Propeller Cavitation

As described in sections Mad, Mbe, and Nh, cavitation begins when small "cavitation nuclei" or microbubbles are convected into regions of low pressure on the propeller blade and subsequently grow to macroscopic size before collapsing again. Each occurrence of this is known as a cavitation event and each of these events produces a pulse of noise and damage potential. As the speed of the propeller is increased, the lowest pressure on the propeller blade is further decreased and the possibility of a cavitation event is increased. A non-dimensional parameter known as the cavitation number, σ, is used to define the combination of pressure and velocity that govern this relation (see section Mbec). The conditions under which the number of events exceeds a prescribed threshold are known as "cavitation inception conditions" and define a non-dimensional quantity known as the "cavitation inception number" (see section Nh), σ_i. The early stage of the development of cavitation is known as "traveling bubble cavitation"; as σ is decreased below σ_i, the number of cavitation events increases and the events begin to interact.

Figure 1 presents examples of "traveling bubble cavitation on a marine propeller. On the left, the four photographs in which the propeller blade is moving toward the right show the progressive development (as you view from upper left to upper right to lower left and then lower right) of cavitation as σ is decreased. The right-hand photograph in Figure 1 presents an "end-on" view of a propeller blade. More detail on the microfluidmechanics of individual travelling bubbles are given in sections Nhf and Nfg.

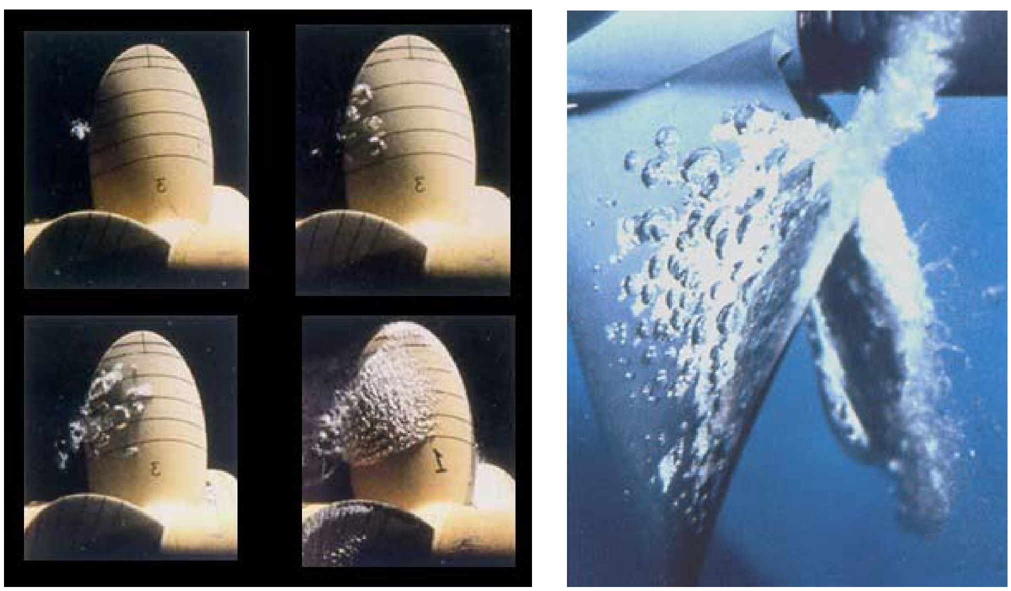

Figure 1: Traveling bubble cavitation on propellers.

As exemplified by the trend on the left in Figure 1, with further reduction in the cavitation number, the bubbles may combine to form large attached cavities or vapor-filled wakes on the suction surfaces of the blades. In a more general context, this is known as "attached cavitation". In the context of propellers, it is often called "blade cavitation". Figure 2 presents examples of blade cavitation on a propeller.

One of the most common features of the flow around a propeller blade at an angle of attack is the tip vortex. It follows that cavitation inception often occurs in these vortices and that, with further reduction

