Numerical and experimental investigation of the gas - powder flows created by diverse coaxial nozzles during LMD process

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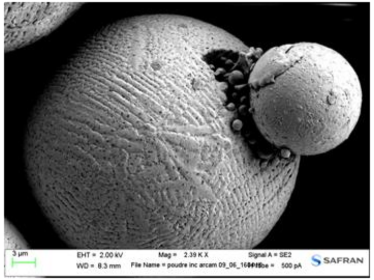
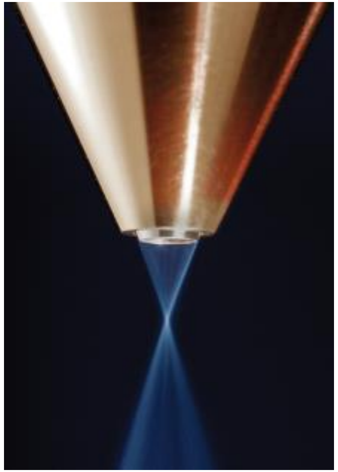
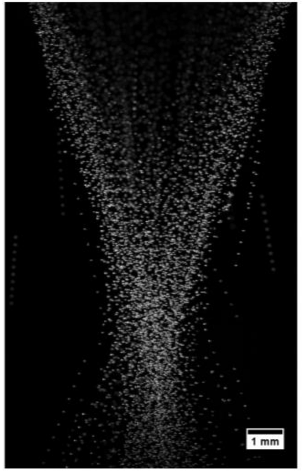
Outline of the presentation

- The manufacturing process
  - Definition, applications
  - Goals and means of the study
- First model : gas flow in inert atmosphere
  - Numerical modeling
  - Experimental study
- Second model : gas flow in air-based atmosphere
  - CFD module
  - TDS module
  - Particle tracing
- Conclusions



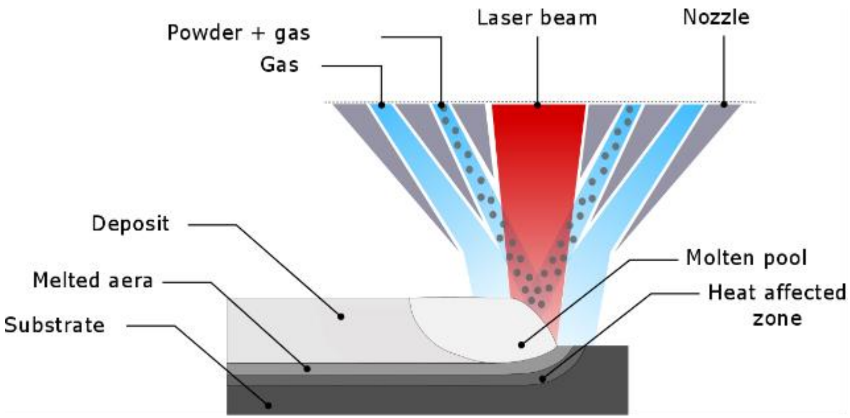




THE MANUFACTURING PROCESS

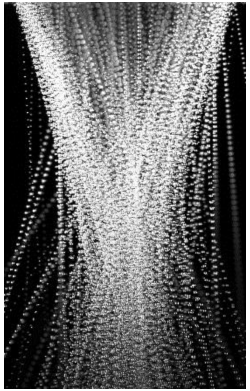
The manufacturing process

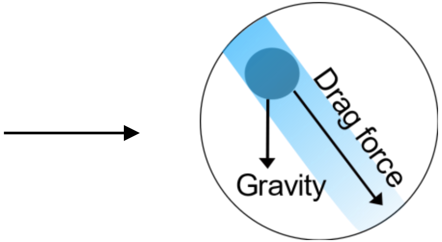
- Additive manufacturing process
  - Produce parts layer by layer
  - LMD : Laser Metal Deposition
- Complex deposit nozzle, multiple channels
  - Laser beam
  - Gas streams
  - Metallic powder jet
- Process application
  - Produce 3D new net shape components
  - Add of coating of functions
  - Repair technology



