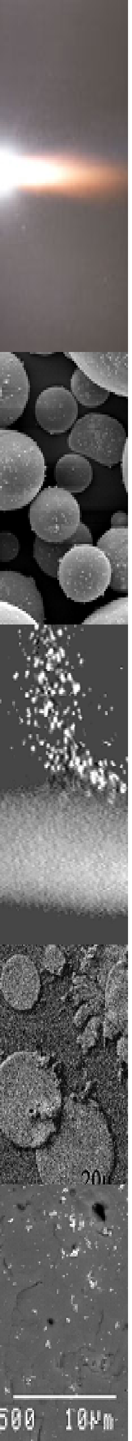

Club des Utilisateurs de *Code_Saturne*

26-27/11/2007

Droplet Breakup by a Plasma Jet

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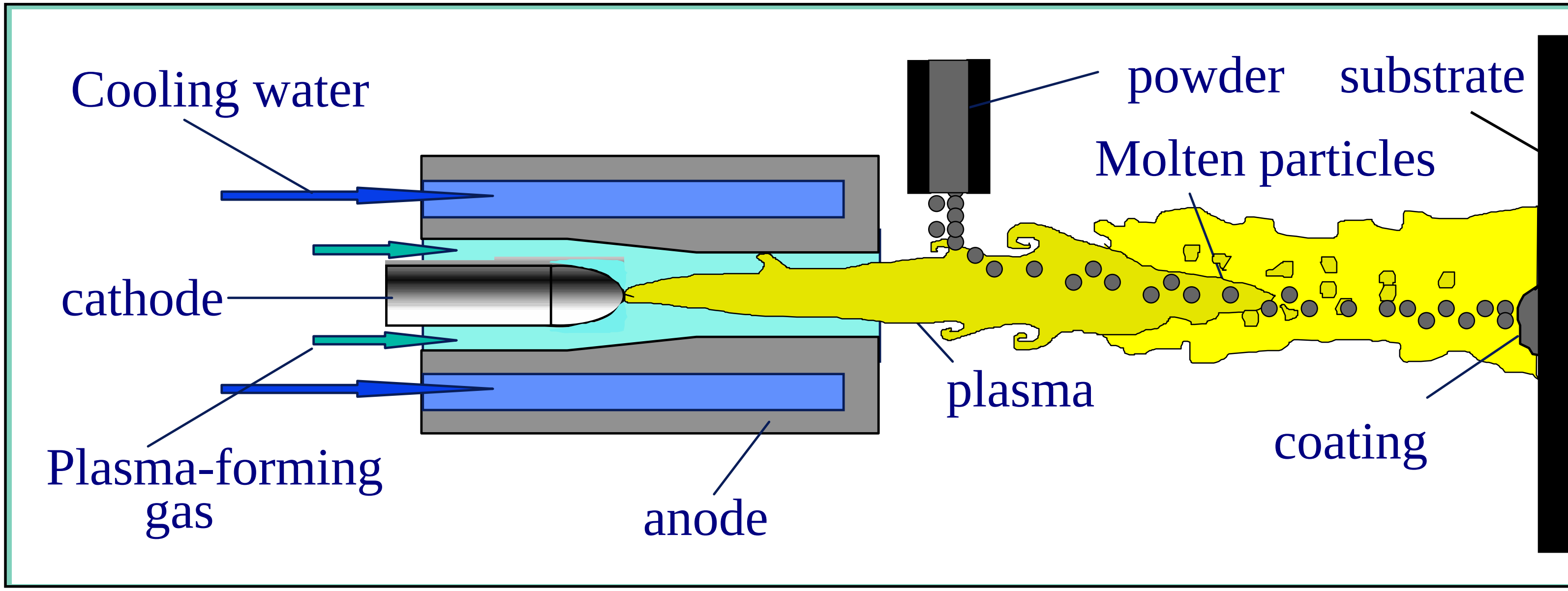
Conventional Powder Plasma Spraying



Plasma with high velocity (> 1 000 m.s-1) and high temperature (T > 10 000 K)

