A computational study of turbulent non-premixed methane jet flames in a crosswind

G. Chamberlain[1], D. Bradley[2], P. H. Gaskell[2], X. J. Gu[3] and D. R. Emerson[3]

[1]Shell Global Solutions, P.O. Box 1, Chester CH1 3SH, UK
[2]School of Mechanical Engineering, University of Leeds LS2 9JT UK
[3]Department of Computational Science and Engineering, Daresbury Laboratory, Warrington WA4 4AD, UK

5th International Seminar on Fire and Explosion Hazards

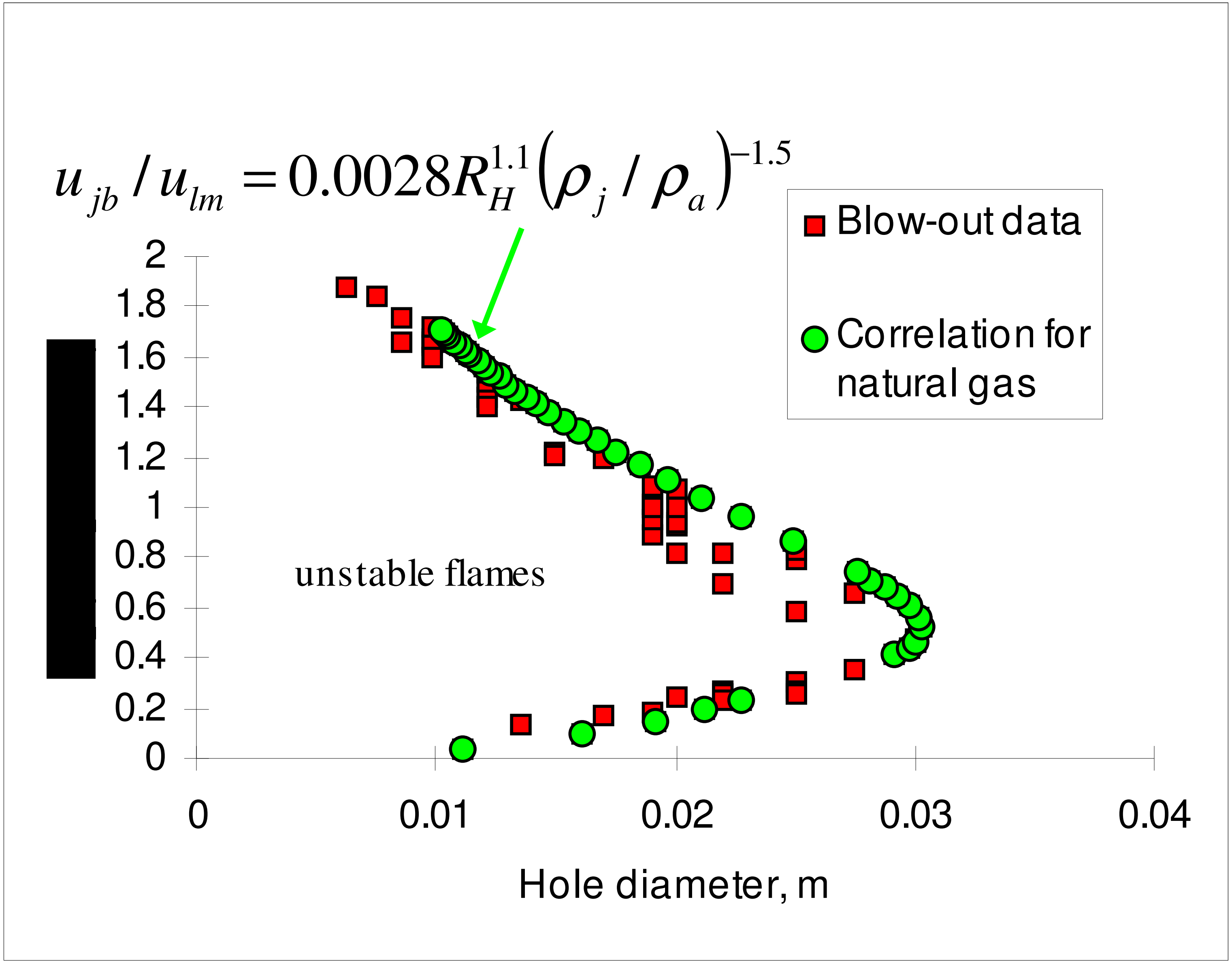
Background

In accidental release, some flames may lift off from the release point and even self-extinguish. In windy conditions, some flames stabilise in the wake of the burner, other flames are lifted and tilted.