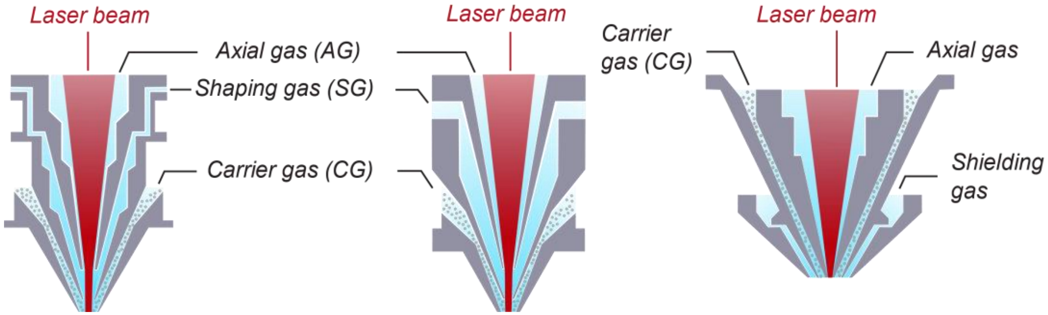
Goals and means

- Aim of the study :
  - Modeling of the powder supply
    - → *gas flow modeling*
    - → *powder jet behavior*





- Means of the study :
  - 3 diverse coaxial nozzles
    - *Design*
    - *Gas flow rate*
    - *Number of gas channels*
    - *Function of gas channels*



Nozzle A *Nozzle B* *Nozzle C*

FIRST MODEL

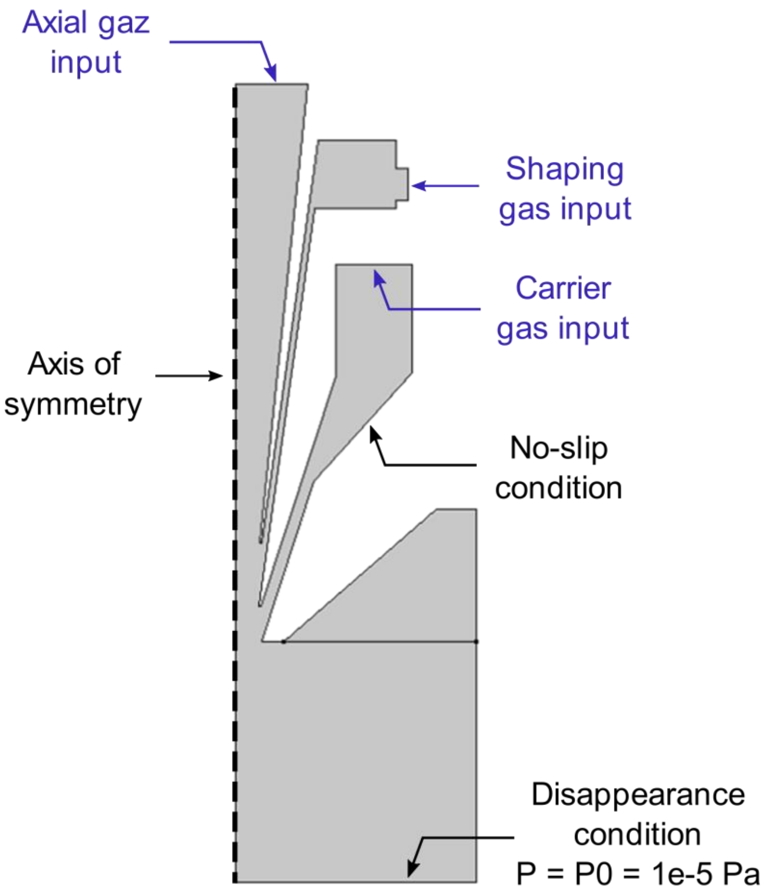
GAS FLOW IN INERT ATMOSPHERE

Gas flow in an inert atmosphere

- Geometrical modelling
  - 2D axisymmetric model
- Gas properties and assumptions
  - Flows and external area : argon properties
  - Incompressible (Ma < 0.3) Newtonian gas flow
  - High Reynolds number → Turbulent flow

