MEASURES TO REDUCE THE GENERATION OF "SNOW SMOKE" BEHIND HEAVY VEHICLES

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Abstract

On cold days with light snow partly covering the pavement, trucks and buses generate clouds of suspended snow at the sides and at the rear, which is called “snow smoke”. The snow smoke reduces the visibility and cause difficult and hazardous driving conditions.

To improve the problems with the generation of snow smoke one may; (1) improve the winter maintenance (2) implement salting on all roads (3) redesign trucks and buses to reduce tendency to generate snow smoke. Improved winter maintenance, included salting, may help considerably, but will probably be too costly on low traffic volume roads and in cold climates.

Any improvements on the design of the trucks to reduce the snow smoke conditions should also look into the possibility to reduce the drag and to improve the conditions for spreading dirt and water droplets.

The wind tunnel experiments carried out to investigate the use of spoilers indicate that cavity spoilers located down and in rear may improve both the snow smoke and the drag conditions. Some positive effects are also recorded for curved spoilers on top and rear of the truck in order to direct the air flow downwards. The experiments will be continued with spoilers in front and at the sides of the trucks.

1. Introduction

On cold days with light snow partly covering the pavement, trucks and buses generate high wind shear stresses along the pavement and thus cause the snow to be set into motion. At high traffic speeds this kind of suspended snow, “the snow smoke”, dramatically reduces the visibility for the traffic in rear. In all Nordic countries several severe traffic accidents are recorded due to the difficult driving conditions made by the “snow smoke”.

To study the effect of the snow brought into suspension in the wakes behind heavy vehicles wind tunnel experiments were carried out at the Norwegian University of Science and Technology (NTNU). The “snow smoke” is modeled by smoke to record the patterns and the distribution of the wakes. The measures to be tested were different kind of spoilers.

The report presents the physical background for snow generation, the aim for any countermeasures to reduce the problems and the result of the wind tunnel experiments.

2. Generation of “Snow Smoke”

The problems with snow smoke are usually found in areas with cold winter climates and on roads that are not treated with salt during the winters. In the Scandinavian countries salt is only used on the major roads and only at temperatures above –6 to –8^o C. Snow smoke may thus be considered as a general problem in all areas with a stable winter climate.

In such areas some snow are usually found on all roads at temperatures below 0^o C, even in periods with no precipitation. Such snow consists of very small, non-coherent snow particles that seldom stick to the pavement or the snow/ice crust on the roads. Any traffic on the roads cause these small particles to drift back and forth due to the shear forces and wakes generated below and in the rear of the fast moving cars.

The numbers of particles and the height the particles are lifted are dependent on the energy transferred from the car to the surrounding air. The snow smoke generated by passenger cars is thus fairly small, in opposition to the snow smoke behind trucks and buses, which can cover the whole width of the road, and are much higher than the height of the drivers. Figures 1 and 2 demonstrate quite clearly that the snow smoke reduces the visibility to almost zero.

To drive behind trucks under such conditions makes the driving conditions difficult and exhausting and in many cases hazardous. The most hazardous situations occur during bypassing heavy cars and trucks. In all Scandinavian countries serious accidents are reported due to drivers that have lost their patience and made a bypass despite the visibility was rather poor. That might especially be the case on low trafficked roads where the probability to meet cars is low.

Other secondary effects due to the generation of powerful wakes in the rear of heavy trucks are the removal of anti-slippery measures like sand and salt and the spreading of dirt and water droplets that deposits on windows and lights.

Figure 1. Photo of a meeting truck showing that the generated snow cloud reduces the visibility to almost zero in the rear of the truck. (Photo courtesy: Dagfinn Moe, SINTEF, Trondheim)

Figure 2. The reduced visibility in the rear of trucks due to the "snow smoke". Note the silhouette of the truck and the reduced visibility on the left hand side. (Photo courtesy: Dagfinn Moe, SINTEF, Trondheim)

3. Scope of actual measures

To reduce the problems with the generation of snow smoke there are principally three different solutions.

1. To improve the winter maintenance of roads in order to remove the thin layer of non-coherent snow particles on the roads.
2. To implement salting on all roads on days when such problems occur
3. To redesign heavy vehicles to direct or reduce the generation of the snow smoke

In some ways the winter maintenance of roads may be improved, but never to the extent that the small particles can be totally removed from the roads. In periods with snow falling or with stable cold weather, there will always be particles available to reduce the visibility to almost zero.

