SPLASH AND SPRAY BY LORRIES

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SUMMARY

Accidents caused by splash and spray are possibly underestimated in statistics, being classified, as they mostly are, as skidding accidents or rain and wet road accidents. In general such a specific problem has a relatively low rate in accident statistics. The problem often arises in critial circumstances like rain, wind and overtaking. The splash and spray is caused by lorries mainly. Measures to prevent or decrease splash and spray can be divided into measures for the road and measures for the vehicle.

Improvements for the road may be aimed at the prevention of the presence of waterlayers on the road. Changes on the vehicle can be divided into improvements for the tyres, aerodynamics and for the wheels. Besides energy saving, aerodynamic devices can be a means to diminish the spray and to prevent zones of low pressure at the wheels. For each type of vehicle different types of devices will be necessary. It is useful to make a difference between trucks and articulated vehicles.

Shields on the wheels can be easily at low costs, and they can be lightweighted. Further research should be done on the effect of the development of heat in the brakes when such shields are applied.

The relationship between the amount of splash and spray and the visual hindrance is still insufficiently studied. The relationship is not linear.

A study on the improvement of the efficiency of windscreen wipers is also recommended.

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PREFACE

This report was drawn up as the result of a request from the Traffic and Transportation Engineering Division of the Public Work Department RWS to the Institute for Road Safety Research SWOV to advise on the effects on road safety arising from the application of means to reduce spray from lorries.
The nature and scope of the problem is examined, not only in terms of accidents, but also in terms of visibility hindrance under critical conditions such as rain and wind and by overtaking. The link between the splash and spray phenomenon and road surface is dealt with, as well as appropriate road measures.
Subsequently, the occurrence of splash and spray from lorries etc. is examined and various modifications for this category of vehicles are mentioned.
A discussion on the results obtained is added, together with recommendations for closer research.

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1. INTRODUCTION

In conditions of rain or a wet road surface, vehicles throw up water in the form of relatively big drops, which stay comparatively close to the vehicle: splash. In addition to this, these drops, together with rain, are scattered into small drops and atomized by wind and aerodynamic effects next to and even far behind the vehicles: spray.
Especially, big vehicles with a lot of tyres (lorries) cause splash and spray: the extent to which this happens depends mainly on the thickness of the water layer on the road surface, the driving speed and the tyre design. Wind speed and direction are important for the diffusion of the water particles.
In terms of accidents, this problem is not known, partly because the problem as such is not statistically recognized. The "spray" phenomenon can, however, cause serious visibility hindrance in critical conditions, such as rain, wet road surface and wind when overtaking. Such conditions occur relatively often. Especialy when overtaking, when course deviations as the result of wind and aerodynamic influences have to be coped with, the fast and precise detection of these deviations is of the utmost importance. An added factor is that on a wet road, therefore having less skidding resistance, course corrections cannot be made so efficiently and the danger of skidding increases. Further course corrections, needed as the result of visibility hindrances, are even more undesirable then.

The splash and spray problem will probably have increased over the last few decades due to the higher power and speed of engines and the increased average size of vehicles.

2. THE SPLASH AND SPRAY PROBLEM

2.1. Problem description

Rain falls on the road. This rain is partly stored in the macro-texture of the pavement surface, and partly drained off the road surface. The latter results in a certain water layer on the road surface. Where the tyre touches the road surface, the water is pushed outwards, to the back as well as to the sides. Part of this repelled water splashes away, another part is carried along by adhesion and at a certain height is flung off the tyre. This flung off water hits solid parts of the vehicle or other tyres and is atomized into spray; it is also directly atomized by wind and aerodynamic effects around the vehicle. These relatively light and small drops form a mist which can reach as high as several metres above the road surface and which descends very slowly. This mist, which can form a "tail" of up to 200 metres behind the vehicle, hinders the visibility. Another form of visibility hindrance occurs when this mist, which is often polluted by particles taken from the road surface, hits the windscreen of other vehicles. If the windscreen wipers can no longer cope with this water, or if in winter the mist on the windscreen freezes, the visibility is practically reduced to zero. For a detailed physical description and modelization of this phenomenon, see Weir et al. (1978). Sandberg (1980) lists the following aspects of splash and spray, important for road safety:

- the visibility of oncoming traffic is limited by spray-mist;
- water suddenly hits the windscreens of oncoming vehicles which seriously hinders visibility; this can result in a panic-reaction, like braking abruptly, this while the road surface is wet;
- vehicles behind the spray-inducing vehicle have a limited visibility, due to spray-mist in the air and a water film on the windscreen; the latter can of course be avoided by efficient wipers;
- dirty headlights restrict the visibility of the driver at night;
- rear-view windows and mirrors get dirty which limits rear visibility;
- traffic signs and roadside reflectors get dirty and become less visible.