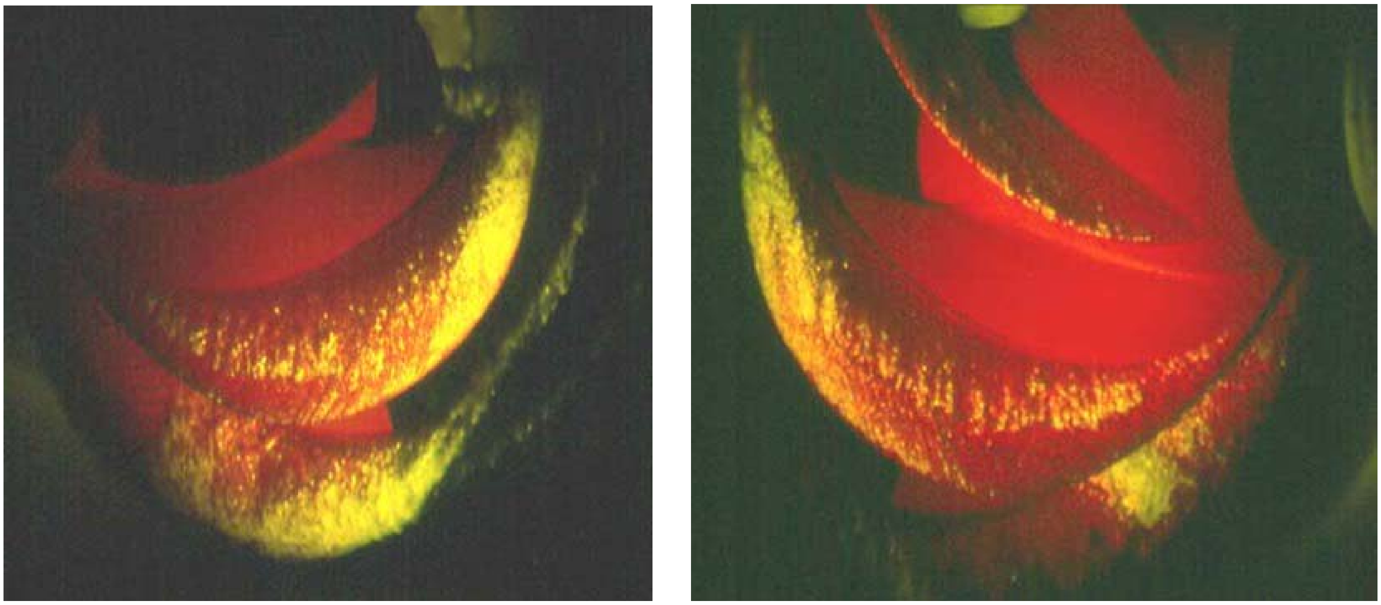

Figure 2: Attached blade cavities on a propeller. From Duttweiler and Brennen (19??).

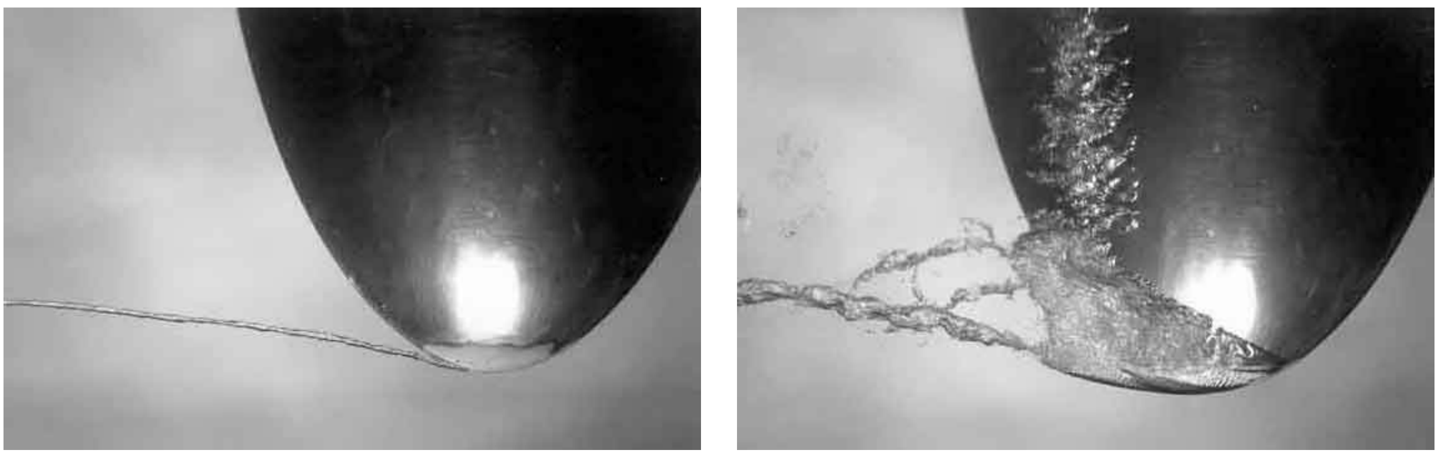

Figure 3: Cavitating tip vortices generated by a single propeller blade at an angle of attack. On the left is a continuous tip vortex cavity at a cavitation number, $\sigma = 1.15$, and an angle of attack of 7.5°. On the right, the tip vortex emerges from some surface cavitation at a lower value of $\sigma = 0.43$ (angle of attack =9.5°). Reproduced from Higuchi, Rogers, and Arndt (1986) with the authors' permission.

