CFD analysis of an enhanced nozzle designed for plasma figuring of large optical surfaces

Nan Yu, Renaud Jourdain, Mustapha Gourma, Paul Shore* *Email: n.yu@cranfield.ac.uk*

1. Introduction

This project is about the design, fabrication, and characterisation of novel Inductively Couple Plasma (ICP) torch nozzles. These nozzles will enable the creation of highly collimated energy beams characterised by a material removal footprint of a few millimetre in diameter.

In 2012, Castelli demonstrated the fast figure correction capability on a 420mm substrate using Helios 1200 (Fig. 1). 31nm RMS form accuracy from an initial 373nm RMS was achieved within 2.5 hours. However Mid Spatial Frequency (MSF) errors were induced by the sub aperture process itself [1]. MSFs were highlighted through Power Spectrum Density (PSD) analysis (Fig. 2).

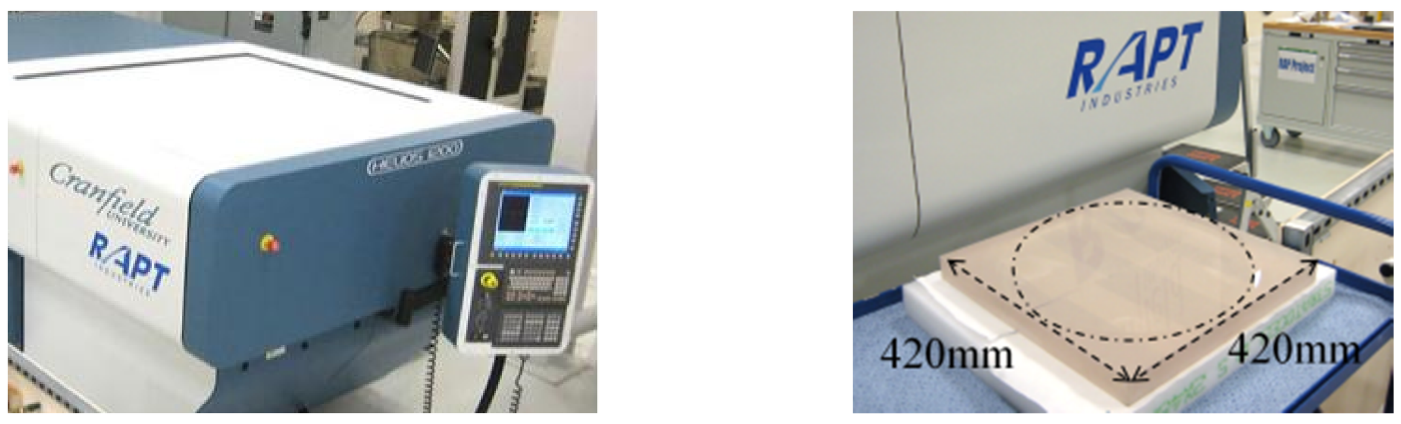

Fig. 1 Helios1200 machine (left), 420mm ULE substrate (right).

