Cavitation Performance of Propellers

To proceed to consider the performance of a cavitating propeller in a water tunnel, we supplement the analysis of section (Mfc) with an empirical relation defining the dependence of the deviation angle, θ, on the cavitation number. This takes into account the fact that the deviation will be increased by the presence of cavitation on the propeller blades. Specifically, we adopt the following empirical model:

$$\theta = 0 \qquad \text{for} \qquad \lambda > \lambda_{cr}$$

$$\theta = \{\beta_2 - \arctan(v_{mp2}/R\Omega)\}\{1 - (\lambda/\lambda_{cr})\}^2 \qquad \text{for} \qquad \lambda < \lambda_{cr} \qquad \text{(Mfg1)}$$

where we have introduced the parameter $\lambda = \sigma^*/2\alpha$, where $\sigma^* = 2(p_{p1} - p_v)/\rho R^2 \Omega^2$ is the operating cavitation number of the propeller (p_v denotes the vapor pressure) and $\alpha = \beta_1 - \arctan(v_{mp2}/R\Omega)$ is the incidence angle on the propeller blades. The argument for this single parameter representation, $\theta(\lambda)$, is that classical linear theory (Tulin 1953, Brennen 1994) shows that the cavity length to chord ratio is a function only of λ and consequently the expected deviation should similarly be a function of λ. Though non-linear and three-dimensional effects may generate departures from this simple functional dependence, it seems appropriate to begin with this approximate analysis.

Equation (Mfg1) has the properties that, if the cavitation is small (λ is large), the flow discharges from the propeller parallel to the blade. At the other extreme, when the cavity is very long ($\lambda \to 0$), the propeller performance will be degraded and the flow turning angle through the propeller will be diminished (there may be a certain small λ at which the propeller breaks down but this detail is neglected for simplicity.) The critical value, λ_{cr}, below which the deviation begins, could be determined theoretically or empirically. Herein we will use a typical value of $\lambda_{cr} = 1$.

Figure 1 presents the thrust coefficient, C_F, and the flow coefficient, J_p, plotted against the advance ratio, J_1, for various cavitation numbers, σ. Recall that in this model the presence of cavitation affects the results only by altering the exit flow angle (equation (Mfg1)). Figure 2 shows the thrust coefficient, C_F, plotted against the cavitation number, σ, for various advance ratios, J_1. Note that the deterioration of the thrust coefficient as a result of cavitation is well simulated by introducing the deviation angle due to the presence of cavitation modeled by equation (Mfg1).
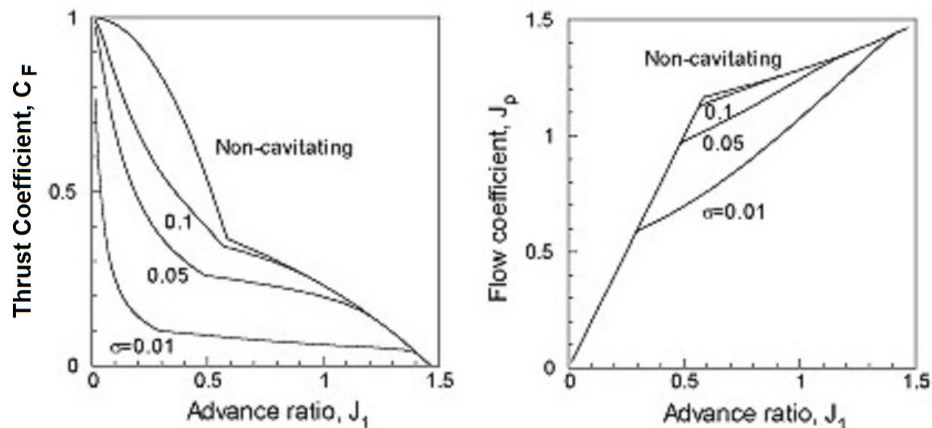

Figure 1: Effect of cavitation number on thrust coefficient, C_F, and propeller flow coefficient, J_p, for $A^*/A_p = 2$.
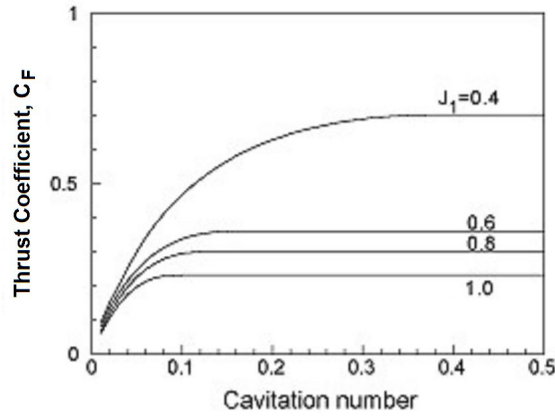
Figure 2: Thrust coefficient, C_F, plotted against the cavitation number, σ, for various advance ratios J_1.

