FACTORS INFLUENCING THE SPREAD PATTERN FROM SALT SPREADERS

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ABSTRACT

Air movements around the salt spreader caused by wake or windy conditions may seriously affect the spread pattern when distributing salt on roads. Methods for reduction of this influence are very important from safety and environmental reasons

Full scale in-door tests have shown the influence on the spread pattern for different salt types in situations with and without cross wind up to 4.5 m/s. The results from these tests show that the wind may move the spread pattern 2-3 m depending on salt particle size.

Visual tests have shown that the salt distribution behind the spreader at normal driving speeds may result in "fish tail distribution" patterns which differ from the spread pattern found in-door at low driving speeds.

In order the find reasons for differences, laboratory tests have been carried out to show air movements around the spreader. The laboratory tests were carried out using spreader/truck scale models in wind tunnels. By adding smoke the movements around the scale models has been visualized. It has been observed how vacuum is established behind the salt truck causing air movements upward and from side to side (von Karman effect) behind the spreader.

1. INTRODUCTION

The spread pattern determined in tests under full scale laboratory conditions may differ considerably from the spread pattern achieved when distributing salt on roads. Air movements created by the salt truck with hopper will be considerable at higher driving speeds on the road. Cross wind will affect the spread patterns at any driving speed. Only limited knowledge is found in literature on these topics.

Providing knowledge of the airflow patterns behind a salt spreader truck as a function of truck geometry and driving speeds is included in the broader research project "Standardization of test method for salt spreader" supported by the Nordic State Road Agencies, that subsequently will report to CEN/TC 337/WG 1 "Winter maintenance equipment".

Different technologies are described in the literature on how to modify the airflow patterns around a moving vehicle, e.g. an airplane, a racer car or a transport truck. These technologies are aimed at other purposes than to influence the airflow patterns behind the vehicle. To be usable they need to be specifically adapted to salt spreading.

This paper describes

1. the effect on the spread pattern of cross wind of 4.5 m/s under full scale laboratory conditions

2. observations of how the spread patterns are affected by the air movements created behind a full scale salt truck with hopper when driving on an outdoor test road
3. visualization of the air movements created behind 1 to 15 scale salt truck models in a wind tunnel.
4. methods to maintain optimum spread pattern when distributing salt on roads.

2. CROSS WIND

The effect of cross wind was determined behind a stationary and a moving salt spreader during calm and at crosswind of 4 - 5 m/s, Strøm 2012a [1]. The spreader had two contra-rotating spreader discs at 40 cm above ground. They were fed rock salt from a hopper via two conveyor belts.

The 12 by 6 m test area with concrete floor was divided into 1 by 1m test squares on which the deposited total weight and the distribution on particle size were to be determined. The salt was collected manually from each test square as shown in figure 1 and saved in numbered buckets for weighing and determination of salt particle size distribution. For the moving spreader the salt was collected on a smaller test area consisting of a row of 12 test perpendicular to the driving direction.

Figure 1 - Manual collection of salt deposited on each test square.

The crosswind was created by a bank of four axial fans on one side of the test area. Looking from the experimental area towards the fan bank a view of the lay-out is shown in figure 2. The average wind velocity in the experimental area at height 40 cm was 4.5 m/s and at height 20 cm slightly lower at 4.3 m/s. In the test area used for the moving spreader the average velocity was 0.3 to 0.4 m/s higher than used for the stationary spreader.

Figure 2 - View of the experimental area with the spreader stationary at the reference point.

The salt spreader was placed at the reference point. The spreader discs were run for 30 seconds and a picture of the resulting salt distribution is shown in figure 3. There is a concentration of deposited salt within 1 m from the reference point and a semicircular concentration arc close to 3 m from the center at no crosswind.

Figure 3 - Salt distribution from the stationary spreader at no crosswind.

With the spreader at the reference point, the fans were switched on and the spreader run for 30 seconds with the same settings as used previously for the no wind situation. This resulted in a concentration of deposited salt ca. 1 m from the reference point as at no crosswind. The concentration arc close to 3 m from the center became however more elliptic with salt concentrated on the downwind side. There was nearly no salt deposited upwind more than 2.5m from the center line as shown in figure 4.

