NOTES

Upwind Distortion Due to Probe Support in Boundary-Layer Observation

E. MOLLO-CHRISTENSEN

Department of Meteorology, Massachusetts Institute of Technology, Cambridge 02139

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ABSTRACT

An obstacle in a boundary-layer flow creates a disturbance upwind of the obstacle, consisting of a stationary vortex extending downstream on both sides of the obstacle. This flow disturbance may interfere with observation of wind profiles or fluxes. The distance of the vortex from the obstacle is of the order of the obstacle width or height, whichever is the smaller, and for obstacles which do not possess an obvious length scale, the separation distance is of the order of the boundary-layer displacement thickness. Observation from ship-mounted booms or from oil platforms should be designed so as to avoid the upstream disturbance in the boundary layer. Illustrations and examples given are taken from wind tunnel tests of R/V *Flip*.

The comparisons of mast and boom wind speed data of Kidwell and Seguin (1978) illustrate the need for caution in boundary layer observation near the sea surface. The discrepancies they find in the GATE wind data may in part be attributed to instruments placed in the boundary layer in the distortion field created by a ship in the upwind boundary layer. An obstacle creates a pressure field such that the pressure is increased upwind of the obstacle. As a result, the airflow is accelerated away from the ship in the boundary layer upwind of the ship. This acceleration may be sufficient, especially near the water surface, where the speed of approach is small, to reverse the flow for some distance above the water surface. The result is that directly upwind of the obstacle a vortex forms at a constant distance upwind. This vortex continues downwind on both sides of the obstacle. The process is illustrated in Fig. 1, where the velocity profile ahead of the obstacle, the distortion wind field and the flow reversal associated with the vortex are indicated. Fig. 2, taken from Schwind (1962), illustrates the effect further by showing the upwind streamline field in the plane of symmetry upwind of an obstacle piercing a boundary layer. Fig. 3 shows the same flow, consisting of a boundary-layer flow approaching a vertical wedge; when the streamlines in the flow reversal zone are made visible by smoke injection, the view, which is from above, shows the vortex bent downstream on both sides of the wedge.

Most wind tunnel tests of probe supports have addressed the problem of probe interference in a uniform flow; the possibility of free-vortex formation, as shown by Schwind (1962) and previously recognized by Gregory and Walker (1951), does not seem to have received much attention. Signs of what may be incipient flow separation near the sea surface can be seen in the wind tunnel tests of the Research Vessel *Flip* that I did some years ago in preparation for the BOMEX experiments. These tests were carried out

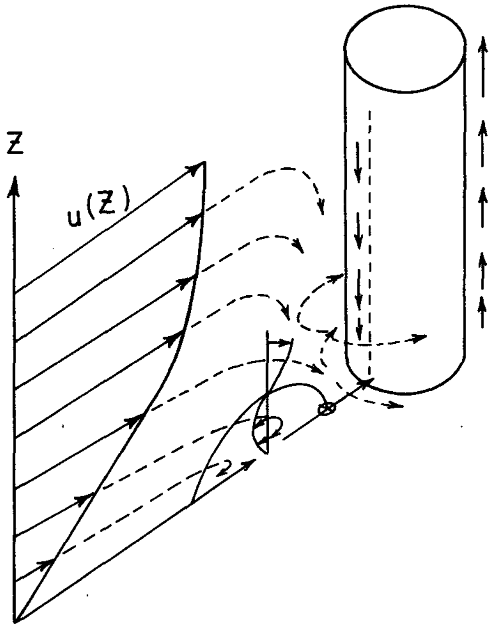

FIG. 1. Sketch of a boundary-layer flow approaching an obstacle, indicating streamlines in plane of symmetry, position of separation near lower surface, upflow in wake of obstacle and downflow along upwind side.

