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National Highway
Traffic Safety
Administration

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Update on the Status of Splash and Spray Suppression Technology for Large Trucks

Comprehensive Review and Evaluation of Spray Suppression Measures That Could Be Employed on Heavy Duty Vehicles (over 8,500 pounds GVWR) to Provide Clearer Highway Visibility and Safety During Periods of Adverse Weather Conditions

Report to Congress
March 2000

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EXECUTIVE SUMMARY

The National Highway Traffic Safety Administration (NHTSA) spent a great deal of its resources and energy in the 1980's looking at the possibility of requiring heavy trucks to be equipped with splash and spray suppression devices, primarily special flaps and side skirts around the wheels of the trucks. This effort was based upon public dislike of the spray clouds generated by large vehicles on wet roads. At the end of this effort, NHTSA announced on May 25, 1988, that no available technology had been demonstrated to significantly reduce splash and spray and significantly improve visibility of drivers on the public roads. Absent such evidence, NHTSA concluded it should not require these devices on large trucks.

In 1993, Congress asked for an update on technological developments in this area and whether a demonstration of effectiveness had been made. In March 1994, NHTSA reported to Congress that some new efforts were underway, and that the 1988 conclusions about the absence of demonstrated effectiveness remained valid. The Senate Appropriations Committee, in its report on NHTSA's appropriation for fiscal year 1999, asked the agency to review recent advances in splash and spray suppression as follows:

> *Spray suppression research*.–The Committee acknowledges the work previously undertaken by NHTSA in the area of spray suppression research and evaluation of abatement technologies and continues to support further research by NHTSA in this area to make travel on the Nation's highways safer and less stressful. The Committee is aware of the progress made in the European Union in designing beneficial performance standards and implementing roadway spray suppression regulations to improve highway visibility. The Committee directs NHTSA to update its research by conducting a comprehensive review and evaluation of spray suppression measures that can be employed on heavy duty vehicles (over 8,500 pounds gross vehicle weight rating) to provide clearer highway visibility and safety during periods of adverse weather conditions. NHTSA shall publish and report its findings to Congress within 12 months of enactment.

This report responds to that request.

A notice requesting comment was published in the *Federal Register* on May 7, 1999, (64FR24709) so that the agency would have the benefit of input from the public. Comments were received from a number of interested parties. In addition, an additional independent comprehensive review and evaluation of spray suppression developments that have occurred since the 1994 review was conducted along with a review of the recent data on the extent of the current safety problem.

This report found significant interest in splash and spray suppression by government and the private sector. To date, however, the technologies that purport to reduce splash and spray cannot be shown to translate into real world visibility improvements for drivers. For instance, Europe has a directive specifying how spray suppression devices will be evaluated for effectiveness in a laboratory test. However, when we contacted European governments, we learned that there are no data that show devices that are approved under their laboratory test result in better visibility on vehicles on the road. Similarly, a number of States have passed laws requiring spray suppression devices. However, when we contacted Florida, which has the broadest law, we learned that the state does not know how to evaluate whether the devices that work in laboratory tests help drivers on the road.

NHTSA also reexamined the available databases to document the safety problem posed by splash and spray from heavy trucks. As was the case in 1988 and 1994, the number of crashes from splash and spray is extremely small.

Given that no significant safety problem appears to exist, and the currently available technologies cannot be shown to effectively address the problem, NHTSA does not believe it would be a prudent to spend its limited resources on another round of splash and spray suppression research. NHTSA will however monitor developments in this area and respond to any future technological developments or research studies.

The University of Michigan Transportation Research Institute (UMTRI) assisted NHTSA in portions of this report by reviewing and evaluating recent spray suppression developments. The principal UMTRI author was Charles MacAdam of the Engineering Research Division. Other UMTRI contributors were Daniel Blower from the Analysis Group of the Center for National Truck Statistics, and Paul Green, of the Human Factors Division. Chapters 3 and 4 of this report comprise the majority of the UMTRI work.

CHAPTER 1 INTRODUCTION

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CHAPTER 2 DEFINITIONS OF SPLASH AND SPRAY

The terms "splash and spray" are commonly used together to describe the adverse effects on visibility caused by vehicles traveling on wet roads. "Splash" consists of very large liquid droplets that fall ballistically to the ground. Truck-induced splash does not contribute greatly to the reduced visibility experienced either by motorists traveling adjacent to a truck or by the truck driver because the splashed droplets typically remain close to the ground, out of the line of other driver's vision. Occasionally, splash may strike adjacent vehicles' windshields if there is puddling or uneven wetting of the roadway surface in front of the truck (or other vehicle). This condition can obscure vision for a brief period.

"Spray" consists of very small liquid droplets that remain airborne for a long time in the form of a fog cloud before falling to the ground. It is formed when three elements are present: (1) water, (2) a hard or smooth surface struck by the water, and (3) a turbulent air flow to pick up and carry the water. The interaction of the three elements produces small droplets of water which remain airborne for a time, in the form of a "fog" cloud projecting from the surface which they struck last. Because the "fog" can linger as long as the cloud's water is replenished, spray can surprise and confuse a driver who is not able to orient himself and his vehicle because of the inability to see through the cloud of airborne water droplets.

CHAPTER 3 REVIEW OF CURRENT RESEARCH FINDINGS ON SPRAY SUPPRESSION

3.1 OVERVIEW

The findings reported here focus primarily on splash and spray developments since the last Report to Congress in March of 1994 (NHTSA 1994). This includes splash and spray initiatives that were undertaken somewhat prior to 1994 but have not had sufficient time to be evaluated properly within the previous report. An example is the European experience and the EEC Directive (91/226/EEC) enacted in 1991 that certifies candidate splash and spray devices for use on heavy vehicles in Europe through successful completion of a specified laboratory test procedure. This Directive (European-Economic-Community 1991) has been phased in over time with most EEC countries now adopting it in either a mandatory or voluntary manner.

Other developments include various devices or materials that have been proposed for use in spray suppression. Examples of in-use, or proposed, spray suppression devices range in nature from conventional mud flaps containing various surface treatments ("astro-turf" grass, grooves, slots, etc.) to more novel designs that are largely proposed by individual inventors or offered by miscellaneous automotive hardware suppliers. More complete spray suppression systems often include combined use of spray suppressant mud flaps, side-skirt valances running along or around the wheel housings, and fenders around wheels that help to further contain the wheel spray. Examples would include various manufacturer packages tailored to different wheel locations and offered for sale in Europe and the U.S.

Fairly recent research conducted in Europe by Mercedes-Benz AG in 1995 (Geotz and Schoch 1995) provides some interesting insights and results from full-scale road tests of heavy trucks. A basic conclusion of that work is "the current state of production can be considerably improved" and goes on to cite a newly proposed grooved fender design and water-channeling scheme that is claimed to "extremely reduce the water spray." More detail on these recent research findings are provided in Section 3.4 and Appendix A.

A full-scale road test procedure for evaluating the effectiveness of any proposed spray suppression system has also been proposed and developed by the Society of Automotive Engineers (SAE). It is titled "Recommended Practice for Splash and Spray Evaluation J2245," and was published in April of 1994, one month after the last Report to Congress on this topic. It essentially brings forward certain portions of the widespread research on splash and spray conducted in the 1970's and 1980's and attempts to identify a potential test procedure that could be utilized to evaluate any proposed on-vehicle spray suppression system operating under more realistic wet-weather highway conditions.

A recent study in 1998 by Laval University in Quebec (Dumas et al. 1998) conducted for the Quebec Department of Transport compared several different spray suppression devices during a series of full-scale road tests. This study utilized an extended version of the above SAE Recommended Practice test procedure to better characterize the spray cloud at different lateral distances from the test vehicle.

Various truck manufacturers in the U.S. and Europe continue to offer varieties of mud flap and spray suppression options on new vehicles and in some cases conduct their own spray suppression research. Aerodynamic treatments offered by truck manufacturers also have varying claims made for assisting in spray suppression as a beneficial byproduct of streamlined or low drag truck designs. Certain fleet operators such as UPS operate trailers with drop-bottom or lowered floor designs that help to lessen the amount of spray generated by trailer underbodies between the wheels. UPS also equips most vehicles with spray suppression mud flaps and side-fairings around each wheel to further reduce spray. After-market automotive suppliers also offer various types of mud flap or side-skirt devices that are intended to help to attenuate road spray.

While not being emphasized in this report as a solution meeting more near-term goals for reducing road spray, it is generally recognized that certain concrete and asphalt road surface compositions also serve to reduce the amount of spray generated by a passing vehicle. This might be viewed as a more logical long-term road construction strategy that could further help in spray suppression.

Specific examples of legislative initiatives that address the splash and spray problem include: A) the European EEC Directive (91/226/EEC) enacted in 1991, B) a State of Florida legislative bill (Section 316.252, 1997-1998) that covers all heavy trucks but excludes agricultural-related vehicles, and C) legislation in five other states (Kansas, Missouri, Indiana, Ohio, and Oklahoma) that apply specifically to long combination vehicles (doubles and triples) usually operating on restricted highways.

The crash record on splash and spray continues to be problematic insofar as it provides very few actual cases of reported involvement or crash causation by splash and spray. Current review of crash records back to 1991 provides a similar profile as reported in the 1994 Report to Congress for its preceding years. There are several reasons for this which are probably related to under-reporting of crashes on police logs, the nature of the splash and spray encounter, and the low probability of wet travel conditions overall in the U.S. This is addressed further in Section 3.2.

Finally, there is the thorny human factors issue of how average drivers typically react to splash and spray. In some cases drivers may be more annoyed or aggravated by the increased workload associated with having to deal with periodically increased demands of the driving task, while others may react in unpredictable ways when presented with a sudden loss or degradation of vision. In most cases, the encounter adds to uncertainty in the driving experience and thereby increases the general level of anxiety for drivers. Adding to this complication is the generally unrecognized factor that truck drivers themselves can also be affected by surrounding spray (mirror obscuration included) and are likewise unable to see following or overtaking vehicles as effectively.

Overall, while there are individual efforts undertaken to further study and improve upon the splash and spray problem, very little coordination or large-scale research has been directed at the problem since the 1980's, as also noted in the last Report to Congress in 1994. Various confounding issues such as ambient crosswinds or snow and ice build-up on certain types of mud guards continue to plague significant advancements in spray suppression. These legitimate problem areas are also typically cited by opponents of current spray suppression devices as primary reasons for not undertaking rulemaking to require some form of federally-mandated equipment on heavy trucks.

The remaining sections of this chapter delve into specific areas of interest for the splash and spray topic. These include: a) the crash record, b) human factors issues, c) types of spray suppressant ideas, d) methods of evaluating anti-spray devices, e) examples of specific spray-suppressant devices on the market, f) truck and trailer manufacturer views, g) other views solicited from the docket, and h) existing legislation addressing splash and spray. The next two chapters, four and five, contain 1) a summary of observations, and 2) potential actions that could be undertaken.

