Simulation of gas flow field of an air blast swirler fuel injector with LES and comparison with experiments

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ABSTRACT

The gas flow field of an air blast type of oil fuel injector for the ABB GT10 gasturbine was investigated by experiments (PIV and LDV) and LES simulations at cold and atmospheric conditions. Misplaced droplets are suspected to create problems with coking and burn damages in the burner. The purpose of this work was to enhance the understanding of the flow field from the injector and to create a basis for further experimental and computational investigation of the gas flow field and trajectories of fuel droplets. LES results for several inflow conditions have been computed. Experimental data include both PIV, instantanious and time mean velocity field. At selected positions a continous velocity component was measured by LDV. Due to difficulties in imposing similar inflow boundary conditions in the experimental and the LES set up, so far only qualitative comparisons have been done.

INTRODUCTION

The flow in the burner in a gas turbine has to be stable, provide complete combustion, without smoke or overheat the combustor walls. In the ABB GT10 one type of burner used is of air blast type. The air blast swirler gives a finer spray over the load range at low fuel pressure [Lefebvre]. The burner is designed for use with heavy diesel oils and uses a high shear sheet between two high speed air streams to atomise the liquid fuel which is injected from a prefilmer surface into the shear region. The air flow which is swirling also produces a flame holding by recirculating hot combustion products in a recirculation zone in the combustion chamber. To keep the flame in the right position giving a stable flame and prevent over heating of the combustion chamber walls and injector it is crucial to atomise the fuel well and to keep the droplets away from the cold walls. Changes in the air flow field and droplets trajectories when changing the design of the injector can be investigated using CFD model. Some model validation can be done for in atmospheric conditions. The air flow field can then be used for calculations with droplet injection and to study changes when varying droplet initial injection angle and velocity. These droplet trajectories can then be used to estimate wheter design changes will case coking and possible burning of the combustor/injector.

The present investigation is was done by measuring the isothermal flow generated by the burner placed in a box. The measurements were done by (2-D) Particle Image Velocimetry (PIV). By averaging a set of PIv data, the mean the fluctating components of the flow were found. By using LDV at certain points, we got a good temporal resolution of the flow.

The numerical calculations were LES based. An essential factor in such calculations is having reasonable boundary conditions. For the present experimental setup, we found it difficult to replicate computationally the experimental inflow conditions. Therefore, a series of LES results were obtained having different inflow conditions to asses the sensitivity of the LES results.

TEST BURNER

The injector investigated was a liquid fuel injector for the ABB GT10 gas turbine. The injector was of an air-blast type meaning that air at high speed was used for atomisation of the fuel.

The injector consisted of two co-rotating swirlers of 45°. In between the two swirling air flows the fuel was injected as a liquid sheet on a pre-filmer surface. The liquid sheet was destructed and atomised in the high shear region. The swirling air created a recirculation zone inside the combustion chamber thus providing a flow induced flame holding.

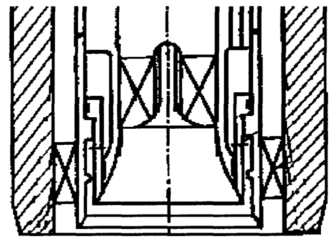

Figure 1. Injector nozzle geometry

EXPERIMENTAL SETUP

The combustion chamber replaced by a perspex box of 500x140x300 mm. At one of the 140x300 wall a combustor swirler from the GT10 was mounted and the injector was fit into it. The swirler produces also a co-rotating swirl at 45°. Air was sucked into the box through the injector and the combustor swirler. The air suction was produced by a centrifugal fan placed in direct connection to the test stand. The air mass flow was measured with an orifice plate applying to ISO5167. This arrangement yields three co-rotating swirling jets. The outlet from the box was through two round holes of diameter 60mm. The holes were positioned at the other end from the injector with one hole at the top and one at the bottom. This arrangement was done for two reasons. First it gave an unobstructed view perpendicular to the injector. Secondly the two off-set outlets weakend the swirl giving a better flow to the orifice plate. The fan gave a massflow of 59g/s at room temperature.

In the experiments the diesel fuel was replaced by water. The water was fed from a barrel positioned one meter over the model. The flow was set with a needle valve and measured with a rotary meter. The liquid flow was scaled to 2,5-3 g/s giving the same air-fuel mass ratio as for the real case.
Large amounts of water droplets hit the walls and was thus collected on the bottom of the model. This water was drained by a pump trough a hole at the same axial position as the outlets.

