Plume release CFD benchmark

Participants:

Air Liquide, CEA, JCR, NCSRD, PSA
Following B. Cariteau GAMELAN experiments

- Injections of helium in a closed/vented cavity
- Covered plume up to jet regimes of injection (1NL/min up to 360 NL/min) through 5mm up to 32mm diam.
- General good agreement between theory (Worster and Huppert) except at very low injection rates => unanswered questions
  - Is the assumed constant entrainment coef the problem ?
  - Are Ri dimensionless numbers appropriate to model the physics.

=> Need for a better understanding of the flow structure through CFD or new experiments
The modeled facility GAMELAN

TABLE I: Experimental conditions.

<table>
<thead>
<tr>
<th>$D$ (mm)</th>
<th>$Q_{he}$ (Nl/min)</th>
<th>$Ri_0$</th>
<th>$l_m$ (m)</th>
<th>$T$ ($^\circ$C)</th>
<th>injection time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>4</td>
<td>3</td>
<td>0.03</td>
<td>19.5</td>
<td>1200</td>
</tr>
</tbody>
</table>
GAMELAN – sensors position

Sensors vertical lines positions

Injection

1260mm

1140mm

1060mm

940mm

820mm

700mm

580mm

460mm

340mm

220mm

100mm

Injection at 210mm from the floor
The physical models

- AL, CEA, PSA: Boussinesq approximation
- JCR: isothermal approach
- NCSRD: fully compressible equations

- L.E.S: (CEA) 2D axi approach. Smagorinsky $\mu_t = C_s^2 V_h \sqrt{S_{ij} S_{ij}}$
  $Cs = 0.2$

- Laminar approach (CEA, JCR): laminar viscosity and diffusivity but upwind scheme and limited spatial resolutions
The physical models

- RANS approach (AL, JCR, NCSRD, PSA)

<table>
<thead>
<tr>
<th>TABLE II: $k-\epsilon$ parameters.</th>
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<tbody>
<tr>
<td>parameters</td>
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<td>----------------------</td>
</tr>
<tr>
<td>$Sc_t$</td>
</tr>
<tr>
<td>$C_\mu$</td>
</tr>
<tr>
<td>$C_{1,\epsilon}$</td>
</tr>
<tr>
<td>$\sigma_k$</td>
</tr>
<tr>
<td>$\sigma_\epsilon$</td>
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<tr>
<td>injection % turbulence</td>
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</table>

- RANS k-epsilon (NCSRD)

- SST (JCR)
The numerical models

- CEA: Cast3M. Quadratic finite elements. Double projection. BDF2. Centered convection scheme. 10 nodes in the injection diam. 10000 nodes.
- AL: 3D, 8 nodes in the injection. 500000 nodes. BDF2 scheme. Fluent VF. Upwind.
- NCSRD: 2 cells in the source (new calculations since this paper). 25000 nodes. 3Rd order Quick.
- JCR: CFX. BDF2. Many tetraedral mesh tested.
Results – C vertical profiles at 115s

The graph shows the concentration he (%) at different altitudes (m) over time at 115 seconds. The graph includes various data sets such as JRC laminar, JRC SST, NCSRD laminar, NCSRD k-eps, NCSRD RNG, CEA EXP, JRC k-eps, AL k-eps realizable, CEA LES, PSA k-eps, and CEA laminar. The x-axis represents altitude (m), and the y-axis represents concentration he (%). The graph illustrates the vertical distribution of concentration at the specified time.
Results – C vertical profiles at 275s
Results – C vertical profiles at 875s
Concluding remarks

- RANS approach: too dispersive, too much diffusion leads to lower concentration at the top and higher concentration at the bottom of the cavity.

- Laminar approach: not really laminar, grid not fine enough, it is not DNS because of upwind scheme. Not diffusive enough because fluctuations and entrainment mechanism not well captured.

- 2D-axi approach (LES): not diffusive enough, axisymmetry blocks the fluctuations along the axis of the jet.
Work in progress and perspectives

- UU made very promising 3D-LES calculations. Good agreement with experiments.

- Comparisons with new experiments are to be achieved. CEA has started a new GAMELAN set of experiments with PIV measurements
  - Gives access to velocity maps at the cavity scale
  - Access to 3D components velocities in the jet with fine resolution (0.05 mm).
Future experimental validations
Mean values and entrainment

- Normal profile even at close distance will allow to calculate entrainment coef with vertical velocity.