

Demande de financement - projet de recherche

Nom du correspondant : CAMELLO BARROS Diogo

Nom du projet: Laser Velocimetry of Supersonic Cold Spraying (LAVESCOS)

Résumé du projet

During the cold spray process, micron-sized particles are accelerated by a supersonic nozzle and projected onto a substrate for coating purposes. Due to their relatively large size in a high-speed turbulent flow, particle inertia plays a fundamental role in the process. A detailed knowledge of the gaz/particle velocity fields is hence essential for the prediction of the particle deposition rate. This project aims to provide, for the first time in this flow, coupled gaz/particle measurements by the use of two-color particle image velocimetry.

Contenu scientifique

OVERVIEW AND GOALS

Cold spraying has emerged as a promising coating and additive manufacturing process, with a wide range of applications including transport, energy, and environmental technologies (An *et al.* 2020). Its principle relies on the aerodynamic acceleration of micro/nano particles to be deposited onto a solid substrate. The large energy carried by these particles traveling at supersonic speeds induce bonding and deposition process. The plastic bonding only takes place when the impacting particle velocity achieves a critical value, commonly over 500 m/s (Papyrin *et al.* 2006). In addition to the critical particle velocity, the complex structure of the supersonic gas stream plays a key role in cold spraying process. The presence of turbulence together with complex shock waves in the supersonic stream significantly affect the impacting particle velocity, hence the deposition rate (Pattison *et al.* 2007, Buchnam *et al.* 2013). **The fluid-particle interaction during the coating process is thus of primary importance.**

Due to their non-intrusive nature, multiple optical diagnostics have been employed to characterize fluid-particle velocities. Laser-Doppler Anemometry measurements have shown that particles with diameter between 20 and 50 microns moves significantly slower than the local gas stream due to the large particle inertia (Sommerfeld 1994). Pattison *et al.* 2007 performed whole-field particle image velocimetry (PIV) to characterize the velocity of 20-micron particles sprayed into a substrate close to the nozzle's outlet. They detected a complex shock wave structure next to the substrate, which greatly decreased the particle impacting velocity. PIV experiments were also employed by Zahiri *et al.* 2009 to measure the dispersed particle velocity profile along the nozzle axis. They demonstrated that metallic particles with diameter of approximately 30 microns displayed considerable decrease of velocity just few diameters downstream of the nozzle's outlet. **In all these previous investigations, the velocimetry method was applied to compute only the dispersed particle velocity, without measurements of the gas flow field.**

Attempts to characterize both the gas flow structure and the particle velocity included coupled high-speed imaging, digital inline-holography, and particle tracking velocimetry (PTV) (Buchmann *et al.* 2013; Kim *et al.* 2020). However, the small resolution of the current ultra-high-speed cameras precludes spatially resolved flow characterization. While the aforementioned methods have considerably improved our understanding of the multiphase flow process at play in cold spraying, they are unable to provide us coupled gas-particle velocity measurements. The knowledge of gas-particle information is critical to

1

improve existing numerical models of turbulent multiphase compressible flows, in particular for cold spray applications where fluid-particle interaction is crucial (Yin *et al.* 2019).

The goal of this project is to achieve, for the first time, coupled gas-particle velocity measurements in a supersonic flow for the prediction of cold spraying deposition rate. This research program has been recently started at IUSTI by a preliminary collaboration between two research teams working on optical diagnostics and high-speed flows in the framework of the CNRS funded PEPS Mécanique du Futur project ODISCOS (Optical Diagnostics for Supersonic Cold Spraying, 2021-2022).

CHALLENGES, METHODOLOGY AND EXPECTED RESULTS

The experimental acquisition of simultaneous gas-particle coupled velocity is a challenging problem in supersonic flows. To measure the gas velocity, submicron-sized flow tracers are injected in the stream and imaged by a high-sensitive camera using a laser sheet. The scattered light from the tracer particles allows one to compute the velocity field using particle image velocimetry. However, as the flow is also feeded with larger, coating particles (5-100 microns), the higher scattered light from the dispersed phase not only induces saturation of the camera's sensor but also a misleading intensity of the flow tracers. A decrease of the laser power output solves the saturation problem but precludes the observation of the submicron flow tracers required for supersonic flows. While phase discriminant methods have been employed to determine gas-particle velocity in low-speed flows (Khalitov & Longmire 2002; Lecordier *et al.* 2005), their application in supersonic multiphase flows needs careful extension and has not been reported in the literature.

Here, we propose to perform coupled gas-particle velocity measurements in a simplified cold spray model feeded with both the flow tracers (0.5-1 microns) and the coating particles (20-100 microns). Particle Image Velocimetry (PIV) will be applied to measure the velocity of fluorescent flow tracers while particle tracking velocimetry (PTV) will compute the dispersed particles' velocity.

The proposed experimental setup is sketched in the figure bellow. The high-pressure line is connected to the particle feeder to inject 50 μ m calibrated polyamid spherical particles in the nozzle. These particles mimic the coating particles in the real cold spraying technology. The high-pressure line also feeds the aerosol generator capable of generating submicron fluorescent droplets that will serve as flow tracers. The field of view will be illuminated using a laser sheet generated by a Nd:YAG system (532 nm, 65mJ/pulse). Both the tracers and the 50 μ m particles will be imaged using a high sensitivity 9Mpx CCD sensor equipped with a 100mm objective to attain required spatial resolution.

The fluorescent flow tracer droplets will scatter the incident 532nm laser light with a peak nearly 590nm, while the larger, dispersed phase particles will scatter light at the laser's wavelength. To separate them in each CCD image, a NOTCH filter will be used to block the laser wavelength and to image the flow tracers. Separately, but still feeding the flow with larger particles, the filter will be removed, and the larger particles will be imaged. The images will be processed using the DantecDynamics PIV correlation algorithm to obtain highly resolved velocity profiles of the supersonic jet. The laser/camera and PIT/PTV software were recently acquired by the IUSTI laboratory.