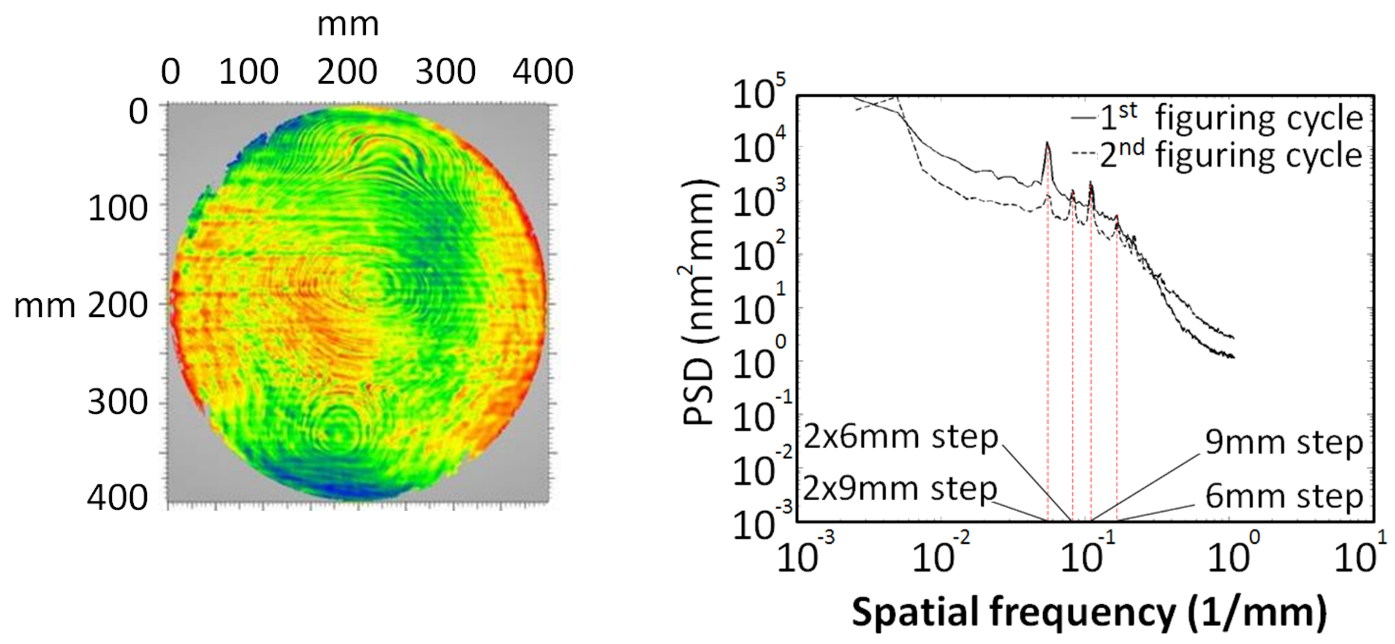

Fig. 2 Topography map (left), and directional PSD plots (right) (Dr Castelli).

2. Research motivations

Enhancement of the plasma figuring capability is the research motivation for this work. This aim will be reached through the development of optimised torch nozzles. The author's approach is the creation of a model using Computational Fluid Dynamic (CFD) method. The key results of this CFD model are used to investigate and determine the aerodynamic properties of the plasma jet [2]. First, the two investigated torch nozzles are presented.

3. Enhanced De-Laval nozzle design

The benefit of a De-Laval nozzle is to amend the energy beam characteristics. Prototype nozzle mounted at the end of ICP torch is shown in Figure 3 left. Since 2013, research on enhanced nozzles has been undertaken. In addition to altering the energy beam footprint, enhanced nozzles were designed to be easily fitted. The copper nozzle body was divided into two components that have different duties. The De-Laval ring was designed to transport the plasma. Mid ring and sleeve parts were designed to cool down the nozzle (Fig. 3 right)

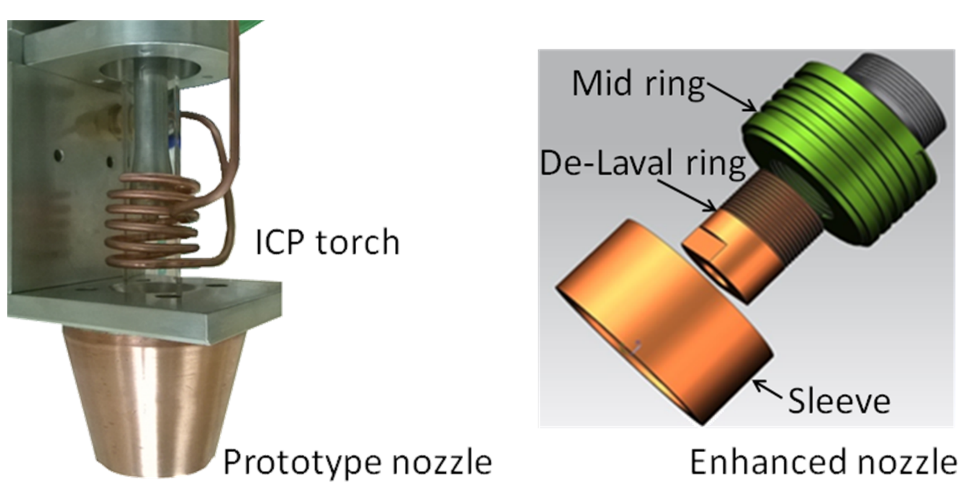

Fig. 3 ICP torch and prototype nozzle (left), enhanced nozzle (right).

