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Thermal fluctuations induced in a conducting wall by mixing sodium jets : an application of TRIO-VF using Large Eddy Simulation modelling.

By Bernard MENANT and Michel VILLAND.
Commissariat à l'Energie Atomique.
Centre d'Etudes Nucléaires de GRENOBLE.
Service de Thermohydaulique des Réacteurs,
17, rue des Martyrs 38054 GRENOBLE CEDEX 9
FRANCE.

The general-purpose thermal-hydraulics program TRIO-VF allows explicit simulation of the main instabilities in an uncompressible flow : it has been applied to the prediction of flow instabilities in a sodium hot jet through a transverse cold flow, in front of a conducting wall. The temperature fluctuations induced in the flow and the wall are studied and an accute skin-effect is evidenced.
The temperature gradients (including three components) are analysed : temperature gradients up to 20000 degrees per meter are currently seen in the skin. They are due to the very strong value of the unstationary component normal to the fluid-wall interface.
The limitations of TRIO-VF in the present state, and the lack of experimental support for validation does not allow to promise quantitative applications of this modelling to complex industrial situations nowadays, but we hope these applications are for tomorrow.

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1. Introduction

In order to understand the mechanisms of thermal stripping, it is necessary to know in details the thermal loading of the structures.
Flow instablities are complex ; their modifications in the near-wall region are usually evaluated using some "heat-transfer" coefficient which are of poor sense out of a statistical approach.
As the source of thermal stripping is not the statistical value of fluctuations (which are evidently null), one has to try to analyse explicitly the transfer of fluctuations towards and inside the wall.
The TRIO-VF thermal-hydraulic program allows to make the first steps towards such an analysis : it was applied to the problem of thermal stripping in an inert conducting wall in front of a hot jet in a transverse cold flow.
The TRIO-VF program is shortly presented, then the modelling of the mixing jets is described and the results analysed.
Conclusions are drawn on further work.

2. Presentation of TRIO-VF

2.1 General lines.

TRIO-VF is a general purpose program for thermal-hydraulic analysis in complex configurations (1, 2 or 3 space dimensions, steady states or transients, mechanical and thermal interactions between fluid and structures).
Two approaches are possible for unstabilities and turbulence : the classical approach, using the statistical K-Epsilon model allows to get good results for the fields filtered by the so-called turbulent viscosities, and by big-size meshes ; a more recent approach is the Large Eddy Simulation in which the use of tiny meshes and of precise numerical schemes allows to describe explicitly the main instabilities, using turbulent diffusivities only for undergrid turbulence.
This last approach has been recently implemented in TRIO-VF using the so-callled 'structure function' modelling subgrid diffusivities [1]. Then more interesting modelling for thermal wearing and stripping are possible.

2.2 Validation of TRIO-VF using LES.

The validation of LES simulation in TRIO-VF program is underway. It was firstly performed on the academic case of the backward facing step (with or without thermal stratification [2], [3]).
Then some progress has been made towards industrial applications when it has been used for the interpretation of the sodium thermal stratifiation experiment CORMORAN [4] which gave very promising results.

3. Thermal stripping in a nozzle

3.1 Genenral presentation.

In many industrial installations, fluids of differing temperatures mix in nozzles. The temperature fluctuations generated in the flow may induce thermal wearing and stripping of the ducts.
This problem is well known in nuclear plants and it is necessary to know more about it. That is why it was undertaken to use TRIO-VF with LES : indeed LES modelling in the fluid coupled to 3D thermal conduction in the wall allows to get a lot of interesting results.

3.2 Description of the computed problem.

An horizontal square duct of .48 m length and .01 m2 section is bordered by 3 insulating walls. The fourth wall is made of stainless steal with a thickness of .02 m. It is linked by conduction to the fluid, and insulated on the other faces.
The main flow of sodium (-20 deg, .25 m/s) comes from the left to the right on the whole section of the duct.
A secondary flow of sodium (100 deg, 1.25 m/s) comes in front of the stainless steal wall, perpendicular to it, on a square section of .0004 m2 at .07 meters from the inlet of main flow.
It is clear that real ducts are not square, but it was easier to apply TRIO-VF (structured finite

√2

volumes) to this geometry for a first demonstration.

