Cavitation Inception Data

In section (Mbec) the important role played by cavitation nuclei in determining cavitation inception was illustrated by reference to the comparitive ITTC tests. It is now clear that measurements of cavitation

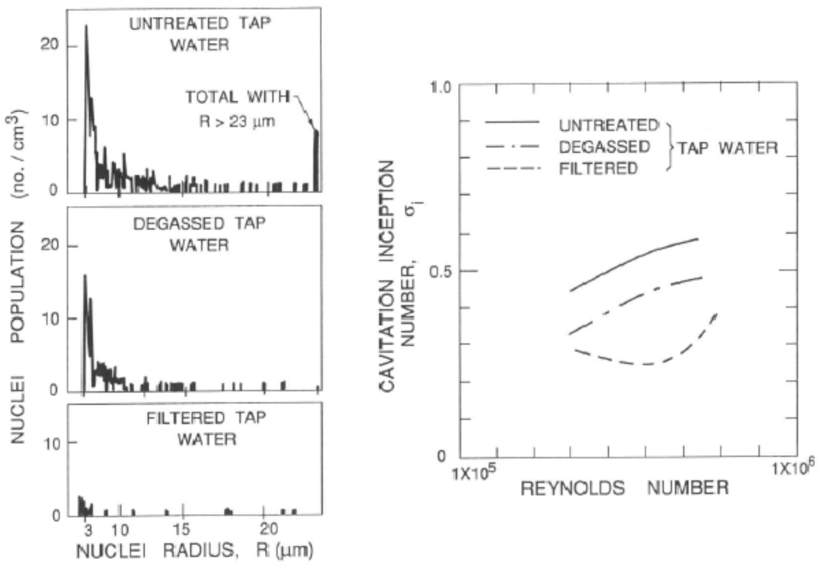

Figure 1: Histograms of nuclei populations in treated and untreated tap water and the corresponding cavitation inception numbers on hemispherical headforms of three different diameters (Keller 1974).

inception are of little value unless the nuclei population is documented. Unfortunately, this calls into question the value of most of the cavitation inception data found in the literature. And, even more important in the present context, is the fact that this includes just about all of the observations of cavitation inception in pumps. To illustrate this point, we reproduce in figure 1 data obtained by Keller (1974) who measured cavitation inception numbers for flows around hemispherical bodies. The water was treated in different ways so that it contained different populations of nuclei, as shown on the left in figure 1. As one might anticipate, the water with the higher nuclei population had a substantially larger inception cavitation number.

One of the consequences of this dependence on nuclei population is that it may cause the cavitation number at which cavitation disappears when the pressure is increased (known as the "desinent" cavitation number, σ_d) to be larger than the value at which the cavitation appeared when the pressure was decreased, namely σ_i. This phenomenon is termed "cavitation hysteresis" (Holl and Treaster 1966), and is often the result of the fact mentioned previously that the cavitation itself can increase the nuclei population in a recirculating facility. An example of cavitation hysteresis in tests on an axial flow pump in a closed loop is given in figure 8, section (Mbej).

One of the additional complications is the subjective nature of the judgment that cavitation has appeared. Visual inspection is not always possible, nor is it very objective, since the number of "events" (an event is a single bubble growth and collapse) tends to increase over a range of cavitation numbers. If, therefore, one made a judgment based on a certain critical event rate, it is inevitable that the inception cavitation number would increase with nuclei population, as in figure 1. Experiments have found, however, that the production of noise is a simpler and more repeatable measure of inception than visual observation. While still subject to the variations with nuclei population, it has the advantage of being

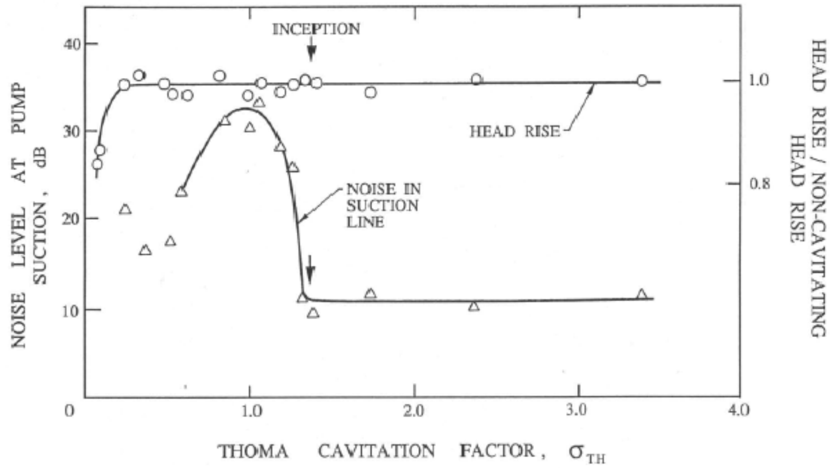

Figure 2: Head rise and suction line noise as a function of the Thoma cavitation factor, σ_{TH}, for a typical centrifugal pump (adapted from McNulty and Pearsall 1979).

quantifiable. Figure 2, from McNulty and Pearsall (1979), illustrates the rapid increase in the noise from a centrifugal pump when cavitation inception occurs (the data on inception in figure 3, section (Mbee), and table 1, section(Mbee), was obtained acoustically).