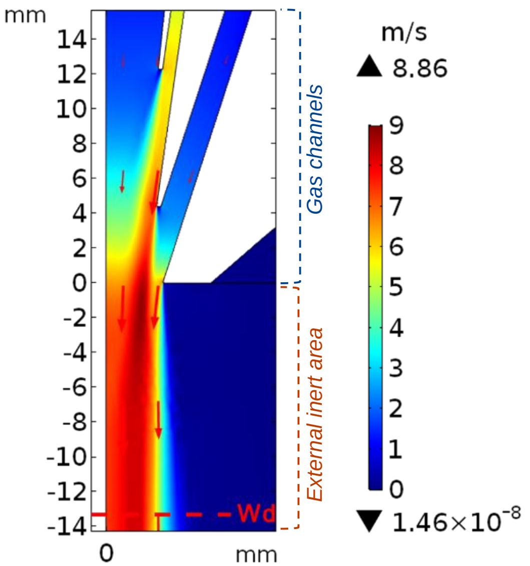
    → *RANS (Reynolds Average Navier-Stokes) models*

    → *K-ϵ turbulence model*



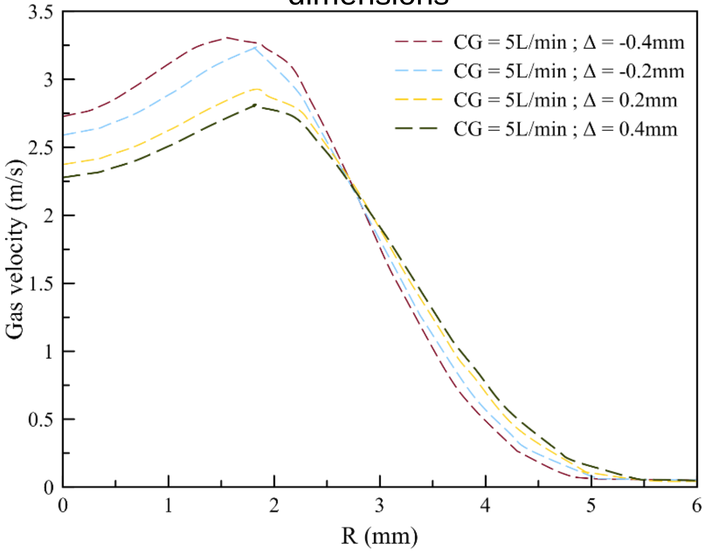
Turbulent gas flow in an inert atmosphere