The problem is illustrated on figure 1 :

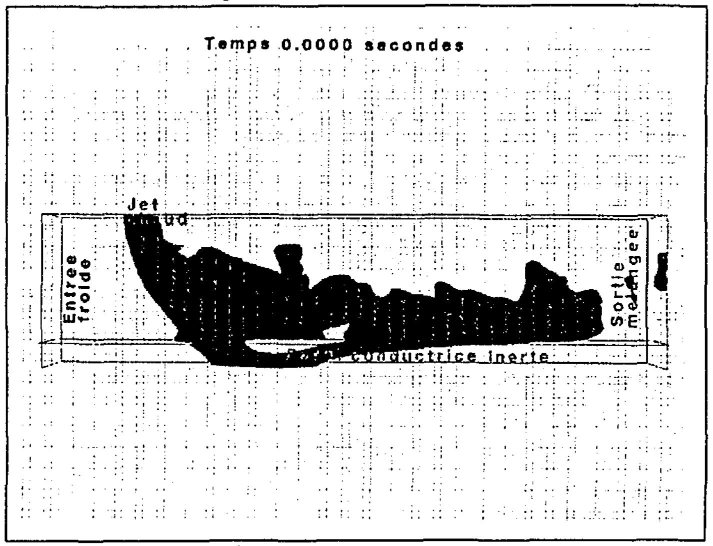

Figure 1 : Illustration of the computed area

4. Mainlines of the computation

For LES computation the refinement of the mesh is very important. For this preliminary work, we have chosen to perform a computation involving classical means : the basic mesh is coarse (cubic meshes of .00333 meters side), but sufficient to hope an explicit description of the main instabilities in the flow.
As our purpose was to analyse the thermal fluctuations of interest for thermal stripping, the mesh was progressively refined at the sodium to wall interface up to .0005 m.

No thermal resistance was assumed between the sodium and the wall, and the heat transfers in this region are modelled by classical wall-laws.

A no-slip condition is assumed on the 4 borders of the duct, and thermal-hydraulic conditions at the outlet of the duct are horizontal pressure gradients equal to zero and constant mean outlet pressure.

All the remaining is very classical use of TRIO-VF : when a quasi-steady-state is reached, a data bank is constituted : all the temperature fields in sodium and steal are stored every .004 seconds during about 2.8 seconds.
This data bank is available for post-treatment including static and cinematic analysis of instantaneous temperature fields and gradients, as well as statistical treatments.

5. Results of the computation

5.1 Topological description of the flow.

On figure 1, page 3, we have drawn in green a volume the temperature of which lies between 10 and 11 degrees. This illustrates the shape of the hot jet. When animating these views, periodic instabilities near the inlet of the hot jet,and more complex ones far downstream are evidenced in the fluid whereas the results seem very stable in the wall. We will now make a more complete analysis of the temperature fields.

5.2 Temperature field instabilities in the sodium.

In order to get an idea of the temperature fluctuations, it is possible to draw the evolution of the temperature of any mesh versus time : this has been done for 8 meshes located each side of the fluid-solid interface in the mid plane of the hot jet and on two normals to the wall respectively located .07 and .4 meters downstream of the inlet of hot jet.
On figure 2, page 5, the periodic oscilllations of the jet, and the damping of fluctuations in the near-wall region and in the wall are clearly evidenced.
The fluctuations illustrated on figure 3, page 5, are no more periodic : they result of the degeneration of jet instabilities towards turbulence. Nevertheless, the damping of fluctuations is always clear : high frequency fluctuations are completely rubbed-out, and those of greater period are all the more damped than the cell is deeper in the wall.

Another way to illustrate the instabilities of temperature is to visualize animations of temperature cuts. The first image of such a moovy is illustrated on figure 4, page 6.