4. Numerical analysis of the nozzles and results

CFD modelling was utilized to investigate the aerodynamic properties of a plasma jet streamed through two De-Laval nozzles. These nozzles were the prototype and one of enhanced nozzles. A 2D axis-symmetric numerical model [3] was used to perform calculations on a high temperature gas mixture. The temperature distributions in the domains are displayed in Figure 4.

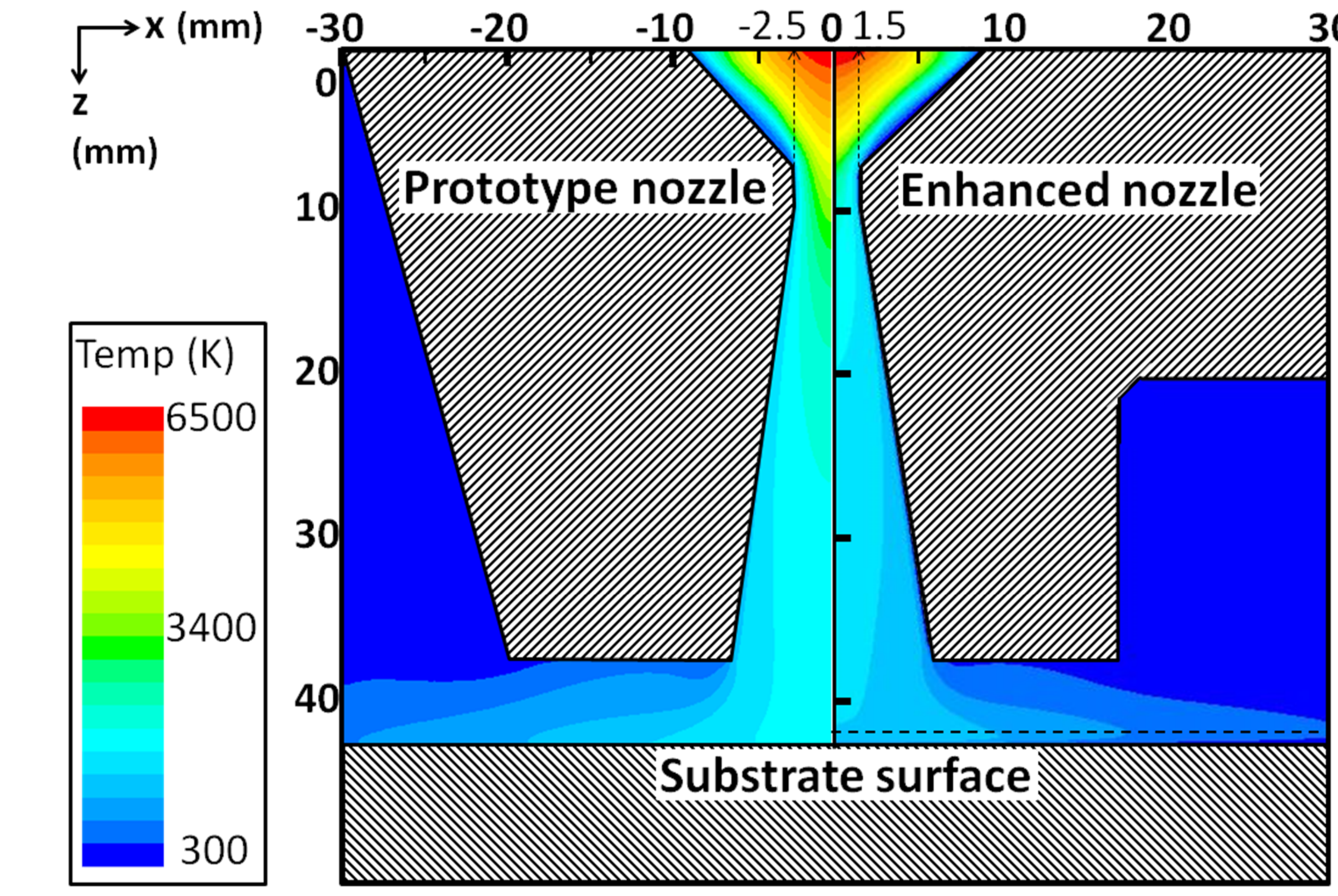

Fig. 4 Surface topography showing the MSF features.

Data were logged along the symmetric axis as shown in Fig. 5.

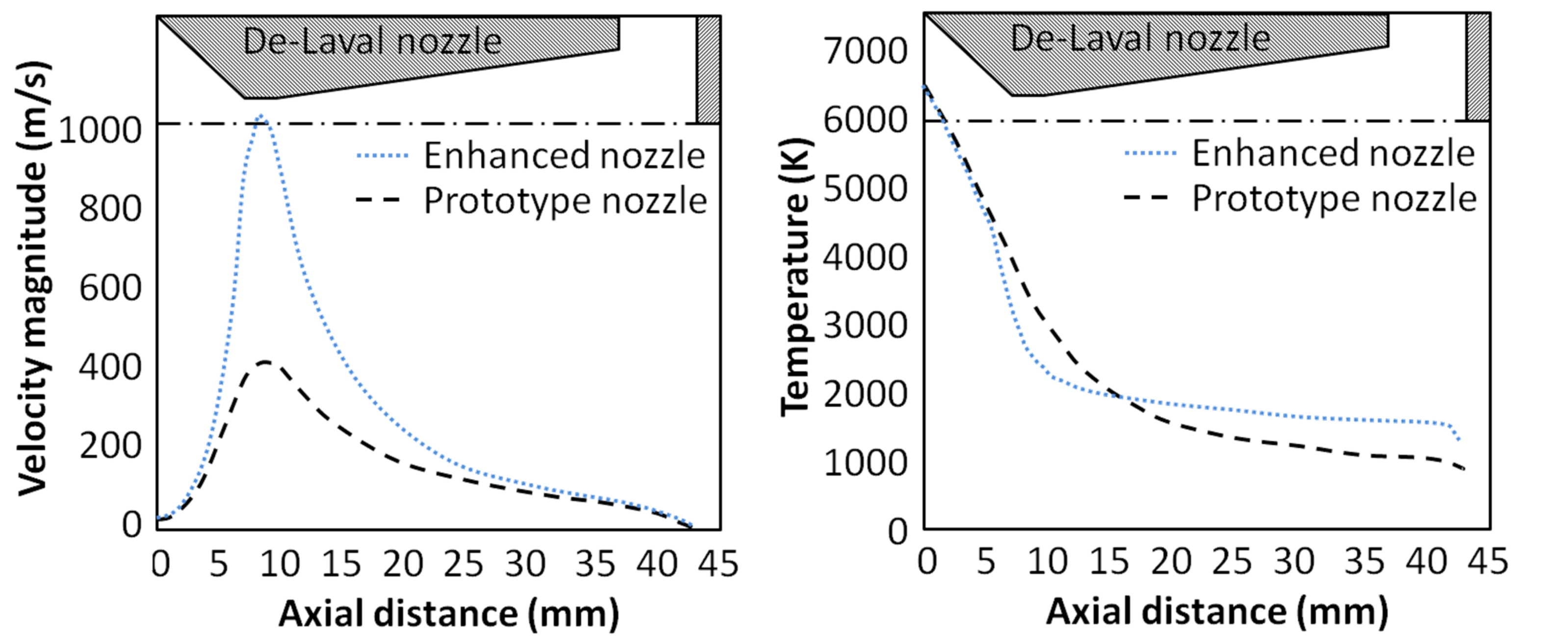

Fig. 5 Axial profiles of velocity and temperature along the symmetric axis.

Data were logged along the impinged surface as shown in Fig. 6.

