Bluff Body Flameholder

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Numerical Method

- 3D Simulations are carried out by the solving Navier-Stokes equations using a finite volume scheme that is second-order accurate in space and time which employs Large Eddy Simulation (LES) approach.
- Reaction rates are modeled by using the Linear Eddy Mixing (LEM) and the Eddy Break Up (EBU) model.
- The chemical kinetic mechanism used comprised a single step, global mechanism for heptane/air combustion which involved 4 species (C_7H_{16}, O_2, CO_2 and H_2O).
- The liquid jet in cross flow is modeled by means of a Lagrangian approach. Breakup approach is not yet considered in this simulation.

Simulation conditions

- **Inflow**
  - Mass flow rate : 0.1596 kg/s
  - Static temperature : 873 K
  - Static pressure : 111350.33 Pa
  - Velocity : 126.68 m/s
- **Inflow composition**
  - Y_{C7H16} : 0.0000000000
  - Y_{O2} : 0.1745032727
  - Y_{CO2} : 0.0480192657
  - Y_{H2O} : 0.0224646204
  - Y_{N2} : 0.7550128412
- **Fuel Injection**
  - Heptane mass flow rate :
    m_{C7H16} ($\Phi_{overall} = 1$) = $8.536267\text{x}10^{-3}$ kg/s
  - 4 injectors of radius 0.50 mm
  - Velocity of injection : 15 m/s
  - Injection Temperature 286.11 K
  - SMD radius $30\text{x}10^{-3}$ mm
  - Sigma = 0.5
- **Cooling**
  - Air flow rate : 0.110 kg/s
  - Temperature 348.89 K

Computational domain

- Computational domain is composed of 50 domains containing 2.65 millions cells approximately with a minimum resolution of 0.0005mm. The span of this computational domain is 1/12 of the actual span

- **Boundary conditions**

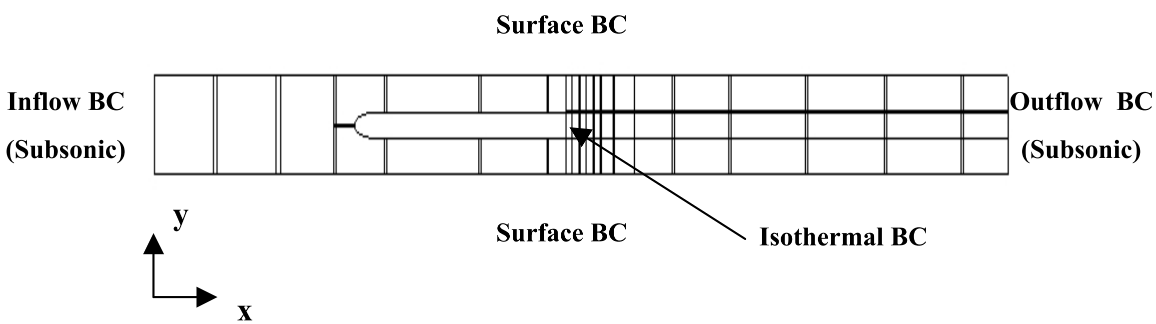
  Inflow Boundary
  Inflow conditions as described in the inflow simulation condition in the previous slide

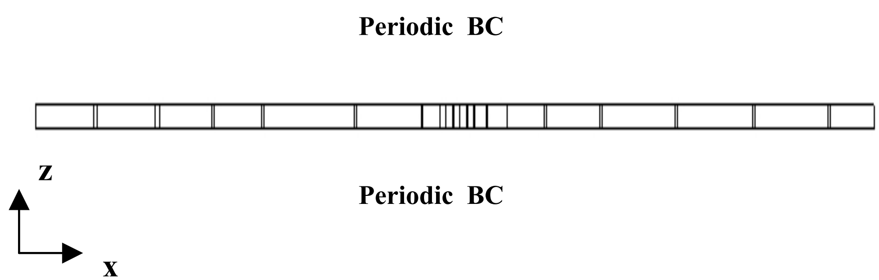
  Outflow Boundary
  Characteristics outflow boundary conditions

  Surface Boundary
  No slip and adiabatic conditions at the bluff body surface and at the rig surface in the y –direction

  Periodic Boundary
  Periodic condition at the rig surface in the z-direction.