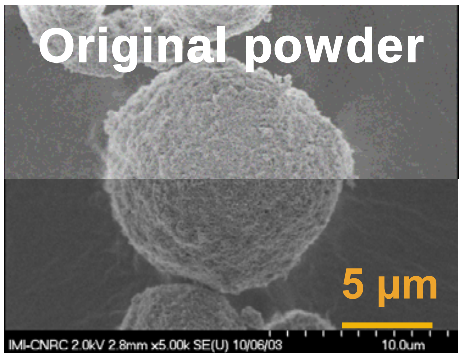
➡ Micro-structured coatings

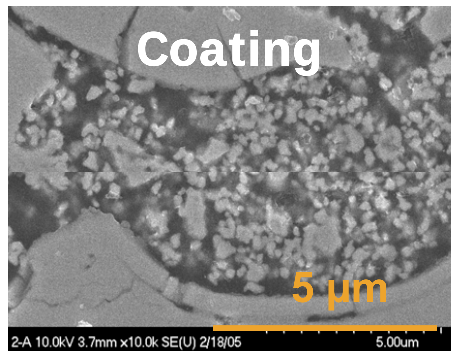
Nano-structured Coatings by Plasma Spraying

Better mechanical properties of nano-structured coatings

Solid feedstock : powders

Spraying of agglomerates of nano-size particles

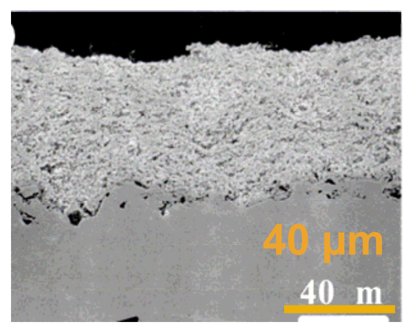




R. Lima, B. Marple
JTST, 16(1), 2007, pp 40-63

Liquid feedstock

Use of stable and homogeneous liquid feedstock with a low viscosity



M. Gell et al, SCT, 183, 2004, pp 51-61

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Liquid Precursor Plasma Spraying

Two main difficulties:

❶ **Injection and penetration** of the liquid into the plasma flow

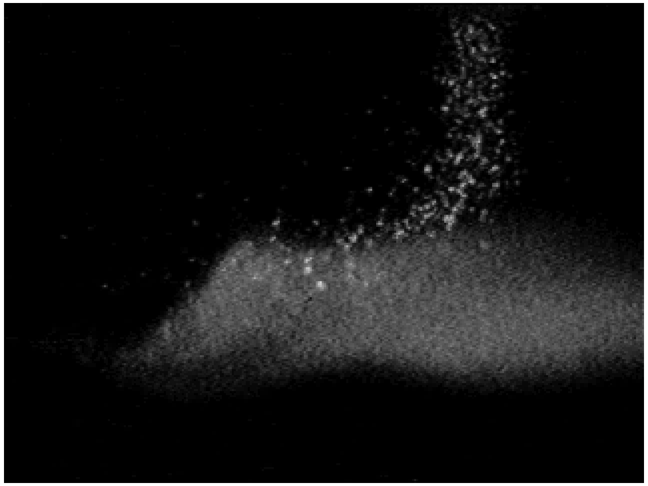
Penetration: $\rho_\ell v_\ell^2 \geq \rho\, v^2$

❷ **Heterogeneous behavior** of the droplets in the core and periphery of the plasma jet

Similar problems in conventional powder plasma spraying

But with liquid feedstock, they are aggravated because of:

- the low specific density of droplets
- the breakup process



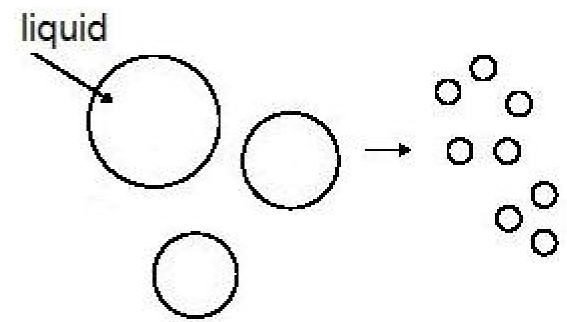
Injection of Mo particles in Ar-H_2 plasma jet

