Sixth Workshop on the Turbulent Calculations of Sprays, TCS7

June 16, 2019, Santa Cruz de Tenerife, Spain

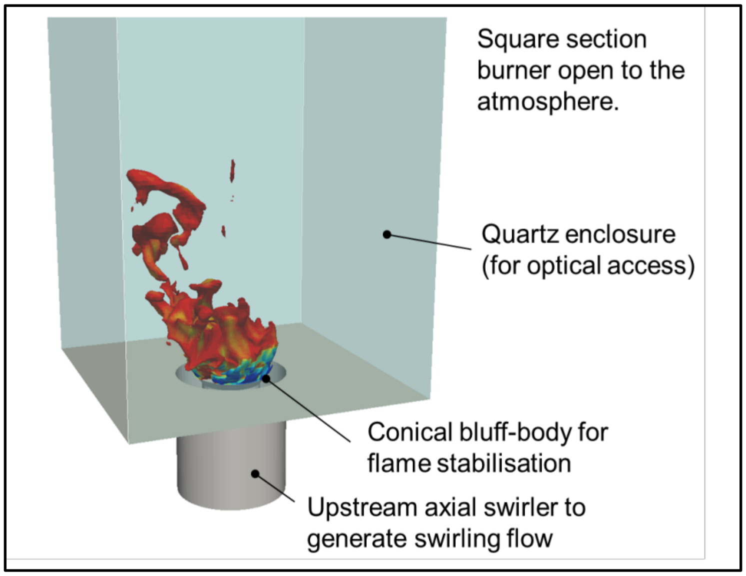
Cambridge swirl spray flame

Guide for groups who intend to submit calculations for comparisons

Deadline for Submissions
Friday 17th May 2019

A. Background

The Cambridge swirl spray flame is one of the target flames of TCS7. The main objective of this configuration is the investigation of local extinction and blow-off in turbulent spray flames. Capturing the local extinction and blow-off in turbulent flames is one of the main challenges for current generation turbulent combustion models and this series of experiments allows further validation and assessment of the available models. Experiments have been performed with different fuels, ranging from ethanol to heavy hydrocarbons and jet fuels to allow investigation with liquids characterized by different physical and chemical properties. For each fuel, measurements with different air bulk velocity, at condition relatively close to the global extinction, are available. In this workshop (TCS7) a comparison between the capability of different modelling approaches to predict the behavior of these flames is attempted. The presence of a swirling flow introduces an additional challenge to the simulation. It is suggested to first simulate the non-reacting cases, to assess the capability of the modelling approach (turbulence model and computational grid) to correctly predict the velocity field. As far as the reacting cases are concerned, for some of the fuels (n-heptane and ethanol flame series) numerical simulation performed at the University of Cambridge are already available for comparison. However, also simulations for heavy hydrocarbons are very welcome to explore the effect of fuel volatility on the flame structure and extinction behavior.



The proposed coordinator for plotting the results for these calculations is:
Dr Andrea Giusti from Imperial College London (a.giusti@imperial.ac.uk).

Submissions require the addition of your full name in the email subject line, e.g. TCS7-AndreaGiusti. To facilitate comparisons, contributors are requested to submit their calculations in the format specified below in section *D: Guide for submission of calculations*. This is very important since it is simply not possible for the coordinators to re-format individual submissions.

B. Objective and plan for TCS7

The objective for TCS7 (related to the Cambridge Spray Flame) is to explore the capability of current modelling approaches to predict the flame structure and extinction (local and global) behavior of turbulent spray flames operated progressively close to blow-off, for a number of different fuels. Authors are encouraged to employ different models for (i) droplet evaporation and (ii) combustion. In a second stage, one should also start to look at the effect of (iii) heat transfer at the wall. More specifically, some important questions to be addressed are as follows:

1. What is the effect of spray boundary conditions on the shape of the flame?
2. What is the effect of the evaporation model on the flame structure?
3. How capable are different combustion models in terms of computing the mean flame shape and the local extinction behavior?
4. How do different combustion model compare in the prediction of blow-off?
5. What is the role of wall heat transfer in the evolution of local extinctions and flame blow-off?

Proposed simulations:

To achieve the above objectives and make progress in the upcoming Workshop, interested research groups are invited to perform a set of simulations that assist in resolving the questions stated above. The available cases are summarized in the following table (more information can be found at http://swirl-flame.eng.cam.ac.uk/cond).

