Engineering Notes

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Bubble Track Technique for Velocity Measurement in Stratified Liquids

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THE difficulties involved in measuring nonuniform velocity distributions in slow speed flows are such that recourse is often made to some sort of direct flow visualization technique. Examples include the H_2-bubble and pH-sensitive dye methods and various marker-particle injection procedures.[1-3] Each of these has its own regime of applicability. However, for reasons to be discussed subsequently, none is suitable for studying stratified flows in which the local Reynolds number and the local Internal Froude number are both small. ($F = V/DN$, where V is the velocity; D, a characteristic dimension; and N, the Vaisala frequency.) This particular situation is of current interest in connection with studies of the relaminarization of turbulent wakes in a variable-density liquid.

Fortunately, in this case several circumstances combine to make possible a new measurement technique. First, small bubbles rising in a liquid at sufficiently low Reynolds numbers (around 20, say, based on mean bubble diameter and rise speed) proceed in a direct path to the surface.‡ The wake of such a bubble is a sharply defined laminar "track" which is readily visible by shadowgraph (Fig. 1) if the fluid is stratified to the extent that $N > \frac{1}{2}\ \mathrm{sec}^{-1}$ (roughly speaking) where

$$N \equiv [(-g/\rho)(d\rho/dz)]^{1/2} \tag{1}$$

(ρ is the density, g the gravitational acceleration, and z, the vertical coordinate.) Second, due to the pronounced gravitational resistance to vertical motion, flows in stratified fluids tend to be "horizontal" in nature. This eases somewhat the objection to the measurement of velocities based on timeline information alone.[1] (The term, "timeline," implies a continuous line of marked fluid elements —in this case the bubble wake—which is distorted by advection as time proceeds.) For present purposes, then, the flow is treated as quasi-parallel and quasi-steady as far as data reduction is concerned.

Description of Method

One important feature of the bubble track method is that the marker-tracks can be generated conveniently at any time and at any point without placing wires or probes in the region of interest. This means, for example, that the flow close to the centerline of a moving body can be investigated. The bubbles are produced by means of a pulsed d.c. electrolytic circuit similar to that used in the H_2-bubble technique. (Hydrogen bubbles are formed at the negative electrode and oxygen at the positive electrode.) The distinction is that the bubble track method requires that the electrode area, voltage level and pulse width be arranged to generate on command a single bubble of the desired size rather than a stream of fine bubbles. The bubble diameter is much larger (~0.030 in.) than that usually incorporated in the H_2-bubble technique (~0.0001 in.). The most important difference, however, is that it is the wake produced by the bubble rather than the bubble itself which is used as a marker.

A detailed description of a specific piece of apparatus will not be given here since it has been found that a good deal of trial-and-error is always involved in producing a satisfactory set-up. This is due largely to the vagaries of electrode chemistry, many aspects of which remain in the realm of black magic. However, a few of the more general observations are as follows:

1) Teflon-coated, pure copper wire is a suitable electrode material. Single-bubble electrodes can be made by recessing the electrode wire in a small cavity having a volume about the same magnitude as that desired in the generated bubble. One means of achieving this is simply by extending the insulation over the end of the wire. However, platinized Pt wire electrodes (0.016-in. diam sheathed in glass tubing) have been the most successful instrument for achieving well-controlled single bubble generation. If it is desired to generate several bubbles simultaneously at different locations in the field of view, care must be taken to make all electrodes as similar as possible. Otherwise, the bubble sizes and release times may be vastly different.

2) The electrical characteristics required depend upon many variables such as the conductivity of the fluid. For cases involving dilute saline solutions (e.g., conductances of the order of 10^{-1} mho/cm), a voltage of ~30 v and a pulse-width of several msec are suitable. Under these circumstances, a typical single-bubble electrode will draw a current of about 200 ma.

3) The quality of bubble generation by a given electrode often changes markedly with time. Thorough cleaning before the initial immersion as well as an extended "aging" process in which the electrode is repeatedly pulsed for several hours are both required. Reversing polarity can be tried as a means of restoring quality, but more often than not this only succeeds in making matters worse.

