# Flow through a de Laval nozzle.

Computional Simulations of Combustion Processes.

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# Contents

# 1 Introduction

The aim of this project is to observe and describe transformation from subsonic to supersonic flow in a de Laval nozzle. This phenomenom is accompanied by the creation of the shock wave. To solve and simulate aforementioned case was used OpenFOAM.

# 2 Preprocessing

## 2.1 Mesh

De Laval nozzle is 400 mm long, has widest diameter 200mm and narrowest 160 mm. Axissymmetric mesh was made in ANSYS Fluent and imported to OpenFOAM case.

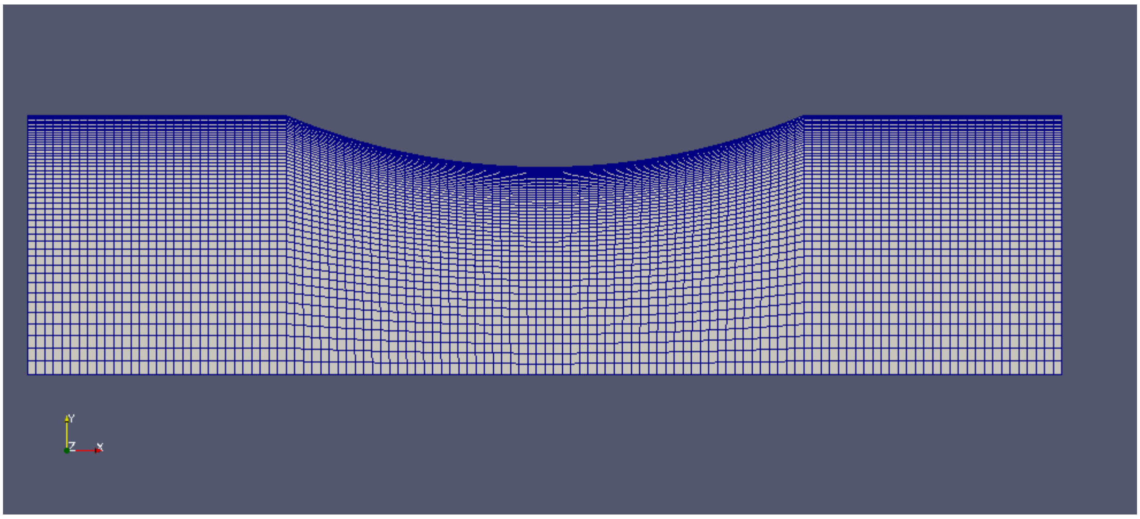

Figure 1. Mesh

## 2.2 Assumptions

Laminar flow was assumed in order to simplify calculation, moreover the main goal was to focus on schock wave and therefore thorough examination of flow near wall and turbulent processes were neglected. Case was solved using rhoCentralFoam, flow was treated as compressible,viscous and steady.

## 2.3 Boundary and initial conditions

Boundary and initial conditions were set on inlet, outlet, wall, axis and internalField.

a) Inlet

Velocity: type pressureInletOutletVelocity

$$U_x = 250\frac{m}{s}$$

Pressure: type totalPressure

$$P_o = 120000Pa$$

$$Static\ pressure = 93000Pa$$

Temperature: type fixedValue

$$T = 294K$$

b) Outlet

Velocity: type zeroGradient

Pressure: type zeroGradient

Temperature: type zeroGradient

c) Wall

Velocity: type zeroGradient

Pressure: type zeroGradient

Temperature: type noSlip

d) Axis

Velocity: type symmetry

Pressure: type symmetry

Temperature: type symmetry

e) iternalField

Velocity:

$$U_x = 250\frac{m}{s}$$

Pressure:

$$P = 101325Pa$$

Temperature:

$$T = 294K$$

# 3 Results

## 3.1 Convergence

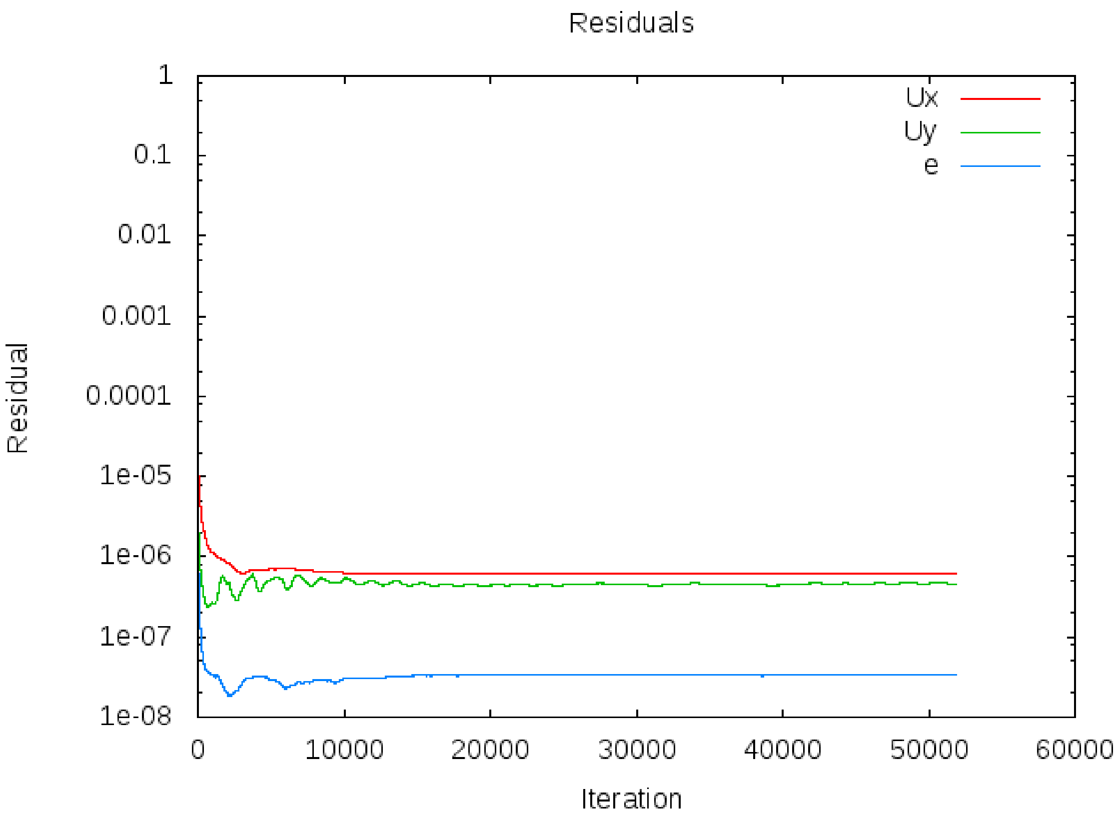


Figure 2.

Plot of residuals, all of them converged at least to order of magnitude of 1e-06

### 3.2 Vectors of velocity

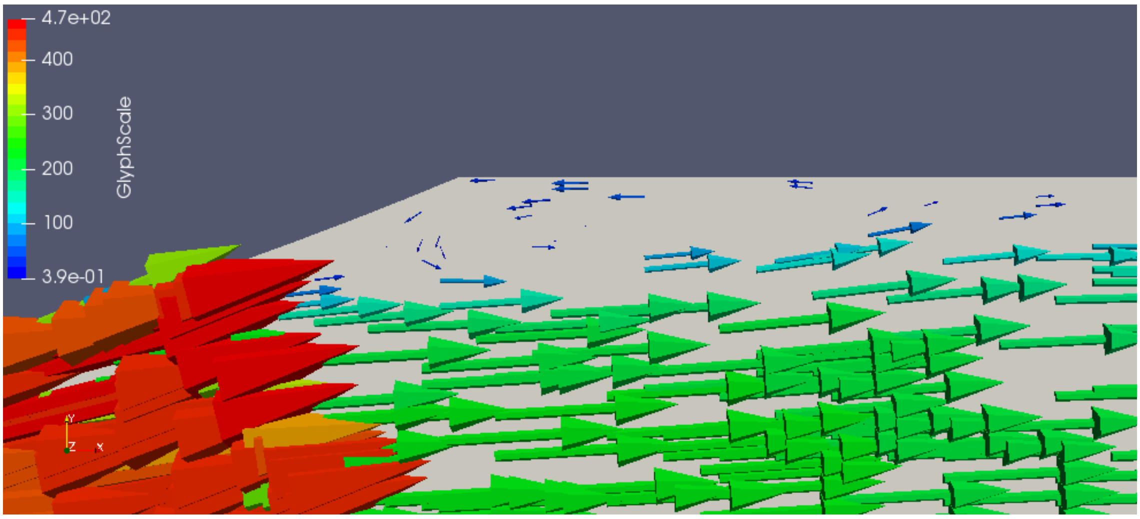

Figure 3.
This is the only place where disconnection of a boundary layer and swirl can be observed.

