Transonic Small-Disturbance Theory for Non-equilibrium, Non-isothermal and Homogeneous Condensation in Compressible Nozzle Flows

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ABSTRACT

A small-disturbance model is developed to describe steady, inviscid transonic flows of steam undergoing non-equilibrium and homogeneous condensation by expansion through a nozzle or around an airfoil. This model allows the exploration of non-linear interactions between the near-sonic speed of the flow, the amount of condensate formed as a result of changes in pressure and temperature and the geometry of the device. The condensation rate and droplet characteristics are obtained through classical nucleation theory which is modified to include non-isothermal effects. The model results in an extended transonic small-disturbance (TSD) equation to evaluate properties of the flow coupled with four ordinary differential equations for the description of condensation properties. The asymptotic analysis yields similarity parameters which govern a transonic flow of steam. These are the classic transonic similarity parameter K which describes how close the speed of the upstream flow is to sonic speed, the rate similarity parameter K_J which characterizes the nucleation rate of droplets being formed, the number of molecules within a characteristic droplet, n_c, and the parameter K_t which defines the ratio of flow convection time to characteristic time of condensation. An iterative numerical scheme is used to solve the TSD model equations utilizing the Murman & Cole (1971) type changing method and Simpson's classical integration method. The computed results show that computations converge with mesh refinement for both dry and condensating steam flows. An agreement with experiments performed by Moore, Walters, Crane & Davidson (1973) is found. The results demonstrate that condensation becomes more pronounced and moves upstream with the decrease of total temperature. The results this study can be used to further the understanding of condensation phenomena found in transonic flows of steam through converging-diverging nozzles and around airfoils. The understanding gained from this method of solution will aid in the design and optimization of flow devices such as atomizers, fuel injection nozzles and steam turbine cascades.