Design of Small-Scaled De Laval Nozzle for IGLIS Experiment

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Abstract

De Laval nozzles are used in aeronautics and aerodynamics in supersonic aerodynamical tubes and engines. On the other hand they are employed for the production of cold gas jets to be used e.g. in chemical reactions studies under special conditions. Recently, cold gas jets have been proposed of In-Gas Laser ionization Spectroscopy (IGLIS) experiments of short-lived isotopes of interest in nuclear physics (Kudryavtsev et al, 2013).
The de Laval nozzle consists of a converging and a diverging parts with a throat between them. High gas pressure and temperature, and low velocity are present before the converging part, while low pressure and temperature and high velocity are reached after the diverging one.
For the IGLIS experiments an uniform jet of noble gas (argon or helium) with Mach number up to 12 is required, while the stagnation pressure has to be of the order of 1 bar. The throat diameter needs to be less than 1 mm because of the limited evacuation capacity of the pumping system. The nozzles for aeronautical and chemical applications usually have Reynolds number at least two order of magnitude larger.
To design a nozzle, an inviscid core calculation should be performed, complemented with a boundary layer correction (Sivells, 1970). Because of small value of the Reynolds number for our problem, the boundary layer is not thin compared with the nozzle diameter, therefore it cannot be calculated separately. To take viscous effects into account, the COMSOL Multiphysics® software has been used.
In practice, an inviscid core is calculated by using of the method of characteristics and the resulting nozzle contour is implemented in COMSOL Multiphysics®. The simulation is performed with the High Mach Number Flow interface. After the velocity, density, and entropy distributions are calculated, the flow is split onto two parts: the inviscid core and the boundary layer. The value of entropy is the criterion. It is found that up to 40% of the mass flows through the boundary layer, therefore both parts need to be corrected. By a separate script the displacement thickness and the amount of mass flowing though the core are calculated. For the next step, the nozzle contour is a sum of the inviscid core scaled by the mass flow-rate factor and the displacement thickness. These steps are iterated several times until the difference between the two subsequent solutions becomes negligible.
The de Laval nozzle contours for a monatomic gas for required Mach numbers have been designed. The final nozzle contours are achieved after 6 - 15 iteration steps. Disagreements of the Mach number within 6% with respect to the nominal values are reached. The results are present for the M=8 nozzle. Figure 1 displays the Mach number distribution inside the nozzle.

The dashed line indicates the initial contour calculated for the inviscid gas. Figure 2 shows the radial Mach number distribution across the exit plane of the nozzle.
The designed nozzles will be manufactured and will be tested in the IGLIS laboratory at KU Leuven.

Reference

1. Yu. Kudryavtsev et al. The in-gas-jet laser ion source: Resonance ionization spectroscopy of radioactive atoms in supersonic gas jets, Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms, 297, 7-22 (2013)
2. J.C. Sivells, Aerodynamic Design of Axisymmetric Hypersonic Wind Tunnel Nozzles, AIAA Journal of Spacecraft and Rockets, Vol. 7, No. 11, pp.1292-1299 (1970)

Figures used in the abstract

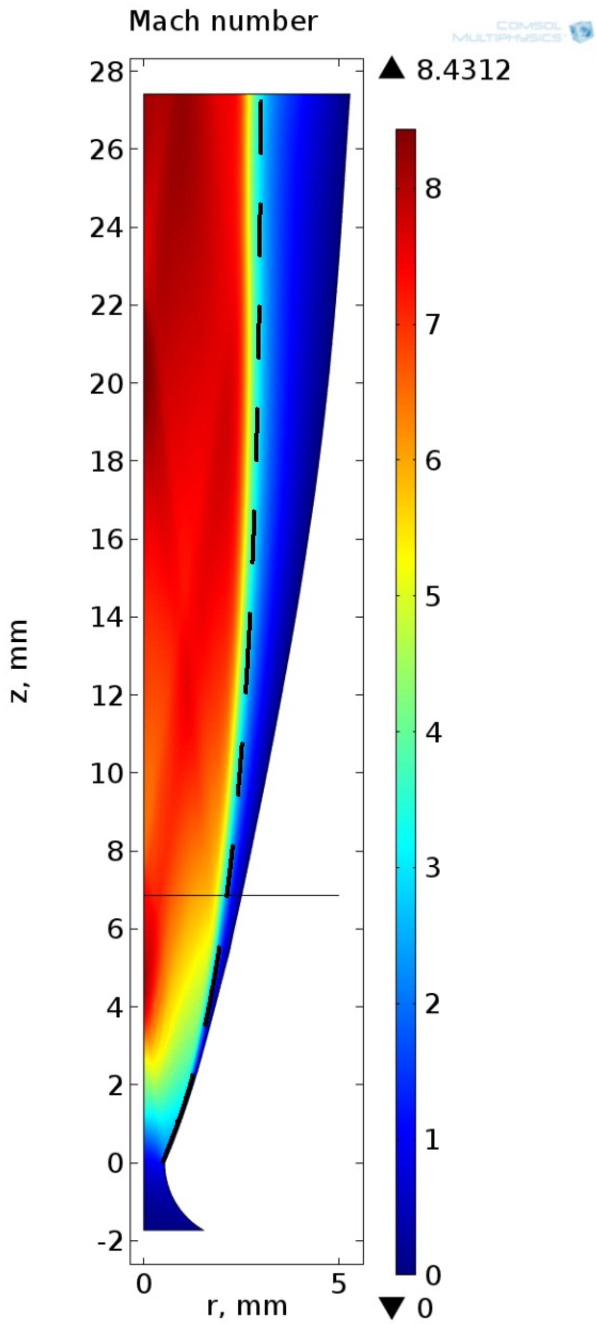

Figure 1: Mach number distibution in the nozzle. The dashed line indicates invicid solution

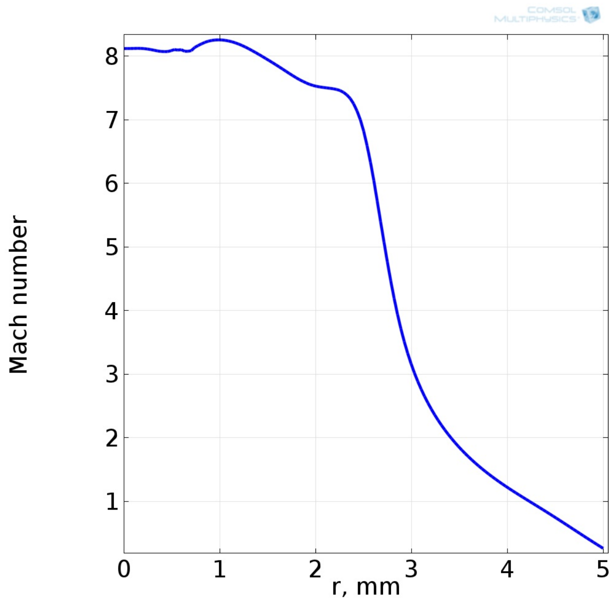

Figure 2: The radial Mach number distribution in the exit plane