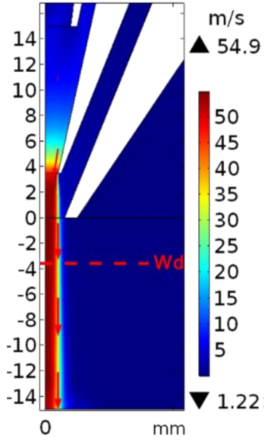
- Results and discussion



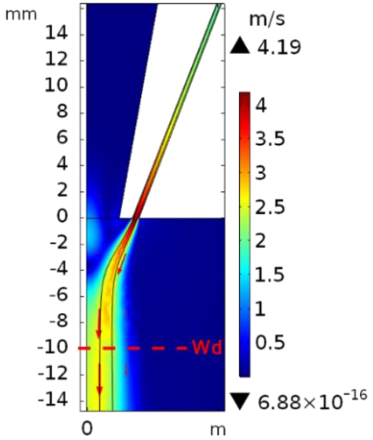
Gas behavior of nozzle B

Influence of gas flow rate and channels dimensions





Gas behavior of nozzle A

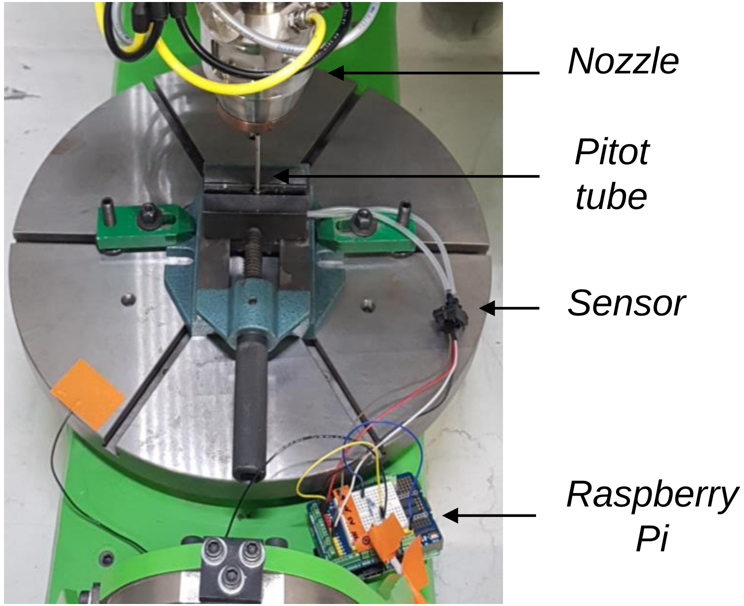


Gas behavior of nozzle C

Experimental setup

- Pitot tube :
  - Differential pressure anemometer
  - Localized fluid velocity measurement
  - Bernoulli's equation (for Re > 100) :

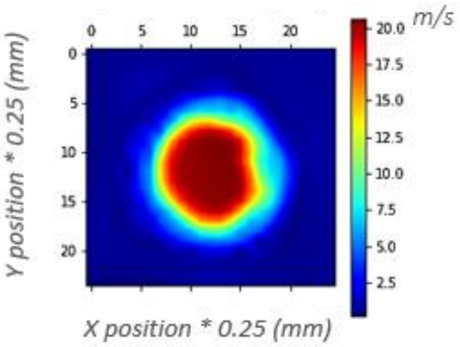
$$v = \sqrt{\frac{2\,\Delta P}{\rho}}$$



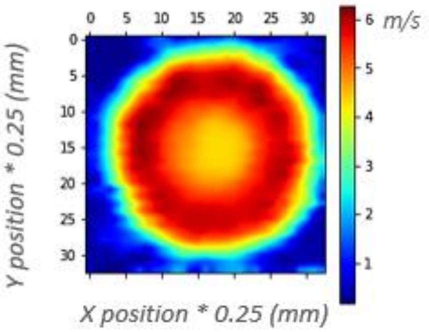
Experimental setup

- Results

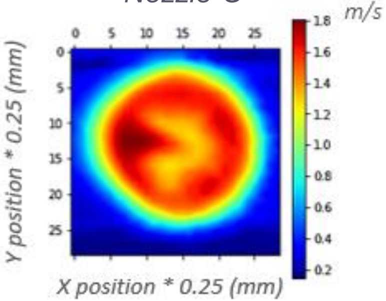
Nozzle A



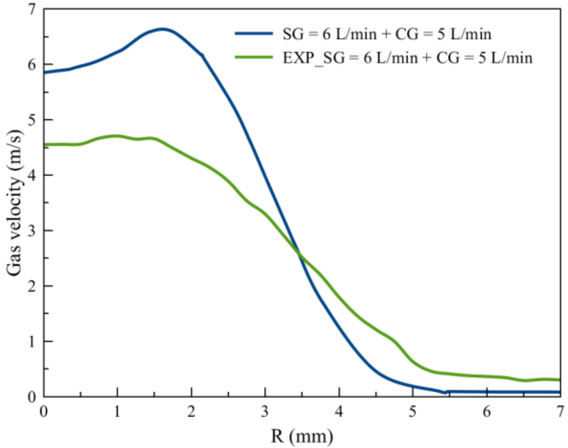
Nozzle B



Nozzle C



- Comparison



Nozzle design	A	B	C
Experiment (m/s)	20	5.5	1.5
COMSOL model (m/s)	55	8.5	2.5

SECOND MODEL

GAS FLOW IN AN AIR-BASED ATMOSPHERE

Laminar gas flow in an air-based atmosphere

- Multiple physics
  - Argon and air atmosphere interaction
  - Powder stream behavior