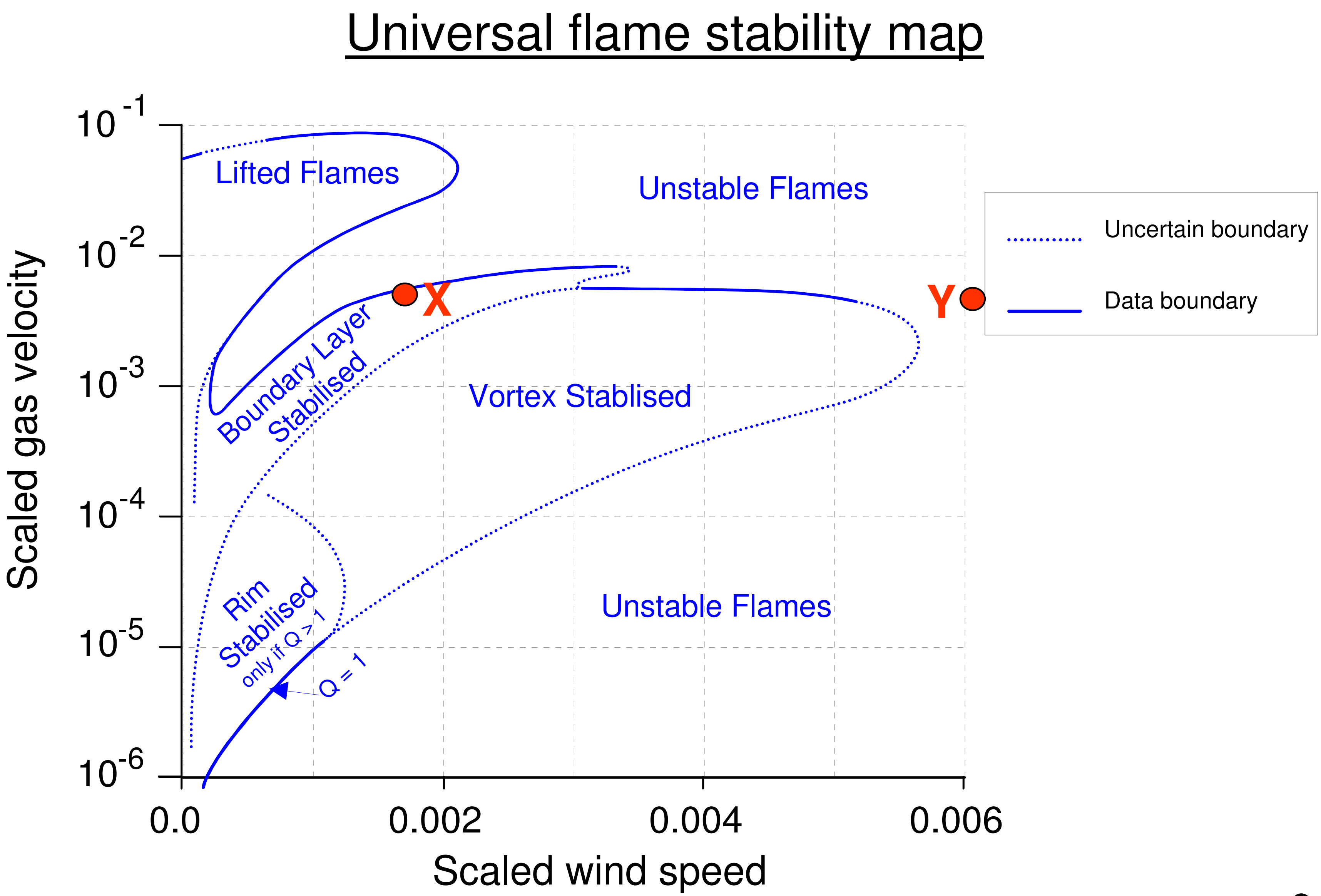
Knowledge of flame stabilisation is important in hazard analysis and flaring.

Turbulent non-premixed jet flames have been studied experimentally and numerically by many researchers.