Droplet Breakup Processes under Plasma Conditions

- **Aerodynamic Breakup**

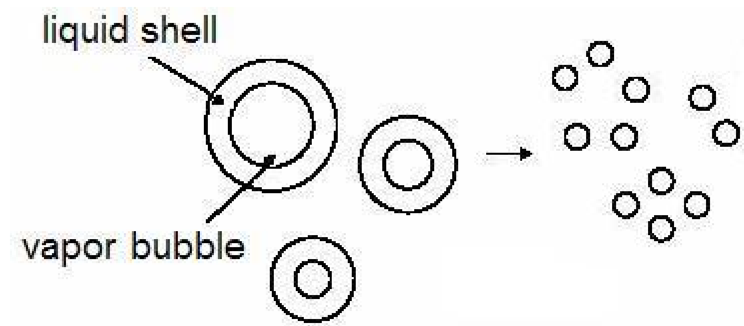
  Secondary breakup

  High relative velocity
  at the interface of two phases



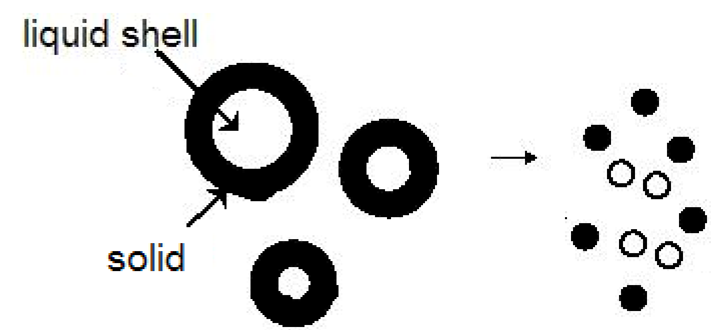
- **Thermal Breakup**

  Inner boiling of liquid



- **Liquid droplet: Sphere rupture**

  Formation of solid shells
  + pressurization of inner liquid



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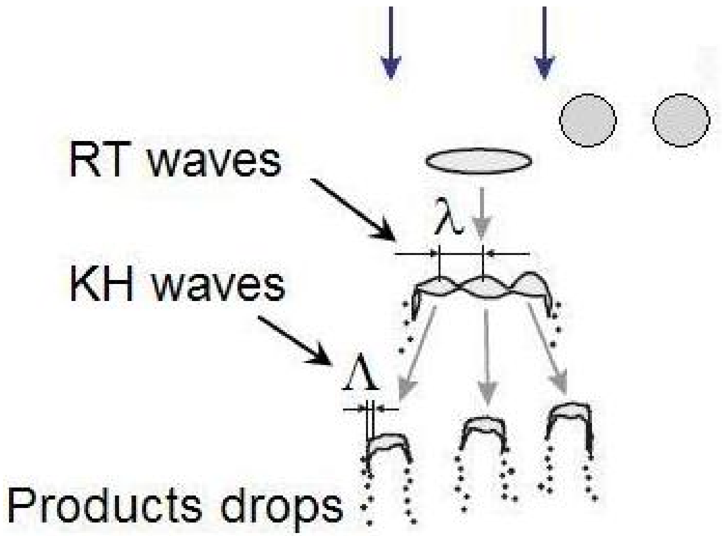
Aerodynamic Droplet Fragmentation

Secondary Atomization



Hwang & al., Atomisation & sprays, 6, 1996

Breakup results from:
- **Rayleigh-Taylor instabilities**: density difference
- **Kelvin-Helmholtz instabilities**: velocity difference

ρ_{plasma} (1000 K) ~ 0.4 kg.m^{-3} / ρ_{water} ~ 1000 kg.m^{-3}
v_{plasma} (1000 K) ~ 1000 m.s^{-1} / v_{water} ~ 30 m.s^{-1}

Weber dimensionless number

$$We = \frac{\rho \Delta U^2 d}{\sigma}$$

Fluid momentum flux

$$\frac{\text{fluid's inertia}}{\text{surface tension}}$$

ρ : fluid density
ΔU : velocity difference between plasma and droplet
d : droplet diameter
σ : surface tension

