Further Time-Mean Measurements in Confined Swirling Flows

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Abstract

NONSWIRLING and swirling nonreacting flows are investigated in an axisymmetric test section with expansion ratio $D/d=2$, which may be equipped with contraction nozzles of area ratios 2 and 4. The effects of several geometric parameters on the flowfield are investigated, including: sidewall expansion angle $\alpha=90$ and 45 deg, swirl vane angle $\phi=0$, 38, 45, 60, and 70 deg, and contraction nozzle location $L/D=1$ and 2 (if present). Data acquisition is via a five-hole pitot probe enabling three time-mean velocity components in the axial, radial, and azimuthal directions to be measured. Velocities are extensively plotted and artistic impressions of recirculation zones are presented in the full paper, with the major results being summarized here.

Contents

The present study is based on a recently completed M.S. Thesis,[1] in which the results are extensively tabulated in a form suitable for associated computer code prediction studies.[2] It extends earlier work[3] (restricted to 0, 38, and 45 deg of swirl) to higher swirl strengths and clarifies the effect of typical downstream contraction nozzles on the flowfield.

Experimental Approach

The confined jet facility is described at length elsewhere.[1] In terms of nondimensional flow characteristics further downstream, typical operating velocities are in the Reynolds number insensitive range for this facility. The inlet swirler has 10 vanes that are individually adjustable to any angle ϕ and has a hub with a streamlined upstream nose and a flat downstream face. The nose has a hyperbolic shape with a very smooth surface so as to offer minimal flow interference. The flat blades are wedge shaped to give a constant pitch-to-chord ratio of 0.68, which should give good turning efficiency. Extensive data on the performance and exit velocity profiles from this swirler are available for a full range of swirl strengths.[4] Two downstream contraction nozzles of area ratios 2 and 4 are being used and their effect on the upstream flowfield investigated. The weaker one has its upstream face contoured in a quarter circle, as found in practical ramjet combustors. The stronger contraction has its upstream face in a 45 deg slope, more typical of gas turbine combustion chamber exits. These blocks may be located at any axial position in the test section. The instrumentation employed with the five-hole pitot probe measurement technique and the data reduction methods are the same as used previously.[3]

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Results and Discussion

Effects of Swirl on Sudden Expansion Flows

The present study extends the range of swirl strengths from those investigated earlier.[3] With the swirler removed, the nonswirling sudden expansion flows exhibit the expected uniform axial velocity entering the test section, with a corner recirculation zone extending to just beyond $x/D=2$, approximately eight step heights downstream of the expansion corner. A central recirculation zone is observed only in the swirl flow cases investigated, with a precessing vortex core of high swirl velocity gradients with low negative axial velocities. The size of the central recirculation zone increases with the increasing swirl vane angle until a certain angle is reached (about 40 deg). Then its length begins to decrease under stronger swirl conditions, but its width continues to increase. The core vortex was present at all values of the swirl vane angle used in this investigation. As with the central recirculation zone, the vortex core gets continuously wider as the swirl vane angle increases.

Figure 1 shows axial and swirl velocities in the sudden expansion flow without the contraction nozzle and with the inlet swirl vanes at 70 deg. A considerable back flow around the hub is observed for $\phi=70$ deg, as shown in the figure. For all values of the swirl vane angle used in this study, the corner recirculation zone does not extend beyond $x/D=0.5$, the closest axial measuring location to the expansion block; indeed, the maximum axial velocity is observed close to the top at $x/D=0.5$. The effects result from strong centrifugal forces present in the incoming swirling flow.

Effects of a Gradual Expansion

Gradual expansion flows with $\alpha=45$ deg were also investigated over the same range of swirl strengths. The effects were primarily confined to the upstream flowfield less than one chamber diameter downstream of the inlet. Velocity profiles for a gradual expansion follow a similar trend to those for a sudden expansion. The major effect of a gradual inlet expansion is to encourage the air to flow along the side sloping wall, to shorten the corner recirculation zone, and to accelerate the axial velocities close to the top wall. The influence on the central recirculation zone for the swirl flow cases in minimal.