3.2 THE SPLASH AND SPRAY CRASH RECORD

The crash record relating to splash and spray incidents was analyzed by the Statistical Analysis Group of the Center for National Truck Statistics at the University of Michigan Transportation Research Institute. Crashes in which splash and spray is a factor were only identified in two files: the Fatality Analysis Reporting System (FARS) and the NASS General Estimates System files.

FARS is a census file of all traffic crashes involving at least one fatality. In that file, splash and spray is identified in a "driver-related factors" variable: a code level records cases of "driver vision obscured by splash or spray of passing vehicle." Up to three driver-related factors may be coded, so there are three opportunities to code splash/spray for each driver.

The GES file is a nationally-representative sample file of police-reported traffic crashes. A multi-step, stratified sampling procedure is used in GES to sample police reports, and data are coded from those sampled reports. The GES file includes a variable for "Vision obscured by:" and one of the possible code levels is "splash or spray of passing vehicle." Only one item may be coded.

A total of seven state police-reported accident files was also reviewed: Michigan, Ohio, Missouri, Florida, North Carolina, Texas, and Washington. In none of those files is “splash or spray” (or anything similar) identified as a crash cause. The state files simply do not consider splash or spray in terms of crash causation (or anything else).

In the FARS data, from 1991 through 1997, 29 crashes out of a total of 255,928 (0.011 percent) identified splash or spray as a contributing factor. This rate is somewhat higher than the rate from the FARS data of 1982-1987 as reported in the 1994 Report to Congress, but the numbers are too small to have any significance.

Of the 29 FARS crashes, only one truck was physically involved and the death occured to the driver of a passenger car. FARS codes “splash/spray from a passing vehicle.” There is no way to determine the type of vehicle generating the spray. There would also be no record in FARS for the vehicle responsible for the splash/spray if that vehicle did not make physical contact with any other vehicle.

However, the information that is available in FARS does not support the case that splash/spray (as coded) is exclusively a truck problem or confined to high-speed roadways. That is, a common stereotype crash, when thinking of splash/spray, is initiated by the presence of a spray cloud generated by a truck traveling near posted speeds down a highway. Yet eight of the crashes recorded in FARS 1991 through 1997 involved pedestrian fatalities, seven of those on urban streets. It is impossible to reconstruct the sequence of events in the crash from the variables recorded in FARS, although several of them seem to indicate that it is plausible that no truck was involved, or no spray was involved. Five of the 29 occurred on *dry* pavement for example. Assuming the splash/spray coding is correct, the critical event was perhaps hitting a puddle, after the rain.

The GES is a sample file, with weights to generate nationally representative results. In the GES file, a total of 17 crashes were recorded during 1991-1997, with a weighted estimated total of 1622 splash/spray-related crashes in the nation. This is 0.0036 percent of the total of 45,024,000 crashes estimated to have occurred over those eight years. Just as in FARS, it is impossible to know if trucks were responsible for the splash/spray. Four of the 27 total vehicles crashing were trucks. The number of splash/spray crashes estimated in GES is extremely small and thereby statistically unreliable insofar as permitting meaningful conclusions to be drawn regarding the significance of a relationship between splash/spray incidents and crash causation.

In summary, the crash analysis indicates that:

- The number of recorded splash/spray crashes is extremely small.
- The existing computerized crash record cannot indicate whether a truck was responsible for the splash/spray.
- It seems likely that a number of splash/spray *fatal* crashes did not involve a truck and are likewise extremely small in number.
- It is unlikely that there is any crash file with better data than FARS or GES. It is unlikely that any state file can provide meaningful data on the question.

3.3 HUMAN FACTORS ISSUES SURROUNDING SPLASH AND SPRAY

To understand the human factors issues, it is useful to identify the scenarios that might lead to crashes. As shown in Table 1, the potential consequences of splash and spray can be thought of as both short term and long term. The short term consequences of spray are mainly a loss of visibility as outlined by Sandberg (Sandberg 1980). This includes drivers following spray-generating vehicles not being able to see ahead and the driver of the spray-generating vehicle not being able to see a vehicle following them, following vehicles obscured by spray not being visible to others at intersections and to oncoming vehicles on two-lane roads. Splash can be a problem for drivers of following vehicles attempting to pass (or driving in adjacent lanes) and oncoming vehicles, with the concern being a potential loss of control. Most vulnerable are motorcycles and bicycles. The cumulative consequences of splash and spray are primarily depositing dirt on surfaces critical to visibility -- windshields and windows, mirrors, signs, and vehicle bodies -- influencing what drivers can see and how well they can be seen. Visibility and driver vision issues related to splash and spray can also play a significant role in terms of pedestrian safety.

There have been a limited number of human factors studies of this issue, all of them emphasizing the measurement of visibility, the spray problem. The most relevant studies consider how well drivers can see through fog and the effectiveness of various lighting treatments to make vehicles visible in fog (Blaauw and Padmos 1982; Blackwell 1971; Hahn et al. 1995; TRB 1978). Virtually no human factors works has been done that considers splash. A relatively recent study of splash and spray treatments is presented in Koppa and Pendleton (1987).

Table 1. Potential Consequences of Splash and Spray.

Category	Problem for	Potential Problem
short term/ real time	lead vehicle	spray obscures following vehicles
	follower	visibility-spray from lead vehicles obscures lead vehicles, signs, edge lines, other traffic at intersections, traffic signals
	follower	visibility-doused during passing, lane change
	opposing vehicles (2 lanes are adjacent)	visibility-spray obscures vehicles in passing lane; spray obscures lead vehicles, signs, edge lines, other traffic at intersections, traffic signals (in own lane)
		visibility-doused during encounter causes loss of control
	opposing vehicle - divided road	visibility-spray drift from vehicle in opposing lanes obscures lead vehicles, signs, edge lines, other traffic at intersections, traffic signals
	motorcycles, cyclists, pedestrians	numerous visibility problems
		knowing they cannot be seen, they navigate differently
		doused when vehicle passes
long term	lead vehicle	dirt on windshield obscures forward view
		dirt on mirrors obscures side view
		dirt on rear window obscures rear vision
		dirt on headlights obscures lead vehicles, edge lines
	follower	dirt on taillights obscures lead vehicle, especially at night
		dirty lead vehicle makes it hard to see in poor daytime visibility (e.g., fog)

Another study by Wright (Wright et al. 1990) had 20 drivers repeatedly watch a vehicle approach them while seated in a stationary vehicle. To simulate looking through spray, subjects looked through a frame of multiple layers of acetate and stated when the approaching vehicle was clearly a car. They reported that the Snellen acuity in the simulated spray condition (from a standard Snellen chart) and contrast sensitivity function for looking through the simulated spray in the laboratory, were correlated with each other, the recognition distance for the car in the field, and a Figure of Merit determined by digitizing a checkerboard pattern as seen through the simulated spray. All correlations were in the 0.84 to 0.89 range. This suggests that any one of these measures could be used to explore visibility degradation due to spray with the measure selected being the most convenient.

Given the lack of direct work on this topic, some insights may be gained by examining analogous situations. The three sources of performance impairment (degraded vision, momentary visual loss, startle) are considered separately.

What is the impact of degraded vision on driving?

Spray makes seeing ahead, behind, and to the sides more difficult. This loss has similarities to the loss of driver visual acuity due to age, and, driving at night and in fog.

If vision is lost for a moment (e.g., due to splash), how long is acceptable?

This topic was recently reviewed by Sivak and Flannagan (Sivak and Flannagan 1999), with relevant work also appearing in Green (Green 1998). Shown in Table 2 is a modification of their summary of potentially relevant situations. Note that all of the activities in Table 2 are initiated by drivers at times they select.

Table 2. Various Human Factors Studies of Driver Visual Interruption During Different Tasks.

Activity	Duration (ms)	Comment
periods with no visual activity during eye blinks	200	no awareness of interference due to eye blinks
voluntary occlusion of vision in visual occlusion experiments	500-2000	In these studies, drivers wear a device (often goggles) that allows them to see for 0.5 s and then blocks their vision until they request vision again.
fixations to rearview mirrors, controls, and displays	1000	
fixations on navigation systems	>1500	to turn-by-turn display or map
head turns prior to lane changes	1500	
time-to-collision and time-to-line-crossing at initiation of corrective action	>1500	Time-to-line-crossing is how long it will take for any tire to touch an edge line if at any given moment, the driver freezes and the road continues as is.

These data suggest that if the driver is forewarned of a potential loss of vision, 200 ms is clearly acceptable, 500 ms will generally be acceptable, and in some situations, 1500 ms may be acceptable. Acceptable times for unexpected situations are unknown. These figures can be compared with typical truck-passing episodes in which spray may obscure vision for periods on the order of 10 seconds (70ft. long truck, speed difference 5mph or 7.3 ft/sec), thus establishing that the spray-based obscurations can be very long relative to human tolerance limits.

How do drivers react when they are startled?

When spray strikes a windshield there is both a loss of vision and the unexpected sound of the splash. No experimental evidence seems to exist that addresses this particular scenario. In a weakly-related study of braking behavior and sight distance, Olson (Olson et al. 1984) examined driver response to an unexpected foam obstacle visible after cresting a hill. The authors did not observe any startle reactions in this particular set of experiments.

Several gaps remain in the human factors literature pertaining to splash and spray.

1. There appears to be no work on the effects of driver age and the ability to see through splash or spray. The literature treats degradation due to spray as being a loss in visual acuity. Given the generally poorer vision of older drivers, the effects of spray on driving for them is likely to be larger than that for younger drivers.

2. There is no research on the impact of splash on driving. Common experience suggests that splash is extremely disruptive to driving although the extent is unknown. Exploring splash experimentally poses some challenges as much of the impact of splash is a result of it being a surprise. Accordingly, the number of times each subject might be exposed to splash events will be extremely limited, complicating experimental design.

3. There is no research on driver reaction to slush. Responding to slush on one's windshield is much more difficult than splash. With slush, adequate clearance may require multiple sweeps of the windshield for clearance to occur. If freezing of the slush begins, then the driver may need to operate the defroster and wait for the defroster to be effective, actions that do not occur in an instant. Furthermore, slush may contain a fair amount of solid matter that may need to be washed away after clearance by the wiper has occurred. In any case, the troubling aspects of slush appear to be outside of the scope that is proper to the splash and spray discussion.

4. There is no modeling of either the physical factors or driver responses related to splash and spray. The impact of wind on spray clouds and likely sight distance or the ability of drivers to perform various tasks as a function of spray characteristics has not been quantified. The development of such models may advance certain investigations of the effectiveness of various treatments to counteract spray and splash via a computational rather than experimental means.

