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EXPERIMENTAL STUDIES OF THE EXISTENCE OF POLARIZED TURBULENCE IN FLAT RECTANGULAR CHANNELS

E.M.SPARROW

DATE: SEPTEMBER 8,1949

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September 8, 1949

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ABSTRACT

It was found experimentally that for rectangular channels of width/depth ratios 8, 12, and 24 the same type of flow existed in the plane of the width and the plane of the depth. Mixing lengths were observed to be the same in the two flow planes.

Observations by Coons (1,2) of one-dimensional fluid flow in rectangular channels of large width to depth ratios suggest the coexistence of laminar and turbulent motions. Coons observed that the dispersion of a thread of colored dye in the channel was much greater in the plane of the width than in the plane of the depth. He noted that when looking in a vertical direction (in the plane of the width) the dye appeared to be completely dispersed, while observation of the side of the channel showed the thread to be only slightly wavy. A physical picture of the inferred phenonemon may be obtained by considering a deck of playing cards. The side of the deck may be taken to represent fluid laminations between which there would be no mixing. Mixing would occur in the faces of the cards or fluid laminations. Since eddies and vortices would be confined only to the faces, turbulence would exist in one plane and may be termed polarized.

It was deemed desirable to experimentally investigate the existence of polarized turbulence because of the following: (1) heat transfer characteristics are closely related to the manner of fluid flow; and (2) observation of the motion of floating bodies such as corks on the surface of a flat open channel in polarized turbulence could provide a new approach to turbulence studies. Since the turbulence would be confined to the plane of the surface, the movement of the corks would truly conform to the eddy motion in the stream; whereas in a non-polarized stream, the floating properties of the corks would prevent coincidence of the cork and eddy motions.

This investigation was carried out by observing the motion of a stream of black ink in a water-filled plexiglass channel. Three channels having the following dimensions were employed:

Width, in.	Depth, in.	Width/depth	Length, ft.
6	0.75	8	6.5
6	0.5	12	6.5
6	0.25	24	6.5

For each of the channels, several hours of careful observation showed that the same type of flow existed in both the narrow and wide planes of flow. It was also observed that the transition from laminar to turbulent flow, as indicated by the diffusion of the dye stream, occurred at the same longitudinal position in both flow planes. Studies of the development of eddies indicate that the dispersion of the dye per unit length of channel was the same for the two flow planes, thus implying identical mixing lengths.

Photographs of the motion of the dye stream are presented in Figs. 1 and 2. By the use of a mirror, it was possible to simultaneously record flow patterns in the plane of the width and the plane of the depth. Breakdown of laminar motion in the channel of width/depth ratio 8 is shown in Fig. 1, while Fig. 2 is a similar photograph of the channel of width/depth ratio 12. Photographic difficulties made it impractical to record the flow patterns in the channel of width/depth ratio 24.