The implementation of salt as a de-icing agent on the secondary roads is a political and economical question. Traditional salt, NaCl, can in addition only be used down to temperatures of -8^{o} C. At lower temperatures salt types that are more expensive and doing more harm to the environment have to be introduced. The conclusion is that the problems with the snow smoke may be reduced by improving the winter maintenance, but only to a limited extent.

The idea behind the present project was to study actual measures on the redesign of trucks to reduce the negative effects of the snow smoke. This can either be done by:

- Reducing the amounts of particles that are brought into suspension by the generated wakes
- Directing the particles to the right hand side of the road.

An additional effect of the redesign should preferably be to reduce the total air resistance of the trucks in order to save fuel and to improve the spreading of dirt from the pavement. This is not an unrealistic aim since the generation of the snow smoke cloud and the spreading of dirt are directly related to the energy transferred from the trucks to the air.

The preliminary studies presently reported have concentrated on the use of spoilers mounted on the rear of the trucks in order to bring as few particles into suspension as possible and to keep the height of the wakes to the minimum. So far, any use of spoilers in the front and at the sides of the trucks has not been tested.

Spoilers may also be used to direct the airflow to the right hand side. An adverse effect of such spoilers may be that the wind speed off the road may be so strong that they represent a hazard for pedestrians and cyclists traveling on the right hand side of the road. Any measures to reduce the hazard for one type of road users should not be introduced on the compensation of the traffic safety for other road users.

4. The physics of snow smoke

Physical effects to be studied

The most important physical effects to be analyzed, when studying the snow smoke are:

- The shear stresses found at the road surface as a result of the air set in motion by the trucks.
- The effect of wakes to generate high shear stresses at the road surface and to bring air close to the surface into the wakes.
- The size and pattern of the wakes generated at the sides and the rear of the trucks.

Drag on the trucks

Drag is the air resistant force acting on the truck, and it has always a direction parallel and opposite the direction of the truck. The drag is usually expressed by a drag coefficient, C_D, and the total drag, D, is expressed by the equation:

$$D = C_D \tfrac{1}{2} \rho \cdot v^2 A$$

Where: ρ=density of air
v=velocity of the truck
A=exposed area of the truck (cross-section area)

The drag coefficient is highly dependent on the shape of the cars, and to some extent also to the speed. However, for actual traffic speeds, the drag coefficient may be regarded as a constant, and independent of the speed.

The effect of the shape on the drag coefficient may be shown clearly by Figure 3, where the drag coefficient is shown for different shapes. The rectangular cylinder in Fig. 3a has a C_D of 2,0. By rounding its nose the C_D may be reduced by 45 % to 1,1. A further reduction of the C_D is only possible by streamlining its rear to a sharp trailing edge. In the presented case the drag coefficient is reduced to 0,15, or only 7,5 % of the original rectangular cylinder.

The effect of rounding the fronts of bodies to reduce the drag coefficient is known for trucks by mounting spoilers on the top of the roof. Spoilers at the rear of trucks are, however, only used to a minor degree. A typical C_D coefficient for buses and trucks are 0,5-0,8 and 0,7-1,0 respectively.

The drag coefficient is also dependent on the clearance between the road surface and the truck. Generally the coefficient is increasing with less clearance. This is due to the increased velocity gradients and the formation of side vortices due to the canalizing of the airflow in the gap between the road surface and the truck. The drag at the underside of the truck may be reduced by making a flat underside or by mounting plates at the sides.

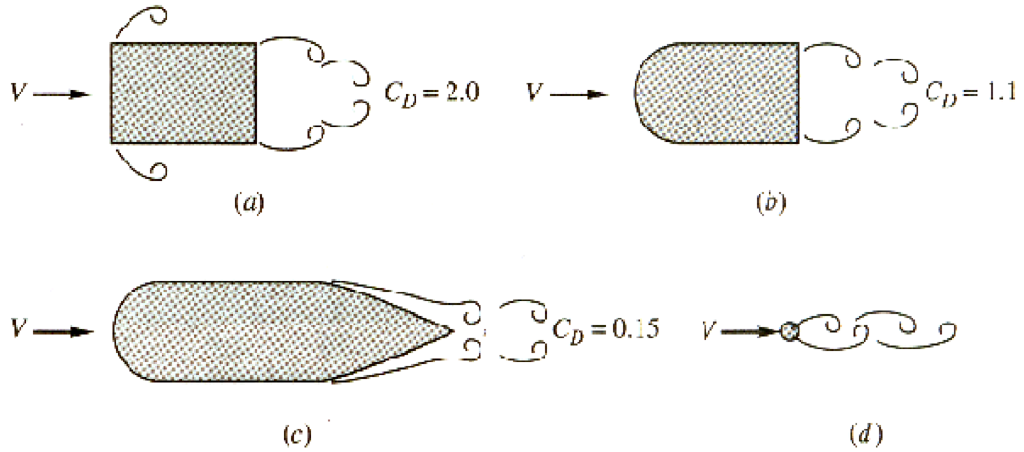


Figure 3. The importance on streamlining bodies in reducing the drag coefficient. (a) rectangular cylinder (b) rounded nose (c) rounded nose and streamlined trailing edge (d) circular cylinder with the same drag as case c. (White 1994)