  Isothermal Boundary
  Temperature of 2198.5 K is fixed at the base of the bluff body.





No scale

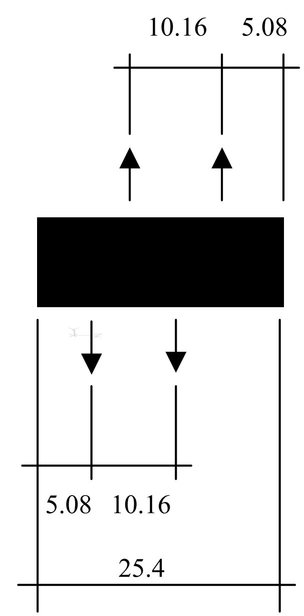
Flameholder and Injector arrangement

(No scale)

SIDE VIEW

Main stream direction

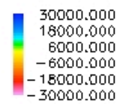
REAR VIEW

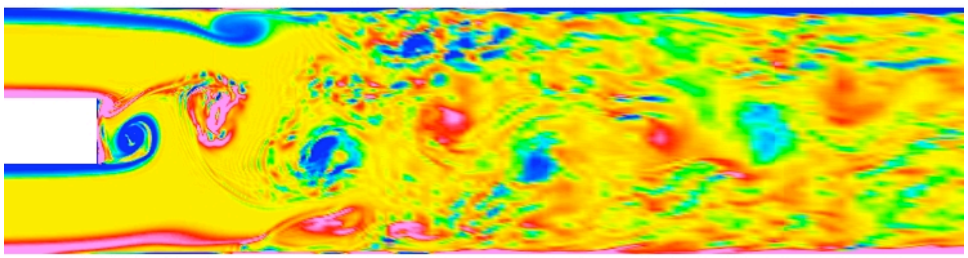


- Lengths are in millimeters
- Fuel injectors are symbolized by the black arrows

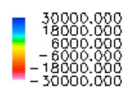
Results

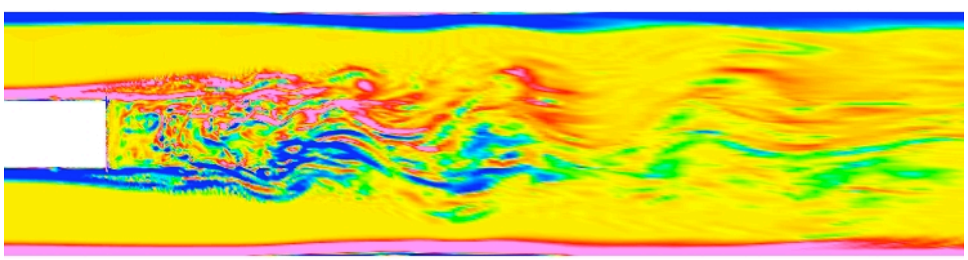
Non reacting flow





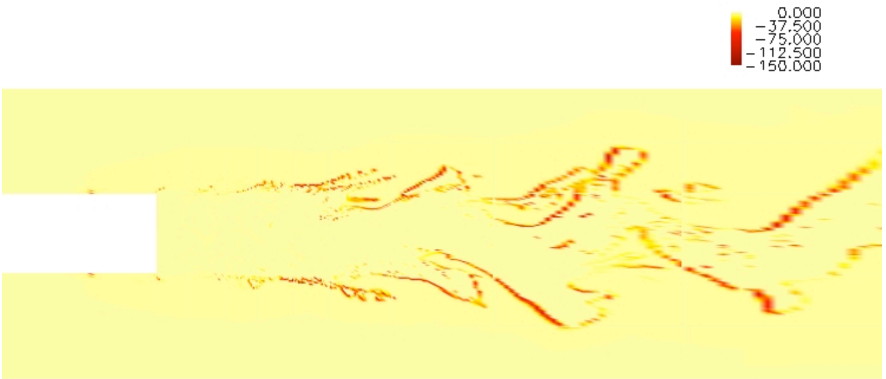
Reacting flow - EBU



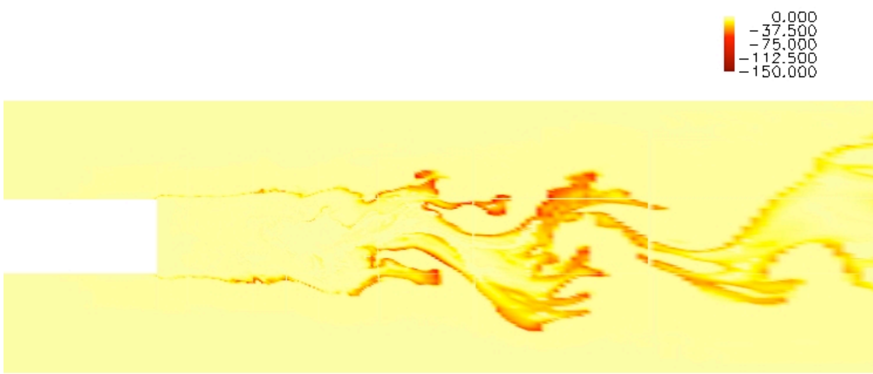


- The flow solution at the at a z = const plane corresponding to the middle plane of the rig.
- Results are reported for a simulation duration of 1.4 flow through times – not strictly reached statistical stationarity but both LEM and EBU studies have evolved a similar extent to carry out qualitative comparison
- The non reacting case is dominated by asymmetrical vortex shedding as evident from the Von Karman vortex street.

