Lagrangian particles evolution through RRE refraction structure

M. Dutreuilh

Tsinghua University

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Outline

1. Regular Refraction with Reflected Shock (RRR)
2. Theory and equations : gas dynamics
3. Results given by the inert gas dynamics theory
4. Use of CHEMKIN II to compute chemistry calculus
5. Results of the chemical calculus

Regular Refraction with Reflected Shock (RRR)

Strength χ and Mach number M_{sh} domains

For this structure, an angle of incidence of $\omega_i = 21.5°$ has been chosen so as to explore the largest range of Mach numbers which finally leads to :

$$\chi \in [0.6; 1] \iff M_{sh} \in [1; 1.26] \iff M_1 \in [2.76; 3.41] \tag{1}$$

The method employed for this structure will be highly similar to the method used for the RRE structure, and even simpler because of the reflected wave : a shock instead of an expansion fan.

Theory and equations : gas dynamics

Change and rotation of frame of reference

The change and rotation of frame of reference keeps the same and the symbols used for this structure are very similar with the previous ones : here is a little reminder

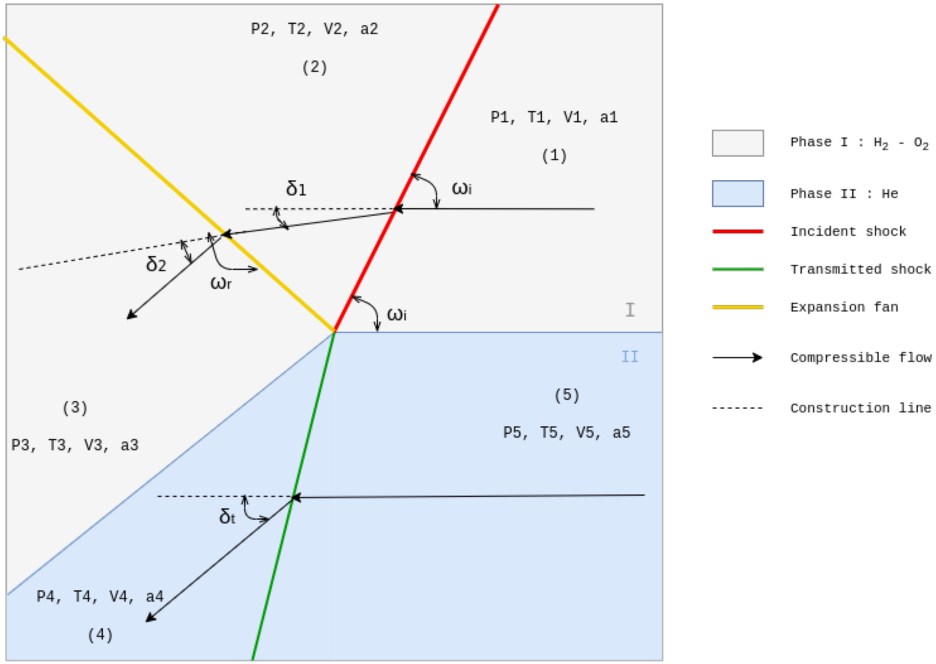


Figure 1: Symbols, zones and angles for computation

Measure (unit)	Symbol	Value
Pressure (Pa)	$P1$	101 325
Temperature (K)	$T1$	600
Specific Volume	$V1$	$V1 = R_I * T1/P1$
Mach number	M1	6
Angle of incidence (deg)	ω_i	21.5
Normal mach number	$M1_n$	$M1_n = M1 \sin(\omega_i)$
Speed of sound (m/s)	a_1	$a_1 = \sqrt{\gamma_I R_I T1}$

Table 1: Initial conditions

Definition of the normal Mach number $M1_n$ is not changed.

Theory and equations : gas dynamics

From zone (1) to zone (2): oblique shock

$$M1_n = M1\sin(\omega_i)$$

$$M2_n^2 = \frac{1+\frac{\gamma_I-1}{2}M1_n^2}{\gamma_I M1_n^2-\frac{\gamma_I-1}{2}}$$

$$\mathrm{M2} = \frac{M2_n}{\sin(\omega_i-\delta_1)}$$

$$\frac{V2}{V1} = \frac{(\gamma_I+1)M1_n^2}{2+(\gamma_I-1)M1_n^2}$$

$$\frac{P2}{P1} = 1+\frac{2\gamma_I}{\gamma_I+1}(M1_n^2-1)$$

$$\frac{T2}{T1} = \frac{P2}{P1}\frac{V2}{V1}$$

where δ_1 is the angle of deflection behind the incident shock.

$$\tan(\delta_1) = 2\cot(\omega_i)\frac{M1_n^2-1}{M1^2(\gamma_I+\cos 2\omega_i)+2}$$

