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Closure of “Flow Patterns in a Four-Branch Junction with Supercritical Flow”

by Emmanuel Mignot, Nicolas Rivière, Richard Perkins, and André Paquier

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The authors would like to thank the discussers for their interest in the experimental work carried out here.

In the paper, the authors identified three flow types which occur in supercritical flow in a junction composed of four channels intersecting at 90°. The first two flow types – referred to as “Type I” and “Type II” flows – had already been identified by Nania *et al.* (2004). Type I is a flow pattern with a normal jump within each upstream branch while Type II is a flow pattern with a normal jump in an upstream branch and an oblique jump in the junction. The

paper (Mignot *et al.*, 2008) provides a theoretical explanation for the existence of these two flow types, based on the fact that each incoming flow deflects the other incoming flow, but there is a limit to the deflection angle that can occur. Ippen (1951) showed that in supercritical flow there is a maximum deflection angle θ_{max} which depends on the Froude number; the higher the Froude number, the higher θ_{max} . If the other incoming flow imposes a deflection such that $\theta < \theta_{max}$, the flow is deflected by an oblique jump. On the other hand, if the deflection is such that $\theta > \theta_{max}$, the deflection takes place with a transition to a subcritical flow through a normal jump in the upstream channel and then by streamline curvature in the junction. On the basis of this analysis, it was suggested that a third flow type should exist – a “Type III” flow. This corresponds to a flow pattern with two oblique jumps in the junction. Unfortunately, Type III could not be observed in the original experimental set-up due to slope limitations. A modification of the set up was performed in order to create the conditions necessary for the formation of a Type III flow, with non-uniform upstream flow conditions together with backwater effects in the downstream branches. The discussers doubt that a Type III flow could actually be observed in the original experimental set-up with upstream uniform flow conditions and downstream supercritical flow conditions.

Thus, for this closure, the original set-up has been recreated, with the upstream slopes set to 7.4%, in a geometrically symmetric configuration. Two flow configurations with high upstream Froude numbers are studied (see Table 1): a symmetrical one (Case 1) and an asymmetrical one (Case 2). The relatively high discharges ($>6L/s$) used in Cases 1 and 2 lead to high uniform upstream depths ($h_n \sim 12-16$ mm). Therefore, the uncertainties in water depth measurement remain limited to about 0.5 mm, as estimated in Mignot *et al.* (2008); this corresponds to about 3% of the flow depth or 6.5% of the upstream Froude numbers.

In Case 1 (the symmetrical configuration), each upstream flow is deflected by an angle $\theta=45^\circ$. Both deflected flow directions are then parallel to the main diagonal of the square intersection

(Fig. 1). Since the upstream Froude numbers are greater than 5, we have $\theta_{max} > 45^\circ$ (according to Ippen, 1951) from which $\theta < \theta_{max}$. The deflection in each channel occurs via an oblique jump, so the flow undoubtedly corresponds to the Type III flow as previously described (Fig. 1). This Type III flow cannot be confused with a Type I flow, which would have occurred only if the incoming Froude numbers had been smaller than 5. In that case the maximum deflection angle would have been less than 45° from which $\theta > \theta_{max}$. Thus, the deflection of each incoming flow would have been by a transition to subcritical regime through a normal jump as in the Type I flow configurations reported by Nania *et al.* (2004) and Mignot *et al.* (2008). In fact, no Type I flow can exist for upstream Froude numbers larger than 5.

Furthermore, the appearance of a Type II flow cannot be explained only by a small difference in the inlet velocities as has been suggested by the discussers. For Case 2 (the asymmetrical configuration), $Q_{xi} > Q_{yi}$ so Q_{xi} is deflected by an angle slightly lower than 45° whilst Q_{yi} is deflected by an angle slightly larger than 45° , as shown in Fig. 2. Both upstream Froude numbers remain high enough that $\theta < \theta_{max}$ for both incoming flows, so an oblique jump develops in each direction, forming undoubtedly a Type III flow (Fig. 2). However, if Q_{yi} were to be significantly reduced (say to 2L/s), the incoming flow in the 'y' branch would be deflected through an angle larger than θ_{max} , requiring a transition to the subcritical regime through a normal jump; then the flow pattern obtained for such a configuration would be a Type II.

