Some New Measurements on the Drag of Cavitating Disks

By G. J. Klose[1] and A. J. Acosta[1]

As part of an experiment on unsteady flow past a cavitating circular disk, it was necessary to make calibrating measurements of the drag on disks in steady flow. The measurements were made for greater cavitation numbers than have been previously recorded, and show that the drag coefficient is essentially linearly dependent upon cavitation number up to values of this parameter as high as 1.3.

Nomenclature

A = area of disk

C_d = drag coefficient = $\frac{D}{\frac{1}{2}\rho V^2 A}$

C_{d_0} = C_d for $\sigma = 0$

d = disk diameter

d_0 = tunnel diameter

D = drag force

p_c = pressure in cavity

p_∞ = pressure in undisturbed approaching flow

V = velocity of undisturbed approaching flow

ρ = fluid density

σ = cavitation number = $\frac{p_\infty - p_c}{\frac{1}{2}\rho V^2}$

THE present experiments were carried out in the high-speed water tunnel of the Hydrodynamics Laboratory at the California Institute of Technology [1][2]. The model disks were supported from the downstream side on a stem which, in turn, was attached to the strut support of the three-component force balance [2] of the tunnel. The strut was surrounded by another strut, which shielded the active strut from the force of the flowing water. The pressure within the cavity was measured by a piezometric tube communicating with the cavity behind the disk. Ventilating air could also be introduced through the base of the shielding strut to vary the cavity pressure. The three disks used had diameters of 2¼ in., 3¼ in. and 4¾ in., the tunnel working section being 14 in. dia.

The test procedure consisted of setting the tunnel velocity at the desired value and then decreasing the tunnel pressure until a long, clear cavity was established. With the flow stabilized, all measurements were taken at the moment the force balance had reached a steady reading. Incidentally, it was difficult to establish steady conditions in the tunnel for these large disks except relatively near the "choked" condition.

Fig. 1 shows a top view of the cavity behind the 2¼-in. disk. The tip projecting from the front of the disk

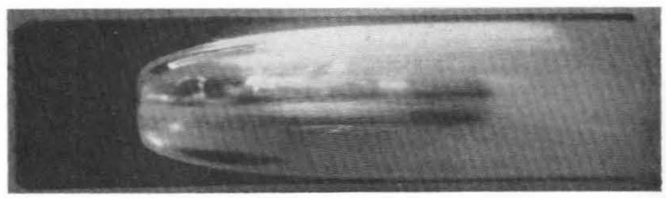

Fig. 1 Top view of Cavity behind the 2¼ in. circular disk.

was used only for photographic purposes and not for the data runs reported herein.

Tunnel velocities ranged from 27 to 32 fps for the 2¼-in. disk, from 18 to 24 fps for the 3¼-in. disk, and from 14 to 19 fps for the 4¾-in. disk. Vapor cavities were used with the 2¼-in. disk, air-supported cavities with the 3¼-in. disk, and both air-supported and vapor cavities with the 4¾-in. disk. Although the cavity pressure varied from 0.085 to 0.105 ft Hg (abs) for vapor cavities and from 0.472 to 0.828 ft Hg (abs) for air-supported cavities, the method of establishing the cavities, namely, pumping down the tunnel ambient pressure until an essentially choking cavity was established, caused the cavitation numbers to fall in a narrow range for each of the disks. The flow conditions then were similar for all the data points for each disk regardless of the way the cavity was formed.

Before discussing the results of the present investigation, reference should be made to previous measurements. Fig. 2 shows points obtained by Reichardt with vapor cavities in a free-jet tunnel [3], by Kermeen with vapor cavities in the high-speed water tunnel at CIT and by O'Neill with air cavities in the free-surface water tunnel at CIT [4], and by Eisenberg and Pond with "partial" vapor cavities at David Taylor Model Basin [5]. (Under partial cavitation conditions, the cavity appears smooth and opaque to the eye; but high-speed photography reveals that the cavity is in fact filled with a rapidly pulsating vapor-water mixture and has a quite irregular envelope, only the average of which is seen by the eye.) The data points for Reichardt, Kermeen and O'Neill were replotted from O'Neill [4], while Eisenberg and Pond's were taken from their report [5]. Although there is

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[2] Numbers in brackets designate References at end of paper.