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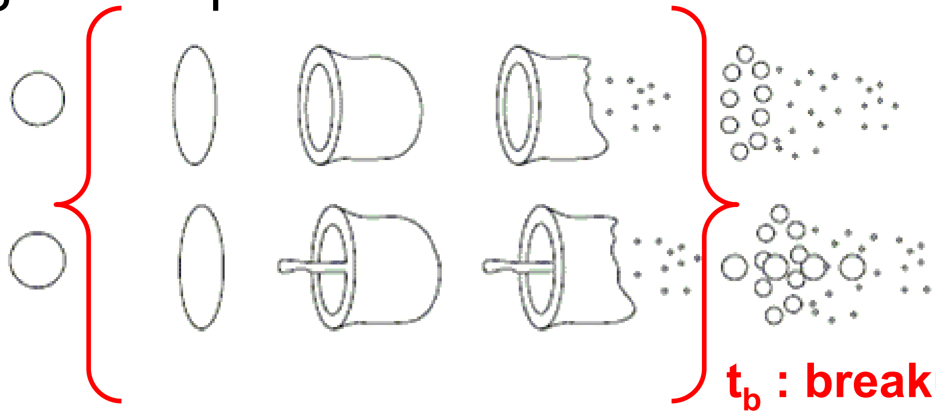
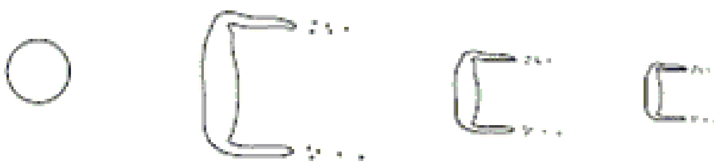
Aerodynamic Breakup Regimes

Bag breakup: We<100

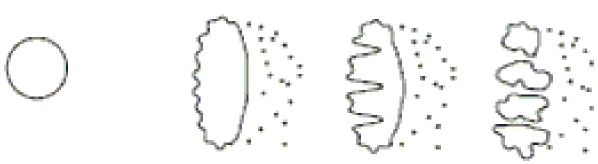


t_b : **breakup time**

Stripping (shear): 100≤We<350



Catastrophic (surface wave) breakup: We≥350



Models

TAB Model for low We
O'Rourke, 1987

ETAB Model
Tanner, 1998

Wave Model for We>100
Reitz, 1982

Pilch & Erdman, Int. Multiphase Flow., 13, 6, 1987

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ETAB Model

$$\frac{dn(t)}{dt} = 3K_{br}\,n(t) \Rightarrow n(t) = e^{3K_{br}t}$$

- We ≤ 160: $K_{br} = k_1\omega$
- We > 160: $K_{br} = k_2\omega\sqrt{We}$

$$\overline{m}(t) = m_0 / n(t)$$

r : droplet radius
n(t) : number of product droplets
m : droplet weight
K_{br} : proportionality constant
ω: instability growth rate
t : breakup time

	Experimental conditions used for validation of ETAB Model ***(Schneider, 1995)***	**Operating conditions for the injection of liquid in the plasma jet**
Liquid feedstock	**Fuel**	**Solution: Dissolved metal salt in water**
Injection	**$P_{injection}$ = 300 bars** $d_0 \sim d_{injector}$ = 150 µm **v_0 = 183 m.s^{-1}**	**$P_{injection}$ ~ 5 bars** $d_0 \sim d_{injector}$ = 300 µm **v_0 ~ 30 m.s^{-1}**
Atmosphere	N_2 P_{N2} = 15 bars **ρ_{N2} = 12.7 kg.m^{-3}**	Plasma gas T_{plasma} = 300 K – 10 000 K **ρ_{plasma} < 1 kg.m^{-3}**