3.4 EEC DIRECTIVE ON PERFORMANCE OF SPRAY SUPPRESSION DEVICES

One significant development that was not discussed in our March 1994 report to Congress on splash and spray was the European experience with spray suppression technology. The European Economic Community (EEC) issued a directive in 1991 (91/226/EEC) that specifies laboratory tests used to approve spray suppression devices for use on heavy vehicles in Europe. These laboratory tests consist of pumping water at the spray suppression device and then measuring how much of the pumped water is collected in a container below the tested device. The theory behind this test is that to the extent the water falls straight down from the device, such water will not be in a position to form a spray cloud. The higher the percentage of water collected in the container, the better the spray suppression device is performing in this test. Appendix B to this report shows figures that illustrate the EEC test procedures.

One obvious question is whether better performance in the laboratory tests corresponds to better spray suppression performance on vehicles on the road. In 1988, NHTSA looked at this issue as we were considering whether to require splash and spray suppression devices in the United States. The 1991 EEC Directive, and the laboratory test it specifies, were adopted from a pre-existing 1984 British government regulation. This British Motor Vehicle Regulation 1984, No. 1543, required all heavy trucks in Great Britain to be equipped with spray suppression devices that met the laboratory test measuring the percentage of pumped water collected beneath the tested spray suppression device. In 1988, NHTSA's notice terminating splash and spray rulemaking stated:

> Furthermore, the statute requires this agency to make a determination of whether any devices "can significantly reduce splash and spray from truck tractors, trailers, and semitrailers, and can significantly improve visibility of drivers, as demonstrated during testing on highways, at test facilities, and in laboratories to take into account possible wind and rain conditions." *NHTSA is not aware of any testing to date of devices mandated in the United Kingdom that satisfies the above-emphasized requirements of the statute*. ... The agency is not aware of ... any testing programs on real highways that show the devices mandated by the British standard significantly reduce splash and spray and significantly improve visibility on those highways. 53 FR 18861, at 18867,
> May 25, 1988. (Emphasis added)

In connection with this updated look at the European experience with splash and spray suppression, one of the University of Michigan researchers contacted the government of Great Britain to learn if Great Britain had conducted any studies at test facilities or on road to demonstrate visibility gains from vehicles equipped with approved spray suppression devices. Mr. William S.J. John, an engineer with the Road Safety and Environment Directorate responded in a July 8, 1999 letter, which is attached as Appendix C to this report. Mr. John indicated that Britain has "no recently published work regarding the production of spray from goods vehicles." Mr. John indicated that Great Britain's recent research has tried to assess the level of spray produced by real vehicles, but the research was not successful.

Absent any research in this area, Mr. John said that "Currently the situation exists from observation in the wet, it is known that a vehicle fitted with spray suppression equipment complying to Council Directive 91/226/EEC produces far less spray and splash than a vehicle not fitted with any spray suppression equipment." In NHTSA's previous consideration of splash and spray, we acknowledged that lasers could measure the spray cloud generated by vehicles with splash and spray suppression devices was less dense than vehicles without those devices. However, the question was whether the less dense clouds translated into better visibility for drivers, and, thus, better safety on the roads. In 1987, NHTSA said, "Even with the measured reductions in spray cloud density, the spray clouds that resulted from the vehicles with the proposed [splash and spray suppression] devices were still too dense to allow acceptable visibility." 52 FR 36285, at 36287; September 28, 1987. NHTSA is not aware of any studies that have been conducted since 1987 that call into question the continuing validity of that conclusion.

3.5 TYPES OF SPRAY SUPPRESSANT TECHNOLOGIES

The most common device offered today on heavy trucks to help reduce wheel spray is the traditional mud flap that is enhanced with surface materials ranging in nature from Astroturf® or grass-like material to grooved surface treatments. The basic intent of a grass-like substance is to absorb and dissipate the energy of the water spray, trapping large portions of it within its texture prior to draining it on to the road surface behind the tire(s). Grooved or similar surfaces are intended to help collect the water spray and channel it into more concentrated streams that flow back onto the road surface. In controlled laboratory tests that measure the amount of water collected by such surfaces, the grass-like substance seems to perform considerably better than more rigid-like or smooth surfaces (European-Economic-Community 1991). Mud flaps may also be shaped or slotted to provide better concentration and collection of the impinging water spray. In some cases, water collected at the bottom of the flap is redirected by a pipe to the center of the vehicle for deposit to the road surface (Geotz and Schoch 1995). Many of these more involved treatments are offered by individual inventors or researchers attempting to genuinely improve upon the traditional mud flap concept (Adler 1999; Geotz and Schoch 1995; Szakurski and ZAAK-System 1999).

Another common offering is the side-skirt or valance that is fitted to the side of the vehicle body just above a wheel to help further contain the spray emanating from the wheel-well area. These may be flat panels that have grass-like material on their inner surface or compliant fringe-like material that allow air to pass back and forth while acting as water collectors on the spray. A similar approach is obtained by utilizing brush-like material around the outside perimeter of wheel areas to also help contain and collect wheel spray. The basic mechanism at work in most of these concepts is either energy absorption or air-water separation (Hucho 1998; Schlegel ; Solutia/Symplastics).

A third basic approach is to utilize fenders around each wheel or provide similar body structures around each wheel area to help contain wheel spray within a close space (Jeco-Plastic-Products). Fender-like approaches may be easier to retro-fit to conventional truck and trailers. Body structures that contain the spray are more likely associated with newer vehicle design options that might typically accompany streamlined or more aerodynamic vehicle body shapes (Hucho 1998; Olson and Fry 1988).

Each of these various options may be offered in some form by most manufacturers of new vehicles. After-market automotive suppliers are also major providers of such devices. There is no Federal mud flap requirement.

Recent research by Mercedes-Benz AG in Europe in 1995 (Geotz and Schoch 1995) identifies a new fender design with a grooved channel profile that is said to “extremely reduce the water spray.” Full-scale road tests under still-wind conditions were conducted by Mercedes researchers with a three-axle truck to evaluate the new design against other commonly available devices including a) EEC mud flaps approved for use in Europe by the EEC Directive (European-Economic-Community 1991) and b) standard mud guards, but equipped with brushes along the wheel housing perimeter. One surprising finding was that the EEC spray suppressant mud flaps performed more poorly than standard mud guards under these tests. The reason cited was “the large clearance between wheel and wheel arch” which allowed “significantly more splash water to flow out at the sides.” Apparently no side valance skirts were also mounted in conjunction with the EEC mud guard during these tests. It was also observed that the grooved channel fender being proposed by Mercedes was effective at reducing measured spray by 36 percent relative to the non-equipped vehicle and by 60 percent if also equipped with a longer mud flap extending down to within 2 inches of the ground. Mercedes also noted that a standard mud guard equipped with perimeter brushes around the wheel housing reduced measured spray by 25 percent. The ultimate test performed by Mercedes was to study a “full fairing” configuration which essentially provided a containment shroud along the side of the vehicle including the wheels. This somewhat impractical arrangement was primarily intended to demonstrate that road spray could be reduced by as much as 77 percent at highway speeds of 50 mph. This is in basic agreement with Japanese researchers at Mitsubishi that reported similar results in 1977 (Yamanaka and Nagaike 1977) showing measured spray reductions of 90 percent for similar side-shrouded trucks operating at 50 mph.

More recent research conducted in Canada by Laval University in Quebec (Dumas et al. 1998) examined two basic types of spray suppressant devices including several variations in different configurations on a 5-axle tractor-semitrailer. One device was a basic wheel fender design containing aerodynamic slots for assisting in control of airflow around the wheel. The other device was a simple side-valance panel that helps to deflect and contain wheel spray along the side of the vehicle. Both devices and several modifications showed varying degree of success in helping to attenuate the intensity of spray normally generated by the otherwise unequipped vehicle.

A basic observation from this recent research, and prior research conducted in the 1970’s and 1980’s, is that containment of water spray along the side of vehicles, either by valances, wheel covers, or fenders, provides notable improvements in spray suppression, depending on the degree of spray containment provided by a particular design. Newer ideas offered by Mercedes (Geotz and Schoch 1995) provide for capturing wheel water spray into streamlets that are collected in grooved channels of wheel fenders. The collected water is then redirected, at the bottom of mud guards, through collector pipes towards the center of the vehicle prior to deposit back on to the road surface. This concept appears to provide further advantages and could offer new ideas for intelligent management of water collected from the various external surfaces of vehicles during wet weather conditions.

3.6 METHODS OF EVALUATING ANTI-SPRAY DEVICES

Three basic methods for evaluating the effectiveness of spray suppression technologies are identified below. Each has a different level of confidence associated with its ability to correlate and predict how well a candidate device would likely perform in actual on-highway driving conditions.

3.6.1 Full-Scale Road Tests

The first and most trustworthy approach is to mount a candidate spray suppression device on an actual vehicle and operate it on a wetted road surface while measuring the amount of spray generated under these conditions. The Society of Automotive Engineers (SAE) Recommended Practice for Splash and Spray Evaluation J2245," published in April of 1994 is the best documented example of this approach (Society of Automotive Engineers 1994). As each vehicle equipped with a candidate spray suppression device passes over a wetted test track section, cameras and lasers are used to measure the level of degradation in visibility caused by the generated spray along both sides of the vehicle. The camera measurements address the visible spectrum degradation by recording the legibility of a fixed target located forward and to the side of the vehicle, as viewed from a fixed camera position to the rear the vehicle. The laser measurements involve a transmitter and receiver in similar positions and record the degradation in laser transmission through the cloud of spray at the time of vehicle passage. An early application of this type of test procedure was used by the Motor Vehicle Manufacturers Association (MVMA) in a comprehensive study conducted in 1985 (Gorte et al. 1985). The laser and camera measurements conducted in this study on most tractor-trailer combinations equipped with an aero-aid (e.g., a tractor roof-mounted air deflector), side valance "cat whiskers" around wheel locations, and spray suppressant mud flaps, showed an approximate 50 percent reduction in vehicle-generated spray. The same laser and camera measurements showed that spray intensity increases nearly linearly with vehicle speed.

In 1998, the Laval University study (Dumas et al. 1998) extended the SAE splash and spray test procedure (Society of Automotive Engineers 1994) and conducted a series of full-scale road tests on several different spray suppression devices. The basic SAE test procedure was extended by Laval to include laser measurements at 14 additional lateral offsets along the side of the vehicle in order to help characterize the extent and nature of the spray cloud away from the vehicle into adjoining lanes. This characterization was then used in the subsequent data processing to provide a more accurate and consistent evaluation of the spray cloud intensity at different lateral positions (as opposed to the SAE procedure which includes only two lateral laser measurements). See Figure A-4 in Appendix A.