Flame stability for natural gas flames in still air



Flame stability map



Scaling factor is $\left(u_{lm}/\xi_f\right)\left(u_{lm}d/\nu\right)\left(\rho_a/\rho_j\right)\left(D/d\right)$

Combustion Model(1)

When a turbulent fuel jet discharges into air, the shear-generated aerodynamic strain rate is initially sufficiently high to mix the fuel and surrounding air, and also to quench both premixed and diffusion flamelets. Further downstream, the strain rate relaxes and premixed burning ensues.

Allowance must be made for the effects of local flame extinctions in the modelling of the complex highly non-linear interaction between turbulence and the chemical reactions in non-premixed flames.

Combustion Model(2)

The strained laminar flamelet model, is based upon premixed rather than diffusion flamelets.

Second-order conditional moment closure (CMC) procedures evaluate a conditional probability density function (pdf), of the reaction progress variable (based on H_2O) and conditional upon a value of the mixture fraction, ξ.

This is essential for calculation of the reaction source terms.

Combustion Model (3)

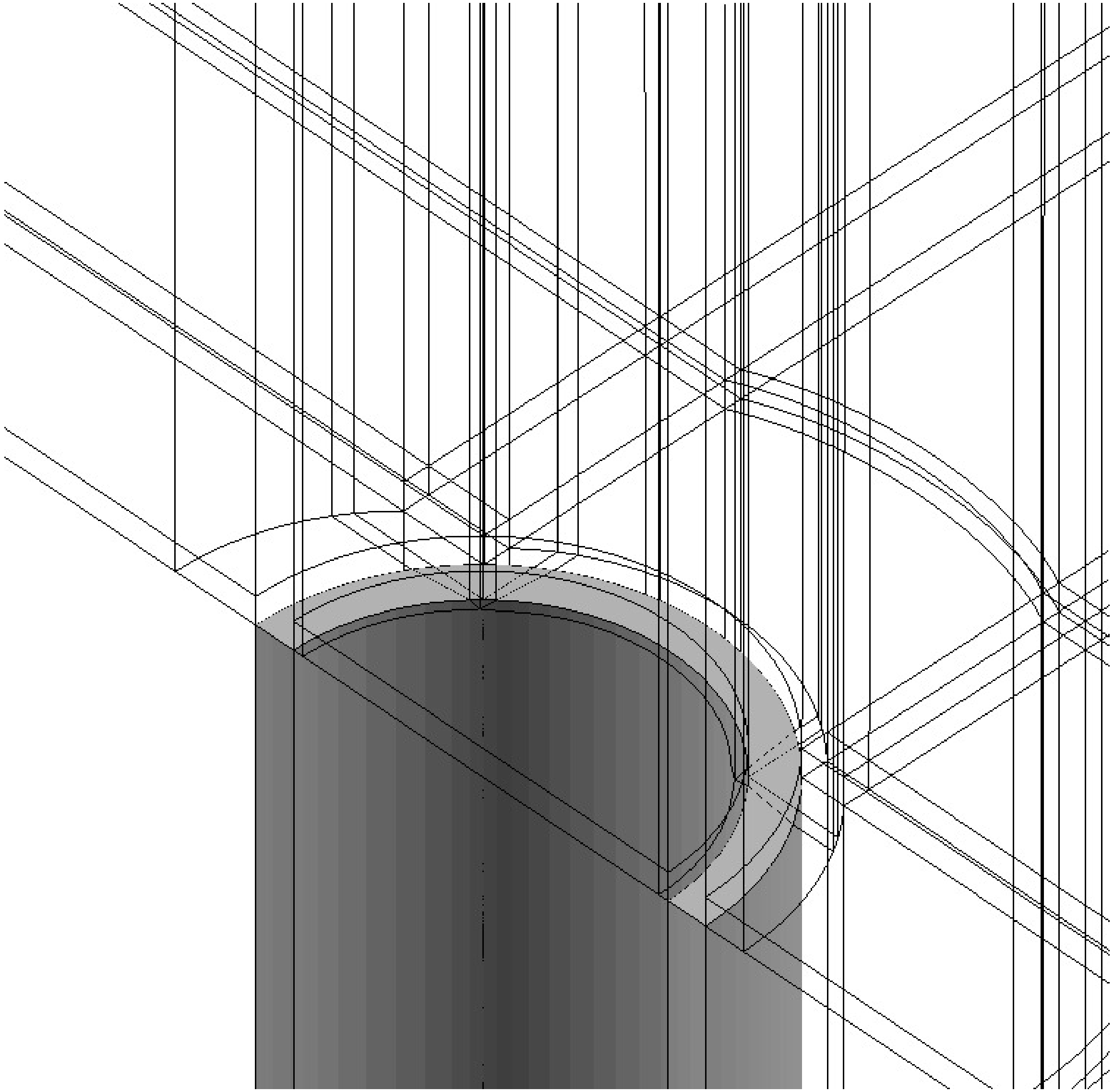
non CMC 3D-equations (8)