Modeling the Turbulent Flow outside the Plasma Torch

Main assumptions

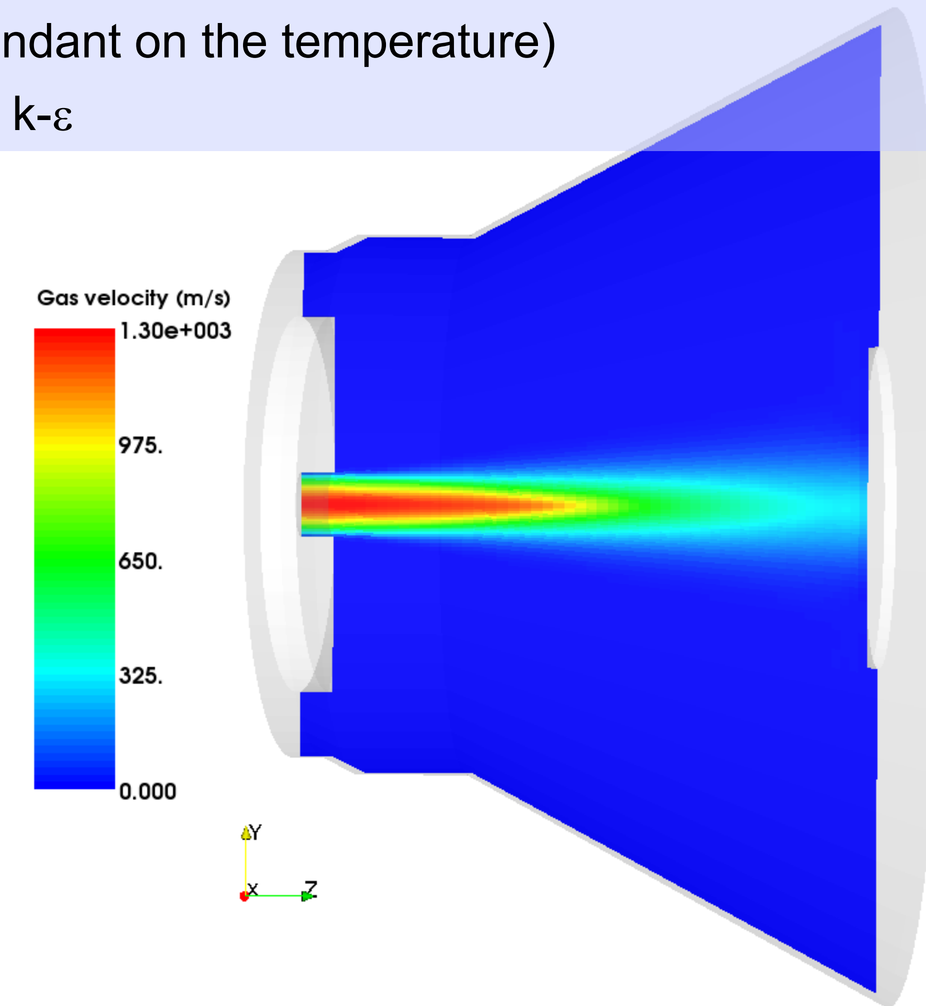
- 3-D geometry
- 2 gases : plasma (Ar-H_2) and ambient air (no demixion and chemical reactions)
- Mixing laws to calculate properties (dependant on the temperature)
- Turbulent flow outside the plasma torch : k-ε

Plasma torch operating conditions

- Torch nozzle diameter: 6mm

- Velocity profile
(vmax = 1300 m.s-1)

- Temperature profile
(Tmax = 13400 K)



Modeling the Liquid Penetration on the Plasma Jet

Main assumptions

- Spherical, punctual and pure liquid droplets (no interactions between droplets)
- Droplets (ϕ = 300 µm, v_0 = 30 m.s^{-1}) subjected to the fluid turbulent dispersion
- Phenomenon: aerodynamic breakup only (no thermal effects or evaporation)

ETAB Model Breakup

We ≥ 12: breakup possible ➔ calculation of breakup time t_b

$t_b \leq \Delta t$:

breakup during current time step

$$n(t) = e^{3K_{br}t}$$

Breakup delay = t_b

$t_b > \Delta t$:

droplet progress, t_b is calculated again (new_t_b)

new_t_b ≤ initial_t_b :

Breakup delay = new_t_b

new_t_b > initial_t_b :

Breakup delay = initial_t_b

Created droplets with new characteristics at the current time step: diameter, mass, velocity and trajectory