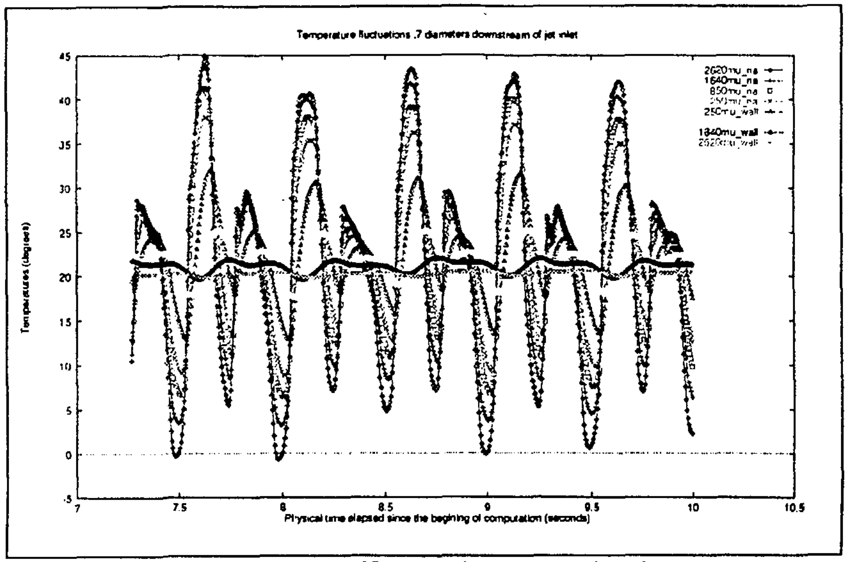

Figure 2 : Temperature fluctuations .07 meters downstream of hot jet

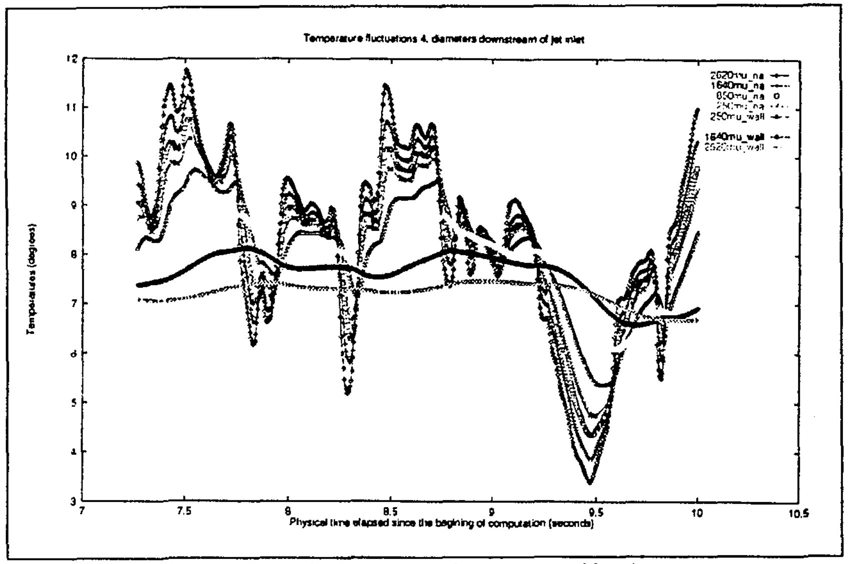

Figure 3 : Temperature fluctuations .4 meters downstream of hot jet

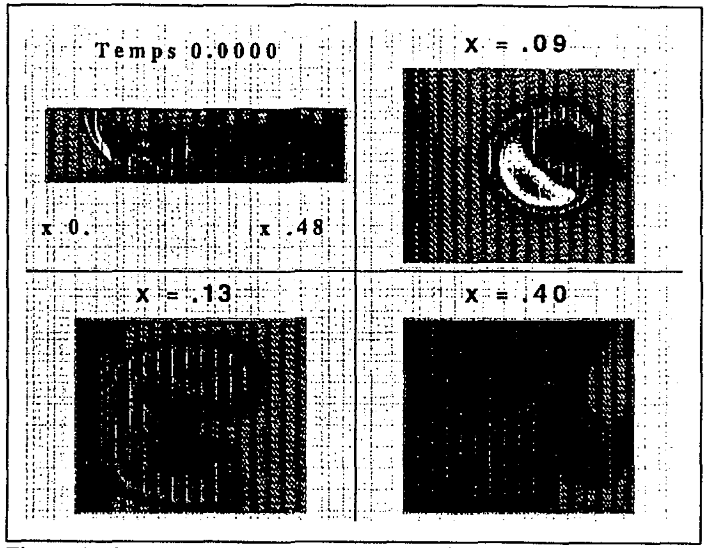

Figure 4 : Snapshot on temperature cuts through the jet

On the upper-left corner of the view, a cut through the mid-plane illustrates the entrainment of the hot jet by the main flow ; the position of the 3 cuts normal to the axis of the duct is shown also. The three other views illustrate the jet with its un-centred position (upper-right corner), the impact of the jet on the wall, and the remaining temperature non uniformity near the outlet of the duct. The motions of all these views, when animated, are very interesting.

5.3 Temperature field in the vicinity of the fluid-solid interface.

The impact of an unstationnary jet on the conducting wall induce very interesting phenomena which may be analysed in details. On figure 5, page 7, a snapshot at time 0. illustrates the temperature fields in the region of the impact for 3 cut-planes parallel to the fluid-solid interface, localised on the view of the lower-right corner. At .002 m depth in the sodium, two hot spots are seen whereas in the wall there remain only one hot spot ; the animation of this view gives a lot of results about the way these spots move with big amplitude in the skin of the wall, and with very low amplitudes only .002 m from the interface.