LEM - Fuel reaction rate (kg/m^{3}s)



EBU - Fuel reaction rate (kg/m^{3}s)

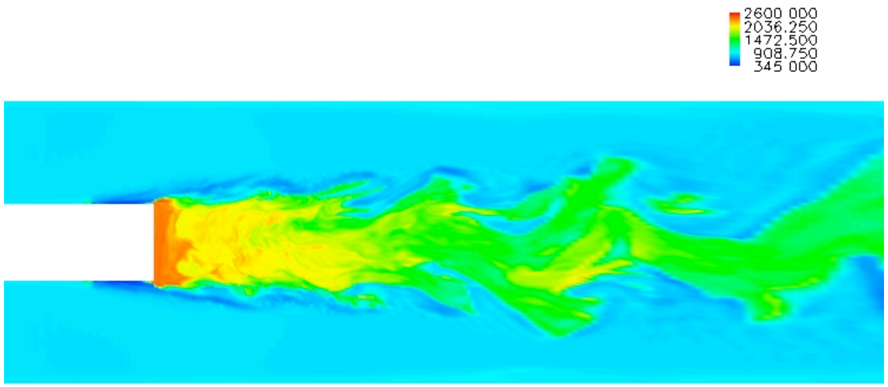


- The recirculation zone at the base of the bluff body is a source of heat which allows the combustion process to occurs in which . the flame is stabilized. However, the flame exhibits an unsteady pattern
- The LEM predicted flame structure is much thinner and located in the high shear regions whereas the EBU flame shows more local thickening. The LEM prediction is a subgrid model using finite-rate kinetics coupled with molecularl diffusion and turbulent mixing and the profiles are the LEM-filtered fields.
- Downstream of the nearly symmetric flame region, the flame exhibits a sinuous pattern due to the vortex shedding .
- At the region where the vortex is shed, local extinction may be occuring. At these locations, the flame is broken creating regions of hot products which are convected and react with unburned mixture downstream.

