Investigation of the near-field of a swirling turbulent jet

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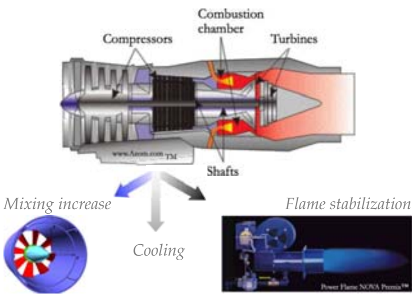
Practical application

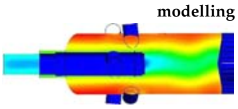
Swirling jets, where an azimuthal velocity component is superimposed on the axial flow, are used in many engineering applications, because among other things it is known that rotating jets spread and mix with the ambient fluid faster than their non-swirling counterparts.

Combustors



Axial Separators

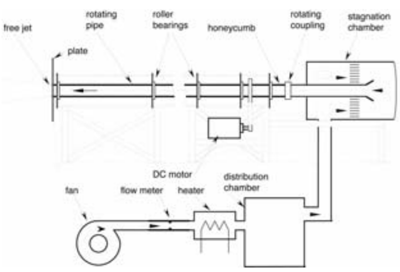
Turbulence modelling



Experimental setup

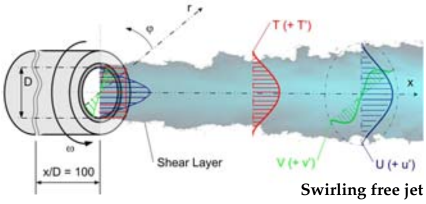
For the present study a new experimental facility has been designed and implemented at the *Fluid physics laboratory* of *KTH Mechanics*. To generate swirling jets, where the flow characteristics are independent of the specific geometry of swirl generators, a 6 m long axially rotating pipe (D=60 mm) was used in order to obtain both well defined streamwise and azimuthal velocity profiles at the pipe exit making it possible to investigate the characteristics and the dynamics of the jet with and without rotation. [1]

Additionally the effect of rotation on the spreading of a passive scalar as well as the momentum and scalar transport was investigated by heating the jet slightly. To ensure a constant radial temperature the outer pipe surface is insulated with a foam material.



Physical quantities

Fully developed axially rotating pipe flow



Swirling free jet

Main parameters

Reynolds number

$$Re = \frac{U_b D}{\nu}$$

swirl number

$$S = \frac{V_w}{U_b}$$

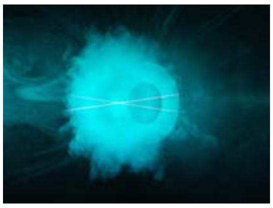
bulk velocity $U_b = \frac{\text{flow rate}}{\text{area}}\Big|_{x/D=0}$

V_w: *azimuthal velocity of the rotating pipe*

Measurement technique

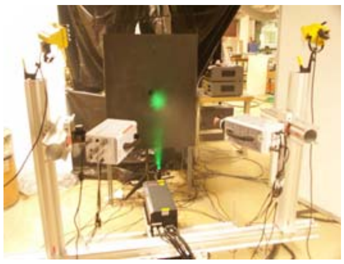
Several advanced measurement techniques were used to investigate the turbulent velocity and temperature field in the pipe flow as well as in the near-field of the non-swirling and swirling free jet. *Hot-wire anemometry* (HWA), *Laser doppler velocimetry* (LDV) and *particle image velocimetry* (PIV) were used for the isothermal jet [2].

- Laser doppler velocimetry



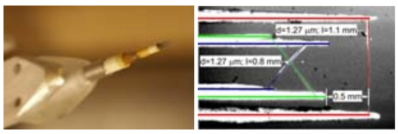
One dimensional and two dimensional LDV systems were used to examine the mean and fluctuating velocities as well as the Reynold's stresses. Furthermore their results were used to test different correction methods for the response of hot-wires in near-wall regions and high shear flows.

- Stereo-Particle image velocimetry



The detection of coherent structures plays a major role in the current research. For this reason as well as to obtain a complete impression of the flow field a stereoscopic-PIV system was used.

- Integrated X-wire and cold-wire



X-wires were used to analyze velocity statistics and to perform spectral analysis in the isothermal jet, whereas for the heated jet a combined X-wire and cold-wire technique for simultaneous acquisition of two velocity components and temperature were used. Through an instantaneous temperature correction against changes in fluid temperature the axial and azimuthal heat fluxes could be determined. [3]

Problems

- Numerics:

Despite the importance of swirling jets, there are only few theoretical and numerical analyses which can be used in practical applications. The limitations are due to:

- *only low Reynolds number for DNS*
- *lack of good turbulence models for RANS*

- Experiments:

Many experimental investigations have been performed in different laboratories. However comparisons between these studies are hindered and moreover there is still a lack on physical insight:

- *swirl profile depends strongly on how the swirl is generated*
- *lack of reliable investigations of the velocity field in the near-field of swirling jets*
- *lack on experimental data about scalar transport in swirling jets*

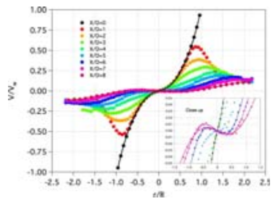
Need for new experiments under well-controlled conditions

New physical insights

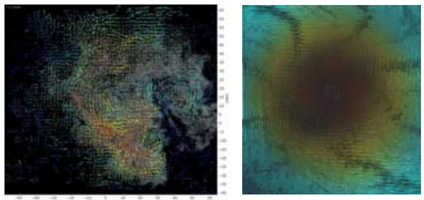
Data-base for numerical validation

Results

Despite many observations only two results are shown here. First the detection of a counter-rotating core at some distance downstream relative to the rotation of the pipe is shown. This unexpected effect, which has been observed in both experiments and DNS simulations [4], is explained by the influence of the cross flow Reynolds stress originating in the rotating pipe flow.



An impression of the turbulent flow field with its swirling patterns and structures is given by the instantaneous velocity plot across the jet. The average over these snapshots will plot the time averaged mean velocities.



Acknowledgments

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References

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[3] R. Örlü, P. H. Alfredsson, N. Tillmark, A. Talamelli, 2005 *A heated swirling jet emanating from a fully developed turbulent pipe flow*, 6th ExHFT conference proceedings

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