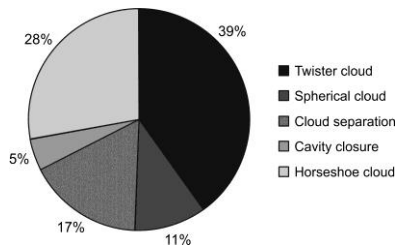

Figure 3. The relative importance of individual mechanism.

One can see that, the cloud implosion combined (the sum of the importance of the twister cloud, the horseshoe cloud and the spherical cloud) contributes to almost 80 % of the damage – it is clear why numerous researchers stressed so much importance to it. Between the mechanisms the twister cloud implosion is the one to be most considered. It appears frequently and is aggressive; hence it contributes to 39% of the sustained damage. A very important mechanism is also the horseshoe cloud implosion – mainly due to its aggressiveness. It is possible that its importance is even greater in channels with wider span, where the horseshoe vortex can more easily develop.

Surprisingly important is the mechanism of cavitation cloud separation from the attached part of the cavity, which was, prior to this study, probably mistaken for the mechanism of cavity closure, since they both contribute to damage in a similar region. The later is of an insignificant importance.

4. Conclusions

The study presents an original experimental technique where the cavitation structures and cavitation damage are observed simultaneously at a relatively high frame rate (30000 fps).

It was shown that the process of cavitation erosion is much more complex than previously thought. New phenomena were observed – for example the development and focused collapse of the twister cloud and damage occurrence in the region of cavitation cloud separation.

References

[1] Reisman G E, Wang Y C and Brennen C E 1998 J. Flu. Mech. **355** 255-83
[2] Bark G, Friesch J, Kuiper G and Ligtelijn J T 2004 Proc 9th Symposium on Practical Design of Ships and Other Floating Structures, Luebeck-Travemuende.
[3] Foeth E J, van Terwisga T and van Doorne C 2008 *ASME J. Fluids Eng.* **130(7)**,071303
[4] van Rijsbergen M, Foeth E J, Fitzsimmons P and Boorsma A 2012 Proc 7th International Symposium on Cavitation, Singapore, Singapore.
[5] Pereira F, Avellan F, and Dupont J M 1998 *ASME J. Fluids Eng* **120(4)**, 719-27
[6] Kawanami Y, Kato H, Yamaguchi H, Maeda M and Nakasumi S 2002 *JSME International Journal* **45(3)**, 655-61.
[7] Petkovšek M and Dular M 2013 *Wear* **300(1/2)**, 55-64
[8] Dular M and Coutier-Delgosha O 2009 *Int. J. Numer. Meth. Fluids* **61**,1388–410
[9] Wang J, Petkovšek M, Liu H, Sirok B and Dular M 2015 *ASME J. Fluids Eng* **137(5)**, 1-9.
[10] van Terwisga T, Fitzsimmons P A, Ziru and Foeth E J 2009 Proc 7th International Symposium on Cavitation, Ann Arbor, Michigan, USA