Assessment of a quantum computing approach for the design of aeronautical refrigerant ejectors

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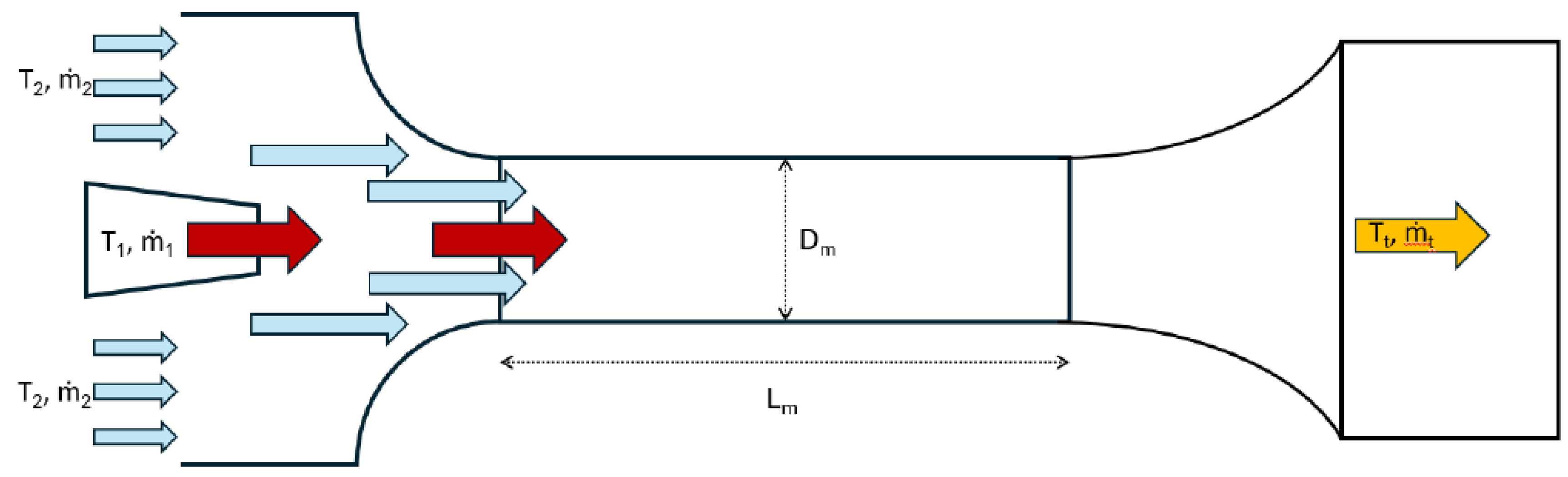
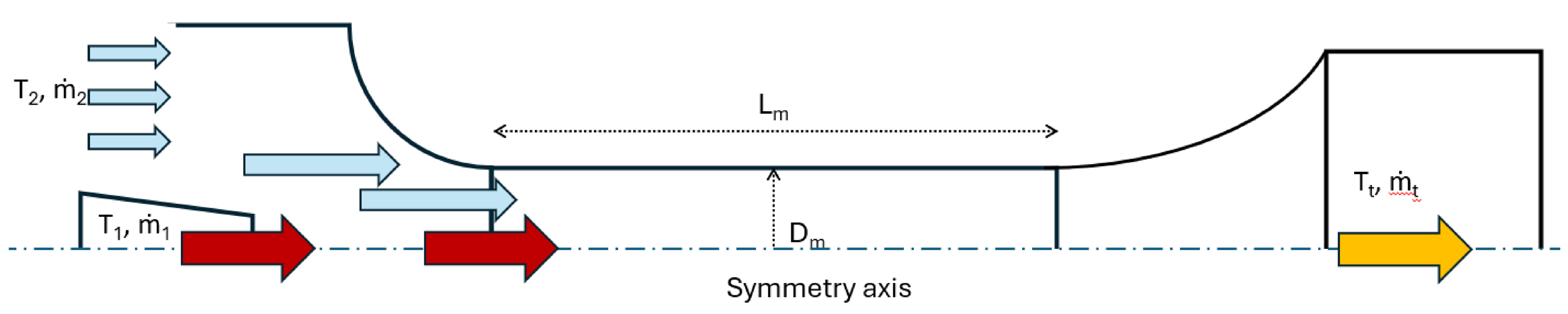