of the cavitation number, the entire core of the vortex may become filled with vapor. Naturally, the term "vortex cavitation" is used for these circumstances. Figure 3 consists of photographs of cavitating tip vortices on a single propeller blade at an angle of attack. In those experiments of Higuchi, Rogers, and Arndt (1986) cavitation inception occurred in the vortex some distance downstream of the tip at a cavitation number of about $\sigma = 1.4$. With further decrease in pressure the cavitation in the core becomes continuous, as illustrated by the picture on the left in Figure 3. This transition is probably triggered by an accumulation of individual bubbles in the core; they will tend to migrate to the center of the vortex due to the centrifugal pressure gradient. With further decrease in σs, bubble and/or sheet cavitation appear on the hydrofoil surface (Figure 3, right) and disturb the tip vortex which is nevertheless still apparent.

Continuous cavitating tip vortices occuring at the tips of the blades of a propeller create a surprisingly stable flow structure. As illustrated by Figure 4 (left) the intertwined, helical cavitating vortices from the blade tips can persist for a long distance downstream of the propeller. The cavitating vortices are also very stable structures. In Figure 4 (right) at least one of the tip vortices impacts the strut of the motor assembly and appears again on the far side as if it had passed through the structure. Figure 5 shows vortices created by counter-rotating propellers and demonstrates how the vortices can be woven together in complex patterns.

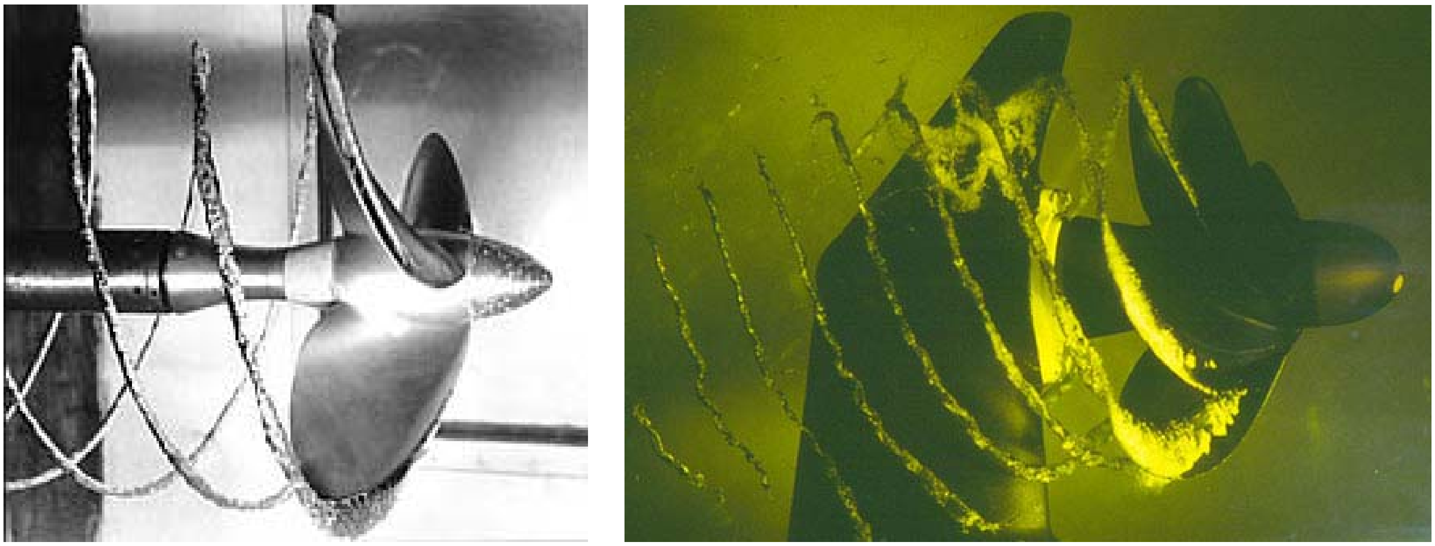

Figure 4: Cavitating tip vortices in water tunnels. Left: a typical ship propeller. Right: a typical naval propeller mounted on an outboard motor assembly.

Figure 5: Tip vortex cavitation on counter-rotating propellers. Reproduced with permission of the Netherlands Maritime Research Institute and Lips B.V.