J. Fluid Mech. (1967), *vol.* 27, *part* 2, *pp.* 367–368
Printed in Great Britain

A note on the existence of wakes behind large, rising bubbles

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(Received 9 June 1966)

Using simple flow-visualization techniques, it has been shown that as a large volume of air rises through a quiescent liquid it produces a well-defined wake and that the drag on the bubble appears as a momentum defect within this wake.

The wakes of rising bubbles

There is a belief that the motion of a large gas bubble through a liquid produces no wake. This is apparently due to an overzealous interpretation of some remarkable flash-shadowgraph photographs by Davies & Taylor (1950) of air bubbles rising through nitrobenzene. These show a large bubble with a spherical cap and ragged rear followed by an almost spherical blob of turbulent fluid. Further downstream, the flow is apparently smooth. The interpretation has been that around the spherical region, made up of the cap of the bubble and the turbulence, the flow is a potential flow, which closes up smoothly behind the spherical region forming no wake. That this interpretation must be wrong is obvious from elementary momentum arguments. Since the bubble eventually rises at a uniform velocity, it must experience a finite drag and this drag must appear downstream as a momentum defect. Far from the bubble, the wake will spread under the action of viscosity in a conventional way completely unaware of the exact nature of its origin.

If a bubble is allowed to rise through a region of heavy dye-concentration into a region of clear water, if a wake exists, it will drag some of the dye with it. Pictures of such a situation are shown in figure 1 (plate 1) for a bubble with a volume of 2·5 cc rising in a 6 in. square tank. The dye column and its mixing with clear, outer fluid are clearly shown.

In order to put this simple observation on a more quantitative footing, the following experiment was performed. A thin, 0·001 in. diameter platinum wire was stretched horizontally across the tank. Fluid motions could then be observed by pulsing the wire with millisecond pulses of 100 V d.c. and photographing the resultant lines of hydrogen bubbles as they were convected by the flow. When a rising 1·5 cc bubble had passed the wire and was a known distance above it, the axial velocity in its wake could be observed by pulsing the wire and photographing the hydrogen bubbles formed a short time later. Such a photograph is shown in figure 2 (plate 2). It is obviously turbulent! If this experiment is repeated many (20) times, so that we can get some statistical information about the wake a known distance behind the bubble, we can very crudely construct a mean velocity profile†, as shown in figure 3. From this we calculate the drag coefficient of the bubble to be 3·2, being within 30 % of the value (2·5) calculated from the velocity of rise of the bubble.

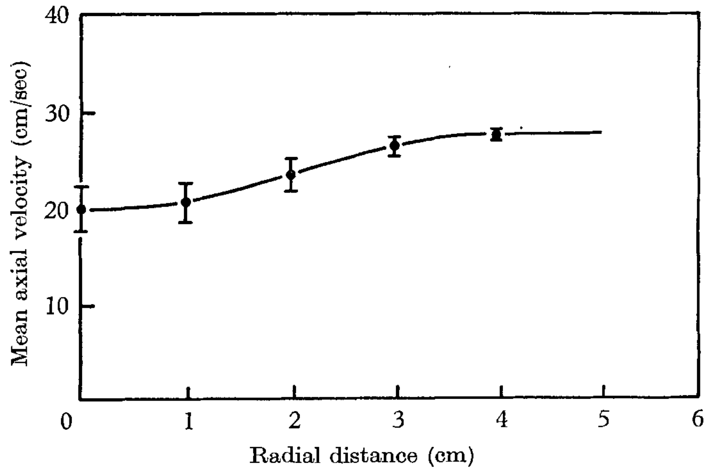

FIGURE 3. Mean velocity profile in wake 25 cm behind a 1·5 cc bubble.

Drs D. W. Moore and P. G. Saffman pointed out to the author the existing misconception about bubble wakes and provided the encouragement both to perform the experiments and publish their results.