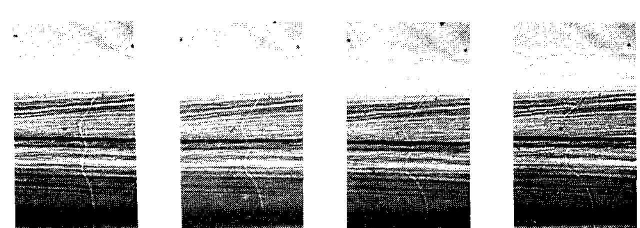

Fig. 1 Bubble track sequence.

Received July 7, 1972. This work was supported under Navy Contract N-00017-72-C-4401

Index category: Hydrodynamics.

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‡ This is not the case for larger bubbles (e.g., having an order of magnitude larger Reynolds number) which swing from side-to-side as they rise due to periodic vortex shedding.

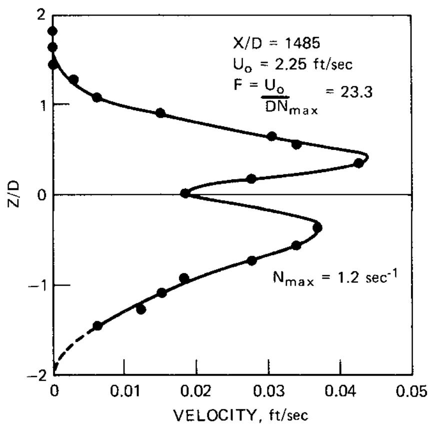

Fig. 2 Near-axis velocity profile in the wake of a towed body.

4) No unusual arrangements are required for the shadowgraph, but since resolution is important, a small source size is indicated. Short-arc Mercury vapor lamps are suitable for this purpose.

Sample Results and Discussion

Shadowgraphic motion pictures taken at some known framing rate provide the displacement vs time information required to compute the velocity profile.§ An example of such a sequence is shown in Fig. 1, and the resulting velocity profile is given in Fig. 2. This particular flow was generated by towing a bluff body in a fluid which was stratified by means of a variation in salinity with depth. The asymmetry evident in the results is real and is due to the specific manner in which the wake was formed, and to a purposeful lack of symmetry in the stratification distribution. Correction for refraction errors has not been made; however, it is possible that in some applications this may be important.

One final point that needs to be made concerns the relative buoyancy of the fluid in the bubble wake. While this had not been quantified, direct observation suggests that the buoyancy effect is small (but necessarily nonzero), especially in comparison with the H_2-bubble and pH dye methods. This is an important consideration for stratified fluid studies. Both of the latter techniques have been investigated in our laboratory, and the buoyancy effects have been too large.¶ This problem suggests as a possible solution the introduction of some sort of neutrally buoyant particle as a fluid marker. However, the difficulty with the use of such particles is that they cannot be conveniently positioned. Moreover, (and of more fundamental concern) they do not accurately portray the behavior of the fluid when dealing with mixing problems. Since it avoids many of the troubles associated with these other methods, the bubble track technique promises to be a valuable laboratory tool for analyzing laminar stratified flows.

References

[1]Schraub, F. et al., "Use of Hydrogen Bubbles for Quantitative Determination of Time-Dependent Velocity Fields in Low-Speed Water Flows," *Transactions of the ASME, Journal of Basic Engineering,* June 1965, p. 429.

[2]Baker, D., "A Technique for the Precise Measurement of Small Fluid Velocities," *Journal of Fluid Mechanics,* Vol. 26, Pt. 3, Nov. 1966, p. 573.

[3]Clutter, D. et al., "Technique of Flow Visualization Using Water as the Working Medium," Rept. E-S29075, April 1959, Douglas Aircraft Co., Long Beach, Calif.

§Multiple exposure techniques using a single photograph are also possible.

¶ The pH dye method supposedly generates a neutrally-buoyant dye marker by merely changing the hydrogen ion concentration around the electrode. Our experience has been that even with careful titration this always entails the production of some bubbles if a sufficient concentration of color-altered dye is achieved. The buoyancy of the resulting mixture is too large for present purposes.