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# Numerical and experimental study of mixed and forced convection in a junction

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**Abstract**—This paper presents a theoretical and experimental investigation of the laminar steady 2D-mixing flow in a junction. The numerical method developed by Gosman *et al.* has been applied to derive velocities and temperatures profiles in the mixing zone. The effects of the angle between the two branches of the junction and the air-flow rate upon the structure flow are analysed, for both forced and mixed convection cases. The experimental procedure is based upon a flow visualization technique and L.D.V. velocity measurements: a reasonably good agreement between theoretical and experimental results is found.

## 1. INTRODUCTION

BECAUSE OF its biochemical applications such as the study of blood flow in human vessels and engineering applications such as ventilation systems, the interaction of two forced flows in a junction has been the subject of a few works in the past 20 years. As summarized in refs. [1, 2], several flow configurations are possible, but most of the published reports treat tee junctions and dividing flows.

Some numerical investigations have been devoted to this problem: Blowers [3] examined the case of two-dimensional mixing and dividing flows in a tee junction whereas Pollard [2] treated the three-dimensional case for both laminar and turbulent flows. Some authors such as Bramley and Sloan [4] have studied the effect of the angle between the two branches of the junction for a two-dimensional laminar dividing flow. In this paper, the size of the recirculating zones which develop downstream of the junction was investigated. More recently, Hayes and Nandakumar [5] have undertaken a study of the mixed convection in a vertical planar tee branch. This work is also devoted to the dividing flow case and the results show the influence of the Reynolds and Grashof numbers on the structure flow.

From an experimental point of view, the dividing forced flow case has been studied by many investigators because of its biomechanical applications (see for example refs. [6, 7]). In these studies, only the structure flow is investigated. For the mixing flow case, Karino *et al.* [8] have performed a flow visualization in order to show how the two streams interact whereas Sparrow and Kemink [9] and Kawashima [10] measured the local Nusselt number downstream the mixing region. They found a substantial increasing of the heat transfer coefficient in this region.

For the problem of mixing flow and low velocities (laminar flow), the free convective effects cannot be neglected when a constant heat flux is specified on the walls of the mixing zone, the temperature of the fluid in the two entrance zones being the same. Except for a first approach by the present authors [11], a survey of the literature shows that free and forced convection heat transfer with mixing flows in branching systems has not yet been studied. This is the subject of this paper in which the theoretical analysis allows us to show the effects of the air-flow rate and the angle between the two branches of the junction upon the structure flow, for both forced and mixed convection cases. An experimental procedure based upon a flow visualization technique and L.D.V. velocity measurements provides a comparison with these theoretical results.

## 2. PROBLEM STATEMENT AND GOVERNING EQUATIONS

The physical model is shown in Fig. 1: the fluid is introduced through branches 1 and 2, respectively,

## NOMENCLATURE

| | |
|---|---|
| $a$ | thermal diffusivity of the fluid [$m^2 s^{-1}$] |
| $g$ | gravitational acceleration [$m s^{-2}$] |
| $H$ | height of the exit branch (along $y$ axis) [m] |
| $K$ | ratio: (air flow rate in branch 2)/(air flow rate in branch 1) |
| $p$ | pressure [$N m^{-2}$] |
| $Pr$ | Prandtl number |
| $q$ | intensity of the wall heat flux (mixed convection case) [$W m^{-2}$] |
| $Re$ | Reynolds number |
| $Ri$ | Richardson number |
| $T$ | temperature of the fluid [K] |
| $T_0$ | temperature of the fluid on sections AB and GH (Fig. 1) [K] |
| $\Delta T$ | difference $(T-T_0)$ [K] |
| $u$ | $Ox$ velocity component [$m s^{-1}$] |
| $U_0$ | mean velocity in the exit branch [$m s^{-1}$] |
| $v$ | $Oy$ velocity component [$m s^{-1}$] |
| $x, y$ | dimensional coordinates [m] |
| $X, Y$ | dimensionless coordinates. |

Greek symbols

| | |
|---|---|
| $\alpha$ | angle between the two inlet branches [°] |
| $\beta$ | coefficient of thermal expansion [$K^{-1}$] |
| $\theta$ | dimensionless temperature |
| $\lambda$ | thermal conductivity of the fluid [$W m^{-1} K^{-1}$] |
| $\nu$ | kinematic viscosity of the fluid [$m s^{-2}$] |
| $\rho$ | density of the fluid [$kg m^{-3}$] |
| $\phi$ | stream function [$m^2 s^{-1}$] |
| $\psi$ | dimensionless stream function |
| $\omega$ | vorticity [$t^{-1}$] |
| $\Omega$ | dimensionless vorticity. |

before interacting and exiting through the main branch 3. The cross-section of the inlet branches is S/2 and the angle between them, noted $\alpha$, may vary from 1 to 90°. Boundary conditions are fixed by assuming a fully developed flow in the inlet and outlet sections (AB, HG and DE, respectively). The length of the exit branch, CE, is deduced in order to verify this assumption and its cross-section is S, so that the mean velocity remains constant. The walls of the junction may be subjected to various thermal conditions which will be developed later. Consideration is given to a steady laminar two-dimensional flow with constant physical properties, except for the density changes which are modelled according to the Boussinesq approximation. Experiments showed that two-dimensionality is a good assumption if the distance between lateral walls of the channel is rather high. This assumption also allows to make some comparisons with previous published numerical results for some limiting cases. It can be noticed that there are many industrial codes that can handle this problem. However, these codes need a computer with very large memory capacities and such a computer was not available in our laboratory, so that it was necessary to perform a specific numerical procedure. A Cartesian coordinates system was chosen with $u$ and $v$ denoting

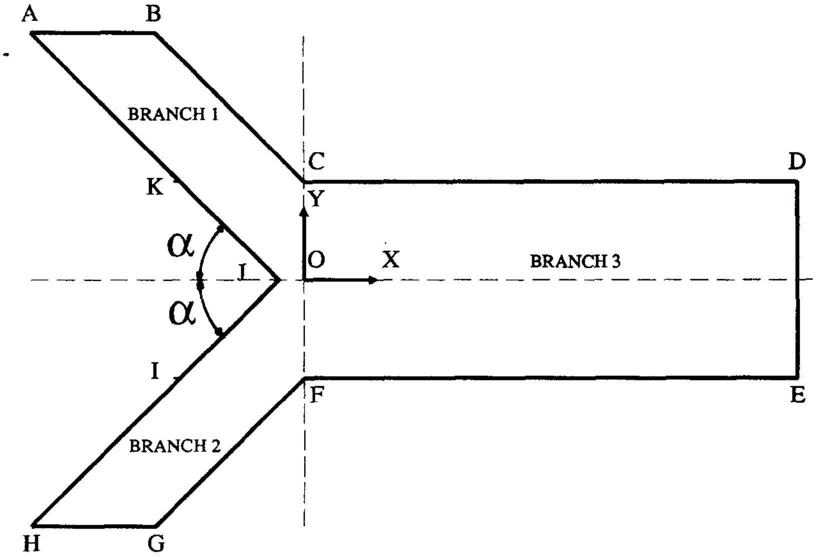

Fig. 1. Physical model and definition of the coordinates system.