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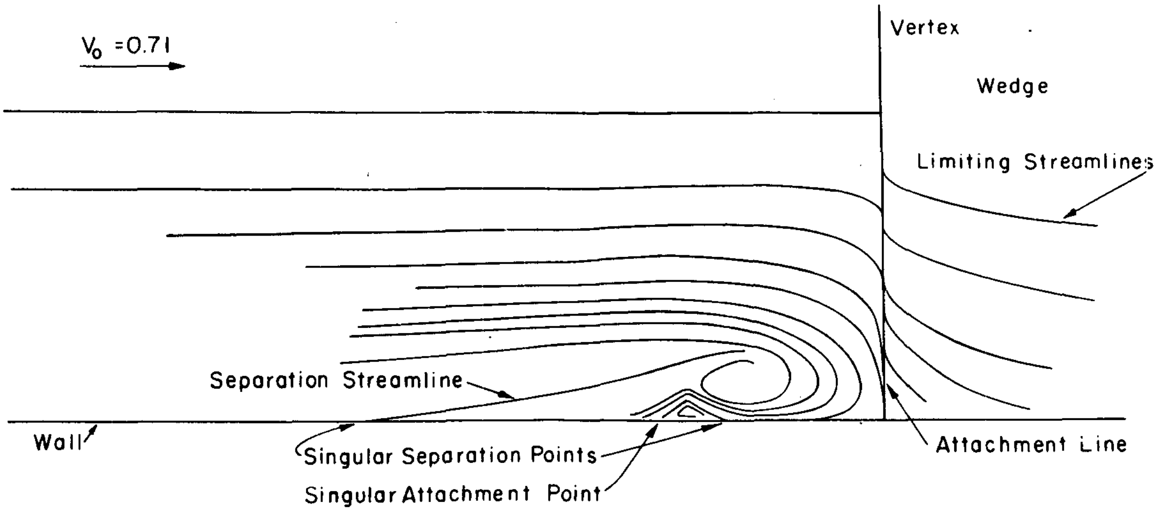

FIG. 2. Streamline plot in a plane of symmetry, obtained by Schwind in experiment on boundary-layer flow approaching a vertical wedge. Note vortex, separation points and downflow near wedge.

on a 1:30 scale model of the above-water portion of the *Flip* in the upright position. The tests were carried out at a wind tunnel speed of 40 m s^{-1}, corresponding to the Reynolds number of the full-scale model in a wind velocity field of 1.3 m s^{-1}. The Reynolds number, based on model height and free stream velocity, was 1.3×10^6. The velocity profile on the tunnel floor in the absence of the model is shown in Fig. 4. The wind profile is nearly logarithmic up to a height of 20 cm, corresponding to 5 m on the full-scale ship. Two examples of wind interference field observations are shown in Figs. 5 and 6. The measure of interference chosen is the change in wind velocity at the measurement location due to the presence of the model, divided by free stream velocity and expressed in percent.

Note that the wind field disturbance is small ($<5\%$), while the effect on apparent surface stress or fluxes, which were not measured, could of course have been more. In Fig. 5, the disturbance profiles directly abeam of the *Flip* are shown, with the deck of the *Flip* facing into the wind. Note that for run 34, the acceleration of the flow near the *Flip* is apparent. This disturbance, as confirmed by other observations, is similar to the flow over a sphere similar in size to the upper part of the *Flip*. Near the water surface, the flow disturbance may be caused by the presence of a vortex very near the water surface, below the lowest probe position, and inboard of the positions where observations were made. The asymmetry between port and starboard is due to the presence of a flat skiff in davits on the one side as indicated. Further observations, taken along vertical lines going through the forward facing boom, where one may choose to make ob-

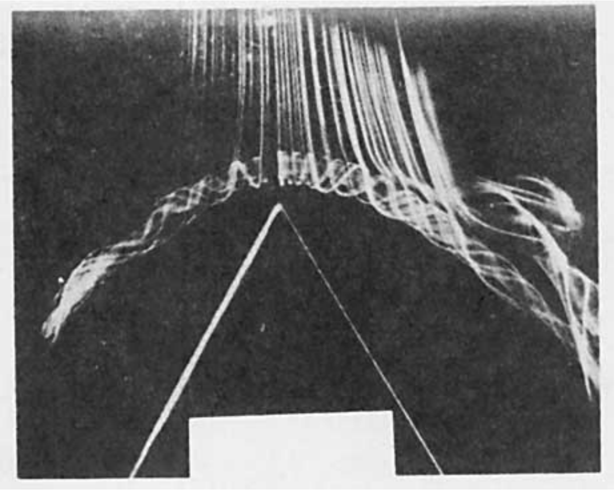

FIG. 3. The vortex of Fig. 2 seen from above and made visible by smoke.