Another spray measurement methodology developed by Mercedes-Benz in 1995 (Geotz and Schoch 1995) also uses road test measurements, but mounts a vehicle-based "light curtain" device behind and outboard of the test vehicle to record reflected light from the vehicle generated spray as a measure of spray intensity. See Figure A-5 in Appendix A. This approach has the advantage that it is portable and not dependent upon any specific section of test pavement for conducting spray measurements since the sensor and light source travel with the test vehicle.

Although the on-road measurement approaches appear to have many advantages in terms of approximating a realistic set of operating conditions, certain problems remain. First, there is the issue of vehicle type. A standard reference vehicle such as a 5-axle tractor-semitrailer may seem to be a logical choice covering a large portion of such vehicles on the road for use in such testing. However, enough variety in vehicle types still remain to raise questions about the effectiveness of a particular device when fitted to a different style of vehicle. Previous studies have shown this sensitivity (Koppa and Pendleton 1987; Olson and Fry 1988; Scheltens and Luyombya 1987; Yamanaka and Nagaike 1977).

Another issue relates to the ambient wind conditions present at the time of testing. Crosswinds above 8 mph or so have been shown to effectively diminish or negate much of the benefit of spray suppression technologies studied during the 1970’s and 1980’s. This presumably is still the case today, unless some of the more recent invention ideas under development will have true impact on mitigating the influence of such crosswinds. (It should also be noted that the presence of crosswinds, while diminishing the effectiveness of spray suppression devices for vehicles traveling in one direction because of associated lateral shifts in vehicle-generated spray clouds into an adjoining passing lane, also benefits vehicles traveling in an opposite direction by shifting the spray cloud out of the passing lane.)

In spite of these various concerns and imperfect operating conditions during splash and spray tests, full-scale road tests are still the best and most direct means available for accurately evaluating the effectiveness of a particular spray suppression technology.

3.6.2 Laboratory Tests

The second basic approach for evaluating the effectiveness of proposed spray suppression devices is to conduct laboratory tests on material samples or mock-ups of vehicle assemblies equipped with the proposed device(s). Known amounts of water are sprayed on to the material or assemblies for a specified amount of time. The amount of water collected below the test rig is then compared to the amount of water known to have been sprayed on the device and a percentage collection rate is calculated. If the collection rate is at least as great as some specified figure (e.g., 70 percent), the device is certified and approved for use on vehicles. A logical complaint and shortcoming with this approach is that it does not account for the influence of the overall vehicle as an interactive system that provides many different mechanisms for spray generation and corresponding affect on the effectiveness of a particular spray suppression device. However, it can be a good method for identifying water absorbing materials, irrespective of how those materials are utilized within a spray suppression system. It does not appear from recent evidence (Geotz and Schoch 1995; Scheltens and Luyombya 1987) that a very strong correlation exists between how a material performs in absorbing water during laboratory tests and how well it will perform in suppressing road spray under actual highway conditions.

The current EEC Directive is essentially a laboratory-based certification process. Initial recommendations by the EEC Directive to adopt a supplementary vehicle-based, full-scale road test have not yet been developed. The EEC test is conducted in a lab, on a test sample, in still air, and requires no vehicle parts. One procedure tests a sample of an energy-absorption spray suppression device by spraying the vertically suspended test sample, at a 500 mm distance, with a one liter of water and measuring the amount collected at the bottom of the sample to determine effectiveness. The EEC test on spray suppression devices of the air/water separator type, is a 5 minute test using a pressurized air/water pulverizer with a flow rate of 1 liter/min with a 50mm circular spray pattern - exposing the vertically suspended test sample and measuring the water collected below the test sample. The EEC tests do not measure real world performance on a vehicle. Appendix B illustrates the ECE test.

Recent research proved inconclusive due to large variations in ambient conditions, thereby confounding attempts to propose a test method that was consistent and repeatable under full-scale road test conditions. As Mr. John notes in a recent communication (John 1999),

> " Our recent research has concentrated on assessing the level of spray produced by vehicles in a scientific and quantifiable manner in order to develop a test that can be applied to whole vehicles, allowing a case by case comparison of the spray produced by a certain type of vehicle and allowing a pass or fail criteria to be applied.

This research however proved inconclusive due to the large variations that were found to exist in ambient conditions, which could not be relied upon to prove the reliability of the modeling criteria and propose a test method that was both consistent and repeatable."

3.6.3 Computational Fluid Dynamics Methods

A third and largely untested approach is to utilize large-scale computational fluid dynamics models to represent and evaluate air flow around vehicles equipped with various types of spray suppressant devices. Computations could conceivably be performed to identify predicted spray suppression sensitivities corresponding to different configurations for later testing and evaluation in laboratory or full-scale road tests. The idea would be to use a computer modeling approach as an initial screening tool to help identify different mechanical assemblies and their geometric layouts as potential candidate spray suppression devices worthy of further laboratory or road testing. The clear challenge for this approach is the ability to model and represent the myriad of conditions and effects present in a truck and road spray environment, even in an approximate manner, let alone the details needed for characterizing the various spray suppressant devices under study. However, if ever developed successfully in the future, such an approach could have enormous capabilities for investigating and evaluating wide ranges of spray suppressant designs, including the basic aerodynamic treatments of the vehicle itself for spray suppression (McCallen 1999). At present, a common view is that the level of practice is at a very early stage and probably inapplicable to the splash and spray problem for the near term (McCallen 1999; Olson and Fry 1988).

3.7 EXAMPLES OF SPECIFIC SPRAY-SUPPRESSANT DEVICES ON THE MARKET

Solutia (formerly Monsanto Chemicals) and Symplastics, Inc., offer a range of spray suppressant mud flaps and side valances under the trade names of "Clear Pass" and "Spray Guard" for use on various types of truck configurations. An example photograph appears as Figure A-1 in Appendix A. Solutia manufactures the grass-like or "astro turf" material that lines the surface of the product. Symplastics provides a polyurethane resin backing material and assembles the final product. The spray suppressant mud flaps are mounted on the inner surface of existing mud guard fenders, or separately as conventional mud flaps mounted vertically behind individual or tandem wheel sets. The valances are mounted on the outside of the vehicle body just above each wheel location or along outer perimeter of existing mud guard fenders. The basic intent is to provide energy absorption and containment of water spray at individual wheel locations. The estimated cost of a Solutia/Symplastics mud flap and side valance per wheel is approximately \$20 - \$30, depending on the size. This would place an average cost per trailer unit containing four wheels at about \$100. Solutia estimates that it supplies perhaps 70 percent of the European market.

Schlegel manufacturers brush-like valances (air-water separators), commonly referred to as "cat whiskers," that surround the outside of wheel perimeters and help to contain water spray within the wheel-well area. These are commonly seen on UPS highway trailers. Other manufacturers of side valances are Thomas Hardware and Reddaway who offer rectangular energy absorbing valances located above each wheel along the a outside of the vehicle body. Estimated costs for these types of side-valance devices range from 15 to 30 dollars per wheel depending upon the size.

Wheel fenders are also used at individual wheel locations for water containment purposes. An example manufacturer would be Jeco (Jeco-Plastic-Products). A more complex type of fender that contains wind vanes for capturing airflow along the side of the vehicle and redirecting it inward to the wheel housing is the Air Fender device marketed by Air Fenders Systems located in Georgia (Becker and Air-Fender-Systems 1999). Example photographs are seen in Figures A-2 of Appendix A. The basic intent of the Air Fender is to control wheel spray by utilizing aerodynamics around the wheel area to contain and redirect the water spray. This device also claims an advantage in terms of providing additional cooling to the tire and brake assemblies. In the recent testing in 1998 by Laval University in Quebec for the Department of Transport, the Air Fender system was shown to have reduced spray by approximately 50 percent on average utilizing an enhanced version of the industry-developed SAE J2245 Recommended Practice test procedure. These tests also showed that the Reddaway system (see Figure A-3 in Appendix A), utilizing side valances along the outer top portion of each wheel, reduced spray in the same tests less effectively near the vehicle, but more effectively as lateral distance to the side of the test truck increased beyond 8 feet or so. The best performing system was a hybrid combination in which the Air Fender system was combined with a Reddaway valance on the tractor front axle. That is, the trailer configuration seen in Figure A-2 combined with the tractor configuration seen in Figure A-3.

A list of current suppliers of miscellaneous mud flaps and fenders is also available on the INTERNET at URL:
www.heavytruck.com/hdt/buyersguides/replace/chassis/mudflaps_&_fenders.html.

3.8 EXAMPLES OF NEWLY PROPOSED DEVICES

In addition to the standard array of spray suppressant options that have been available for some time, newer ideas for improving upon the traditional mud flap, side valance, and fender concepts are being proposed. Examples would include efforts by individual inventors or researchers. One example is the research undertaken by Goetz and Schoch at Mercedes-Benz AG and reported in 1995 (Geotz and Schoch 1995). As discussed above in Section 3.4, Goetz and Schoch proposed a new fender design that contains longitudinal groves that collect the water contained within the fender area and channel the water downward in streamlets to the bottom of the fender and mud flap area. See Figure A-5 of Appendix A. The water is collected at the bottom of the fender/flap area and routed towards the center of the vehicle prior to draining back on to the road surface. The basic idea here is to contain and collect as much wheel spray water as soon as possible (not allowing it to travel very far after leaving the rotating tire and thereby avoid opportunity for atomization) and then to capture the water in streamlets along grooved channels located on the inner surface of the fender. A variant feature is to deposit the water back on to the road surface away from the wheel tracks — in the center of the vehicle — using a water collecting pipe located at the bottom of the mud guard assembly that drains water towards the centerline of the vehicle as seen in Figure A-6 of Appendix A. Road tests and spray measurements performed by Goetz and Schoch under still-wind conditions indicate a 36 percent to 60 percent reduction in the amount of generated spray at 50 mph for the grooved fender design, depending on the length of mud flap used in conjunction with their grooved fender. These measurements were performed according to their "light curtain" test procedure noted in Section 3.5 and Figure A-5.

An example of a new invention that more or less modifies commonly used hardware is provided by Mr. Joseph Szakurski of Pennsylvania (Szakurski and ZAAK-System 1999). Mr. Szakurski has designed a mud flap device (the Zaak Truck Spray Control system) that is curved to help better contain wheel spray and which also provides vertical slots within the device to help funnel water into a larger stream as it exits the curved flap at the bottom of the device. The Zaak system also contains side valances with vanes to utilize air flow for helping to further contain wheel spray. The Zaak device is being tested on local trucking fleets in Pennsylvania by Mr. Szakurski.

A docket item (Adler 1999) offered by Mr. Daniel Adler identifies a patent application for a spray suppression invention currently under review.

Occasional improvements also continue to be made to existing devices such as those offered by Air Fender Systems or for mud flap designs offered by companies such as Solutia/Symplastics.

Other examples of proposed devices are offered to NHTSA as unsolicited proposals by individual researchers or inventors.

