Fast modelling of plasma jet and particle behaviours in spray conditions

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Abstract.

This paper presents a simplified code allowing to find in a few minutes the trends of the d.c. plasma spray process, at least for a single particles or a particles in flight. It is based on a parabolic 2D flow for the plasma jet and a 3D calculation for the heat and momentum transfer to particles. It neglects the carrier gas flow rate- plasma flow interaction but the obtained trends are in good agreement with those obtained with 3D sophisticated codes. However results depend strongly on the turbulence model, the plasma effect corrections chosen for the heat and momentum transfer. Thus, as with 3D codes, the model has to be backed by experiments. It can be used to train operators and let them “see” almost immediately the effects of the different macroscopic spray parameters. The code and the plasma properties used can be freely downloaded.

Key words: plasma spraying, fast modelling, particle behaviour

1 Introduction

Numerous numerical modelling for the direct current (d.c) plasma jets used for spraying have been published since the eighties (see for example [1]). However it is only very recently that the complexity of the modelling has been taken into account with 3-dimension (3D) transient models accounting for the arc root fluctuation at the anode [2,3]. These fluctuations [4], when using plasma forming gases containing diatomic gases such as H₂ or N₂ can induce, with the restrike mode, transient voltage V(t) fluctuations of ±25% at frequencies in 5000 Hz range, resulting for current I source in power fluctuating of ±25%. Thus the corresponding plasma jets are fluctuating in length and position. A recent calculation [2], assuming a uniform power generation in a given volume V inside the anode (V(t)*I/V) as well as experiments show that the plasma temperature
and velocity fluctuate accordingly.

It is thus quite understandable that most flow models are based on the stationary behaviour of plasma jets with velocity and temperature distributions matching with the plasma gas mass flow rate and enthalpy [5, 7]. However the calculation results are strongly linked to the choice of inlet profiles, grid and turbulence model [2, 3].

As soon as particles are injected, as in the plasma spray process, the problem becomes more complex. Even the calculation of the trajectory, velocity and temperature of a single particle injected with a given injection velocity vector is not straightforward. This is due to the specific effects of the plasma [9-13]:

- temperature gradient in the boundary layer surrounding the particle,
- non continuum effect,
- thermal buffer constituted by the vapour resulting from the particle evaporation and travelling with it because of the low Reynolds number of the latter,
- the radiation emitted by the particle and principally by the metal vapour when evaporation occurs,
- the heat conduction within the particle,
- the turbulent dispersion of small particles.

However in the process numerous particles are simultaneously injected (for example about $10^8 \, s^{-1}$ for alumina particles $20\mu m$ in diameter, with a flow rate of $3 \, kg/h$). Thus the three following problems have to be accounted for [13,14-21]:

- The dispersion of the particles at the injector exit particle size and injection velocity vector distribution the latter being due to their collisions between themselves and the injector wall [14].
- The perturbation of the plasma flow by the powder carrier gas. As emphasized by different authors [18, 8, 6, 2, 19 and 20] it plays a major role due to the interaction of the plasma flow with the cold gas which has a high momentum (the injector internal diameter being below $2 \, mm$) and the level of turbulence generated.
- The effects of the plasma jet fluctuations on the particle temperature, velocity and trajectory distributions [18, 21].

Even when neglecting the effects of the plasma jet fluctuations and using stationary models the
particle treatment should be 3D [6, 19, 20 and 22].
For example in the recent work of Remesh et al. [22], the influence of the carrier gas flow rate
was studied versus the spray conditions and results confirmed by measurements. However, if the
general trends given by such models are good, many parameters have to be adjusted to get a good
agreement with experiments such as:

- the inlet temperature and velocity radial profiles for the plasma flow
- the turbulence model (of course with a low Reynolds to account for the laminar
  plasma core),
- the specific effects of the plasma on particles,
- the stochastic approach of the distribution of particle
- the perturbation of the plasma jet by the cold carrier gas…

One of the main drawbacks of these sophisticated codes is the computing time which is not
compatible with industrial needs. That is why there is a boom for simplified models able to give
quickly (in a few seconds) at least good trends. This is the goal of this paper where the most time
consuming part of the model i.e. the flow modelling has been simplified while the particle
injection was kept 3D. It of course, means that the influence of the cold carrier gas on the plasma
jet is neglected.

