Generation of 'Snow Smoke' behind Heavy Vehicles

ROADEX SUB PROJECT B PHASE II
SUPPLEMENTARY REPORT

PROJECT IS FUNDED BY ERDF,
ARTICLE 10 NORTHERN
PERIPHERY PROGRAMME

PREFACE

The main goal of the Roadex project is to exchange information on experiences and practices on the maintenance of low traffic volume road network in the sparsely populated northern regions of Europe. The fields of the sub project B “Winter Maintenance” concentrated on winter maintenance of remote roads in harsh winter climates, and the need for information to the maintenance crew and the traffic users.

One of the conclusions from sub project B is that all the regions shared the problem of reduced visibility for drivers due to the generation of snow smoke by suspended snow particles in the rear wake of heavy vehicles. This issues a major concern for the traffic safety on cold winter days. The Roadex Steering Committee thus asked the sub project group B to carry out model experiments on the generation of such “snow smoke” and to investigate any countermeasures.

Model experiments were done in a wind tunnel at the Department of Applied Mechanics, Thermo- and Fluid Dynamics at Norwegian University of Science and Technology (NTNU). This report presents the results and main conclusions of these model studies.

Michael Mielnik and Lars Sætran at NTNU wrote the report.

Trondheim, 20. September 2001

Harald Norem,
Chairman of sub project B

MTF Report 2001-06(C)

GENERATION OF ‘SNOW SMOKE’ BEHIND HEAVY VEHICLES

-A WIND TUNNEL INVESTIGATION

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September 2001

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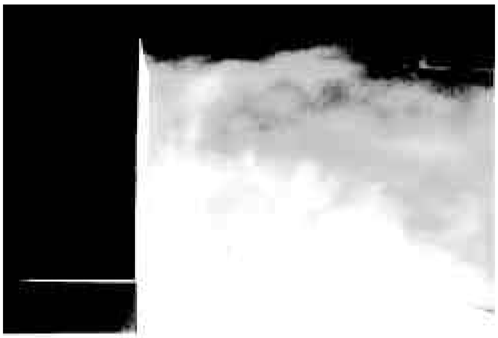
Summary

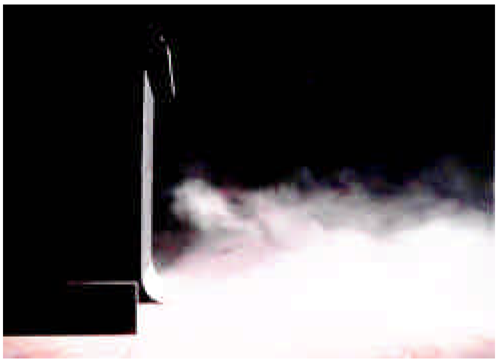
Heavy vehicles, when in movement, create disturbances in form of vortices and turbulent motion in the surrounding air. These disturbances are capable of rising particles, such as water droplets, dust or snow, into suspension in the air, creating a dense cloud which severely reduces the visibility of drivers both behind and those driving in the opposite direction of the vehicle. This in turn constitutes a serious hazard to traffic safety.

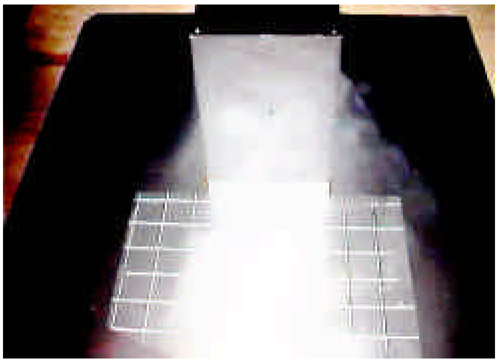
This report contains an experimental investigation of the spreading of ‘snow smoke’ around a downscaled, simplified model of a heavy vehicle. Different types of spoiler configurations are examined by means of smoke visualisation and drag measurements. Results from a total of twelve different set-ups are presented. The potential of spoilers as a means for visibility improvement in traffic on roads covered with water, dust or snow is illustrated.

