THEORETICAL AND EXPERIMENTAL ASPECTS REGARDING NON-ISOTHERMAL AND INHOMOGENOUS AIR JETS

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Abstract. The practical applicability of non-isothermal and inhomogenous air jets determined researchers concerned with their study to analyze from a mathematical and experimental point of view the technical elements related to this phenomena. The identified aspects were likely to generate the circumstances for the practical improvement of the systems that involve the presence of the non-isothermal and inhomogenous air jets, the researches highlighting different methods for determining the relevant technical parameters from this perspective.

Keywords: Non-isothermal; inhomogenous; air jets; modeling.

1. Introduction

Over time, jet theory has attracted the attention of many researchers through the multitude of practical applications and their relevance in all technical fields.

The specialized literature briefly presents some of the specific characteristics of jets: the pressure in the jet is practically constant and equal to

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the pressure in the surrounding environment, thus the law of conservation of momentum is applicable for infinitesimal amounts of mass in the nozzle and in the jet, the dimensionless distribution of velocities in the transversal section is identical along the movement and also the rapid variation of speed in the transverse direction by comparison with the variation in the horizontal direction (AIIR, 2010).

However, in practical applications, air jets are frequently used in conditions that involve both temperature variations and various adjacent obstacles, which disrupt the normal flow of the fluid, an aspect that led researchers to perform analyzes on the complex mathematical calculation generated in the conditions of non-isothermal and inhomogeneous air jets.

2. Research methodology

Sforza and Herbst (1970) were the first to deduce the existence of horseshoe-shaped vortices inside the jets, by identifying some irregularities in the lateral flow direction of the jets. Davis and Winarto (1980) determined, by correlating the velocities measured in the plane perpendicular to the jet flow direction, the importance of the significance of the lateral spread of the jet flow direction. Iida and Matsuda (1988 and 1990) identified clear evidence for the existence of secondary flows adjacent to the initial jet, studying the evolution of the jet at distances up to three times the nozzle diameter. Ewing and Pollard (1997) continued Matsuda's investigations by studying the area located at distances between three and ten times the nozzle diameter, confirming the existence of the horseshoe-shaped structures identified in the jet, according to figure 1.

![Fig. 1 – The horseshoe shape identified in the jet by Ewing and Pollard.](image-url)
The issue of axial-symmetrical jets, having in the adjacent area a wall/floor parallel to the axis of the respective jet, was intensively addressed from the perspective of the fact that it is widely used in construction installations. However, the cases that assume the flow of non-isothermal jets have been addressed less, especially for the situations that assume low speeds, where the effect of the ascent forces is the most important.

For three-dimensional non-isothermal jets, the lateral growth rate is much higher than the normal growth rate, perpendicular to the wall. Launder and Rodi (1983) demonstrated this aspect for the first time through the prism of the characteristic equations of the jets.

Turbulent flows, like jets, are surrounded by adjacent areas with static fluid, so the interface between the turbulent flow and the non-turbulent area is usually small. This interface is in a continuous deformation, closely dependent on the properties of the flow and the fluid, causing a gradual change in the respective area from a turbulent flow to a non-turbulent one. The identification of some scientific explanations of how this interface is created and behaves has been the subject of many scientific researches, in order to establish the cause of the driving process that determines the transformation of the area with irrotational fluid into a turbulent area (Westerweel et al., 2011).

With regard to non-isothermal jets of air, researchers have demonstrated that while the jet evolves downstream, the effects of the ascension force are increasingly pronounced. The lifting force will have an important role both on the spreading rate of the jet and, implicitly, on the entrainment rate of the surrounding fluid. In fact, the explanation translates into the fact that "in the far field of the jet, the impulse can no longer suppress the effects of the ascent force, and the baroclinic effects can generate (or suppress) the formation of turbulence", these being demonstrated by Bhat and Narashima (1996), respectively Agrawal and Prasad (2004).

A complex experimental study of the deformation mode of non-isothermal jets by comparison with isothermal ones was carried out by Kuznik, Rosaouen and Brau (2011). They created an experimental stand with dimensions of LxWxH - 3.10x3.10x2.5 meters, the diameter of the nozzle of the jet being 0.12 meters, also the same distance representing the length from the edge of the mouth to the floor of the stand. Practically, they carried out 4 different experiments: the first suggestively named "I" is the case where the temperature of the air in the jet is equal to the ambient temperature, the second case named "H" in which the temperature of the air in the jet is higher than the ambient temperature, and the other two cases "C1 and C2" in which the air temperature in the jet is lower than the ambient temperature. Figure 2 shows the velocity vectors at similar distances from the jet mouth in all 4 cases, thus having an exhaustive picture of the jet deformation mode, justifiable by means of the mathematical calculation methods highlighted above in this work.
In case "I", the authors justify the attachment of the jet to the ceiling after a distance of 0.72 meters through the prism of both natural expansion and the Coandă effect. Likewise, the vectors with the highest speed gradually move away from the wall, an aspect also demonstrated by Benaissa (2004). In the second case, that of the warm jet, the authors observed a faster attachment of the jet to the ceiling than in the first case, also due to the ascension force. Thus, it is experimentally reconfirmed that by moving the fluid away from the discharge nozzle, the force arising due to the difference in density surpasses the inertial force imposed on the fluid. In the cases with the cold jet, it is observed that the jet loses its height precisely through the prism of the effect of the Archimedean forces.