Note also that the flow coefficient has a steeper slope against the advance ratio for smaller cavitation numbers as shown in Figure 1. This is because, as the cavitation number is decreased, the thrust coefficient decreases because of the losses through the deviation angle associated with the presence of cavitation on the propeller blades. Then the flow rate through the propeller must decrease to compensate for the decreased thrust. The steeper slope of the flow coefficient against the advance ratio means that the flow rate through the propeller is more sensitive to the upstream flow variation and the mass flow gain factor is larger because a small advance ratio change makes a large propeller flow rate change. This will tend to promote a surge instability.

Note that, only for the case with $\sigma = 0.15$, is the parameter $\lambda = \sigma/2\alpha$ less than unity and therefore only in this case is there head deterioration with increasing deviation angle.
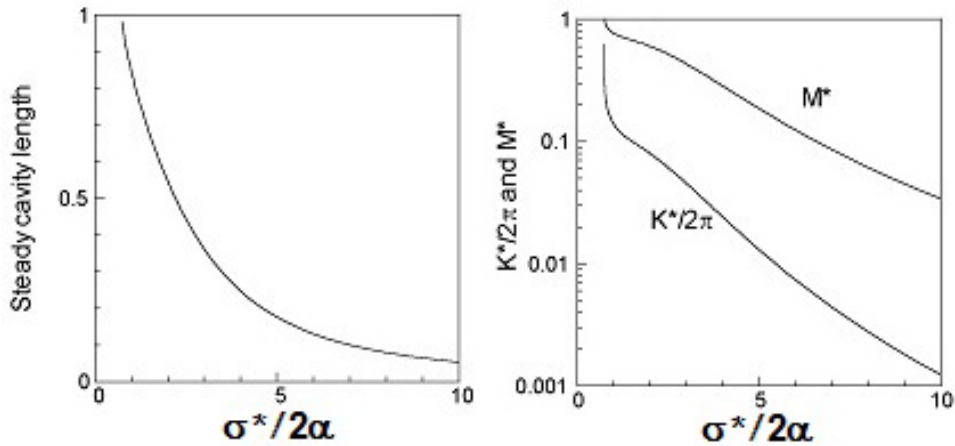

Figure 3: Steady cavity length and the quasi-static cavitation compliance and mass flow gain factor plotted against $\sigma/2\alpha$ obtained from a free streamline theory (Watanabe 1998) for solidity $= 1.0$, blade angle $\beta_2 = 25°$ and $Z_R = 5$.

Figure 4 shows the values of $\sigma/2\alpha$ just upstream of the propeller plotted in a graph of σ against J_1. In a later section the stability of these flows will be indicated in such a graph.
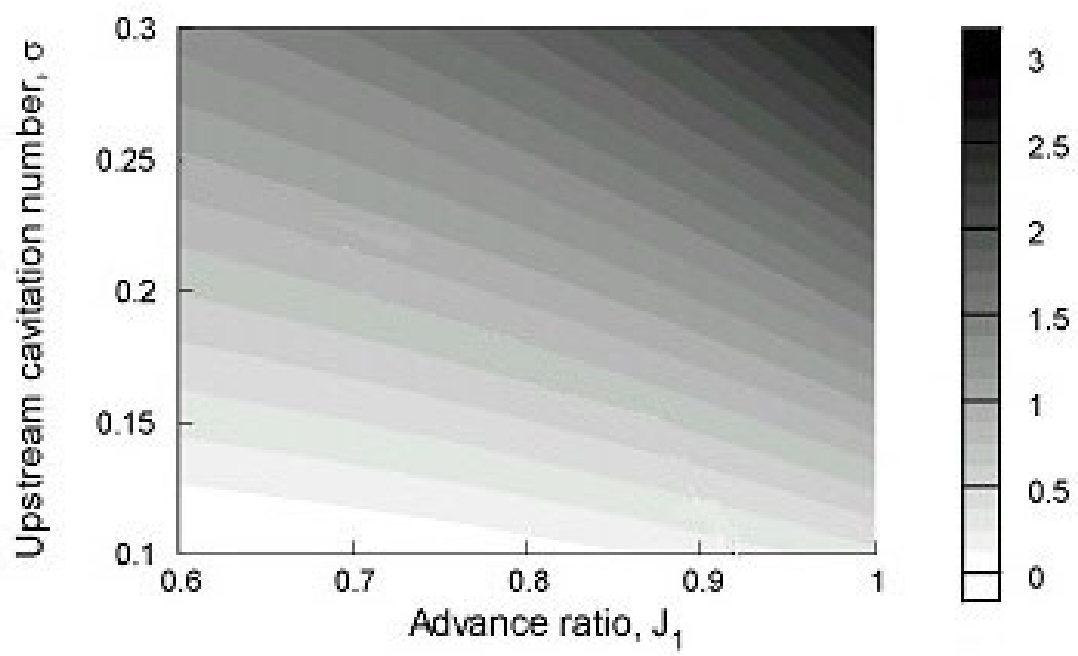
Figure 4: Values of the ratio of cavitation number to incidence angle (divided by 2), $\sigma/2\alpha$, presented in a plot of the upstream cavitation number, σ, against the advance ratio, J_1.