It was found that the optimal configuration for reduction of spreading of snow smoke is the combination of sideskirts, which cover most of the gap between the chassis and ground, a spoiler on the bottom rear part, and a spoiler on the top rear part of the vehicle. With this configuration, a reduction of the size of the snow cloud of approximately 50% was achieved, see pictures below.



Visualisation of snow smoke behind a model of a heavy vehicle without spoilers.





Visualisation of snow smoke behind a model of a heavy vehicle with spoilers.

1. Introduction

1.1. Background

Every moving vehicle creates disturbances in form of vortices and turbulent motion in the surrounding air, especially under, behind and on the sides of the vehicle. The shear stresses exerted on the road surface due to the vehicle's movement can raise particles of dust, dirt, water or snow into suspension in the air, whereafter the particles are distributed by turbulent transport mechanisms to fill the entire wake of the vehicle. If the concentration of particles is sufficiently high, the entire wake may appear as a dense cloud, severely reducing the visibility of drivers both behind the vehicle and those driving in the opposite direction, which in turn constitutes a serious hazard to traffic safety. Especially, when the vehicle is large, such as a bus or a semitrailer, the cloud of particles is large and may extend far into the opposite lane.

Figure 1. Cloud of snow smoke behind a heavy vehicle

1.2. Aim

The aim of this study is to investigate possibilities for reduction of the particle cloud (hereafter called snow smoke) behind a heavy vehicle. The main objective is to test several different types of spoilers by means of flow visualisation and point out which give the best performance. Any optimization of these, however, is beyond the scope of this study. Drag measurements are also performed on each spoiler set-up.

The investigations are carried out in a series of wind-tunnel experiments on a downscaled, simplified model of a heavy vehicle.

2. Wind tunnel experiments

2.1. Experimental setup and procedure

The experimental setup was essentially the same as the one used by Mælum (2000) and is here only briefly described. For more details, see reference.

All tests were performed in the large offshore windtunnel at the Department of Applied Mechanics, Thermodynamics and Fluiddynamics, Norwegian University of Science and Technology (NTNU), Trondheim, Norway. This is a closed-loop windtunnel with a testsection 12.5x2.7x1.8 m^3, and a velocity range 2-30 m/s.

In all visualisation experiments, the wind velocity was 6.5 m/s. All drag measurements were performed at 12.3 m/s. The reason for the choice of different velocities for the two experiments was that it was found difficult to obtain good visualisation images at high velocities, and at the same time low velocities would produce less distinguishable differences in drag between the different setups. This is, however, not of importance to the overall results, as it was shown by Mælum(2000) that the drag coefficient for the model is constant within this velocity range.

In order to simulate the conditions of a moving vehicle in still air, a fasle floor was mounted in the wind tunnel, removing most of the boundary layer along the floor.

The model was a rectangular box with dimensions 1.5x0.6x0.4 m^3, equipped with four 75 mm high rectangular wheels.

View of the floor and model setup inside the windtunnel is shown in figure 2.

Figure 2. View of the model and the false floor inside the wind tunnel

Drag measurements were performed using a six-component aerodynamic balance manufactured by Karl Schenck AG. The voltage signals were amplified and sampled via a Metrabyte Dash-16 board onto a personal computer. The measurements were performed at 20 Hz, each series lasting for 30 seconds, giving 600 samples per series. Each measurement was repeated twice.

In the visualisation experiments, smoke was realeased from a chamber with its top side leveled with the wind tunnel floor beneath the model. The chamber, shown in figure 3, was covered with a grating in order to ensure momentum-free release conditions. A splitter plate, giving the possibility to open and close the chamber, was mounted under the grating. Smoke was injected into the closed chamber for approximately 30 seconds, whereafter it was instantaneously released by removing the splitter plate. The smoke release area was 75x40 cm.