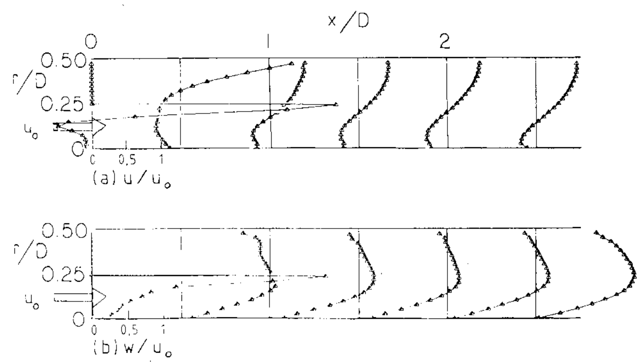

Fig. 1 Velocity profiles for sudden expansion flow without contraction nozzle, with inlet swirl vane angle $\phi=70$ deg.

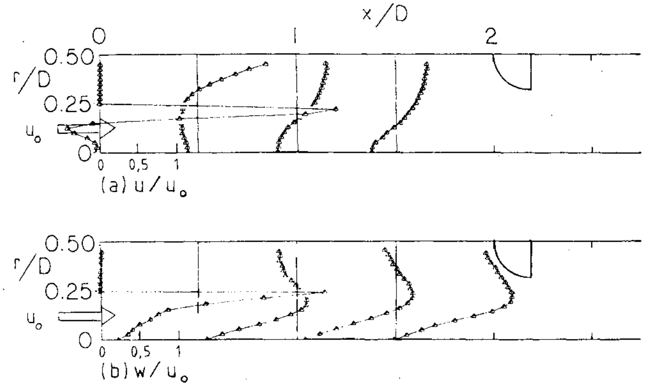

Fig. 2 Velocity profiles for sudden expansion flow with weak contraction nozzle at $L/D = 2$, with inlet swirl vane angle $\phi = 70$ deg.

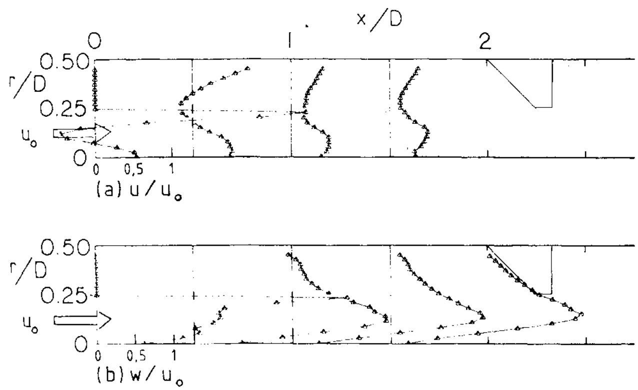

Fig. 3 Velocity profiles for sudden expansion flow with strong contraction nozzle at $L/D = 2$, with inlet swirl vane angle $\phi = 70$ deg.

Effects of a Weak Contraction Nozzle

The effect of a weak contraction nozzle with area ratio 2 was investigated with the contraction block located at $L/D = 1$ and 2 for a range of swirl strengths $\phi = 0$, 45, and 70 deg with a sudden expansion only at $\alpha = 90$ deg. It was found that a weak contraction nozzle has the most effect on the intermediate swirl case of $\phi = 45$ deg. In this case, its contraction effect is strong enough to overwhelm the swirling recirculation region and to cause forward movement of previously recirculating flow, except in a region close to the inlet. However, the weak contraction has little effect on weakly or strongly swirling flows, which are dominated by forward flow and centrifugal forces, respectively. For example, Fig. 2 shows axial and swirl velocity profiles when the weak contraction nozzle is located at $L/D = 2$. The velocity field has changed little from the open-ended case of Fig. 1.

Effects of a Strong Contraction Nozzle

The effect of the stronger contraction nozzle of area ratio 4 was similarly investigated and found to have a more dramatic effect on the flowfields, particularly affecting both the intermediate and strong swirling flow cases. The central recirculation zones are shortened considerably and the axial velocities near the facility axis become highly positive. The core regions become narrower with very strong swirl velocity magnitudes and gradients. For a swirl vane angle $\phi = 70$ deg, the axial and swirl velocity profiles are given in Fig. 3 with the strong contraction blockage located at $L/D = 2$. The axial velocity near the axis is highly positive and the central recirculation region is very small, extending in an annular region to less than $x/D = 1.0$, much less than its corresponding case with the weak contraction block of Fig. 2 and considerably less than the no-blockage case in Fig. 1.

Acknowledgments

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