In the paper are presented successively:

- The fast software Jets&Poudres [23] built on the GENeral MIXing (Genmix)
  computer code improved by using thermodynamic and transport properties closely
  related to the local temperature and composition of the plasma. These properties are
  obtained from T&TWinner database [24]. This way heat and momentum transfers to
  single particles are calculated and stochastic distributions are imposed to particles at
  the injector exit.
- The results obtained for a conventional Ar-H\textsubscript{2} d.c. plasma jet where zirconia particle
  are injected and the discussion of the results according to the effect of different
  parameters.

2 Description of the model Jets&Poudres

Various clever numerical methods were developed in the past to simulate 2-D parabolic gas flows
for laminar boundary layers or jets. For example, the Genmix algorithm developed by Spalding and Patankar [25]. It is known as the Bikini method because it requires a very low-cost memory and computing time.

2.1 Flow simulation

The model Jets&Poudres, forecasts the dynamic of a single or multi particles fed in a plasma jet (see fig.1). This model, built in Visual Basic, allows a convivial exchange. Its aim is not to forecast a result very close to experiment but to:

1. compute rapidly the parameters of the plasma spray;
2. present synthetic and explicit results;
3. give the tendencies and phenomena orders of magnitude.

Genmix handles the two-dimensional, parabolic flows, i.e., those of high Reynolds and Peclet numbers based on the cross stream dimension, with no recirculation. "parabolic" flows are:

- steady,
- predominantly in one direction, defined as that in which the velocity vector has nowhere a negative component;
- without recirculation or diffusion effects in that direction.
- besides the conditions, the flow is assumed to be in Local Thermodynamic Equilibrium (LTE), the carrier gas flow perturbation being neglected and the flow...
assumed to be with no swirl.

These conditions have been used as a first approximation of plasma jets. Genmix embodies a self-adaptive computational grid, which enlarges or contracts to cover only the regions of interest (hence it explains the relatively small demand on computing power and its nickname, i.e., the Bikini method). The turbulence can be simulated by different models, but in the case of a plasma jet it is the classical mixing length which appears to be the simplest and fastest.

In Jets&Poudres the input data are:

- the mixing length value
- the mass flow rate \( m_g^0 \) and the composition of the plasma forming gas,
- the composition of the gas atmosphere far away from the jet,
- the electric current intensity \( I \),
- the electric power \( P \) with such previous conditions (obtained from experiments),
- the efficiency of the energy transferred to the gas \( \rho^{th} \)

The temperature evolution of plasma properties are deduced from those of pure gases by using mixing rules and the code T&TWinner [24].

Then the specific enthalpy \( h = \rho_{th} P / m_g^0 \) is calculated from the ratio of effective power \( \rho_{th} P \) to the mass flow rate and the enthalpy temperature is obtained from the equilibrium properties at atmospheric pressure. From this temperature the specific volume of the gas is calculated and thus its mean velocity. Uniform radial profiles of temperature and velocity are assumed such as the gas enthalpy and mass flow rate at the nozzle exit are conserved. It is worth to underline that, whatever may be the profiles at the nozzle exit within a few tenth of mm the code creates its own profile independently of the starting ones.

### 2.2 Particle simulation

#### 2.2.1 Behaviour of a single particle in the plasma jet

For the particles sprayed by a plasma jet two types of phenomena are of interest. One is the dynamic of the movement of particles with their trajectories, velocities and accelerations. The second is their thermal history, i.e., their temperature, melting or freezing, as well as the heat flux
a/ Momentum exchange between a single particle and the plasma jet.

Under the assumption that the Stoke’s drag is the dominant force [10, 14] in the dynamic of the particle injected in the plasma jet, the movement equation can be written as:

\[
m_p \frac{dv}{dt} = -\frac{1}{2} C_D \cdot \pi \cdot \frac{d_p^2}{4} \cdot \rho_\infty \cdot |U - v| \cdot (U - v) + F_x \]

(1)

where: \(C_D\) is the drag coefficient depending of the morphology of the particle and the Reynolds number; \(d_p\) is the initial diameter of the particle (m); \(v\) is the particle velocity (m.s\(^{-1}\)); \(U\) is the plasma velocity (m.s\(^{-1}\)); \(\rho_\infty\) is the plasma specific mass (kg.m\(^{-3}\)) and \(\mu_\infty\) the plasma viscosity (kg/m.s), both outside the dynamic boundary layer surrounding the particle. \(C_D\) is an empirical function of the Reynolds’ number

\[
Re = \frac{2\rho_\infty |U - v|}{\mu_\infty} \]