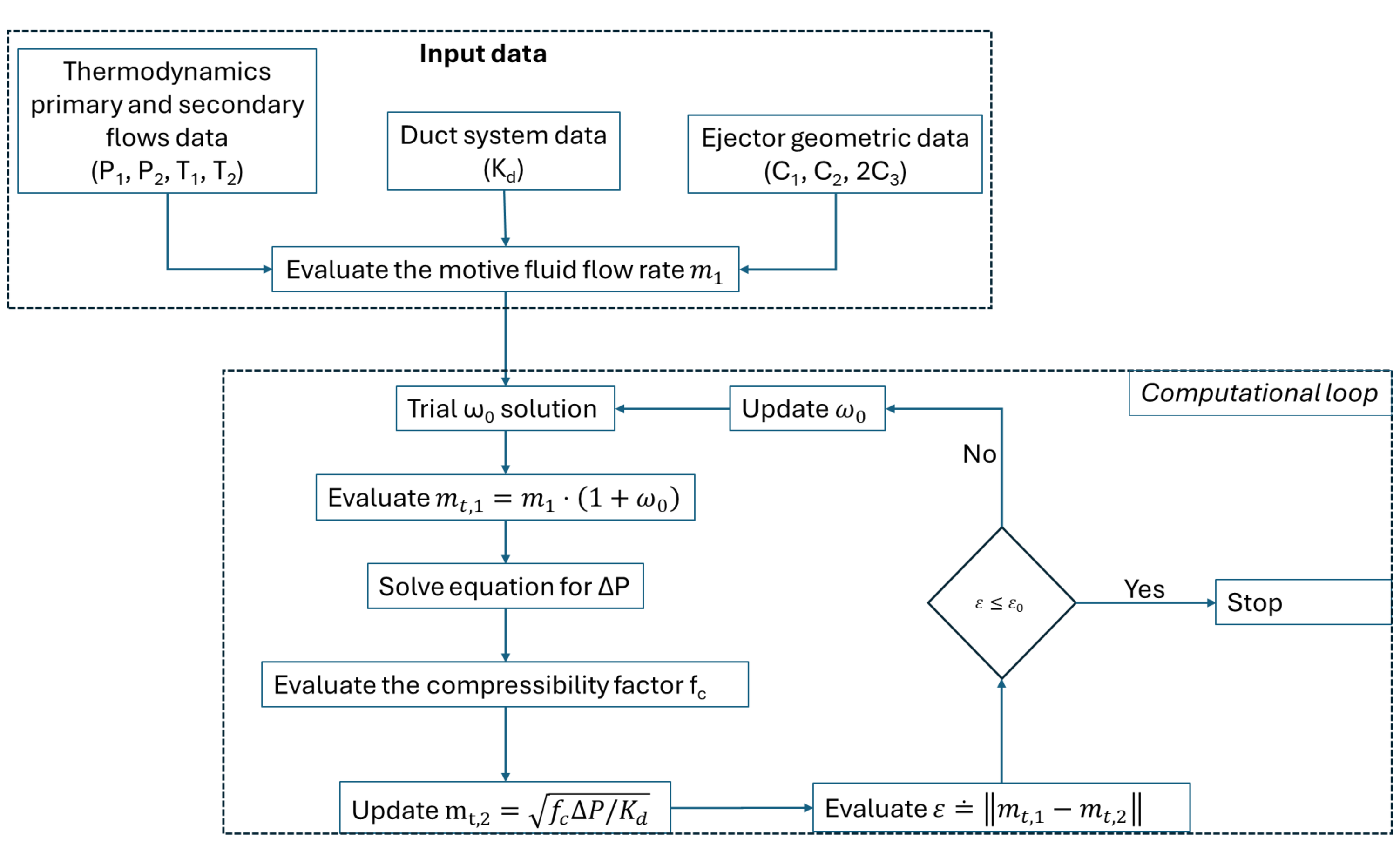
Ejector, also known as jet pump, is a reliable and quite efficient device based on Bernoulli's principle and its purpose is to mix two flows. This type of device is widely used in several applications, from nuclear boiling water reactor plant to aeronautical environmental control system