Theory and equations : gas dynamics

From zone (5) to zone (4) : oblique shock of unknown angle

$$M5_n = M5 \sin(\omega_t)$$

$$M4_n^2 = \frac{1+\frac{\gamma_{II}-1}{2}M5_n^2}{\gamma_{II}M5_n^2-\frac{\gamma_{II}-1}{2}}$$

$$M4 = \frac{M4_n}{\sin(\omega_t-\delta_t)}$$

$$\frac{V4}{V5} = \frac{(\gamma_{II}+1)M5_n^2}{2+(\gamma_{II}-1)M5_n^2}$$

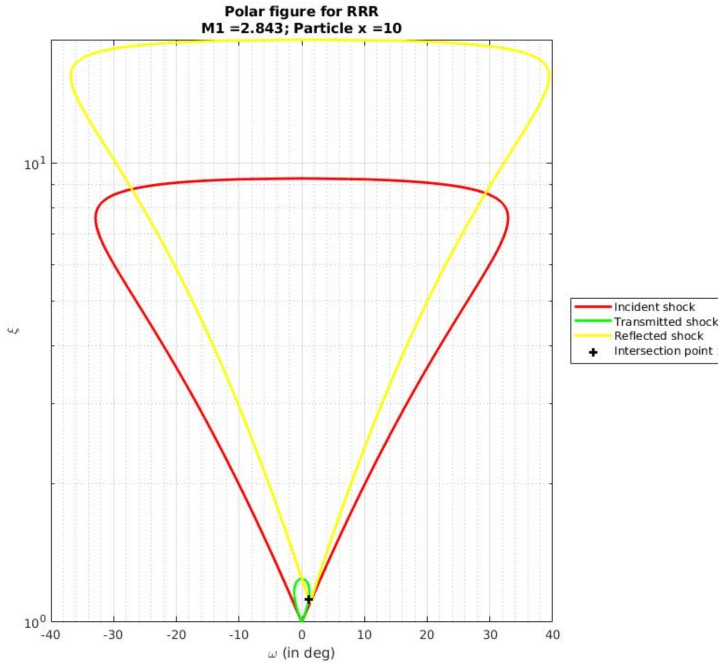
$$\frac{P4}{P5} = 1 + \frac{2\gamma_{II}}{\gamma_{II}+1}(M5_n^2 - 1)$$

$$\frac{T4}{T5} = \frac{P4}{P5}\frac{V4}{V5}$$

where δ_t is the angle of deflection behind the transmitted shock. Unfortunately, ω_t, the angle between the transmitted shock and the flow in zone (5), remains unknown.

Theory and equations : gas dynamics

Membrane equilibrium between zone (4) and zone (3)



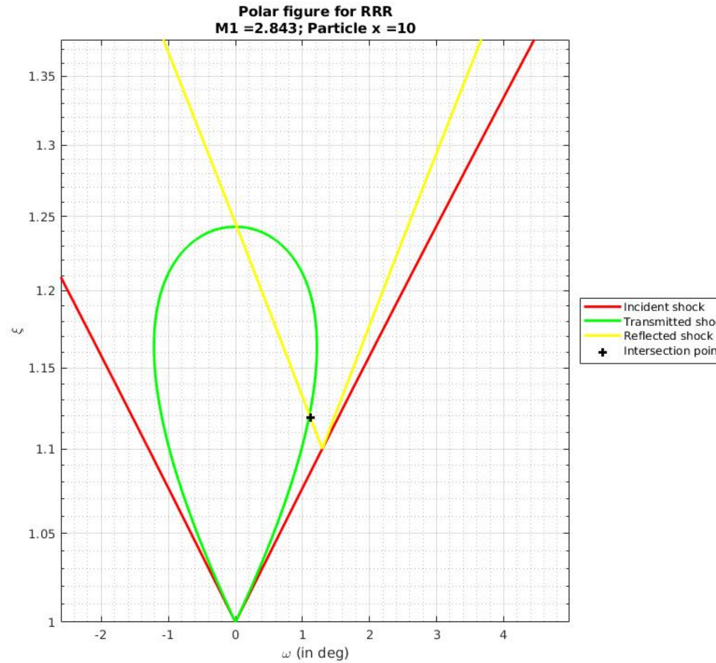
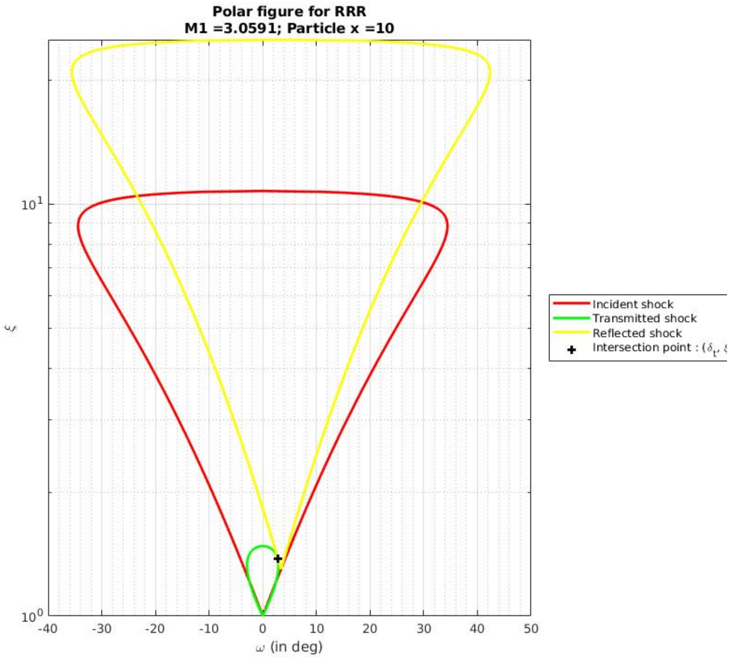
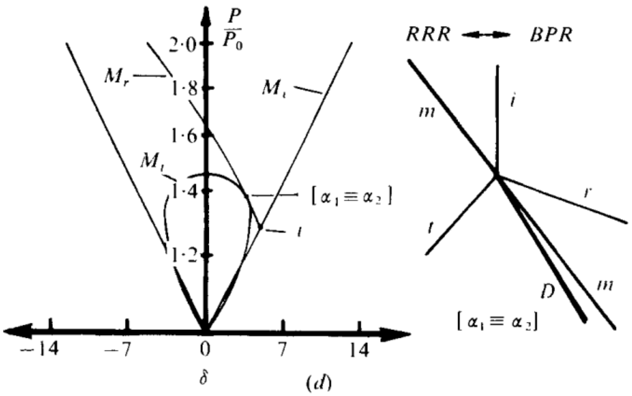