The same authors also analyzed the mode of expansion of the jets in the 4 cases, concluding that the jets can be included in two different categories. The
first category consists of the isothermal and cold jets, characterized by a greater vertical expansion than the horizontal one, and the other category formed by the non-isothermal jets that attach to the ceiling and are characterized by a greater lateral expansion than the vertical one.

Kuznik, Rosouen and Brau (2011) appreciate that "it is a real challenge to characterize the turbulent structures within the different types of flow specific to jets, the goal being a better understanding of their behavior, but also providing effective tools to be able to be implemented in the numerical simulations carried out within the computerized fluid mechanics (CFD). Isothermal jets and cold jets that do not attach to the wall develop non-isotropic and mainly symmetric turbulent structures. Thus, in CFD simulations, the use of turbulence models with two equations is considered inappropriate. Regarding the non-isothermal jets that attach to the wall, from the analyzes presented, they are subject to instabilities and lateral expansions. The primary vortices inside the jet at the intersection with the wall, generate the prerequisites for the formation of those horseshoe-shaped structures that have an important role in the lateral direction of the fluid in the jet, aspects that would be appropriate to be verified experimentally. Thus, the CFD modeling of these non-isothermal flows requires a correct approach in terms of choosing the appropriate turbulence model."

Also, in the context of attaching jets to adjacent surfaces, we must not omit the importance and implications of the Coandă effect. The Romanian Henri Coandă became aware of this phenomenon for the first time during the flight of the first jet plane in the world, when he noticed that the jet of exhaust gases practically "stuck" from the plane's fuselage, causing a fire. The experiments carried out in the wind tunnel, as well as other tests, led to the phenomenological confirmation of the fact that the gas jet attaches itself to the solid walls in the immediate vicinity. Henri Coandă received the patent for the fluid jet propulsion device, and also for the invention of "method and device for the deviation of a fluid into another fluid", this last discovery based on the physical phenomenon "the deviation of a plane jet that penetrates into another fluid, in the vicinity of a convex wall", later called the "Coandă effect." (Constantinescu, 2013).

The Coandă effect assumes that a jet of fluid flows along a wall with which it makes a certain angle depending on the respective direction of flow. When the wall is located near the fluid jet, a depression zone appears between the wall and the jet, which determines the conditions for the attachment of the jet to the wall. Thus, it is precisely the pressure difference between the ambient environment and this area that causes the jet to head towards the wall.

In the case of the partial limitation of a jet with a solid wall, an asymmetry appears in the velocity distribution due to the phenomenon of attracting the jet to the surface of the wall, due to the Coandă effect. This aspect manifests itself through an increase in speed, but also through changes in flow directions. The attraction of the jet to the wall is determined, as already mentioned, by the appearance of local areas of depression on the adjacent solid surface due to the
exhaustion of the gas mass contained between the wall and the upper limit of the jet. The jets projected at a certain angle on a solid surface have industrial applications related to, for example, the heating or cooling of contact surfaces. Countless experiments have been carried out on heat transfer for air jets created at the exit of linear nozzles, but also for air jets created at the exit of radial nozzles with a reattached jet (Constantinescu, 2013).

However, the modeling of the fluid flow in situations where the Coandă effect is incident can also be carried out with the help of numerical methods. Until the development of the calculation techniques, the study of this effect was done by using semi-empirical methods or simple mathematical models, in which case is relevant the study proposed by Metral (1939).

3. Results and discussion

According to the previously detailed aspects, the theory of non-isothermal and inhomogeneous air jets is generally based on data obtained experimentally, in the context of the complexity of the mathematical apparatus that describes these fluid flows.

Also, the current stage of the evolution of research on non-isothermal and inhomogeneous air jets highlights the opportunity to use semi-empirical calculation methods in order to make determinations regarding non-isothermal and inhomogeneous air jets, in the context of the much too long periods of time required for mathematical calculation effective.

Regarding the practical applicability of these phenomena in construction installations, an eloquent example used on a large scale in current practice are the smoke and heat exhaust ventilation systems from underground parking lots, provided with jet-impulse fans, in the operation of which occurs the phenomenon of non-isothermal and inhomogeneous air jets, taking into account the existing temperature differences in the underground parking lot in case of fire, the multiple obstacles for fluid flow determined by the architectural elements, as well as the interferences between the jet fans placed successively with the role of transporting the products resulting in case of fire towards the smoke and heat exhaust devices.

4. Conclusions

Considering the theoretical and practical aspects presented, it was concluded that through a bivalent approach, on the one hand experimental and on the other hand, semi-empirical, in the analysis of non-isothermal and inhomogeneous air jets, positive results can be obtained on the level of improvement the functioning of the technical systems that require their use.
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ASPECTE TEORETICE ȘI EXPERIMENTALE CU PRIVIRE LA JETURILE DE AER NEIZOTERME ȘI NEOMOGENE

(Rezumat)

Aplicabilitatea practică a jeturilor de aer neizotermes și neomogene i-a determinat pe cercetătorii preocupați de studiul lor să analizeze din punct de vedere matematic și experimental elementele tehnice legate de acest fenomen. Aspectele identificate au fost de natură să genereze circumstanțele pentru îmbunătățirea practică a sistemelor care presupun prezența jeturilor de aer neizotermes și neomogene, cercetările evidențând diferite metode de determinare a parametrilor tehnici relevanți din această perspectivă.