In conclusion – and this is the main point of the discussion – the additional set of experiments performed using the original experimental set-up does not modify in any way the conclusions presented in the paper, but reinforces them. The flow patterns presented in this closure confirm the validity of the theoretical explanation of the three flow types occurring in a 90° junction of four open channels with supercritical flows.

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	Q_{xi} (L/s)	Q_{yi} (L/s)	h_{xi} (mm)	h_{yi} (mm)	Fr_{xi}	Fr_{yi}
Case 1	9.6	9.6	15.5	15.5	5.3	5.3
Case 2	9.5	6.9	15.2	12.5	5.4	5.2

Table 1 : Flow parameters with Q the upstream flow discharge, h the upstream uniform water depth, Fr the corresponding Froude number. Channel width is equal to 0.3 m and upstream branch slopes are set to 7.4%.

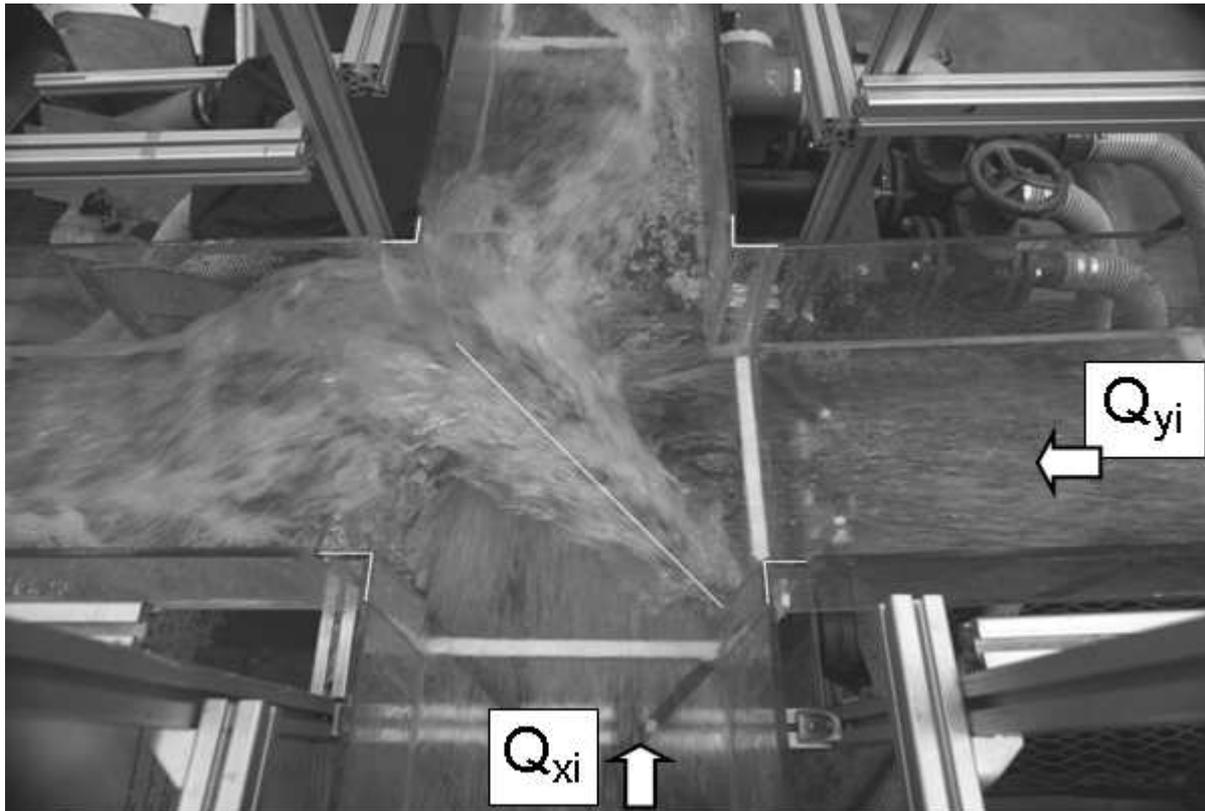


Figure 1 : Aerial photograph of Case 1 flow. The continuous white line is the main diagonal of the square intersection.

