Standardisation of test method for salt spreader: Air flow experiments

Report 3: Simulations of airflow patterns

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Objective
One of the objectives of the air flow experiments was to visualize the airflow patterns and stability around a salt spreader. A Computational Fluid Dynamics (CFD) model was made of a box salt spreader model, and the calculated flows compared with flow patterns observed in the wind tunnel using laser sheet visualisation (Strøm, 2011). The main focus was an overall picture of the turbulent airflow around the box truck with special emphasis on airflow patterns and stability at and downstream of the spreader plate.

Methods
The simulations were carried out using a number of k-ε models. The validation experiments were carried out in the wind tunnel in the Air physics laboratory at the Engineering Centre Bygholm (Strøm, 2011).

A simplified box model with the same outer dimensions as the scale model truck (figure 1) was used in the CFD simulations. It was also used for visualization experiments (Strøm, 2011), and the results are thus available to validate the results of the simulations. In order to make laser sheet visualization more effective the box model was painted flat black as shown in figure 2.

Figure 1. Outer dimensions of the model trucks.
The instrumentation for the visualization experiments is also described by Strøm (2011)

**CFD mesh**
The mesh used for the CFD simulations is shown in figure 3. The volume surrounding the box model was divided into a number of volumes. Places where major changes in flow directions were expected were divided into a number of smaller sub-volumes than elsewhere, typically at the corners of the box model. This is needed in order to increase the accuracy of the simulations.

In order to reduce the number of sub-volumes the sidewise flow around the model was expected to be symmetrical, and only the right half of the box model was included in the simulations.

**Flow in the horizontal plane**
A k-ε model was used to simulate the overall flow in the horizontal plane at height 3 cm (0.5 cm under the bottom of the model). The result is shown in figure 4. The velocity is seen to increase as the air is turning around the front, right corner leaving a wake with lower velocities along the side of the box model. Behind the model there is a zone of very low velocities from $1/2$ a box model length to $11/2$ length and then gradually increasing further downstream.
In figure 5 is shown the airflow patterns observed in the wind tunnel in the horizontal plane behind the box model at a height equivalent to the underside. The airflow is seen to curve from the right hand side towards the left hand side. In other cases the airflow curved in the other direction from the left to right. An eddy was seen rotating in the centre plane close to the rear end, but not being symmetrical around the centre line as assumed in the CFD simulation.

A detailed picture of the velocity distribution under the box model is shown figure 6. The distribution is uniform except for the influence of the simulated wheels, creating a wake directed slightly outwards. A similar picture of the flow was not available from the visualization experiments.
Flow in the vertical, central plane using k-ε model

The result of a simulation of the airflow patterns in the central, vertical plane is shown in figure 7 using a k-ε model. The velocity is seen to increase as the air is turning around the front, top corner leaving a wake with lower velocities along the top of the box model. Behind the box model there is a zone of very low velocities trailing ½ a model length and a smaller low velocity zone attached to the road. The two are separated by a narrow higher velocity jet. Around 1½ box model length and further downstream the velocity close to the road is gradually increasing.

![Figure 7. CFD simulation by k-ε model in the vertical, central plane](image)

A more detailed picture of flow around and behind the box model is shown with streamlines in figure 8. At the upstream end of the box model the airflow is divided into an upward and a downward going flow. The downward flow creates a high velocity zone under the front of the box model and continues downstream under the box model as a uniform flow.

Behind the model the flow is turning sharply upwards in an s-shaped curve with contra rotating eddies at the bottom and the top. At a distance of ½ the box model length downstream of the rear end the bottom flow joins the top flow, and no return flow is seen close to the road. Some of the streamlines near the road in the bottom flow is seen to continue downstream escaping the upward flow attaching to the rear end of the truck.

![Figure 8. Streamlines and velocity around the box model using CFD simulation with a k-ε model.](image)
In figure 9 is shown the airflow patterns observed in the wind tunnel in the vertical, central plane as the airflow hits the front end of the box model. The airflow is seen to split into an upward and a downward going flow. The downward flow creates a high velocity zone under the front of the box model as predicted by the CFD simulations.

![Figure 9. Airflow at the upstream end of the box model](image)

As the airflow leaves the underside of the box model the flow detaches the road and curves upwards into an eddy attached to the rear end. The eddy at the bottom is clearly seen while the top, contra rotating eddy predicted by the CFD simulation is less visible.

![Figure 10. Airflow in the centre plane behind the truck](image)

In order to clarify if there is a return flow close to the road the smoke is supplied vertically downwards in the centre plane between the rear wheels, figure 11. It shows that all the air from under the box model turns upwards, and none continue directly downstream as predicted by the CFD-simulation, either attached to the road or as a narrow higher velocity jet below and independent of the upwards in directed s-shaped curve.

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Simulations with alternative k-ε models
A number of alternative k-ε models were used to see if one made more precise simulations of the flow near and behind the salt spreader. The results are shown in figure 12. Dark blue colours are high velocities downstream and red colours low velocities or recirculation airstreams.

All the simulations fail to show that all the air from under the box model turns upwards, and none continue directly downstream either attached to the road or as a narrow higher velocity jet below and independent of the upwards in directed s-shaped curve.

To determine how important this is for the salt spreading picture the airflow model needs to be combined with a mass spreading model taking into account the effect of initial dynamic energy of the salt particle being ejected from the spreader plate, gravity, air velocities and air resistance.

It is expected that the airflow patterns will be of increasing importance as the particle is losing its initial kinetic energy. At some for now unknown distance the velocity fields will determine the spread picture. At this distance a better model than a k-ε model e.g. a large eddy model should be evaluated to describe the instability of the airstreams and also capture better the return flow fields near the road and the non-symmetry in the horizontal.
**Conclusions**

The airflow patterns observed in the wind tunnel in the horizontal plane behind the box model at a height equivalent to the underside was seen to curve from one side towards the other in a fluctuating manner. An eddy was seen rotating in the centre plane close to the rear end, but not being symmetrical around the centre line as assumed in the CFD simulation.

In the vertical, central plane behind the box model all the simulations failed to show that all the air from under the box model turns upwards, and none continue directly downstream either attached to the road or as a narrow higher velocity jet below and independent of the upwards in directed s-shaped curve. Abetter model than a k-ε model e.g. a large eddy model should be evaluated to describe the instability of the airflows and also capture better the return flow fields near the road and the non-symmetry in the horizontal.

For salt spreading purposes the airflow models need to be combined with a mass spreading model taking into account the effect of initial dynamic energy of the salt particle being ejected from the spreader plate, gravity, air velocities and air resistance. It is expected that the airflow patterns will be of increasing importance as the particle is losing its initial kinetic energy.

**Literature**