The instantaneous velocity fields will be used to compute statistics of the supersonic jet in the whole field of view. The gaz/particle velocity profiles will be compared and will provide key information about the coating particle acceleration/deceleration in the supersonic gas stream. The results are key to improve deposition rate models in cold spraying and will serve as a database for future turbulence modelling of multiphase and compressible flows. The experiments will serve as a basis for future projects of the investigator, in particular the deposition of a Young Investigator (JCJC) ANR proposal and a CNRS Prematuration proposal following the awarded PEPS ODISCOS project led by the investigator.

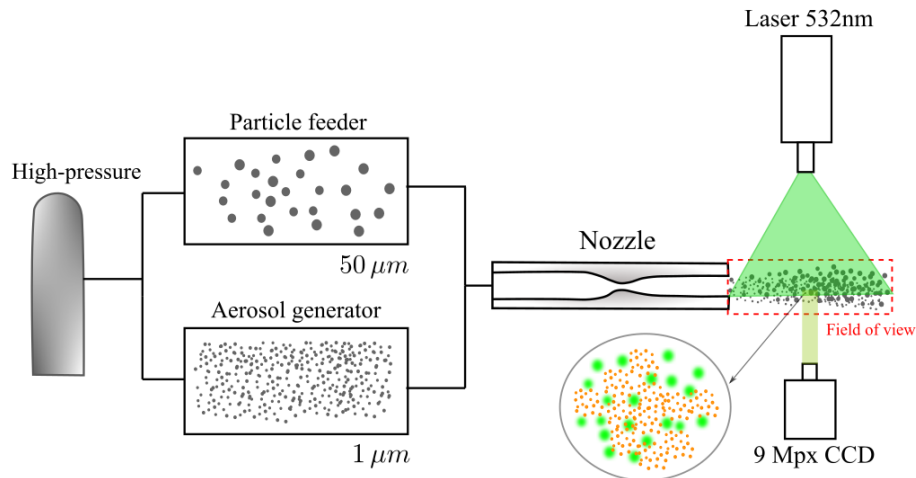


Figure. Two-color PIV-PTV experimental setup for coupled gaz/particle velocity measurements.

PROJECT TASKS

The project will be conducted during a 12-month period following the subsequent tasks:

- To + 2 months : setting up of the aerosol generator and PIV measurements
- To + 4 months : setting up of the fluorescence PIV measurements
- To + 7 months : coupled two-color PIV/PTV velocity measurements
- To + 10 months : data analysis: images, velocity fields, statistics of velocity profiles
- To + 12 months : final report, conference, and journal communications

REFERENCES

- An, S., Joshi, B., Yarin, A. L., Swihart, M. T., & Yoon, S. S. (2020). Supersonic Cold Spraying for Energy and Environmental Applications: One-Step Scalable Coating Technology for Advanced Micro-and Nanotextured Materials. *Advanced Materials*, 32(2), 1905028.
- Buchmann, N. A., Atkinson, C., & Soria, J. (2012). Ultra-high-speed tomographic digital holographic velocimetry in supersonic particle-laden jet flows. *Measurement Science and Technology*, 24(2), 024005.
- Khalitov, D. A., & Longmire, E. K. (2002). Simultaneous two-phase PIV by two-parameter phase discrimination. *Experiments in Fluids*, 32(2), 252-268.

- Kim, T., Ni, R., Capecehatro, J., Yao, Y., Shallcross, G. S., Mehta, M., & Rabinovitch, J. (2020). The dynamics of inertial particles in underexpanded jets: An experimental study. In *AIAA Scitech 2020 Forum* (p. 1326).
- Kosiwczuk, W., Cessou, A., Trinite, M., & Lecordier, B. (2005). Simultaneous velocity field measurements in two-phase flows for turbulent mixing of sprays by means of two-phase PIV. *Experiments in Fluids*, 39(5), 895-908.
- Mitchell, D. M., Honnery, D. R., & Soria, J. (2012). The visualization of the acoustic feedback loop in impinging underexpanded supersonic jet flows using ultra-high frame rate schlieren. *Journal of Visualization*, 15(4), 333-341.
- Morgan, R., Fox, P., Pattison, J., Sutcliffe, C., & O'Neill, W. (2004). Analysis of cold gas dynamically sprayed aluminium deposits. *Materials Letters*, 58(7-8), 1317-1320.
- Papyrin, A., Kosarev, V., Klinkov, S., Alkhimov, A., & Fomin, V. M. (2006). *Cold spray technology*. Elsevier.
- Pattison, J., Celotto, S., Khan, A., & O'Neill, W. (2008). Standoff distance and bow shock phenomena in the Cold Spray process. *Surface and Coatings Technology*, 202(8), 1443-1454.
- Sommerfeld, M. (1994). The structure of particle-laden, underexpanded free jets. *Shock Waves*, 3(4), 299-311.
- Yin, S., Cavaliere, P., Aldwell, B., Jenkins, R., Liao, H., Li, W., & Lupoi, R. (2018). Cold spray additive manufacturing and repair: Fundamentals and applications. *Additive Manufacturing*, 21, 628-650.
- Yin, S., Meyer, M., Li, W., Liao, H., & Lupoi, R. (2016). Gas flow, particle acceleration, and heat transfer in cold spray: a review. *Journal of Thermal Spray Technology*, 25(5), 874-896.
- Zahiri, S. H., Yang, W., & Jahedi, M. (2009). Characterization of cold spray titanium supersonic jet. *Journal of Thermal Spray Technology*, 18(1), 110-117.