PHYSIC 1 **Laminar compressible flow (CFD)**

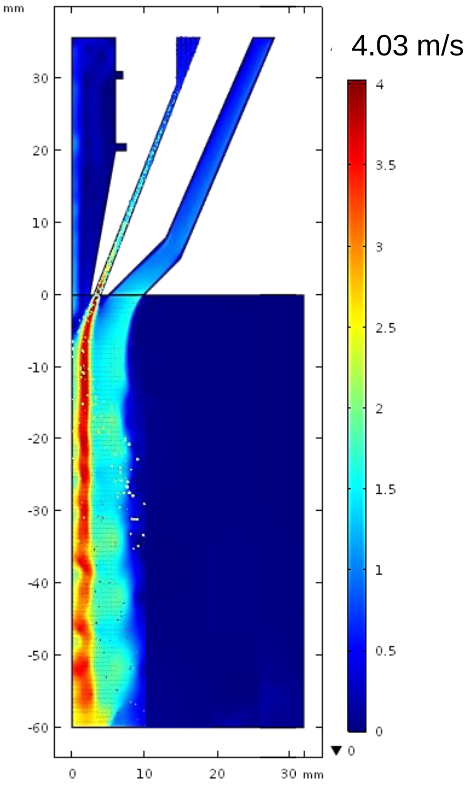
$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho u) = 0$$

$$\rho(u \cdot \nabla)u = \nabla \cdot \left[-pI + \mu\left(\nabla u + (\nabla u^T)\right) - \frac{2}{3}\mu \, (\nabla \cdot u)I\right]$$

with u : gas velocity, p : gas pressure, ρ : gas density and μ : gas dynamic viscosity

PHYSIC 2 **Convection and diffusion (TDS)**

PHYSIC 3 **Particle tracing**



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Laminar gas flow in an air-based atmosphere

- Multiple physics
  - Argon and air atmosphere interaction
  - Powder stream behavior

PHYSIC 1 **Laminar compressible flow (CFD)**

PHYSIC 2 **Convection and diffusion (TDS)**

$$\frac{\partial c}{\partial t} + \nabla \cdot (-D\nabla_c) + u \cdot \nabla c = R$$

$$N = -D\,\nabla c + u_c$$

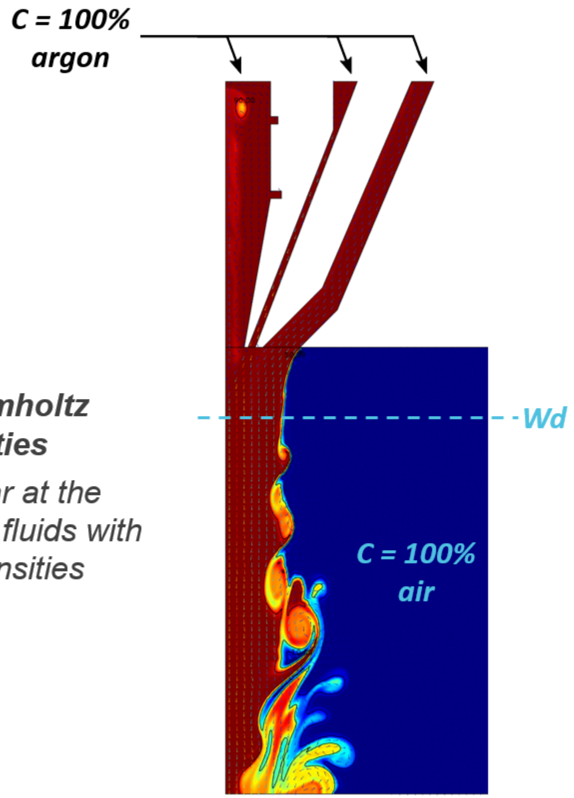
$$\rho_{mix} = c\,\rho_1 + (100 - c)\,\rho_2$$

with D the diffusion coefficient and c : the seek concentration of the gas flow

PHYSIC 3 **Particle tracing**

Kelvin-Helmholtz instabilities

velocity shear at the interface of two fluids with different densities



Laminar gas flow in an air-based atmosphere

- Multiple physics
  - Argon and air atmosphere interaction
  - Powder stream behavior

