DISCUSSION

C. Brennen[2]

I should first like to comment again on the fact that wall effects are clearly a dominating factor in the results presented. The wall effect on the cavity size, shape and separation angle have, as the authors point out, been fairly well documented in the past. But I am curious to know whether the authors considered the possibility of a significant wall effect on the unsteady part of the flow manifest in the observed value of the Strouhal number. Indeed in the same vein I should like to point out that there is an inherent difference between the single phase wakes such as those studies by Roshko and cavity flows for the latter can excite monopole-like oscillation of the whole tunnel system due to fluctuation in the volume of the cavity. Such excitation would not arise in incompressible wake flows and I wonder whether the authors have considered the possibility of such system effects on the Strouhal number.

Secondly, I should like to ask a specific question on the modified cavitation number, k_m. In a recent paper (Wu, Whitney, and Brennen (1971)] we recommended the use of a cavitation number k' given by

$$k' = (2k + k'')/3$$

where k'' was based on the minimum *wall* pressure and velocity as well as the cavity pressure. This was based on theoretical considerations and was supported by the experimental measurements. Since the authors make reference to this work, I am curious to know how their data reduced when based on this number.

Finally a remark concerning the comparison of the authors' data on separation angle with previous results. The reader is left with the feeling that Sarpkaya's data on wake separation (i.e., noncavitating) conflicts with any data for the cavitating case (Brennen (1970)) not only quantitatively but also in terms of the trend with changing Reynolds number. I do not think this is the case. It is necessary in comparing the two situations to realize that while the base or cavity pressure is an independent quantity in the cavity flow, it is, on the other hand, a direct Reynolds number determined quantity in single phase wake flow. If one compares the wake separation angle as a function of Reynolds number with the cavity separation angle for the *same* base pressure coefficient (or cavitation number) as occurred in the wake measurements than the two curves are similar in trend and differ only a little in numerical value.

J. William Holl[3]

The cavity flow over cylindrical elements is certainly an interesting and complex problem. I have three points for discussion. The author should present data to compare with the results of Young and Holl [3]. The authors indicate that the Strouhal number increases with decreasing cavitation number (k) at k's less than those reported by Young and Holl [3]. Why is this so? Also, the authors should document the incipient and choking values of k for their experiments. During the discussion of this paper at the Houston meeting it was indicated that the cavitation number for blocked conditions can be expressed as a function of two differently defined cavitation numbers. Reference was made to a paper by C. Brennen and T. Wu in the *Journal of Fluid Mechanics*.

[2]Division of Engineering and Applied Science, California Institute of Technology, Pasadena, Calif.

[3]Professor of Aerospace Engineering, Garfield Thomas Water Tunnel, Applied Research Laboratory, The Pennsylvania State University, State College, Pa.

[4]Head, High Performance Craft Powering Branch, David W. Taylor Naval Ship R&D Center, Bethesda, Md.

G. F. Dobay[4]

It is amazing that apparently useful results were obtained in experiments of such a small scale. In a test-section 1/2 in. wide and 4 in. high, cavity-shape and cavity shedding frequency were observed behind 0.4 in. to 1 in. diameter cylinders, spanning the half-inch width of the test section.

The authors of the paper appear to have assumed that the flow *in the test section* was two-dimensional. It is likely, however, that the boundary-layer of the sidewalls occupied a large portion of the 1/2 in. test-section width. Has a velocity-survey been taken across the width of the section?

Unless the test section to model size ratio is very large, the definition of upstream pressure and upstream velocity becomes somewhat nebulous. In the present case the test bodies occupied up to 20 percent of the cross-section area of the test section, and this should have a large effect on the upstream flow values. I feel especially uneasy about the velocity determination in the paper. Is the average velocity ahead of the body, determined from flow-rate measurements, representative of the "upstream infinity" velocity for the test-bodies? Figs. 5 and 6 of the paper do in fact show how irrelevant is the author's "upstream velocity" to the flow over the cylinders. Tests made with 1 to 2 in. disks perpendicular to the flow in a 36 in. cross-section flow facility have conclusively shown that the cavities are geometrically similar up to their choked flow value. The measured drag-coefficients, however, differed; indicating that, even in relatively large test-sections, wall-effects on the forces of cavitating bodies may be significant.

The interpretation of Fig. 7 by the authors appears to be incorrect. The parameter should be relative body-size and *not* Reynolds number. It seems more likely that blockage-effects influenced the angles of detachment more so than the Reynolds number. The authors *have* data of this nature, over a range of speeds, for the same test body. How do these data compare with Fig. 7?

Because of the large blockage and small scale one should be cautious in assigning significance to the data presented in Figs. 9 through 12. Strouhal number is rather sensitive to flow boundaries. It is also believed that items 1 through 4 of the conclusions in the paper ought to be reserved until a larger scale experiment in fact verifies the stated trends.

Authors' Closure

We appreciate Dr. Brennen's remarks that wall effects might influence the unsteady part of the flow and that fluctuations in the volume of cavity can excite mono-pole-like oscillation of the whole tunnel system. These system effects have not been considered by us. We have not tried a plot of our data against the cavitation number K' suggested by Wu, Whitney, and Brennen [7]. We intend studying this and reporting the result shortly. However, it may be said that the formation of the cavitation number K' as a sum of K and K'' would result in improved correlation compared to those using K alone.

Turning to the discussion of Mr. Dobay we wish to say that a velocity-survey across the width of test-section was taken and the velocity distribution was found to be fairly uniform across the test section. The boundary layers were about 0.04 in. on either wall. As surmized, the average velocity ahead of the cavitation source was determined from flow-rate measurements. The variation of angle of detachment at different Reynolds numbers with cavitation number for data at various speeds was studied. This also indicated a decrease in angle of detachment

[5]Dobay, G. F., "Experimental Investigation of Wall Effect on Simple Cavity Flows," of the *Proceedings*, Symposium on Testing Techniques in Ship Cavitation Research, Pub. No. 99, The Norwegian Ship Model Basin, Trondheim, Norway, Dec. 1967, pp. 175–231.

with increase in Reynolds number in the range of values reported.

The question of Professor Holl, as to why the Strohal number increases with decreasing cavitation number close to choke conditions, needs more detailed study before it be satisfactorily answered. One possible reason could be that near the choke conditions, the flow is highly unsteady with the result the Strouhal number exhibits a spectrum of values compared to the phenomenon at higher cavitation numbers. The average values of incipient and choke cavitation numbers, K_i and K_{ch}, in our experiments are as follows:

d_{cm}	K_i	K_{ch}
2.54	2.65	1.22
2.22	2.69	1.13
1.90	2.76	0.96
1.59	2.61	0.85
1.27	2.63	0.71
0.95	2.51	0.42

Professor Wislicenus in a private communication has asked whether the values of angles of detachment show a unified variation with modified cavitation number, K_m. This was studied and the plot exhibited a unified variation as in Fig. 6.