

CONSTRUCTION OF AN AUTOMATIC SIMULATION TOOL BASED ON THE ZONAL MODEL APPROACH

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ABSTRACT

In this paper, we are particularly interested in the automatic generation of zonal model. We show how a program can deduce with expert rules a partitioning suitable for the main driving flows encountered in the room under study and how appropriated local model are chosen and connected each other. To illustrate our purpose, we solve the case of a ventilated bidimensional cavity.

KEYWORDS

Zonal model, Expert rules, Jet.

1 INTRODUCTION

The first works lead in the 70's [Lebrun, 1970], are arisen from the both necessities :

- one is to manage the energy in buildings because of the energy crisis at this period.
- the other is to find an intermediate method between the multizone model too much imprecise and the numerical simulations using CFD codes, too much greedy in computational resources for large scale problems.

The goal of zonal modeling is then to describe the thermal stratification taking account of the heating and ventilating system to predict the thermal needs and the system efficiency, the thermal comfort and the air quality in rooms [Laret, 1980],[Howarth, 1980],[Inard, 1988],[Inard and Duing, 1991]. The domain is divided in zones corresponding to elementary flows expected in the room that is expertised by the concepthor. To each zone, energy and mass balance, eventually state equations are provided. Then, the concepthor built the model for the special problem under study and the equational system is solved.

The main drawback of this approach is the generated model depends totally on the concepthor's analysis needing in the same time, physical expertise and modelling knowledge. Actually, the partitioning requires experimental studies to give an idea to the users of the global dynamical behavior of the air in the room.

So, instead of doing the partitioning by the user himself, we propose to build a tool which can do its own qualitative analysis using expert rules based on the geometry and the boundary conditions and which is able to adapt itself to different kind of problems. We illustrate the analysis process with a ventilated bidimensional enclosure.

2 THE AUTOMATIC GENERATION OF ZONAL MODELS

2.1 The structure and the functions

The zonal model generator is composed by three parts:

The first part is the knowledge database divided in the facts database and the rules database. The facts database describes the problem. The rules database uses the facts database in order to deduce others facts.

The second part is the library where all the local models are stored.

The third part is the qualitative motor whose functions are the recognition of the elementary flows using rules, the determination of the boundaries of zones associated to each elementary flow and the choice of the appropriated model in the library.

Each part of the zonal model generator must be independant and extensible that is new rules, new models can be easily added to treat others types of problems.

2.2 The domain partitioning

Now, we concentrate our attention on the partitioning of a two-dimensional cavity (H meters high and L meters long) with an horizontal isothermal jet through an inlet h meters wide (figure 1). The jet velocity at the inlet exit is V_0 and its temperature T_0 is equal to the walls temperature T_p . Because of the hypothesis of air incompressibility, the mass flow rate arriving into the cavity is equal to the outgoing one.

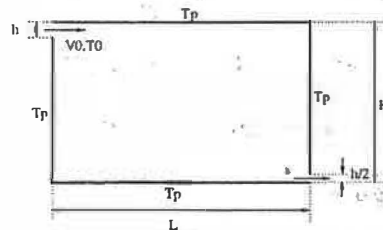


Figure 1: Two-dimensional cavity with an horizontal isothermal jet.

To solve this problem the generator of model follows five main steps in the following order:

1- Definition of the main driving flow

If we suppose that two-dimensional geometry can be described by a set of line segments defined by two points, the data are the coordinates of two points, the thermal and dynamic boundary conditions and a string distinguishing walls and internal boundaries. Then, a set of rules tests these facts to deduce others facts : for example, a single heat flux on a segment generates a plume perpendicullarly to the segment, in the same way a single mass flow generates a jet, a segment which is a hot or cold wall versus a fixed reference temperature generates a natural convection flow. (cf figure 2).

