Turbulent Dividing Flow on 60º Bifurcations

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Summary

The local energy losses established in pipe junctions, which are common features of piping networks, are highly dependent on some geometrical features and on flow characteristics. For the development of a generalized predictive model addressing those energy losses, it is essential to define a database covering wide ranges of the mentioned variables so that comparisons and validations can be made.

The present work was based on an experimental study developed on a FCT experimental project that was on the basis of a M.Sc. thesis of one of the authors. The aim of this study was to obtain detailed information of the flow over a 60-degree junction and of the influence of the area ratio (branch-to-straight pipe - A_b/A_s) on the flow development, relating it to the correspondent energy losses.

For this study two different geometries were considered – one with a branch-to-straight pipe area ratio (A_b/A_s) equal to 1 (geom. 1) and the other with that ratio equal to 0,7 (geom. 2) – and experimentally investigated for a diverging flow configuration. The Reynolds number, defined at the inlet pipe, was in the range of 5000 to 40000 and the working fluid used was water. The energy losses were determined by means of characterization of the pressure fields correspondent to the referred Reynolds number range, for different flow division (Q_1/Q_3).

The physical explanation of those losses was tried by means of the study of the turbulent flow on the bifurcation, through the characterization of the velocity field and of the separation zones.

Test Rig And Instrumentation

The experimental set-up is presented in Figure 1 and is similar to the one used for the 90º tee junction study of Maia et al [3]. A volumetric pump supplied by a constant head tank drove the water flow. A variable speed controller operated the pump and three inflow/outflow valves controlled the distribution of flow rate through the two outflow pipes. The 60° bifurcations test sections were carefully machined from rectangular blocks of acrylic and positioned at the intersection of three long (acrylic) pipes.

These components were manufactured with internal diameters of 30 mm (except for the branch pipe components of the second geometry investigated, with 25mm).

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The flow rates were monitored by three magnetic flow meters, one in each pipe, and the temperature of the water was monitored by means of a sensor located in the tank.

Pressure measurements were performed along the three pipes by means of a differential pressure transducer considering seven measuring stations on each pipe.

Mean and turbulent velocity measurements were carried out by means of a laser-Doppler anemometry system, using a miniaturized fiber optics component.

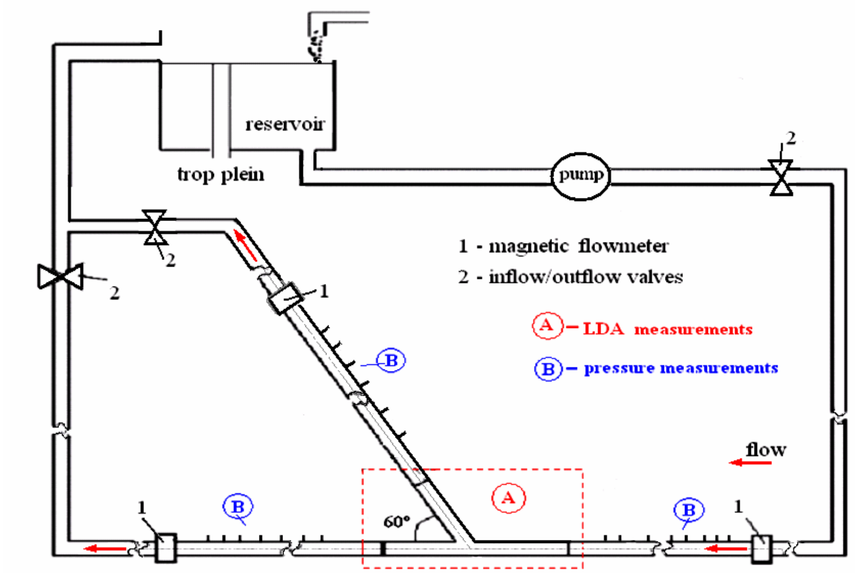

Figure 1 - Schematic representation of the experimental set-up.

Pressure-Field Characterization

The pressure measurements were carried out for Reynolds number at the inlet pipe (Re_3) in the range $5000 \leq Re_3 \leq 40000$ while the flow partition ratio (Q_1/Q_3) was varied from 0 to 1.