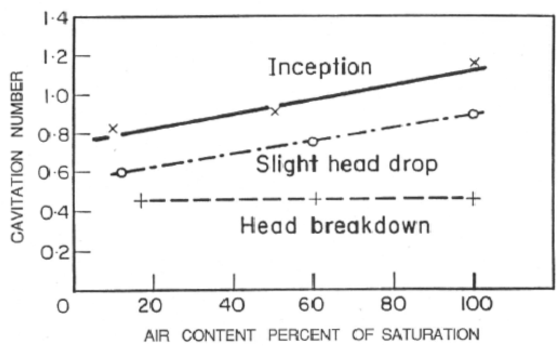

Figure 3: The effect of air content on the critical cavitation numbers for a centrifugal pump (Schoeneberger 1965, Pearsall 1972).

Though information on the nuclei are missing in most experiments, the total air content of the water is frequently monitored. One would suppose that the nuclei population would increase with the air content, and this is usually the case. Some data on the dependence of the critical cavitation numbers for a centrifugal pump on the total air content is included in figure 3. As expected, the cavitation inception number, σ_i, increases with air content. Note, however, that the breakdown cavitation number, σ_b, is quite independent of air content, an illustration of the fact that, once it has been initiated, cavitation is much less dependent on the nuclei population.

Having begun by questioning the value of much of the cavitation inception data, we will nevertheless proceed to review some of the important trends in that data base. In doing so we might take refuge in the thought that each investigator probably applied a consistent criterion in assessing cavitation inception, and that the nuclei content in a given facility might be fairly constant (though the latter is very doubtful). Then, though the data from different investigators and facilties may be widely scattered, one would hope that the trends exhibited in a particular research project would be qualitatively significant.

Consider first the inception characteristics of a single hydrofoil as the angle of incidence is varied. Typical data, obtained by Kermeen (1956) for a NACA 4412 hydrofoil, is reproduced in figure 4. At

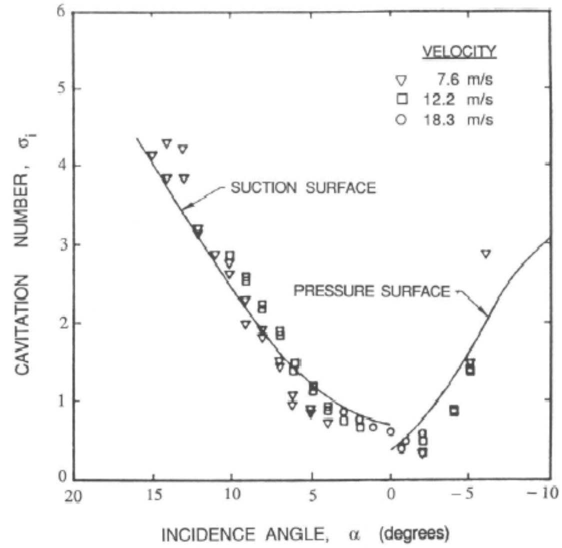

Figure 4: Cavitation inception characteristics of a NACA 4412 hydrofoil (Kermeen 1956).

positive angles of incidence, the regions of low pressure and cavitation inception will occur on the suction surface; at negative angles of incidence, these phenomena will shift to what is normally the pressure surface. Furthermore, as the angle of incidence is increased in either direction, the value of $-C_{pmin}$ will increase, and hence the inception cavitation number will also increase.

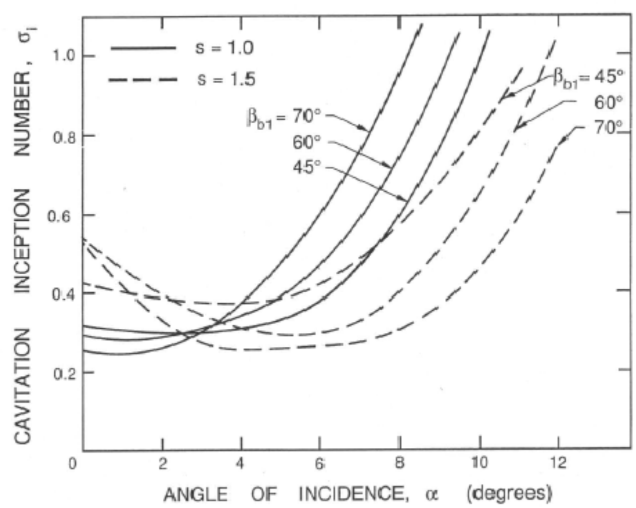

Figure 5: Calculated cavitation inception number, σ_i (or $-C_{pmin}$), as a function of blade angle, β_{b1}, solidity, s, and incidence angle, α, for a cascade of NACA-65-010 hydrofoils (Herrig *et al.* 1957, Pearsall 1972).