These factors not only constitute a potential accident hazard, but they also cause the driver intensified stress. In addition to that, the surrounding environment particularly suffers in winter because road-salt is carried high and far away from the road by spray water.

The above already indicates the kind of measures which can be taken:
- limiting the quantity of water on the road surface by adequate road geometry and road-surface properties;
- optimizing tyre design;
- applying air conduits to vehicles (this could coincide with measures for fuel-economy and anti-crash provisions like side-shields on lorries);
- retention, shielding and draining of spray water at the wheels;
- improving wiper systems.

Considering driving speed has a great influence on the splash and spray phenomenon, speed-limit measures ought to be mentioned as well. This, however, is viewed as rather unrealistic at this time.

2.2. The scope of the problem

The scope of the problem can be described in terms of accidents, visibility hindrance, driving speed, vehicle categories and of combiations of critical conditions.

2.2.1. Accidents

The scope of the splash and spray problem in terms of accidents is not known in the Netherlands. However, data on rainfall, wet road surfaces and wind are available.
In the Netherlands, it rains on average for about 6% of the time and the road surface is wet for about 12% of the time. Rain accounts for 15% of all road accidents, and wet road surfaces for 30%, clearly showing an increased amount of risk (SWOV, 1984).
Strong wind (more than 9 m/sec) occurs about 11% of the time in the coast provinces, and about 5% of the time inland. A link between accidents and wind has not been established so far, but on theoretical grounds this seems probable (Wouters, 1983).
Sabey & Taylor (1980) quote 7,000 accidents with injury as the result of

splash and spray out of a total of 260,000, or 2.6% (United Kingdom, 1977); this is 28% of all wet-road accidents that year. It is not clear whether statistical evidence or estimates have been used.
Casella & Vivari (1971) cite a study in Connecticut, U.S. (1965-1970): one out of 6,500 accidents is thought to be the direct result of splash and spray = 0.2‰. The basis of these data are accident forms.
Maycock (1966) ascribes 4‰ of all motorway accidents in the United Kingdom (1959-1963) to splash and spray (this is 1.3% of all wet-road accidents). The basis of these data too are accident forms.
Figures vary considerably. Firstly, little is known about the scope of splash and spray induced accidents, often because the problem as such is not statistically recognized. Secondly, a lot of time has passed between the cited reports. Furthermore, local differences can play an important part.
What does become clear is that the problem in terms of accidents is rather small, something which will generally apply to that sort of specific problem.

2.2.2. Visibility hindrance

Splash and spray induced visibility hindrance is very hard to quantify. The generated amount of spray depends on the thickness of the water layer, the macro-texture of the pavement surface, tyre profile and tyre profile depth, axle-fitting and vehicle speed. This will be examined more closely in subsections 3.1 and 3.2. The amount of spray causing visibility hindrance, depends, among other things, on the lateral position of the hindered vehicle in relation to the hindering vehicle, the nature of the encounter (overtaking, following), and the effectiveness of the wiper system. Visibility hindrance in turn depends on the density of the spray-mist, the water film on the windscreen, general conditions, like day and night, and driver characteristics.
Experiments have been carried out by Weir et al. (1978), Chatfield et al. (1979) and Sandberg (1980) with lorries on artificially wet road surfaces, whereby the visibility of objects has been determined by means of lasers, photometric equipment and visual judgements of photographic and film material. These measurements are, however, primarily, meant to draw comparisons between various kinds of modifications to vehicles. See further subsection 3.2.

Padmos & Varkevisser (1977) have made an attempt to measure visibility hindrance by performing, from a following vehicle, a visual detection test on a preceding target-vehicle, during the overtaking of a lorry with trailer in a rain-shower. The study, which had an exploratory character, has unfortunately not been completed and the results are not usable for our aim.