Figure 2: Polars for RRR structure, zoom on the intersection point on the right

Theory and equations : gas dynamics

Membrane equilibrium between zone (4) and zone (3)





$$\delta_t = \delta_1 + \delta_2$$

$$P3 = P4$$

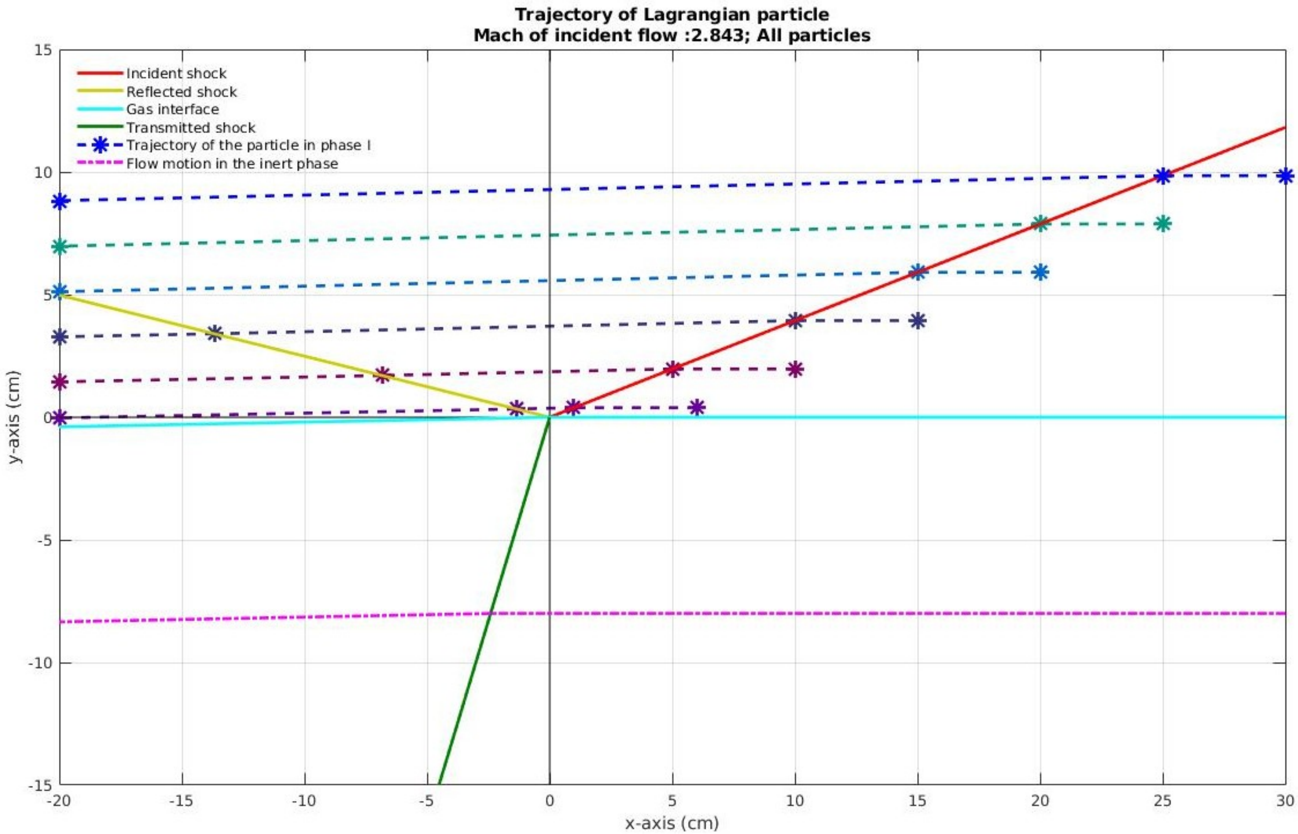
Figure 3: Polars for RRR structure, reference from Henderson et al. 1978 on the right

From zone (2) to zone (3) : oblique shock of unknown angle

Thanks to the polars of the shock, δ_t and ξ_t can be determined (intersection of expansion and transmitted shock polar) : $P4$ thus $P3$ are known. Then $\xi_r = \frac{P3}{P2}$ can be computed and all quantities in zone (3) can be easily deduced.