### 3.3 Velocity

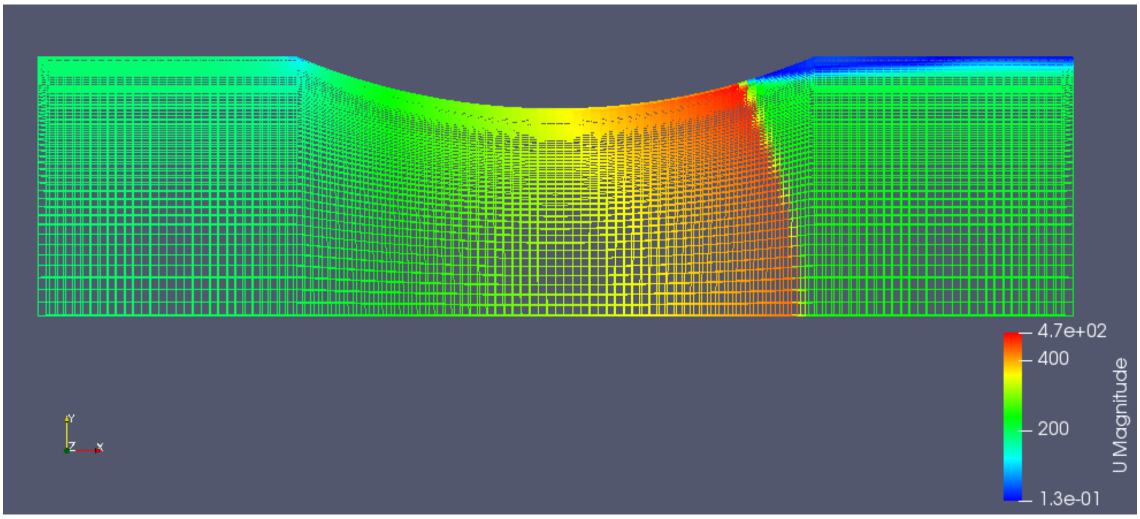

Figure 4.
Line of transformation between subsonic and supersonic flow can be easily seen, there one can observed schock wave.

## 3.4 Mach Number

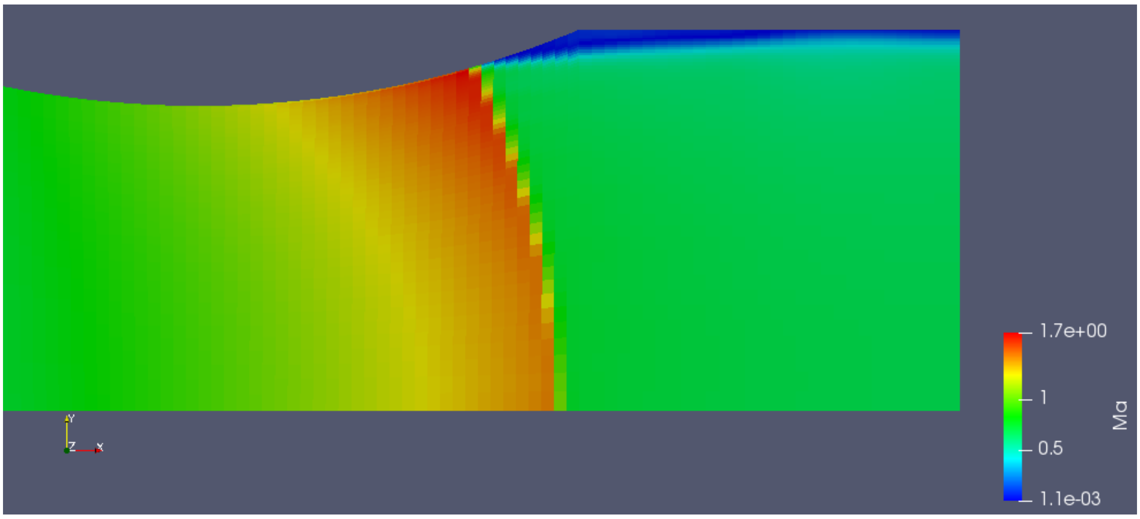

Figure 5.
Maximum Mach number observed in flow is 1.7 . There is no doubt that schock wave is produced in a nozzle.