2.2.3. Speed

Maycock (1966) states that with driving speeds under 40 km/h the spray density is very low and, moreover, rises rapidly according to the following formula: spray density = constant x $(\text{speed})^{2.8}$, valid for speeds of approximately 70 to 120 km/h. This means that if lorries exceed the speed limit of 80 km/h by 20 km/h, the spray density caused by them increases by no less than 87%.
Chatfield et al. (1979) state that spray at a driving speed of less than 64 km/h is insignificant.

2.2.4. Vehicle categories

Spray is predominantly caused by heavy vehicles, with consequences for lighter vehicles, such as passenger cars, motor cycles and bicycles. Motorcyclists are extremely disadvantaged because they do not have a wiper system and have to perform its function by hand. The handlebar is then - on a wet road surface - only held with one hand, which can be considered far from ideal when overtaking in rain and wind. Cyclists, too, can experience serious hindrance when being startled by a splash of (dirty) water. Drivers of heavier vehicles sit higher up and therefore are less inconvenienced by spray.
Sandberg (1980) compared the splash and spray of a passenger car doing 90 km/h with that of a 3-axle lorry doing 80 km/h. The visibility decrease for the passenger car was 1/7 that of the lorry.

2.2.5. Critical conditions

As critical conditions during splash and spray, we can list wet road surfaces, rain and wind.

In conditions of rain or a wet road surface, the following phenomena occur: the skidding resistance of the road is lower, the visibility is generally poorer so that fellow drivers, road marks and traffic signs can be less clearly seen. Although in the Netherlands it rains for about 6% of the time on average and the road surface is wet for about 12% of the time on average, 15% of all accidents occur in conditions of rain and 30% on a wet road surface, clearly indicating an increased risk (SWOV, 1984). Strong wind (more than 9 m/sec) occurs about 11% of the time in the coast provinces, and about 5% of the time inland. When the wind blows this strongly, hindrance will particularly occur at certain locations and under certain circumstances, probably causing it to be "subjectively" underestimated. The co-occurrence of wind with rain or a wet road surface is extra dangerous. Although the link between accidents and wind has not been established so far, it seems highly acceptable on theoretical grounds (Wouters, 1983).

The overtaking of lorries, lorry-trailer combinations and coaches can be, especially in windy weather, a tricky and fearful business. When the overtaking vehicle is on the lee-side of the vehicle to be overtaken, it will experience a backwash, a drop in wind and a slipstream, in that order.

Keeping course is carried out by looking ahead to establish the course angle and by establishing the lateral position on the road through peripheral vision (Weir et al., 1978). Under conditions of serious visibility hindrance, such as for example splash and spray, this task can be made even more difficult, resulting in abrupter steering movements, which on a wet road surface are especially undesirable. If on top of that wind should occur, diffusing even more water, critical conditions can be the result.

3. SPLASH AND SPRAY AND POSSIBLE SOLUTIONS

3.1. Road surface

The necessary condition for splash and spray to occur is the presence of a layer of water on the road surface. A logical step is, therefore, to prevent or limit the presence of such layers on the road surface. This means that rain falling on the road surface has to be drained off as quickly as possible. This can be done in two ways: off the surface of the road or through it. The draining of water off the road surface is determined, among other things, by the road design (geometry) and the road-surface properties; drainage through the pavement surface is determined by the drainage capacity of the material used.

3.1.1. Drainage off the road surface

In order to prevent water lying on the road surface, an appropriate combination of longitudinal and transverse gradient is needed. In addition, the creation of puddles has to be prevented.
Puddles occur for example in ruts and when the road situation makes good drainage impossible. This is for example the case on large crossroads or when the banking (transverse gradient) of the road is very shallow. The latter occurs with banking transitions between consecutive opposite curves. Besides shallow banking, the drainage trajectory is long, possibly causing thick water layers. The water drainage occurs more or less parallel to the traffic direction, causing excessive surface water (Welleman, 1980). Wind-force and thermoplastic markers can also hinder water drainage. Finally, long drainage trajectories on very wide roads can also cause problems.
The more the texture depth (macro-roughness) of the pavement surface increases, the thinner the layer of water on the surface becomes, albeit minimally. What is important with a considerable texture depth, is the creation of a canal network, ensuring a rapid water drainage at the points of contact between tyre and road surface (Welleman, 1979). The more water that is pushed away through this canal network, the less water that can be thrown up and repelled by the tyre.
Good maintenance and close scrutiny of the road-surface quality is an

important factor in the fight against layers of water on the road surface. If excess water is created by ruts, these can be filled or the surface can be planed, or a new top layer can be applied (see Welleman, 1979).