The relative contribution of the different parts of the trucks on the drag coefficient is shown in Fig 4. Only 5 % and 20 % of the drag is found at the front and the surface of the trucks respectively, as the major part, 25 % and 50 % are found at the underside and at the rear respectively.

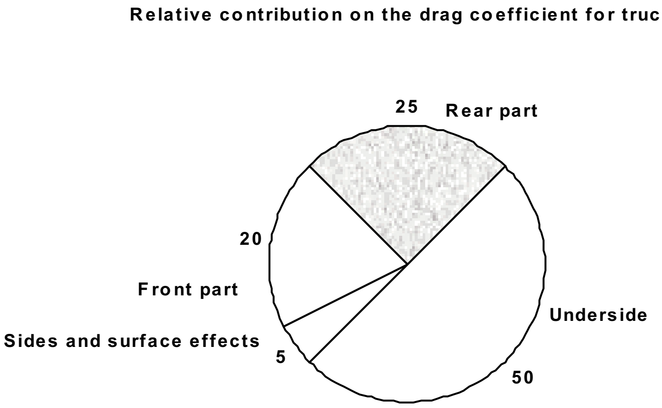


Figure 4 The relative contribution on the drag coefficient from different parts of trucks. (Filippone 2000)

Forming of wakes

The major part of the drag is due to the tendency of air masses to travel with the vehicle. This transportation of air masses is mainly caused by generation of wakes. Wakes are generally formed at abrupt changes in the car design as at the top of the windscreens, at the sides of the cars and at the rear. The air flow is drawn at the separation points into wakes that have a rotational character, which, after a short time is released to the free flow and new wakes are generated. The areas with wakes can easily be detected by observing where dirt from the road surface usually collects. On winter days the areas with wakes are also represented by suspended snow particles.

Of special interest for this project is the wakes forming at the sides of the trucks and at the rear. At the front of the car there will be a stagnation pressure and the air will be pressed partly above, to the sides and below the truck. Below the truck the friction between the air and the truck will in addition set the air below the truck in motion. Both effects result in an increased pressure below the truck and part of the air is then pressed to the sides. This results in separation and generation of wakes along the sides of the truck. The effect of the wakes is easily seen on Fig 1, where the snow smoke is pressed to the sides and totally reduce the visibility on the free lane of the road.

The flow pattern in the rear of trucks has been studied by Mason and Beebe (1978). They found that part of the airflow passing under the trucks was drawn into major wakes forming at the rear, and part of it followed the surface downstream, fig 5. The lower part of the air involved in the wake has a backflow close to the rear side and the upper part of the wake is drawn into the flow from the top of the truck. The loose snow particles on the road surface are suspended due to the effect that they are drawn into the wake and lifted to considerable heights.

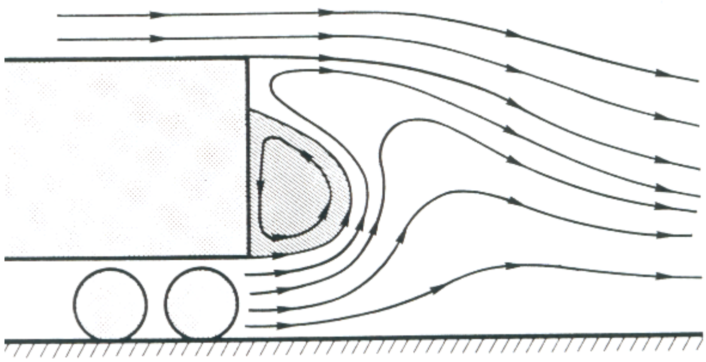


Figure 5. Flow patterns in the rear of trucks. (Mason and Beebe 1978)

5. Previous experiments with spoilers

The use of spoilers may have different aims, of which the most common are:

- To reduce the drag
- To reduce deposits of dirt on rear windows
- To avoid dust from the road surface to be thrown into the air

