Atomization of Impinging Liquid Jets in a Supersonic Crossflow

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Abstract

THIS work describes a method to improve the performance of transverse liquid jet injectors in a high-speed gas flow. The measures of performance are the extent of the cross-stream penetration of the bulk of the liquid and the fineness of the droplets in the spray plume. It has been found that simple round injector ports often provide inadequate penetration and atomization for port sizes and injectant flow rates in the range of practical values—approximately 1 mm and $\bar{q} \equiv \rho_j V_j^2 / \rho_\infty V_\infty^2 \approx 5$-15. A simple, passive type of injector is preferred for reasons of cost and reliability. We have studied the benefits to be gained by employing two smaller, inclined injectors so that the jets impinge just above the boundary surface rather than using a single perpendicular injector. Arrangements where the plane of the jets was aligned with and across the gas flow were both tested.

Contents

Approach

The tests were conducted in the VPI 23×23 cm wind tunnel at $M_\infty = 3.0$ with $p_0 = 4.2$ atm and $T_0 \approx 300$ K. Water was used as the injectant for safety and cost reasons. The methods of observation were: 1) spark photomicrographs (10^{-8} s) to show instantaneous jet structure, 2) streak photographs (10^{-3} s) to give the time-averaged outer boundary of the plume for penetration measurements, and 3) diffractive scattering of a laser beam to give mean droplet size following the method of Refs. 1 and 2.

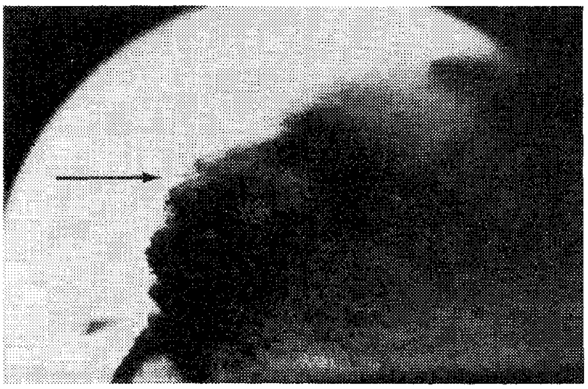
The injector was mounted in a 15.4×24.5 cm flat plate supported from the floor of the test section. After some preliminary testing, an injector with two 0.65 mm diam ports, inclined at 30 deg to the vertical and spaced to intersect 4.0 mm above the plate surface, was selected for intensive study. An injector with a single perpendicular port of 0.91 mm diam with the same total flow area as the impinging jet injector was used as a reference case.

Results

Typical spark pictures are shown in Fig. 1. These photographs show that when the injector is aligned with the flow, the plume formed after the impingement follows a vertical path up to a certain point, where it then disintegrates into clumps. This point corresponds to the location where the flow just behind the curved bow shock first becomes supersonic. For the case where the injector was oriented transverse to the freestream, the plume was not nearly as vertical as in the aligned case.

The most important piece of data obtained from the streak pictures is the penetration of the liquid into the freestream. It was originally thought that in the process of angled injection and jet impingement, vertical momentum would be lost and penetration might be less than that of a circular injector. However, this was found not to be the case. Penetration measurements were taken at a station 20 mm downstream of the injector over a range of $\bar{q}$ for both the aligned injector and transverse arrangements. The nondimensional penetration h/d_j was then plotted against the dynamic pressure ratio $\bar{q}$ and compared to the present results for a circular injector of equal total area and a data correlation for circular injectors from Ref. 3. This plot is shown as Fig. 2. It can be seen that the transversely oriented injector displays penetration almost identical to the circular injector; however, the aligned injector shows a significant increase in penetration, especially at low $\bar{q}$.

The results of the droplet size measurements are of special interest, since a clear benefit will be derived from finer atomization of the spray. The optical arrangement used in this investigation yielded an average droplet size in an area the size of the laser beam (.071 cm²). The droplet size distribution was found at various stations in the plume. Measurements were made at $\bar{x} = x/d_j$ locations of 10, 15, 25, 50, 90 from the injector. The y locations were chosen according to the height of the plume at each station. The results are presented graphically in Figs. 3 and 4 for $\bar{q} = 4$ and 12, where mean droplet diameters are plotted as a function of position along the plume centerline. The $\bar{x}$ and y/h axes locate the space coordinates along the plume, and mean droplet diameters are plotted along the normal axis. The results for the single

a) 

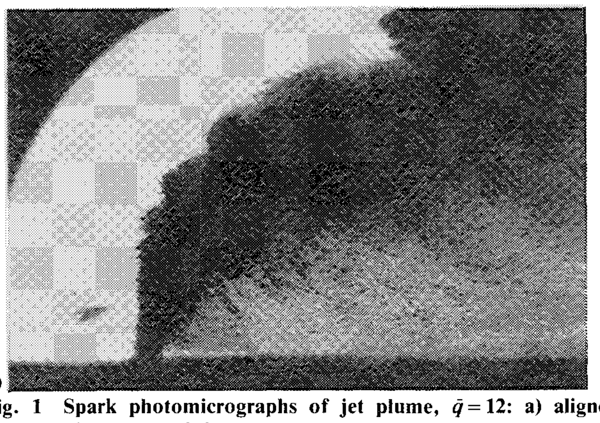
b) 

Fig. 1 Spark photomicrographs of jet plume, $\bar{q} = 12$: a) aligned injector, b) transverse injector.

