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SURFACE VEHICLE RECOMMENDED PRACTICE

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RECOMMENDED PRACTICE FOR SPLASH AND SPRAY EVALUATION

Foreword—This Document has not changed other than to put it into the new SAE Technical Standards Board Format.

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1. Scope—This SAE Recommended Practice provides general guidelines for measuring the splash and spray produced by vehicles operating over wet pavements. The guidelines describe both the video digitizing and the laser methods of analysis. The video-digitizing method uses video images and contrast measurements between black and white checkerboards when a spray cloud is superimposed on them as a means of measuring the obscuring spray. The laser method uses laser transmittance through the spray cloud as the means of measurement. It is left to the users of this practice to decide which method is best suited to their needs. There is no implied relationship between these two methods, although it is expected that the ranking of relative spray reduction between test vehicle configurations would be approximately the same. All sections listed in this document are to be considered as common to both methods, unless otherwise noted.

There are complex interactions of variables that affect splash and spray, and by its nature, it is a very chaotic, turbulent phenomenon. This document attempts to address these variables as completely as they are understood at this time. Until they are better understood, it is necessary to limit this recommended test procedure to the following conditions:

a. It only applies to "A-B" comparisons done under the "same" conditions as outlined in the test procedure.
b. Tests done at different sites may not necessarily be comparable, depending on the exact conditions and specific site locations at the time of the tests.
c. Because uncontrollable variables such as wind speed and direction, water depth, humidity, and temperature can have a profound effect on measured results, small differences (on the order of 10 to 15%) in measured splash and spray may not be meaningful and the relevance of such small measured differences should be viewed with caution.
d. Results from the testing should be reported as the difference between the 95% confidence bands and not as the differences between averages.
e. Each configuration tested shall have a separate value with 95% confidence bands reported for each of eight wind conditions using the downwind rule, as outlined in the data reduction.

This shall ensure that the variability of each wind condition is accounted for with the 95% confidence bands and compared as separate data sets. The results shall in no way be misrepresented as absolute numbers.

2. *References*

2.1 Applicable Publications—The following publications form a part of the specification to the extent specified herein. Unless otherwise indicated the latest revision of SAE publications shall apply.

2.1.1 ASTM PUBLICATIONS—Available from ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

ASTM E 501-88—Specification for Standard Tire for Pavement Skid Resistance Tests
ASTM E 524-88—Specification for Smooth Tread Standard Tire for Special-Purpose Pavement Skid Resistance Tests

3. Test Vehicles—This test procedure compares vehicle configurations under the "same" conditions. The comparison is most accurate if the test vehicles are essentially identical except for the splash and spray treatments under evaluation. Each test vehicle used for evaluating splash and spray shall be full-scale, in a configuration that is commonly operated on the highway (e.g., a loaded tractor-trailer combination). Certain specifics should be noted about each vehicle's configuration to allow meaningful comparisons (see Figure 1 for the vehicle data sheet). Photographs of the side and front view of the vehicle are required. Additional detailed photographs of any splash and spray reduction devices should be included. It is recommended that tires have full-thread depth and be inflated to the manufacturer's recommended cold inflation.

Treatment (or combinations of treatments) for reducing splash and spray should be very specifically noted and supported by photographs. Layout and installation details of the treatment are very critical to ensure that the treatment can be meaningfully compared with others.

4. *Test Site*

4.1 General Location and Layout—Evaluating splash and spray on heavy trucks requires a large area closed to other traffic, sufficient uprange distance to bring the test vehicle to a steady velocity in advance of the test section, and sufficient downrange distance to brake the test vehicle safely. Maneuvering space is also necessary to ready the test vehicle for successive runs through the test section. All surfaces on which the test vehicle will operate should be smooth highway surfaces at minimum grades in order to meet the criterion of reaching test velocity in advance of the test section. Direction of travel through the test section should be oriented as close as possible to 90 degrees from the prevailing winds so that crosswinds predominate during testing. If possible, the test layout should be bi-directional so that a test vehicle may be run in opposite directions on successive runs. This layout permits relative wind direction to be varied by 180 degrees on the same test day.

4.2 Test Section—The recommended test section consists of an asphaltic concrete surface with a clear path 3.66 m wide by 121.92 m long (12 ft wide by 400 ft long). The asphalt texture should vary as little as possible with an average depth of 0.08 cm (0.030 in) and have a rib tire skid number of approximately 65 and smooth tire skid number of approximately 20, as measured according to ASTM E 501-88 and ASTM E 524-88, respectively..

A cross slope of 1% in the test section is recommended for even water runoff. Slope in the direction of travel of the test vehicle should be less than the cross slope to ensure water flow across the direction of travel.