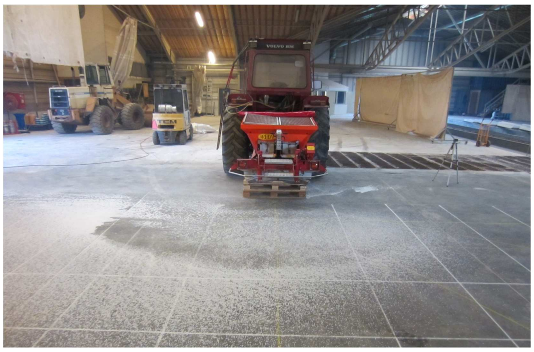

Figure 4 - Salt distribution from a stationary spreader with crosswind.

The effect of crosswind for the stationary spreader is shown in figure 5. At no crosswind (test 1) the maximum salt weight was 18 % +0.5 m from the center line Exposed to crosswind (test 2) the maximum salt weight moved 2 m in the downwind direction. For the rest of the curve the displacement was 1.5 to 2 m in the downwind direction.

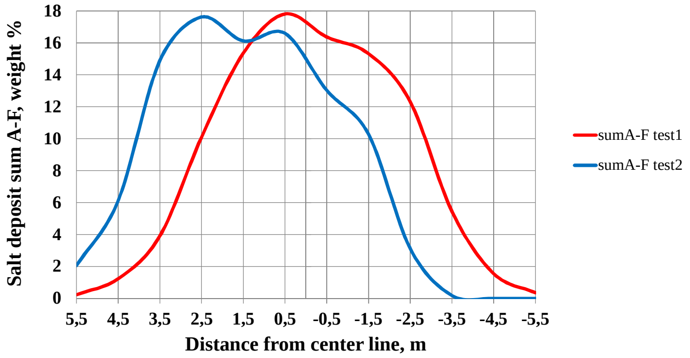

Figure 5 - Sidewise distribution of salt weight behind the stationary spreader at calm (test 1) and at crosswind (test 2).

In order to determine the salt distribution behind a moving spreader the tractor with spreader was started some 10 m from the reference line and driven at slow, constant speed of 0.726 m/s or 2.6 km/h for a distance of 40 m passing the experimental area on its way. The slow driving speed was selected to ensure that the air movements created by the tractor and hopper was minimal.

The result is shown in figure 6. The distribution curve is skewed in the downwind direction with a fairly flat maximum of 12 to 13% per row at distances between -1.5 and +2.5 m from the center line. A distinct maximum peak of 17% of the deposited salt appeared 3.5m downwind of the center line.

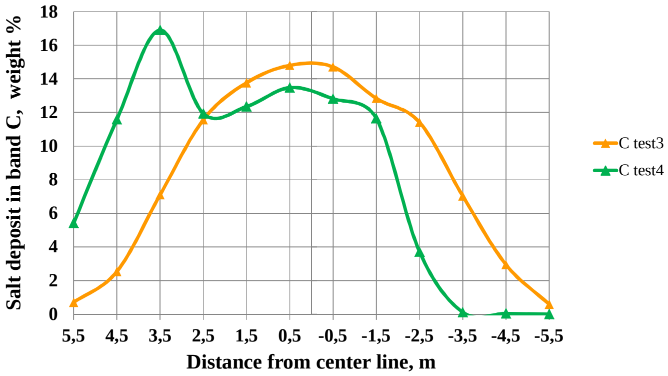

Figure 6 - Sidewise distribution of salt weight behind the moving spreader at calm (test 3) and at crosswind (test 4).

The reason for the distinct, asymmetrical peak may be that small salt particles are more sensitive to crosswind than large particles. In figure 7 is therefore shown the sidewise weight distribution on particle size behind the moving spreader at calm. There is only seen a minor effect of the two spreader discs on the distribution for the medium size particles with a nearly flat level of 5% at ±2.5 m from the center line. For the two other particle sizes and for the total weight the distribution is symmetrical with a maximum at or within ±0.5 m from the center line.

