

ADVANCEMENTS IN THE STUDY OF UNDERWATER PHENOMENA

Session Chairman: K. E. SCHOENHERR

Dean of Engineering, University of Notre Dame

INTRODUCTORY REMARKS

In this session two papers will be presented, one by Dr. James W. Daily on "The Water Tunnel as a Tool in Hydraulic Research" and one by Dr. John S. McNown on "Pressure Distribution and Cavitation on Submerged Boundaries."

Professor Rouse in his paper brought out that at relatively low velocities, the flow pattern around a solid body completely submerged in the fluid medium is the same whether the medium is air or water. At relatively high velocities, however, this is no more the case. When the velocity in air approaches the speed of sound, an entirely different flow pattern is formed, and when the velocity in water reaches a value at which the local pressure on the surface of the body approaches the vapor pressure of the medium, disruption occurs and streamline flow no longer prevails. The latter phenomenon is appropriately called cavitation, since at the point of disruption vapor-filled cavities are formed which persist for a short time interval and then collapse.

The occurrence of cavitation is highly undesirable, causing reduction in efficiency, abnormal increase in rpm, erosion of the surfaces, and noise. It is highly important, therefore, to the designer of hydraulic machinery to know exactly how far he may go in the matter of speed without engendering serious cavitation.

The history of cavitation may not be familiar to hydraulic engineers and may be worthy of brief discussion. Cavitation first came to the attention of engineers in connection with the speed trials of the British torpedoboat DARING in 1896. This vessel was designed for a speed of 27 knots, but on her first trial reached only 24 knots with the engines wide open. To explain this disappointing

result, Mr. Sidney W. Barnaby, chief engineer of the DARING'S builders, postulated that, as a result of high speed and loading of the propeller blades, the overlying hydraulic head was insufficient to feed the water to the propellers and cavities were formed. Proceeding on this assumption, new propellers with much greater blade area were designed and the vessel easily reached the designed speed in subsequent trials.

Although Mr. Barnaby's explanation was stated in somewhat crude terms, it was remarkably accurate. A more precise explanation based on Bernoulli's Theorem is briefly as follows: For flow through a Venturi at Section 1 of cross-section area A_1 and Section 2 with a much smaller cross-section area A_2 , V_1 , and V_2 are the corresponding velocities and p_1 and p_2 the corresponding pressures at the two sections. From Bernoulli's Theorem:

$$p_2 = p_1 - \frac{\rho}{2} (V_2^2 - V_1^2)$$

where ρ is the density of the medium. Now, cavitation at Section 2 will occur when p_2 becomes equal to the vapor pressure p_v of the medium. For the inception of cavitation, the equation can therefore be written:

$$\frac{\rho}{2} (V_2^2 - V_1^2) = p_1 - p_v$$

or:

$$(V_2/V_1)^2 - 1 = \frac{p_1 - p_v}{\rho V_1^2/2}$$

It will be noticed that the term on the right-hand side of this equation depends only on the prevailing hydrostatic pressure at the reference Section 1, the vapor pressure of the medium, and the speed of the flow at Section 1; that is, it depends on operating conditions which are entirely independent of the peculiarities of the hydraulic machine under consideration. The term on the left-hand side of the equation on the other hand depends principally on the geometrical configuration of the machine. Thus, for instance, in the case of the Venturi, we can write:

$$\frac{V_2}{V_1} = \frac{A_1}{A_2}$$

whence :

$$V_1 = \sqrt{\frac{p_1 - p_v}{\frac{\rho}{2} \left[\left(\frac{A_1}{A_2} \right)^2 - 1 \right]}}$$

Inserting numerical values, we find that when p_1 is atmospheric pressure and the ratio of the diameters of Sections 1 and 2 is 2:1, cavitation at the throat of the Venturi occurs when the approach speed is approximately 12 feet per second.

This simple analysis can also be applied in more complicated cases. If the ratio V_2/V_1 for a given case is known or can be estimated, the speed at which cavitation occurs can be calculated.

In most cases it is impossible, however, to predict the value V_2/V_1 and it must be determined experimentally. It should be noted that this unknown is a non-dimensional ratio, and may be determined just as well on a geometrically similar model as on the prototype. Such model tests are greatly facilitated by an apparatus usually designated a Water Tunnel. In the papers to follow a complete description of this apparatus and its use will be presented.

The idea of a Water Tunnel in which speed and pressure can be regulated at will was proposed at least as early as 1904 (for instance by Wagner) and some initial attempts were made at the construction of such a tunnel. Water Tunnels of the type we have today were not constructed, however, until about 1930, one at the U. S. Experimental Model Basin in Washington, D. C., the forerunner of the present David Taylor Model Basin, and the second one, at the Hamburg Model Basin in Germany. At the present time, there are a number of such tunnels in operation; one of them is in the laboratory of the Iowa Institute of Hydraulic Research. An opportunity will be given to see this tunnel in operation after the close of this session.

For future designers of such equipment, it will be extremely valuable to have complete descriptions of existing tunnels on record. It is fortunate, therefore, that a paper is to be presented on this subject. The author is Dr. James W. Daily, who graduated from the Stanford School of Engineering in 1935, became a member of the Hydraulic Machinery Laboratory at the California Institute of Technology in 1936 and was later its manager. From 1940 on, he divided his time between teaching Hydraulics and acting as

Hydraulic Engineer on the high-speed Water Tunnel. He is particularly qualified to discuss the role of the Water Tunnel in hydraulic design.

The second paper, on the determination of the pressure distribution on submerged boundaries, has been prepared by Dr. John S. McNown. Dr. McNown studied at the Universities of Kansas, Iowa, and Minnesota and obtained his doctorate from the latter institution in 1942. For five years, he was a member of the teaching staff of the University of Minnesota and for a year was with the U. S. Navy Radio and Sound Laboratory on the West Coast. At present he is research engineer at the Iowa Institute of Hydraulic Research.

During the past war when the writer was with the Taylor Model Basin, the staff was confronted almost continuously with new and unfamiliar problems. In one particular problem submitted to the Basin for solution, it was necessary to know the pressure distribution on submerged boundaries of special shape. No data were in existence and the test facilities at the Taylor Model Basin were already occupied to capacity. Fortunately, the Iowa Institute had just completed its water tunnel and was in a position to accept work under government contract. Negotiations were entered into and the cavitation studies in the Iowa water tunnel resulted. This is just one example of the successful solution of a problem resulting from cooperation between the government laboratories and the universities during the war. It is hoped that now that the war is over, this cooperation will continue.