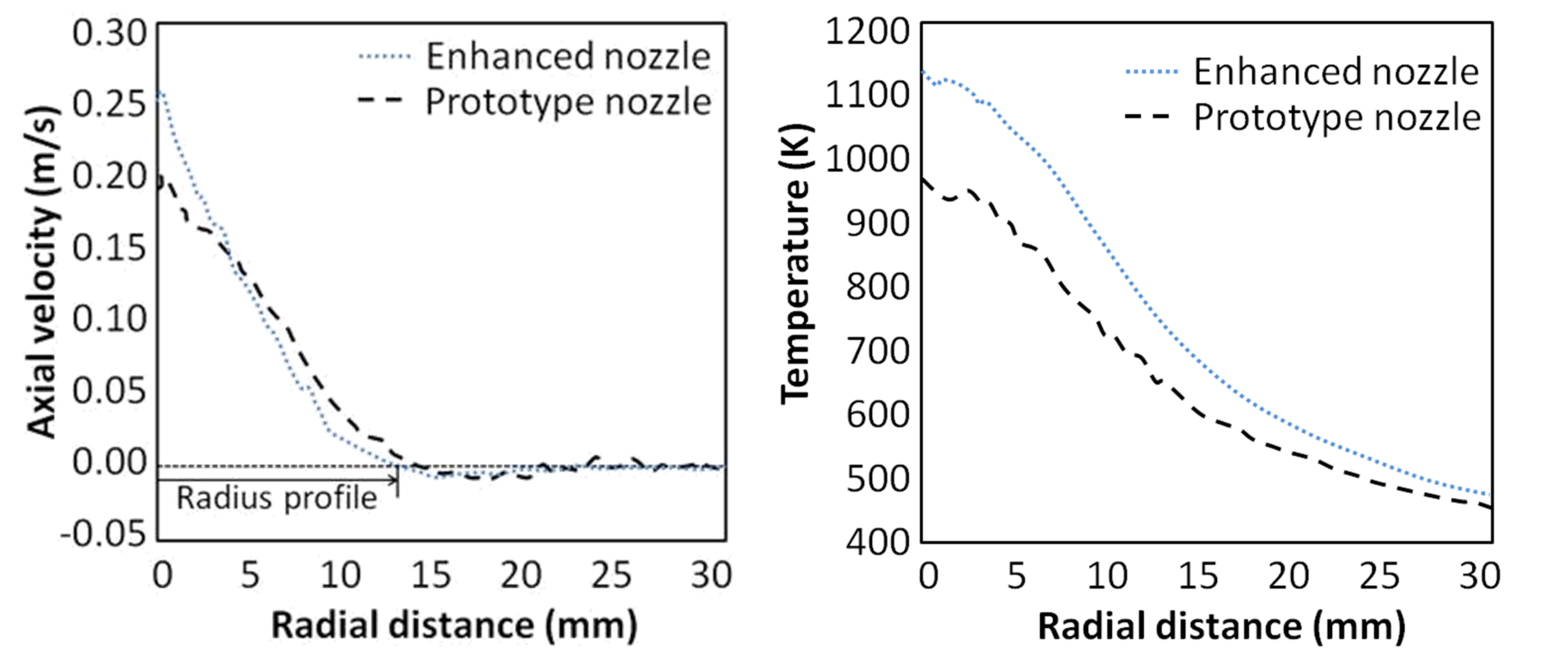

Fig. 6 Radial profiles of axial velocity and temperature along the surface.

5. Conclusion

This paper highlights the increased performance of an improved nozzle design. This nozzle is expected to enhance the processing capability of plasma figuring by reducing the MSF errors. This enhanced nozzle is predicted to deliver 12.5% smaller footprint and 15.5% higher temperature. The validation of these results will be carried out shortly in the laboratory.

6. Reference

[1] Castelli M, et al. Precision Engineering. 2012 36 467-476
[2] Yu N, et al. ASPE annual meeting, Boston, USA. 2014
[3] Yu N, et al. Intl Journal of Adv Manuf Tech. 2016 (accepted)