Numerical simulation of the cold-gas dynamic spray process

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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
- Objective of the research is to gain an understanding of the fluid dynamics behind the process

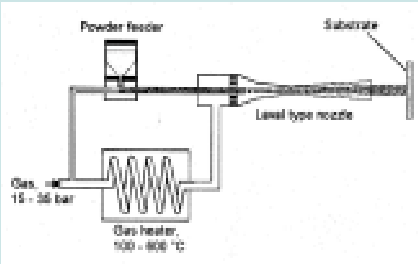

Figure 1: Coldspray process. [2]

- The flow characteristics of the cold-gas dynamic spray process is that of a two-phase supersonic impinging jet
- Figure.2 shows a flow visualisation of a supersonic impinging air jet obtained using shadowgraph photography
- The jet region is bounded by a jet shock formed by the merging of compression waves from the constant pressure jet edge
- The flow speed jumps from supersonic to subsonic after traversing through the standoff shock

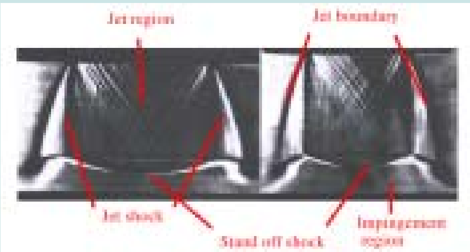

Figure 2: Supersonic impinging jet at NPR = 3 at (Top) = 2, (Bottom) y_N = 3 [3]

- Our initial research has focused on simulating the flow through the de-Laval nozzle using the MacCormick method [1]

Numerical calculations using the MacCormick method

- Assumption in the computation include steady, inviscid one dimensional flow
- Governing flow equations are derived from conservation of mass, momentum and energy principles:

$$\frac{\partial \rho'}{\partial t'} = -\rho' \frac{\partial V'}{\partial x'} - \rho' V' \frac{\partial (\ln A')}{\partial x'} - V' \frac{\partial \rho'}{\partial x'} \quad (1)$$

$$\frac{\partial V'}{\partial t'} = -V' \frac{\partial V'}{\partial x'} - \frac{1}{\gamma} \left(\frac{\partial T'}{\partial x'} + \frac{T'}{\rho'} \frac{\partial \rho'}{\partial x'} \right) \quad (2)$$

$$\frac{\partial T'}{\partial t'} = -V' \frac{\partial T'}{\partial x'} - (\gamma - 1) T' \left[\frac{\partial V'}{\partial x'} + V' \frac{\partial (\ln A')}{\partial x'} \right] \quad (3)$$

- MacCormick method [1] is a predictor-correcter method where the flow properties are marched forward in time using Eqs. 4-6

$$\rho_i^{t+\Delta t} = \rho_i^t + 0.5 \left[\left(\frac{\partial \rho}{\partial t} \right)_i^t + \left(\frac{\partial \rho}{\partial t} \right)_i^{t+\Delta t} \right] \Delta t \quad (4)$$

$$V_i^{t+\Delta t} = V_i^t + 0.5 \left[\left(\frac{\partial V}{\partial t} \right)_i^t + \left(\frac{\partial V}{\partial t} \right)_i^{t+\Delta t} \right] \Delta t \quad (5)$$

$$T_i^{t+\Delta t} = T_i^t + 0.5 \left[\left(\frac{\partial T}{\partial t} \right)_i^t + \left(\frac{\partial T}{\partial t} \right)_i^{t+\Delta t} \right] \Delta t \quad (6)$$

- Boundary conditions are defined using the method of characterisitics
- To ensure stability the CFL criterion is applied to the size of the time step

$$(\Delta t)_i^t \leq C \frac{\Delta x}{a_i^t + V_i^t} \quad (7)$$

Results and Discussion

- Figure.3 shows the variation of air temperature, pressure and density through the nozzle as it is accelerated from subsonic to supersonic speed

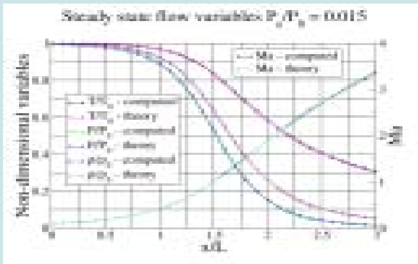

Figure 3: Steady state results for subsonic-supersonic flow through a converging-diverging nozzle

- If nozzle exit pressure is high relative to the nozzle inlet pressure, the air will remain at subsonic speed as shown in Figure.4

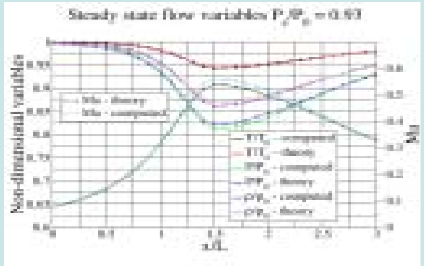

Figure 4: Steady state results for subsonic-subsonic flow through a converging-diverging nozzle

- If nozzle exit pressure is below subsonic conditions, a shock will develop in the divergent section of the nozzle. See Figure.5

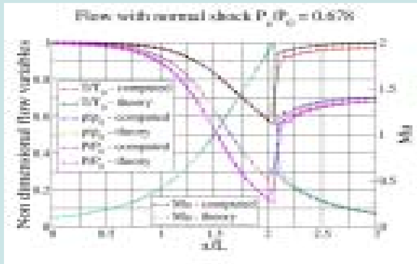

Figure 5: Steady state results for flow through a converging-diverging nozzle with shock (with artificial viscosity)

Summary and future work

- Flow simulation highlighted three different possible flow regimes inside the nozzle depending on exit pressure
- For the complete cold spray model, the current simulation needs to account for viscous, turbulence and multi-dimensional effects
- Figure.2 gives an indication of the complexity behind the modelling of a two-phase three-dimensional, turbulent supersonic impinging jet

References

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