The small particles are practically not present further than ±3.5 m from the center line. The medium particles are present up to ±4.5 m and the large particles up to ±5.5 m from the center line.

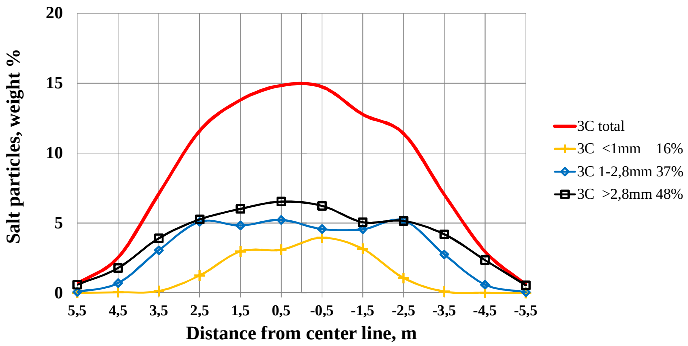

Figure 7 - Distribution of size fractions and total salt deposition in band C 2.5 m behind the moving spreader at calm wind.

In figure 8 is shown the sidewise size distribution behind the moving spreader at crosswind. The effect of the crosswind is particularly visible for the small particles which have been concentrated between 2.5 and 5.5 m downwind with a remarkable 5% peak 3.5m downwind of the center line. The distribution curve for the medium sized particle still have a flat level of 5% that have been moved downstream from -2.5 / +2.5 m to -1.5 / +4.5 m relative to the center line. The downwind limit for the large particles moved 2 m from 5.5m to 3.5 m; the maximum value at 0.5m downwind of the center line is increased from 6.5% to 8.4% of the deposited salt.

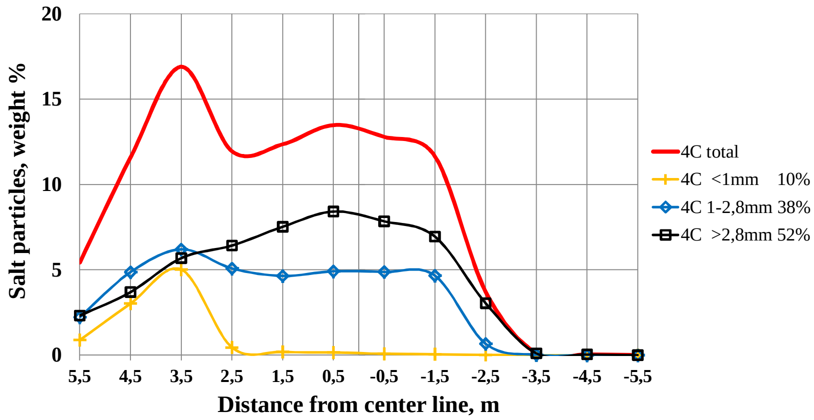

Figure 8 - Distribution of size fractions and total salt deposition in band C 2.5 m behind the moving spreader at crosswind.

The net result is that the total weight curve that was symmetrical at no wind has become unsymmetrical. The crosswind has caused a distinct 16.9% peak 3.5m downstream of the center line. The peak is primarily due to the dislocation of the small particles indicating that small salt particles are more sensitive to crosswind than large particles.

3. FISH TAIL DISTRIBUTION

The turbulence generated by a moving full scale truck with salt hopper and the effect on salt distribution patterns was visualized outside at normal driving speeds on the asphalt test road at Engineering Centre Bygholm, Strøm 2012b [2] The driving speeds were between 15 and 50 km/h, typically 30 km/h. Most runs were done without application of salt, but for some runs rock salt was used at a normal application rate of 30 g/m^2.

An example of an uneven salt distribution pattern after one passage of the salt spreader truck is shown in figure 9. The salt was concentrated in a few narrow bands with areas with low visual coverage in between

Figure 9 - Salt distribution patterns after passage of salt spreader truck.

