After the aspirator is attached at *A* and turned on, the system is evacuated roughly through *B* so that the impure liquid may be drawn in through *C* to fill the 4-l flask *D*. The closures at *B* (*C* and *N*) are Teflon stop cocks or Teflon seated ball valves, bellows valves or glass capillary liquid freeze valves. The liquid in *D* is brought quickly to the desired boiling temperature through adjusting the power to the Glass-Col heater *E*. As the vapor boil-up time increases, the fractionating column *F* packed with $\frac{1}{4}$ in dia. stainless steel wire (20 ga.) helical segments gets warm allowing the vapor to reach the condenser *G*. The non-condensable gases collect above the condenser and pass through the heated sonic orifice *H* (0·001 in dia.) to the aspirator. The ratio P_2/P_1 for most gases must be maintained below 0·5. The 10 W–110 V heating element insures that there is no condensation in the orifice.

The amount of condensate produced in *G* is adjusted through the choice of coolant (air, water, refrigerant) its rate, and the size of the condenser surface provided. It is directed from dropping points *J* in a funnel *K* so that the reflux is distributed from the center rather than running down the walls of the fractionator. The funnel *K* is supported in a ring fastened at three points to the fractionator wall allowing the vapor unobstructed passage around the funnel. Weep holes above the dropping tips *J* prevent the trapping of non-condensable gases there. The reflux ultimately returns to *D*.

As the dissolved and absorbed gases are removed, the boiling would proceed in a chaotic and disruptive fashion were it not for the vapor introduced under the liquid in *D*. When the heat input to heater *L* (75 W–110 V) is adjusted to give 3–10 vapor bubbles/s, the distillation proceeds uniformly and well. Wide fluctuations in system pressure may momentarily interupt this flow of vapor. With large increases in system pressure a larger heat input to *L* may be required or the feed line *M* should be insulated to reduce the condensation rate there.

When all the non-condensable gases have been removed, the system pressure may be increased by increasing the boil-up rate, and by reducing the condensation rate. The vapor is removed through *N*. A condenser may be introduced here if the product is desired as a liquid. The residual liquid in *D* may be removed by inserting a small diameter Teflon tube to the bottom of *D*.

This system has been used to produce gas-free water, CCl_4, and other organic solvents. In producing gas-free water, the water in *D* will become increasingly cloudy due to the precipitation of SiO_2 and other silicates dissolved from the fractionating column and condenser walls. Small amounts of organic impurities can be removed by destructive oxidation by putting in basic $KMnO_4$ in *D*.

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LAMINAR FLOW OVER RECTANGULAR CAVITIES†

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(*Received* 2 *November* 1967 *and in revised form* 16 *February* 1968)

INTRODUCTION

THE INTEREST in flows over rough surfaces stems originally from the desire to interpret more completely heat-transfer results for forced convection over rough surfaces [1]. In this connection a series of flow experiments were initiated. In a previous paper which appeared in this Journal [3], the results of a study on the flow over a set of transverse rectangular slots were reported. In those experiments the slots were exposed to a turbulent outer boundary layer and the slot depth was from three to thirty times that of the laminar sublayer (defined as $y^* = 5$). This size relationship is typical for rough surfaces and the purpose of the investigation was to obtain a better understanding of the flow conditions. It was found that when the slot size was less

† The work on which this paper is based has enjoyed the support of the National Science Foundation under Grant No. GK 572.

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than about twenty times the sublayer thickness the flow in the slots was unsteady; a vortex would form in the slot which would subsequently be destroyed by disturbances occurring randomly in time. In between disturbances the vortex would reform. It was thought that these disturbances originated in the turbulent boundary layer outside of the slots. There were some thoughts, however, that the observed disturbances might be due to an inherent instability of the vortex flow in the slots themselves. For this reason it was felt desirable to conduct a control experiment in which a set of slots would be exposed to a laminar flow, keeping all other boundary conditions for the flow in the slot as similar as possible. The purpose of the present paper is to report the results of this control experiment. Details of the experiment may be found in [2].

