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IMPLICIT LARGE EDDY SIMULATION OF HIGH-SPEED IMPINGING JETS

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Abstract. The dynamic process to be characterized by the following narrative comprises a supersonic jet impinging onto a flat surface, which produces complex fluid dynamic phenomena that are dominated by the intrecate shockwave structure of the jet ([1] and [2]). Even though the mean solution is relatively well understood, the growing of unsteady instabilities in the shear layer at the nozzle gives rise to oscillations in the dominant flow structures which travelling upstream perturb again the shear layer completing a loop usually known as feedback model [3]. Regrettably, the exact dynamic of this phenomena and the influence of the different parameters involved on it is still not well understood. This configuration has been thoughtfully studied experimentally by [4]. An Implicit Large Eddy Simulation methodology has been used in the computations. Although LES simulations have demonstrated their ability to predict the behavior of weakly compressible turbulent flows [5], their applicability to supersonic configurations remains to be validated [6]. The present study seeks to understand the mechanisms leading to the appearance of instabilities in impinging jets. In the longer term, it is hoped that flow control guidelines will emerge from these types of studies.

1 INTRODUCTION

Impinging jets are commonplace in industrial applications, including mixing and spraying, where flow steadiness is desirable. In the aerospace industry, rocket launches represent a critical phase during which jet instabilities can lead to payload damage and loss of flight control.

The discussion of high-subsonic impinging jets onto flat plates finds its starting point in the characterization of the fluid field which is formed in the surroundings of the nozzle exit. The jet-plate interaction produces a wide range of fluid phenomena that consist of several flow modules, each of them having its own distinctive characteristics. Typical parameters involved in the flow configuration are: the Nozzle Pressure Ratio (NPR) as the difference between the ambient and nozzle pressure, the Reynolds number (Re) and the impingement distance ($\frac{h}{d}$). This particular problem has caught the attention of the researchers who have, hence, enhance their efforts in order to shed some light upon the process that is held once the impinging jet configuration is established, not just by means of identifying the underlying factors but also because of the already pointed out technological applications. The various experimental studies made until these days have managed to reveal a significant part of the phenomena that is carried out when the aforementioned scenario is set up.

The process, therefore, is explained by what it has been named as the aeroacoustic feedback loop model, which is supposed to work thusly (Powell 1961; Tam & Block 1978): waves generated at the impingement locations travel upstream where they perturb the shear layer at the nozzle. These perturbations at the nozzle exit grow into large scale structures in the shear layer through a process termed collective interaction [3]. The impingement of these structures on the surface of the downstream plate in turn creates the upstream travelling waves, closing the loop.

Strong support for the feedback loop hypothesis has been provided by several researchers. Ho & Nosseir [3] used microphones placed in several positions along the jet's near field and succesfully confirmed the existance of two wave trains travelling both upstream and downstream the jet. In a comprehensive study using microphone measurements and phase locked shadowgraphy, it was suggested that the generation of the upstream acoustic waves was produced by the collapse of the standoff shock generating a fluctuation in the wall jet (Henderson, 2002). Further studies using phase locked shadowgraphy, schlieren and Particle Image Velocimetry provided support for the hypothesis that the axial motion of the standoff shcok produced pulsatile behaviour in the wall jet, resulting in the production of discrete frequency sound (Henderson *et al.*, 2005). In general terms, the main parameters that govern the process once it has been unleashed are well understood, and a deeper insight of the studies is expected to bring little knowledge on what is known about the evolution of the feedback loop.

The main hurdle of the problem, however, lies upon the fact that gives birth to the instabilities which lead to the described feedback model. Though different theories have been proposed to explain the growth of these instabilities, they have always encountered obstacles in their way to reach the acceptation. One of the most popular models which has already been mentioned before, named as collective interaction, shows the idea of an oscillating shear layer at a frequency much lower than its intrinsic most unstable frequency, which leads to the merging of many small vortices together to form large coherent structures [3]. However, researchs carried out lately [4] seem to refuse the mentioned mechanism, and thereby the task of finding a proper theory about the formation of the instabilities remains open; as the difficulty of obtaining reliable experimental data is the main impediment to conclude the work, it seems that the proper tool to continue with further investigations is placed within the computational branch, upon which falls the mission of discovering the instabilities' mechanism. The work presented herein, thus, intends to both validate a code with the already known experimental data and, once the software proves to be reliable, try to predict how the mentioned feedback loop is merged from the nozzle exit shear layer perturbations.