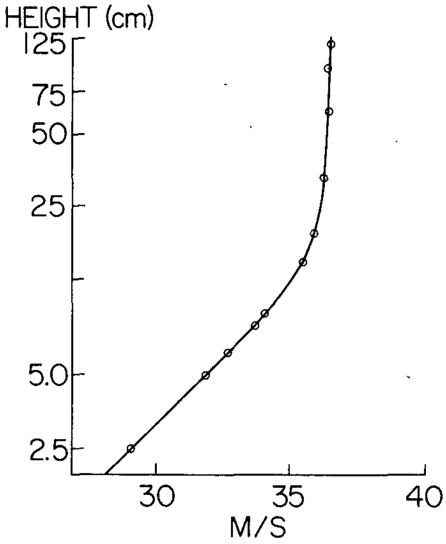

FIG. 4. Boundary-layer profile for the R/V *Flip* wind tunnel tests.

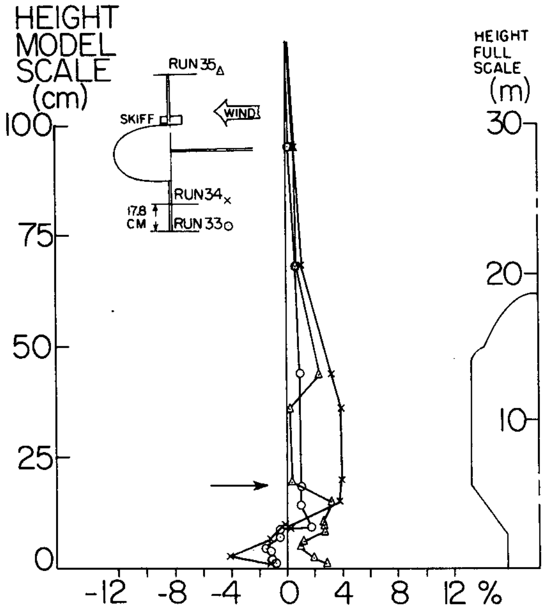

FIG. 5. Velocity field distortion measured in wind tunnel tests of 1:30 scale model of the *Flip*, showing the distortion along vertical lines at the side booms when the deck faces into the wind. Right-left asymmetry attributable to presence of skiff on davits, serving as a baffle to inhibit vertical flow. Note acceleration around body of obstacle and near-surface boundary-layer disturbance.

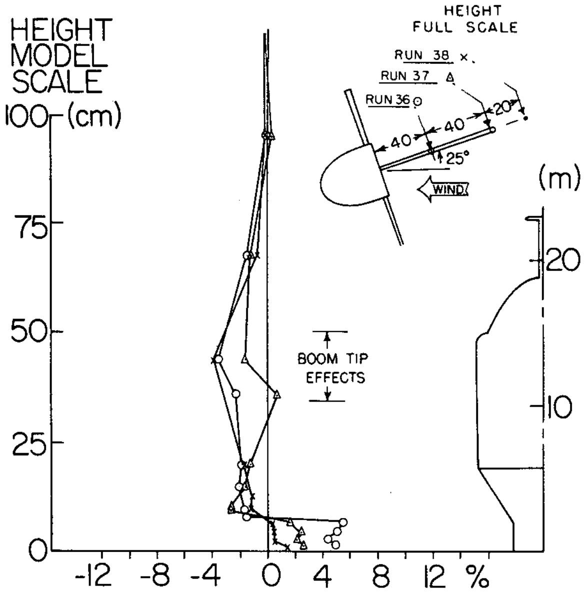

FIG. 6. Same as in Fig. 4, with *Flip* deck facing 25° from upwind, showing distortion field along forward boom. Note effects in boundary layer, showing flow deceleration near the surface.

servations, are shown in Fig. 6. The *Flip* is oriented with the boom making an angle of 25° with the upwind direction, as shown, and the surveys were made at positions corresponding to 12, 24 and 30 m from the deck along the boom. The distortion shows the flow slowed down upwind of the *Flip*, as should be expected for any obstacle, and a disturbance near the surface which also may, in part, be attributed to the flow accelerating around a spherelike obstacle; but also showing shear variation, near the surface, that is part of the disturbance field induced in a boundary-layer flow by the presence of an obstacle.