The “fish tailing patterns” in the distribution of salt behind the salt truck indicates the presence of a von Kármán vortex street, i.e. a repeating pattern of air vortices caused by the unsteady separation of air from the truck. In figure 10 is shown the simulated flow around a rectangle. Eddies are shed continuously from each side, forming rows of vortices in its wake. The alternation leads to an eddy in one row being opposite the point midway between two eddies in the other row, probably giving rise to the distinctive patterns observed at salt spreading.

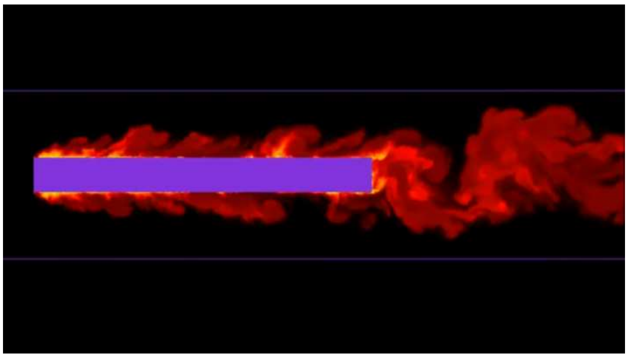

Figure 10 - Simulated flow around a rectangle.

Ultimately, the energy of the eddies are consumed by viscosity as they move further downstream, and the regular pattern disappears, but at this point most of the salt may be unevenly distributed on the road.

This development was followed on the test road using a stationary video camera. A few screen dumps of the result are shown in figure 11. The top figure shows the spreading pattern as the truck passed an observer 13 seconds after the start of the recording. A heavy concentration line has developed in the middle of the road ending at the blue arrow. One second later a weaker salt line continued in a sinusoidal way to the left of the road marked by the green arrow being fully developed at 15 seconds, i.e. within 2 seconds of starting to develop.

During the test runs the distance between the tops of the sinusoidal concentration lines was observed to be 12 to 24 m. For lack of concrete data the distance may be estimated. Assuming the truck speed was 30 km/h and the time between two tops was 2 seconds, the distance between the tops may be estimated to be 17 m. This is in fair agreement with the visual observations.

In order to obtain good understanding of the spreading process good data for the truck speed is essential. Because the truck was driving at 30 km/h moves 8 meters per second, recording of elapsed time in 0.1 seconds instead of 1 second would be helpful for the detailed study of distribution patterns.

As illustrated the salt may end up concentrated in narrow bands separated by areas with low coverage in between due to the large eddy turbulence created by the truck and the salt hopper. Ultimately, the energy of the eddies are consumed by viscosity as they move further downstream, and the irregular pattern disappears, but at this point most of the salt may be unevenly distributed on the road.

Figure 11 - Development of salt spreading during passage of the truck.

The air movement created by a truck may be visualized by mist or droplets stirred up on a wet highway. It is experienced as showers on the wind shield and turbulence hitting the car. The effect is particularly noticed as you pass the wheels where showers are emitted.

Watching the truck from behind makes it possible to watch air/mist that is moving from the rear wheels inwards to a point where the air from the two sides meet and move upwards as shown in figure 12. The upward movement is continued till it meets with the air from the top of the trailer and joins the wake behind. The upward moving air also mixes with turbulences from the side of the trailer. The triangular limit to the inwards movement of the air behind the wheels and the instability of the eddies created near to the road are also visible.

Dependent on light conditions the droplets and mist may be clearly visible. They give no information of the distance behind the truck where the droplets are coming back on the road, however, and the behavior of droplets from that point will not be representative of bouncing salt particles.

Figure 12 - A truck creating turbulence and discharging water droplets and mist to the sides and backwards.

4. AIR MOVEMENT AROUND SPREADER

In a wind tunnel at the Air physics laboratory at the Engineering Centre Bygholm an air flow experiments was performed to visualize the turbulent airflow created around spreader models with special emphasis on airflow patterns and stability near the spreader position, Strøm 2011 [3].

Average velocities up to 5 m/s could be generated in the experimental cross section, but for flow visualization low velocities are preferable. The experiments were therefore carried out at a free airflow velocity of 0.3 m/s. Air movements were visualized using smoke from an airflow indicator tube illuminated with a laser sheet.