2 SOFTWARE SETUP

The code used for the simulations that have been carried out, known as **ISAAC**, which stands for **I**ntegrated **S**olution **A**lgorithm for **A**rbitrary **C**onfigurations, is a compressible Euler/Navier-Stokes solver [7]. It implements several turbulence models which cover from the two-equation ones to the full differential Reynolds-stress-equations, and therefore provides a flexible environment as for the swapping of configurations in order to compare and select the most suitable one according to experimental data.

The software has been run in several test cases provided by the programmer before beginning with the simulations, resulting in satisfactory output data.

3 CASE SETUP

The configuration to be simulated is depicted on figure 1. The idea is to carry out a proper research as far as the election of the adecuate turbulence model is concerned. This task will cover the study concerning the comparison between several cases and the gathered experimental data. However, it can be already stated that the two main parameters of the problem, which are the nozzle pressure ratio (NPR) and the impingement distance ($\frac{h}{d}$) have been set to 3.2 and 4 values, respectively, in concordance with the experimental setups. As just a pair of models have been run so far, a deeper explanation of the selected case will be presented in the final paper.

4 RESULTS

The schemes depicted within the appendix A are a preview as for the ones that will be finally presented. Though a non-turbulent case has been simulated, the aforementioned main flow modules can be fully identified at first glance. Figure 2 shows a 2D section of the density field where the growth of the shear layer instabilities can be figured out.

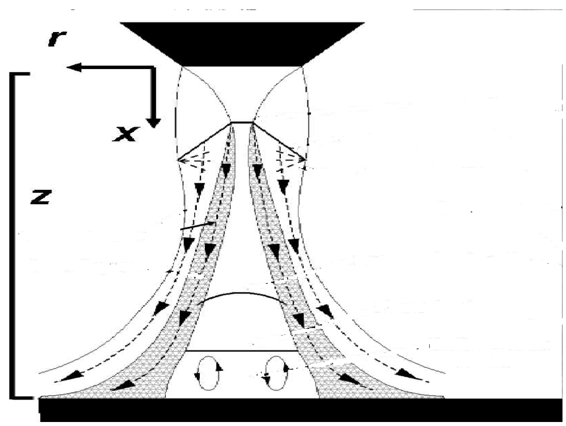


Figure 1: Schematic of one possible configuration of steady state flow for an impinging jet

The jet core and the so well known Mach-diamond patterns can be guessed by looking at figure 3a, together with the already cited growth of the instabilities which clearly create a sine-shaped perturbation of the shear layer. The radial velocity field has been represented in figure 3b, giving a wider idea of how the mixture of the shear layer perturbations is carried out and, thereby, acting as a backup as for the previous data. The last figure intends to transmit the idea of the complexity that characterizes the flow configuration, as well as a picture of the jet and its near flow field as a whole. A more exhaustive study is expected to lead into both a deeper comprehension of the problem and a more profound analysis of the computational data to be obtained.

Appendix A: FIGURES

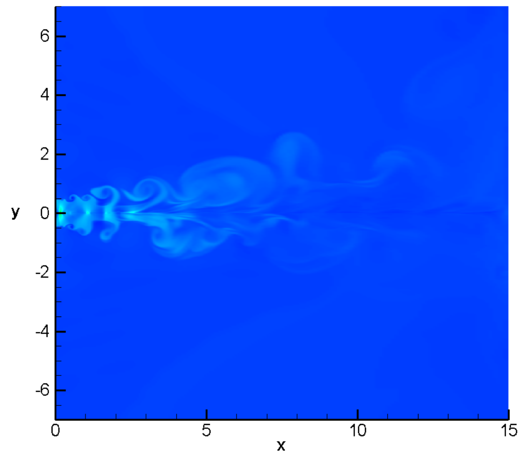
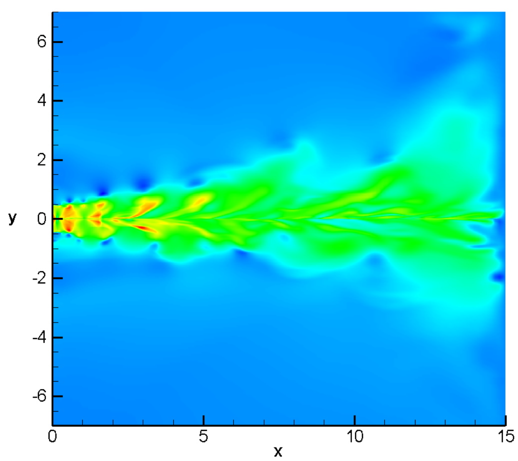
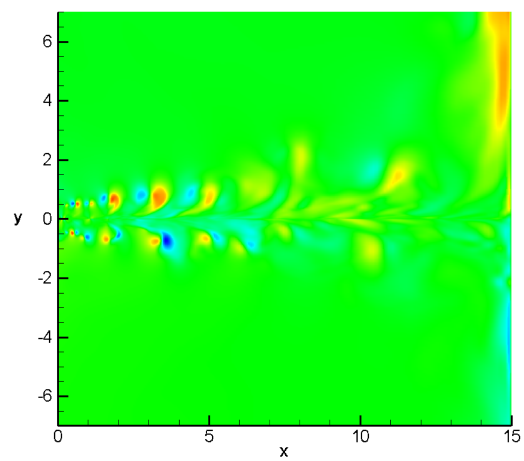


Figure 2: density field in a 2D section.