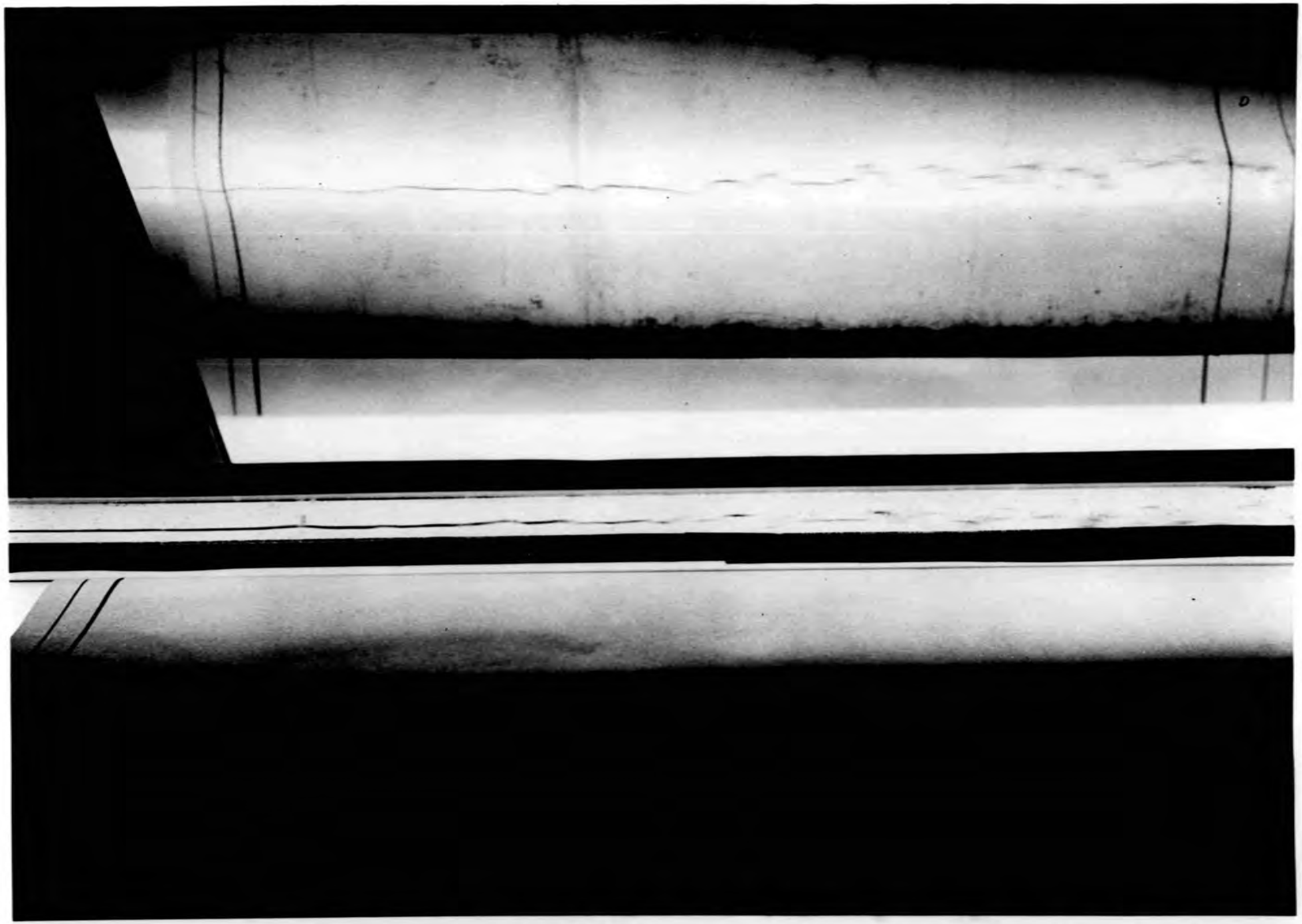

FIGURE I. DYE STREAM MOTION IN PLANE OF WIDTH AND PLANE OF DEPTH
RECTANGULAR CHANNEL OF WIDTH / DEPTH RATIO 8

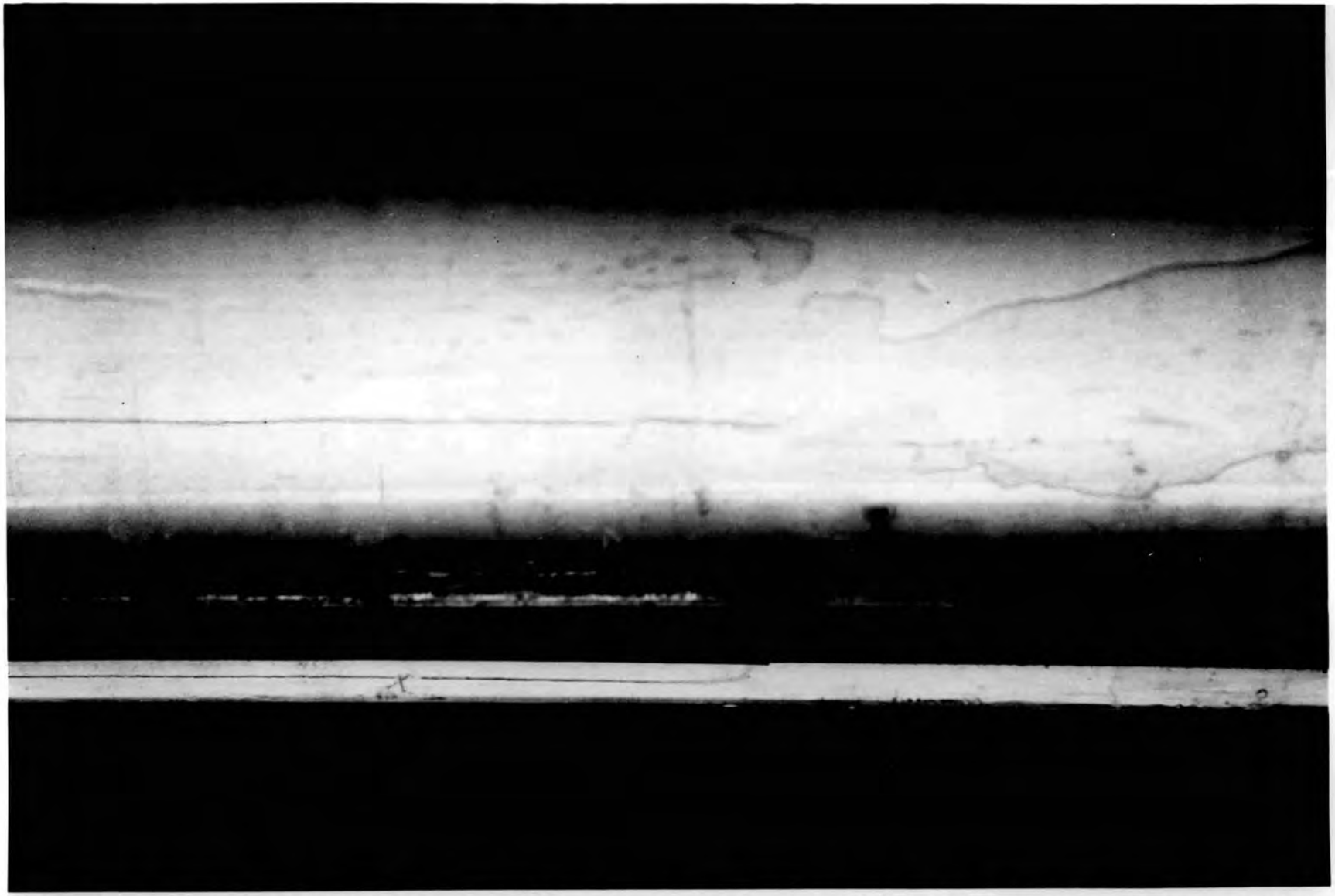

FIGURE 2. DYE STREAM MOTION IN PLANE OF WIDTH AND PLANE OF DEPTH
RECTANGULAR CHANNEL OF WIDTH/DEPTH RATIO 12

It was found that the completely laminar flow in the channel existed up to Reynolds Numbers of 2000 - 2500, a good agreement with results of Coons (1). For increasing Reynolds Numbers, the point of transition from laminar to turbulent motion moved upstream toward the channel entrance.

The existence of polarized turbulence may be questioned on the basis of theoretical considerations. It is first necessary to introduce the notion of the vortex line, which is a line drawn in the fluid so that the tangent to it at any point has the direction of the axis of the vorticity at that point. Then, the existence of polarized turbulence is assumed, and from this a contradiction is discovered. For, since the vorticity would be confined to the plane of the width of the channel, the vortex line must be normal to this plane. However, if laminar flow exists in the plane of the depth, points on a vortex line would be moving with the different velocities because of the parabolic distribution; so that even if the line was normal to the plane of the width at one instant of time, it could not be at the next instant - thus contradicting the original hypothesis.