Approach lanes for vehicle run-up and braking shall connect with the test section so as to provide minimum discontinuity, through the use of suitable ramping.

Configuration: ______________________ Dates: ______________ to ______________

TRACTOR
Make/Model/Year ______________________ VIN ______________________
No. of Axles __________ Wheelbase (cm) (in) __________ 5th Wheel Location (cm) (in) __________
Sleeper Style/Size
Tires: Size/Type/Make/Model ______________________
Aerodynamic/Spray Reduction Treatments ______________________

TRAILER
Make/Model/Year/VIN ______________________ Type ______________________
Type of Side ______________________ Type of Corner ______________________
Height (cm) (in) __________ Length (cm) (in) __________ No. of Axles __________ GVW (kg) (lb) __________
Cab to Trailer Gap (cm) (in) ______________ Side Fairing to Trailer (cm) (in) ______________
Trailer to Trailer Gap (cm) (in) ______________ / ______________
Tires: Size/Type/Make/Model ______________________
Aerodynamic/Spray Reduction Treatments ______________________

Inflation Pressure (cold) (psi) (kPa) / Tread Depth (cm) (in):

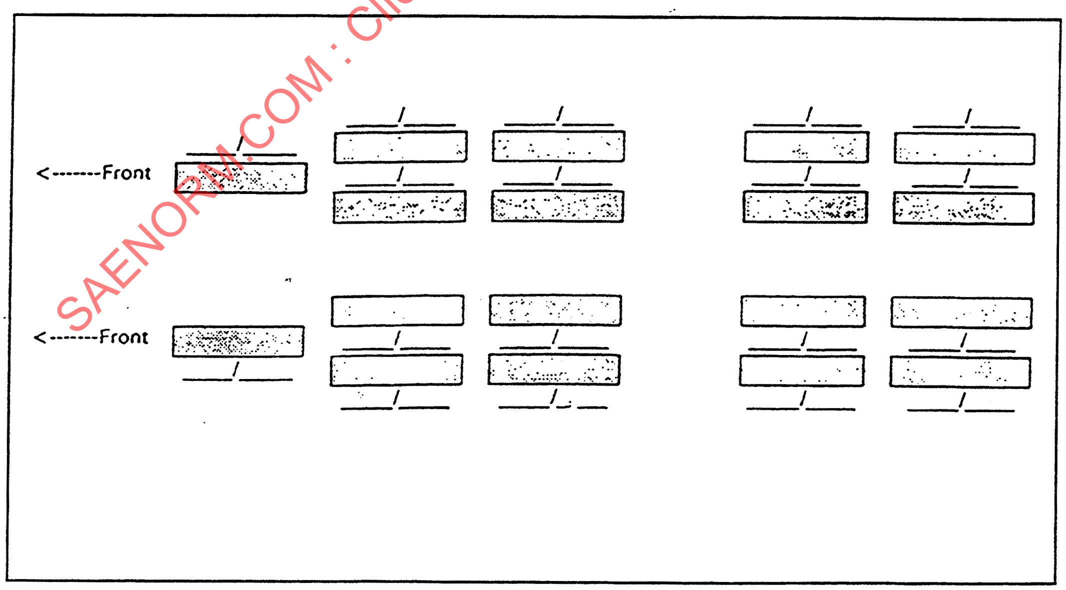

FIGURE 1—VEHICLE DATA SHEET

Side view of truck.

Front view of truck.

FIGURE 1—VEHICLE DATA SHEET (CONTINUED)

Splash and spray reduction devices on a tractor.

Splash and spray reduction devices on a trailer.

FIGURE 1—VEHICLE DATA SHEET (CONTINUED)

4.2.1 DIGITIZING METHOD—The cameras shall be located approximately 60.96 m (200 ft) from the checkerboards. The anemometer shall be located approximately 25.91 m (85 ft) from the checkerboards, 5.49 m (18 ft) from the centerline of the test section, and centered on either checkerboard. The first electronic eye used to trigger the camera for the control image shall be located 24.38 m (80 ft) before the cameras (or 85.34 m (280 ft) before the checkerboards). The second electronic eye shall be located 10.67 m (35 ft) before the checkerboards and outside of the field of vision of the cameras. A rectangular section of pavement 3.66 m (12 ft) to the sides of each checkerboard and 7.32 m (24 ft) in front of the checkerboards shall be painted with a flat black paint in order to reduce variability from reflected light. The checkerboards shall be located 3.35 m (11 ft) apart and 1.68 m (5.5 ft) from the centerline of the track. See Figure 2 for details.