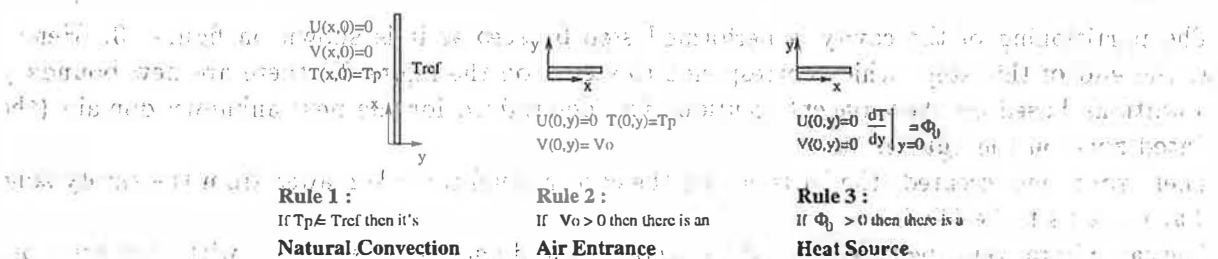


Figure 2: Three examples of qualitative rules.

In our case, the main flow is the air jet due to ventilation, tangential to the ceiling. By testing the sign of the initial mass flow rate and the position of the inlet in the cavity, the generator knows the flow direction.

2- Definition of the specific elementary flow to be generated

Qualitative rules specify as much as possible the model. For instance, in case of the jet on figure 1, a rule distinguishes a wall jet from a free jet, another one specifies if it is a cold, a warm or an isothermal jet, other rules specify its position (vertical or horizontal) and evaluate its penetration depth, D_p [Adre and Albright, 1994]. According to the jet penetration depth and the wall proximity, a corner is detected or not. All these informations are contained within a string, Model, available for consultation at each step of the partitioning process and written as following :

Model = ['JET,WALL,ISOTHERMAL,HORIZONTAL,Dp=0.9 L','COIN']

3- Definition of the boundaries of the zone

Once the nature of the local flow is known, the generator of zonal models has to determine the boundaries of the zone where the detected elementary flow is available.

To estimate the maximal thickness δ of the isothermal jet, we suppose the jet velocity limit is equal to 1% of its maximal value. Then, δ is the solution of equation 1 written from the velocity profil established by [Schwartz and Cosart, 1961] :

$$0.01 = \exp[-0.937 \left(\frac{\delta}{b_V} - 0.14 \right)^2] \quad (1)$$

with b_V , the characteristic jet dimension [Rajaratnam, 1976], (cf. figure 4) :

$$b_V = 0.068(x - 10h) \quad (2)$$

The jet zone is a polygon (cf. figure 3).

4- Definition of the appropriated model

Using qualitative rules, the appropriated model for each zone is attributed. The inputs of the elementary models are the geometry descriptors which delimitate the domain where the model is available, plus the boundary conditions on the segment which is used to find the model.

The outputs are the new boundary conditions on each boundaries, the calculus of heat and mass flows and the local analytical solution.

The models can be issued from the literature like the integral methods for the boundary layers. They can be also empirical correlations for plumes or jets. All the models are stored in a library. Note that to implement the analytical models, we need to manipulate or derive symbolic expressions. So, we use a computer algebra system: Maple V.

5- Updating of the data and definition of the overall partitioning

The partitioning of the cavity is performed step by step as it is shown on figure 3. Hence, at the end of this step (which corresponds to step 1 on the figure 3), there are new boundary conditions based on the adjacent solutions just determined for the new unknown domain (the tinted zone on the figure).

Then, zones just created (the jet zone and the corner zone) are taken away from the empty zone that remains to be filled.

The same iteration is performed until the whole initial domain has been filled with local solution. The end of the partitioning is summed up on the figure 3.