(2)

In this paper, according to the literature, it has been chosen [13]

\[
C_d = \left( \frac{24}{Re} \right) \left[ 1 + 0.11 \cdot Re^{0.81} \right] f_0 \]

(3)

\(f_0\) is a correction factor to take into account property gradients in the boundary layer around the particle. In this paper it has been chosen

\[
f_0 = \left( \frac{\rho_\infty \mu_\infty}{\rho_p \mu_p} \right)^{0.45} \]

(4)

as proposed by Lee et al. [26], where subscribes \(\infty\) and \(p\) respectively indicate plasma and particle specific mass and viscosity.

The external forces \(F_x\) are rather well represented by the thermophoresis force resulting from the very high thermal gradient in the fluid and the gravity force which have been neglected here, both being low compared to the drag force.

b/ Heat exchange between a single particle and the plasma jet

The heat transfer mechanisms to the particle in the plasma jet can be expressed by four successive steps [15]: the heating of the solid particle, its melting, the heating of the molten
particle and its vaporization. The governing differential equations for the temperature time evolution of a spherical particle are the following:

- **Solid particle heating**

The particle temperature \( T_P \), neglecting the heat propagation is calculated through the total heat energy in a film at the particle surface. Its expression is:

\[
\frac{dT_P}{dt} = \frac{6 \cdot Q_n}{\pi \cdot d_p^3 \cdot c_p \cdot \rho_p}
\]

where: \( Q_n \) is the energy required for heating up the particle, it is a conduction-convection heat energy (W); \( c_p \) is the specific heat at constant pressure of the particle depending of the material (J/kg.K).

In this paper, to take into account the steep temperature gradients within the thermal boundary layer around the particle, the integrated thermal conductivity

\[
\bar{\mathbf{K}}(T) = \frac{1}{T_{\infty} - 300} \mathbf{\int_{300}^{T} K(\theta) d\theta}
\]

is used instead of the thermal conductivity \( K(T) \). Then with the radiative cooling it comes:

\[
Q_n = \pi d_p^2 \left\{ (T_\infty - 300) \bar{\mathbf{K}}(T_\infty) - (T_p - 300) \bar{\mathbf{K}}(T_p) - \varepsilon \sigma S (T_p^4 - T_{\infty}^4) \right\}
\]

where \( T_\infty \) is the temperature outside the boundary layer, \( T_a \) is the surrounding temperature, \( \varepsilon \) is the particle emissivity (taken as 0.8) and \( \sigma S \) the Stephan-Boltzmann constant (\( \sigma S = 10^{-9} \text{ W K}^{-4} \text{ m}^{-2} \)).

- **Melting of the particle at constant temperature \( T = T_F \)**

When \( T_P = T_F \) (melting temperature), it is assumed that the total energy from the plasma to the particle is converted into the latent heat of fusion \( \Delta H_F \). The melting mass fraction \( X_P \) is governed by

\[
\frac{dX_P}{dt} = \frac{6 \cdot Q_n}{\pi \cdot d_p^3 \cdot \Delta H_F \cdot \rho_p}
\]

where: \( \Delta H_F \) is the latent heat of fusion (J/kg). \( X_P \) is in the range 0 to 1. If \( X_P = 0 \), the particle is solid and if \( X_P = 1 \), it is fully melted.
- **Heating of the liquid particle**

Two assumptions are possible in this step: the liquid phase of the particle vaporizes or not. If the liquid phase of the particle is not vaporizing, the heating of the liquid is similar to that of the solid particle (eq. 4) with the specific heat at constant pressure of the liquid. If the liquid particle vaporizes its diameter decreases according to the following equation:

\[
\frac{d(d_p)}{dt} = \frac{6 \cdot Q_n'}{\pi \cdot d_p^3 \cdot \Delta H_{\text{vap}} \cdot \rho_p}
\]

where: \(\Delta H_{\text{vap}}\) is the specific latent heat of particle vaporization (J.kg\(^{-1}\)); \(Q'_n\) is the thermal energy lost when vaporizing the particle (W). When \(T_p = T_b\) (boiling temperature), the total energy from the plasma to the particle is converted in latent heat of vaporization. The diameter evolution of the particle is given by an equation similar the last one (eq. 8).

