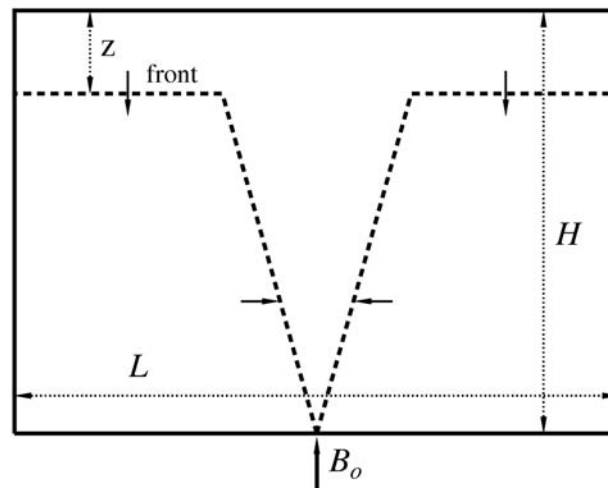


## **Tutorial 5 - Round Buoyant Jet in a Confined Region - Dynamic Coupling of Jet and Surrounding Fluid**

The previous tutorials illustrate the ability of the VISJET 3 system in predicting mixing characteristics (e.g. dilution, trajectory, and mixing zone) of any 3D multiple jet groups in arbitrary ambient conditions in the near field. Computations of the near field model cease once the simulated jets reach the trapping level or hit a boundary (water surface or sea bed). In reality, the pollutant cloud would continue to spread due to the remaining density difference with the surrounding ambient water (gravitational spreading); the dilution process would continue but at a much slower rate. This zone is given the name intermediate field. Further away from the intermediate field is the far field, where the mixing and dilution are governed by the ambient current, passive turbulent dispersion and biochemical processes such as bacterial decay. The DESA technology has been developed to dynamically coupling the near and far field models to enable seamless simulation of the dilution processes from the near field to the far field region.

In the following tutorial cases, the functions and uniqueness of the VISJET 3 system employing the DESA technology will be illustrated.



The effect of continuous convection from a source of buoyancy on the properties of the environment in a confined basin (e.g. typhoon shelter) is studied. A round buoyant jet is situated at the centre of a tank 57.2 m x 48.4 m in plane and 30 m deep. Different kinematic buoyancy flux  $B_o = \frac{Q_o g \Delta \rho_o}{\rho_o(0)}$ , where  $Q_o$  = discharge volume flux, can be tested. The

buoyant plume mixes with the ambient fluid by turbulent entrainment; when it rises to the water surface the mixed fluid spreads sideways as a surface layer, with negligible vertical mixing (damped by density difference). The thickness of this layer of mixed fluid increases with time, and the front of this surface layer advances with a velocity  $dz/dt$ . A 13 x 11 x 10 model grid with horizontal grid size 4.4 m by 4.4 m and 10 uniform vertical layers is used to simulate the round buoyant jet.

The main parameters are as follows:

Basic Data:

Outfall Parameters:

Depth (z)	30 m
Flow	0.046 m <sup>3</sup> /s
Temperature	20 °C
Salinity	0 ppt
Concentration	100 relative units

Initial Ambient Parameters:

Depth	30 m
Temperature	20 °C
Salinity	40 ppt
Current velocity	0.0 m/s (Current angle 90°)

An initial relative density difference  $\frac{\Delta\rho_o}{\rho_a(0)} = 0.030$

Jet Parameters:

Diameter	0.3 m
Vertical angle	90°
Horizontal angle	0°

General Notes:

1. *Opening the exiting scenario*


- (i) Click **File** at the menu.
- (ii) To open an exiting scenario, select **Open**.
- (iii) Select the directory roundjet01.
- (iv) Select the file roundjet01.vj3.

A view of the basin with the jet at the centre from the top will appear in the right-hand side visualization panel, while the initial ambient conditions and the outfall parameters are shown in the panel in the left-hand side. Click on Outfall #01, the Outfall Parameters will be displayed. Click on Jet #01, the Jet Parameters will be shown.



## 2. *Navigate around the basin*

- (i) Left click any point on the screen, the clicked point will automatically become the centre point of the screen.
- (ii) Scrolling down and up will allow you to zoom in and out with the selected point in step (i) as centre
- (iii) left click and hold the mouse button, and freely move the mouse to view the topology at different orientations


## 3. *Near field simulation*

- (i) As the previous tutorial cases, the near field simulation will be performed by clicking “**Start Near Field VISJET simulation**”  at the toolbar.
- (ii) The near field *jet characteristics* of each Lagrangian element can be examined in the same manner as: the first four tutorial cases.