Fuel type	Condition name	Case	$\dot{m}_f$	U_{bulk}	Φ	U_{bulk} / U_{BO}
			g/s	m/s		
Cold flow	C1	Stable	-	14.3	-	-
Cold flow	C2	Stable	-	18.5	-	-
Ethanol	E1S1	Stable	0.27	17.1	0.19	0.79
Ethanol	E1S2	Stable	0.27	20.0	0.16	0.93
Ethanol	E1B	Blow-off	0.27	21.6	0.15	1
n-Heptane	H1S1	Stable	0.27	17.1	0.32	0.75
n-Heptane	H1S2	Stable	0.27	20.0	0.27	0.88
n-Heptane	H1B	Blow-off	0.27	22.8	0.24	1
n-Decane	D1S1	Stable	0.27	17.1	0.31	0.84
n-Decane	D1S2	Stable	0.27	20.0	0.27	0.99
n-Decane	D1B	Blow-off	0.27	20.3	0.27	1
n-Dodecane	DD1S1	Stable	0.27	14.3	0.38	0.71
n-Dodecane	DD1S2	Stable	0.27	17.1	0.32	0.85
n-Dodecane	DD1B	Blow-off	0.27	20.1	0.27	1

It is suggested to first perform simulations of non-reacting cases (C1 and/or C2) and then move on to one of the reacting cases. The assessment of capability of a numerical approach to capture the trend in local extinction at conditions progressively close to blow-off (for a given fuel) is a very interesting investigation. Therefore, for each fuel, it is recommended to perform simulations with different air flow-bulk velocities. At this stage, ethanol and n-heptane flames are proposed as benchmark cases, but submissions for the other fuels are also encouraged.

C. <u>Burner and database:</u>

The Cambridge bluff-body swirl burner consists of a burner base with a D_b = 25 mm conical bluff-body and a D = 37 mm annulus with a swirler upstream. Four quartz plates are supported by the burner body, forming a square enclosure 97 mm wide and 150 mm tall. The outlet is open to the atmosphere. The atomizer, fitted into the bluff-body, consists in a hollow cone pressure atomizer (Lechler 212/220 series). Further details about the burner and the complete data set may be found at the following link:

http://swirl-flame.eng.cam.ac.uk/geom

For more information, please also contact Prof. Epaminondas Mastorakos (em257@cam.ac.uk).

Note:
Access to the Cambridge Spray Flame data requires a password. If you plan to submit calculations and you require access, please contact Dr Andrea Giusti (a.giusti@imperial.ac.uk).

D. <u>Guide for submission of calculations</u>

There are various experimental measurements that contributors may use to assess and validate their numerical model. We suggest to provide comparisons for the following quantities whenever available – some of the measurements are not available for all the flames.

<u>1) Cold flow data</u>

Data for the mean values of three velocity components and the *rms* of the respective fluctuations are available for two cases. Cold flow data should be used to assess the capability of the underlying numerical setup and computational mesh to adequately predict the mean flow.

<u>2) Spray location and dispersion</u>

Mie scattering images are available for most of the cases. Mie scattering gives a qualitatively indication of the location of the liquid droplets and can be used to assess the reliability of the injection model. The Mie scattering signal is, with a good approximation, proportional to the sum of the square of the droplet diameter. Therefore it can be directly compared with the numerical simulations if, for each cell, the sum of the square of the droplet diameter of droplets crossing the cell is computed (see also Giusti et al., FTaC, 2016). It is suggested to plot the Mie scattering data (and the equivalent CFD quantity) in log-scale to better identify the presence of liquid droplets downstream of the injection location.

3) Droplet Diameters and velocity

PDA measurements of the droplet Sauter Mean Diameter and velocity at different distance from the bluff-body surface are available. Such data should be used to validate the injection model and the combined effect of the evaporation and combustion models.

4) Mean flame shape

The mean flame shape is revealed by the mean OH-PLIF signal and the Inverse Abel-Transformed mean OH* chemiluminescence signal. The former can be compared with the mean OH mass fraction, whereas the second gives an indication of the location of heat release rate and therefore can be compared with the mean heat release rate from the simulation.