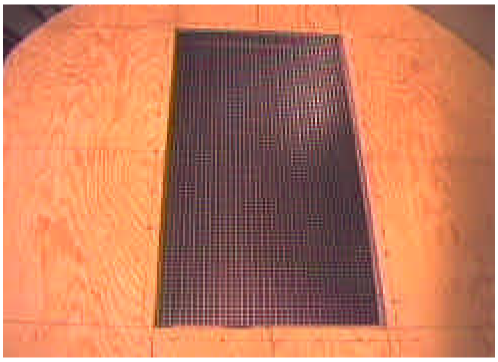
 

Figure 3. Smoke chamber. Left picture: seen from inside the windtunnel; Right picture: seen from below.

All visualisation experiments were performed using a digital video camera, JVC-GR-DVM1, and each experiment was repeated twice. From each video sequence, at least 4 images were captured via a framegrabber and processed afterwards to find maximum spread of the simulated snow fog using image analysis software.

2.2. Spoiler configurations

Schematics of the different spoiler configurations that were testet in the current experiments are shown in figures 4 and 6. In order to be able to see the effects of different spoilers, visualisation experiments were performed both in sideview and in topview.

The sideview visualisations were:

- model only (reference)
- model with bottom spoiler, see figure 4a)
- model with top spoiler, see figure 4b)
- model with both top and bottom spoilers, see figure 4c)

In addition to this, two different top spoilers were tested, one with 90^o bend and one with 40^o bend, giving a total of six different configurations. The top spoilers were mounted symmetrically about the model's upper rear corner, extending approximately 40 mm above the top and behind the rear sides of the model. The bottom spoiler extended approximately 90 mm into the rear of the model.

Figure 5 shows pictures of the model with top and bottom spoilers (left) and the different spoilers used in the current investigations (right).

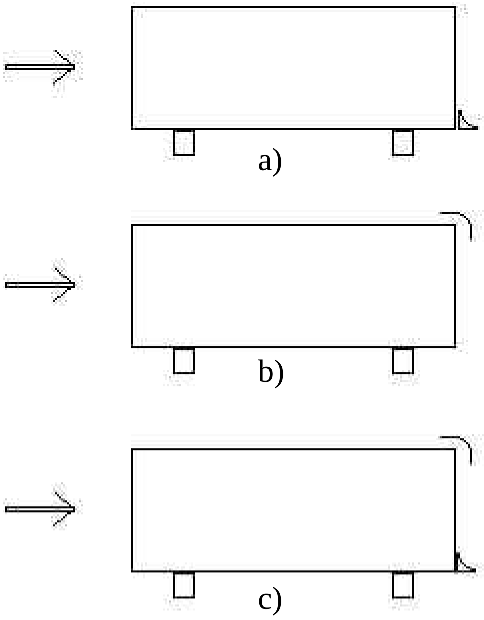


Figure 4. Schematics of spoiler configurations used in sideview visualisations. a) bottom spoiler; b) top spoiler; c) top and bottom spoilers. Wind direction from left to right.

Figure 5. Left picture: model with top and bottom spoilers; Right picture: photograph of the different spoilers. From left to right: sidespoilers, bottom spoiler, bottom front spiler, top spoilers.

The topview visualisations were:

- model only (reference)
- model with sideskirts, see figure 6a)
- model with side spoilers, see figure 6b)
- model with both sideskirts and side spoilers
- model with bottom front spoiler, see figure 6c), d) and e)

The sidespoilers had a 30^o bend and were mounted approximately 35 mm from the model sides and extended 70 mm beyond the rear of the model. The sideskirts were 1.5 meters long, and extended the model's sides down towards the floor by 71 mm (4 mm above floor level), covering most of the gap between the chassis and the ground. The bottom front spoiler was tilted 45 degrees downwards from the model's bottom surface extending 63 mm down towards the floor (figure 6c)), and mounted at 60^{o} relative to the wind direction (figures 6d) and e)). In addition, it was mounted in two different positions on the model's bottom surface, one where the entire spoiler was hidden under the model and one where the spoiler extended forward beyond the front surface of the model, as indicated by figures 6d) and e), respectively.