4.2.2 LASER METHOD—The laser and sensor shall be separated by at least the length of the longest vehicle which will be evaluated in the test section, or a minimum of 15.24 m (50 ft). The four installations shall be located with respect to the vehicle path as shown in Figures 3 and 4. The four beams are located parallel to the vehicle path such that the splash and spray cloud is interposed between the laser and its respective sensor. The four beams are situated above the plane of the test section at a height which approximates the AASHTO Design Driver Eye Height of 106.7 cm (3.5 ft).

4.3 Water Supply and Distribution

4.3.1 SUPPLY—The test section shall be provided with a steady source of fresh water. Up to 189 271 L (50 000 gal) may be necessary for a test day, with flow rates of approximately 189 L/min (50 gal/min). The water supply shall be regulated to maintain an even flow of ±18.9 L/min (±5 gal/min).

4.3.2 DISTRIBUTION—The test section shall be provided with a water-distribution system capable of applying an even layer of free-flowing water on the pavement. Any system of sprinklers, irrigation pipe, or other water-distribution device that can place the water on the surface may be used. The water-distribution system shall deposit water on the surface such that:

a. No splash or stream impinges upon the vehicle path through the test section, but rather, the vehicle encounters a wet pavement, exclusively.
b. The depth of water is between 0.05 cm (0.02 in) and 0.13 cm (0.05 in), as measured at a minimum of six randomly selected locations in the vehicle path on the 121.9 m (400 ft) test section.

5. Test Instrumentation

5.1 Splash and Spray Measurement

5.1.1 DIGITIZING METHOD

5.1.1.1 *Cameras and Lenses*—Two cameras and matching lenses are needed. The cameras should be high-resolution, black and white, with a zoom lens capable of fitting a 2.44 x 3.66 m (8 x 12 ft) image—full screen—at 60.96 m (200 ft). It is preferable to have remote contrast and zoom adjustments so that the cameras can be adjusted while monitoring the computer and framegrabbers.

5.1.1.2 *Framegrabbers*—Two framegrabbers are needed to allow simultaneous grabbing of an image from both cameras. To reduce costs, the framegrabbers should be able to operate while plugged into the same computer. There should be enough memory on board for the framegrabbers to acquire and store at least five images apiece in real-time video speed (30 frames per second). The framegrabbers should be capable of measuring a pixel intensity (or gray scale) of 256 (an illumination scale of 0 to 255 is common). Efficient handling of the large files generated requires, at a minimum, a 386 computer with a math coprocessor and 200 MB hard disc. A 150 MB tape backup is recommended to store digitized test images for later reference and analysis.