1. Global mass conservation (1)
2. Momentum (3)
3. Turbulent equations for k and ε (2)
4. First and second moments of mixture fraction (2)

CMC 4D (3D+Mixture fraction) equations (9)

1. First moment equations for 7 species (7)
2. Second moment equation for H_2O (1)
3. First moment for temperature (1)

Computational Domain



To fit the grids on the circular tube and run on 64 processors, the $2.2 \times 0.38 \times 1.44 m^3$ computational domain is divided into 130 blocks.

3.27million grid nodes in space.

Mixture fraction dimension: 50 grid points.

Code: THOR

All equations are implemented in a general purpose CFD code THOR. It can deal with highly complex geometries through the use of multi-block grids and body-fitted coordinates.

It has been parallelised using standard grid partitioning techniques and communication is through the use of the MPI standard.

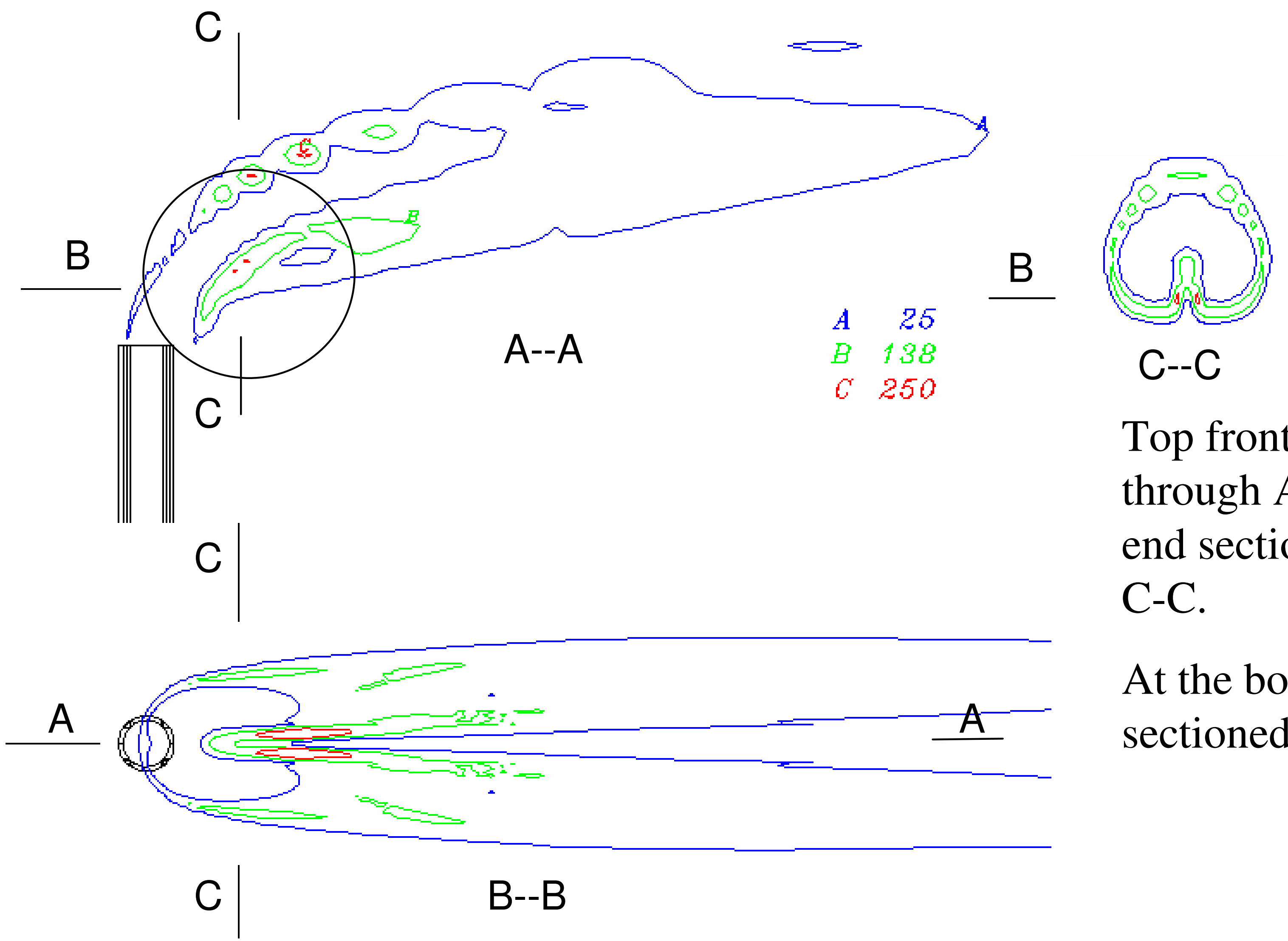
Flame in a cross wind: computed results

Fuel jet pipe: inner diameter = 10 mm
outer diameter = 12 mm

Cross wind speed 5.5 and 20 m/s

Fuel jet mean velocity: 20 m/s

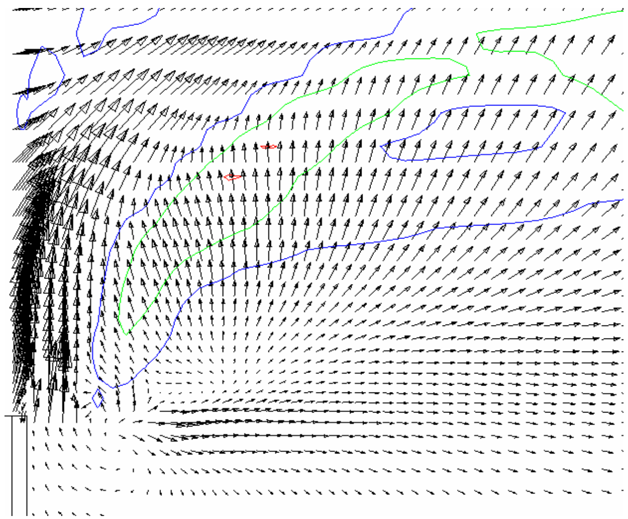
Cross wind speed 5.5 m/s: contours of mean volumetric heat release rate, MW/m^3



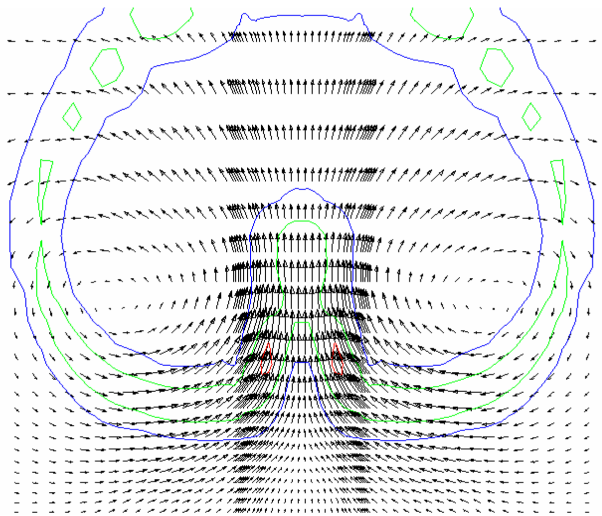
Top front sectioned view is through A-A. At its side is the end sectioned view through C-C.

At the bottom is the plan sectioned view through B-B.

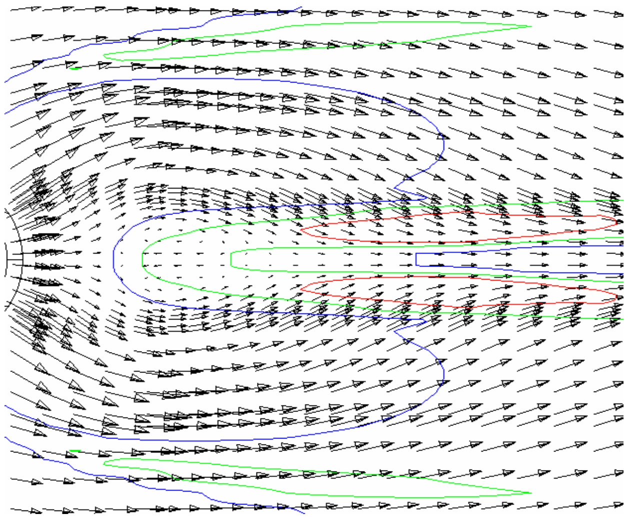
Cross wind speed 5.5 m/s: mean velocity field in three views