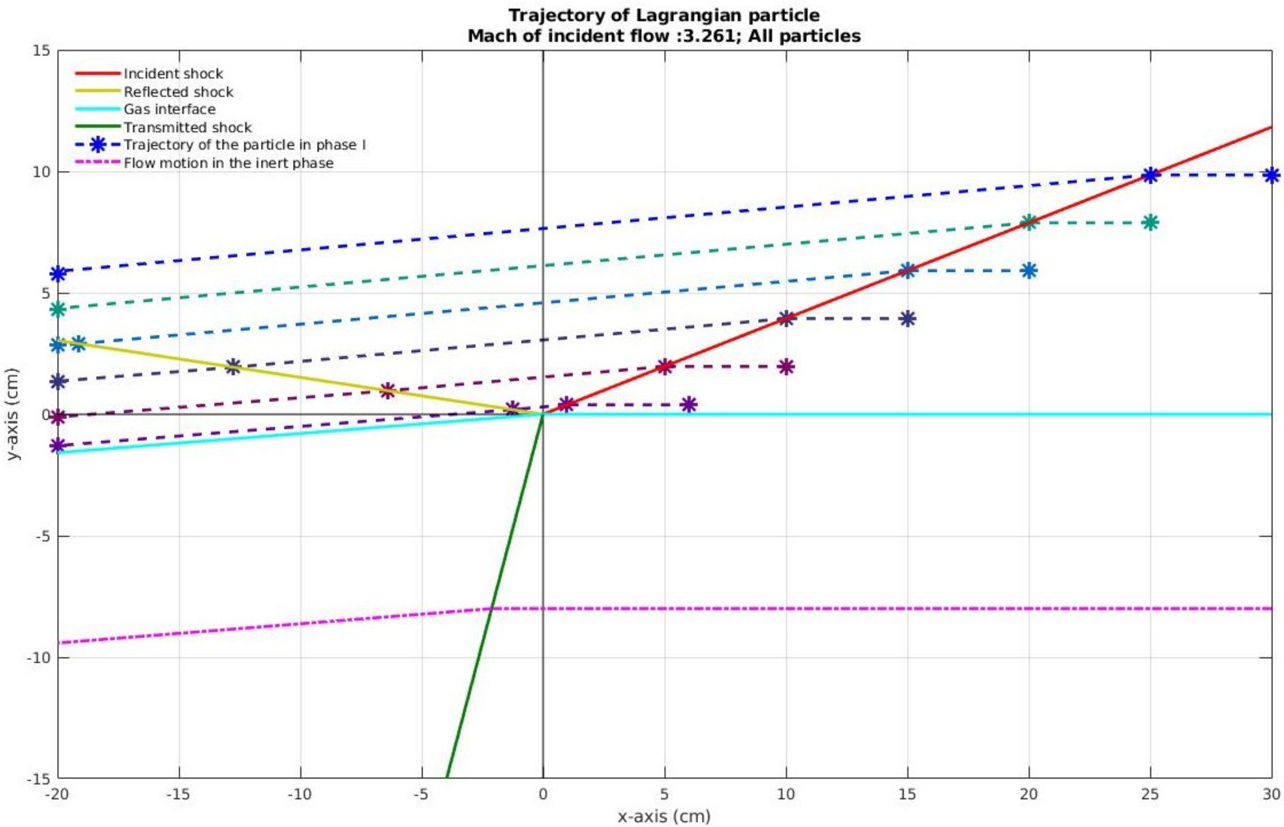
Results given by the inert gas dynamics theory

Evolution depends on position of the particle...



Results given by the inert gas dynamics theory

Evolution depends on position of the particle...