These skin-effects have to be analysed in term of temperature gradients, which is done in the next paragraph.

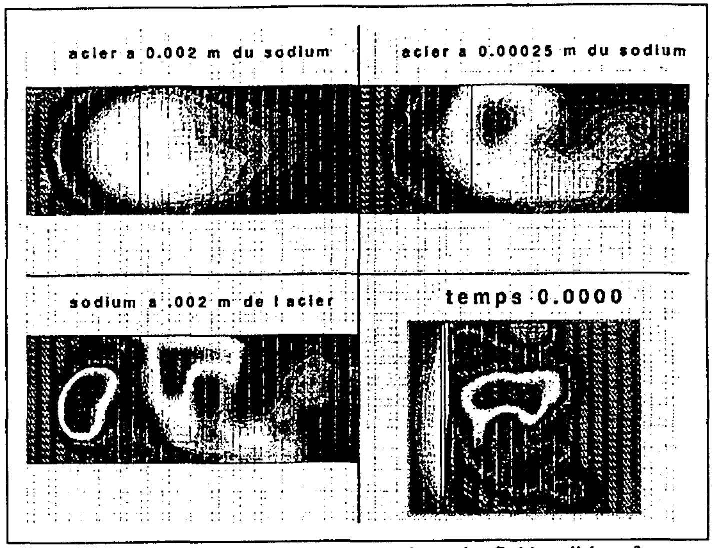

Figure 5 : Snapshot on temperature cuts along the fluid-wall interface

5.4 Statistical analysis.

5.4.1 Temperature fields.
On figure 6, next page, the results of statistical analysis of the temperature field at .00025 meter depth in the wall are illustrated. The regions of strong fluctuations are located near the impact of the central part of the jet and of its upper and downer boundary-layers.

5.4.2 Temperature gradients.
The modulus of the temperature gradient vector at a depth of .00025 meter in the wall is represented on figure 7, next page. A snapshot shows the complexity of the instantaneous temperature gradient map (upper-left corner). On the upper right corner the map of the maximum values of temperature gradients shows values up to 20000 degres per meter whereas the mean values are at the maximum of the order of 8000 degres per meter (lower-left corner). At end the mean-time temperature field illustrated on the lower-right corner shows that maximum gradients are , in the context of our studdy, also maximum temperature regions.
Another way to analyse temperature gradients is proposed on figure 8 (page 9) : it is clear that temperature gradients mainly due to a skin effect, decrease quickly with the depth in the wall.