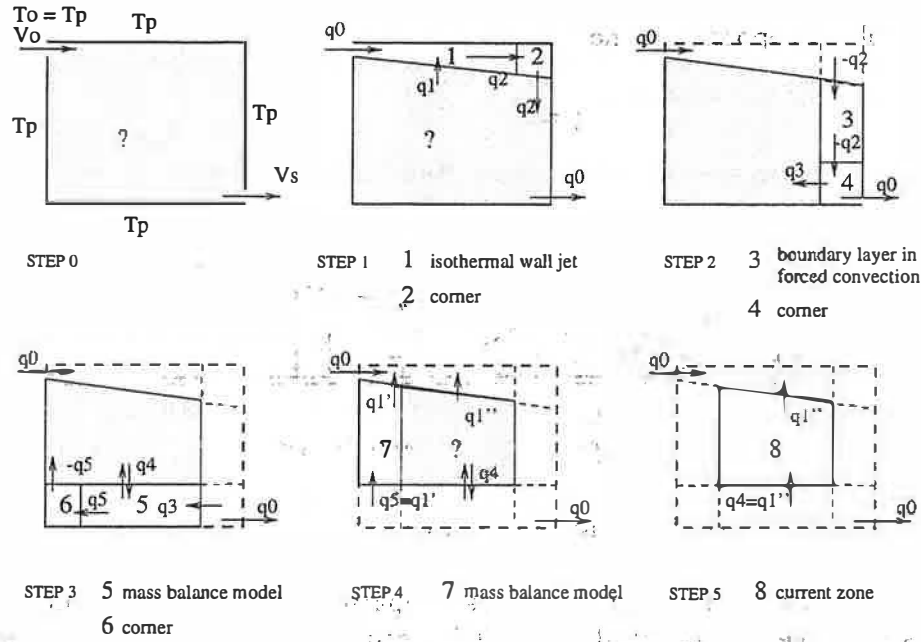


Figure 3: Example of the partitioning progress

The connection between zones is checked by the continuity of mass flow rates. In the jet zone (zone 1), mass flow rates are evaluated by the analytical model exposed in the paragraph just after. In the boundary layer zone (zone 3), the simplified Navier-Stokes equations are solved with the Karmán-Pohlhausen integral method [Holman, 1990]. The mass flow rate at the exit is expressed from the velocity profile. Corners (zones 2, 4, 6) and zones 5, 7 are used as transition zones where the mass balance is only provided. Note that, in case of the zone 5, an unknown (noticed q_4 on the figure 3) is introduced. This is written in function of q_5 whose sign could be guessed from the flow direction. The latest equations of the global system to be solved are the mass balance equations on the current zone (zone 8). Disregarding equations in zones 2, 3 and 6, the global system is :

$$\begin{aligned}
 q_2 - q_0 - q_1 &= 0 & \text{zone 1} \\
 q_0 - q_3 - q_2 &= 0 & \text{zone 4} \\
 q_3 - q_5 + q_4 &= 0 & \text{zone 5} \\
 q_1' - (-q_5) &= 0 & \text{zone 7} \\
 q_1'' - q_4 &= 0 & \text{zone 8} \\
 \text{with } q_1' + q_1'' &= q_1
 \end{aligned}$$

2.3. Results

The model used for the isothermal wall jet is issued from the work of [Schwartz and Cosart, 1961] and [Rajaratnam, 1976]. The notations are reported on the figure 4. The velocity profile used is an exponential pattern one :

$$V = V_m \exp[-0.937(\eta - 0.14)^2] \quad \text{avec} \quad \eta = y/bv \quad (3)$$

$$V_m = V_0 3.5 \sqrt{\frac{h}{x}} \quad V_m, \text{ the maximal velocity} \quad (4)$$

The mass flow rate inside the jet is estimated in the shear layer region :

$$q = \rho V_0 h \left[1 + 0.04 \left(\frac{x}{h} \right) + 0.0046 \left(\frac{x}{h} \right)^{0.8} \right] \quad (5)$$

and in the full developed jet region :

$$q = \rho V_0 h 0.248 \sqrt{\frac{x}{h}} \quad (6)$$

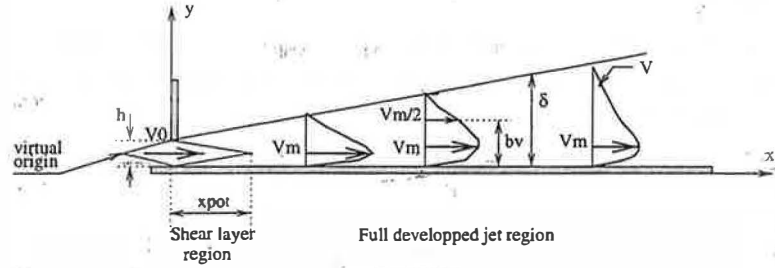


Figure 4: Isothermal wall jet

To test the relevance of our approach, we compared the mass flow rate obtained by analytical models with the results calculated by a CFD code, (figure 5). The initial data values are : $V_0 = 0.91 \text{ m.s}^{-1}$, $T_0 = T_p = 293 \text{ K}$, $H = 3 \text{ m}$, $L = 9 \text{ m}$.