A scale model of a salt spraying truck was used together with a simplified box model with the same outer dimensions. In order to make laser sheet visualization more effective the box model was painted flat black as shown in figure 13.

Figure 13 - The scale model of a salt spraying truck and the simplified box model with the same outer dimensions.

In the box model a hole was drilled to provide different smoke supply downwards in the centre of the bottom. The airflow is seen to be moving backwards to the back end where it detaches the road and curves upwards creating a distinct, rotating eddy before joining the airflow above the model, figure 14.

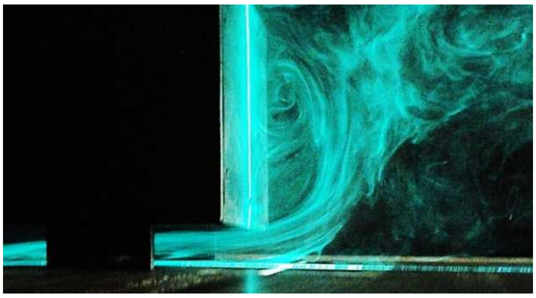

Figure 14 - Smoke supplied vertically downwards in the centre plane shows how the airflow detaches the road in the centre plane behind the truck.

In the model truck smoke was supplied downwards in the centre plane behind the rear axles of the model truck as shown in figure 15.

Figure 15 - Smoke was supplied downwards in the centre plane behind the rear axles to study the development of the flow behind the model truck.

The resulting flow in the centre plane behind the truck is detaching the road in the same way as behind the box truck before it curves upwards into an eddy attached to the rear end of the truck, figure 16. The attached eddy is not as well defined as for the box model, probably indicating that the shape of the rear end and the equipment attached to the truck here is of importance for the airflow patterns.

Figure 16 - Smoke supplied vertically downwards in the centre plane behind the rear axles shows how the airflow detaches the road behind the model truck.

In figure 17 the horizontal plane at a height equivalent to the underside of the truck the air is seen to curve from the left hand side towards the right hand side with an eddy rotating in the centre plane close to the rear end.

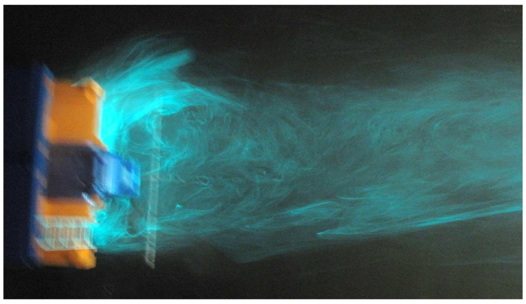

Figure 17 - Airflow in the horizontal plane at a height equivalent to the spreader disc is seen to curve from the left hand side towards the right hand side.

In figure 18 the air is seen to curve the other way from the right towards the left hand side, i.e. the opposite direction of figure 17.

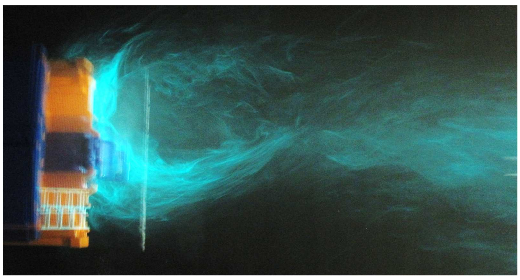

Figure 18 - Airflow in the horizontal plane at a height equivalent to the spreader disc is seen to curve from the right hand side towards the left hand side.

The two last figures indicates the presence of a von Kármán vortex street, i.e. a repeating pattern of swirling vortices caused by the unsteady separation of air flow. This will explain why fish tailing patterns are observed in the distribution of salt after the salt truck.

5. METHODS TO MAINTAIN OPTIMUM SPREAD PATTERN

The purpose of a literature study was to identify methods to reduce the large eddy turbulence generated by the salt truck with salt hopper and thus to reduce the tendency to generate uneven, fish tailing salt distribution. Most literature is focused on control of airflow over a moving surface, not so much on what happens downstream of the surface. For salt application the prime focus is on the air flow pattern in the space behind the truck to the point where the salt has settled. Not much literature is available on how to reduce salt snaking.