A--A

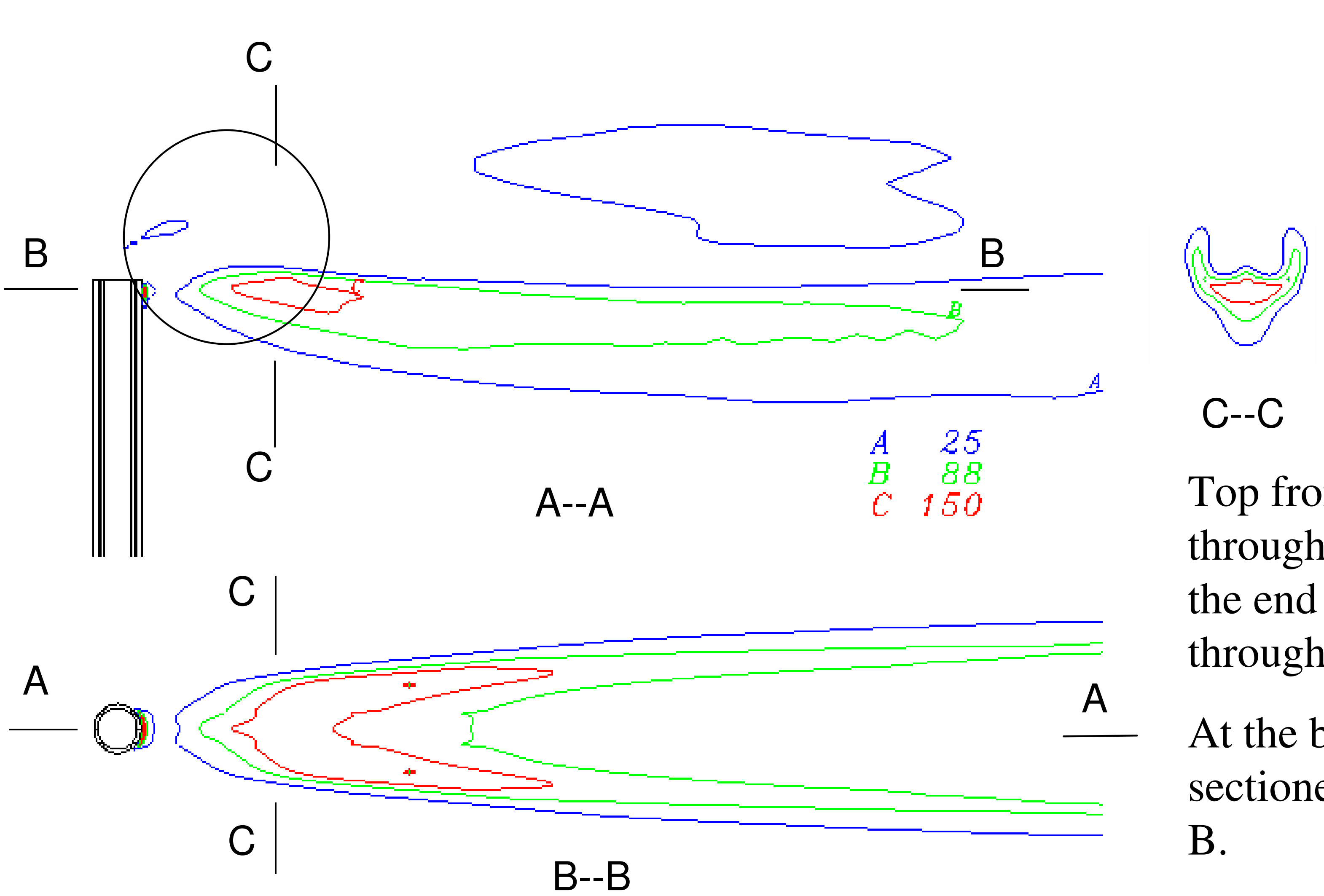


C--C



B--B

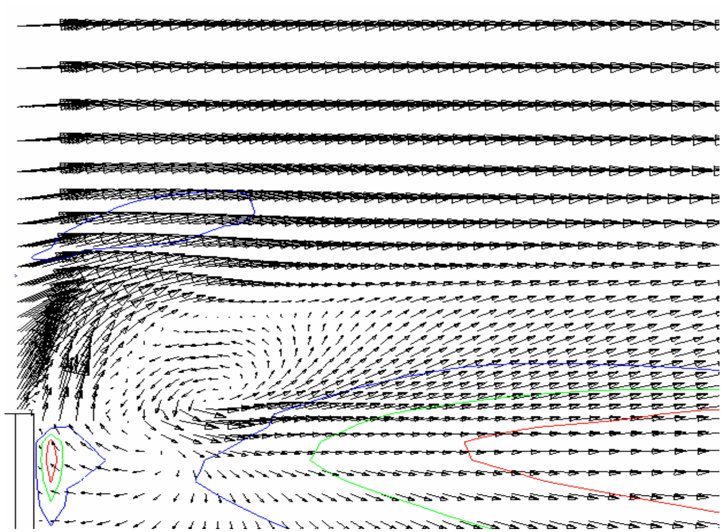
Cross wind speed 20 m/s: contours of mean volumetric heat release rate, MW/m^3

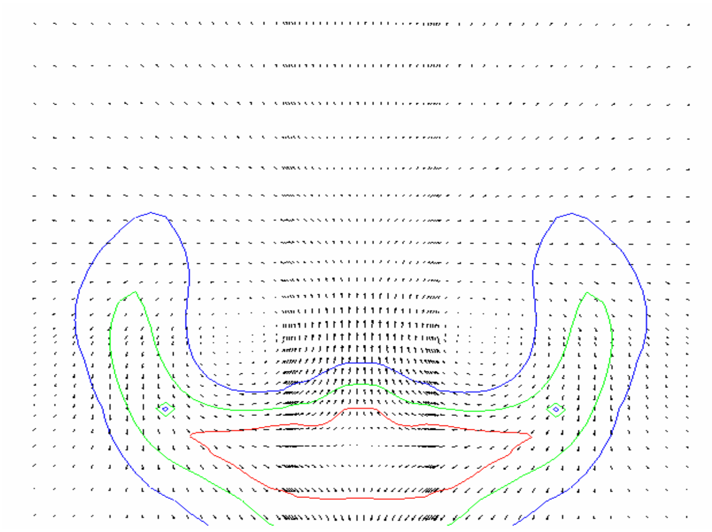