This paper presents the results of one phase of research carried out at the Jet Propulsion Laboratory, California Institute of Technology, under Contract No. NAS7-100, sponsored by the National Aeronautics and Space Administration.

REFERENCE

DAVIES, R. M. & TAYLOR, G. I. 1950 The mechanics of large bubbles rising through extended liquids and through liquids in tubes. *Proc. Roy. Soc.* A **200**, 375.

† Dr F. H. Abernathy was apparently the first to use this multiple sampling technique, and the author is greatly indebted to him for the inspiration to use it in this particular case.

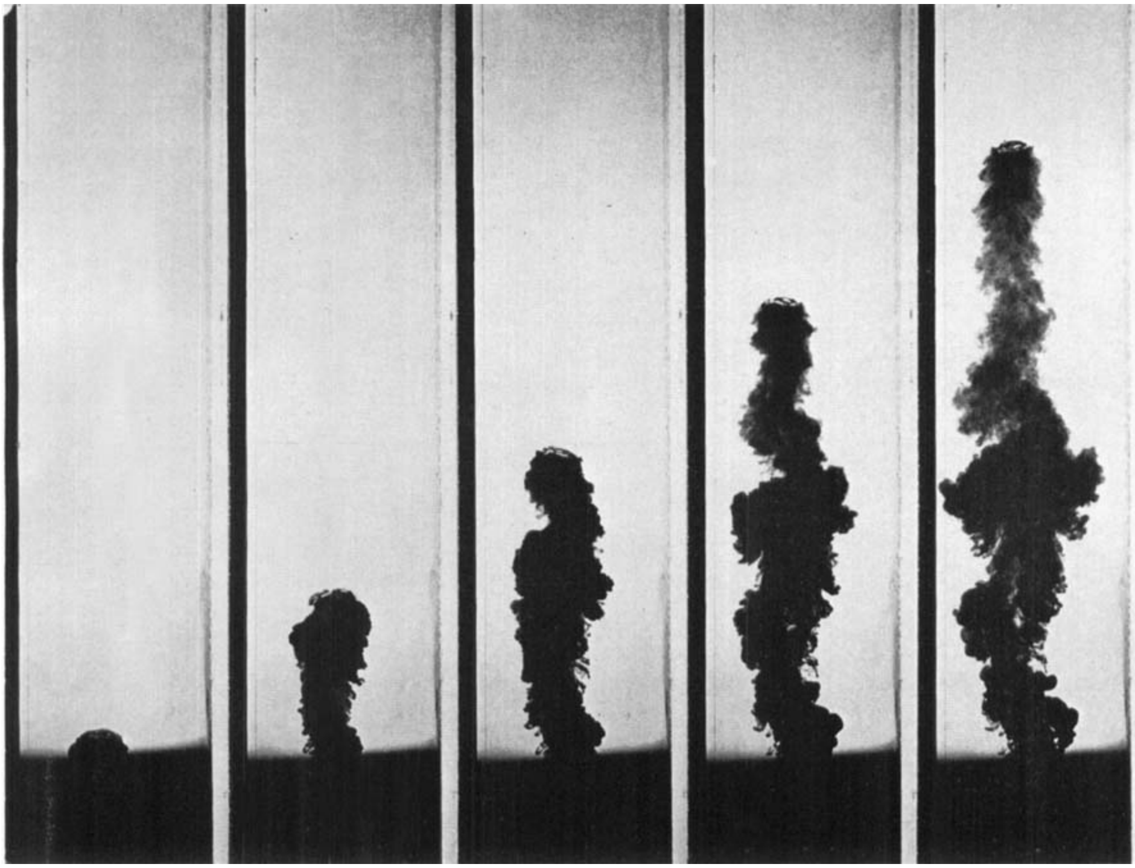

FIGURE 1. A 2·5 cc bubble leaving a region of dye concentration and rising into a region of clear water. Photographs taken approximately 1/3 second apart.