Airflow control is used in number of applications, both in enclosed environments and in the open air. Below is a short survey of methods for airflow control found for aviation, racing cars and road transport, Strøm 2012c [4]. In the selected three areas the use of airflow control techniques are focused on the flow close to the vehicles surfaces, and not much on the flow patterns after the vehicle has passed.

In aviation the effect of providing a streamlined fairing around the cylinder is shown in figure 19 in the form of a symmetrical wing section in a wind tunnel. At zero angle between the wing and the upstream airflow, the angle of attack, the air is following both the upper and lower surfaces with little disturbances left downstream.

At an angle of attack of 10° the air follows the su rfaces of the airfoil most of the way, except near to the trailing edge of the upper surface, where some turbulence is created and are left behind as a narrow wake of disturbed air.

Increasing the angle of attack to 20° the air is no longer attached to the upper surface and creates a highly fluctuating wake downstream. The wing has stalled, and an increase in angle of attack will no longer create more lift, a situation of major concern aircrafts during takeoff and landing. Increasing the angle of attack above stall results in a wider and more violently fluctuating wake

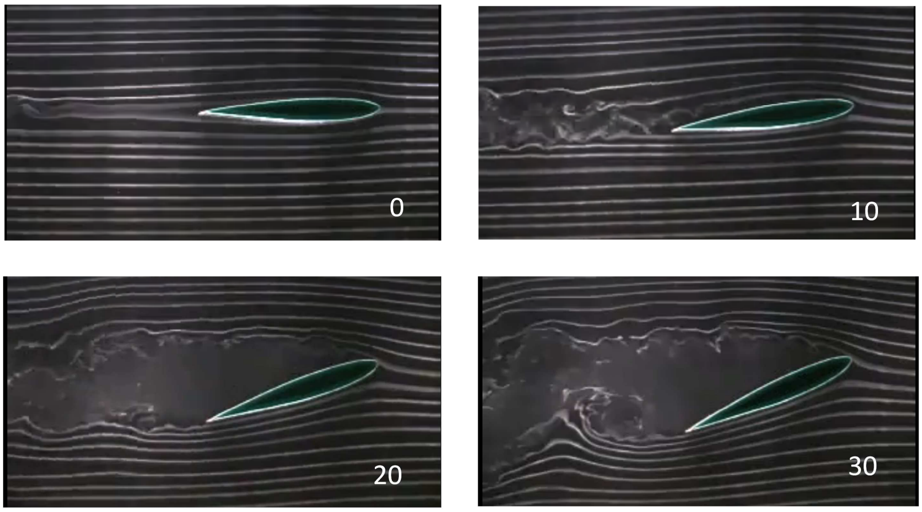

Figure 19 - Flow around and downstream of a wing with symmetrical cross-section in a wind tunnel.

The principles above may be used to reduce the magnitude of the fish tailing air patterns in the wake behind the salt truck by designing components streamlined. Streamlined fairings should be parallel to the direction of the airflow. For the salt spreading truck that generally means parallel to the driving direction.

In aviation airflow control is a major concern. Most relevant for salt spreading is probably the methods used to increase angle of attack before the wing stalls. By doing so the landing speed can be reduced, and control of the airplane is maintained to a lower speed. The technologies considered are vortex generators and air strakes.

Vortex generators are a row of small vanes that creates a tip vortex which draws energetic air from outside into the slow-moving boundary layer near to the aircraft skin, figure 20. The boundary layer normally thickens as it moves along the aircraft surface. Vortex generators are used to remedy this by re-energizing the boundary layer and thereby reducing the separation of airflow over the wing as the angle of attack increases. The vortex generators are typically installed on the front third of a wing. They can also be seen on the horizontal and vertical tails of many airliners where separation of the airflow is unwanted.