The fundamental laws governing the ejector functioning are basically the classical physics conservation laws. Additionally, there are to be considered equations that couple mass flowrate with back pressure ΔP and the effects of compressibility σ, obtaining a non-linear set of equations:

$$\begin{cases} \Delta P^* = T_r \cdot \left(C_1 - C_2 T_r^{0.8} \omega^2 - C_3 T_r^{0.4} \omega + \dfrac{K_p^*}{T_r} \right) \\ \sigma \cdot \Delta P^* = \dfrac{K_d \cdot \dot{m}_1^2}{\frac{1}{2} \rho_2 v_1^2} \cdot (1+\omega)^2 \\ \sigma \cdot (1 + T_r \omega) = \dfrac{P_2}{\rho_2 R_g T_1} \cdot (1+\omega) + \dfrac{1}{2 \rho_2 R_g T_1} \cdot \Delta P_0 \cdot (1+\omega) \end{cases}$$

Besides the resolution with numerical methods (i.e., CFD), traditional (classical) resolution of this system relies on an iterative method starting from a trial solution of entrainment ratio ω, followed by evaluation of pressure rise ΔP and compressibility σ.



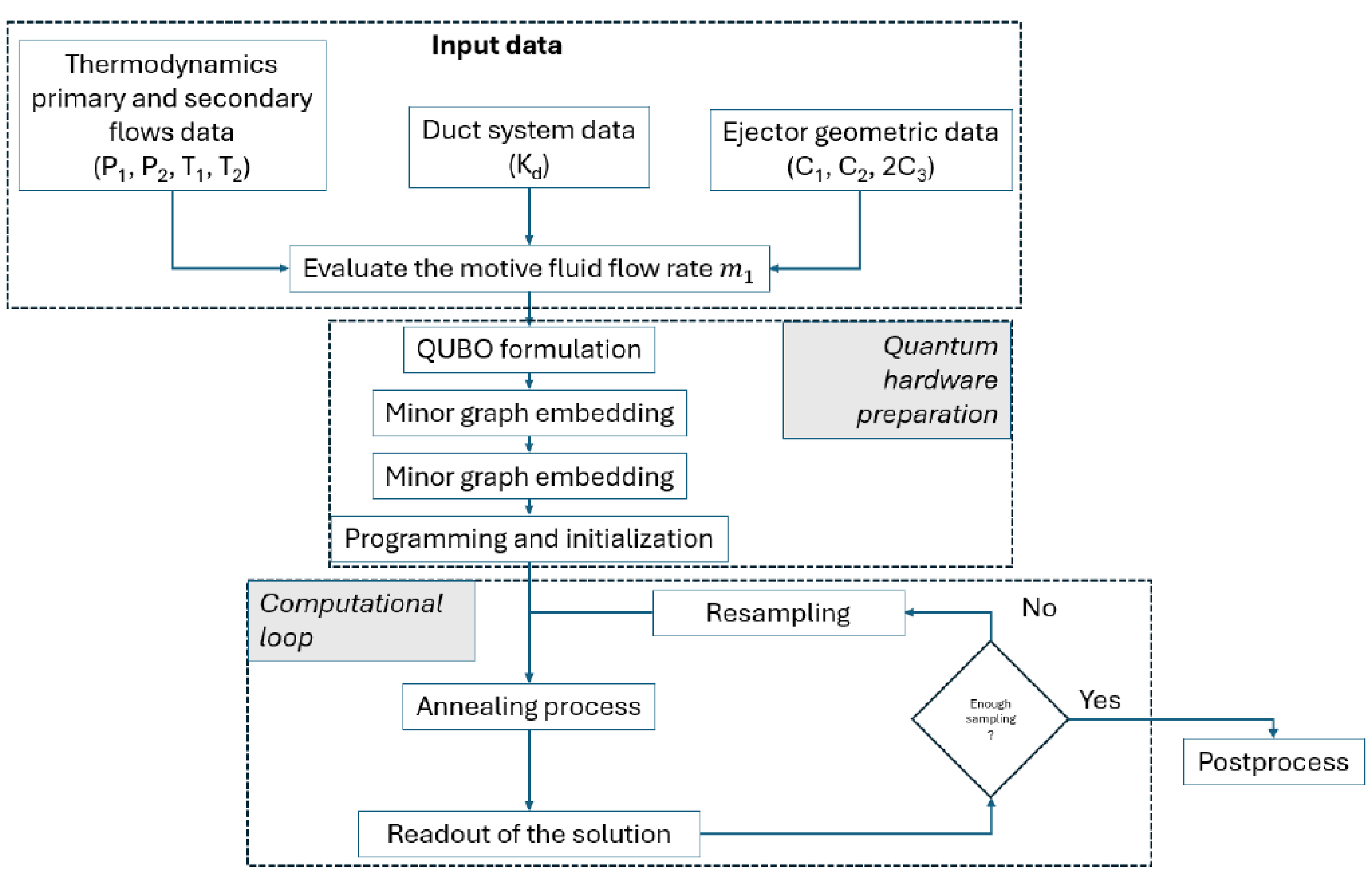
The major drawback of this approach consists in the selection of the trial entrainment ratio ω_0 and in the algorithm used for the minimization of the error, because the trial entrainment ratio ω_0 shall be constrained between 0 and a maximum entrainment ratio ω_{max}, the latter being the maximum value of ω that renders no negative the pressure rise ΔP. If not correctly addressed, this issue could lead to numerical errors and instabilities.