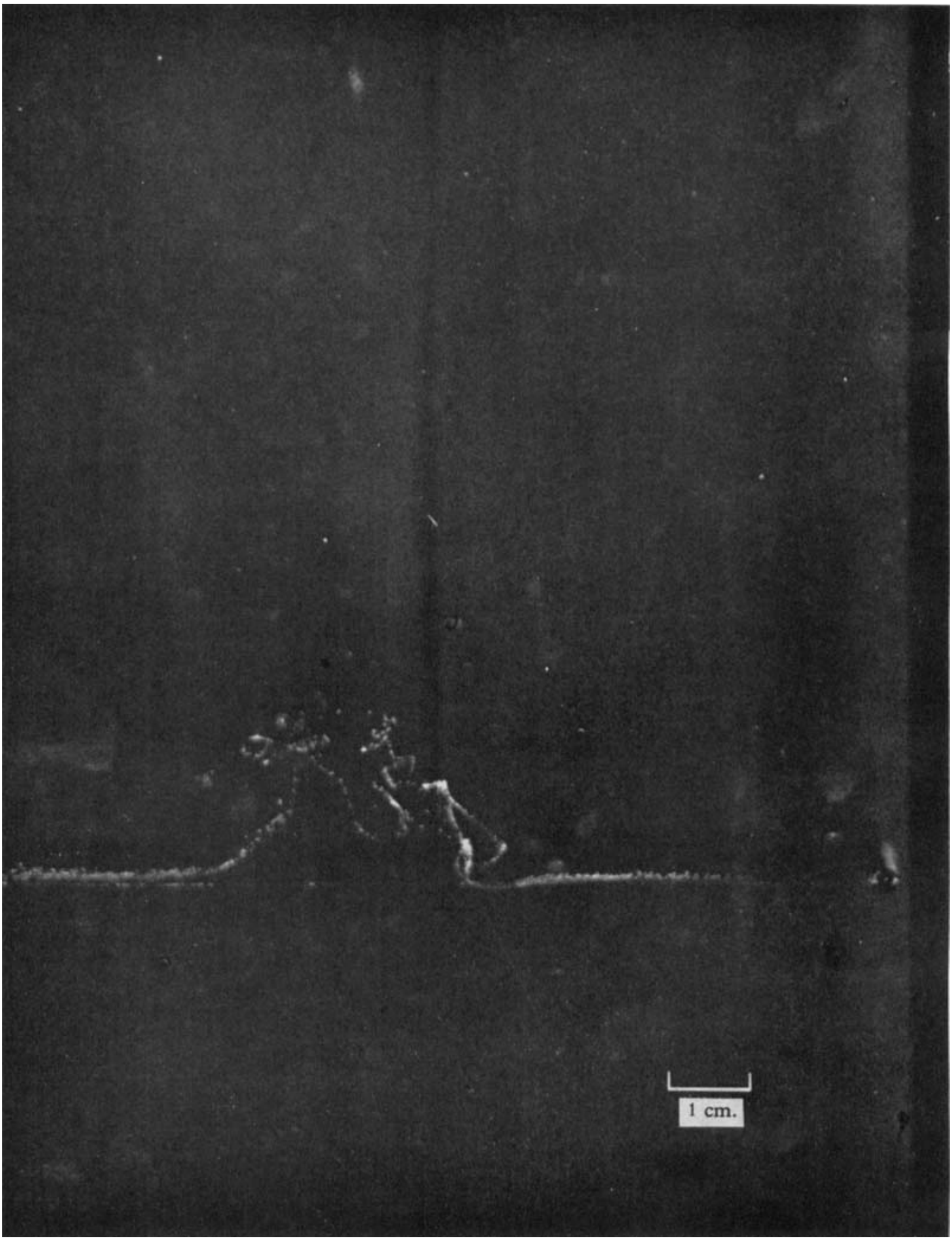

FIGURE 2. Hydrogen bubble picture of the instantaneous velocity profile 25 cm behind a rising, 1·5 cc bubble.