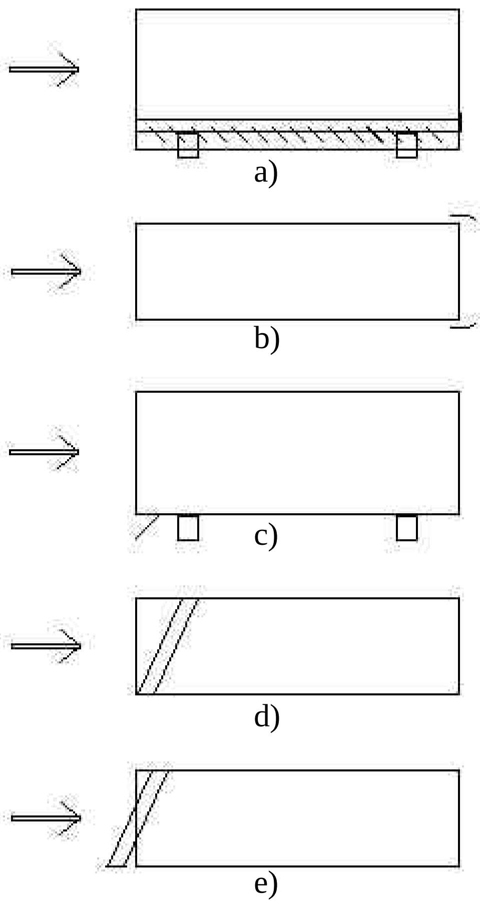


Figure 6. Schematics of spoiler configurations used in topview visualisations. a) sideskirts (sideview); b) side spoilers (topview); c) bottom front spoiler (sideview); d) and e) bottom front spoiler in two different positions (topview).

3. Results

3.1. Model without spoilers

Figure 7 shows visualisation of snow smoke and its spreading behind the model without any spoilers. The smoke is seen to fill the entire region behind the model, and also spreads in the lateral direction due to sidevortices emerging from underneath either side of the vehicle. It is clear from the figure that the visibility behind and in the opposite lane of the model is severely reduced.

The drag coefficient of the model was found to be 1.3. This value is in good agreement with values stated by White (1994).

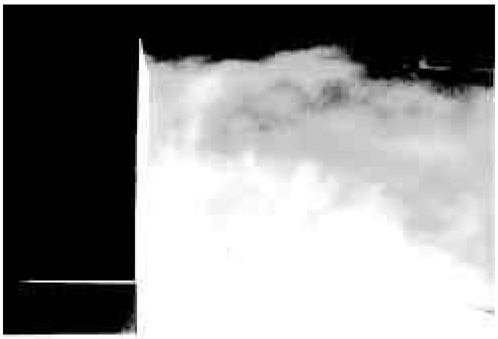


Figure 7. Snow smoke visualisation of model without spoilers. Left picture: sideview, wind direction from left to right; Right picture: topview, wind direction downwards.

3.2. Model with top spoilers

Figure 8 shows the spreading of snow smoke with two different spiolers mounted at the upper rear corner of the model (left picture: 90^{o} bend; right picture: 40^{o} bend). Both spoilers result in a reduction of the size of the snow smoke cloud, and the steepest spoiler is clearly most effective.

The height of the snow smoke cloud is reduced by app. 50%. This is due to the redirection of air from above the model and down into the wake, causing the snow cloud to be partly 'blown away' and forced downwards. The difference in effectiveness of the two spoilers implies that some optimalisation of spoiler geometry should be carried out in order to achieve the best effect.

The drag coefficient for both spoilers was $C_d = 1.4$, which is 8% higher than the value of the model without spoilers. This increase in drag coefficient is probably due to the fact that the spoiler enlargens the effective frontal area of the model.