Results

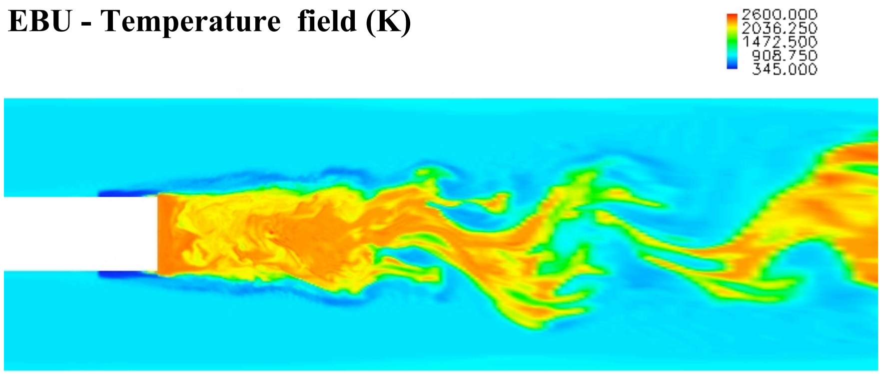
Instantaneous Near fields

LEM - Temperature field (K)

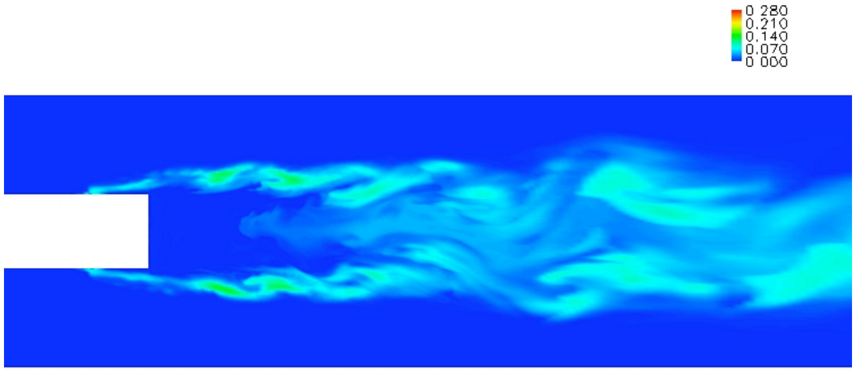


- The temperature field given by LEM gives slightly lower temperature in the symmetric region when compared to that given by EBU; however, the temperature near to the base of the bluff body is similar in both cases

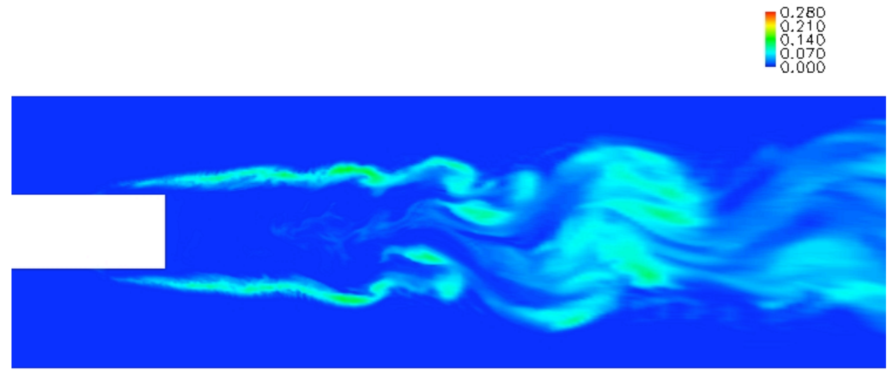
EBU - Temperature field (K)