### 2.2.2 Behavior of a powder

To simulate the formation of a deposit, a large quantity of particles \((10^8-10^{10}/s)\) has to be inject within the plasma jet. Unfortunately the particles in a powder have different diameters. The particle size analysis of a commercial powder shows that they have roughly a Gaussian distribution in diameter. Thus, two cases are studied to simulate a powder, either that with the distribution given by the experimental particle size analysis or that with a Gaussian distribution according to the limit central theorem with twelve shots randomly numbered.

The powder is injected by a carrier gas in the plasma jet. This phenomenon could be rapidly complex, so to simplify the model the assumptions are the following: the particles have a velocity derived from that of the carrier gas, they are not interacting between themselves, the carrier gas flow rate does not vary with time, the injector walls are smooth and straight, and the velocity of the carrier gas is not time dependent and constant.

The mean injection velocity is adjusted to the mean size of the particles in such a way their trajectory makes an angle of 3.5° with the plasma jet axis.

The particle collisions between themselves and with the injector wall induce a dispersion of the particle jet at the injector exit. To integrate this phenomenon, which has been measured [14] for -45\(\mu\)m alumina particles as a cone with an angle of 20°, the model attributes to each particle an inclined angle of the exit injector velocity between 0 and 20°by firing at random a number. In order to rapidly obtain results only 32 000 particles are generated to build a sample of powder.
which allows the computation of the deposit height distribution.

### 2.3 Coating formation

The coating is constructed by taking into account only particles over their melting temperature, those below rebounding.

The particle flattening has been assumed to follow the Madjeski’s formula with disk shaped splats:

\[
\frac{D}{d} = 1.29 \frac{\rho_d}{\rho_p} Re_{\rho}^{0.2}
\]

(10)

If the impacting particles covers more than 50% of an already deposited splat it is disposed over it, part of the new splat creating a void, while if it is covers less than 50% it is disposed aside the previously deposited splat.

### 3 Results and discussion

#### 3.1 Spray conditions

The spray condition are summarized in fig 1 where the torch thermal efficiency is \(\rho_{th} = 55\%\) for a d.c. plasma torch PTF4 type with an anode nozzle 7mm in i.d.

The powder properties (specific heat at constant pressure, specific mass, thermal conductivity, latent heat of melting and vaporization are assumed to be constant what ever may be the temperature in the solid or liquid states.

#### 3.2 Comparison of Jets&Poudres and 3D model Estet3.4.

The plasma jet and its plume have been computed using the sophisticated code Estet3.4 [8,14] for a flow rate of 45/15 slm Ar-H2, a nozzle internal diameter of \(\phi = 7\) mm, an effective power of 21.5 kW (65 V, 600 A, \(\rho_{th} = 55\%\)). The turbulence model of Estet was k-ε RNG and the 3D grid was 71, 88 and 71 according to the x, y, z directions. Figures 2a, 2b, 2c compare the radial profiles of velocity, temperature and surrounding atmosphere concentration at 0.0004 m, 0.0222 m, 0.0314 m, 0.0594m (thin lines) calculated both with Estet and Jets&Poudres (thick lines). It can be seen that for temperatures and velocities near the nozzle exit and far away from it profiles are very close but at the intermediate axial distance (0.0314 m) the profiles are somewhat different. In fig. 2c it can be seen that the dilution of the plume by the surrounding atmosphere is more important in the forecast from Jets&Poudres.

However it should be noted that Estet underestimates the experimental results obtained with an enthalpy
probe at that distance.

Fig. 2d presents the comparison of the axial profiles for temperature and it can be seen that Estet code (Estet) forecasts a smoother evolution of temperature than Jets&poudres with standard mixing length $l_0$ (Jgenuine) in the intermediate axial distance from the nozzle exit. However with the modified mixing length

$$l_m = l_0 \left( \frac{T(r)}{300} \right)^{\frac{1}{9}}$$

the trend of Jets&Poudres is the same as that given by Estet. The modified mixing length is determined as that it is not change for room temperature and a laminar behaviour at high temperature in the plasma jet core. The power coefficient is adjusted in better agreement with experimental measurements.

### 3.3 Treatment of a single particle

In the section will be studied the influence, on the treatment of a single particle, of the following parameters: on the one hand mixing length and temperature gradients in the particle boundary layer for a given particle diameter and injection velocity and on the other hand the influence of the injection velocity on the particle trajectories, temperatures and velocities.