From those measurements the local energy coefficient losses (K_{31} and K_{32}) variation was obtained as a function of the established flow rate division, as well as a function of the inlet flow characteristic Reynolds number, as presented in Figure 2 a) and b).

Predictably, the energy losses between the upstream pipe and the downstream straight pipe are similar for the two geometries investigated (see Figure 2 b). The same behavior can be found in experiments referred in the literature ([1], [2]) where the data corresponding to the K_{32} coefficient presents an independence of the branch pipe angle, for a range considered between 15º and 90º.

Between the main pipe and the branch pipe (Figure 2 a) the losses are similar for a flow division range between 0,0 and 0,4. For flow divisions higher than 0,4 the energy losses are increasingly different and the major values come associated with the geometry with a reduction of diameter on the branch (geom. 2)

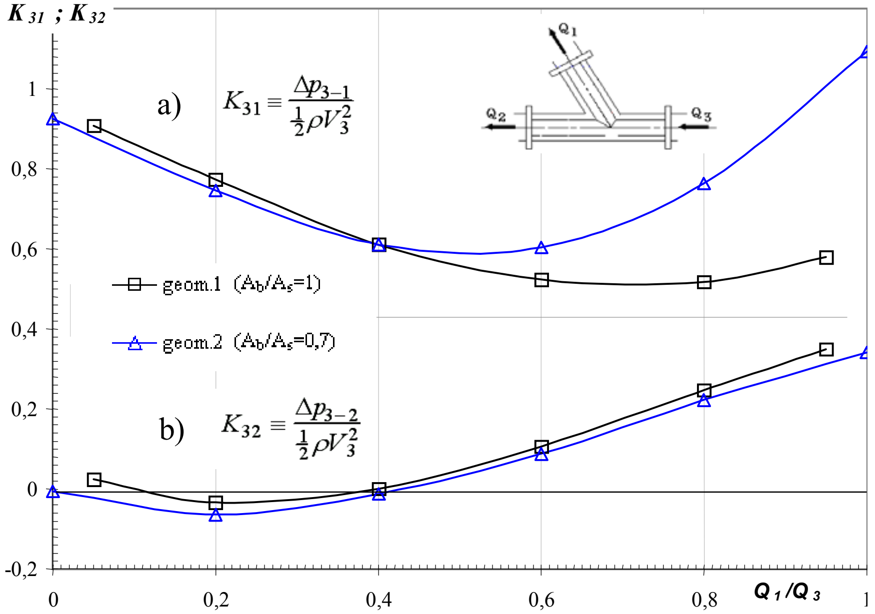

Figure 2 – Comparison between the two 60º junction geometries for the local loss coefficients: a) K_{31}; b) K_{32}.

Mean flow field

The mean flow characterization for a flow division Q_1/Q_3 equal to 0,5, based on the performed measurements, is presented in Figure 3 for geometry 1 ($A_1/A_3 = A_b/A_s = 1$) and is very similar in both geometries, especially on the main pipe. For the branch pipe the major differences are related directly with the recirculation zones, and these were particularly evaluated for different flow partitions. The measuring sections considered are also presented in Figure 3 and were defined as multiples of the inlet pipe diameter (D). The reference used for the definition of the different measuring sections was the upstream corner of the pipes (main/branch) intersection. By means of the analysis of Figure 3 the general characteristics of the mean flow can be accessed, namely:

- in the inlet pipe the flow deviates towards the pipe wall next to the branch, and that is more significant in the downstream half of the bifurcation region (after section 0,577D).
- in that same pipe, the strong deceleration of the flow along the wall opposite to the branch (after the bifurcation region) favors the formation of a recirculation zone, and that could be confirmed for flow partitions Q_1/Q_3 higher than 0,5.
- in the branch pipe, and immediately after the bifurcation, a recirculation zone is formed, which is about 2,0D long along the upstream pipe wall for geometry 1 (1,5D long for geometry 2) and has a maximum width that enables it to reach the pipe axis on both two geometries.