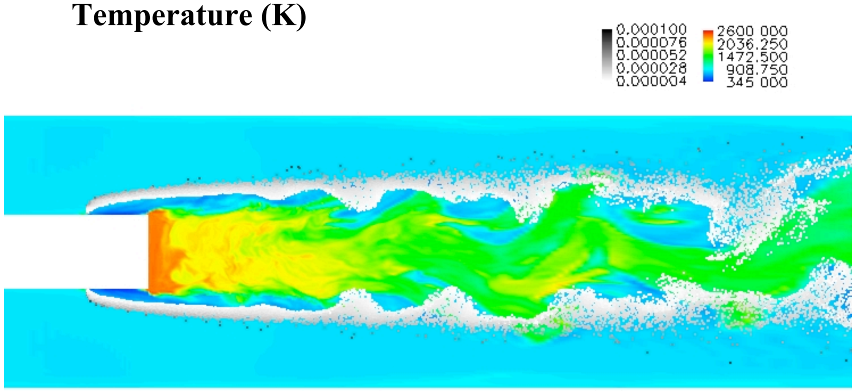
LEM – Fuel mass fraction



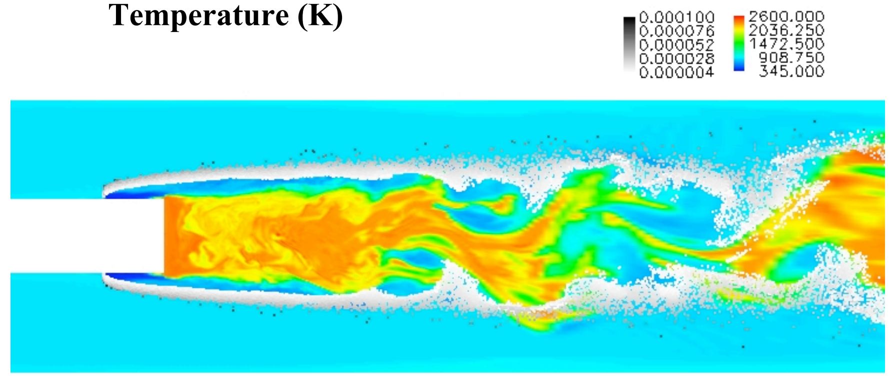
EBU – Fuel mass fraction



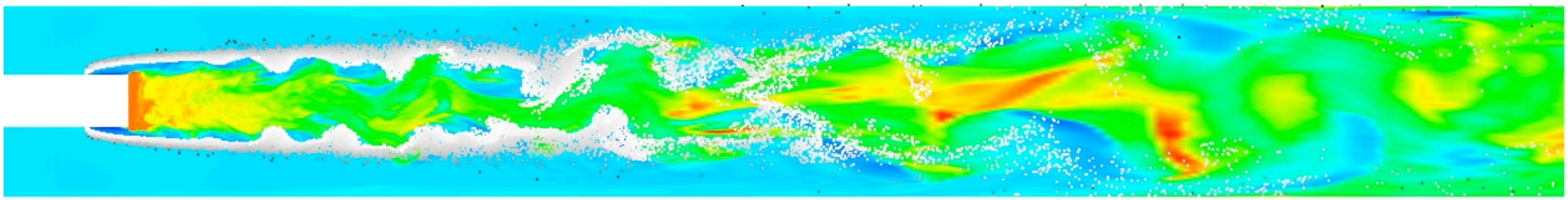
LEM – Droplet radius (grayscale) and Temperature (K)



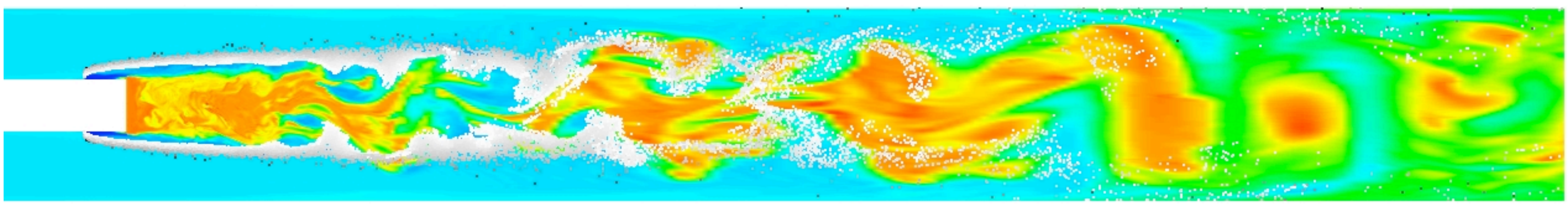
EBU – Droplet radius (grayscale) and Temperature (K)