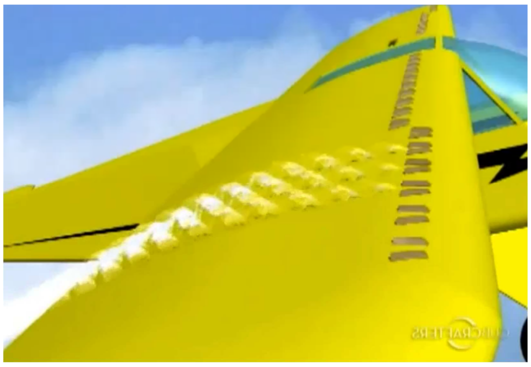

Figure 20 - Vortex generators placed on the upper wing surface.

An air strake is a single, large vortex generator that is mounted on the fuselage, or more often, on the engine nacelles, figure 21. The strake creates a small energetic, swirling vortex that reduces the separation of airflow over the downstream wing surface at high angle of attack. During takeoff and landing the combination of high angle of attack and low speed may cause the flow of air to become erratic as it tries to move around the large nacelle, particularly in the region close to the fuselage or wing. The vortices created by the strake helps to reduce this separation of airflow over the downstream wing surface as its angle of attack increases.

Figure 21 - Condensation vortices from a nacelle strake at takeoff.

In aviation the focus of airflow control is to reduce stall speed. It is less to reduce turbulence in the wake. This is, however, of major concern for reduction of spacing between aircrafts cleared for landing. No specific methods to this end have been found that may be applied to salt spreading, but the use of vertical air strikes at the lower, rear end of the truck may be considered.

The main purpose of aerodynamics for racing cars is to increase the down force on the car without increasing drag. A front and a rear wing is basically an inverted air foil that instead of lift produces a downward force. The wind creates an aerodynamic pressure on the upper surface and suction on the lower. The rear wing is positioned above the wake from the upstream part of the car for maximum efficiency, figure 22.

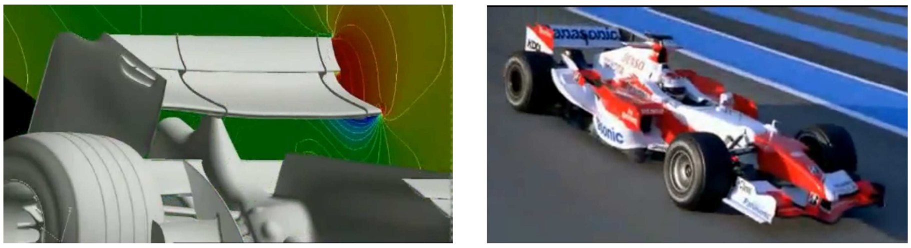

Figure 22 - Example of the rear wing on a racer car.

The diffuser in the rear car underbody, figure 23, enhances the transition between the airflow underneath the car and the free stream airflow of the ambient atmosphere. It works by providing a space for the underbody airflow to expand without causing excessive flow separation and drag. The diffuser may also direct some air upwards increasing velocity at the underside of the rear wing and thus contribute to the down force.

Figure 23 - Example of rear diffuser on a racer car.

The principle from the racing cars is also being applied to personal cars as shown in figure 24. The diffusor is seen as a rounded rear end with curved fins to guide the air flow.

Figure 24 - Example of a paneled underbody and rear diffuser on a car.

Airflow control is primarily considered as a means to reduce drag and thus fuel consumption in road transport. Lack of trailer streamlining causes a partial vacuum to form at the rear of the trailer at highway speeds. This causes turbulent air in the form of large eddies to tumble into the partial vacuum and the large alternating eddies cause the trailer to sway. Disturbances from passing vehicles or obstacles tend to amplify these eddies and increase the trailer's tendency to sway, increasing drag and lowering fuel economy.

Streamlining the trailer would be the best solution but is not practical due to a necessary reduction in trailer capacity and massive changes to docking and loading facilities. These factors are not of the same importance to salt trucks. A manufacturer claims that the use of their vortex generators may improve the truck stability by reducing the 'fish tailing' on trailers especially in gusty cross wind conditions or when passing or being passed by other vehicles by changing alternating formation of large eddies to a line of dozens of small vigorous ones. This principle may be applicable to salt trucks.