#### 3.3.1 Mixing length

For the comparison of the flow results obtained with the Genmix and Estet3.4 code, it has already been shown in section 3.2 that to achieve a good agreement between both models along the jet axis, the Genmix mixing length $l_m$ has to be modified.
Figure 2. Radial distributions of velocity (a), temperature (b) and percentage of surrounding atmosphere (c) calculated with Jets&Poudres (J curves) and Estet3.4 computer code (E curves) at different distances from the nozzles exit: E0022, J0022 at 0.0022 m, E0031, J0031 at 0.0031 m, E0060, J0060 at 0.0060 m, for an Ar-H2 (45-15 slm, d.c. plasma jet, P= 36300 kW, $\rho_{\text{th}} = 0.50$, anode nozzle i.d. = 0.0007 m. (d) Comparison of the axial profile for temperature forecast by Estet code (Estet), Jets&Poudres (J) and Jets&Poudres with standard $l_m$ (Jgenuine) and Jets&Poudres with modified length (J&p)
In Fig. 3 are represented the mixing length effect on the flow expansion and trajectory of a zirconia particle (d=30µm, injected in all cases with the same injection velocity adapted to achieve a trajectory making an angle of 4° with the jet axis for \( l_m = l_0 \)).

\( l_m \) has been taken as \( l_m = l_0 \) Genmix case reference, \( l_m \) from equation (10) to a slightly under-expanded jet, \( l_m = 0.5*l_0 \) corresponding to an under-expanded jet and \( l_m = 1.5*l_0 \) corresponding to an over-expanded jet. The consequences on the particle velocities are presented in Fig. 4. As it could be expected the lowest velocity is obtained when the over expanded jet and in it increases drastically when the jet cone angle diminishes with the mixing length decreases.
Of course the same trend is obtained with the particle surface temperature. Such results emphasize the drastic influence of the chosen turbulence model. The same variations were obtained with the 3D Estet code [2, 8].

3.3.2 Corrections to the drag coefficient
These corrections as well as those to the heat transfer coefficient are very important. They are illustrated in Fig 5 for the drag coefficient calculated without correction (see eqn. (3)) and with the Lee-Pfender correction for temperature gradients. (see eqn. (4))

As it can be seen in Fig. 5, for the same injection velocity and a 30 µm diameter particle the trajectory obtained with the corrected drag coefficient is more divergent than that without correction. Of course correspondingly the velocity is lower with the corrected $C_D$. The other corrections such as those related to vaporization, Knudsen effect (especially for particle with $d_p < 20\mu$m) exhibits similar effects.
3.3.3 Injection angle influence.

The divergence of the particle at the injection exit (due to their collision with the injector wall and between themselves) can be represented by injecting them at the same point with different angles (see fig. 6). This approximation is justified by the size of the injector internal diameter (<2µm).

As it can be seen in Fig 8 particles injected at counter-current of the jet reached, due to their longer residence time, higher temperature than those injected normally to the jet and of course much higher than those injected in the flow direction. Such results are very important when considering the powder injection and no more a single particle injection.
Figure 6. Different injection angles corresponding to particle dispersion at the injection exit.

Figure 7: Influence on the particle (ZrO$_2$, d = 30µm) surface temperature of the injection angle (same injection velocity : 20 m/s)
3.3.4 Injection velocity influence (injection orthogonal to the jet)

Fig. 8 shows the 30µm diameter zirconia particles trajectories for different injection velocities (between 4.71 and 47.5 m/s). For the chosen power level of 43 kW the optimum injection velocity is 20 m/s. Particles with lower injection velocity penetrates much less in the jet while those with a higher velocity cross the jet correspondingly \( v=20 \text{ m/s} \) result in to the highest particle velocity (see fig.9) and also the highest temperature.

![Graph showing particle trajectories for different injection velocities](image)

Figure 8: 30 µm diameter zirconia particle trajectories for different injection velocities within the 43kW Ar-H2 plasma jet.
Figure 9: 30 µm diameter zirconia particle velocities for different injection velocities within the 43kW Ar-H2 plasma jet.

To underline the importance of the adjustment of the carrier gas flow rate or the particle injection velocity to the spray conditions, for a given injection velocity optimized for P=43kW and d_p=30µm, the dissipated power in the torch has been raised to 66 kW and lowered to 22 kW of course without changing V_inj. As the jet momentum is lower with 22 kW the particle trajectory is more deviated than that obtained at 43kW while it is the contrary for the 66kW power (see fig. 10).
Figure 10: 30 µm diameter zirconia particle trajectories for three power dissipated: 66, 43 and 22 kW with an injection velocity optimum for P=43 kW.