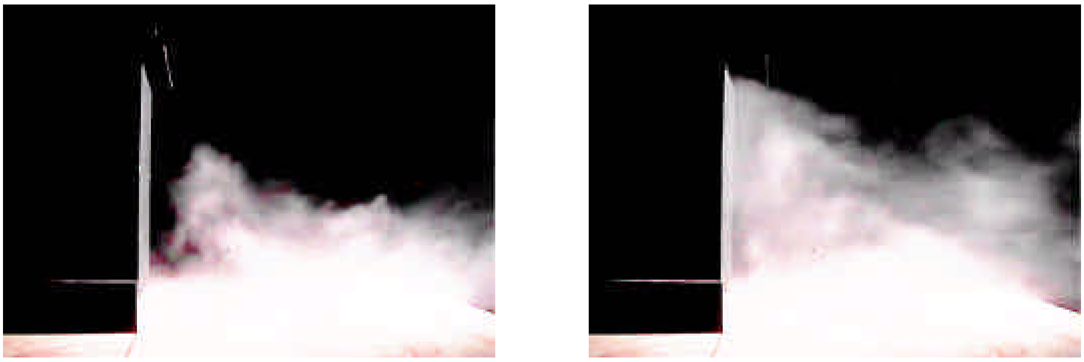


Figure 8. Snow smoke visualisation of model with spoilers. Left: 90^o bend spoiler; Right: 40^o bend spoiler.

3.3. Model with bottom spoiler

Figure 9 shows snow smoke visualisation of the model with bottom spoiler. It can be seen that the smoke cloud fills most of the area behind the model, but its height decreases slightly downstream. During experiments, however, it was observed that random fluctuations in the wake occasionally rose up to cover the entire height of the model with snow smoke, even far downstream. Therefore, although the bottom spoiler seems to constitute an improvement with regard to spreading of the smoke cloud, it is not a very stable one.

The drag coefficient for this setup was found to be 1.3, which is the same value as the drag coefficient for the configuration without any spoilers.

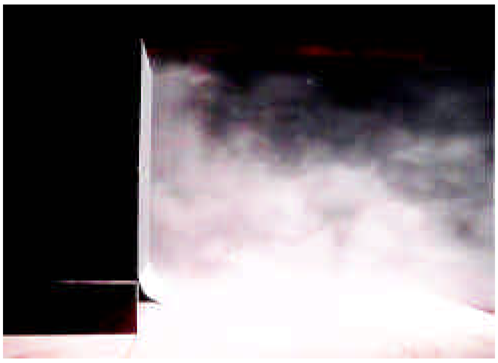


Figure 9. Snow smoke visualisation on model with bottom spoiler.

3.4. Model with top and bottom spoilers

Figure 10 shows the visualisation results for model with bottom and top spoilers (Left: 90^o bend top spoiler; Right: 40^o bend top spoiler). It is clearly seen that the 90^o bend spoiler (left picture) yields a great reduction in the size of the snow smoke cloud, decreasing its height by app. 50%. This reduction is similar to that obtained with the top spoiler only, but in combination with the bottom spoiler, the effect is better close to the rear end of the model (compare with fig. 8, left picture). The 40^o bend spoiler also causes some reduction in the size of the snow cloud, but is not by far as effective.