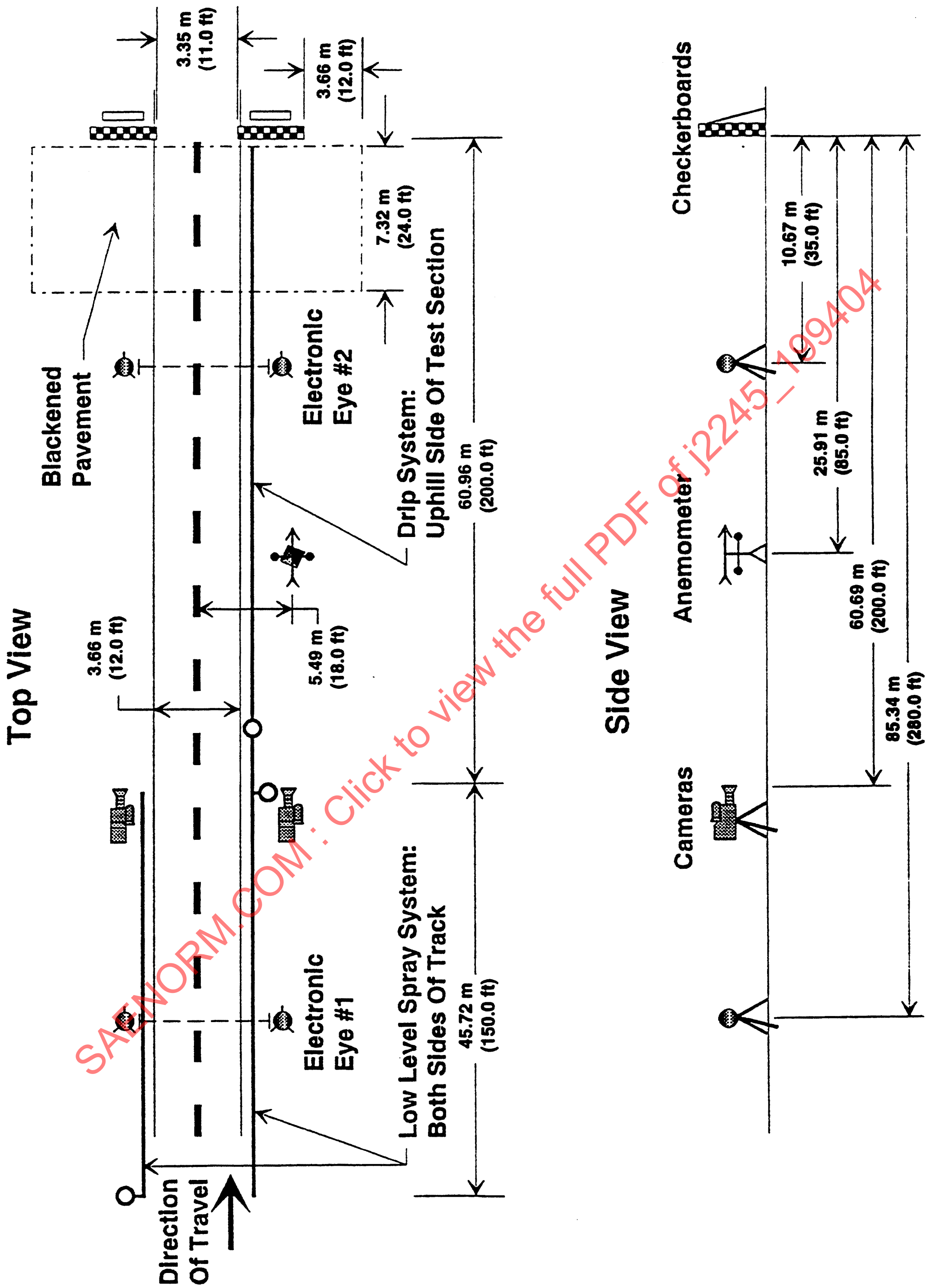

FIGURE 2—TEST SECTION LAYOUT—DIGITIZING METHOD

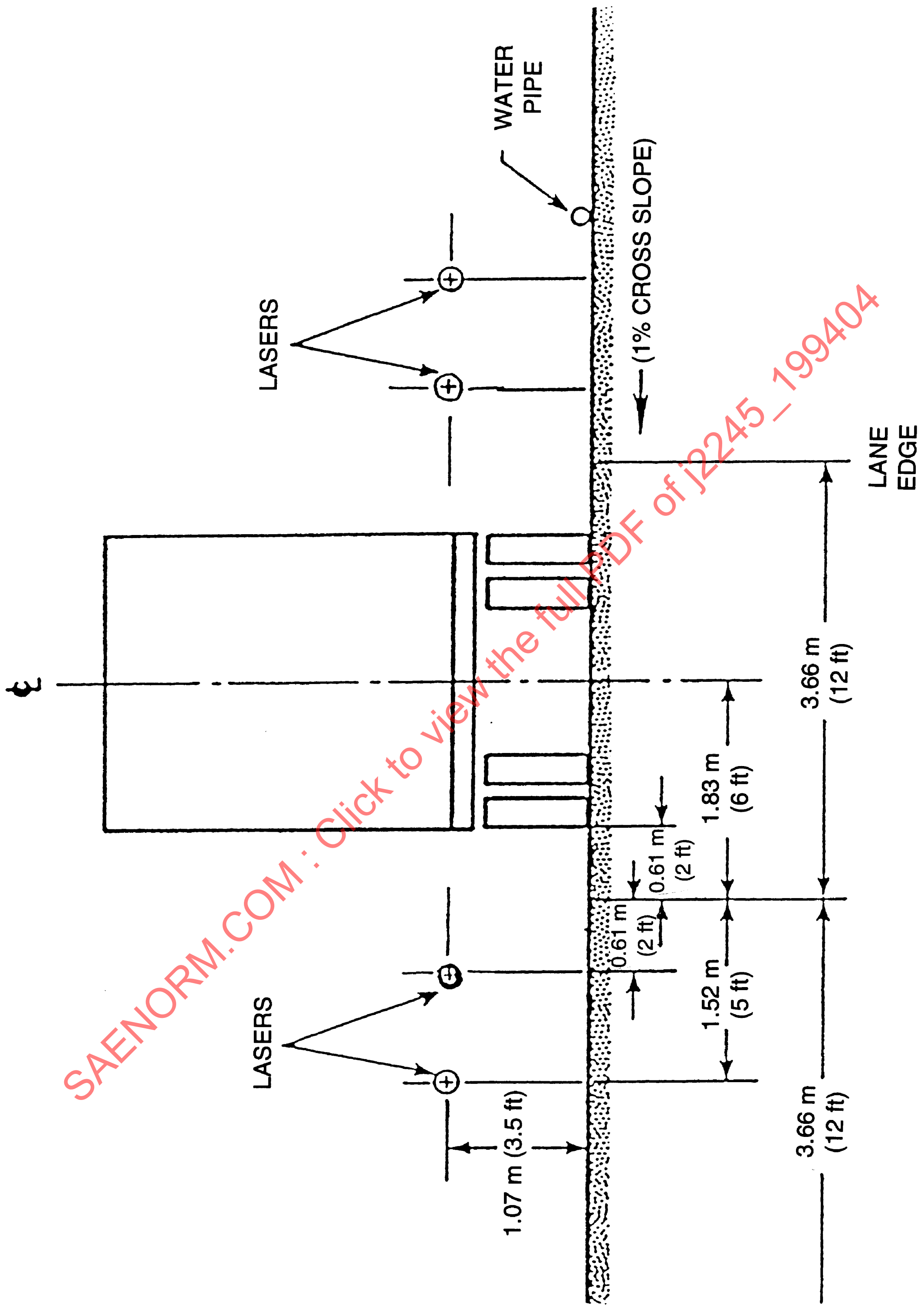

FIGURE 3—LATERAL PLACEMENT OF LASERS WITH RESPECT TO TEST VEHICLE

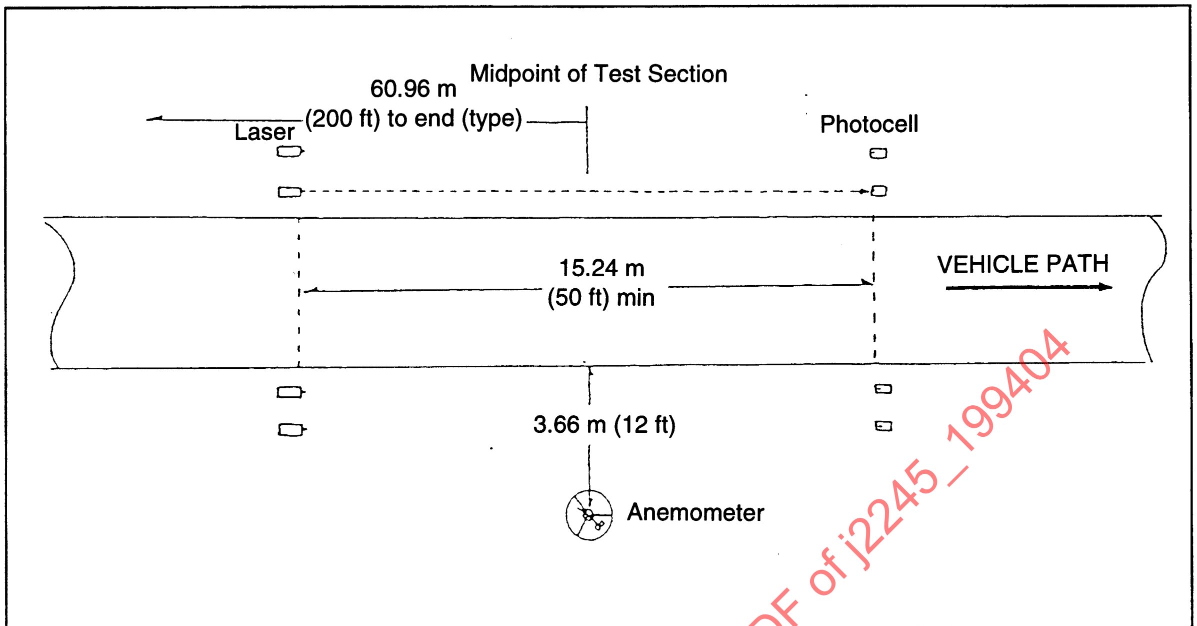

FIGURE 4—ANEMOMETER SET LOCATION

5.1.1.3 *Checkerboards*—Each checkerboard, 3.66 m (12 ft) wide and nominally 2.44 m (8 ft) tall, must be divided into black and white squares measuring 0.3 m (1 ft) across and at least 0.3 m (1 ft) high. The aspect ratio of common framegrabbers typically is not perfectly square. If this is the case, then the checkerboard can be expanded in the vertical direction to match the aspect ratio, but the checkerboard shall remain 3.66 m (12 ft) wide in all cases. It is critical to match the aspect ratio of the pixels in the framegrabber because the computer will divide the checkerboard into distinct black and white regions, and a pixel cannot overlap two different regions or else the contrast measurements will be inaccurate.[1] The upper left-hand square is to be white.