3.9 TRUCK MANUFACTURERS ASSOCIATION COMMENTARY (representing Ford, Freightliner, General Motors, Mack, Navistar, PACCAR, Volvo NA, and Western Star Trucks)

On May 7,1999, NHTSA published in the Federal Register (64 FR 24709) a Notice stating that the agency was conducting a comprehensive review and evaluation of spray suppression measures that could be employed on heavy duty vehicles to provide clearer highway visibility and safety during periods of adverse weather conditions. The notice invited any interested person to provide NHTSA with any information or data that the person believes NHTSA should consider before preparing the report to Congress on this issue.

The response to the docket on splash and spray by the Truck Manufacturers Association (TMA) (Leasure and TMA 1999) has noted that not much has changed since the last Report to Congress in 1994 aside from ongoing considerations in truck design voluntarily undertaken by manufacturers to reduce splash and spray. The TMA does not cite specific examples of spray reduction offerings in new truck designs, but it is assumed that it this would cover aerodynamic modifications and/or spray suppression mud flaps or fenders offered as options requested by a buyer. The TMA notes that the EEC Directive on Splash and Spray initially called for establishment of a performance test on vehicles equipped with spray suppression devices — beyond just the laboratory tests on the devices themselves. This pending procedure has not been identified or defined as yet, nor is its current status. TMA does note that the industry did complete the development of the SAE J2245 Recommended Practice for Splash and Spray Evaluation published just after the last Report to Congress.

TMA also cites associated problems with the overall splash and spray problem including ambient winds, road surface characteristics, vehicle aerodynamic properties, and tire tread configurations — all well established as factors affecting the intensity of the spray environment induced by heavy trucks operating on wetted road surfaces. TMA further comments that the crash record does not support a position that heavy truck splash and spray is a major safety problem. However, it should be noted that for reasons relating to insufficient collection of crash data on this topic as discussed in Section 3.2, under-reporting of such cases is probable and therefore the scarcity of existing crash data is not necessarily conclusive one way or the other on this issue. TMA concludes with a recommendation that rulemaking not be pursued on this topic on the basis that practicable solutions have not been identified for consistently and significantly reducing splash and spray caused by trucks.

3.10 AMERICAN TRUCKING ASSOCIATION COMMENTARY

The American Trucking Association (ATA) (Suski and ATA 1999) notes that prior research has identified crosswinds as a major problem in terms of counteracting the effectiveness of spray suppression devices in reducing spray generated by trucks. It also comments that for some devices that have been shown to reduce the intensity of a spray cloud, the reduction is not sufficient. ATA notes that aerodynamic streamlining improvements made to vehicles can help reduce spray, but feels that no current spray suppression device is effective at managing the volume of water picked up by a truck’s tires. It also expresses some pessimism that any such a device can be developed. ATA also cites the recent Goetz study (Geotz and Schoch 1995) as evidence that mud flaps alone, even EEC-certified spray suppression mud flaps, are largely ineffective in reducing wheel spray. It also notes that ice-buildup on such mud flaps can be a problem so as to cause tearing of the flap.

ATA concludes that little has changed since the last report to Congress in 1994 (NHTSA 1994). It also cites porous pavements, reduced truck speeds, and improved truck aerodynamics as methods for reducing the amount of generated spray. Passenger cars and sport utility vehicles are identified by ATA as the majority of highway vehicles and ATA feels that such vehicles should also share in the effort to mitigate the amount of highway spray.

3.11 OWNER-OPERATOR INDEPENDENT DRIVERS ASSOCIATION COMMENTARY

The Owner-Operator Independent Drivers Association (OOIDA) (Johnston et al. 1999), like the TMA and ATA, notes that crosswinds and ice and snow build-up are major problems influencing the effectiveness of spray suppression devices. It concludes that ice and snow build-up and its potential to dislodge on to the highway can be more detrimental to the motoring public than the minimal spray reduction gained by the use of most spray suppression devices. OOIDA hopes that effective spray suppression devices can be developed at reasonable costs to the truck owner.

3.12 A A A COMMENTARY

The AAA (Pikrallidas and AAA 1999) notes that the splash and spray problem has been studied for many years without much success. AAA cites splash and spray as among the first items mentioned by motorists as a logical starting point to improve safety on the highway. The AAA truck safety policy recommends "development and implementation of an effective splash suppressant device as standard equipment on trucks." AAA also notes that alternate pavement texture or material may provide a means for addressing safety concerns.

Better crash data on truck/car involvements are needed, according to AAA, to more effectively address issues related to truck safety. Likewise it sees the need to better understand the dimensions of the safety problem caused by splash and spray so as to develop solutions.

AAA notes that in Britain, motorist feedback to its UK affiliates have declined since the adoption of spray suppression regulations in 1986. AAA counterparts in Britain also see a link between the stress of driving through spray and overall driver fatigue, which they view as a major cause of crashes.

The AAA Foundation for Traffic Safety will also be conducting its own research into the splash and spray issue (AAA 1999). The study is tentatively scheduled for completion sometime in 2000.

3.13 ADVOCATES FOR HIGHWAY AND AUTO SAFETY (Advocates) COMMENTARY

Advocates (Donaldson and Advocates 1999) call special attention to the issue of stress during driving and note that the legislative charge to NHTSA in report language accompanying the Fiscal Year 1999 Senate Appropriations bill was specifically "to make travel on the Nation's highways safer and less stressful." Advocates accordingly regards the agency's responsibility to not only review potential countermeasures but also to reduce stress and fearfulness associated with driving near large trucks. Advocates notes that NHTSA has cited on numerous occasions the benefits of reducing the overall stressful character of operating passenger cars, particularly for older drivers. Advocates goes so far as to argue that even if specific crash avoidance splash and spray countermeasures do not demonstrate substantial effects, reinforcing the confidence of drivers can redound to the benefit of highway and traffic safety.

Advocates regards the splash and spray problem as a systems engineering issue requiring attention not only to vehicle spray suppression devices but to road surface and windshield wiper improvements. The Federal Motor Vehicle Safety Standard No. 104 for windshield wiping systems is regarded by Advocates as currently inadequate.

Advocates recommends that NHTSA address the splash and spray problem by means of a multi-factorial approach including heavy vehicle spray suppression, revision of FMVSS 104, and cooperation with FHWA to guide states on use of pavement materials that provide reduced splash and spray.

3.14 TRUCK TRAILER MANUFACTURERS ASSOCIATION COMMENTARY

Mr. Donald Vierimaa (Vierimaa 1999) on behalf of the Truck Trailer Manufacturers Association (TTMA) recommends that the DOT develop a criteria with which to judge splash and spray suppression devices or systems. He suggests that such systems should be capable of (1) reducing spray under typical side winds by some specified amount, (2) operating in mud, tar, ice, and snow conditions, (3) not increasing brake and tire heat buildup, and (4) allowing ease of inspection of tires and brakes.

Mr. Vierimaa also notes vehicle width issues, cost per wheel, and porous road surface treatments as additional factors that should be considered.

3.15 OTHER DOCKET COMMENTARY

Mr. John Becker of Air Fender Systems (Becker and Air-Fender-Systems 1999) claims that its current Air Fender product is effective in all types of conditions and crosswinds. It cites recent testing in 1998 in Quebec as evidence for its claims. Air Fender Systems also claims that a beneficial byproduct of its air flow control around each wheel helps to promote cooling of the tire and wheel assemblies, thereby promoting longer tire life and brake life. Estimated cost for the Air Fender System is $200 per wheel.

Mr. Joseph Szakurski and William Szymczak identify their invention (Szakurski and ZAAK-System 1999), the Anti-Spray Suppression System of Mud Guards and Louvered Panels (also known as the Zaak Truck Spray Control invention), as an effective device for suppressing truck spray. They note an assembled cost of approximately $45 per wheel for their system. Szakurski and Szymczak cite increased highway speeds as a reason for truck spray to become even more hazardous. The Zaak system is being evaluated by local fleets and a portion of PENNDOT in Pennsylvania.

Mr. Daniel Adler of Aurora, CO (Adler 1999) replied to the docket to notify NHTSA and others that a patent of his for a spray suppression device is currently under review. His device is available for review upon completion of the patent application.

Mr. Don Watson (Watson 1999) of Forest Park, GA calls attention to the Georgia Department of Transportation's use of a porous asphalt mix that facilitates water drainage on the pavement as another method to help reduce splash and spray.
Mr. Watson cites an article (Watson et al. 1993) in the Transportation Research Record No. 1616 titled "Asphalt Pavement Construction and Surface Mixtures" as a source of more detail.

Mr. Kenneth Fahy (Fahy 1999) of Greenbrae, CA cites his own harrowing experiences during 59 years of driving as reasons for regulations to prevent mud and water from being splashed by trucks and trailers on the windshields of passenger cars. Mr. Fahy requests that priority be given to legislation supporting the requirement for heavy vehicle splash and spray suppression.

3.16 MISCELLANEOUS ISSUES

3.16.1 Higher Speeds and Traffic Densities

Highway speeds and traffic densities have generally increased over the last five years or so (NHTSA/FHWA/DOT 1998; US-DOT 1997). Increased speeds may largely be a result of higher speed limits. Vehicle miles are also being recorded at a faster rate than new road construction. This combination further increases the likelihood for splash and spray encounters between heavy trucks and passenger cars as well as the intensity of the spray, since studies have shown that truck spray intensity increases more or less linearly with travel speed.

3.16.2 Crosswinds

Crosswinds are commonly cited as a primary factor in diminishing the effectiveness of spray suppression devices. This is normally because the presence of a crosswind above 8 mph or so can cause the trailing spray cloud behind a truck to be shifted laterally downwind and thereby be increasingly concentrated into an adjacent passing lane. However, crosswinds also assist vehicles traveling in upwind locations relative to a truck. Winds appear to have little effect on spray suppression devices under headwind or tailwind scenarios.

3.16.3 Potential Ice Build-Up

Ice build-up in northern climates may be a problem for certain types of spray suppression devices. The associated concern is that ice can negate the effectiveness of certain devices or cause breakage of certain components to occur, such as mud flaps. It is not generally clear how to determine whether or not a particular device is more prone to ice build-up, without testing or a history of usage in cold climates.

3.16.4 Mud flaps

Mud flaps, including the spray suppressant variety, seem to show limited benefit when used by themselves for suppressing spray. Some companies which offer spray suppressant mud flaps also offer side valances in conjunction with the mud flaps as part of a more complete spray suppression and containment system. Since much of the spray problem emanates from the wheel water exhausting sideways out of the wheel areas into adjacent lanes, spray suppression devices focusing on lateral containment of water spray seem to provide more benefit. Streamlining of the vehicle shape also seems to assist in this lateral containment by providing an altered aerodynamic “bow wave” and reduced low pressure profile along the side of the vehicle. Even use of side valances on the tractor front wheels, in conjunction with fenders on remaining vehicle wheels, showed notable improvement in spray reduction performance, as demonstrated in the recent Laval University tests.