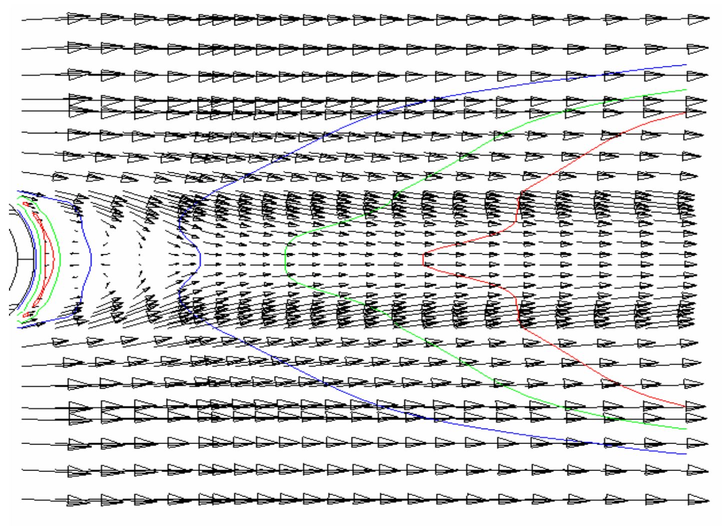
Top front sectioned view is through A-A. At its side is the end sectioned view through C-C.

At the bottom is the plan sectioned view through B-B.

