Supercavitating Cascades

We now turn to the free streamline analyses which are most pertinent to turbomachines, namely solutions and data for cavitating cascades. Both partially cavitating and supercavitating cascades (see figure 5, section (Mbef)) have been analysed using free streamline methods. Clearly cavities initiated at the leading edge are more likely to extend beyond the trailing edge when the solidity and the stagger angle are small. Such cascade geometries are more characteristic of propellers and, therefore, the supercavitating cascade results are more often applied in that context. On the other hand, most cavitating pumps have large solidities (> 1) and large stagger angles. Consequently, partial cavitation is the more characteristic condition in pumps, particularly since the pressure rise through the pump is likely to collapse the cavity before it emerges from the blade passage. In this section we will discuss the supercavitating analyses and data; the next section will deal with the partially cavitating results.

Free streamline methods were first applied to the problems of a cavitating cascade by Betz and Petersohn (1931) who used a linearized method to solve the problem of infinitely long, open cavities produced by a cascade of flat plate hydrofoils. Extensions to this linear, supercavitating solution were generated by Sutherland and Cohen (1958) who solved the problem of finite supercavities behind a flat plate cascade and by Acosta (1960) who generalized this to a cascade of circular arc hydrofoils. Other early contributions to linear cascade theory for supercavitating foils include the models of Duller (1966) and Hsu (1972) and the inclusion of the effect of rounded leading edges by Furuya (1974). Non-linear solutions were first obtained by Woods and Buxton (1966) for the case of a cascade of flat plates. Later Furuya (1975) expanded this work to include foils of arbitrary geometry.

A substantial body of data on the performance of cavitating cascades has been accumulated through the efforts of Numachi (1961, 1964), Wade and Acosta (1967) and others. This allows comparison with the analytical models, in particular the supercavitating theories. Figure 1 provides such a comparison between measured lift and drag coefficients (defined as normal and parallel to the direction of the incident stream) for a particular cascade and the theoretical results from the supercavitating theories of Furuya (1975) and Duller (1966). Note that the measured lift coefficients exhibit a clear decline in cascade performance as the cavitation number is reduced and the supercavities grow. However, it is important to observe that this degradation does not occur until the cavitation is quite extensive. The cavitation inception numbers for the experiments were $\sigma_i = 2.35$ (for 8°) and $\sigma_i = 1.77$ (for 9°). However the cavitation number must be lowered to about 0.5 before the performance is adversely affected. Consequently there is a significant range of intermediate cavitation numbers within which partial cavitation is occurring and within which the performance is little changed.

For the cascades and incidence angles used in the example of figure 1, Furuya (1975) shows that the linear and non-linear supercavitation theories yield similar results which are close to those of the experiments. This is illustrated in figure 1. However, Furuya also demonstrates that there are circumstances in which the linear theories can be substantially in error and for which the non-linear results are clearly needed. The effect of the solidity on the results is also important because it is a major design factor in determining the number of blades in a pump or propeller. Figure 2 illustrates the effect of solidity when large supercavities are present ($\sigma = 0.18$). Note that the solidity has remarkably little effect at the smaller angles of incidence.

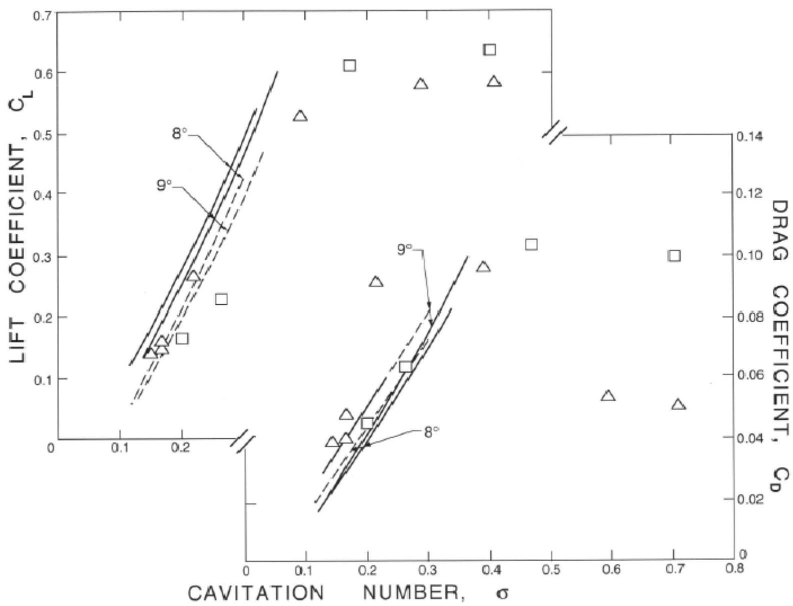

Figure 1: Lift and drag coefficients as functions of the cavitation number for cascades of solidity, 0.625, and blade angle, $\beta_b = 45° + \alpha$, operating at angles of incidence, α, of 8° (△) and 9° (□). The points are from the experiments of Wade and Acosta (1967) and the analytical results for a supercavitating cascade are from the linear theory of Duller (1966) (dashed lines) and the non-linear theory of Furuya (1975) (solid lines).

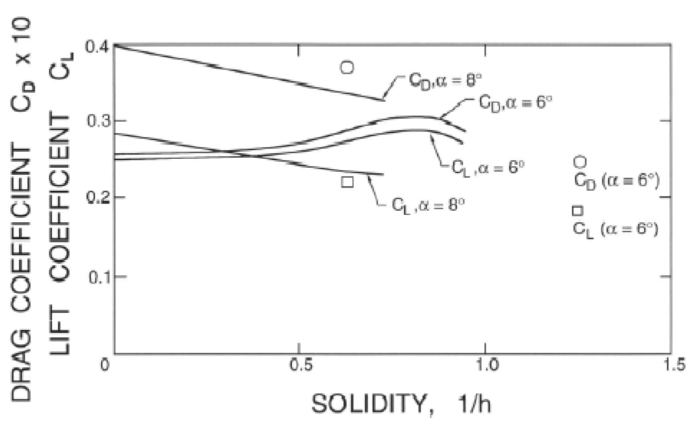

Figure 2: Lift and drag coefficients as functions of the solidity for cascades of blade angle, $\beta_b = 45° + \alpha$, operating at the indicated angles of incidence, α, and at a cavitation number, $\sigma = 0.18$. The points are from the experiments of Wade and Acosta (1967) and the lines are from the non-linear theory of Furuya (1975). Reproduced from Furuya (1975).