Data Article

Numerical data concerning the performance estimation of a Vaporizing Liquid Microthruster

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Abstract

The data presented in this data article were on the basis of the study reported in the research articles entitled “A novel quasi-one-dimensional model for performance estimation of a Vaporizing Liquid Microthruster” (De Giorgi and Fontanarosa, 2018). The reference study presented a numerical analysis of the performance of the Vaporizing Liquid Microthruster (VLM) experimentally investigated in the data article entitled “Performance evaluation and flow visualization of a MEMS based Vaporizing Liquid Microthruster” (Cen and Xu, 2010). For the purpose, a novel quasi one-dimensional model was proposed, and results were compared with the numerical predictions provided by 2D and 3D CFD computations.

Due to the scarcity of experimental data concerning the flow characterization inside a Vaporizing Liquid Microthruster, the present Data in Brief aims to provide the entire dataset coming from the numerical predictions for benchmark purposes and comparisons with different numerical approach.

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Specifications table

| Subject area       | Aerospace Engineering |
|--------------------|-----------------------|
| More specific subject area | Micro Propulsion, Micronozzles, Micro flow boiling, Numerical modeling, Vaporizing Liquid Microthruster |
| Type of data       | Tables, figures,.xlsx files |
| How data were acquired | Matlab code, OpenFOAM CFD toolbox |
| Data format        | Raw, analyzed |
| Experimental factors | The performances of a Vaporizing Liquid Microthruster were investigated. In particular, the VLM developed by Cen et al. [2] was analyzed. The thruster is fabricated in silicon, it has a planar geometry, and it consists of a rectangular plenum upstream, followed by a heating chamber composed of nine parallel microchannels and a convergent-divergent planar nozzle having a throat width of $1.5 \times 10^{-4} \text{ m}$. |
| Experimental features | The one-dimensional analytical model sequentially solved the two-phase flow into inlet plenum and microchannels, and the gas flow region inside the micronozzle. Furthermore, both 2D and 3D simulations of the gas flow through the micronozzle were performed by using the open source CFD toolbox OpenFOAM version 3.0.1 [5]. |
| Data source location | Lecce, Italy |
| Data accessibility | Data of current article |
| Related research article | “A novel quasi-one-dimensional model for performance estimation of a Vaporizing Liquid Microthruster” [1] |

Value of the data

- The dataset allows for investigation of the performance of silicon-based Vaporizing Liquid Microthrusters composed of an inlet plenum, a heating chamber made of parallel microchannels, and a planar micronozzle.
- The computational data can be used to verify modeling predictions of the boiling flow inside the heated region as well as the gas expansion inside the micronozzle.
- The data can be used for comparison with numerical predictions coming from different numerical approaches by providing a benchmark.
- It can be used for CFD user training and improvement of the accuracy of numerical simulations of rarefied supersonic gas flows inside planar micronozzles.

1. Data

The dataset is documented by distinguishing the numerical modeling, as follows:

- Data of the one-dimensional steady-state boiling flow inside the inlet plenum and microchannels;
- CFD data of the supersonic flow inside the micronozzle.

The one-dimensional solution of the boiling flow into the two-phase flow region (inlet plenum and microchannels) is tabulated into the file named File1.xlsx. In particular, the axial distribution of the density, the static pressure, the temperature, the axial velocity, the vapor quality, the specific enthalpy, the heat transfer coefficient (HTC), the Nusselt number and the heat flux are provided for each operating condition investigated in [1].

Furthermore, both width-wise and depth-wise distributions of the temperature, the velocity, the static pressure, the density, the Mach number are given in correspondence of ten stations placed between the throat and the exit sections were given for 2D and 3D simulations.
Consequently, they are organized in three different files as follows:

- 2D CFD solution with pure slip condition at walls (File2.xlsx);
- 2D CFD solution with partial slip condition at walls (File3.xlsx);
- 3D CFD solution with partial slip condition at walls (File4.xlsx).

2. Experimental design, materials, and methods

The data are related to a Vaporizing Liquid Microthruster. The Vaporizing Liquid Microthruster consists of three parts: the inlet chamber or plenum through which the propellant is fed, the heating chamber where the propellant is vaporized, and the convergent–divergent micronozzle, which accelerates the superheated vapor flow to supersonic velocities.

In particular, the VLM developed by Cen and Xu [2] was analyzed. It has a planar geometry with depth $1.2 \times 10^{-4}$ m and it consists of a rectangular plenum upstream, followed by a heating chamber composed of nine parallel microchannels of $8 \times 10^{-5}$ m width, and a convergent–divergent planar nozzle having a throat width of $1.5 \times 10^{-4}$ m.