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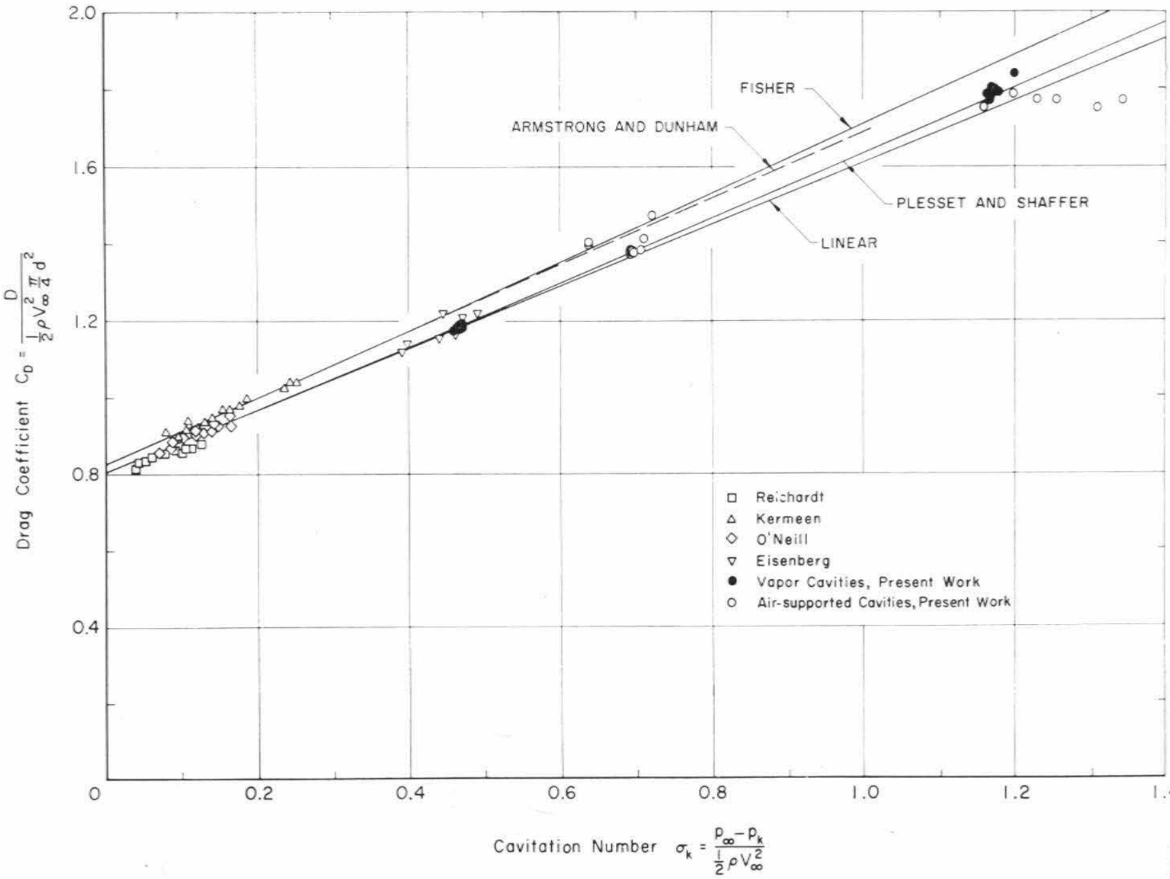

Fig. 2 Drag coefficient versus cavitation number for the circular disk

some scatter in all these points, the agreement with the widely used approximate formula

$$C_d = C_{d0}\,(1 + \sigma),\ C_{d0} = 0.805 \qquad (1)$$

is quite good up to $\sigma = 0.5$, which is the limit of these previous observations.