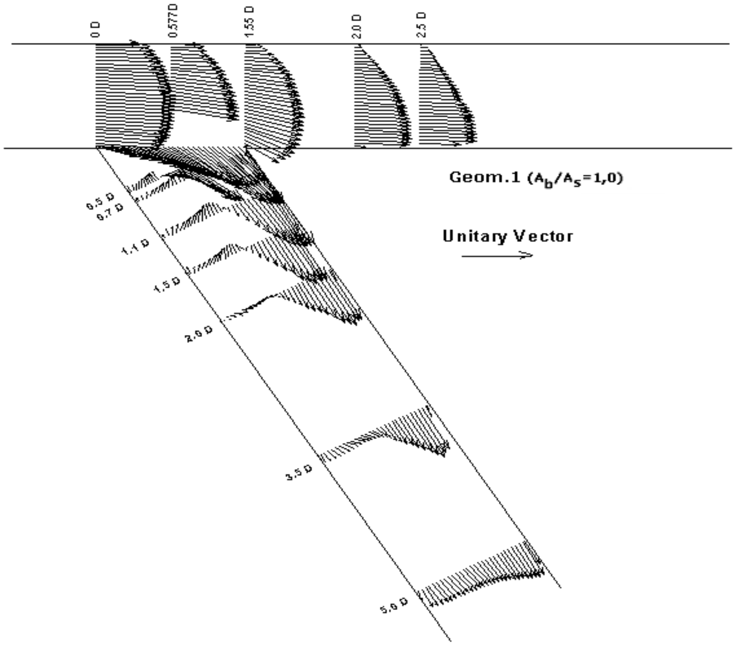

Figure 3 – Vector plot of u and v mean velocity components in the horizontal center plane for the 60º bifurcation (geom.1 - $A_b/A_s = 1,0$).

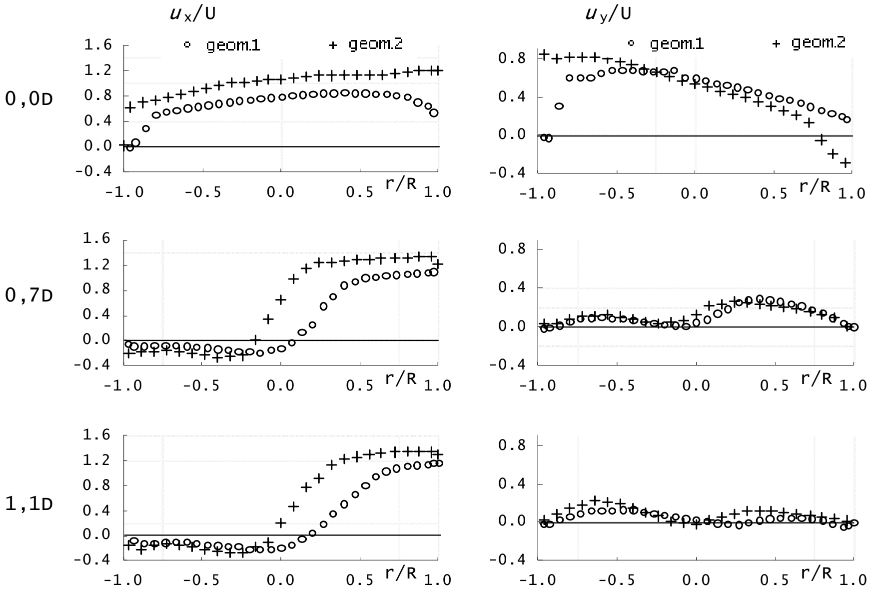

Figure 4 – Branch pipe mean flow characteristics. Comparison of the two geometries studied (r/R – radial distance to the pipe axis, r, normalized with the pipe radius, R).

Concerning specifically to the branch pipe and the mean flow measurements (axial, U_x, and transverse, U_y, components), some main features between the two geometries analyzed may be emphasized (see Fig. 4):

- the flow at the entrance of the branch pipe shows the suction effect more clearly in the second geometry, imposing the alignment of the fluid with the pipe (see section 0D, U_y component);
- on each measuring section, the axial velocity component (U_x) presents a similar behavior inside and outside the separated flow region, for the two geometries;
- the separated flow region extension is larger in the first geometry; nevertheless,
- the recirculation region in the second geometry creates a stronger shear layer at its edge (sections 0,7D and 1,1D); and also,
- the negative values of axial velocity component (inside the recirculation region) are more relevant in geometry 2 (sections 0,7D and 1,1D).

