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Maximizing pressure recovery using lobed nozzles in a supersonic ejector

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ABSTRACT

Novel designs for supersonic ejectors in refrigeration applications focus on the reduction of the primary fluid flow rates required (entrainment ratio), as well as, increasing the total pressure recovery. This work improves the performance by enhanced mixing through flow instability by adding lobes to the circular nozzle design, combined with the profiling of the mixing channel. The objective was to determine the impact of the aspect ratio and total perimeter of the lobes on system pressure recovery and entrainment ratio. Using the conditions and geometry from the Eames [1] profiled mixing channel as the baseline and integrating a lobed nozzle, an improved pressure recovery of 6.4 from 4.0 with a perimeter value of 30 mm was achieved. Increasing the perimeter beyond this value drives the frictional losses along the wall surfaces to dominate the process and the recovered pressure reduces back to the circular nozzle.

1. Introduction

Supersonic ejectors work on the principle of transferring mass to the primary flow to increase pressure of the mixed flow as it exits the ejector [2]. A significant amount of research has been done in the area of supersonic ejectors from refrigeration applications. In earlier work, Keenan et al. [3] developed a one dimensional analytical approach to assist in design using first principles (i.e., continuity and energy equations). Building off of Keenan et al., Munday et al. [4] developed a theory to account for the effective choke area for the secondary flow. Later, other researchers continued to improve on the models by accounting for irreversibilities within the system [5–7]. From these analytical models came numerous experimental efforts that explored wide ranges in operating conditions [4,6,8–10], as well as comparisons to computational fluid dynamic (CFD) simulations [11–14].

Refrigerant systems are small in size and flow rates. For large military or industrial applications, there can be a need to reduce the weight and overall footprint of the pressure recovery system. Thus the motivation to maximize the pressure recovery for a given entrainment ratio needs to be further explored. Research done in refrigerant systems has sought improved efficiencies. For instance, Eames [1] proposed a profiled geometry for the mixing channel in order to remove normal shocks. The profile does not directly reduce the primary fluid requirements, but dramatically increases the pressure recovery. A redesign of parameters may allow for the reduction of fluid requirements for a given pressure recovery. Eames provides a one-dimensional analysis that generates the profiled channel for a given set of boundary conditions. Varga et al. [15] also reports that there is an optimum distance from the primary nozzle exit position to the entrance of the mixing channel to provide the largest entrainment of the two fluids. The shape of the primary nozzle was explored by Srikrishnan et al. [16]. They observed enhanced mixing of a six-lobed nozzle compared to a round nozzle at Mach 1.67 into a sonic secondary flow with equal boundary conditions. The degree of mixing was quantified by the distribution of the momentum at a given location downstream. Similarly, Chang et al. also looked at a six-lobed nozzle in their experiments and concluded that the lobed nozzle outperformed a round nozzle, but the flow field was not well understood [17].

Other researchers [17–19] have proposed different nozzle geometries to promote flow instabilities to enhance the entrainment of the secondary flow. Hui et al. reports that lobed nozzles have great differences in turbulent structures and vortex scales compared to circular nozzles, which enhance mixing [20]. These elliptical or lobed structures emanating from a central point create the shedding of vortices from the nozzle tip due to Kelvin-Helmholtz instabilities. However, as one increases the surface area of interaction the internal frictional losses in the nozzle prior to injection will hinder performance (i.e. average mach numbers will drop as a result of frictional loses). By taking a circular exit nozzle and adding lobes, vortices for mixing are created. If more and more lobes are added, the nozzle exit returns to a circular shape. Therefore, the hypothesis is that there has to be an optimum number of lobes, or perimeter of the shear layer, resulting in the maximum amount of mixing of the entrained flow.

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