Photographs of the apparatus used in this investigation are shown in Figs. 3, 4, and 5. The flow circuit is most easily traced in Fig. 3. Water entered the system at the large calming and storage tank shown at the right of the photograph. The stream passed into the rectangular channel through a bell-mouth metal funnel which extended into the tank. At the downstream end of the channel a second tank equipped with an outlet valve provided a means for controlling the flow rate in the channel. The rectangular channel was joined to the tanks by means of plexiglass flanges.

The inlet tank and dye injection system are pictured in Fig. 4. Baffles welded to the bottom of the tank calmed and directed the flow of water. The bell-mouth funnel was constructed to fit into a slot in the tank wall whose dimensions were identical with those of the largest channel (3/4" x 6"). Dye was injected into the water stream through a tapered glass capillary tube which was joined rigidly to a copper tube leading to the reservoir. The orientation of the capillary was adjusted by altering the position of a large flat plat lying on the top of the tank to which the copper tube was attached. Lead bricks and shims were employed in adjusting and stabilizing the position of the capillary.

Channel dimensions were varied by inserting the long plexiglass sections shown in Fig. 5, thus changing the depth and not the width. Additional bell-mouth funnels as well as accompanying plexiglass bars used to fill the 3/4" slit in the tank wall are also shown.

During preliminary operation of the apparatus, it was found that the eddies caused by water flowing into the storage tank were of sufficient magnitude to disturb the stream entering the channel. To avoid this situation, the storage tank was filled between experiments and no water was introduced into the storage tank while observations were being made.