The effect of spoilers mounted on different parts of trucks may be summarized in the following paragraphs:

- *Spoilers in front of the truck*

  Spoilers are used frequently on racing cars. The aim is preferably to increase the pressure on the front wheels, rather than to reduce the drag. The effect of such spoilers to reduce the snow smoke is not studied so far, but may be interesting. Some practical experiments were done last winter in Norway by driving a snowplough truck, with the snowplough lifted approximately 10 cm above the pavement. The test revealed that a considerable part of the loose snow particles on the pavement were blown off the road and collected half a meter outside the road. These tests will be continued in the model as well as in the field. Hucho (1987) reports that skirts on front of the front axle reduce the spreading of dirt from the front wheels. The skirts, however, cause a small increase on the drag.

- *Spoilers on the top and rear*

  Spoilers are used on buses and station wagons to avoid dirt to be deposited on the rear window. Such spoilers tend to increase the drag, (Hucho 1987). A special use of such spoilers are shown in Fig 6, showing a winter maintenance truck mounted with a spoiler to prevent snow to collect on the salt spreading disc.

Figure 6. Winter maintenance truck with spoiler to prevent deposits of snow on the salt spreading disc. (Photo Thordarson)

- *Spoilers at the bottom and rear*

Sometimes a plate is mounted at the rear to reduce the clearance between the truck and the pavement in order to stop dust particles and water dropletsthrown up by the tires. Such plates cause the wake to be more powerful and rotate more close to the surface. The plates will thus increase the drag, and will probably increase the number of snow particles brought into suspension.

Another type of spoiler tested in wind tunnel for use on trucks is the cavity type spoilers, which are plates mounted as an elongation of one or more sides. The use of these spoilers result in a small, but distinct, reduction on the drag.

- *Side skirts*

Modern design of buses and trucks is to cover the cars with side skirts or fairings. These measures are reported to reduce the drag coefficient considerably, and to have a significant improvement on the spreading of dirt ((Hucho 1987). The improvements are both a result of smoother surface and less formation of wakes along the sides of the truck. Probably, such plates will also have a considerable positive effect on the snow smoke since there will be less air involved in wakes at the sides of the truck.

6. Model techniques

The model experiments were carried out in a wind tunnel at Department for Mechanics, Thermo- and Fluid dynamic at NTNU. The wind tunnel is 12,5 m long, 1,8 m high and 2,7 m high. The wind velocities may be varied within 0,5-30 m/s.

The model of the truck consisted of a rectangular box, 1,5 m long, 0,6 m high and 0,4 m wide, and the model represents a scale of 1:5. The wind speed during the tests was 5 m/s, which represents a full-scale speed of 18 m/s. The reason for the low velocity is to obtain the best conditions for visualizing the effect of the spoilers, It is not assumed that the low velocity affects the results, as the tests are still made in the range of the Reynolds number where the drag coefficient is constant. The Reynolds number was 5.10^5

When carrying out model experiments it is important to prove that the boundary layers are modeled correctly. The model was placed on a raised false floor to have the best conditions, and it was proved that reattachment of the flow was obtained at the rear of the model truck.

The flow behavior and the existence of wakes were visualized by use of smoke, introduced at different places. The smoke was made visible at certain sections by illuminating the flow in small sheets by help of laser. All tests were photographed to present the effect of the different test configurations.

It is assumed that smoke would be effective as the settling velocity of the snow particles is very low. One may thus assume that the density difference and the settling speed within the snow cloud do not affect the results.

In total four different configurations were tested, of which three are presented:

1. Model truck with no spoiler (Figure 7)
2. Curved spoiler top and rear to direct the flow at the top downwards (Figure 8)
3. Curved spoiler down and rear to direct the flow upward
4. Curved spoiler top and rear and cavity spoiler down and rear (Figure 9)

For each tests a series of photos were taken and drawings to describe the effect on the flow behavior were made.

7. Results of the model experiments

Test 1. No spoiler

The tests with no spoiler show clearly how the airflow below the truck is drawn into the wake in the rear of the truck, and that the air close to the pavement is lifted at least to the half height of the truck. The test results are not far from the results presented by Mason and Beebe (1978)

Figure 7. Results of the tests with no spoiler. Photo and the assumed streamlines. (Mælum 2000)

Test 2. Curved spoiler on top and rear

The test with a curved spoiler on top and rear is similar to spoilers used on buses to prevent dirt from being deposited on the rear window and similar to the spoiler shown on fig 6. The main idea for this experiment was to test if the spoiler was effective on pressing the wake to a lower level. The amount of snow suspended to the eye level of the drivers would then be reduced.