In banking transitions, drainage lenght can be reduced drastically by making small discharge channels transversely to the traffic direction. At certain locations in the Netherlands, these 4 to 5 cm-deep channels function satisfactorily (Welleman, 1980). If the macro-roughness is insufficient, this can be improved by cutting grooves. This can be done longitudinally as well as transversely. The cutting of transverse grooves is more laborious than the cutting of longitudinal ones. With longitudinal grooves, the danger exists that single-track vehicles, like motorcycles, will experience hindrance. An investigation into this problem is currently being carried out (IZF-TNO, THD). The working-life of these grooves in asphaltic concrete is, however, minimal; in cement concrete pavement, they keep longer. With the latter, furthermore, surface treatments can be applied (see Welleman, 1979).

The listed measures will not only benefit the fight against splash and spray, but, due to the reduction of the water layer thickness on the pavement surface, will also contribute to the general prevention of accidents on wet road surfaces.

3.1.2. Drainage through the road surface

The splash and spray phenomenon will not occur if water falling on the pavement is immediately disposed of through the surface and is stored in the upper pavement layer. This requires a top layer with a high proportion of hollow cavities. If the water is to be removed through this layer to the verge, these hollow cavities have to be interconnected.

There is a bituminious paving material which meats these requirements: porous asphaltic concrete. This material ensures the drastic reduction of splash and spray excess and offers relatively good reflection properties under conditions of rain (Welleman, 1979). The skidding resistance is of course higher than with other materials because of the reduced water layer on the road surface (Wegen, 1984). Porous asphalt also reduces driving noise. A difference of about 3dB (A) has been noted between

porous asphalt and gravelled asphaltic concrete (Wegen, 1984). Brown (1979) arrives at similar conclusions about skid-resistance, driving noise, splash and spray suppression etc. based on a two-year experiment with test sections on a British motorway. Ivey et al. (1984) cite recent American literature which also makes similar statements. Against these positive aspects, a few setbacks have to be mentioned: the hollow cavities, for example, seem to gradually clog up with dust, sand, dirt and oil residues. This reduces drainage capacity, though not the skidding resistance. Another problem is the prevention of slipperiness in winter. Especially with snowfall, a road section with a porous asphaltic concrete top layer demands extra attention.
In Wegen (1984), the fact is mentioned that on roads where spreading is done intensely, no problems occur, and that on other roads the spreading simply has to be stepped up.
In many cases where water nuisance exists or could exist, the use of porous asphaltic concrete should nevertheless be considered. Construction costs will be barely higher than for the asphaltic concrete mixes generally used (Welleman, 1979).

3.2. The vehicle

As has already been noted in subsections 2.2.4 and 2.2.5, the splash and spray problem is mainly caused by lorries etc. The following, therefore, deals exclusively with this vehicle category.

3.2.1. The tyre

Part of the water layer on the road surface in the path of the tyre, passes the profile grooves. The rest is pushed up to a backwash and partially drained off to the sides. This back- and sidewash forms splash, consisting of relatively large drops which remain rather low and rarely constitutes problems. The water passing through the profile grooves is thrown into the air. A small part of this clings to the tyre by adhesion and is removed by aerodynamic effects. The size of the water-drops from the profile varies from small to relatively large. A proportion of these is atomized high enough to cause visibility hindrance. The rest of the water splashes against other tyres or solid parts of the vehicle, such as

fuel tanks and mudguards. The drops are scattered on these and are diffused at such a height and in such a concentration, that this spray also causes serious visibility hindrance.
The water film on the tyre is atomized into very small drops and causes extreme visibility hindrance because it occurs in a zone of partial vacuum around the lorry, more or less at the same height as the windscreen of passenger cars (Weir et al., 1978). Swedish tests (Sandberg, 1980) have shown that a vehicle with slightly worn tyres (less profile depth and probably different adhesion properties) produces more spray than the same vehicle with similar but new tyres. In view of the above description of Weir et al. (1978), for the same water layer thickness, less profile would have to process more water, pushing this backwards under higher pressure and thus turning it into more spray. An investigation into the effects of tyre-design on splash and spray would be desirable so as to confirm this hypothesis.
Indeed, tyres are especially designed to push the maximum water out of the contact surface. This probably has an adverse effect on splash and spray prevention. Weir et al. (1978) describe models for the occurrence of splash and spray with a single tyre as well as tests to verify these models. These models could be used for optimizing tyre-design.

