Turbulent Compressible Flow in a Slender Tube

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Abstract

Pressure-drop experiments were conducted for the turbulent compressible flow of air in a small slender tube; "scale-up" of the experimental results to other gases at higher temperatures and pressures requires numerical modeling. In this paper, the COMSOL heat transfer module is used with the k-ε turbulence theory to model the axis-symmetric flow and pressure fields. Additionally, based on the numerical results, an analytical 1-D model is derived. The usual boundary conditions are specified pressure at the outlet (here atmospheric) and velocity at the inlet, however, the inlet condition is specified mass flow and the unknown pressure at the inlet is needed to determine the velocity. Therefore, a scalar integration variable is introduced which integrates the mass velocity [kg/m²s] over the inlet area and iteratively equates this to the input mass flow [kg/s]. For computation, the COMSOL built-in library properties for air were used with a constant temperature, which resulted in the isothermal compression of the flow. However, the high-velocity air-flow is closer to adiabatic conditions; thus, the temperature specification was related to the local calculated pressure through the isentropic relationships. The results of the COMSOL computation show significant density variation along the tube and indicate choking at the outlet (Ma ~ 1) for the highest flow. For the adiabatic conditions there is excellent agreement with the experimental data for a wide range of flows, excluding near-choking conditions at the outlet.