## 4. *Coupled near and far field simulation*

- (i) The coupled near and far field simulation with the DESA technology will be performed by clicking “**Start Near-and-Far Field simulation**”  at the toolbar.
- (ii) A pop-up window with the warning message “DESA simulation usually takes hours to finish. Confirm to begin simulation now” will appear. Click “Yes” to proceed.
- (iii) A progress meter coloured in green and the estimated time to completion will appear to the right of . For the present cases, it will take about 5 minutes to complete the simulation in a machine with 1.86 GHz Xeon processor.

## 4. *Visualize the near and far field simulation results*

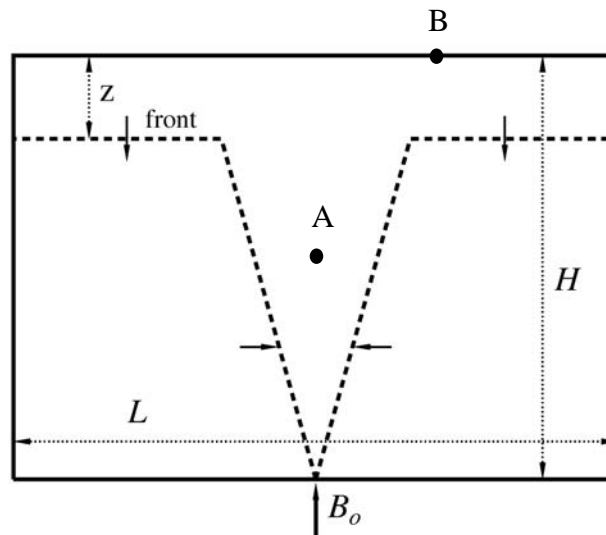
- (i) After the completion of the simulation, click “**Far-field visualization**”  at the toolbar to launch a separated program Visjet Visualizer for visualizing the far field results.
- (ii) Again a view of the basin with the jet from the top will appear initially. A vertical clip plane running across the discharge point is also defined.
- (iii) You can navigate around the basin in the same manner as described above.
- (iv) Press space bar or select the “Play / Pause” option under the “Control” menu to begin the modelling output display.
- (v) A black line is included to indicate the 1:500 dilution contour line.

(vi) The development of the surface layer and the downward movement of the front are clearly visualized.

(vii) Left click at a point in the water surface, a pop-up window will appear showing the time variations of the depth-averaged concentration, water level and current speed.

(viii) The changing in colour in the upper part of the jet can also be observed, which indicates the interaction between the jet and the ambient environment. For the present case, the relative concentration at the top of the jet will increase from about 0.46 to 1.20 (or reduce in averaged dilution from 217 to 84) at the end of the simulation.

### 5. Velocity variation at the surface layer



(i) Click a point at the top of the jet (point B in the above figure).

(ii) Play the simulation starting from the beginning, and observe the velocity variation with the time. (In order to provide a better visualization effect, the animation rate is slowed down by scaling the display time; one day showed in the clock represents 30 minutes in the simulation and the simulation is for a duration of 150 minutes instead of 5 days as shown in the digital clock.)

(iii) At the beginning, the velocity at point B is 0.0 m/s as the jet induced velocity is negligible at B at the beginning. At about Day 1, 02:00 a.m., velocity at B is about 0.001 m/s, then increases steadily with time to a maximum of about 0.060 m/s at Day 2, 02:00 p.m., and starts to fall back to about 0.036 m/s which remains approximately constant in the rest of the time. (From the near-field simulation, it can be seen the vertical velocity at point A is about 0.22 m/s.)

(iv) The variation of this velocity shows that there is a continuous variation in the ambient condition with time. This varied ambient condition affects the mixing characteristics (such as concentration, and velocity) of the jet all the time. By using the DESA, this has been fully

taken into account. The change in jet mixing characteristics can be visualized as well by looking closely to the variation of the jet colour (which represents the jet concentration), and the jet movement due to the ambient condition variation.

#### 6. Concentration variation at the surface layer in the horizontal direction

- (i) Consider again point B in the same figure. This time we will be more focused on its concentration variation.
- (ii) Play the visualization again. The concentration at point B can be seen to increase steadily from 0 unit to 0.5 unit at the end of simulation.
- (iii) Now shift the monitoring point slightly to a point C further away from the centre as shown in the figure, and play the visualization again.
- (iv) Observe the variation of the concentration at point C with time.
- (v) Except a slight observed time shift, the concentration variation at point C is similar to that of point B, with concentration 0.5 unit at the end of the simulation. This shows that the horizontal variation in the surface layer is small.