5.1.2 LASER METHOD—Measured light transmission through the spray cloud shall comprise the primary data for evaluation. Any type of laser beam may be used to excite a photoelectric sensor, the voltage output of which is used to indicate light transmission. The laser devices shall either incorporate an internal regulated power supply or shall be powered by a regulated external power supply to assure a steady level of power in the laser beam. For safety, it is recommended that the power of the beam not exceed 5 mW/cm2. Four such laser and sensor combinations shall be used to measure splash and spray.

Each photoelectric cell excited by a laser beam shall incorporate a simple convex lens of a diameter equal to or larger than the patch of light produced by the laser at the specified distance from the photoelectric cell. The lens shall be positioned at a distance equivalent to its focal length in front of the photocell in the path of the beam such as to focus the laser beam on the surface of the photoelectric cell. A nominal focal length would be 4 diopters.

Output from each photoelectric cell shall be filtered electronically before recording. The filter shall eliminate any frequency above 5 Hz and shall be at least fourth order in its response characteristics. This eliminates any transients or spurious data produced by large droplets of water, which have a negligible effect on visibility.

1. It should be noted that results reported from differently dimensioned checkerboards may not be comparable for a given spray cloud since the calculations are based on the percent of the entire board that is obscured

The laser transmissometers shall incorporate a provision to completely occlude laser-beam impingement on the photoelectric cells in order to effect calibration. Linearity of photoelectric cell output shall be evaluated by interposing photographic neutral density filters in the laser beam and comparing the filter ratings with the light transmission measured by the photoelectric cell. Complete occlusion of the beam = 0% transmission; unobstructed transmission = 100%.

Laser devices and photocells should be mounted in water-resistant housings and shall be rigidly installed at the test section such that vibration and wind gusts from the test vehicle or prevailing winds do not affect measurements.

The voltage output from the photoelectric cells shall be recorded at a sample rate of at least 25/s, with a resolution of at least 1 part in 100.

5.2 Wind Measurement

5.2.1 DIGITIZING METHOD—Wind direction and speed must be measured simultaneously when the truck passes the first electronic eye before the cameras. This ensures that the measurement will not be affected by the airflow around the truck when it passes the anemometer. The wind vane shall be located 25.91 m (85 ft) from the checkerboards. This is about the middle of the truck and trailer when the first test image is taken but still far enough away from the checkerboards to minimize the wind from being blocked by them. The anemometer should also be located about the center-height of the checkerboards to ensure that the measurement is representative of the ground winds that are affecting the shape of the spray cloud. Any anemometer set can be used that measures wind speed from 0 to 32.19 km/h (0 to 20 mph) and wind direction within ±1 degree.

5.2.2 LASER METHOD—Wind velocity and direction with respect to the path of the vehicle shall be continuously measured during a test vehicle pass through the test section. Any anemometer set may be used that can measure wind speed from 0 to 32.19 km/h (0 to 20 mph) and wind direction within ±1 degree. Output from the anemometer set shall be recorded at a sample rate of at least 25/s compatible and synchronized with laser transmissometer readings such that a given observation of laser transmission can be associated with the wind velocity and direction prevailing at the same time. The anemometer set shall be located as shown in Figure 4.

5.3 Humidity and Temperature Measurement—Humidity and air temperature should be monitored during the testing from a housing that is suitably protected from the sun and rain.

5.4 Water Depth Measurement—Water depth may be measured with a precision scale, a capillary wetting device, or by electronic or optical methods designed to measure with an accuracy consistent with the requirements of 4.3.2.

5.5 Test Vehicle Velocity Measurement—The test vehicle velocity may be measured by a calibrated speedometer in the vehicle, a vehicle-sensing device mounted just uprange of the laser transmissometers, or by a radar speed sensor. The use of a trailing fifth wheel is prohibited since splash and spray generation could be affected.

6. Test Procedure

6.1 General Procedure

6.1.1 DIGITIZING METHOD—The general test procedure is to acquire a control image from both left and right checkerboards prior to the truck passing in front of the cameras. This represents the baseline ambient conditions. Then the framegrabbers acquire four test images from both the left and right sides, with the spray cloud obscuring the checkerboards. The contrast of the baseline or control image is then compared to each of the test images to measure the amount of contrast that has been lost because of the obscuring spray cloud.

6.1.2 LASER METHOD—The general test procedure is to drive the truck through the test section, recording the laser output. The lowest reading from all four lasers is recorded as the raw data. These readings are then used to calculate the percent transmittance.