PHYSIC 1 **Laminar compressible flow (CFD)**

PHYSIC 2 **Convection and diffusion (TDS)**

One way coupling

PHYSIC 3 **Particle Tracing**

$$\frac{d(m_p v)}{dt} = F_t$$

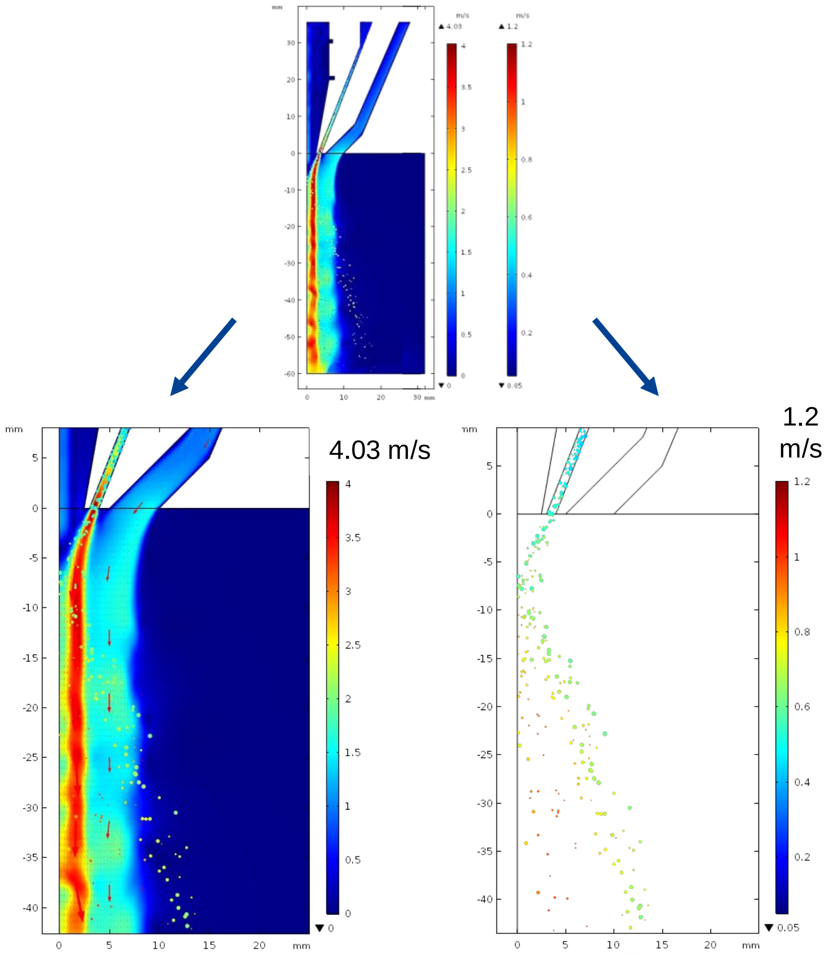
m_p *: particle mass,* v *: particle velocity*

Inputs :

- *IN718 properties, Dm = 4 g/min*
- *Realistic size distribution*

Assumptions :

- *Spherical particles, no collision between particles*



CONCLUSIONS

Conclusion

- **COMSOL Multiphysics software allowed the analysis of the powder delivery system of the LMD process**

- **CFD & Transport of Diluted Species modules**
  - Behavior of the gas flow
  - Partly confirmed with experimental study
  - Impact of the nozzle design, gas configurations and air-based external area

- **Particle tracing module**
  - Powder stream behavior
  - Particle size influence