Results given by the inert gas dynamics theory

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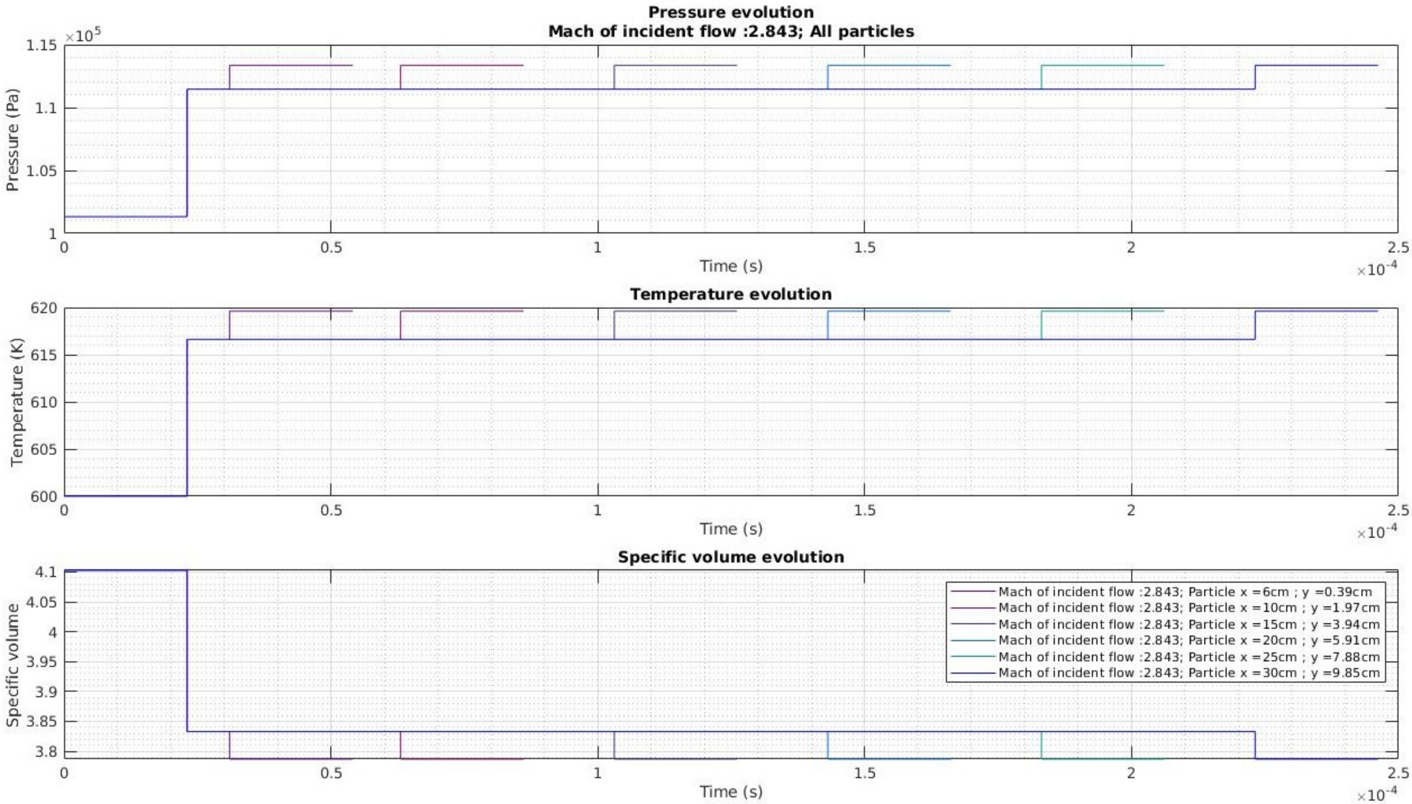
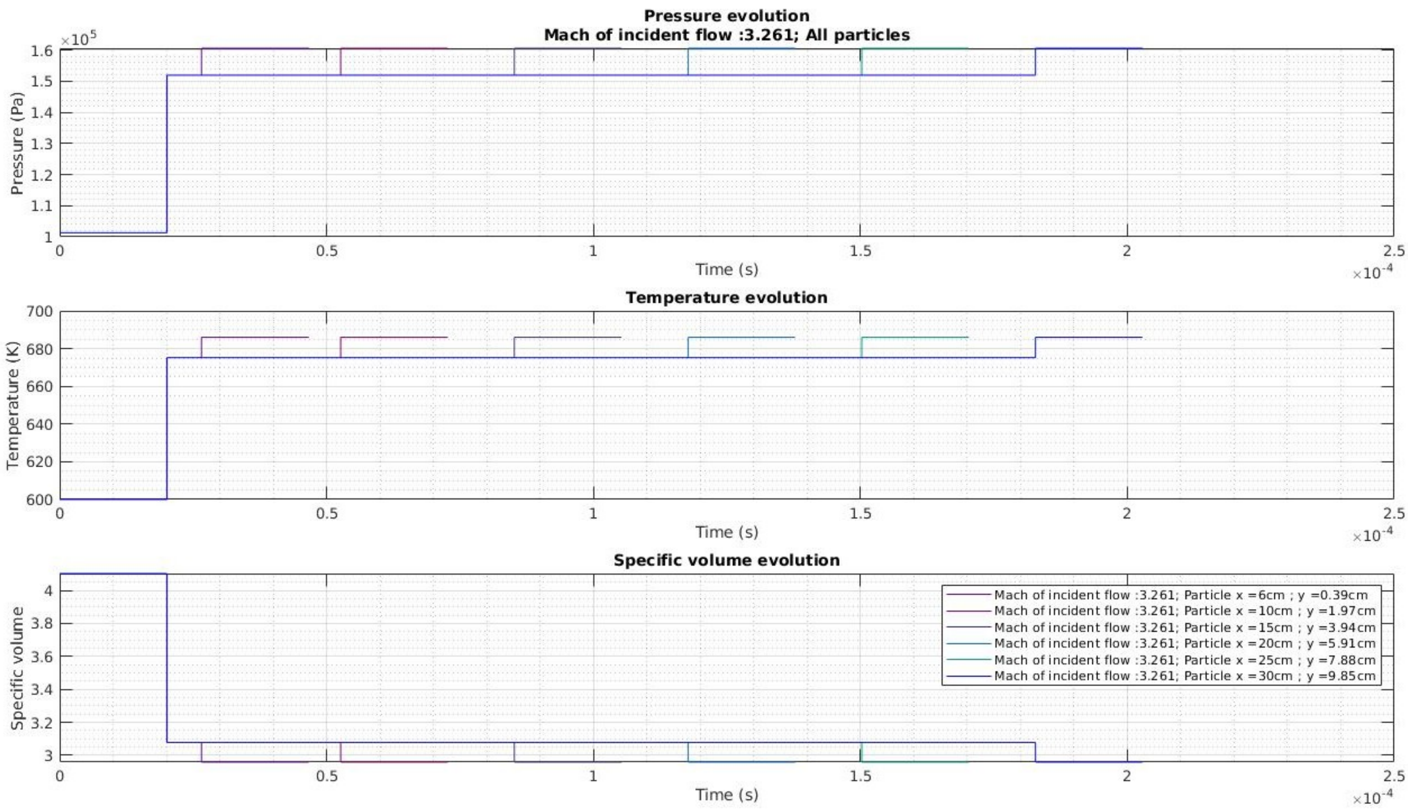