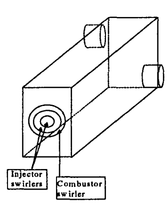

Figure 2. Experimental geometry

MEASUREMENT SYSTEMS

Particle Imaging Velocimetry (PIV)

The PIV measurement technique is based on images of light scattered from tracer particles in the flow. The particles are illuminated twice with a laser light sheet with a short time delay. The particles are assumed to be small enough to follow the local gas flow field between the two images.
In the PIV measurements a PIV system from LaVision was used. A frequency doubled Nd:YAG laser with two oscillators with 25 mJ each were used for illumination. The camera was a peltier cooled cross-correlation CCD camera with a resolution of 1280x1024 pixels.

Laser Doppler Velocimetry (LDV)

The system used in the measurements is a Dantec FlowLite system. The system is a one component system with a 20 mW HeNe laser emitting red light (632.8 nm). The probe was fitted with a lens giving 160 mm focal length and a measurement volume of 75 x 630 μm.

Seeding for both the PIV and LDV was provided by a commercial smoke generator giving droplets with mean diameter <1 μm.

GOVERNING EQUATIONS

The modeling of this highly turbulent and swirling flow was done using large eddie simulation, LES. In the LES modeling the equations of motion are filtered in space rather than in time as is done for example k-e models. This filtering aims at separating the large scales of turbulence from the small scales. The small scales can be assumed to behave more homogeneously in space than the larger anisotropic scales, as described in [Germano,1992] . The universal filter applied to the governing equations can be defined as:

Where G is a filter function (e.g. with a Gaussian

$$\overline{f(x_i,t)} = \int_{-\infty}^{\infty} G(x_i - x_i')f(x_i',t)dx_i'$$

distribution)
The governing equations can after space filtering be in non-dimensional form be written:

$$\frac{\partial \overline{u_i}}{\partial x_i} = 0$$

$$\frac{\partial \overline{u_i}}{\partial t} + \overline{u_j}\frac{\partial \overline{u_i}}{\partial x_j} = -\frac{\partial \overline{p}}{\partial x_i} + \frac{1}{Re}\frac{\partial}{\partial x_j}\frac{\partial \overline{u_i}}{\partial x_j} - \frac{\partial \tau_{ij}}{\partial x_j}$$

As a result of the averaging a Sub-Grid-Scale (GSG) term appears (τ_{ij}). This term accounts for the effect of the small scales on the larger ones, and the interaction among the small (unresolved) scales. Expressing this term is the essence in all LES models.

NUMERICAL METHOD

The above described functions are implemented in a code developed by [Olsson and Fuchs, 1996]. The equations are there discretised on a staggered Cartesian grid. The time integration is done with an implicit method. The subgrid scales are delt with by the artificial viscosity through upwind- and central finite approximations.

SIMULATIONS

The geometry in the simulations was the box as used for experiments. The inlets were placed in one plane and had a flat velocity profile with constant swirl of 45°. The Re was varied between 100 and 100000 and was based on the velocity in the outer swirler and the outer swirler diameter. The mass flow was varied by distributing the velocities at the different swirlers between even distribution and decreased velocity in the center inlet. The number of cells was 2.5-4.0x10^6.

RESULTS

Experiments

The PIV and the LDV mesurements both showed a strong backward flow in the center of the box. The Forward flow was ejected to the walls shortly after the end of the injector. A spectrum analyse of the LDV measurements indicates the presence of coherent structures with frequencies <100 Hz in the flow.

Simulations

The variations in the inlet velocity distribution shows the high sensitivity for the inlet boundary conditions. When inlet velocity was evenly distributed the result was a straight jet but when decreasing the center inlet velocity a recirculation zone starts to formate along the center axis. The three inlet velocities are named v1,2,3 , where v1 is the center swirler.