5) Local extinction behavior and lift-off

A qualitative assessment of the capability of predicting local extinctions can be performed using instantaneous OH-PLIF images. These images generally show some holes in the OH containing regions that may be interpreted as local extinctions along the stoichiometric line. Flame lift-off at the bluff-body edge is also revealed by instantaneous OH-PLIF images and statistics of the lift-off height are available for comparison. Simulation of the ethanol flame using the LES/CMC approach showed that the lift-off can be caused by local extinction in that region. If this is the case, the statistics of the lift-off height can be used as a quantitative measure of the degree of local extinction in such region.

6) Other useful quantities

In order to compare different numerical approaches, it is very useful to show the fields of the mean mixture fraction, mean temperature and variance of the mixture fraction.

D1. DATA FORMAT REQUIREMENTS

Contributors are kindly asked to follow the provided format requirement when submit their final processed data files.

Radial positions should be provided non-dimensionally as r/D_b (where D_b is the jet diameter of the top bluff-body surface, D_b=25 mm, and r is the radial location). Velocities (both mean and *rms* values) should be provided in a non-dimensional form using the airflow bulk velocity as reference velocity. For example, for the mean axial velocity, the value U/U_b should be provided (where U_b is the bulk velocity and U the mean axial velocity). As far as the spray diameter is concerned, the

Sauter Mean Diameter should be computed.

Data at different heights from the bluff-body surface should be submitted in different files. The name of the files should be in the format "z000_X" where "000" should be replaced with the location of the plane in mm (please always use 3 figures) and X is the name of the variable:

- U = axial velocity; Urms = rms of the axial velocity fluctuation;
- V = radial velocity; Vrms = rms of the radial velocity fluctuation;
- W = tangential velocity; Wrms = rms of the tangential velocity fluctuation;
- Us = spray axial velocity; Usrms = rms of the spray axial velocity fluctuation;
- Vs = spray radial velocity; Vsrms = rms of the spray radial velocity fluctuation;
- Ws = spray tangential velocity; Wsrms = rms of the spray tangential velocity fluctuation;
- SMD = spray Sauter Mean Diameter.

Example: axial velocity at the plane z=18 mm → name of the file "z018_U".

Each quantity can be submitted in different files, where data is saved in column format r/D_b, U/U_b, or use the same file for each axial location if the radial coordinate is the same for all the quantities. In this case, the format of the data should be r/D, U, V, W, Urms,..., and the name of the file should report all the quantities in the file (e.g. z018_U_V_W_Urms).

Submitted images for MUST be in 'png' format (300PPI, size 800x600 pixels), using a 20 level JET colormap. Further information on the scale (minimum and maximum value) and physical size in the *x* and *z* direction will be provided soon.

D2. INFORMATION REQUIRED FROM GROUPS

In addition to formatted data submission, a description of the configuration and modeling approaches used for the simulations should be provided. Please address the following topics:

- Domain geometry and grid characteristics: specify if the swirler is included in the geometry, the refinement of the grid in the reacting region and at the walls.

- Wall boundary conditions: indicate the boundary conditions used for the wall, in particular regarding heat transfer (adiabatic, imposed temperature,…).

- Droplet boundary conditions: SMD and distribution of the droplets; spray injection modelling (spray angle, droplet velocity…)

- Turbulence model

- Chemical mechanism and combustion model

- Evaporation model and physical properties for the fuel

Feel free to provide any additional information you think necessary.

E. Previous numerical work

Please find below a list of publications focused on the numerical modelling of the Cambridge Spray Flame.

- Elasrag, H., Li, S. (2018). Investigation of Extinction and Reignition Events Using the Flamelet Generated Manifold Model. Proceedings of the ASME Turbo Expo, paper GT2018-75420. https://doi.org/10.1115/GT2018-75420
- Giusti, A., Mastorakos, E. (2017). Detailed chemistry LES/CMC simulation of a swirling ethanol spray flame approaching blow-off, P Combust Inst, 36:2 2625-2632. https://doi.org/10.1016/j.proci.2016.06.035
- Giusti, A., Kotzagianni, M., Mastorakos, E., (2016). LES/CMC simulations of swirl-stabilised ethanol spray flames approaching blow-off. Flow Turbulence Combust, 97(4): 1165-1184. https://doi.org/10.1007/s10494-016-9762-1
- Tyliszczak, A., Cavaliere, D. E., Mastorakos, E. (2014). LES/CMC of Blow-off in a Liquid Fueled Swirl Burner, Flow Turbulence Combust, 92: 237-267. https://doi.org/10.1007/s10494-013-9477-5