Numerical investigation of cold spray gas particle dynamics

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Introduction

- Cold-gas dynamic spray process (Figure 1) is a coating technique in which solid particles are deposited onto a substrate at supersonic speeds
- Detrimental effects associated with liquefaction such as temperature oxidation, evaporation, melting, residual stresses are minimised
- The flow field between the nozzle exit and the substrate is that of a two phase gas particle supersonic impinging jet

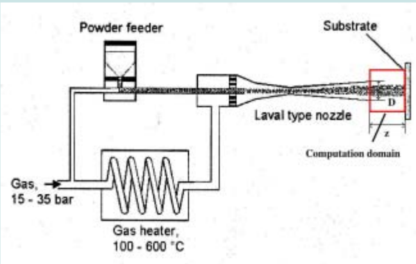

Figure 1: Coldspray process. [1]

- Figure 2 is a flow visualisation of a supersonic impinging gas jet obtained using shadowgraphy
- It reveals the main flow features including a standoff shock, jet shock and jet boundary

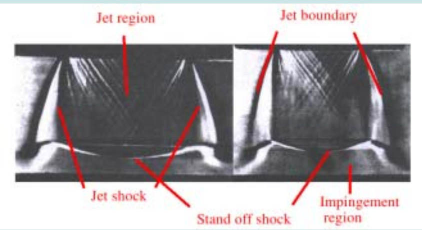

Figure 2: Supersonic impinging jet at *PR* = 3. (Left) *z* = 2D (Right) *z* = 3D. [2]

Aim

- This poster presents simulation results for supersonic impinging gas jets issued from a converging diverging nozzle at pressure ratios PR = 1, 1.2, Ma = 2.2 and impingement distance z (standoff distance) of 2.

$$PR = \frac{P'_e}{P'_{ambient}}, \quad Ma = \frac{u'_e}{c'_e}, \quad z = \frac{z'}{D}$$

Numerical method

- The two-dimensional axi-symmetric Euler equations are used to simulate the planar and radial jet respectively

$$\frac{\partial \mathbf{U}}{\partial t} + \frac{\partial \mathbf{F}}{\partial z} + \frac{\partial \mathbf{G}}{\partial r} + \frac{1}{r}\mathbf{S} = 0 \qquad (1)$$

$$\mathbf{U} = \begin{bmatrix} \rho \\ \rho u \\ \rho v \\ e \end{bmatrix}, \quad \mathbf{F} = \begin{bmatrix} \rho u \\ (\rho u^2 + P) \\ \rho u v \\ (e+P)u \end{bmatrix}, \quad \mathbf{S} = \begin{bmatrix} \rho u \\ \rho u^2 \\ \rho u v \\ (e+P)u \end{bmatrix}$$

- Flow through the converging- diverging nozzle is calculated using one-dimensional isentropic theory
- The governing equations are solved using a symmetric total variation diminishing (TVD) scheme [6]

- The dimensionless variables ρ, P, t, u and v represent the density, pressure, time and velocity in the z and r axes respectively

$$P = \frac{P'}{\rho' c'_e}, \quad \rho = \frac{\rho'}{\rho'_e}, \quad t = \frac{t' c'_e}{D},$$
$$(u, v) = \frac{(u', v')}{c'_e}, \quad (z, r) = \frac{(z', r')}{D}$$

- Subscript 'e' refers to properties at the nozzle exit while the $'$ refer to dimensional variables

Gas dynamics

- Numerical 'schlieren' [5] of supersonic impinging gas jets issued from a de-Laval nozzle with exit diameter (mm)/ throat diameter (mm) = 30/23.4
- The nozzle chamber temperature is assumed to be 288K and ambient pressure at 101325 Pa.