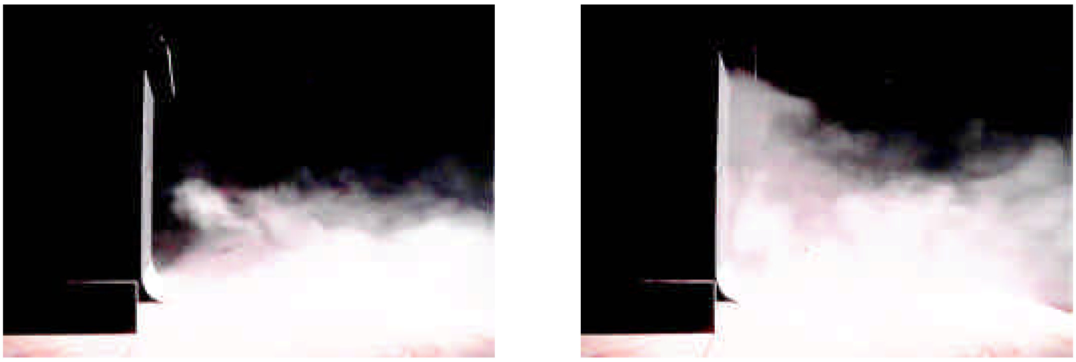


Figure 10. Snow smoke visualisation on model with top and bottom spoilers. Left: 90^{o} bend topspoiler; Right: 40^{o} bend topspoiler.

The drag coefficient for these configurations was found to be the same as for the topspilers alone, i.e. C_d = 1.4

3.5. Model with side skirts

Figure 11 shows snow smoke visualisations of the model with and without sideskirts (right and left pictures, respectively). The visualisation picture on the left is the same as the one shown in figure 7, included here for comparison. It can be clearly seen that sideskirts result in a considerable reduction in the width of the snow smoke cloud (app. 50%), causing the sidevortices to disappear almost completely. For a vehicle coming in the opposite direction, this means a great improvement in visibility.

The drag coefficient of the model with sideskirts was found to be 1.3, i.e. the same as for the model alone. This is in good agreement with Hucho (1987), where it is shown that sideskirts do not have any effect on C_d when the wind direction is along a vehicle's longitudional axis. Sideskirts are, however, known to have a positive effect on C_d in sidewind.

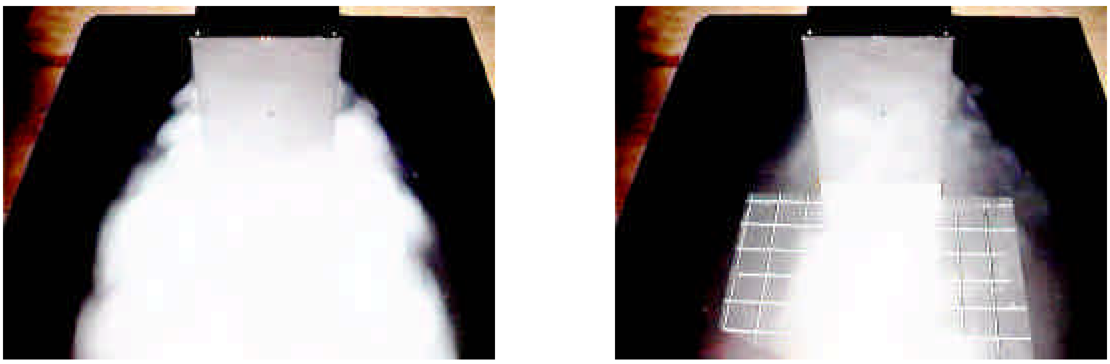


Figure 11. Snow smoke visualisation on model with and without sideskirts (Right and left pictures, respectively).

3.6. Model with sideskirts and sidespoilers

Figure 12 shows snow smoke visualisations on the model with sideskirts and sidespoilers (left picture) and sidespoilers only (right picture). No apparent positive effect on the size of the snow cloud can be seen from these visualisations. The model with sidespoilers has a snow smoke cloud of virtually the same size as the model with no spoilers (fig. 11), while the model with both side spoilers and sideskirts has a smoke cloud similar to that of model with sideskirts only (fig. 11).

The drag coefficient for both configurations was 1.3, which is the same as for the model without spoilers. This is somewhat surprising, as one would expect that the sidespoilers would cause an increase in drag, since they enlarge the effective frontal area of the model. It is difficult to give any explanation of this phenomenon without further investigations. That is, however, beyond the scope of this work.