#### 7. Variation of the interface with time

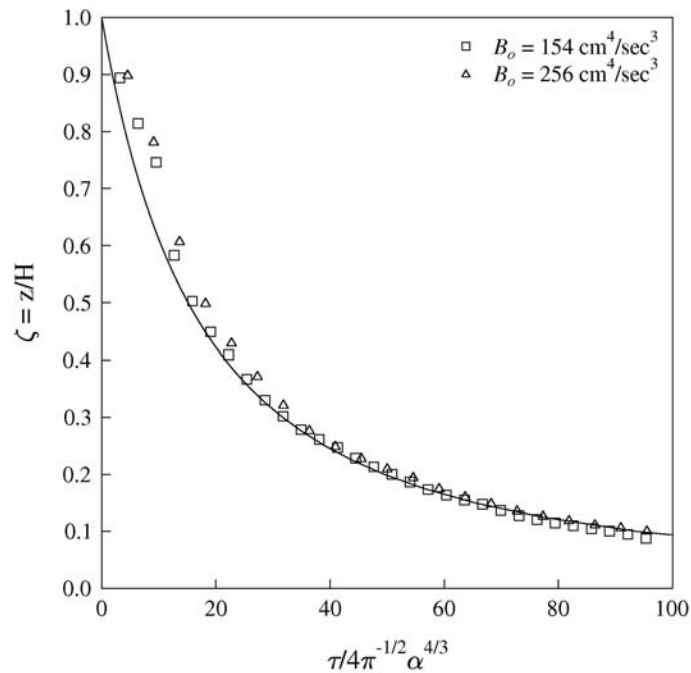
- (i) It can be seen from the visualization that the interface (defined by a certain concentration contour) of the surface layer keeps moving downwards.
- (ii) Baines and Turner (1969) performed laboratory experiments and obtained an analytical solution which describes the variation of the interface defined by the  $0.1\Delta\rho_{\max}$  contour with time, and is given below:

$$\tau = 5 \left( \frac{5}{18} \right)^{1/3} [\zeta^{-2/3} - 1]$$


in which  $\zeta = \frac{z}{H}$  and  $\tau = \frac{4}{\pi^{4/3}} \alpha^{4/3} \left( \frac{H}{R} \right)^2 \frac{(B_o/2)^{1/3}}{H^{4/3}} t$  with  $\alpha =$

entrainment constant = 0.1, and  $R$  is the equivalent radius for the rectangular tank.


- (iii) Try to obtain the interface position from the visualizer at a few time instant according to the definition given above. Compare with the analytical solution given above, are they in agreement?
- (iv) The figure below shows the comparison between the result of the calculations simulating the experiments carried out by Baines and Turner with the laboratory scale (using a 19 x 15 x 20 model grid with horizontal grid size 3 cm by 3 cm and 20 uniform vertical layers) and the analytical solution. The predicted interface position by the DESA is in excellent agreement with the analytical solution, and this cannot be satisfactorily predicted using the conventional “source-only” approaches (Choi and Lee 2007).



#### 8. Jet with greater discharge flow

- (i) To see the effect of greater discharge flow, click on Outfall #01 and change the total flow to  $0.092 \text{ m}^3/\text{s}$  (three times the original flow).
- (ii) Click “**Save Project**”  to save the updated information to the file.
- (iii) Perform the simulation and visualize the results in the same way as described about.
- (iv) A higher concentrations at the jet and the surface indicate smaller dilutions can be observed. The initial relative concentration at the top of the jet increases from about 0.46 to 0.70, i.e. the averaged dilution decreases from 217 to 143. (The similar results can be obtained from the near field simulations).

#### 9. Jet with weaker buoyancy

- (i) To see the effect of a discharge with weaker buoyancy, click on Outfall #01 and change the salinity to 35 ppt (an initial relative density difference equals to 0.004).
- (ii) Click “**Save Project**”  to save the updated information to the file again.
- (iii) Perform the simulation and visualize the results in the same way as described about.
- (iv) It can be observed that an even higher concentrations are resulted indicate a further reduction in dilutions. The initial relative concentration at the top of the jet further increases to about 1.23, i.e. the averaged dilution reduces to 82. (The similar results can be obtained from the near field simulations).