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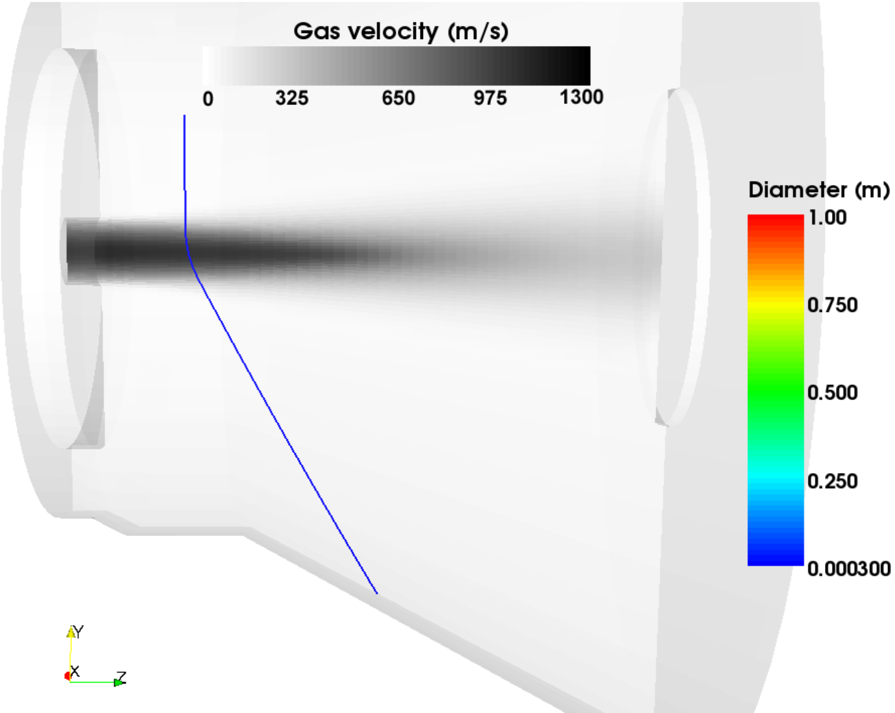
Comparison of the ETAB Model Result and Experimental Observation