Installation of the vortex generators at the rear facing surface of a tanker and a trailer is shown in figure 25.

Figure 25 - Vortex generators installed on the rear facing surface of a tanker and a trailer.

Streamlining the trailer by tapering is proposed as the best solution. Even if the energy savings are modest, the dissolution of large eddies into smaller stream wise eddies may be a worthwhile method of reducing salt snaking behavior at road level. To have effect within the short distance from the salt leaves the spreader till it comes to rest on the road, the vortex generators probably need to be placed closer to the road on the salt spreading truck than seen above.

6. FUTURE WORK

The work will be continued having the aim to show methods for reduction of vacuum/wind disturbances. From the literature, some possible methods for reduction of the disturbances have been identified. This will be evaluated primarily for scale models under laboratory conditions. The most promising methods will then be tested using full scale trucks in a test hall and on an outdoor test road.

The most promising technology to be used to reduce the magnitude of the fish tailing air patterns in the wake behind the salt truck seems to be by designing components streamlined. Streamlined fairings should be parallel to the direction of the airflow. For the salt spreading truck that generally means parallel to the driving direction. A number of other technologies have been used for airflow control in other applications, but they need careful adaptation to salt spreading.

The dissolution of large eddies into smaller stream wise eddies using vortex generators may also be a worthwhile method of reducing salt snaking behavior at road level. Probably the vortex generators need to be placed closer to the road on the salt spreading truck than seen for road transport.

6. CONCLUSIONS

The effect on the spread pattern of cross wind of 4.5 m/s was investigated with full scale salt spreader under laboratory conditions. Behind a spreader moving at slightly more than 0.7 m/s air movements created by the spreader is minimal. At no crosswind small particles with diameter less than 1 mm were practically not present further than ±3.5 m from the center line, the medium particles up to ±4.5 m and the large particles up to ±5.5 m from the center line. Exposed to crosswind the total weight curve, that was symmetrical at no wind, became unsymmetrical. The crosswind caused a distinct peak 3.5m downstream of the center line. The peak was primarily due to the dislocation of the small particles.

The effect on salt distribution patterns of turbulence generated by a moving full scale truck with salt hopper was visualized at normal driving speeds on the asphalt test road at Engineering Centre Bygholm. The driving speed was 30 km/h and rock salt was applied at 30 g/m^2. The salt ended up concentrated in narrow bands separated by areas with low coverage in between. On this calm day only large eddy turbulence created by the truck and the salt hopper may explain the distribution patterns.

In a wind tunnel at the Air physics laboratory at the Engineering Centre Bygholm an air flow experiments was performed to visualize the turbulent airflow created around spreader models with special emphasis on airflow patterns and stability near the spreader position. A scale model of a salt spraying truck was used together with a simplified box model with the same outer dimensions. For the box model the airflow in the center plane was seen to be moving to the back end where it detached the road and curved upwards creating a distinct, rotating eddy before joining the airflow above the model. Behind the model truck the airflow detached the road in the same way curving upwards into an eddy attached to the rear end of the truck. The attached eddy behind the scale model was not as well defined as for the box model, probably indicating that the shape of the rear end and the equipment attached to the truck here is of importance for the airflow patterns.

A literature study was carried out to identify methods to reduce the tendency to generate uneven, fish tailing salt distribution. For salt application the prime focus is on the air flow pattern in the space behind the truck to the point where the salt has settled. Not much literature is available on how to reduce salt snaking. Methods for airflow control were primarily searched within aviation, racing cars and road transport. In the selected three areas the use of airflow control techniques were focused on the flow close to the vehicles surfaces, and not much on the flow patterns after the vehicle has passed.

The work will be continued having the aim to show methods for reduction of vacuum/wind disturbances. From the literature, some possible methods for reduction of the disturbances have been identified. This will be evaluated primarily for scale models under laboratory conditions. The most promising methods will then be tested using full scale trucks in a test hall and on an outdoor test road.

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