There have been several approximate theories for the drag coefficient in axially symmetric cavity flow. Plesset and Shaffer [6] give their results in parametric form and their $C_d - \sigma$ curve has been plotted numerically in Fig. 2. Although it closely resembles a linear relation of the form of equation (1), labelled "linear" in Fig. 2, it is more accurately represented by

$$C_d = C_{d_0}\,(1 + \sigma + 0.028\sigma^2),\ \text{with } C_{d_0} = 0.8053$$

up to $\sigma = 1.5$. For comparison, curves according to the calculations of Armstrong and Dunham and of Fisher [7] also are shown.

As mentioned, the present data points occur in three clusters, corresponding to the three disks used; i.e., near $\sigma = 0.5$ for the $2\frac{1}{4}$-in. disk, near $\sigma = 0.7$ for the $3\frac{1}{4}$-in. disk, and near $\sigma = 1.2$ for the $4\frac{3}{4}$-in. disk. That the flow was fairly close to the choking condition can be seen by considering the blockage cavitation number given in [8],

$$\sigma_\infty = 2(C_d)^{1/2}\left(\frac{d}{d_0}\right)$$

This result gives, with equation (1), values of σ_∞ equal to 0.33, 0.51 and 0.82, respectively, for the three disks. Cavitation of the strut, moreover, causes the limiting blockage cavitation number to be considerably higher than these calculated values.

The vapor-cavity points of the $2\frac{1}{4}$-in. and $4\frac{3}{4}$-in. disks show little scatter and agree with the theoretical curve of Plesset and Shaffer. Although the air-supported cavities with the $3\frac{1}{4}$-in. and $4\frac{3}{4}$-in. disks show more scatter, most of the points follow this curve. The two points that show the largest deviation from the curve, namely, those two with the highest cavitation number, are definitely outside the bounds of probable error; these are the lowest-velocity runs made with the large disk for which it was more difficult to obtain a stabilized flow, so that erroneous readings well could have been taken.

The question arises whether the drag coefficient for a given cavitation number is influenced by the presence of the tunnel walls. Although no calculations exist for axially symmetric cavity flow in a tunnel, an indication of the magnitude of the wall effect can be obtained by considering the corresponding two-dimensional case. Cohen and DiPrima consider this problem [9]; but whereas Fig. 9 of their report shows about 2 to 3 percent difference (decreasing with increasing cavitation number) in the drag coefficient between bounded and unbounded flow up to a cavitation number of 0.3, our own calculations using the results of Betz and Petersohn [10] show that the two curves differ by less than 1 percent for cavitation numbers in the range 0.5 to 1.3 covered in the present work. Thus it is concluded that the effect of blockage on the measured drag coefficient is negligible in this experiment.

In general, then, the results show good agreement with the theoretical results of Plesset and Shaffer, but the curves of Armstrong and Dunham and of Fisher seem to overestimate the drag coefficient somewhat. Within the limitations of the present experiment, however, the linear formula of equation (1) can be used with equal accuracy up to a cavitation number of 1.3.

Acknowledgment

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Hydrostatic Tests of Two Prolate Spheroidal Shells

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ing an assumption made in the derivation of equation (1). Mushtari considered the local stability of the prolate spheroid based on the assumption of a large number of circumferential lobes in the shell at collapse. While this assumption is correct for spherical shells, it is not applicable throughout the range of prolate spheroids since it is obviously invalid for the case of the semi-infinite cylinder. It is not surprising, therefore, that Model FB-2 collapsed at a pressure about 40 percent higher than predicted by the Mushtari equation since the shell failed in a relatively small number of lobes, $n=5$ (for a sphere with the same h/D, $n=10$). Moreover, it can be stated that for a prolate spheroid with a smaller number of lobes at collapse, that is, a less spherical and/or thicker shell than those tested here, the disparity between the pressures calculated by the Mushtari equation and the actual collapse pressure would increase.