(a) axial velocity field in a 2D section.



(b) radial velocity field in a 2D section.

Figure 3: velocity fields.

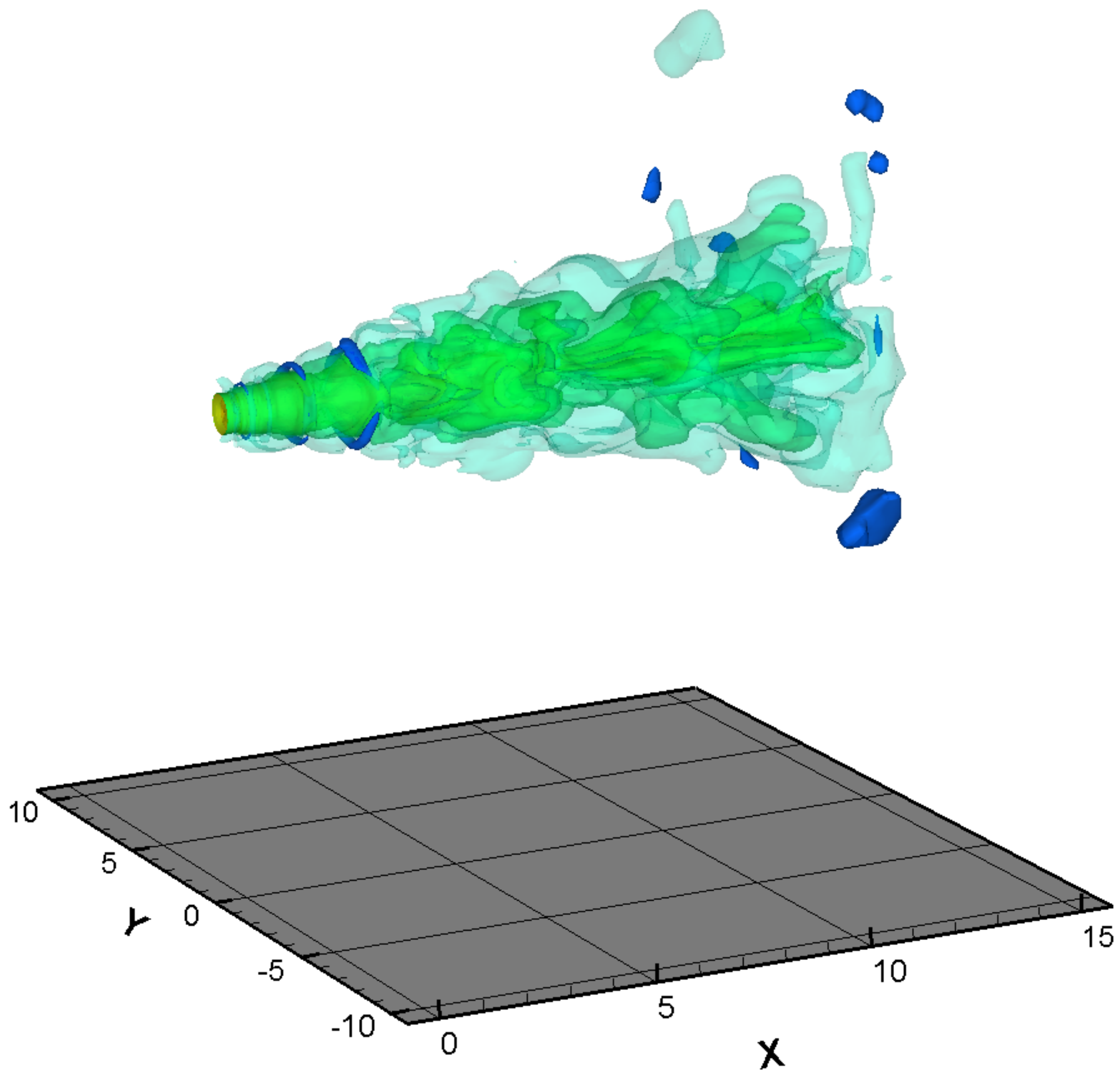


Figure 4: Three-dimensional view showing the axial velocity field as a whole.

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