3.2.2. Number of axles

According to Chatfield et al. (1979), front tyres are the biggest source of spray. Weir et al. (1978) also note this and observe that the occurrence of splash and spray strongly decreases around following axles. This, in any case, argues in favour of shielding off front tyres. The splashed-up water can then no longer hit the vehicle chassis or following tyres and be diffused.
Swedish tests (Sandberg, 1980) show that 5-axle lorry-trailer combinations cause twice as much visibility hindrance as 3-axle lorries. A possible explanation for this apparent contradiction between the results of Weir et al. and those of Sandberg could be that the amount of spray generated is not linearly related to visibility. Presumably, longer vehicles turn more splashed-up water into spray, causing more visibility hindrance. Other factors also partly play a role, for example differences in mudguards.

3.2.3. Air currents around vehicles

Several kinds of air currents around lorries can be distinguished:
- air currents over the vehicle, whereby in certain zones (for example, behind the cabin in lorry-trailer combinations), adverse aerodynamic effects can occur; this can cause spray from preceding vehicles and rain to be whirled up;
- air currents alongside the vehicle, causing adverse aerodynamic effects at points of disturbance, such as the axles, causing the splash and spray generated there to be diffused and whirled up;
- reinforcement of this phenomenon by lateral wind; lateral wind creates zones of partial vacuum at the axles, causing splash and spray to be sucked from under the vehicle.

Improvement of the airflow - the prevention of adverse aerodynamic effects - will probably not only result in a reduction of spray, but also in a reduction of fuel consumption and wind hindrance. Air conduits on the vehicle, like front skirts and lateral shielding, could be integrated in anti-crash provisions and would increase the "crash-friendliness" of lorries.

In general, it is difficult to give rules for the installation and shape of air conduits. Sometimes, certain remedies seem to even worsen the splash and spray problem (Weir et al., 1978). Something similar has already transpired from fuel economies with roof shields on lorries. A careful adjustment of air conduits and wheel shielding on the vehicle is, therefore, extremely important.
Chatfield et al. (1979) describe tests in which, besides wheel shielding (see 3.2.4), the influence of air conduits on the formation of splash and spray was examined.
Various air conduits, mounted on the cabin roof, showed little difference in the spray patterns generated with different sorts of wheel shielding. The omission of these air conduits altogether made little difference to these patterns.
A centrally places vane on top of the container on the trailer, combined with an air conduit mounted on the roof of the cabin, made no difference either. This was probably due to the absence, during the tests, of lateral wind for which this vane was intended.

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A skirt under the front bumper ought to in theory create a zone af partial vacuum under the cabin, limiting the air currents from the wheel casings and between the axles and in doing so limiting the spray.
When in combination with this skirt only standard mudguards were used, little or no improvement was noticed. A clear improvement was noticed, however, when, in addition to the front skirt, the front wheels were shielded from the side and deflectors were mounted beind the front wheels. When the front skirt was raised, the amount of spray did not increase, so that it was assumed that the favourable effect was caused by a better airflow round the front wheels.
Chatfield notes that the test conditions were far from ideal: the weather was dry and hot, with a total lack of lateral wind.
Weir et al. (1978) have also described tests in which the effect of wheel shielding (see 3.2.4) and air conduction on the formation of splash and spray were examined.
In order to reduce air resistance, air conduits on the cabin, vertical air conduction deflectors under the trailer and vertical deflectors between cabin and trailer were examined. In addition, crosswise mounted deflectors between cabin and trailer, angled deflectors at the wheels and an air conduit behind the cabin were especialy studied for their effect on spray. The conclusion was that particularly the air conduit on the cabin roof, in combination with wheel shielding, had the greatest effect. The crosswise deflector between cabin and trailer also had its effect.
Due to Chatfield's remark about the test condition being far from ideal, only Weir's conclusions are considered relevant.
It has to be kept in mind that the application of such measures might require a precise adjustment for each case. In practice, a distinction could be made according to vehicle category and a subdivision according to the main construction variants.