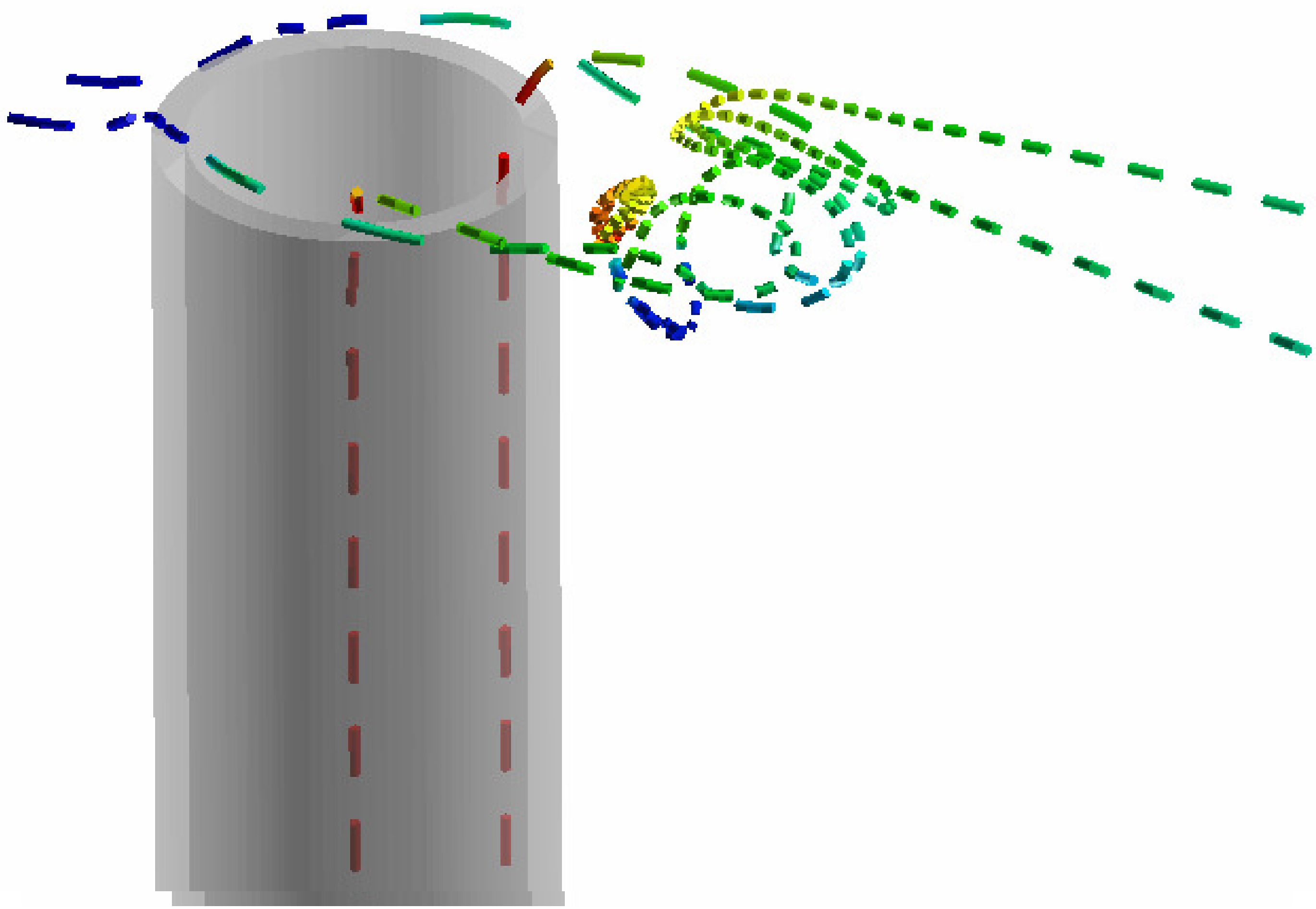
Cross wind speed 20 m/s: mean velocity field in three views


A--A


C--C


B--B

Cross wind speed 20 m/s: stream lines and mixing



Summary

Non-premixed turbulent jet flames in cross winds have been computed with a CMC-flamelet combustion model. It is computational expensive to solve 4D CMC equations.

The value of the study lies in its identification of the modes of flame stabilisation, which are three dimensional . With the smaller cross-wind the flame has the characteristics of a bent, lifted, flame, mainly stabilised by the recirculation zone created by the fuel jet in the vertical direction. Combustion efficiency is 60%.

The larger crosswind flame is in the vortex stabilisation regime, and is stabilised by the recirculation zones generated by the interaction between the crosswind and the jet and the fuel pipe. Combustion efficiency is 90%

Acknowledgements

EPSRC for their support of this work, through the Collaborative Computational Project 12 and the Consortium on Computational Combustion for Engineering Applications.