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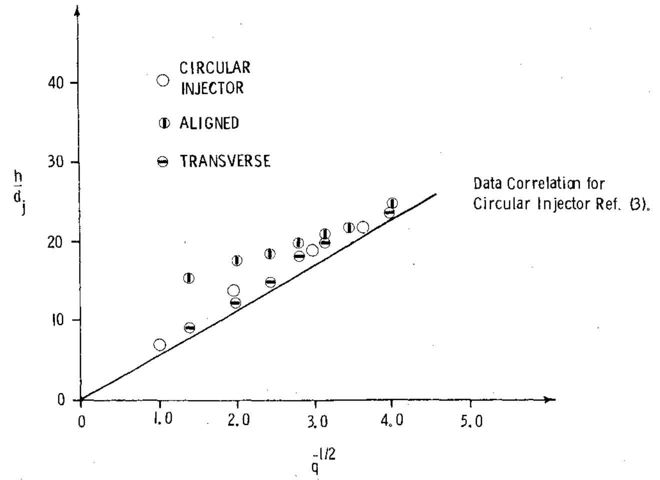

Fig. 2 Plot of penetration vs $\bar{q}$.

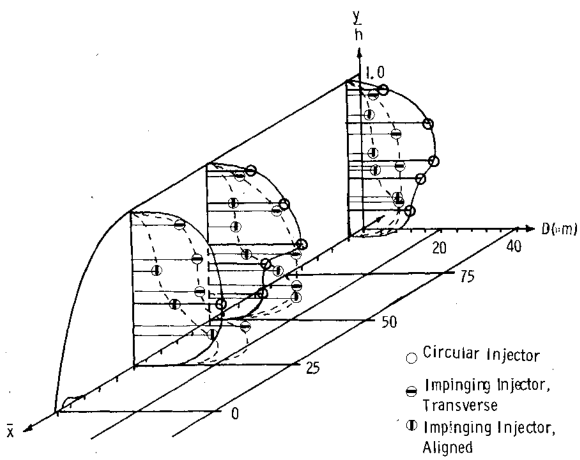

Fig. 3 Droplet distribution in plume, $\bar{q} = 4$.

circular injector are shown as 0 in Fig. 3. The larger droplets occupy the center of the plume, with smaller droplets above and below, forming a somewhat elliptical vertical distribution. The results of the impinging injector oriented transversely to the freestream are shown on Figs. 3 and 4. The same roughly elliptical droplet distribution is evident; however, the droplet sizes are substantially smaller. With the aligned injector (Figs. 3 and 4) it can be seen that the droplet diameters are reduced even further. The larger droplets no longer occupy the center of the plume, but are shifted

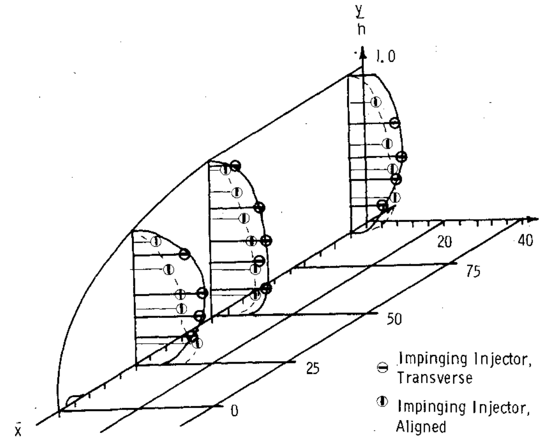

Fig. 4 Droplet distribution in plume, $\bar{q} = 12$.

downward. Several generalizations can be made upon further examination of the data: 1) for a given dynamic pressure ratio, the impinging jets atomized the fluid more completely than a single circular jet; 2) when the impinging jets are aligned with the airflow, the atomization is more complete than for a transverse orientation; 3) in all cases, increasing the dynamic pressure ratio increases the degree of atomization of the fluid; 4) in all cases, as the downstream distance from the injector increases, the mean droplet diameter decreases; and 5) in the case of the aligned injector the larger droplets were concentrated close to the plate, whereas for the transverse and circular injectors the largest droplets followed the center of the plume.

These results show definite improvement over the conventional circular jet injector. The best results were obtained with the jets aligned with the flow.

Acknowledgment

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