The results presented in Fig 8 show clearly that the spoiler generates a strong airflow directed downward, and that there is a limited reduction of the size of the rear wake. The amount of smoke drawn into the wake was also reduced. Based on the model experiments the top and rear spoiler thus seems to be promising.

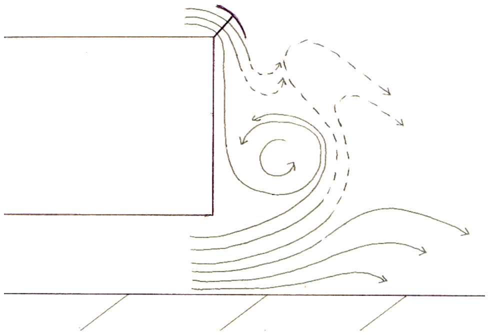
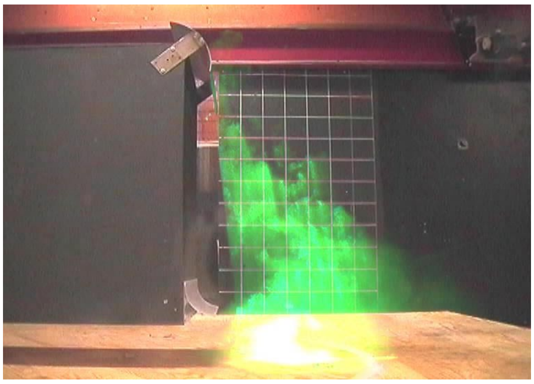


Figure 8 Results of the tests with spoiler on top and rear. Photo and the assumed streamlines. The broken lines represent weak airflows. (Mælum 2000)

Test 3. Curved spoiler on top and cavity spoiler down

The second spoiler test was made with a curved spoiler on top and rear and a cavity spoiler down and rear, Fig 9. The cavity spoilers are known to reduce the drag since they generate almost standing vortices in the wake close to the truck, and thus reduce the tendency to frequent release of the generated vortices.

The results of this spoiler test were rather promising. The cavity spoiler caused the airflow to a greater extent to pass the car and to be drawn into the wakes at a longer distance from the truck, where the intensity of the wakes is reduced. The upper spoiler also seemed to have a positive effect of reducing the size of the wakes and to keep them at a lower level.



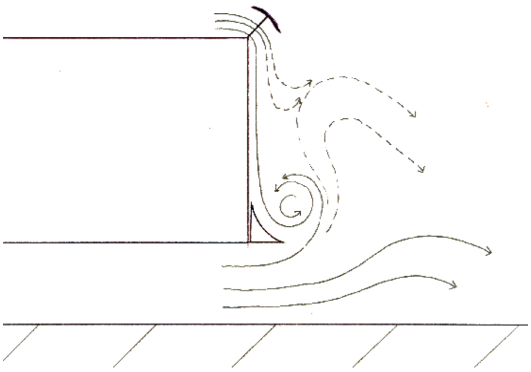


Fig 9 Results of the tests with curved spoiler on top and cavity spoiler down. Photo and the assumed streamlines. (Mælum 2000)

8. Conclusions

The results presented in this report are based on preliminary wind model tests. The continuation of the tests will hopefully bring more reliable understanding of the physics of the “snow smoke” problem as well as more spoiler configurations have to be tested. The most important tests to be carried out are tests with skirts at the front of the truck and side protection. The latter has a significant improvement on the drag, and will probably have the same on the snow smoke.

Other types of tests not yet carried out are spoilers to direct the snow off the road. Such tests may prove the results of the simple field experiments that skirts or spoilers mounted on the trucks may help in removing loose snow from the road surface.

The model tests carried out indicate that some types of spoilers have a positive effect on improving the visibility behind trucks and buses.

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References

Hucho, W.H., (1987)
Aerodynamics of Road Vehicles. Butterworth – Heinemann Ltd, London.

Filippone, A. (2000)
http:/www.aerodyn.com

Mason, W., Beebe, P., (1978)
The drag related flowfield characteristics of trucks and buses.
General Motors Research Laboratories, Warren, Michigan.

Mælum, M. (2000)
Wind tunnel experiments with spoilers on trucks (In Norwegian).
Ms-thesis, NTNU, Trondheim

White, F.M., (1994)
Fluid Mechanics, 3rd ed., McGraw – Hill Book Company Inc.