As a further example of the extent of the ocean-surface disturbance caused by an obstruction penetrating a boundary layer, Fig. 7 shows the pattern of snow on the ground near a grain elevator; the intensity of the velocity disturbance was sufficient to clear the ground of snow inside the horseshoe vortex pattern. This also suggests that tracer experiments, using confetti, smoke or snow may be useful for finding the range of interference at the surface.

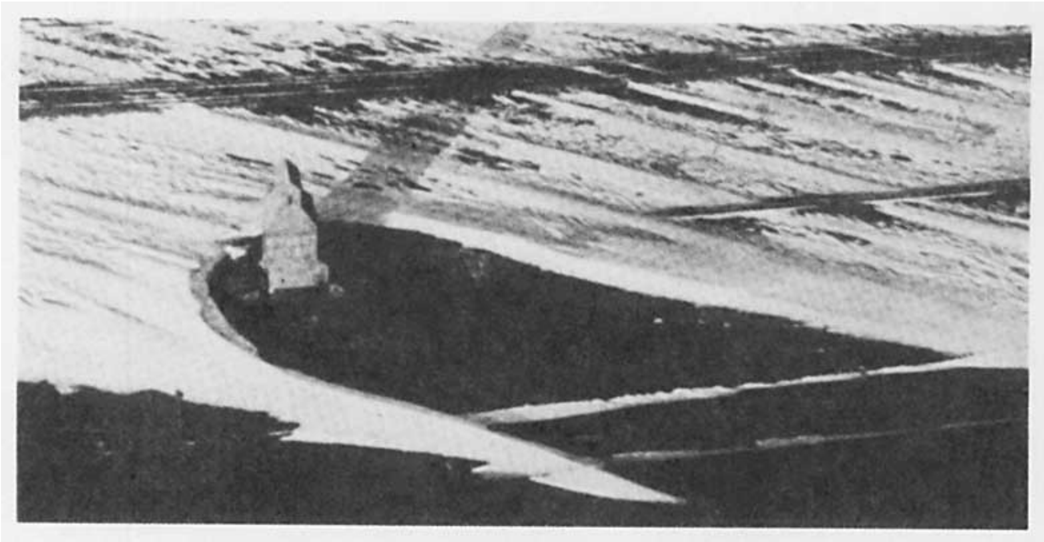

FIG. 7. The snow pattern on the ground near a grain elevator in Boise City, Oklahoma. (Photo courtesy A. Y. Owen, Life Magazine, © 1957 Time, Inc.)

The data available do not permit one to make any firm rules about where one can place probes suspended from a boundary-layer penetrating obstacle but they do serve a cautionary purpose, and they demonstrate that the boundary layer disturbance may be important, in addition to the potential flow effects.

Looking at the results of Thornthwaite *et al.* (1965), Mollo-Christensen and Seescholz (1967) and the data of Gregory and Walker (1951) and the other observation of Schwind (1962), it appears that a first approximation to the location of an upstream vortex near the surface may be at a distance, upstream, of the object equal to its height, its width, or the boundary-layer displacement thickness, whichever is the smallest. For a ship with a bow-mounted boom, this would mean the ship beam or forward freeboard; for a ship crosswind, it would mean the freeboard. For a complicated obstacle, such as a drilling platform, caution suggests the same rule should be applied, even if one can argue that the flow can pass freely under the platform. The main lesson may be that only wind tunnel tests of a model or comparison tests at different distances from the full-scale probe support platform can verify the absence of flow interference. Of course, one must also realize that large flux distortion can be induced by comparatively slight mean velocity disturbances, and that one must not only check the wind velocity distortion, but also the distortion of the flux field, for flux observation programs.

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