Active Flow Control of Single and Two Phase Flows with Applications to Heat Transfer

by

Anna A. Pavlova

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Examining Committee:

Dr. Michael Amitay, Thesis Adviser

Dr. L. Castillo, Member

Dr. I. Herron, Member

Dr. M.K. Jensen, Member

Dr. Y. Peles, Member

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ABSTRACT

This manuscript discusses using synthetic jets to enhance heat transfer for low heat fluxes in impingement cooling and for active control of sprays, with applications to spray cooling for high heat fluxes in the non-boiling regime.

The efficiency and mechanisms of heat transfer by impinging synthetic jets were investigated experimentally and compared to cooling with continuous jets. The effects of synthetic jet formation frequency and Reynolds number at different nozzle-to-surface distances, H/d, were investigated. Synthetic jets were found to be significantly more effective in cooling than continuous jets at the same Reynolds number. High frequency synthetic jet was more effective at small H/d, while low frequency jet was more effective at larger H/d. Flow fields of synthetic jets were investigated with PIV, showing that higher formation frequency jets are associated with breakdown and merging of vortices before they impinge on the surface. In lower frequency jets, the wavelength between coherent structures is larger, such that vortex rings impinge on the surface individually.

Synthetic jets were also used to actively control air-assisted atomized full cone water sprays. Experiments were conducted for a range of momentum coefficients, C_μ, water intake elevations, and spray flow rate ratios; Q_a/Q_w. PIV was used to assess the effect of synthetic jets on global spray behavior, while Shadowgraphy was used to measure microscopic spray characteristics. A single synthetic jet was shown to provide significant vectoring of the spray, with increased vectoring, spray width, and velocity RMS for low Q_a/Q_w and high C_μ. For low Q_a/Q_w, small droplets are moved away from the synthetic jet, increasing their concentration on the opposite side. For high Q_a/Q_w, the number of large droplets is increased along the centerline due to coalescence.

The effectiveness of flow control using four jets, ramped flapping, and on-off flapping on spray cooling performance (in the absence of boiling) was investigated experimentally at several spray nozzle-to-surface locations, H/d_s, and low $Q_a/Q_{,}$ showing that heat transfer from the surface is enhanced by flow control at all H/d_s tested. The mode of flow control, together with spray properties and the distance between the spray and the hot surface play an important role in cooling enhancement.