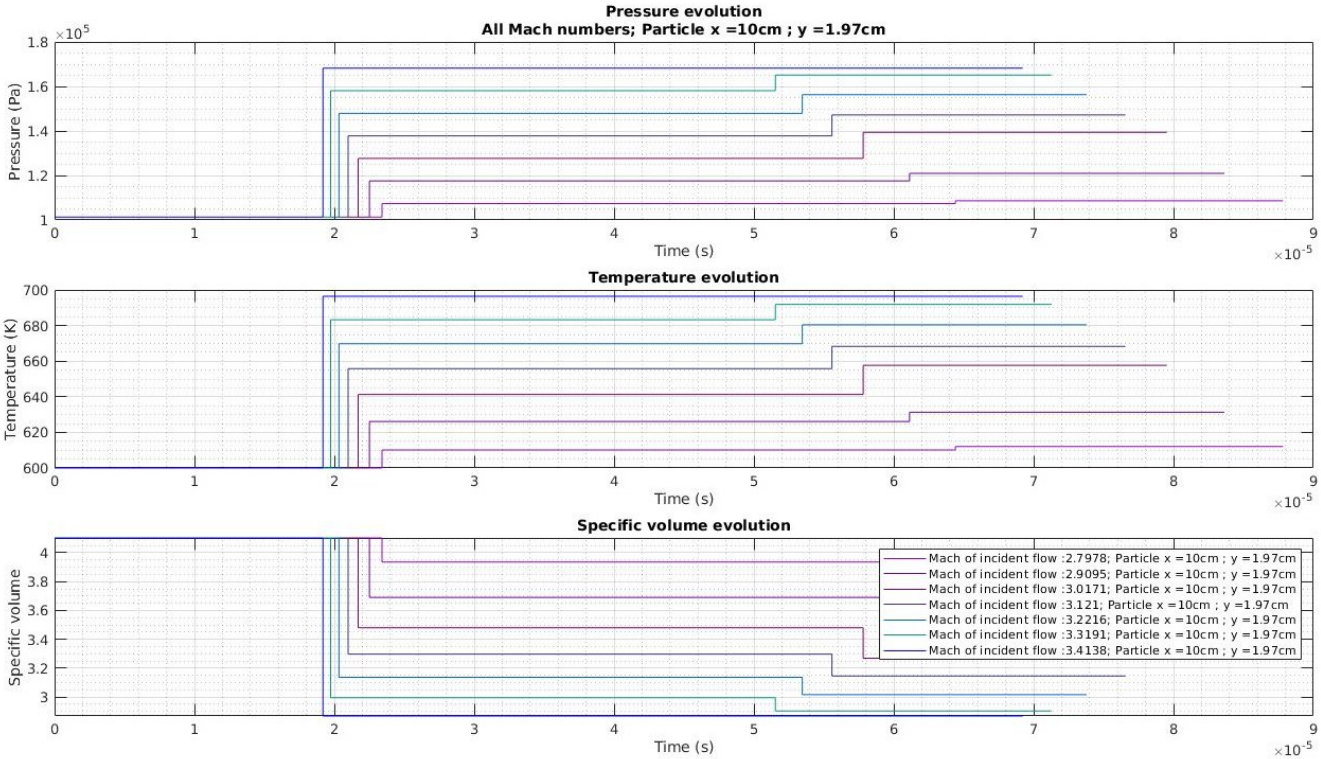
Results given by the inert gas dynamics theory

Evolution depends on position of the particle...