Injection of a liquid 300 µm droplet in the plasma jet

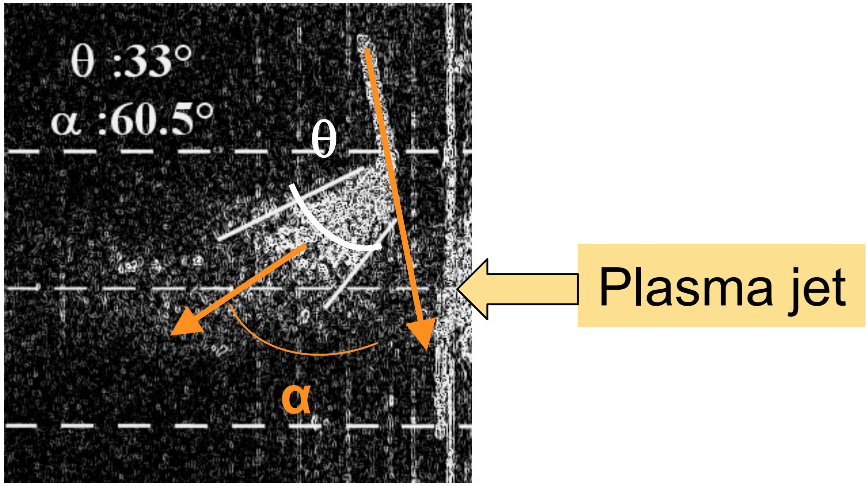
k1 ~ k2 = 1/4,5



Trajectory of a 300 µm droplet
no breakup

Injection of a liquid jet in the plasma jet

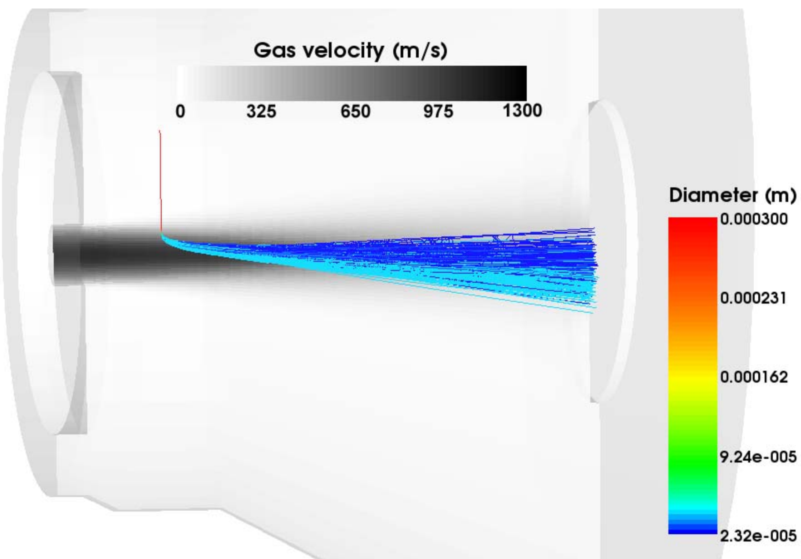
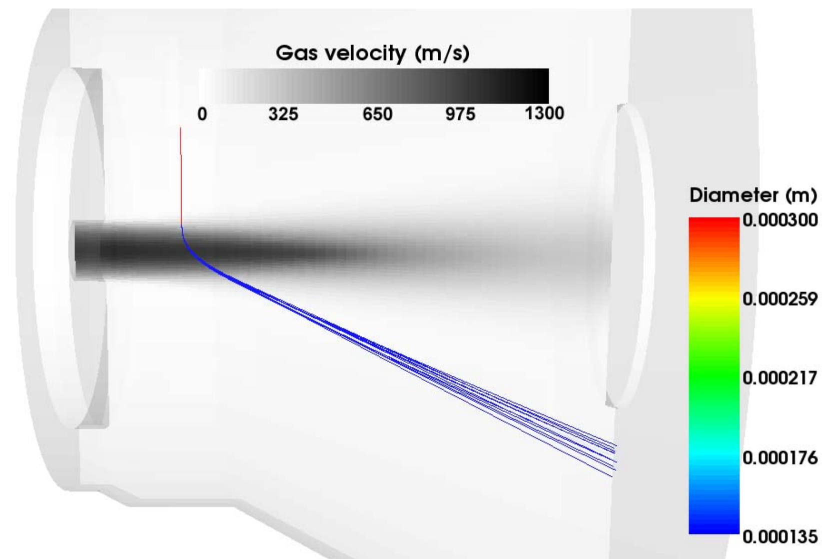
θ: dispersion angle of the liquid spray jet
α: deviation angle of the liquid spray jet



R. Etchart-Salas, V. Rat, J.F. Coudert, P. Fauchais
Université de Limoges, France ITSC 2007

Effect of the k1 Constant on a 300 µm Droplet Breakup

$$n(t) = e^{3K_{br}t}$$ with $K_{br} = k1\omega$ (We ≤ 160) and $t_b = 1/K_{br}$

<table>
<tr><th>k1 = 10</th><th>k1 = 100</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>197 breakup ➔ 980 droplets
t_b max = 7.6 10^{-6} s
We max = 26.9</td><td>1 breakup ➔ 11 droplets
t_b max = 7.6 10^{-7} s
We max = 51.8</td></tr>
</table>