TEST INSTALLATION

The present experiments were conducted in a low turbulence open surface water tunnel. A flat plate was suspended at midheight and a slotted section was inserted in this plate flush with its surface. The plate was provided with an elliptical nose and was adjusted to have a slight angle of attack so as to avoid flow separation on the upper side of the plate. A sketch of the plate with the slotted insert is shown in Fig. 1.

EXPERIMENTAL STUDY

As stated earlier it was desired to examine the flow in the slots when exposed to a laminar outer flow and to compare the observations with those for a turbulent outer flow. In such a comparison "complete" similarity would, of course, defeat the purpose. As the flow in the slots is of prime interest, it was felt that a meaningful comparison could be based on a parameter computed from the cavity dimensions, the viscosity and density of the fluid and the shear at the cavity surface. The corresponding parameter is given the symbol ϵ^* and defined as $\epsilon^* = \epsilon\sqrt{(\tau_0/\rho)}/\nu$, where ϵ is the cavity depth, τ_0 the surface shear (measured immediately upstream of the cavity), ν the kinematic viscosity of the fluid, and ρ the density. The parameter ϵ^* is a Reynolds number characterizing the flow in the slot.

In performing the experiments velocity profiles upstream of the slots as well as above and within the slots were taken; the surface shear stress was determined from those profiles. The fact that the flow was laminar was ascertained by monitoring the velocity fluctuations directly. The profile itself differed from the classic Blasius profile, largely because of a pressure gradient along the surface. No attempt was made to modify the profile, however, since for the present investigation modeling was limited to the shear, τ_0.

In the course of the experiments the size of the slots as well as the velocity were changed so as to cover a range of ϵ^* which would include the region for which the flow disturbances were observed in the turbulent flow experiments.

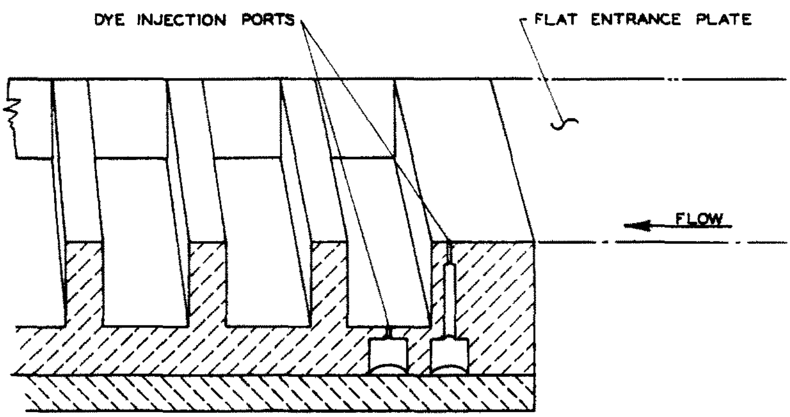

FIG. 1. Cross section of plate with dye slots. The span equals 7 in and $\varepsilon = L = \frac{1}{2}$ in.

Velocities were measured by a hot film technique. The actual probe consisted of a glass tube (0·001-in dia.) on which a film of platinum was deposited which in turn was protected by a quartz layer. The probe was procured commercially. A more detailed description of the equipment may be found in [3, 4].

The flow was made visible by dye injection and photographic records of flow patterns in the first slot, the one of primary interest, were taken.

The observations very clearly indicated that the flow in the slots for an outer *laminar* boundary layer differed drastically from that observed previously for an outer *turbulent* boundary layer. Whereas in the turbulent case the flow in the slot was randomly disturbed, a very steady vortex