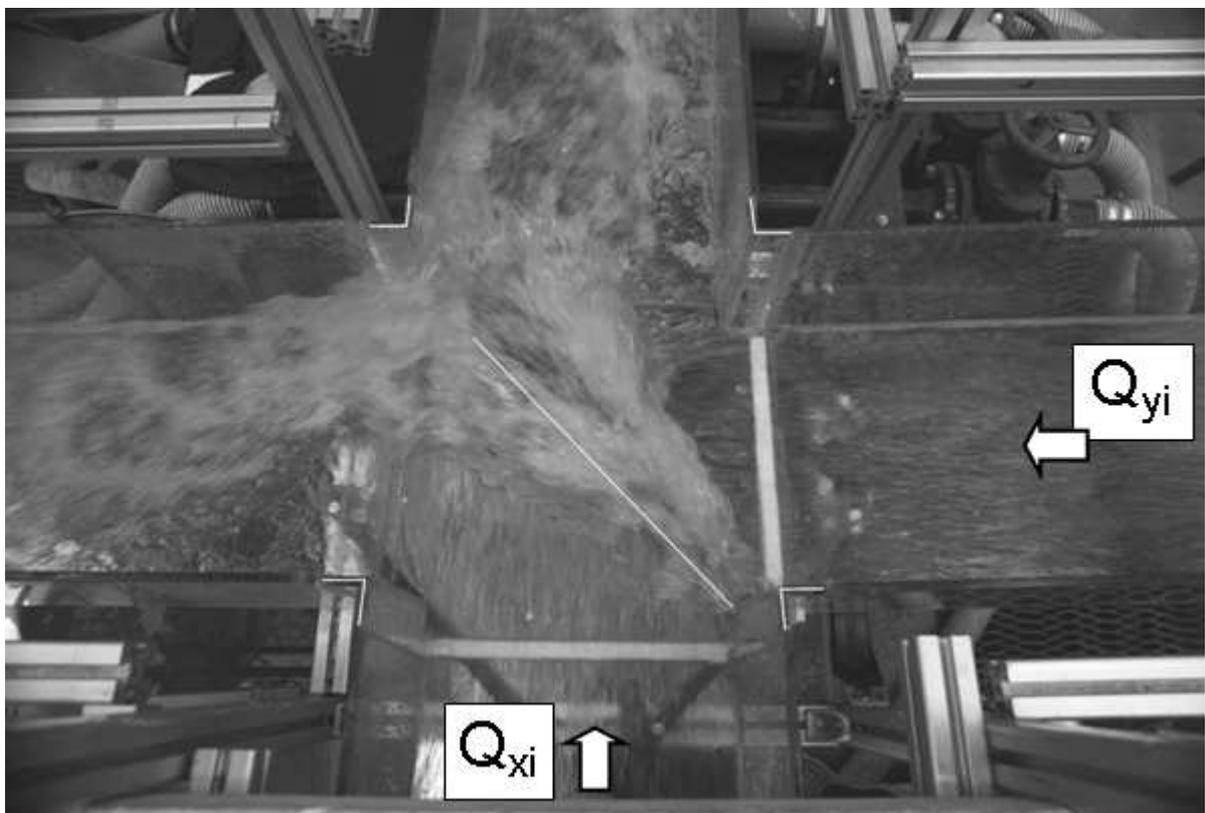


Figure 2 : Aerial photograph of Case 2 flow. The continuous white line is the main diagonal of the square intersection.