Experimental Investigation of Confined Coaxial Swirl Flow


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ABSTRACT

Swirling flows are widely used in combustion chambers and furnaces, due to their effect on flame stabilization, mixing improvement and the reduction of pollutant emissions. In the present work, the isothermal flow field of a coaxial combustor is being studied. Particularly, the influence of the mass flow ratio between the outer (annular) flow and the inner (swirling) jet on the flow characteristics is being investigated. Swirl is produced by means of tangential injection. The swirling jet is introduced into the combustion chamber through a slightly conical nozzle, while a centrifugal fan supplies the annular flow. X-probe HWA measurements of the mean and turbulent flow field are presented for several distances downstream in the combustor. It is shown that variation of the mass flow ratio strongly affects the structure of the shear layer as well as the decay of the jet’s swirl strength.

INTRODUCTION

This work is a part of a computational and experimental effort being conducted in L.A.T., on the investigation of vortical flows and their application to technological processes and combustion schemes.

Swirling flows are widely used in combustion chambers and furnaces, as swirl provides:

- High entrainment and mixing rates close to the exit nozzle.
- Flame stabilization.
- Reduction of the pollutants emissions.

The use of swirl in combustion systems is characterized by the creation of a high radial pressure gradient in the eddy with corresponding reduction of axial and tangential component of velocity and increase of pressure along the flow structure. This phenomena lead to the creation of a powerful recirculation eddy, which increases the entrainment and controls the combustion of the mix. In a coaxial combustor Swirl number $S$ (ratio of the tangential momentum flux to the axial momentum flux) and the flow mass ratio $M$ between the outer and the inner jets are found to be important parameters for a fixed area ratio flow field.

\[
S = \frac{\int_0^R U W r^2 \, dr}{R \int_0^R U^2 r \, dr} \quad (1)
\]

\[
M = \frac{\int_0^R U r \, dr}{\int_0^R U \, dr} \quad (2)
\]
Flows with high swirl numbers (S>0.6) form recirculation zones, which result into fast entrainment but also to a rapid diffusion of angular momentum. Low swirl jets enhance entrainment rates and spread angle but don’t affect dramatically the flow structure. The absence of recirculating zones prevents downstream changes to influence upstream events.

EXPERIMENTAL FACILITY

The experimental facility consists of a conical swirler and a coaxial annular duct from which parallel flow is introduced into the chamber. The test chamber consists of a 400 mm long plexiglass tube of 100 mm inner diameter. Swirl is produced by four tangential injectors (6mm diameter), which are located five diameters upstream from the jet’s exit (28 mm diameter). An air compressor supplies tangential flow, which is measured with a flow meter. In order to avoid flow oscillations a relaxation pressure vessel was used. Also, air pressure is regulated at two points (the exit of the vessel and before the flow meter). A centrifugal fan supplies the annular flow.

Two dimensional velocity measurements were taken using a Dantec X-wire probe and an AALABS anemometer. Calibration of the hot wire was made for 8 velocities (0-8 m/s) and 17 pitch angles (-40°-40°). For the needs of the present work, measurements were taken up to 10 diameters downstream from the jet’s exit. Velocity was measured at 81 stations for each cross-section. The probe was mounted on a L-shape transversing mechanism and software controlled step motors guided its movement.

Time series of the voltage signal were recorded with a scan frequency rate 15000 scans/s applying a 5 kHz low pass filter. A National Instruments16 channel A/D board was used for data acquisition.

In Table 1 the experimental conditions are presented. Reynolds Number is based on the bulk velocity of the swirling jet and the annular flow.

![Figure 1: (a) Side view of the Test Rig (b) Front view](image)

<table>
<thead>
<tr>
<th>Test Case</th>
<th>S_0</th>
<th>M</th>
<th>Re_b ∞</th>
<th>Re_{bs}</th>
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<tr>
<td>a</td>
<td>0.22</td>
<td>12</td>
<td>15884</td>
<td>3757</td>
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<tr>
<td>b</td>
<td>0.17</td>
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<td>15884</td>
<td>8330</td>
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<tr>
<td>c</td>
<td>0.19</td>
<td>9</td>
<td>26473</td>
<td>8330</td>
</tr>
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</table>

*Table 1. Experimental Conditions*
EXPERIMENTAL RESULTS

Mean Flow Field

Fig. 2 (i) Mean Streamwise Velocity Profiles for test cases a. M=12, b. M=5.5 and c. M=9

Fig. 2 (ii) Mean Tangential Velocity Profiles for test cases a. M=12, b. M=5.5 and c. M=9
Streamwise Evolution of Centerline Velocity and Swirl Number

In Figures 2(i) and 2(ii) the evolution of the mean streamwise and tangential velocity radial profiles is presented for the three test cases. Jet profiles (streamwise velocity) reveal the strong interaction between the swirling jet and the annular stream and the flow’s tendency to form recirculation zones close to the exit of the nozzle. As flow develops streamwise profiles become smoother. At 10-jet diameters, flow seems to be fully developed. For test cases a & c jet development is quite similar as the corresponding mass flow ratios are nearly equal. For test case b a more pronounced mixing layer between the swirling jet and the annular flow is observed. The evolution of the jet’s centerline velocity is depicted in Figure 3. It is apparent that in the case of low Mass flow ratio the swirling jet overcomes faster the velocity hysteresis created by the tangential component. Tangential velocity profiles show how the vortex spreads and weakens in the combustor until 8 jet diameters downstream, where its swirl strength remains almost constant. In Figure 4 it is shown that in the case of low Mass flow ratio the swirling jet’s strength decays much slower comparing to cases a & c.

Remarks on Turbulent Flow Field Measurements

Turbulence statistics provide important information to the understanding of flow topology and mixing process in the combustor. In Figures 6 and 7 the evolution of rms velocities (streamwise and tangential) and Reynolds Stresses radial profiles is presented, respectively. Maximum streamwise velocity fluctuations are observed at the interaction zone of the swirling jet and the annular flow.
**Turbulent Flow Field**

![Graphs a, b, and c showing streamwise and tangential velocity profiles and Reynolds stresses profiles for different test cases with Mach numbers M=12, M=5.5, and M=9.](image)

**Fig. 6** Rms Streamwise and Tangential Velocity Profiles for test cases a. \(M=12\), b. \(M=5.5\) and c. \(M=9\)

**Fig. 7** Reynolds Stresses Profiles for test cases a. \(M=12\), b. \(M=5.5\) and c. \(M=9\)
Tangential velocity fluctuations reach maximum value at the boundary between the forced and free-vortex region. Profiles of velocity fluctuations reveal a more uniform distribution of the turbulent kinetic energy in the combustor for test case b. Rms velocity profiles that swirl flows are quite anisotropic. The kinetic energy of the flow decreases downstream as swirl decays. Reynolds stresses become strong at the boundary of the vortex-core and diminish towards the center of the vortex. From the radial profiles of the Reynolds stresses we can see that the shear layer in case b is wider across the combustor cross-section, thus implying that diffusion between the swirling jet and annular flow takes place in a wider area. On the other hand it is pointed out that shear stresses decay is slower for test cases a & c as flow evolves. Practically, mixing process between the swirling jet and the annular flow is completed at 7 and 9 diameters downstream for test case b and a & c respectively.

ACKNOWLEDGMENTS

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REFERENCES