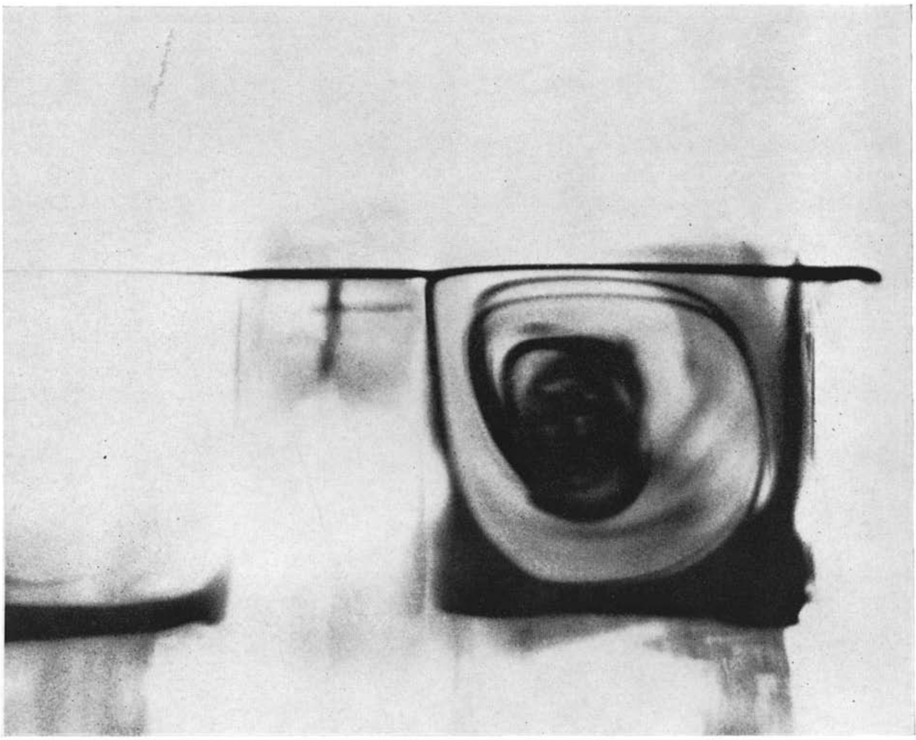

FIG 2. Photograph of cavity flow. Flow is from right to left. $\frac{1}{2} \times \frac{1}{2}$ in cavity, $U_{\infty} = 0{\cdot}50$ ft/s, $\epsilon^* = 143{\cdot}2$.

flow was established for the laminar case. In each cavity in the present series of tests in which the outer flow was laminar the same steady vortex pattern existed for the range of ϵ^* from 16 to 400. A typical photograph of the pattern is shown in Fig. 2.

The values of ϵ^* given here are based on the shear at the surface just upstream of the slot. Based on the shear at the slot opening (midway between the upstream and downstream edge) the corresponding range is bounded by 8 and 200. In any case, however, the range of ϵ^* of the present laminar flow tests embraces that for which the disturbances were observed in the previous work with turbulent flow. In addition, to investigate the flow more closely and to detect any possible three dimensional motion such as cell patterns, a sheet of dye was injected near the upper upstream corner of the slot. For this purpose a special slotted section was constructed in which a dye injection gap of a few thousandths of an inch was provided all along the above mentioned edge. No disturbances, cells or three dimensional motion were observable in this case either.

As a side observation a completely separate phenomenon was noted. Over each cavity, a laminar shear layer developed between the outer stream and the fluid in the cavity. For sufficiently high velocities this layer became unstable and a dye filament injected just upstream of the cavity showed very clear and regular oscillations. The frequency of the oscillations as well as the onset of the instability seemed to depend on the velocity as well as the cavity dimensions. This type of instability is believed to be the same as that studied analytically by Lessen [5] and experimentally by Sato [6]. An experimental installation similar to the present seems well suited for the further investigation of this phenomenon.

SUMMARY AND CONCLUSION

It was the purpose of this study to compare the flow in rectangular slots for an outer turbulent flow on the one hand and a laminar one on the other, maintaining all other conditions as similar as possible. In the turbulent case the flow in the slots was violently disturbed for a certain range of the parameter ϵ^*. No such disturbances were noted when the outer flow was laminar. The results of the present series of tests, therefore, substantiate the hypothesis that the disturbances of the flow in the slots in the earlier experiments originated in the turbulent boundary layer adjacent to the slots.

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