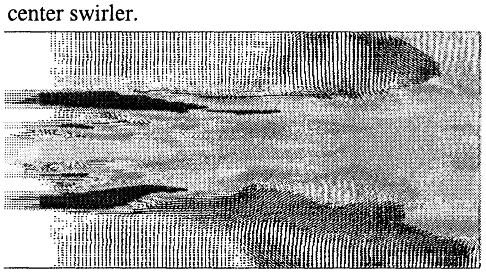

Figure 3. Instantant. velocity field

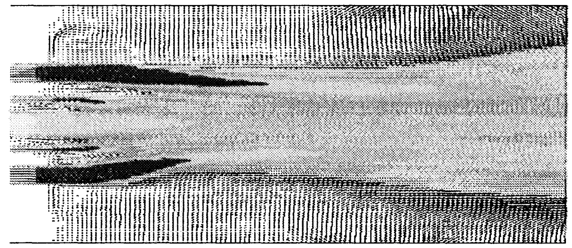

Figure 4. Average velocity field. v1=v2=v3=1

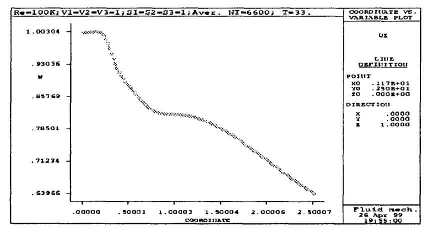

Figure 5. Axial velocity profile. V1=v2=v3=1

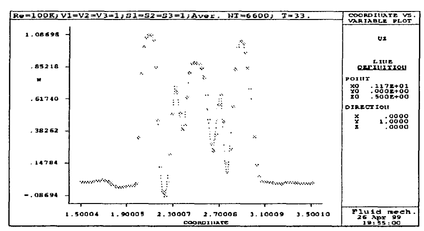

Figure 6. Radial velocity profile. v1=v2=v3=1

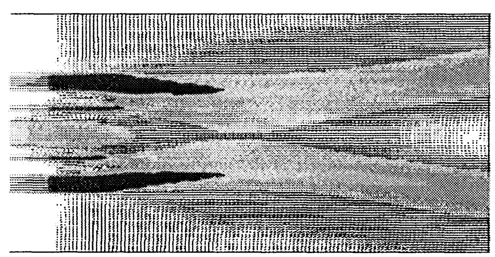

Figure 7. Average velocity field. v1=0.5 v2=v3=1

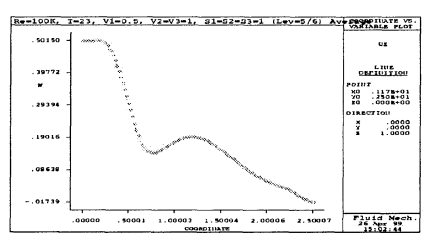

Figure 8. Average velocity field. v1=0.5 v2=v3=1

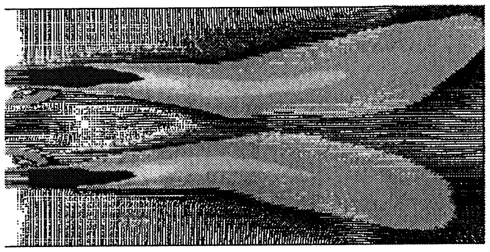

Figure 9. Average velocity field. v1=0.15 v2=v3=1

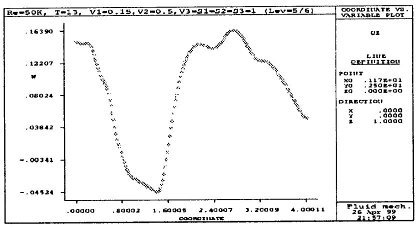

Figure 10. Average velocity field. v1=0.15 v2=v3=1

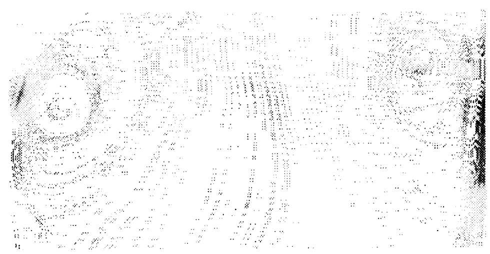

Figure 11. PIV Stream lines average central field. Flow direction from bottom to top

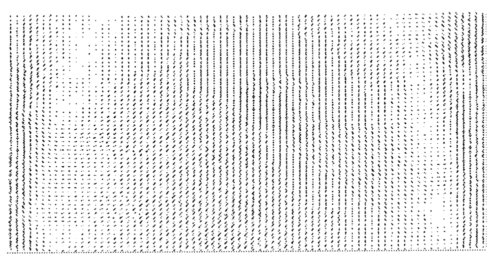

Figure 12. PIV Average vector field for cenral plane. Flow directon from bottom to top

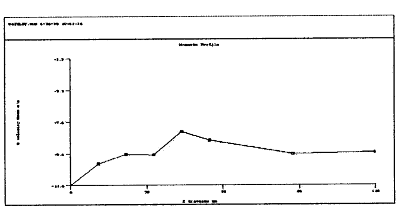

Figure 13. LDV Axial velocity profile along center axis

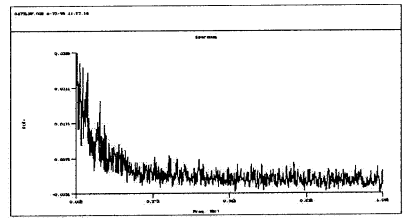

Figure 14. Frequency spectrum for axial velocity 10 mm down stream injector

CONCLUDING REMARKS

The inlet boundary conditions for the LES simulations are very difficult to specify due to that the LES is not time averaged which presents the need for the instantanous flow field.

The sensitivity to the center swirler velocity raise the need to measure the center swirler inlet velocity profile and volume flow in more detail.

The presence of coherent structures in the flow field will be investigated further theoretically and experimentally .

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Olsson, M. and Fuchs, L., 1996, "Large eddy simulation of a spatially developing circular jet", *Phys. Fluids 8, 2125*