3.16.5 Pavement Material

Porous asphalt mixtures or other pavement materials that facilitate water drainage are noted as potential benefit to the splash and spray problem. As transportation agencies gain more experience with such materials in road construction, the practice of utilizing new pavement materials may gain increased usage over time.

3.16.6 Potential Brake and Tire Heat Build-Up

Previous testing has shown this to be a potential problem. This is a reason to evaluate the total vehicle equipped with spray suppression devices. One reference, Dumas, et al. (1998) describes testing of the Air-Fenders system and states in the conclusion that the issue of overheating and wear of brakes, tires, and exhaust still remains to be studied.

3.17 EXAMPLES OF EXISTING LEGISLATION ADDRESSING SPLASH AND SPRAY SUPPRESSION

The next three subsections contain sample language from statutes currently in force in Europe and certain U.S. states pertaining to splash and spray reduction.

3.17.1 EEC Directive (Mandatory fitment in Great Britain, Spain, Northern Ireland, and France; Voluntary fitment in remaining EEC countries or superceded by an alternate national standard.)

The EUROPEAN EEC Directive (91/226/EEC) enacted in 1991 provides for the type approval of candidate splash and spray devices for use on heavy vehicles in Europe through successful completion of a specified laboratory test procedure. This Directive has been effectively phased in over time with some EEC countries adopting it as mandatory and the remainder accepting type approved devices as optionally installed equipment. Example wording taken from the lengthy and comprehensive legislation states:

“COUNCIL DIRECTIVE of 27 March 1991 on the approximation of the laws of the Member States relating to the spray-suppression systems of certain categories of motor vehicles and their trailers (91/226/EEC)

“Whereas, with a view to improving road safety, it is important that all commercial vehicles in higher weight categories and with a certain minimum design speed should be equipped with efficient spray-suppression systems in order to retain water;

“Whereas it is desirable to establish a single performance test for systems of this type on fitting to the various types of vehicles as a means of markedly improving the situation;

“Whereas for the EEC component type-approval of devices of this type account has been taken of the two types of devices currently on the marked, i.e. the energy-absorption type and the air/water separator type; whereas it has been necessary to provide for two different tests depending on the type of device to be approved;

“Whereas, in the light of the studies, research and tests currently in progress, a performance test on the types of vehicles fitted with these devices will be established as soon as possible;

“Whereas Member States should pay attention to the fact that the formation of spray depends also on the characteristics of the road surface, the tyre-tread configuration and the speed and aerodynamic characteristics of the vehicle;

“HAS ADOPTED THIS DIRECTIVE: Article 1 1. Member States shall grant EEC component type-approval for any type of device, hereinafter referred to as 'spray-suppression device', intended to reduce the projection of spray from tyres of moving vehicles, if it satisfies the requirements regarding design and testing set out in Annex II and taking into account the definitions given in Annex I.

“2. A Member State which has granted EEC component type-approval shall take the measures required to verify, in so far as is necessary and, if need be, in cooperation with the competent authorities of the other Member States, that production models conform to the approved type. For this purpose the Member State shall apply the requirements of Annex IV. “

3.17.2 STATE OF FLORIDA LEGISLATION

Section 316.252 of the Florida Motor Vehicle legislation addresses splash and spray suppressant devices as follows:

“(1) No person shall drive or operate, or cause to be driven or operated, any truck of gross vehicle weight of 26,000 pounds or more, any truck tractor, or any trailer or semitrailer the net weight of which is 2,000 pounds or more unless such vehicle is equipped with fenders, covers, or other splash and spray suppressant devices, such as substantial flexible flaps on the rearmost wheels of such vehicle or combination of vehicles, which will effectively prevent or minimize the splash or spray of water or mud and the throwing of other materials on the windshields of following vehicles. The provisions of this section shall not apply to vehicles used exclusively for the purpose of producing, processing, or transporting agricultural products, including horticultural products or forestry products.

“(2) The Department of Transportation shall adopt rules necessary for the implementation of this section.”

To learn about Florida’s experience under this law, NHTSA contacted Captain Ken Carr in the Florida Department of Transportation’s Motor Carrier Compliance Office. Captain Carr reported that no rules were ever adopted in Florida to implement section 316.252. According to Captain Carr, the effort was dropped because it was too complicated for Florida to develop criteria for spray suppression devices that “effectively prevent or minimize” spray. Florida has no experience to report regarding spray suppression devices and are not aware of any studies about the effectiveness of these devices.

3.17.3 OTHER STATE LEGISLATION ON MUD FLAPS AND SPRAY SUPPRESSION

In general, most mud flap and spray suppressant language that appears in state motor vehicle codes is usually applicable only to large combination vehicles operating on turnpikes or similar restricted access highways. (There is no Federal requirement for mud flaps.) Examples include:

OKLAHOMA— requires "mud flaps and splash guards" for long combination vehicles operating on certain restricted interstate highways.

OHIO — requires that "double and triple trailer combinations must be equipped with adequate, properly maintained spray-suppressant mud flaps on all axles except the steering axle." Such vehicles are restricted to turnpike usage in Ohio.

KANSAS— "Antispray mud flaps shall be attached to the rear of each axle except the steering axle. Mud flaps shall have a surface designed to absorb and deflect excess moisture to the road surface." Applicable only to large combination vehicles operating on the turnpike and turnpike access routes.

INDIANA — "Three trailing unit combinations must be equipped with adequate spray-suppressant mud flaps which are properly maintained." Turnpike access only.

MISSOURI — Chapter 307, Section 307.015 pertaining to "Certain motor vehicles, mud-flaps required – violation, penalty" addresses mud flap requirements by:
1. "Trucks, semitrailers, and trailers, except utility trailers, without rear fenders, attached to a commercial motor vehicle registered for over twenty-four thousand pounds shall be equipped with mud flaps for the rear wheels when operated on the public highways of this state." (continues)

MICHIGAN — The Michigan Truck Safety Commission states that relative to Anti-Splash Devices (Mud Flaps), "A commercial vehicle, except a truck tractor traversing between terminals at a speed not to exceed 25 miles per hour, and a combination of a commercial vehicle and trailer or semitrailer, when used on a highway, shall be so constructed or equipped, as to prevent water or other road surface substances from being thrown from the rear wheel of the vehicle or combination at tangents exceeding 22.5 degrees measured from the road surface."

CHAPTER 4 OBSERVATIONS

- The general area of heavy truck splash and spray has not been addressed in a coordinated and systematic manner by any large-scale research program for about ten years. Nevertheless, recent activity on the subject has included a few small studies undertaken by such agencies as the Quebec Department of Transport in 1998, certain EEC attempts at developing a test procedure applicable to whole vehicles, the Recommended Practice on Splash and Spray published in 1994 by the SAE, and various small research studies performed by individual manufacturers and inventors.
- While splash and spray encounters are fairly infrequent for most drivers, when they do occur, the loss, or reduction of visibility/vision to any driver can be highly threatening, posing a potential safety problem during such encounters.
- As in 1994, it remains true today that insufficient crash record evidence exists to accurately, or even approximately, identify the degree of safety problem that ensues during splash and spray encounters. One reason for the scarcity of crash data may likely be due to an under-reporting of such incidents. It is reasonable to assume under-reporting given the nature of the spray encounter — the vehicle producing the spray and precipitating the crash event drives away unaware of any problem and is not subsequently available for crash investigators to record on standard crash investigation forms. Another reason may be the likely categorization of splash and spray incidents by crash investigators into broader and less specific categories such as "driver-related," "weather-related," or "miscellaneous" — depending on the particular accident form being used to record the crash. Absent a better means for recording and identifying true splash and spray-related crash events, the likelihood of performing meaningful analyses of crash data for splash and spray as a causative factor remains very poor.
- A modest portion of the very small number of reported crash events attributable to splash and spray have occurred in urban areas. These urban pedestrian incidents (off Interstates) are probably less likely to be addressed by most spray reduction measures since their origin appears to be more related to puddles and splash-type scenarios.
- Since many splash and spray encounters can induce nearly total vision incapacitation for varying amounts of time during a passing or following maneuver, devices that achieve even moderate levels of spray suppression would seem to have value, if capable of providing modest additional improvements in driver vision during those severe types of operating conditions.
- The two most effective mechanisms for reduction of truck spray, as provided by both recent and previous test track research projects, appear to be (1) aerodynamic streamlining of vehicle bodies, and (2) side-containment of wheel spray by valances and/or fenders. Reduction of aerodynamic "bow wave" effects and its accompanying low pressure profile along the side of the vehicle helps to reduce the tendency for wheel spray to exhaust laterally from the wheel areas. Accompanying side valances and/or wheel fender devices further help to contain, redirect, and concentrate wheel spray to areas closer inwards towards the truck body centerline and trailing path. Simple spray suppressant mud flaps, by themselves, appear to have limited effect in diminishing the

amount of wheel spray generated sideways into adjacent lanes.

- Higher speeds and traffic densities, as have occurred in recent years in the US, aggravate the splash and spray problem. Previous studies have shown that spray intensity increases more or less linearly with vehicle speed. Further, as more vehicles occupy the available highway space, the likelihood of splash and spray encounters is also increased.
- Crosswinds are commonly noted by previous researchers as a primary factor in diminishing the effectiveness of spray suppression devices. This is usually attributed to the fact that the spray cloud normally surrounding a truck in wet weather becomes shifted laterally to one side or another by the prevailing crosswind, and thereby aggravates visibility for drivers of passenger cars on the downwind side of the truck. However, this same argument does not apply to vehicles traveling on the same stretch of highway in the opposite direction. In fact, the same crosswind condition prevailing for those vehicles helps to clear the passing lane for passenger cars on the upwind side of a truck. Winds blowing along the line of travel or as headwinds have little effect. Consequently, the crosswind argument commonly offered as a reason against spray suppression devices really only applies to perhaps one-fourth or so of all wind-exposed vehicles. Another one-fourth are assisted by a favorable crosswind, and the remaining one-half are largely unaffected.
- Crosswinds can pose a significant condition variable that adds variance to the experimental measurement of splash and spray responses.
- Recent attempts by the European community to develop a full-scale test procedure that goes beyond its current laboratory-based certification process has been disappointing. The EEC research was aimed at developing a full-scale road test procedure that was consistent and repeatable. However, results proved to be inconclusive due primarily to large variations in ambient test conditions. Europe still uses the still air laboratory component test method.
- One observation that is not commonly noted in the overall splash and spray discussion is that many truck drivers themselves can be adversely affected by spray-diminished vision, particularly in their rear-view mirrors. Truck spray can hinder the ability of truck drivers to detect oncoming passenger cars and it may also cloud the mirror surface itself, further aggravating the ability to see towards the rear of the truck during wet weather conditions.