Results given by the inert gas dynamics theory

... and on Mach number of the shock



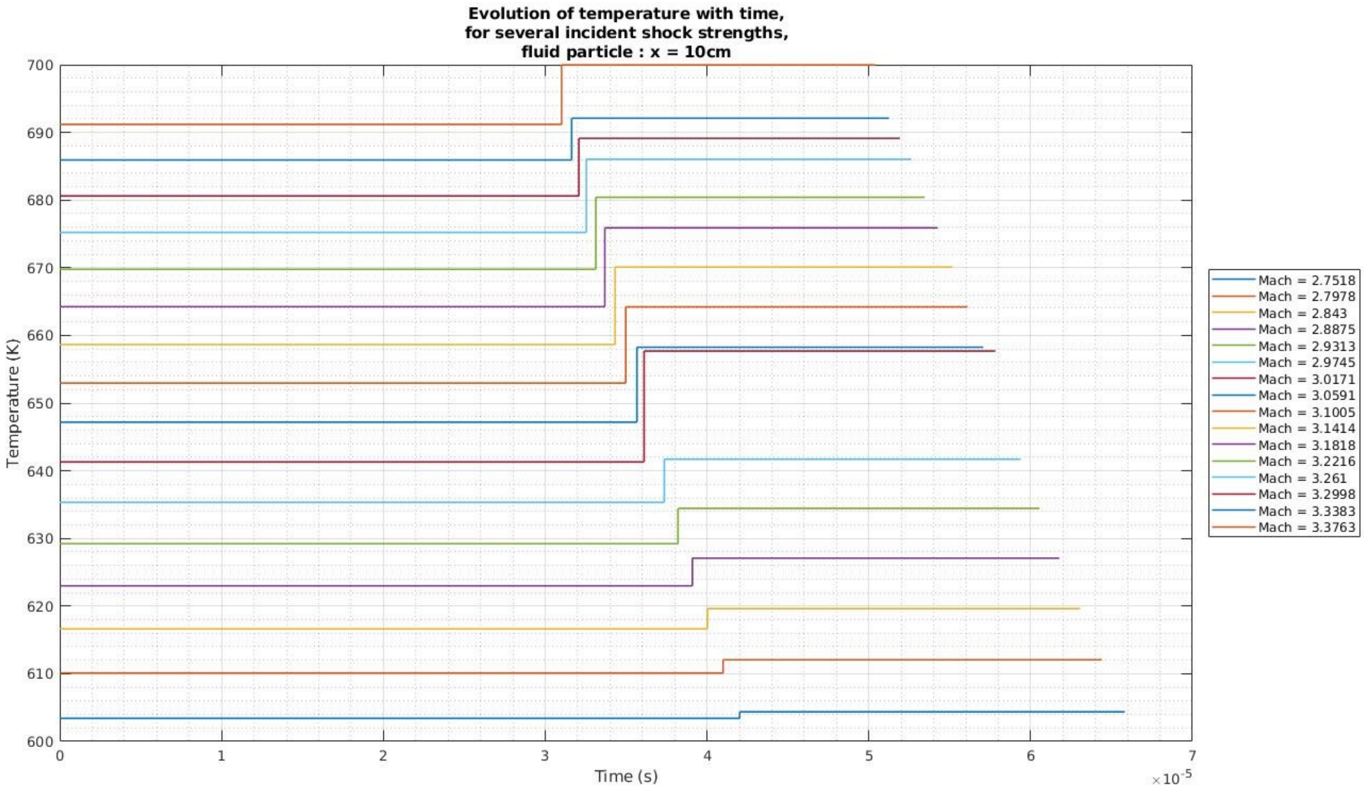
For a single particle, increasing M_{sh} leads to a rise in temperature and pressure : don't forget that $H_2 - O_2$ is a reactive phase. Is an ignition possible under certain conditions?

Main steps

- Calculate evolution of specific volume of different Lagrangian particles, for $\omega_i = 21.5°$, for different Mach numbers (see slide 4).
- Use of CHEMKIN II to calculate chemical reactions in the reactive phase
- Outputs of CHEMKIN II : evolution of pressure, temperature and ratios of chemical species
- Temperature jump in CHEMKIN II output = detonation

Results of the chemical calculus

Ignition doesn't occur for such low Mach numbers



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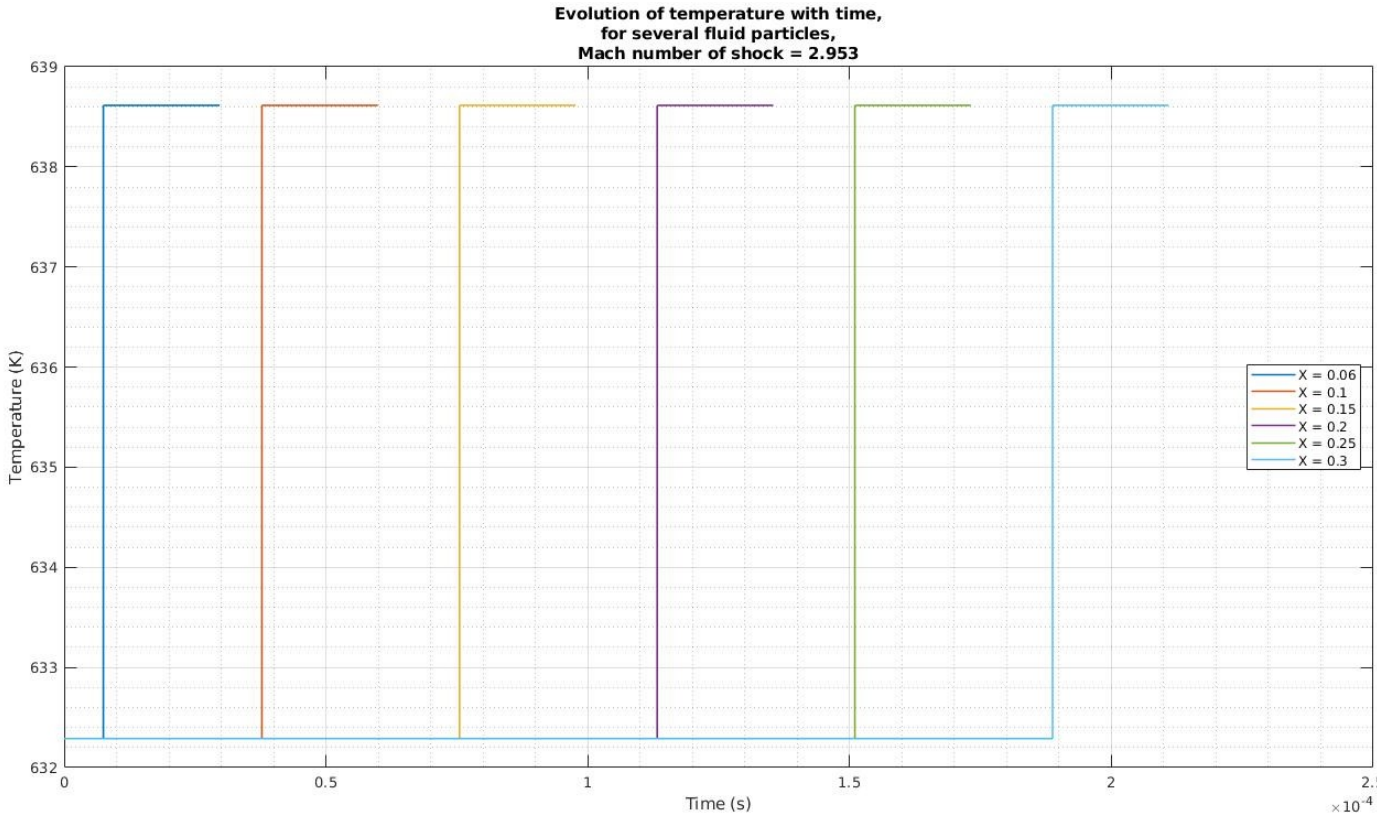