Turbulent flow field

Based on the normal Reynolds stresses ($u_x'u_x'$ and $u_y'u_y'$ measured in all sections; $u_z'u_z'$ measured at some sections, estimated at others) the turbulent kinetic energy was evaluated as presented on Fig. 5.

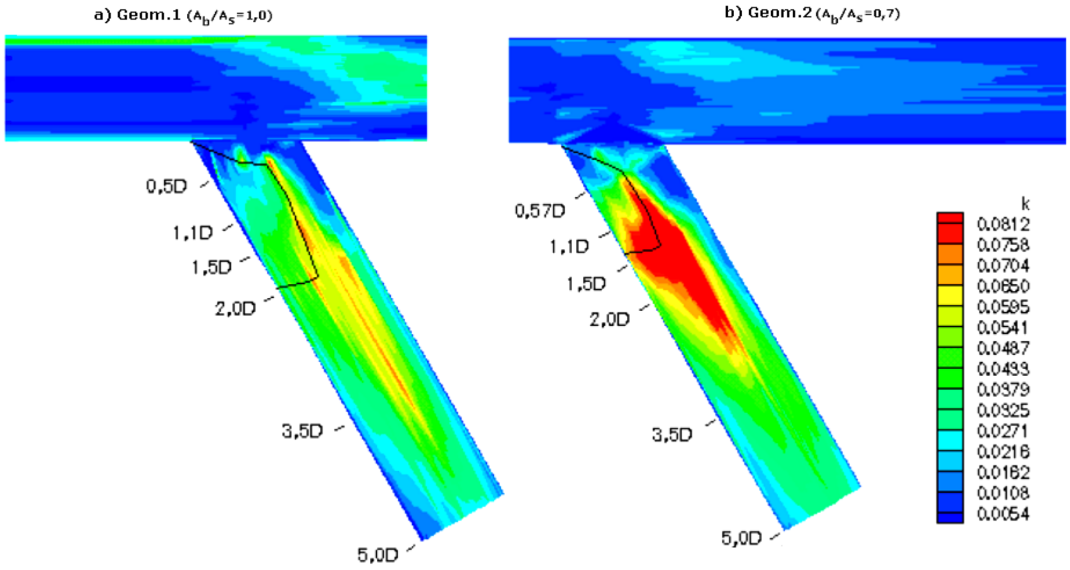

Figure 5 – Contour plot of the turbulent kinetic energy in the diametral horizontal plane and position of the zero mean velocity line for the 60º bifurcation: a) geom.1 ($A_b/A_s = 1{,}0$); b) geom.2 ($A_b/A_s = 0{,}7$).

The turbulent flow features observed in these bifurcations are mainly generated by the various shear layers present in the mean flow.

In the main pipe a local peak of turbulence appears in a region (at the end of the bifurcation) characterized by a strong deceleration of the flow and simultaneously by a strong shear layer.

Along the branch pipe the recirculation region formed creates a very strong shear layer at its edge, next to the centre of the pipe, and this feature is the main cause of the turbulence generated. Inside the recirculation region, and since here the turbulent production is not relevant the peak turbulence noticed is maintained by turbulent transport mechanisms.

A comparative analysis of the two studied geometries elucidates that the levels of turbulent kinetic energy along the main pipe are very similar but, on the other hand, along the branch pipe these values are bigger on the second geometry ($A_b/A_s=0,7$) and that can be related directly with the energy losses measured.

Conclusions

The present experimental work was designed in order to evaluate the structure of the local energy losses present in a 60º bifurcation and analyze the influence of the area ratio (A_b/A_s) in those losses. For the Reynolds number range analyzed, the influence of the area ratio was found increasingly relevant for flow partitions higher than 0,4 (but only for the local energy losses between the inlet and the branch pipes). For that flow partition range, the major values of energy losses are associated with the second geometry analyzed ($A_b/A_s=0,7$).

The 3D structure of the turbulent flow along the 60º bifurcations analyzed by means of LDA elucidates the main characteristics of those losses. Those measurements pointed out the influence of the strong shear layers along the recirculation region (at the entrance of the branch pipe) as the major feature shaping these local losses.

On a further stage, the experimental data obtained will be used to test and validate different turbulence models on numerical simulations of flow on 60º bifurcations.

Reference

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