# Quality Assurance

In this section the descriptions are provided for the different conducted studies with which we can assure the correctness of the results available from the simulations

## Iteration Error Study

These errors occur due to the difference between a fully converged solution of a finite number of grid points and a solution that has not fully achieved convergence. Discretized equations are iteratively solved. It is expected that progressively better estimates of the solution are generated as the iteration step proceeds and ideally satisfies the imposed boundary conditions and equations in each local grid cell and globally over the whole domain. However, if the iterative process is terminated prematurely then errors arise. Convergence errors therefore can occur because of either being impatient to allow the solution algorithm to complete its progress to the final converged solution or applying too large convergence tolerances (criterion) to halt the iteration process when the CFD solution may still be considerably far from its converged state. MAX is the residual type chosen to specify the value for the convergence target. MAX Residuals were monitored after every iteration to check whether they reach the specified convergence target. To avoid such type of errors calculations were performed with MAX Residual < 10-3 to 10-6 and compared with each other and corresponding experimental data.

## Spatial discretisation errors

After the iteration or convergence error is taken care of the numerical errors arising will be concerning the spatial discretisation error. If not taken care of they have a tendency to accumulate through computational processes that may yield unphysical CFD solutions. Hence controlling it will be a crucial step towards obtaining a reliable and meaningful CFD solution.

Spatial discretisation errors are primarily concerned with the approximations of convective terms of the governing transport equations. These errors occur due to the difference between the exact solution of the modeled equations and a numerical solution with a limited spatial resolution. They arise because an exact solution to the equation being solved is not obtained, but numerically approximated. This phenomenon of approximation is termed as differencing scheme and the accuracy of this scheme depends on the form of the algebraic relationship and also on the location of participating grid points (Stencils). As an example of the Taylor series expansion is shown for accuracy of 1st order

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| --- | --- | --- |
|  |  | (1.1) |

where is called the truncation error.

The formulation has the truncation error of order 2 and is therefore second order accurate and so on in the fashion . Halving the elements using the first order scheme will reduce the numerical error by a factor 2 and halving it for the second error scheme will reduce the numerical error by a factor 4. Thus by reducing the number of cells in the grid can reduce the numerical error.

This study was performed to achieve grid independence, which means that the grid needs to be refined by increasing the number of grid points until a solution is achieved where no significant changes in the results occur. This indicates that the discretisation error is reduced to an acceptable error and grid independence is reached. In order to achieve that a hierarchy of 4 meshes have been prepared, by doubling the number of mesh elements, in both direction, per level.

## Additional Quality Assurance studies

### Test of turbulent inlet boundary conditions

This test was performed to check, whether using some different turbulent inlet boundary conditions, apart from turbulent kinetic energy (K), turbulent dissipation (ε) and turbulent eddy frequency (ω) obtained from the interpolated fully developed flow profile at the jet exit plane, improves the comparison with experimental data or not. Also the reason to perform this test was improper documentation of the boundary conditions at fuel jet inlet. In this test turbulent kinetic energy (k) and length scale were used as the turbulent inlet boundary condition for both fuel jet and co-flow inlet. The famous round jet anomaly phenomenon was also addressed in this study, in terms of modification of coefficient Cε1 of the turbulent dissipation (ε) equation in standard k-ε model. At co-flow inlet the inflow conditions were provided with an inlet flow profile, obtained from the experimental measurements, to see whether that helps to resolve the boundary layer or not. Turbulent kinetic energy was calculated for both co-flow and jet inlet, refer eq (), using the experimental data available at the location X/D = 0 and X/D = 4 respectively. For the length scales it was assumed equal to one tenth of the diameter of the respective inlets.

For the purpose of comparison, two new non-dimensionalised quantities were introduced to compare the jet spread and velocity decay.

Velocity u invariant (U invar)

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| --- | --- | --- |
|  |  | (1.2) |

where, *velocity u* is the result obtained from the numerical calculation.

Propane mass fraction invariant (PMF invar)

|  |  |  |
| --- | --- | --- |
|  |  | (1.3) |

### Turbulent Schmidt number study

This study was conducted to check the sensitivity of the jet towards the Sct number and to identify which number predicts the results closest to the real flow. Simulations were performed with the sequence of Sct numbers ranging from 0.6-0.9 with mesh 4 resolution and K-ω SST model and the results were compared with the experimental data.

## Inspection of the results

Along with the convergence target a separate parameter called conservation target was monitored to decide upon the convergence of the simulation. Conservation target can be further understood as the global imbalances over the entire domain for the conserved quantities i.e. mass, momentum etc. Conservation target is specified as a single value and each conserved quantity has to achieve that value. Further information can be found under [12]

Monitoring points were placed in the domain at the specific locations to track how the simulation progresses i.e. when does the mass fraction of fuel reach at a certain location and at what number iteration. At every monitoring point the concentration of various species, velocity components, turbulence quantities etc is tracked. Looking at the monitoring points we can confirm whether any physical changes are occurring in the domain or not.