When such hydrofoils are used to construct a cascade, the results will also depend on the cascade solidity, s. Data on the pressure distributions around a blade in a cascade (such as that of Herrig *et al.* 1957) can be used to determine C_{pmin} as a function of blade angle, β_{b1}, solidity, s, and angle of incidence, α. Consequently, one can anticipate the variation in the inception number with these variables, assuming the first-order approximation, $\sigma_i = -C_{pmin}$. An example of such data is presented in figure 5; this was derived by Pearsall (1972) from the cascade data of Herrig *et al.* (1957). Note that a particular cascade will have a particular positive angle of incidence of, typically, a few degrees, at which σ_i is a minimum. The optimum angle of incidence changes with different s and β_{b1}; however, it seems to lie within a fairly narrow range between 1 and 5 degrees for a wide range of those design variables. In a pump, the incidence angle is usually small in the vicinity of the design flow rate, but will increase substantially above or below the design value. Consequently, in a pump, the cavitation inception number tends to have a minimum at the design flow rate. This is illustrated in figure 6 which includes some data from a typical centrifugal pump, and by the data in figure 7, section (Mbej), for an axial flow pump.

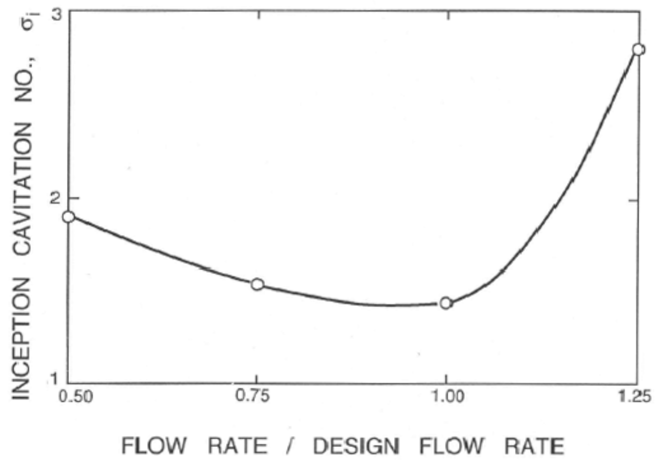

Figure 6: Variation in the inception number with flow rate for a typical centrifugal pump (adapted from McNulty and Pearsall 1979).

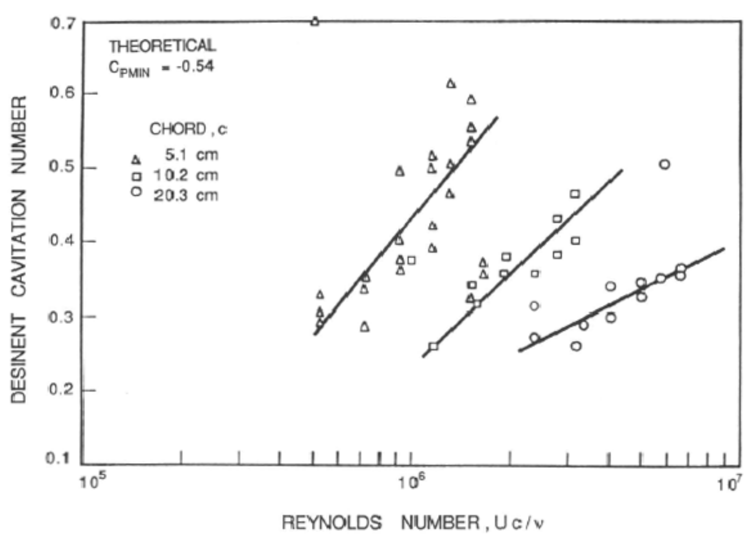

Figure 7: The desinent cavitation numbers for three geometrically similar Joukowski hydrofoils at zero angle of incidence as a function of Reynolds number, Uc/ν (Holl and Wislicenus 1961). Note the theoretical $C_{pmin} = -0.54$.

As we discussed in section (Mbed), the scaling of cavitation phenomena with size and with speed can be an important issue. Typical data for cavitation inception on a single hydrofoil is that obtained by Holl and Wislicenus (1961); it is reproduced in figure 7. Data for three different sizes of 12% Joukowski hydrofoil (at zero angle of incidence) were obtained at different speeds. It was plotted against Reynolds number in the hope that this would reduce the data to a single curve. The fact that this does not occur demonstrates that there is a size or speed effect separate from that due to the Reynolds number. It seems plausible that the missing parameter is the ratio of the nuclei size to chord length; however, in the absence of information on the nuclei, such a conclusion is speculative.