6.2 Test Plan—The test plan shall identify each of the test vehicle treatments to be evaluated, the speed at which the evaluations are to be run, and the number of runs planned for each of eight combinations of wind conditions, as shown in Table 1.

TABLE 1—SAMPLE TEST PLAN

Wind Condition	Wind Speed	Wind Direction	No. Runs
1	Low: 0 to 4.83 km/h (0 to 3 mph)	Head Wind: 350 to 10 degrees	8
2	Low	Tail Wind: 170 to 190 degrees	8
3	Low	Left Crosswind: 191 to 349 degrees	8
4	Low	Right Crosswind: 11 to 169 degrees	8
5	High: 4.83 to 16.09 km/h (3 to 10 mph)	Head Wind: 350 to 10 degrees	8
6	High	Tail Wind: 170 to 190 degrees	8
7	High	Left Crosswind: 191 to 349 degrees	8
8	High	Right Crosswind: 11 to 169 degrees	8

NOTE—Wind directions are referenced to the path of the test vehicle and not to compass directions.

Full evaluation is subject to the following requirements:

a. All eight wind conditions should be obtained for a complete evaluation.
b. A minimum of eight runs for each test vehicle treatment shall be run for each of eight wind conditions for a total of 64 runs.
c. Valid data may not be obtained if the average wind velocity measured during the test interval (the time the vehicle is passing before the camera or laser location) is higher than 16.09 km/h (10 mph) because water-depth control becomes difficult.

6.3 Preparations for Test Run

6.3.1 DIGITIZING METHOD—The cameras should be aligned and zoomed in so that the checkerboards completely fill up the image. All 96 squares should be included and should equally divide the image (±2 pixels) when the cameras are centered and zoomed in correctly.

The gain on the cameras should be adjusted so that, in the automatic iris adjustment mode of the lens, the mean value of a pixel intensity histogram is 125 (±5) on a scale of 0 to 255.

The lens control should then be set to manual iris adjustment (since we are measuring the contrast change between images, we do not want the camera to automatically adjust this out). The iris should then be adjusted so that the standard deviation of the pixel intensity histogram shall be at a maximum (this represents 1/2 the average contrast for the entire image) without over- or under-exposing the image. This will become evident when the histogram cannot be completely contained within the pixel intensity range. In other words, there cannot be any pixels located at the low end (0 pixel intensity) of the scale nor any at the high end (255 pixel intensity) of the scale. These adjustments should be made just before the truck passes through the test section to minimize the possibility of the ambient light conditions changing.

6.3.2 LASER METHOD—Each test run shall be preceded by calibration of laser transmissometers. Calibration is accomplished by occluding the laser beams and recording the output voltages from the photocells. This voltage for each cell represents 0%. Then, the laser beam is allowed to impinge on the photoelectric cell. This voltage reading for each sensor is recorded as 100%. The difference between the two voltages is thus the sensor range for the test run about to occur. The calibration shall be accomplished within 2 min of the time at which the test vehicle is expected to arrive at the test section.

6.4 Test Run Procedure—A complete run log shall be maintained for each test run that is made. All items should be completed on the form (see Figure 5 for the run log). Comments should include any items that may have a bearing on the results.

A minimum of 3 min between test runs shall be maintained in order for the water to completely cover the test section after the truck has passed.

The vehicle path shall be through the center of the test section and the checkerboards, within 15.24 cm (±6 in), to ensure that an equal amount of spray is viewed through each camera.

Water depth shall be checked for at least every four runs to ensure that the depth is within the control limits.

Recommended nominal vehicle speed is 88.51 km/h (55 mph).

6.4.1 DIGITIZING METHOD—The test vehicle driver is advised to drive the vehicle through the test section at the prescribed speed. Weather data shall be recorded when the truck passes the first electronic eye in the test section. It shall not be recorded continuously as the truck passes the anemometer because the airflow around the truck may induce noise into the data. At the same time, the first control image from each side shall be taken. When the truck passes the second electronic eye, the framegrabber shall grab four test images at an interval of 1/30 of a second each. This coves a truck travel distance of approximately 3.28 m (10.76 ft) when traveling at 88.51 km/h (55 mph).

6.4.2 LASER METHOD—The test vehicle driver is advised to drive the vehicle through the test section at the prescribed speed. Recording of laser and wind data shall commence when the vehicle enters the test section and shall continue until the vehicle has exited the test section.

7. Data Reduction

7.1 Digitizing Method

7.1.1 RECORDED IMAGES—The digitized image should be stored and used to make a printed record of the spray cloud for subjective comparisons. This printed image will also serve as a record for future analysis or viewing as the need may arise. A printed image of the mean spray cloud should be made and used in reporting the final results.