The corresponding temperatures are shown in fig. 11a. In spite of a trajectory crossing more the jet the temperature is the highest for P = 66kW. However when the mean trajectories are the same with optimized trajectories (see Fig 11b) after 3 cm trajectory the particles in the P = 66 kW plasma are completely evaporated while the temperature is about the same for 22 and 43 kW due to a longer residence time of the particles in the 22 kW jet (about 1/5 more than with P = 43kW).

At last the importance of the injection velocity will be emphasized on different zirconia particles sizes: 30, 40, 50 and 60 µm in diameter injected in a 43 kW torch with an injection velocity optimized for 30 µm particles. As it can be seen in Fig. 12a the particle velocity decreases when there size increases. The particles bigger than 30µm cross the plasma jet more and more easily.
thus they are less and less accelerated than if their trajectory would have been optimized as shown in Fig 12b. Correspondingly lower temperatures are obtained with non optimized trajectories (in spite of the lower velocities).

Fig. 11 Power effect (22, 43 and 66 kW) on the particle temperature with the injection velocity optimized a) for the 43 kW b) for each power level.

Figure 12: Evolution with the axial distance of particle velocities for different sizes (30, 40, 50, 60 µm). a) all particle injected with the optimum velocity for 30µm particle b) each particle is injected with its optimum velocity.
3.4 Powder injection

Figure 13: Zirconia particle size distribution (number %) for a size range 30 to 40 µm.

Fig. 13 presents the particle size distribution as measured in number % of presence for a rather narrow distribution (10 to 40 µm in order to generate rapidly results only 32000 particles are generated to build a sample (instead of $10^8$/s in reality).

Fig. 14 shows the corresponding particle temperature distribution at impact in the plane of the injector (non-symmetrical distribution see fig. 14a) and in the plane orthogonal to the injector plane. (Symmetrical distribution see fig 14b).
Figure 14: Particle temperature distribution (19605 particles) at impact with vertical injection a) in the injector plane b) orthogonally to the injector plane.

Fig. 15: Screenshot of deposited layer of zirconia powder in the spray conditions of Fig. 1 and with the particle size distribution of Fig. 13.
The values are comprised between 2400K and 3400 K which means that in the jet fringes particles will be below their melting temperature. Similar distribution results are obtained for velocities.

At last Fig. 15 shows the screen shot of the deposited layer (torch and substrate being fixed and the stand off distance 100 mm) height of the randomized set of particles on the target in conditions of Fig. 1.

The comparison with the experiment is acceptable.

4 Conclusions.

Jets & Poudres software appears as a fast simulation a few minutes, to forecast the dynamic of a single particle or a sample of particles fed in a plasma jet. This code is very because the complex simulation of the flow which should be 3D and elliptic has been replaced by a parabolic flow in 2D the turbulence being represented by a mixing length. Of course iot means that the perturbation by the carrier gas flow rate is low. The behaviour of particles within the jet has been kept 3D which allows calculating particle injection vector distributions.

All results are strongly dependent on the mixing length which has to be adjusted to represent well the region at the extremity of the plasma jet core where turbulent mixing with the jet plume becomes drastic. This has been achieved here by using a slightly under-expanded jet compound to that obtained with the current Genmix one. It means that the correction to the mixing length of Genmix damps it the plasma core to account for the fact the latter is laminar. It has to be underlined that the problem is quite similar with sophisticated 3D codes where this region is always badly represented, at least for plasma jet produced in air by d.c. torches.

With this modified length the simplified code gives an axial temperature distribution close to that obtained with the 3D code Estet3.4. However, in spite of the fact that the plasma flow calculated by Genmix can be close to these determined through sophisticated 3D codes, the plasma effects on the momentum and heat transfer to particle are drastic. Thus as with sophisticated codes results are strongly linked to the choice of the parameters to account for temperature gradient, non-continuum, evaporation and vapour buffer effects. Beside the way to generate stochastically particles size and injection velocity vector distributions are not get clear as well as their influence
on the results. The problem is also far to be solved to layer the splats and form a coating. Thus such a code can only give rapidly trends and be a help for training. Any how it has to be backed by experiments and works are in progress to improve it. This code and plasma properties used can be freely downloaded.

5 References