## 3.5 Pressure

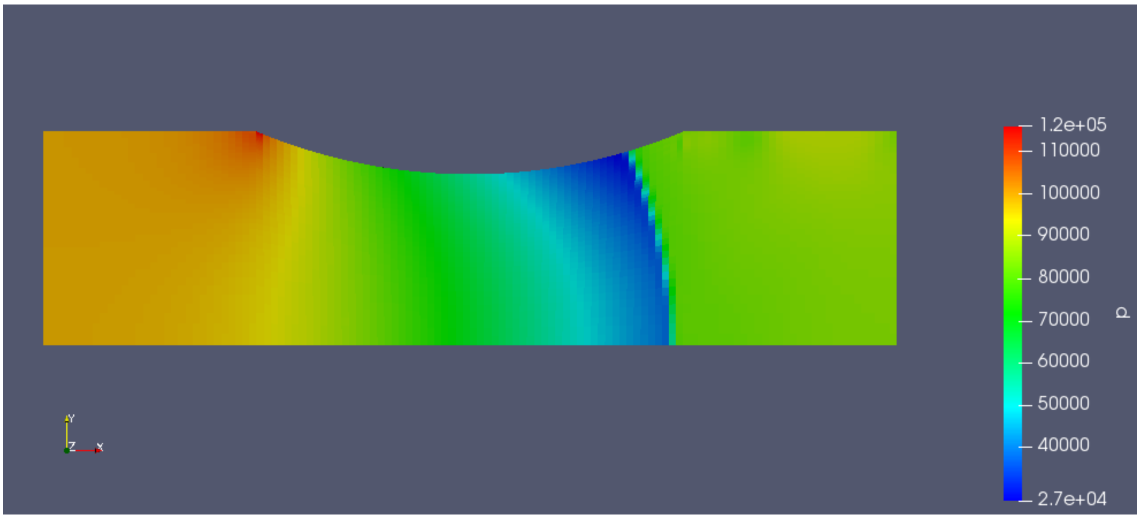

Figure 6.
According to Bernoulli's equations pressure decreases where velocity increases.

### 3.6 Temperature

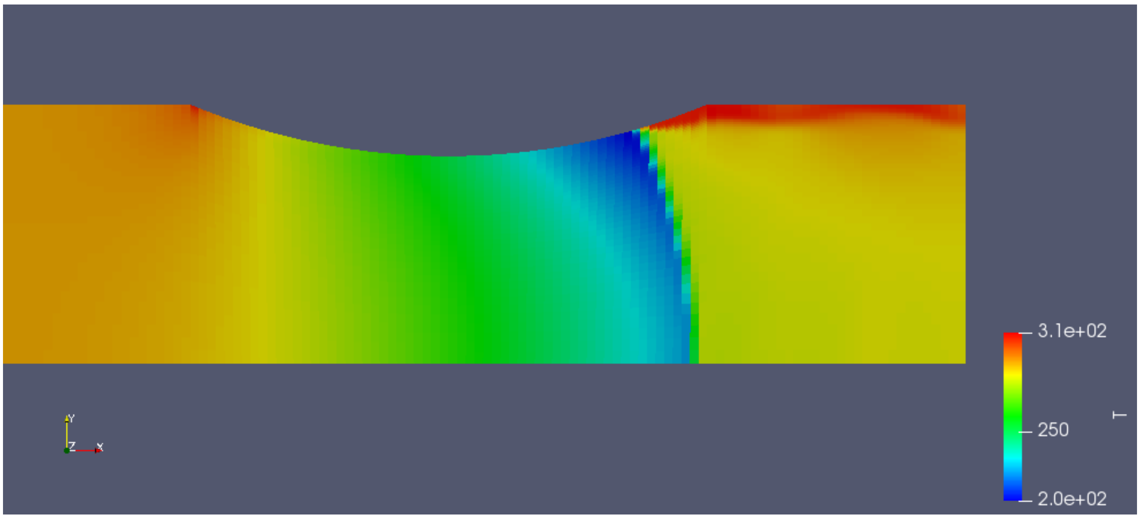

Figure 7.

Such a great fall of temperature near schock wave is hardly possible. It can be an effect of numerical error or wrong boundary and initial conditions.

# 4 Conclusions

First of all, a pressure drop can be observed between inlet and outlet, probably caused by an energy loss. Second of all, although inlet velocity is lower than speed of sound, de Laval nozzle enables operating medium to reach supersonic velocity. Interestingly a swirl can be observed next to schockwave.

# 5 Bibliography

1. www.openfoam.com
2. openfoam.org
3. Introduction to OpenFOAM. Held by prof. Hrvoje Jasak at Ghent University, Belgium, May 2016