CHAPTER 5 RECOMMENDED ACTION

To repeat the findings in Section S3.2 of this report, there are no data demonstrating a substantial safety problem from splash and spray. Specifically,

- The number of splash/spray crashes is extremely small.
- The existing computerized crash record cannot indicate whether a truck was responsible for the splash/spray.
- It is likely that a number of the few splash/spray fatal crashes did not involve a truck.
- It is unlikely that there is any crash data file with data better than FARS or GES. It is unlikely that any State files can provide meaningful data in this area.

Although the available data in the United States and the rest of the world do not demonstrate a significant safety problem, there continues to be broad interest in finding thoughtful, reliable, cost-effective solutions for reducing splash and spray. Unfortunately, to date, no technology has been demonstrated to be effective on the road. The current EEC tests do not measure performance of vehicles equipped with the spray suppression technology. Efforts to develop a scientific and repeatable measure of spray suppression performance on vehicles to date have not been successful.

The costs required to achieve these uncertain benefits are substantial. According to the company that says it supplies about 70 percent of the European market for spray suppression devices, it would cost about $100 to fit a trailer with its product and more for a truck tractor. In consideration of this, NHTSA has concluded that it should not spend its limited resources to initiate a new round of research on splash and spray suppression. At this time, it appears very unlikely that such new research would allow an agency action that would successfully enhance the safety of the American public.

Both NHTSA and the Federal Motor Carrier Safety Administration will monitor the data and technical developments in the area of splash and spray suppression. If future developments make it appropriate to take further action, our agencies will work together to develop appropriate actions.

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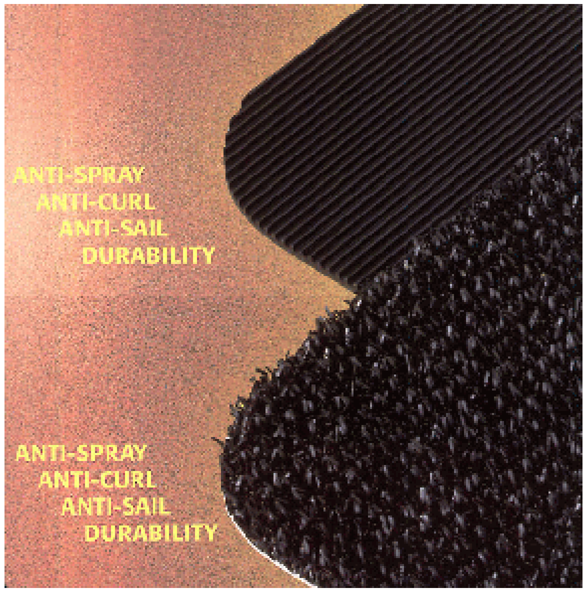
APPENDIX A. PHOTOGRAPHS OF EXAMPLE SPLASH AND SPRAY DEVICES



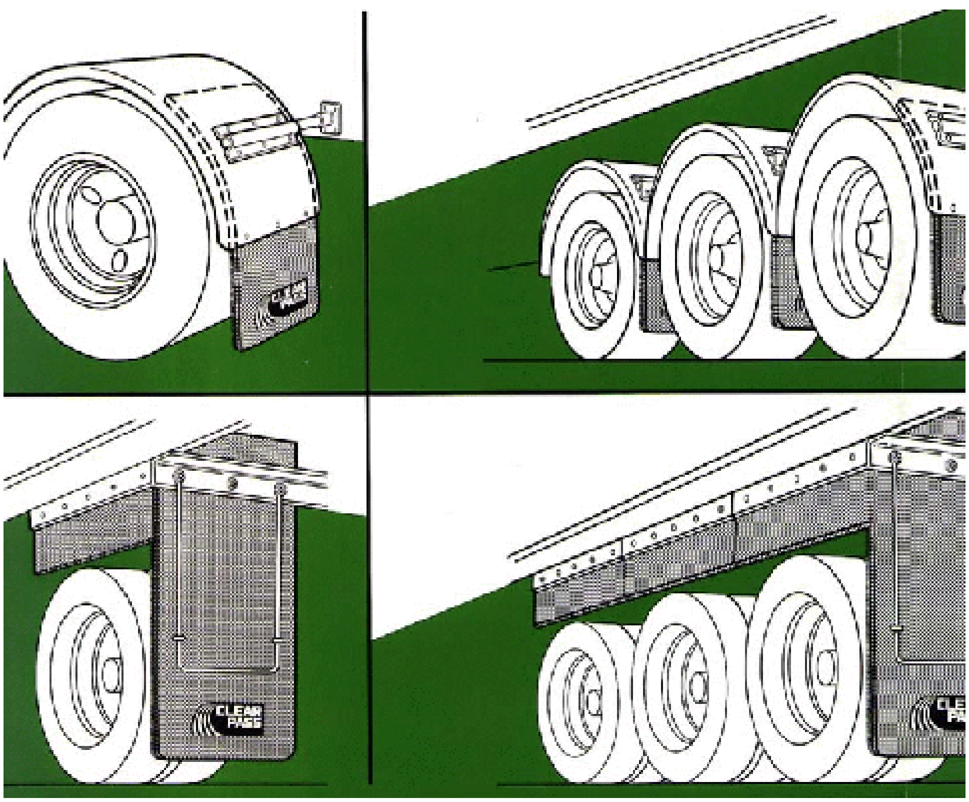


Figure A-1. Solutia (Monsanto) / Symplastics Mud Flap and Spray Suppressant

System.

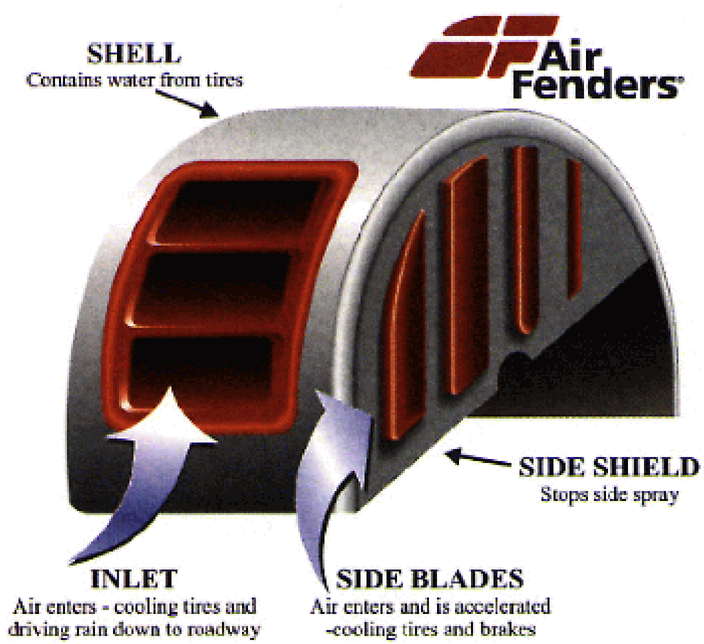


Figure A-2. Air Fender Systems. Example Trailer Mounting and Close-up View of Components (Becker and Air-Fender-Systems 1999).

Figure A-3. Reddaway Side-Valances Mounted on Tractor and Semitrailer (Dumas, Lemay et al. 1998).

Figure A-4. Laval University Test Track and Photo-Diodes Used to Measure Spray Intensity (Dumas, Lemay et al. 1998).

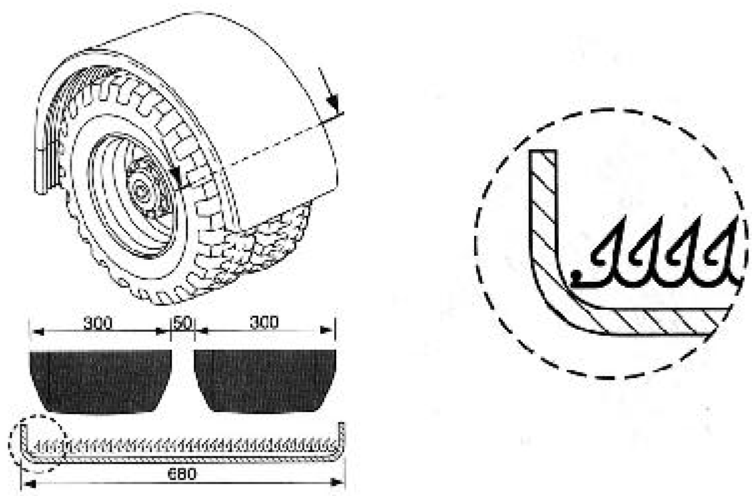


Fig. 9.115 Cross-section of mudguard with grooved section, after H. Götz and R. Schoch [9.40].

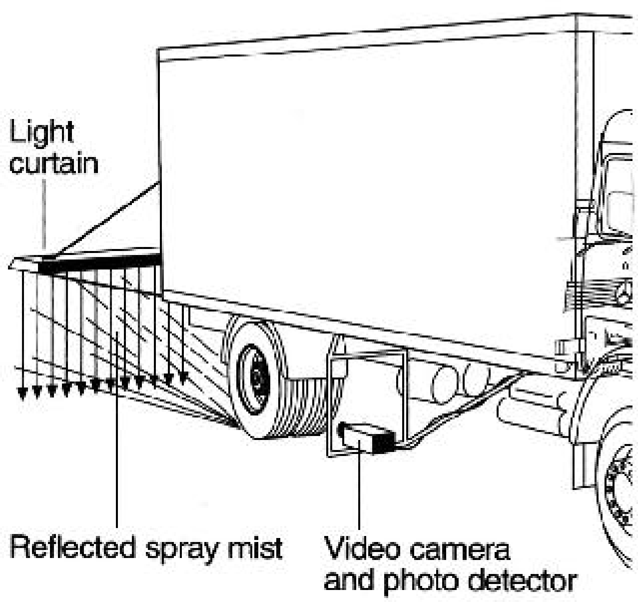


Fig. 9.116 Test setup on commercial vehicle, after H. Götz and R. Schoch [9.40].

Figure A-5. Mercedes-Benz Grooved Fender Design and "Light Curtain" Spray Measurement System Mounted Onboard of Test Truck (Geotz and Schoch 1995; Hucho 1998).