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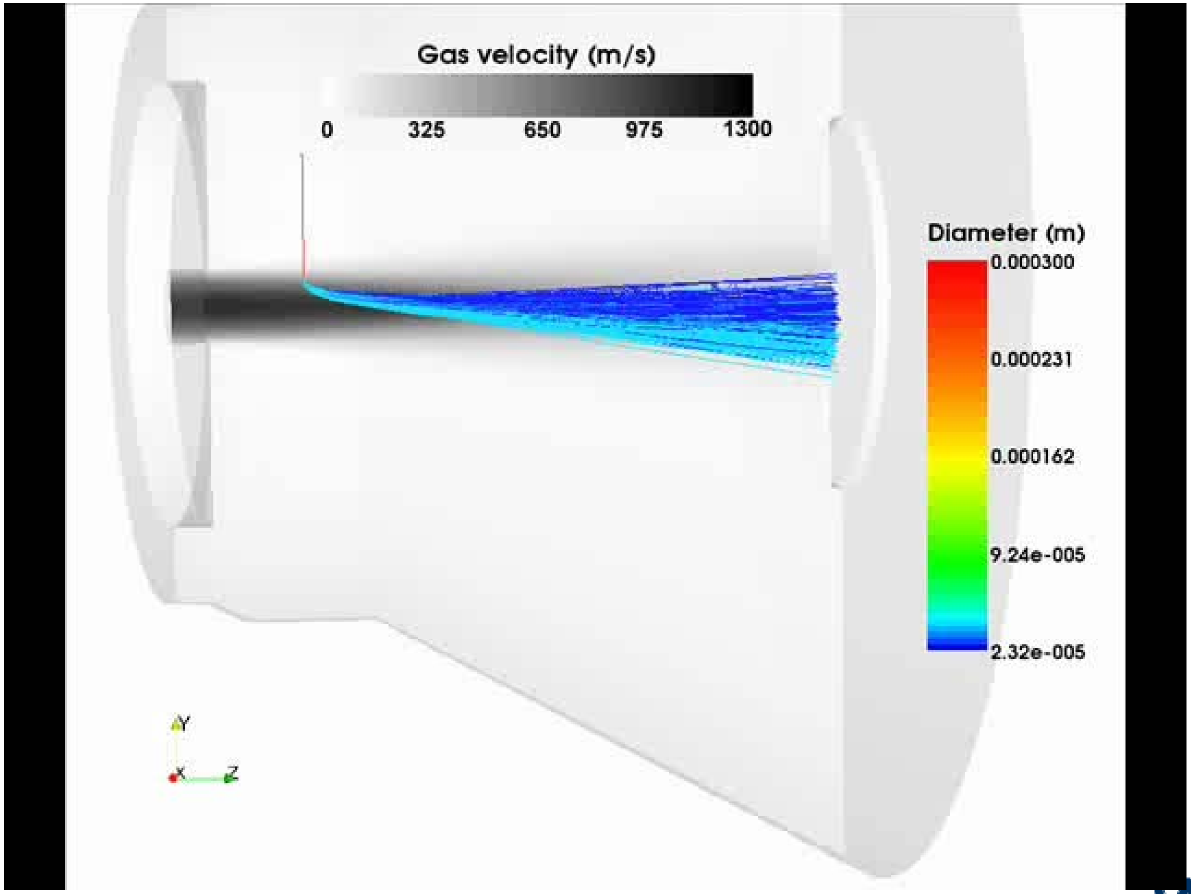
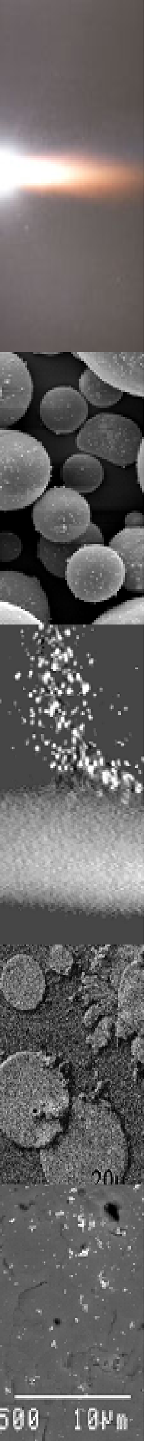
Droplets Trajectories

Visualization of 500 droplets maximum

- if number < 500: all droplets display
- if number > 500: maximum different droplets viewed

k1 = 10 ➔ 980 droplets





Conclusion

Implementation of ETAB model in *Code_Saturne*:

- Qualitative study of droplets breakup
- Influence of the k1 constant on the droplet breakup and trajectories of new droplets

- Statistic study
- Validation of the implementation of the ETAB model in *Code_Saturne* with simulation of Schneider experiment
- Work in progress to determine appropriated constants to plasma conditions

Thanks for your attention