LEM – Droplet radius (grayscale) and Temperature (K)



EBU – Droplet radius (grayscale) and Temperature (K)

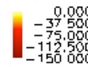


- For LEM as well as EBU simulations, most of the droplet are vaporized inside the domain almost in a distance equivalent to 2/3 of the distance between the flame holder and the exit. However, these simulations need to evolve further to obtain statistical data for analysis.
- New simulation with break-up modeling and LEM is underway to evaluate the sensitivity of the prediction of the simulation to the initial spray quality

Instantaneous Far fields

LEM – Fuel reaction rate

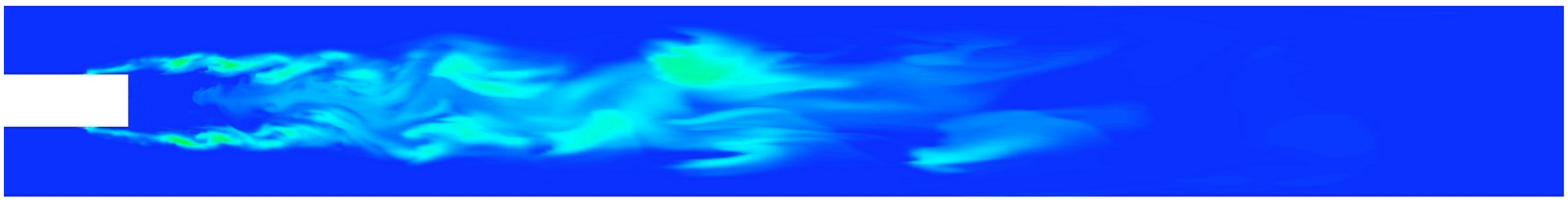
EBU – Fuel Reaction rate



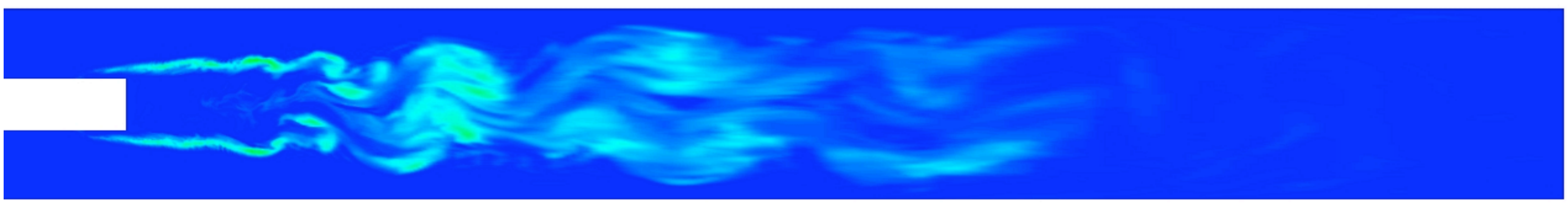
- The reaction rate for LEM is from the subgrid finite-rate kinetics and reflects both subgrid mixing and combustion effect whereas, for the EBU the “filtered” reaction rate is modeled at the LES grid level. Local burning in much thinner sheets is clearly seen for the LEM case, as was expected.

Instantaneous Far fields

LEM – Fuel mass fraction



EBU – Fuel mass fraction



- Fuel is consumed within a few bluff body diameter of the base – still need time-averaged statistics to see the averaged picture.