The one-dimensional analytical model sequentially solved the two-phase flow into inlet plenum and microchannels, and the gas flow region inside the micronozzle, based on an iterative and a two-cycle criterion. In the first cycle, the Nusselt number is supposed constant, equal to 4.96 as suggested by Bejan and Kraus [3]. The flow state at the microchannels exit is thus predicted and a new mass flow rate is computed. By estimating the error between the new mass flow rate with the old one, the mass flow rate is iteratively corrected, until convergence is reached based on a residual tolerance of 0.01. Concerning the second cycle, the two-phase flow inside the heating region is first solved based on the local estimation of the Nusselt number using the experimental correlation by Tibiriçá et al [4]. Hence, a new correction step is introduced on the average heat flux, based on a residual tolerance of 0.01. Therefore, the solution of the gas flow inside the micronozzle is computed starting from the fluid state predicted at the exit of the microchannel. Finally, the Finally, microthruster performances are estimated based on the IRT and the computation of the viscous. The latter leads to the corrected mass flow rate at the end of each cycle loop. Thus, similarly to the first cycle, the mass flow rate correction is performed based on a residual tolerance of 0.01. A detailed description of the modeling is provided in [1]. The full set of test cases and the corresponding initial conditions are reported in Table 1.

The CFD simulations of the vapor water flow inside the micronozzle were performed by using the open source CFD toolbox OpenFOAM version 3.0.1 [5], based on a Finite Volume formulation and with the density-based solver rhoCentralFoam [6]. The compressible Navier–Stokes (NS) equations were solved with the laminar flow approximation. The central upwind scheme of Kurganov and Tadmor [7] was used for the flux terms and the Total Variation Diminishing (TVD) van Leer limiter [8] for interpolation. A maximum Courant number of 0.2 was used. The Peng Robinson equation of state was

| Test case number | $p_{0,\text{inlet}}$ [Pa] | $m$ [kg/s] |
|-----------------|-----------------|--------|
| $T_w$ [K] = 493 |                  |        |
| #1              | $1.5 \times 10^5$ | $3.7 \times 10^{-6}$ |
| $T_w$ [K] = 533 |                  |        |
| #2              | $1.5 \times 10^5$ | $3.52 \times 10^{-6}$ |
| #3              | $1.9 \times 10^5$ | $4.57 \times 10^{-6}$ |
| #4              | $2.2 \times 10^5$ | $5.37 \times 10^{-6}$ |
| $T_w$ [K] = 573 |                  |        |
| #5              | $1.48 \times 10^5$ | $3.33 \times 10^{-6}$ |
| #6              | $1.89 \times 10^5$ | $4.33 \times 10^{-6}$ |
| #7              | $2.18 \times 10^5$ | $5.0 \times 10^{-6}$ |
| #8              | $2.41 \times 10^5$ | $5.67 \times 10^{-6}$ |

Table 1
Analytical model investigations: test matrix and operating conditions. $p_{0,\text{inlet}}$ is the initial total pressure, $T_w$ is the wall temperature, $m$ is the mass flow rate.
used for the water vapour [9]. Furthermore, a partial slip boundary condition at walls was used with a tangential momentum accommodation coefficient (TMAC) of 0.80.

Concerning the computational domains, a radius of curvature equal 75 μm characterized the throat section, while at the inlet eight equivalent microchannels of $9 \times 10^{-5}$ m width preserved the actual cross section area, in combination with a mixing region of $1.8 \times 10^{-4}$ m length before the entrance into the convergent region (see Fig. 1).

The mesh refinement affected mainly the region of the boundary layer. The 2D grid was composed of 23,931 cells, while the 3D mesh consisted of 516,360 cells. Table 2 reports the setting used for the simulations.

The contour plots of the static pressure $p$, the Mach number $M$ and the temperature $T$ resulting from the viscous 2D computations (test case SIM2-2D) are shown in Figs. 2–4, in comparison with the solution provided by 3D computations in the symmetry plane normal to the depth-wise direction. The most relevant isolines are also highlighted in Figs. 2–4, so that a detailed description of the flow field inside the micronozzle is provided.

![Fig. 1. Planar characteristics of the symmetrical half geometry of the micronozzle.](image)

**Table 2**

Test matrix of CFD simulations. $p_{\text{outlet}}$ is the back pressure, $T_{\text{inlet}}$ is inlet temperature, $m$ is the mass flow rate, TMAC is the tangential momentum accommodation coefficient.

| Test case name | Flow type | Tinlet [K] | $m$ [kg/s] | poutlet [Pa] | Slip condition | Test case file |
|----------------|-----------|------------|------------|-------------|----------------|----------------|
| SIM2-2D        | 2D        | 505.58     | $5 \times 10^{-6}$ | 20          | Maxwell, TMAC = 0.8 | File3.xlsx     |
| SIM2-2Dslip    | 2D        | 505.58     | $5 \times 10^{-6}$ | 20          | Pure Slip      | File2.xlsx     |
| SIM2-3D        | 3D        | 505.58     | $5 \times 10^{-6}$ | 20          | Maxwell, TMAC = 0.8 | File4.xlsx     |

![Fig. 2. Contour plots of the static pressure $p$: (a) viscous 2D solution (SIM2-2D); (b) viscous 3D solution (SIM-3D).](image)
Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at https://doi.org/10.1016/j.dib.2018.12.013.

Fig. 3. Contour plots of the Mach number $M$: (a) viscous 2D solution (SIM2-2D); (b) viscous 3D solution (SIM-3D).

Fig. 4. Contour plots of the temperature $T$: (a) viscous 2D solution (SIM2-2D); (b) viscous 3D solution (SIM-3D).

References

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