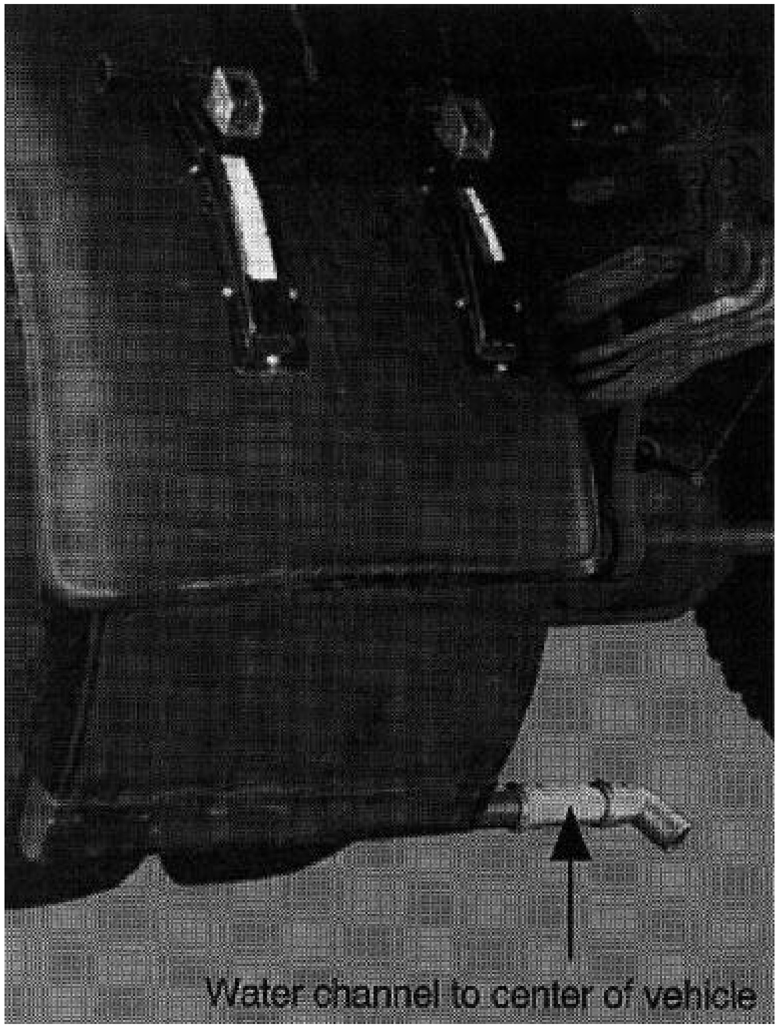


Figure A-6. Mercedes-Benz Water Collection Device Used to Channel Water Collected by Grooved Fender Design Towards Center of Vehicle and Away from Wheel Areas (Geotz and Schoch 1995; Hucho 1998).

APPENDIX B . ILLUSTRATION OF THE ECE LABORATORY TEST FOR SPRAY SUPPRESSION DEVICE SAMPLES

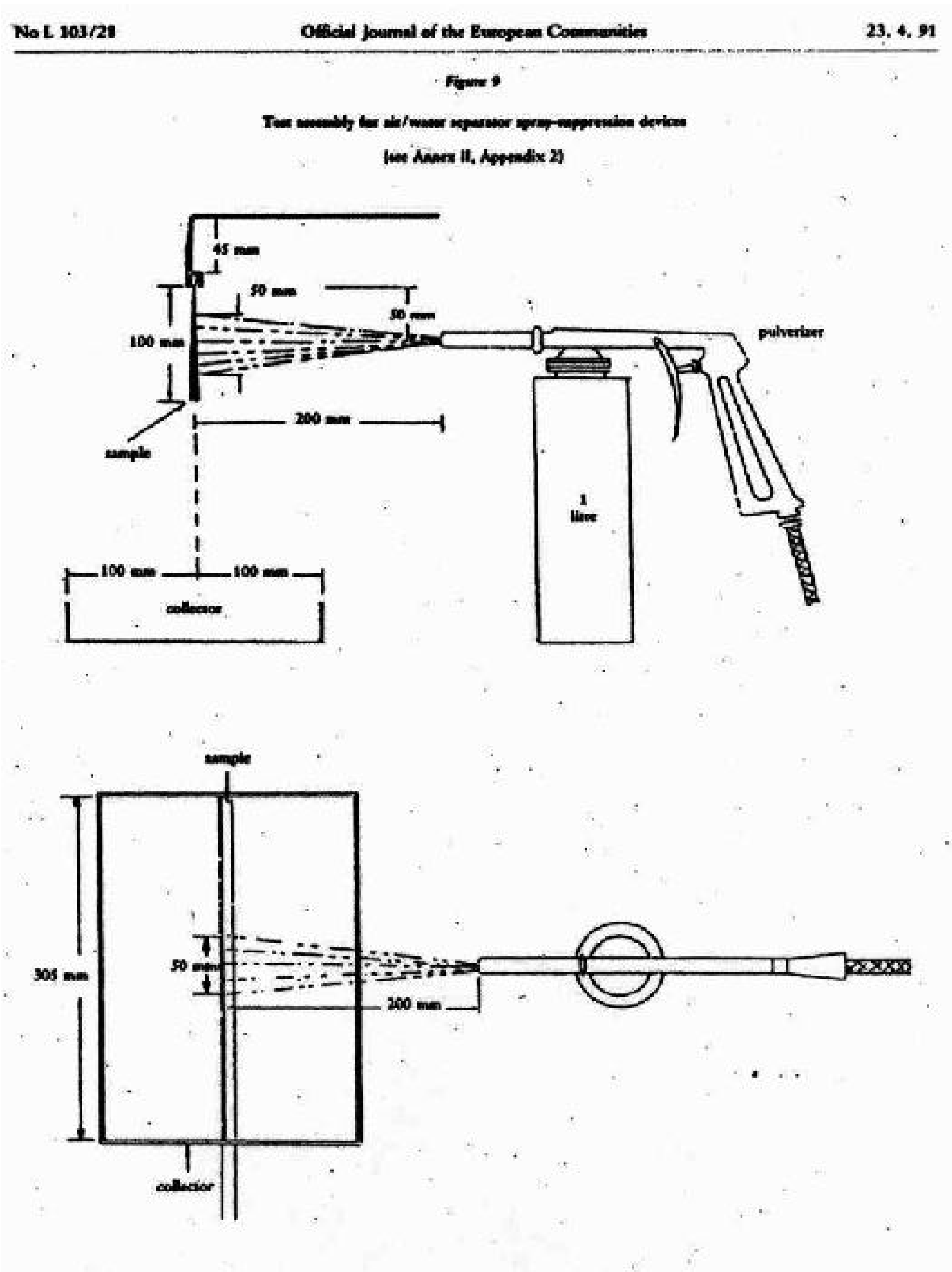

No L 103/28 Official Journal of the European Communities 23. 4. 91

Figure 9

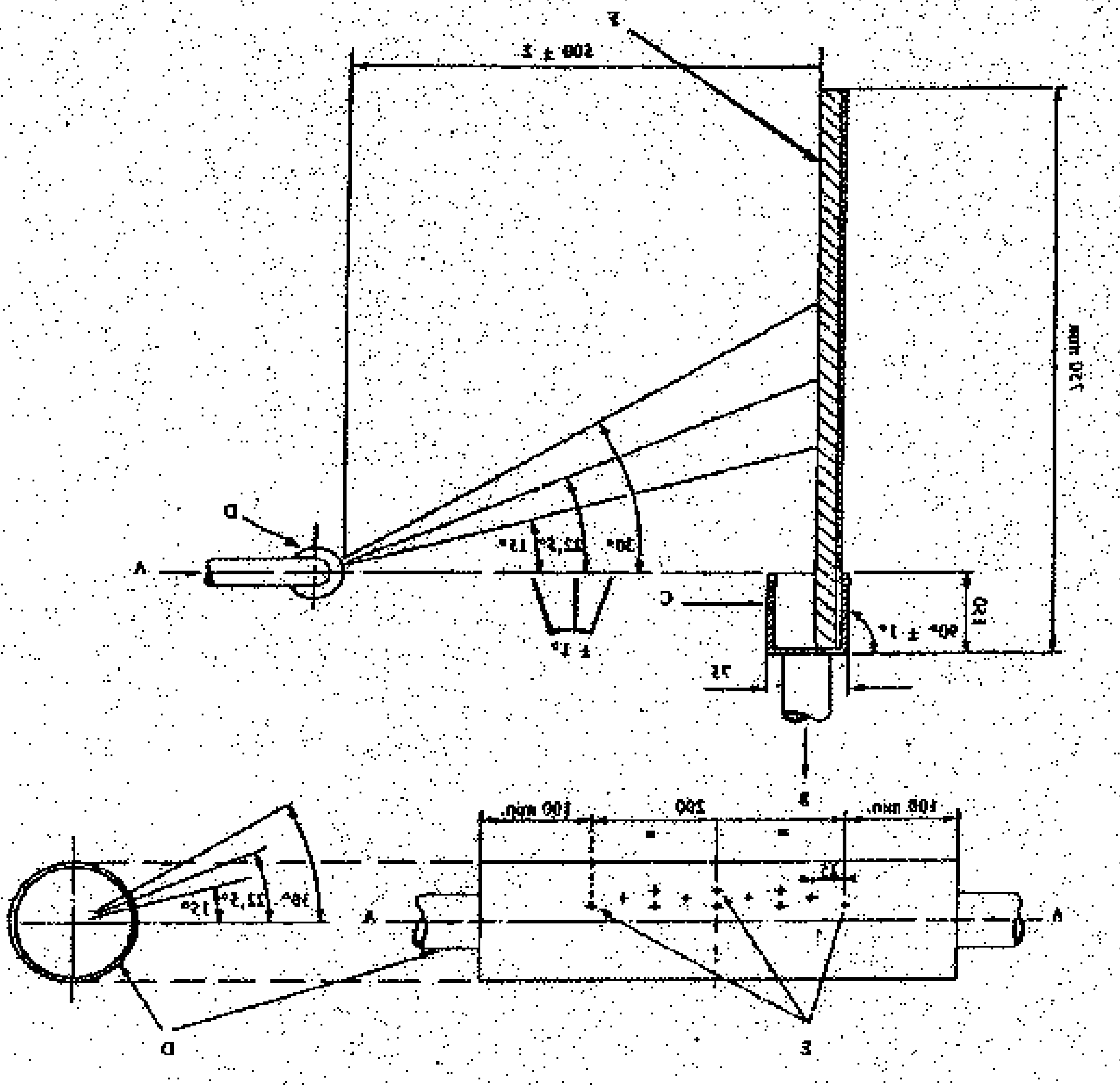
Test assembly for air/water separator spray-suppression devices

(see Annex II, Appendix 2)

Figure 4

Test assembly for energy absorption spray-suppression devices

(See Annex II, Appendix 1)



Note: A = water supply from pump.
B = flow towards collector tank.
C = collector with inside dimension of 500 (+5/−0) mm length and 75 (+2/−0) mm width.
D = thin-wall, 54 mm diameter pipe.
E = 12 holes drilled radially as shown, diameter 1,68 (+0,025/−0) mm.
F = 500 (+0; −5) mm-wide sample to be tested.

All linear dimensions are shown in millimetres.

NOTE: APPENDIX C (Pages 42-43 can be obtained from Docket No. NHTSA -99-5101