Date/Time	Config.	Run No.	Wind Direction (°)	Wind Speed (km/h) (mph)	Average Track Water Depth (cm) (in)	Track Water Depth Range (cm) (in)	Humidity (%)	Air Temp (°C) (°F)	Comments	Initls

NOTES— If using laser method, refer to 7.2 for guidance in selecting wind data to record.
If using digitizing method, refer to 6.4.1 for guidance.
Record humidity and temperature as measured at the start of each run.

FIGURE 5—RUN LOG

7.1.2 IMAGE REDUCTION—The following operations shall be completed on all images:

1. Calculate the average pixel intensity for each square. This reduces the digitized image file to an array file of 96 numbers, each number representing the average pixel intensity for a square (see Figure 6).
2. Next, calculate the contrast for each boundary between each square. This is done by subtracting the black square pixel intensity from the white one. This results in a new array file of 172 numbers for each image, representing the contrast of each boundary (see Figure 7).

7.1.3 SPRAY REGION CALCULATION—The spray region calculation involves first calculating the contrast loss from the control image to the test images for each boundary and then dividing the checkerboard into five different regions by the spray cloud density. These regions represent the spatial characteristics of the spray cloud and are used to get an idea of how much of the checkerboard is covered by what density of obscuring spray cloud (see Figure 8).

Contrast change between the control image (with no spray) and the test image is calculated for each corresponding boundary between the black and white tiles. This change is represented as a percentage (a "Figure of Merit," or FOM) by subtracting the corresponding test image boundary contrast from the control image (should be a positive value), dividing that by the control image contrast, and multiplying that by 100. See Equation 1.

$$\frac{C_{cii} - C_{tii}}{C_{cii}} * 100 = FOM_{ii} \qquad \text{(Eq. 1)}$$

where:

C_{cii} = Contrast control image at location i,i in the contrast array file
C_{tii} = Contrast test image at location i,i in the contrast array file
FOM_{ii} = Contrast loss at location i,i on the checkerboard

This results in eight FOM_{ii} array files (172 numbers in each array file) representing the obscuring amount of spray for four test images from each side of the vehicle (eight total). The four image files per side are then averaged so that two average FOM_{ii} array files for the right and left sides are obtained. Using these array files, each image is divided into five spray density regions. The percentage of the checkerboard that is obscured by each region is then tallied up for the averaged left and right images as shown in Table 2.

TABLE 2—AVERAGE PERCENT AREA OF CHECKERBOARD OBSCURED BY SPRAY[1]

Loss of Contrast Level (FOM)	Spray Density Description	Left Checkerboard	Right Checkerboard
0 to 20%	Minimum	54.7%	51.2%
20 to 40%	Slight	3.5%	5.8%
40 to 60%	Moderate	17.4%	20.2%
60 to 80%	Dense	13.4%	13.0%
80 to 100%	Very Dense	11.0%	9.9%

1. Results reported in the two right columns are examples.

Average Square Brightness

ROW \ COL	1	2	3	4	5	6	7	8	9	10	11	12
1	48	24	52	22	55	23	52	26	47	29	44	29
2	27	50	25	54	22	54	23	50	27	46	28	42
3	48	27	51	24	54	21	51	25	47	27	42	26
4	30	49	27	51	21	51	21	49	26	44	27	42
5	46	28	48	24	48	18	49	23	46	25	43	27
6	27	44	25	45	20	46	20	46	23	43	25	41
7	42	24	42	21	43	17	44	20	44	23	39	24
8	31	42	23	42	20	45	20	44	23	43	24	39

LH CHECKERBOARD BEFORE SPLASH & SPRAY

ROW \ COL	1	2	3	4	5	6	7	8	9	10	11	12
1	40	22	42	20	45	18	44	20	40	23	36	23
2	24	42	22	44	19	45	18	43	22	40	23	35
3	40	24	42	22	45	18	44	20	41	23	36	23
4	26	41	24	43	20	43	18	43	22	38	23	36
5	39	25	40	23	41	17	42	20	41	24	37	25
6	24	38	23	38	20	40	19	42	26	44	32	46
7	35	23	36	22	37	18	40	25	46	39	54	59
8	27	36	22	34	20	38	24	46	45	59	62	63

LH CHECKERBOARD AFTER SPLASH & SPRAY

FIGURE 6—SAMPLE IMAGE SHOWING AVERAGE PIXEL INTENSITY (SQUARE BRIGHTNESS) FOR EACH SQUARE