Cavitation Nuclei Population and Event Rates

Zhenhuan Liu
Graduate Student.

Christopher E. Brennen
Professor.

Division of Engineering
and Applied Science,
California Institute of Technology,
Pasadena, CA 91125

To model the processes of cavitation inception, noise and damage, it is necessary to generate a model of the cavitation event rate which can then be coupled with the consequences of the individual events to produce a complete synthesis of the phenomenon. In this paper we describe recent efforts to connect the observed event rates to the measured distributions of cavitation nuclei in the oncoming stream. Comparisons are made between the observed event rates and event rates calculated from measured nuclei distributions using an algorithm which includes the dynamics of the nuclei motion and growth. Various complications are explored including the effect of the boundary layer, the relative motion between the nucleus and the liquid, the observable bubble size effect, and the effect of bubble growth on neighboring nuclei. All of these are seen to have important influences on the event rate, and therefore, on cavitation inception and other macroscopic consequences. We demonstrate that it is possible to predict the correct order of magnitude of the event rate when an attempt is made to model the important flow complications.

1 Introduction

In order to synthesize the cumulative effects of a stream of traveling cavitation bubbles, it is necessary to supplement the details of individual events with the rates at which these events occur. Many investigators have anticipated a relationship between the cavitation event rate and the concentration of cavitation nuclei in the oncoming stream (see, for example, Schiebe, 1972; Keller, 1972, 1974; Keller and Weitendorf, 1976; Kuiper, 1978; Gates and Acosta, 1978; Meyer et al., 1992). At first sight this seems like a straightforward problem of computing the flux of nuclei into the region for which $C_p < -\sigma$. However, many complications arise which make this analysis more difficult than might otherwise appear and we shall discuss some of the specific issues below. But these difficulties do not account for the lack of experimental research into the relationship. Rather, the difficulties involved in the accurate measurement of the incoming nuclei number distribution function, $N(R)$, have been responsible for the delay in any detailed, quantitative investigation of this component of the problem. (Note that $N(R)dR$ is the number of nuclei with size between R and $R + dR$ per unit volume.) As Billet (1985) remarked in his review of nuclei measurement techniques, the only reliable method of obtaining $N(R)$ has been the extremely time-consuming procedure of surveying a reconstruction of an in situ hologram of a small volume of tunnel water (Gates and Bacon, 1978). However, the time and effort required to construct one $N(R)$ distribution by this method has seriously limited the scope of these investigations.

The recent development of light scattering instruments employing phase Doppler techniques (Saffman et al., 1984; Tanger et al., 1992) has improved the situation. In our laboratory, we have succeeded in validating and calibrating a Phase Doppler Anemometer (PDA) made by Dantec by taking simultaneous measurements with the PDA and a holographic system (Liu et al., 1993). The great advantage of the PDA system is the speed with which $N(R)$ can be measured. After validation, the PDA system could then be used with confidence for investigations of the nuclei population dynamics in a water tunnel (Liu et al., 1993 and 1994) and of the aforementioned relation between $N(R)$ and the cavitation event rate (Liu et al., 1993, Liu and Brennen, 1994).

In this paper, we first present the experimental observations of cavitation event rates on a Schiebe headform with simultaneous measurement of the nuclei distribution in the upcoming stream. We then present an analytical model to synthesize the event rates from the measured nuclei distributions. Then we compare the predicted event rates with cavitation observations in two water tunnels with quite different nuclei population dynamics.

2 Observations of Nuclei Population and Event Rates

The experiments were performed in the Low Turbulence Water Tunnel (LTWT) and the High Speed Water Tunnel (HSWT) at Caltech. Detailed descriptions of these two water tunnels can be found in other literature (see Gates, 1978 and Liu and Brennen, 1995), and will not be repeated here. Figure 1 shows a sketch of the experimental setup. A Schiebe headform with 5.08 cm diameter was installed at the center of the water tunnel. The free-stream nuclei number distribution was measured by a Phase Doppler Anemometer (PDA), which was calibrated by comparing the results with those obtained by a holographic method (Liu et al., 1993). On the other hand, the cavitation event rate on the Schiebe headform was measured by three flush-mounted electrodes on the headform surface (Ceccio and Brennen, 1992 and Kuhn de Chizelle et al., 1992).

In Fig. 2, we present a typical comparison of the nuclei number density distributions in the LTWT and in the HSWT. Also plotted in the figure are measurements in other facilities (Arndt and Keller, 1976; Peterson et al., 1972, 1975; Feldberg and Shlemenson, 1971; Keller and Weitendorf, 1976; and Gates and Bacon, 1978) and in the ocean (Cartmill and Su, 1993). As expected, substantial differences in the nuclei number density distributions in the two water tunnels were found. Although the shapes of the distributions are similar, the differences in the magnitudes were as much as two orders of magnitude. The typical nuclei concentration in the LTWT is quite large, about 100 cm^{-3}; while the nuclei concentration in the HSWT is low at about 1 cm^{-3}. Billet (1985) and Gindroz and Billet (1994) presented useful reviews of the subject of nuclei concentrations and distributions. They found that for deaerated water, typical concentrations are of the order of 20 cm^{-3} with sizes ranging from about 5 μm to about 20 μm. We conclude that the LTWT is nuclei rich and the HSWT is nuclei poor. This was expected

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