We note that the mass flow rate carried into the jet is underevaluated by the implemented model, in the first part of the jet zone corresponding to the shear layer region (cf. figure 4). Consequently, the rest of mass flow rate carried into the second part of the jet zone is overevaluated and the mass flow rate reported at the exit of zones 5 and 6 on the figure 3 are mistaken. These differences shows how the choice of the model is important. We can think reasonably that a model more accurate in the jet shear layer region would bring out better results. In order to improve the analysis process, we could consider several model describing an isothermal wall jet marked in function of their reliability. Hence, the generator of model could propose several possiblity with different faithful degrees.

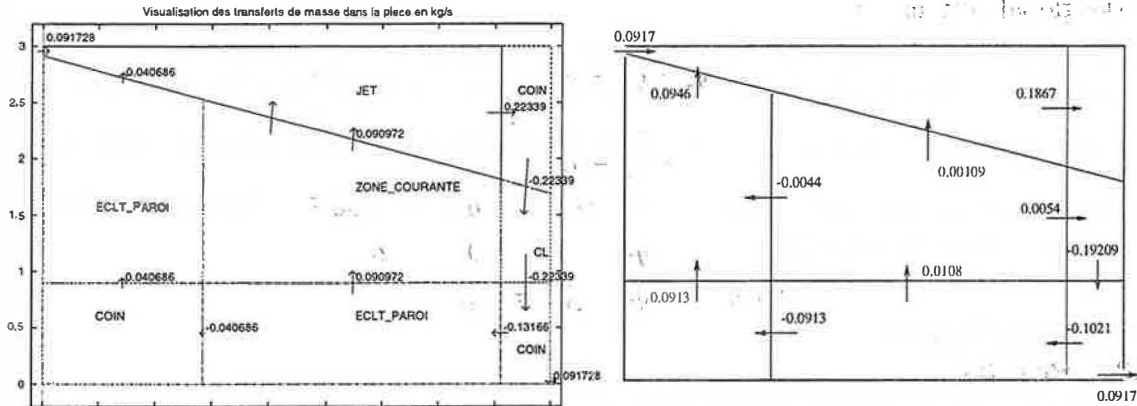


Figure 5: On the left : The mass flow rate (kg/s) calculated by the zonal approach (Game), On the right : The mass flow rate (kg/s) calculated by a CFD code (Fluent)

3 CONCLUSION

We develop a tool which can generate zonal models automatically. We show that a minimum of expert rules can give a good qualitative description of a bidimensional simple problem. More complex problems with, for example, anisothermal jet could be solved. In addition, we have to manage a situation where several main flows conflict with each other. Thus, in the case of a wall plume and a boundary layer in natural convection, two possibilities exist : either the

ambient temperature depending on both main flows is lower than the wall temperature and the flow rises in the boundary layer or inversely the flow goes down in the boundary layer. Solving these problems needs to increase the rules database and the library of models.

At this time, the extension to three-dimensional problems is under way. Instead of segments, we work with facets which can create complications for the partitioning. But the basic principle remains the same.

Finally, in future development, this qualitative information (that is the dimensions and the nature of zones describing the thermal and dynamical behavior of the air inside rooms) could be transmitted to a generator of code.

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Nomenclature

b_V : characteristic thickness of the jet [m]
 h : dimension of the inlet [m]
 H, L : dimensions of the cavity [m]
 $q_i, i=0..5$: mass flow [$kg s^{-1}$]
 T_{ref} : reference temperature [K]
 T_0 : jet temperature [K]
 T_p : wall temperature [K]
 U : velocity component (x direction) [ms^{-1}]
 V : velocity component (y direction) [ms^{-1}]
 V_0 : jet velocity just after the inlet [ms^{-1}]
 V_m : maximal velocity of the jet [ms^{-1}]
 x_{pot} : Shear layer length of the jet [m]
 δ : maximal jet thickness [m]
 Φ_0 : Heat flux $W m^{-1}$