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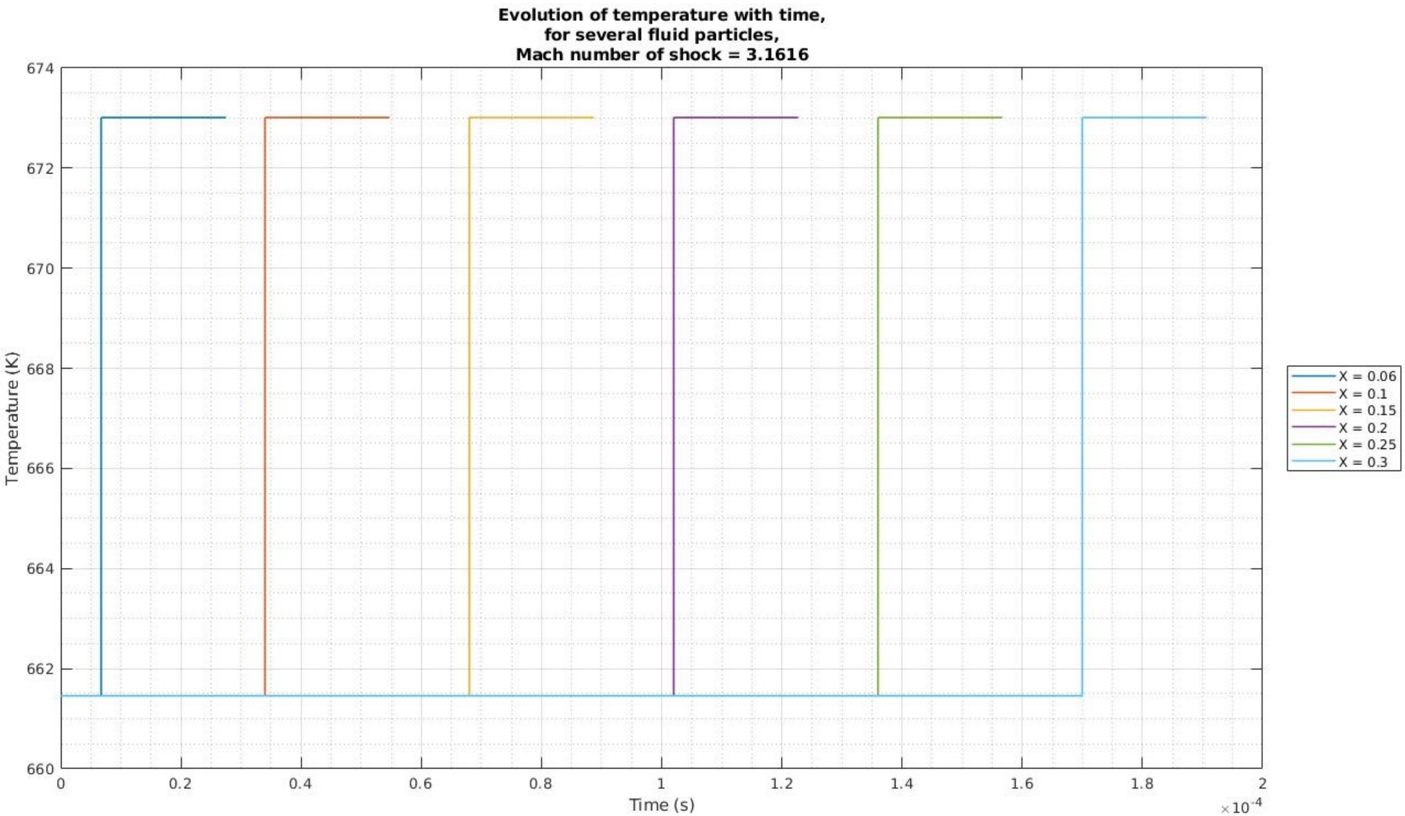

Results of the chemical calculus

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