The procedure followed during the experiments was to fill the storage tank to capacity and then to allow the static head of fluid in the tank to decrease as the water discharged through the channel. Since the average

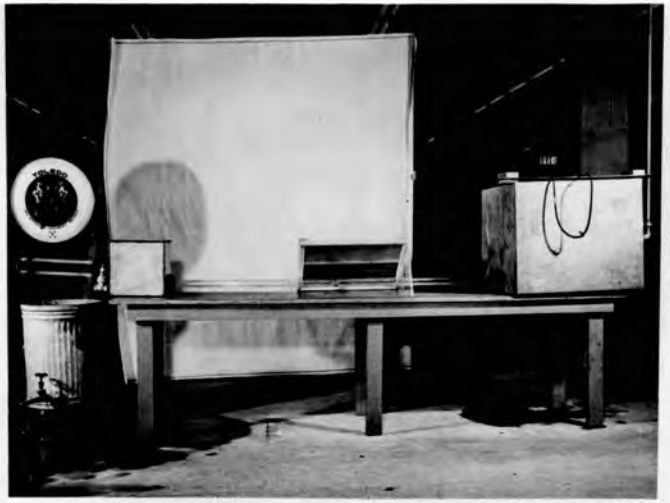

FIGURE 3. COMPLETE ASSEMBLY OF TEST APPARATUS

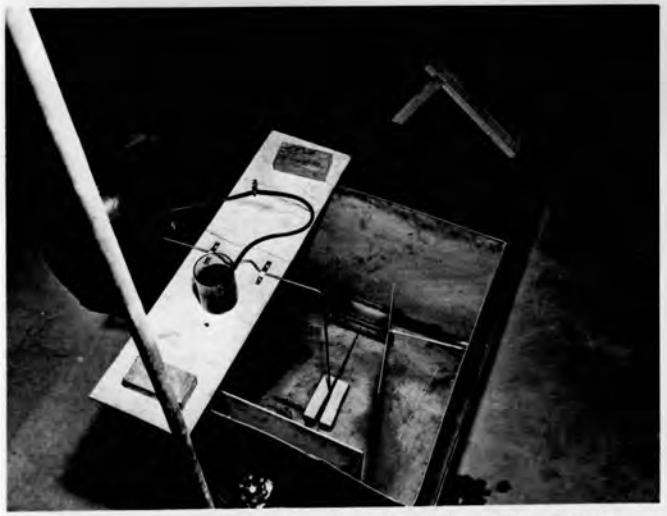

FIGURE 4. DETAILS OF INLET STORAGE TANK AND DYE INJECTION SYSTEM

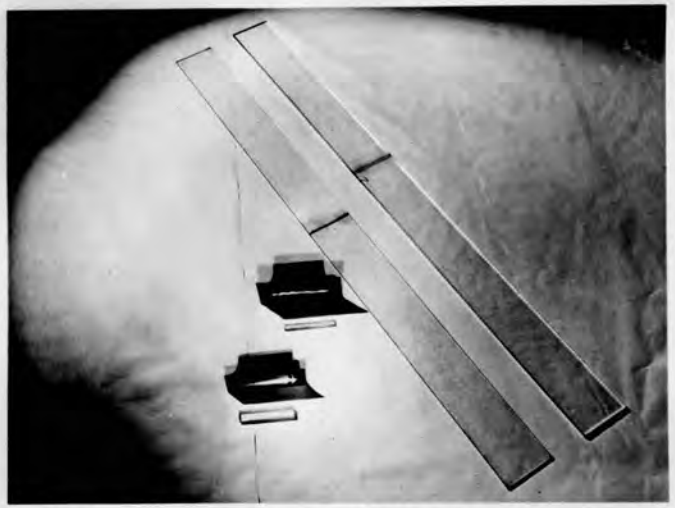

FIGURE 5. PLEXIGLASS SHEETS AND METAL FUNNELS FOR ALTERATION OF CHANNEL DIMENSIONS

velocity in the channel decreased as the static head in the storage tank decreased, the "critical" or transition value of the Reynolds Number was approached from above. Observations were made for Reynolds Numbers, based on the hydraulic diameter, varying from 2000 to 5000.

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Approved by: R. N. Lyon

R. N. Lyon

Literature Citations

(1) Coons, K. W., "Heat Transfer Equipment", Heat Transfer Lectures, Volume 1 - NEPA Heat Transfer Symposium, Oak Ridge, 1947.

(2) Coons, K. W., Personal Correspondence, August 5, 1949.

Acknowledgement

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