3.2.4. Wheel shielding

Chatfield et al. (1979), besides the air conduits already mentioned in 3.2.3, also examined mudguards. Four aspects of this form of shielding were examined: the distance between the mudgard and the road, at the front as well as at the back of the wheel; drainage channels in the flaps; and lateral shielding of the wheels.

The following design criteria were drawn up from the tests:
- The front of the mudguard should start below the wheel axle in order to prevent thrown-up spray from splashing round the flap.
- The back should continue as far down as possible. For normal usage a raising of 200 mm seems to be a good compromise. The lower part of the mudguard should, for practical reasons, be flexible.
- So as to prevent the dispersion of spray as much as possible, the space between the mudguard and the tyre should be closed off by a lateral shielding on the outside of the wheel.
- The mudguard width should be enough to cover the wheels completely.
- Drainage channels in the mudguards bring about some improvement, but Chatfield et al. consider this to have been insufficiently studied. In view of the fact that the front wheels are a great source of splash and spray, extra attention should be paid to this point.

Flexible side-shielding especially might offer a solution in this matter.

Chatfield et al. (1979) come to the conclusion that the mudguards tested in combination with air conduits are of little help: the measurements indicate a spray reduction of 30-40%, but no improvement in visibility was observed. It was noted, however, that the test-conditions (in the main, hot summer weather and an almost total lack of lateral wind) were far from ideal. It was also noted that further research into spray reduction and the improvement of measuring methods was required. No quick solutions to the problem may be expected.

Sandberg (1979) also describes tests on wheel-shielding, coming to the conclusion that it is possible, with suitable shielding, to obtain spray-reduction to such an extent that an objective as well as subjective improvement in visibility of as much as 30% occurs.

As additions to standard mudguards (with rubber flaps) the following can be mentioned: strips of metal gauze on the inside of the mudguards with a small space in between, small side flaps front and back and a strip of gauze between the axles of the tandem set, and replacement of the skirts by strands of polyethylene, resembling grass mats, behind all wheels (and also between the axles of the tandem set) and small side flaps front and back. The "grass" has to be facing the wheels. Both applications retain the splashed-up water and redirect it towards the road surface, while the side flaps prevent lateral dispersion.

Weir et al. (1978) also described tests on wheels shielding. The most effective was a shielding of the same polyethylene (grass mat) as mentioned before, consisting of strands of this material behind every wheel, and side flaps, in combination with a wind conduit on the cabin roof. Without the wind conduit, the system was somewhat less effective. Second came mudguards which were covered by a kind of gauze in the inside, draining the flung-off water between gauze and flaps.

It may be noted that front-wheel shielding and side flaps are extremely important.

As further aspects of the shielding of wheels, the following deserve attention: extra heat-generation in the brakes by shielding-off lateral wind; the behaviour of the shielding when clogged up by dust and dirt and freezing in winter.

Chatfield et al. (1979) investigated heat-generation in brakes for shieldings used in the tests. There appeared to be no problems, probably due to the still relatively large openings in the shieldings.

As far as clogging up by dust and dirt is concerned, it is suspected that certain problems could occur with the gauze constructions as regards the spaces in between. The "grass mats", however, would not constitute a problem.

In summary it follows from the above data that:

- the front wheel is the greatest source of spray, needing to be shielded first;
- apart from shielding at the back of every wheel, side flaps seem particularly necessary;
- materials should be applied which retain the flung-off water and redirect it as closely to the road as possible;
- (carefully selected) air conduction deserves consideration.

4. DISCUSSION

Splash and spray are not statistically recognized as such, and a proportion of the accidents caused by these phenomena are probably classified under "skidding" or "rain or wet-road accidents". This would mean the problem is underestimated.

Generally speaking, such a specific problem will be relatively small in terms of accidents.

It remains a fact, however, that the problem often arises under critical conditions like rain, wind and overtaking, and causes a great deal of nuisance. The bulk of the splash and spray problem is caused by large and heavy vehicles such as lorries.

This is once again illustrated by Baughan et al. (1983), who mention that drivers and motorcyclists cite splash and spray as the most annoying lorry problem; even before speeding and wind hindrance. Cyclists too can experience nuisance. This calls for a closer investigation into the problems of motorcyclists and cyclists as regards splash and spray.