To overcome the iterative resolution and the numerical instabilities that this approach inherently introduces (e.g., the selection of negative square roots), it is possible to envision a direct resolution of ejector's design equations exploiting the binary optimization methods. The idea is to solve the ejector's equations directly and simultaneously, identifying the vector of unknowns {x} given by the entrainment ratio, the non dimensional pressure rise and the compressibility. The second step is to discretize the unknown variables, through a binary mapping:

$$\{x\} \simeq \begin{bmatrix} A_\omega^d & \varnothing & \varnothing \\ \varnothing & A_{\Delta P^*}^d & \varnothing \\ \varnothing & \varnothing & A_\sigma^d \end{bmatrix} \begin{Bmatrix} \{q_\omega\} \\ \{q_{\Delta P^*}\} \\ \{q_\sigma\} \end{Bmatrix} = [A^d]\{q\}$$

The set of equations can be reformulated into a High Order Unconstrained Binary Optimization form (HUBO). The HUBO formulation, consisting of quadratic, cubic, and quartic terms can be traced back to the classic QUBO formulation by introducing auxiliary binary variables.

$$\sum_{j,k,l,m=1}^{n} K_{jk}^i K_{lm}^i q_j q_k q_l q_m + \sum_{j,k=1}^{n} 2 b_i K_{jk}^i q_j q_k + b_i^2 = \varepsilon_i^2$$



The approach has been validated through the comparison of results obtained with numerical simulation (CFD), classical analytical methods and the quantum simulation. The quantum method has proven to be comparable to the classical analytical method in terms of accuracy and precision in the results achieved.