Cavitation Damage

Perhaps the most ubiquitous engineering problem caused by cavitation is the material damage that cavitation bubbles can cause when they collapse in the vicinity of a solid surface. Consequently, this subject has been studied quite intensively for many years (see, for example, ASTM 1967; Thiruvengadam 1967, 1974; Knapp, Daily, and Hammitt 1970). The problem is a difficult one because it involves complicated unsteady flow phenomena combined with the reaction of the particular material of which the solid surface is made. Though there exist many empirical rules designed to help the engineer evaluate the potential cavitation damage rate in a given application, there remain a number of basic questions regarding the fundamental mechanisms involved. Cavitation bubble collapse is a violent process that generates highly localized, large-amplitude shock waves (section (Nhc)) and microjets (section (Nhd)). When this collapse occurs close to a solid surface, these intense disturbances generate highly localized and transient surface stresses. With softer material, individual pits caused by a single bubble collapse are often observed. But with the harder materials used in most applications it is the repetition of the loading due to repeated collapses that causes local surface fatigue failure and the subsequent detachment of pieces of material. Thus cavitation damage to metals usually has the crystalline appearance of fatigue failure. The damaged runner and pump impeller in figures 1 and 2 are typical examples

The issue of whether cavitation damage is caused by microjets or by shock waves generated when the remnant cloud of bubble reaches its minimum volume (or by both) has been debated for many years. In the 1940s and 1950s the focus was on the shock waves generated by spherical bubble collapse. When the phenomenon of the microjet was first observed, the focus shifted to studies of the impulsive pressures generated by microjets. First Shima *et al.* (1983) used high speed Schlieren photography to show that a spherical shock wave was indeed generated by the remnant cloud at the instant of minimum volume. About the same time, Fujikawa and Akamatsu (1980) used a photoelastic material so that they could simultaneously observe the stresses in the solid and measure the acoustic pulses and were able to confirm that the impulsive stresses in the material were initiated at the same moment as the acoustic pulse. They also concluded that this corresponded to the instant of minimum volume and that the waves were not produced by the microjet. Later, however, Kimoto (1987) observed stress pulses that resulted both from microjet impingement and from the remnant cloud collapse shock.

The microjet phenomenon in a quiescent fluid has been extensively studied analytically as well as ex-

Figure 1: Major cavitation damage to the blades at the discharge from a Francis turbine.
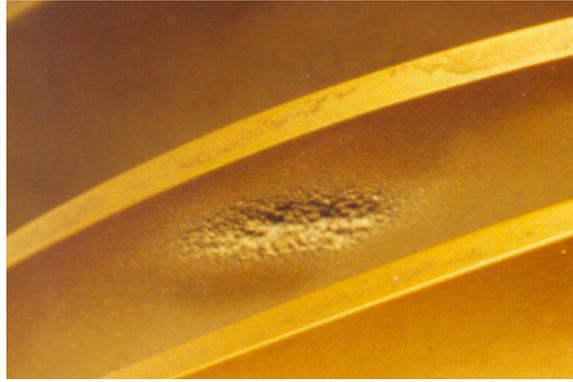
Figure 2: Photograph of localized cavitation damage on the blade of a mixed flow pump impeller made from an aluminum-based alloy.
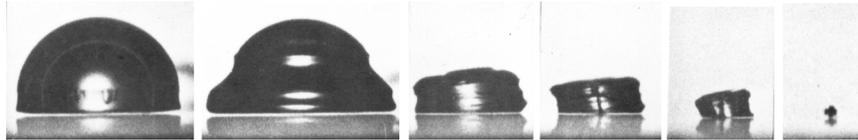

Figure 3: Series of photographs of a hemispherical bubble collapsing against a wall showing the *pancaking* mode of collapse. From Benjamin and Ellis (1966) reproduced with permission of the first author.

perimentally. Plesset and Chapman (1971) numerically calculated the distortion of an initially spherical bubble as it collapsed close to a solid boundary and, as figure **??** demonstrates, their profiles are in good agreement with the experimental observations of Lauterborn and Bolle (1975). Blake and Gibson (1987) review the current state of knowledge, particularly the analytical methods for solving for bubbles collapsing near a solid or a flexible surface.

It must also be noted that there are many circumstances in which it is difficult to discern a microjet. Some modes of bubble collapse near a wall involve a *pancaking* mode exemplified by the photographs in figure 3 and in which no microjet is easily recognized.

Finally, it is important to emphasize that virtually all of the observations described above pertain to bubble collapse in an otherwise quiescent fluid. A bubble that grows and collapses in a flow is subject to other deformations that can significantly alter its collapse dynamics, modify or eliminate the microjet and alter the noise and damage potential of the collapse process. In the next section some of these flow deformations will be illustrated.