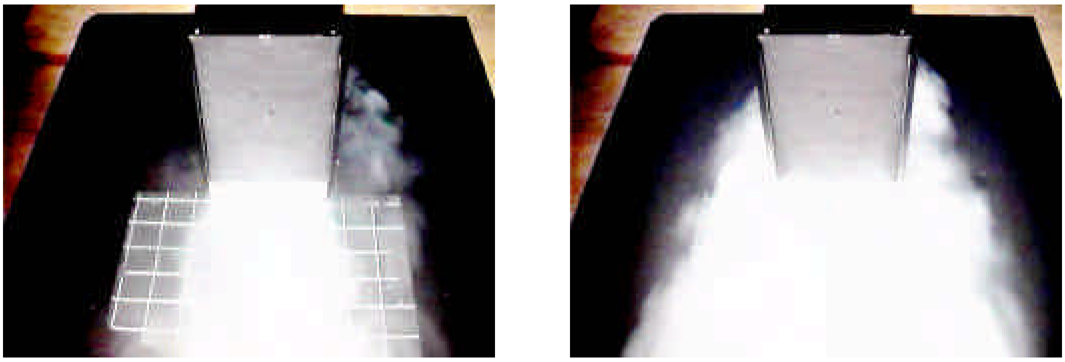


Figure 12. Snow smoke visualisation on model with sideskirts and sidespoilers. Left picture: sideskirts and side spoilers; Right picture: side spoilers only.

3.7. Model with tilted bottom spoiler in front

Figure 13 shows snow smoke visualisations on the model with bottom front spoiler in two different positions. The spoiler is tilted clockwise and meant to direct the snow smoke to the right and away from the left side of the model, which corresponds to improved visibility for vehicles moving in the opposite direction. From the visualisations, it may be clearly seen that when the spoiler is entirely hidden under the model (left picture), the effect is opposite; snow smoke is gathered in the wake behind the spoiler and released on the left side of the model rather than being directed to the right. On the right side of the model, the amount of snow smoke is highly reduced. This result is rather surprising, and implies that in order to reduce the amount of snow smoke on the vehicle's left hand side, the spoiler should in fact be tilted opposite of the intuitively correct direction.

When the spoiler is placed further upstream, beyond the model's front, the situation changes. It can be seen from figure 13 (right picture) that the snow cloud on the left side of the model is in fact thinned out and reduced, while more snow smoke is pushed to the right side of the model.

These results show that the use of bottom front spoiler for reducing the snow smoke behind a heavy vehicle should be carefully examined before real-life application.

The drag coefficient for these configurations was found to be 1.4.

Figure 13. Snow smoke visualisation on model with bottom front spoiler. Left picture: entire spoiler under the model (as in fig. 6d)); Right picture: spoiler extending forward beyond the model's front.

4. Conclusions

An experimental investigation of the spreading of snow smoke behind a downscaled, simplified model of a heavy vehicle has been carried out. Emphasis was put on measures for reduction of the snow smoke cloud in order to improve visibility conditions behind and on the sides of the vehicle model.

Different types of spoiler configurations were examined by means of smoke visualisation and drag force measurements. A total of twelve different set-ups was tested.

It was found that the optimal configuration for snow smoke reduction is the combination of sideskirts, which cover most of the gap between the chassis and ground, a bottom rear spiler and a top rear spoiler with a bend of 90^o. With this configuration, a reduction of the size of the snow smoke cloud of approximately 50% was achieved, leaving the sides of the vehicle in clear sight, as well as causing a considerable reduction in the height of the snow smoke cloud directly downstream of the vehicle. The configuration did, however, cause a drag increase of 8%.

The current investigation clearly demonstrates the high potential of spoilers as a means for visibility improvement in traffic involving heavy vehicles in snowy or dusty areas. Further and more detailed investigations should be carried out in order to optimise the demonstrated configurations for better performance, both regarding visibility and drag.

References

[1] White, F. M., Fluid Mechanics, 3rd ed., McGraw Hill Inc., 1994.

[2] Hucho, W. H. (Ed.), Aerodynamics of Road Vehicles, Butterworth-Heinemann Ltd, 1987

[3] Mælum, M., Hovedoppgave (in norwegian), NTNU, 2000.