Cavity Closure

The flow in the vicinity of cavity closure deserves further comment because it is quite complex and involves processes that have not, as yet, been discussed. First, the flow is invariably turbulent since the boundary layer, which detaches from the body along with the free surface, produces an interfacial boundary layer. This is almost always unstable and undergoes transition to yield a turbulent interfacial layer (Brennen 1970). The level of turbulence in this layer grows rapidly as the closure region is approached, so the flow in that vicinity usually appears as a frothy turbulent mixing motion. Where the two free surface streams collide, some flow is deflected back into the cavity. Observations of this "reentrant jet" were part of the motivation for the reentrant jet model of cavity closure, which is sometimes employed in potential flow solutions (see section (Nub)). However, actual reentrant jets are nothing like as coherent as the jet in that model; they could better be described as a frothy turbulent mass tumbling back into the cavity.

Changes to the structure of the flow in the closure region can occur in horizontal flows when the buoyancy forces become significant. Such will be the case when the Froude number based on cavity length, ℓ, $Fr = U_\infty \big/ (g\ell)^{\frac{1}{2}}$, is less than some critical value denoted by Fr_c. For bodies of small aspect ratio (such as axisymmetric headforms) it appears that $Fr_c \approx 2.5$ (Brennen 1969) and, when $Fr < Fr_c$, the reentrant jet structure no longer occurs. Instead, a pair of counter-rotating vortices with gas/vapor cores form in the closure region (Cox and Claydon 1956); this type of closure is much steadier and less turbulent than the reentrant jet type, which is prevalent at higher Froude numbers. The rate at which vapor/gas can be entrained by the counter-rotating vortex closure is much higher than for the reentrant jet closure (Brennen 1969).

Returning to our discussion of the reentrant jet form of cavity closure, we note that this flow can also exhibit significant fluctuations. These fluctuations can be caused by vortex shedding from the rear of the cavity (Young and Holl 1966); they may also be the result of some other, less well understood instability associated with this complex multiphase flow. Knapp (1955) first described the cyclic process in which a "pinching off" mechanism (similar to that described in the last section) produces vortices that initially have large, bubbly vapor/gas cores (see also Furness and Hutton 1975). As the vapor condenses and the core of the cloud/vortex collapses, the vorticity is concentrated and the vortices become more intense before they enter the normal, single-phase wake flow. After condensation, only small, remnant gas bubbles containing the residual noncondensable component remain to be convected away into the far wake. It is, incidentally, this supply of microbubbles to the tunnel population that necessitates the use of a resorber in a cavitation tunnel.

It should also be noted that under some circumstances this cyclic process in the cavity closure region is more evident than in others. Moreover, there are several other instabilities that can trigger or promote such a cyclic shedding process. We have already discussed one such instability in the preceding section, the partial cavitation instability. A somewhat similar cavity pulsation phenomenon occurs when large super-cavities are created by supplying noncondensable gas to the wake of a body. Such cavities, which are visually almost indistinguishable from their natural or vapor-filled counterparts, are known as "ventilated" cavities. However, when the gas supplied is increased to the point at which the entrainment processes in the closure region (see below) are unable to carry away that volume of gas, the cavity may begin to fluctuate; a pinching-off process sheds a large gas volume into the wake, and this is followed by regrowth of the cavity. This phenomenon was investigated by Silberman and Song (1961) and Song (1962). Finally, we should mention one other process that may be at work in the closure region. In the case of predominantly vapor-filled cavities Jakobsen (1964) has suggested that a condensation shock provides a mechanism for cavity closure (simple shocks of this kind are analysed in section (Nme)).

Both the large-scale fluctuations and the small-scale turbulence in the closure region act to entrain bubbles and thus remove vapor/gas from the cavity, though it is clear from the preceding paragraphs that the precise mechanisms of entrainment may differ considerably from one closure configuration to another. Measurements of the volume rate of entrainment for large cavities with the steady, reentrant jet type of closure (for example, Brennen 1969) suggest that the volume rate increases with velocity as U_∞^n where n is a little larger than unity. Using axisymmetric headforms of different size, b, Billet and Weir (1975) showed that though the volume entrainment rate scaled approximately with $U_\infty b^2$, there was a significant variation with cavitation number, σ, the volume rate increasing substantially as σ decreased and the cavity became larger.

Under steady-state conditions, the removal of vapor and noncondensable gas by entrainment in the closure region is balanced by the supply process of evaporation and the release of gas from solution along the length of the free surface. These supply processes will, in turn, be affected by the state of the interfacial boundary layer. A turbulent layer will clearly enhance the heat and mass diffusion processes that produce evaporation and the release of gas from solution. One of the consequences of the balance between the supply of noncondensable gas (air) and its removal by entrainment is the inherent regulation of the partial pressure of the noncondensable gas (air) in the cavity. Brennen (1969) put together a simplified model of these processes and showed that the results for the partial pressure of air were in rough agreement with experimental measurements of that partial pressure. Moreover, there is an analogous balance of heat in which the latent heat removed by the entrainment process must be balanced by the heat diffused to the cavity through the interfacial layer. This requires a cavity temperature below that of the surrounding liquid. (This thermal effect in fully developed cavity flows is analogous to the thermal effect in the dynamics of individual bubbles described in sections (Ngc) and (Ngf).) The temperature depression produced by this process has been investigated by a number of authors including Holl, Billet, and Weir (1975). Though it is usually small in water at normal temperatures, it can be significant at higher temperatures or in other liquids at temperatures similar to those at which single bubbles experience significant thermal effects on growth (see section (Ngf)).