Measures against splash and spray can be divided in road measures and vehicle modifications, and can be characterized as attacking the source on the one hand, and minimalizing the effects on the other hand.

Road measures are intended to limit the information of water layers on the road surface as much as possible. Taking these measures will, as a rule, only be possible during maintenance of existing roads and the buildig of new ones. The application of porous asphaltic concrete will then be no more expensive than other paving materials; firstly, other measures will be expensive, and secondly, will take time to introduce. It has to be taken into account, however, that with these measures the road surface will be less wet and this for shorter periods, so that the present increased accident risk can be reduced.

Modifications to vehicles can be divided into "tyres", "air condition" and "wheel shielding".

It has been argued above that splash and spray requirements for tyres might be in conflict with the requirement to repel as much water as possible from the contact surface. Further investigation into the matter would be most desirable.

Air conduction could be a suitable means, besides its relevance for fuel economy, of preventing the diffusion of the drops present in the air and

of avoiding the formation of zones of partial vacuum around the wheels, so that no spray is sucked out. Every type of vehicle will, however, require a different kind of air conduction, carefully installed and optimized. It makes sense to distinguish by vehicle category and to divide these further into, for example, single vehicles, lorry-trailer combinations with or without closed superstructure.
For these, wind-tunnel measurements can be conducted. A missing factor could then be examined, namely air conduction and splash and spray effects with following vehicles. Up to now, only single vehicles have been examined.
Air conduction under the vehicle, as with front skirts and lateral shielding, can go together with anti-crash provisions in the vehicle. This calls for an integrated investigation into fuel economy, air conduction, splash and spray effects, and anti-crash provisions in lorries.
The application of wheel shielding seems to have reasonable results in spray prevention, provided at least the front wheels and preferably all wheels are shielded, from the front and laterally, with materials which redirect the retained water as closely as possible to the road surface. The combination of this shielding with air conduction (especially a roof shield) seems to be satisfactory. Considering roof shields have already been widely applied because of fuel economy, and considering that the cost (and the weight) of wheel shielding will be minimal, it ought to be possible to carry out this modification relatively fast and without problems.
An additional investigation will be needed, however, into the problem of heat-generation with shielded wheels, into the clogging up and freezing of certain shield materials and into their practical wear.
The relationship between the amount of spray and the degree of visibility hindrance has as yet been insufficiently studied. The relationship certainly does not seem to be linear.
Finally, an investigation into the improvement of wiper systems would be very useful.

5. CONCLUSIONS

1. Spray-induced visibility hindrance is, in terms of accidents, a relatively small problem, but it occurs under critical conditions such as rain, wind and overtaking. The problem is probably underestimated statistically.
Splash and spray is mainly caused by large and heavy vehicles, such as passenger cars, motorcycles and bicycles.
2. Splash and spray only occurs when there is a water layer on the road surface. This water layer can be prevented or minimalized by certain measures to the road surface. Drainage through porous asphaltic concrete especially gives good results. These measures can, however, only be applied during maintenance of existing roads and the building of new ones, which means their introduction will take time. These measures are, however, also beneficial in the prevention of wet-road accidents.
3. Vehicle modifications in order to reduce splash and spray hindrance consist mainly of air conduction around the vehicle and wheel shielding. The combination of roof shields with wheel shielding, especially gives good results. To this end, every wheel has to be equipped, on top of the traditional mudguards, with shielding behind the wheel and laterally between mudguard and tyre. The materials to be applied have to retain the water and redirect it closely to the road surfaces. The materials should not pose any problems concerning clogging up, freezing and wear.
4. The costs of vehicle modification will partially be regained by fuel economy (with air conductors) and they will be negligible (with shielding).
5. The application of porous asphaltic concrete in the building of roads or maintenance of existing roads is a suitable means for the prevention of splash and spray. By reducing the thickness of the water layer on the road surface the problem of wet-road accidents can also be helped.
6. The application of wheel shielding in lorries for the prevention of spray will also drastically reduce visibility hindrance, which, especially under critical conditions, such as rain, wind and overtaking, could have a positive influence on road safety.
The functioning of wheel shieldings will even be further improved by the application on air conductors to vehicles, for example roof shields.

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