Developed Cavity Oscillation

There are several circumstances in which developed cavities can exhibit self-sustained oscillations in the absence of any external excitation. One of these is the instability associated with a partial cavity whose length is approximately equal to the chord of the foil. Experimentally, it is observed that when the cavitation number is decreased to the level at which the attached partial cavity on a single hydrofoil approaches about 0.7 of the chord, c, of the foil, the cavity will begin to oscillate violently (Wade and Acosta 1966). It will grow to a length of about $1.5c$, at which point the cavity will be pinched off at about $0.5c$, and the separated cloud will collapse as it is convected downstream. This collapsing cloud of bubbles carries with it shed vorticity, so that the lift on the foil oscillates at the same time. This phenomenon is called "partial cavitation oscillation." It persists with further decrease in cavitation number until a point is reached at which the cavity collapses at some critical distance downstream of the trailing edge that is usually about $0.3c$. For cavitation numbers lower than this, the flow again becomes quite stable. The frequency of partial cavitation oscillation on a single foil is usually less than $0.1U/c$, where U is the velocity of the oncoming stream, and c is the chord length of the foil. In cascades or pumps, supercavitation is usually only approached in machines of low solidity, but, under such circumstances, partial cavitation oscillation can occur, and can be quite violent. Wade and Acosta (1966) were the first to observe partial cavitation oscillation in a cascade. During another set of experiments on cavitating cascades, Young, Murphy, and Reddcliff (1972) observed only "random unsteadiness of the cavities."

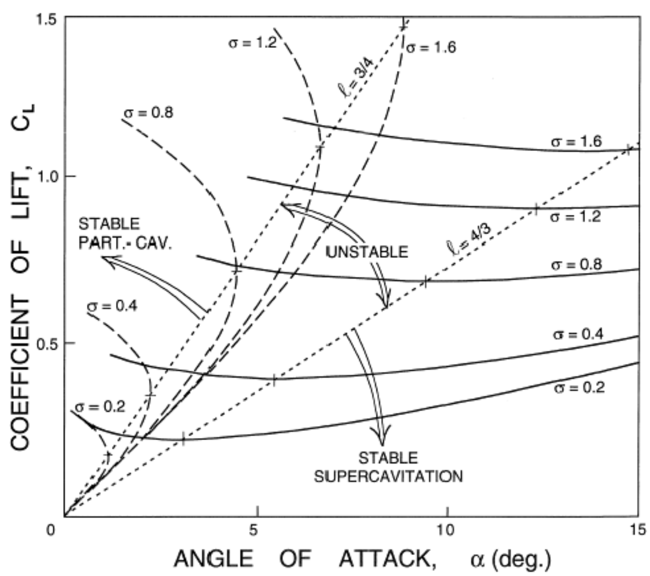

Figure 1: The lift coefficient for a flat plate from the partial cavitation analysis of Acosta (1955) (dashed lines) and the supercavitating analysis of Tulin (1953) (solid lines); C_L is shown as a function of angle of attack, α, for several cavitation numbers, σ. The dotted lines are the boundaries of the region in which the cavity length is between 3/4 and 4/3 of a chord, and in which $dC_L/d\alpha < 0$.

One plausible explanation for this partial cavitation instability can be gleaned from the free streamline solutions for a cavitating foil that were described in section (Mbes). The results from equations (Mbes1) to (Mbes4) can be used to plot the lift coefficient as a function of angle of attack for various cavitation numbers, as shown in figure 1. The results from both the partial cavitation and the supercavitation analyses are shown. Moreover, we have marked with a dotted line the locus of those points at which the supercavitating solution yields $dC_L/d\alpha = 0$; it is easily shown that this occurs when $\ell = 4c/3$. We have also marked with a dotted line the locus of those points at which the partial cavitation solution yields $dC_L/d\alpha = \infty$; it can also be shown that this occurs when $\ell = 3c/4$. Note that these dotted lines separate regions for which $dC_L/d\alpha > 0$ from that region in which $dC_L/d\alpha < 0$. Heuristically, it could be argued that $dC_L/d\alpha < 0$ implies an unstable flow. It would follow that the region between the dotted lines in figure 1 represents a regime of unstable operation. The boundaries of this regime are $\frac{3}{4} < \frac{\ell}{c} < \frac{4}{3}$, and do, indeed, seem to correspond quite closely to the observed regime of unstable cavity oscillation (Wade and Acosta 1966).

A second circumstance in which a fully developed cavity may exhibit natural oscillations occurs when the cavity is formed by introducing air to the wake of a foil in order to form a "ventilated cavity." When the flow rate of air exceeds a certain critical level, the cavity may begin to oscillate, large pockets of air being shed at the rear of the main cavity during each cycle of oscillation. This problem was studied by Silberman and Song (1961) and by Song (1962). The typical radian frequency for these oscillations is about $6U/\ell$, based on the length of the cavity, ℓ. Clearly, this second phenomenon is less relevant to pump applications.