To complete the list of those factors that may influence cavitation inception, it is necessary to mention the effects of surface roughness and of the turbulence level in the flow. The two effects are connected to some degree, since roughness will affect the level of turbulence. But roughness can also affect the flow by delaying boundary layer separation and therefore modifying the pressure and velocity fields in a more global manner. The reader is referred to Arndt and Ippen (1968) for details of the effects of surface roughness on cavitation inception.

Turbulence affects cavitation inception since a nucleus may find itself in the core of a vortex where the pressure level is lower than the mean. It could therefore cavitate when it might not do so under the influence of the prevailing mean pressure level. Thus turbulence may promote cavitation, but one must also allow for the fact that it may alter the global pressure field by altering the location of flow separation. These complicated viscous effects on cavitation inception were first examined in detail by Arakeri and Acosta (1974) and Gates and Acosta (1978) (see also Arakeri 1979). The implications for cavitation inception in the highly turbulent environment of most pump flows have yet to be examined in detail.

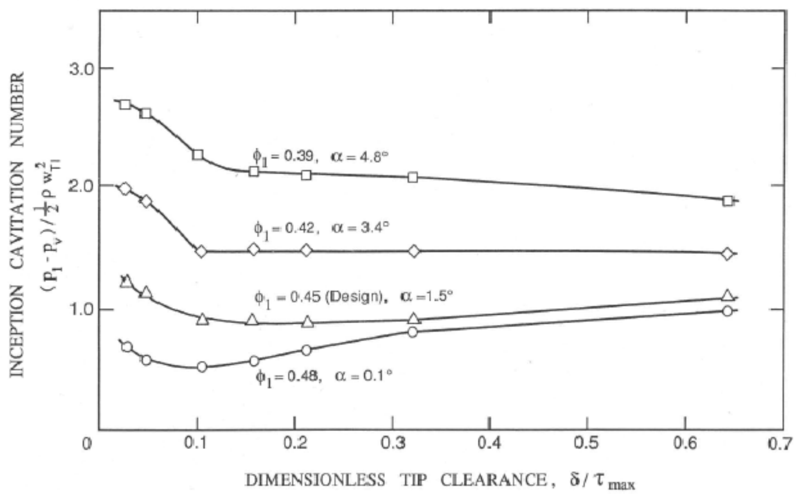

Figure 8: The cavitation inception number, σ_i, as a function of tip clearance, δ (τ_{max} is the maximum blade thickness), in an unshrouded axial flow pump at various flow coefficients, ϕ (adapted from Rains 1954).

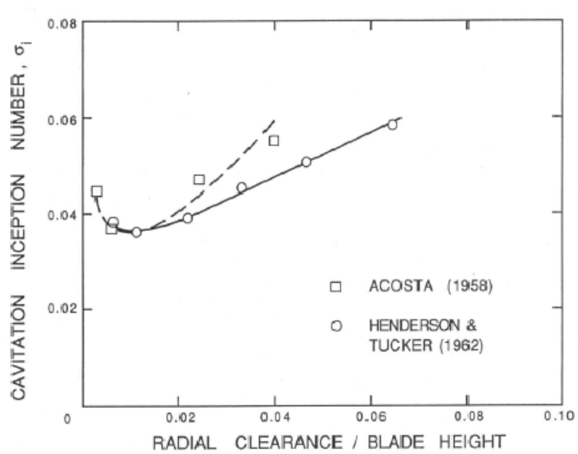

Figure 9: The cavitation inception number as a function of radial tip clearance in an axial inducer (Janigro and Ferrini 1973 from data of Acosta 1958 and Henderson and Tucker 1962).

In unshrouded turbomachinery, cavitation usually begins in the vortices associated with the tip clearance flows, and so it is important to investigate how the tip clearance will affect the inception number. In figures 8 and 9 observed cavitation inception numbers for the tip clearance flows in axial flow impellers are plotted against nondimensional tip clearance. The typical variation with incidence angle or flow coefficients is illustrated in figure 8 (Rains 1954). Since the pressure difference between the two sides of the blade increases with incidence angle, the velocities of the tip clearance flow must also increase, and it follows that σ_i should increase correspondingly, as is the case in figure 8. A second feature that is not clear in Rains' data, but is manifest in the data of Acosta (1958) and Henderson and Tucker (1962), is that there appears to be an optimum tip clearance of about 1% of the blade height. At this optimum, the cavitation inception number is a minimum. This is illustrated in the figure 9.