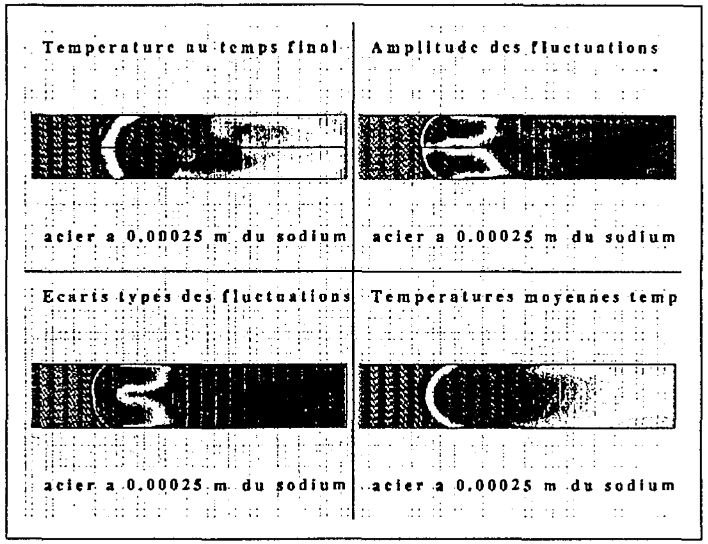

Figure 6 : Statistics on temperature fields.

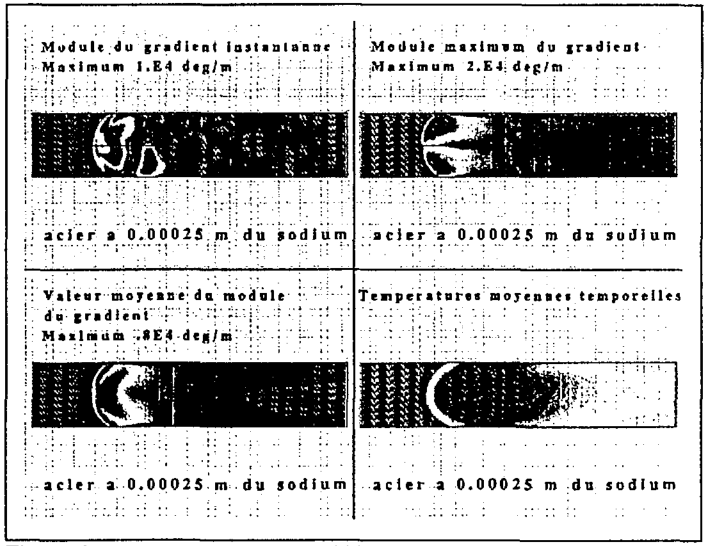

Figure 7 : Temperature gradients .00025 m depth in the wall

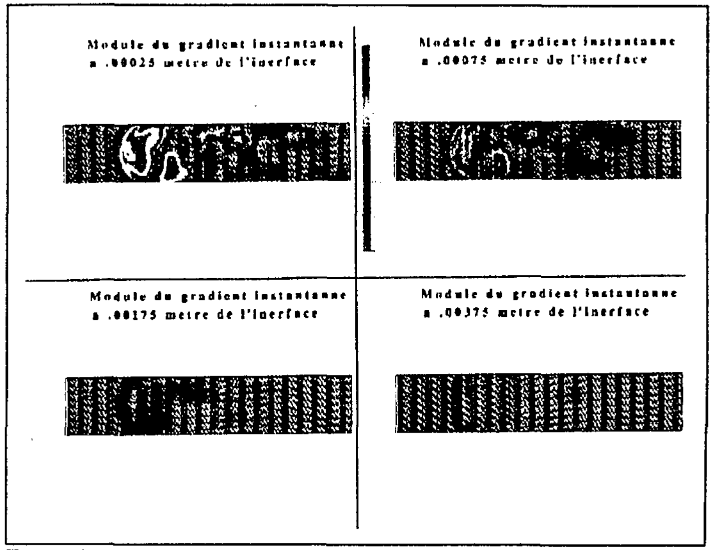

Figure 8 : Snapshot on temperature gradients in function of the depth

6. Conclusions

A new numerical approach of thermal loading of structures in industrial situations have been presented and illustrated in a simple case. The results are very instructive and we think that more efforts have to be done in this way :

* Experimental efforts are necessary to investigate the very thin skin effects involved in thermal stripping.

* Efforts on code development, in order to deal easily with complex geometries and efforts on code validation are also necessary.

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