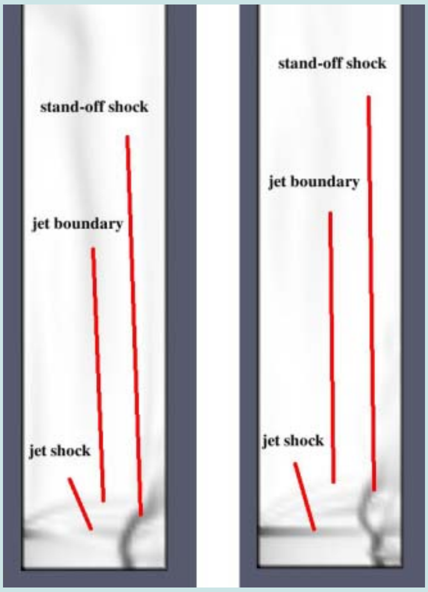

Figure 3: Supersonic impinging jet at T_0 = 288K. (Left) PR = 1.2, z = 2D (Right) PR = 2.0, z = 2D

- Figures 3 clearly shows the stand-off shock located prior to the substrate and the jet shocks
- Figures 4 and 5 show the pressure distribution along the impingement plate (substrate)
- Simulated pressure profile varies with the vertical length of computation domain from 10D to 14D
- This suggest that the free boundary conditions doesn't correctly model the real outflow
- The results shows good qualitative agreement with experimental measurements taken by Lamont [4]

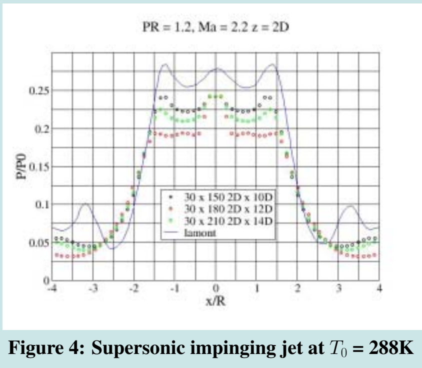

Figure 4: Supersonic impinging jet at T_0 = 288K

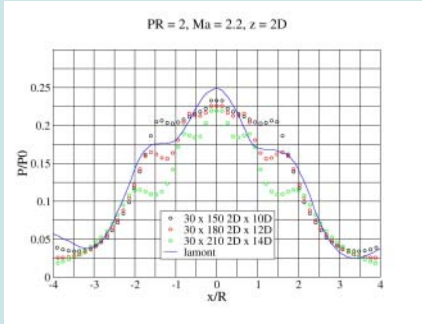

Figure 5: Supersonic impinging jet at T_0 = 288K

Particle dynamics

- For cold spray applications the nozzle chamber temperature needs to be much higher at around 800K
- Individual particle behavior is modelled using Newton's law assuming it's spherical, uniform in properties and does not alter the gas flowfield [3]
- Particle undergoes deceleration after travelling through the stand-off shock while temperature increases

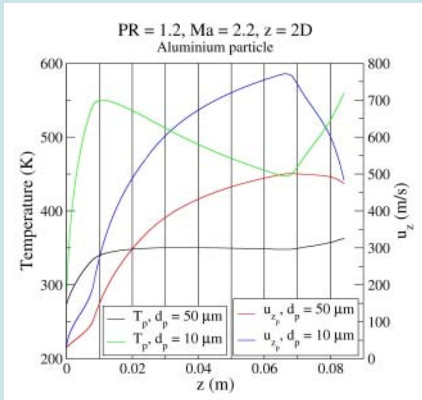

Figure 6: Particle morphology along jet centerline

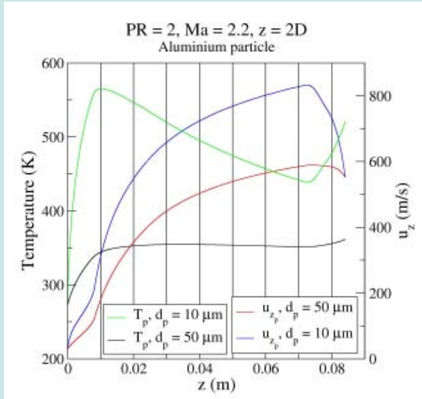

Figure 7: Particle morphology along jet centerline

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