UMTRI-84-27

INSTRUMENTATION FOR MEASURING THE EFFECTIVENESS OF TRUCK SPRAY SUPPRESSION DEVICES

John D. Campbell

Transportation Research Institute
The University of Michigan

August 1984

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
UMTRI-84-27		

4. Title and Subtitle	5. Report Date
INSTRUMENTATION FOR MEASURING THE EFFECTIVENESS OF TRUCK SPRAY SUPPRESSION DEVICES	August 1984
	6. Performing Organization Code
	8. Performing Organization Report No. UMTRI-84-27
7. Author(s) John D. Campbell	
9. Performing Organization Name and Address The University of Michigan Transportation Research Institute 2901 Baxter Road Ann Arbor, Michigan 48109	10. Work Unit No. 11. Contract or Grant No. SC L400015
12. Sponsoring Agency Name and Address Texas Transportation Institute Texas A&M University College Station, Texas 77843	13. Type of Report and Period Covered Final 3/19/84-8/31/84 14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

A methodology for measuring the effectiveness of spray suppression devices on heavy trucks is discussed. An instrumentation system concept is described which would permit field measurements of the apparent contrast of an object, viewed through a spray cloud, separate from the confounding influence of veiling luminance due to uncontrolled ambient lighting conditions. Both transmissivity and scattered light measurements are considered; advantages and disadvantages of each and problems in their application are discussed. An expanded beam laser transmissometer is described which has potential advantages over the simple narrow-beam laser transmissometer commonly used to measure truck spray density. Provided here are results of laboratory experiments conducted to define hardware requirements for the expanded beam laser transmissometer scheme and for instrumentation to make scattered light measurements, using a modulated laser beam to illuminate the spray cloud.

17. Key Words	18. Distribution Statement
truck splash and spray, visibility, laser transmissometer, photometer measurements, light scatter	UNLIMITED

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
NONE	NONE	21	

The project was supported with funds under agreement number TTI 8413-C9191 with the Texas A & M Research Foundation (Project 7002), subcontracted to the University of Michigan under Subcontract Number L300006.

The project was co-sponsored by the Motor Vehicle Manufacturers Association of the United States, Inc., Western Highway Institute, Truck Trailer Manufacturers Association, Inc., Private Truck Council of America, Inc., and American Trucking Associations, Inc.

CONTENTS

1.0 INTRODUCTION

The University of Michigan Transportation Research Institute (UMTRI) under subcontract to the Texas Transportation Institute (TTI) conducted a brief study of "advanced instrumentation" for the measurement of the improved visibility obtained by the addition of spray suppression devices to heavy trucks. Professor Emmett N. Leith, Professor of Electrical and Computer Engineering and Head of the Electro-Optics Laboratory at The University of Michigan, was consultant to UMTRI personnel on the project and provided expert advice as well as optical laboratory facilities.

Visibility is a subjective measure which can vary greatly between different observers. Thus, in order to measure the effectiveness of spray suppression devices, it is desirable to select a quantity which can be objectively measured, preferably with simple instrumentation, and which exhibits a reasonable correlation with visibility. The transmissivity of the spray cloud along the side of the vehicle is the quantity that has been measured in several previous studies [1,2,3,4]. The rationale for selecting this measurement, together with a general discussion of the problems involved in measuring the effectiveness of spray suppressors, is given in Section 2.

Because of the short time duration of this project, only three schemes were considered practical for implementation for field evaluation in this program. These were:

1. The use of multiple (3 or 4) laser transmissometers on each side of the test vehicle to provide a measure of the spray distribution,

2. The use of expanded collimated laser beams (2 inches diameter or larger) to obtain spatial averaging over a larger area of the spray field than obtained with the raw laser beam, and

3. Photometric measurement of laser light scattered or reflected by the spray field.

Because eight laser transmissometers (item 1 above) were implemented at the start of the field test program, no further consideration was given to the multiple laser transmissometer scheme. Laboratory experiments were performed relating to the expanded laser beam and the light scattering measurement schemes. These experiments were intended to define the hardware requirements for implementation of these schemes near the end of the field test program. The laboratory experiments are described and the results are discussed in Section 3.

2.0 VISIBILTY, AND THE MEASUREMENT OF SPRAY SUPRESSOR EFFECTIVENESS

In order for a person to detect or identify an object, he/she must perceive a contrast in the object or between the object and its background. Contrast is the ratio of the luminance of light to dark areas of the object. Simply stated, the visibility of the object will be good if the contrast is high and sharp and it will be poor if the contrast is low and fuzzy. Visibility is also affected by the absolute light level. For example, young people typically can identify a low-contrast object at lower absolute light levels than can older people. A great deal is known about the ability of the human eye to detect objects as a function of contrast and light level. Therefore, contrast appears to be a highly desirable quantity to measure to determine visibility through a water spray cloud.

The contrast of an object measured through a cloud of water spray is affected by the spray in two ways: (1) by scattering of the light coming from the object and (2) by scattering of the light from other light sources or the ambient light in the area.

For example, consider a pair of photometers aimed through a spray field, one focused on a white patch or area, and the other focused on an adjacent black patch or area, representing a high-contrast object. The ratio of the outputs from the two photometers is the apparent contrast of the object. As the light coming from the white area passes through the spray, it is scattered and rescattered by the spray. As a net result, the light received by the photometer focused on the white area is decreased and the light received by the photometer focused on the dark area is increased, thereby decreasing the apparent contrast of the object. Now consider light entering the spray field from another source, namely, the ambient light in the field test situation. This light also is scattered by the spray such that some of this light is received by both photometers, thereby further decreasing the apparent contrast of the object. The scattered light from this extraneous source is called veiling luminance. Generally, more light is scattered in the forward direction than sideways or back toward the light source. Thus, veiling luminance varies with direction and intensity of the extraneous light sources, as well as with the spray density.

In the field test environment, the ambient lighting depends on variations in cloud cover and the angle of the sun. Therefore, veiling luminance cannot be controlled and conventional photometer measurements of target contrast or visibility to determine the effectiveness of spray suppression devices cannot be made accurately. Conceptually, an instrumentation system could be constructed which would be insensitive to the veiling luminance resulting from the ambient light. The effect of veiling luminance could be eliminated by illuminating the high-contrast target with modulated light and then measuring apparent object contrast by the two-photometer method using bandpass-tuned photometers responding only to the modulated light. With this system, controlled veiling luminance could be incorporated in the measurements by directing part of the modulated light source into the spray, thereby permitting an evaluation to be made of the reduction in contrast resulting from (1) veiling luminance and (2) scattering of the light from the object. In a laboratory experiment (see Section 3.2), it was found that the scattered light from an object was several orders of magnitude less than the transmitted light. This fact suggests that veiling luminance is the dominant factor resulting in the reduction of contrast or visibility. Development of this modulated illumination system was beyond the scope of this contract. Furthermore, it is not clear at this time that it would have any significant advantage over the simple measurement of spray transmissivity using the laser transmissometer.

Both the transmissivity and scattering of light in a spray cloud have been found to be highly correlated with spray density. Therefore, either can be measured to obtain a measure of the change in spray density resulting from spray suppression devices. Scattering measurements result in much lower received light levels for a given illumination level than is obtained with transmissivity measurements. Thus, scattering measurements made in the field require the use of a modulated light source and a very sensitive bandpass-tuned photometer in order to detect the low light level and reject background illumination. The laser transmissometer is much simpler instrumentation, and if the laser and receiver are spaced far enough apart, it gives a measure of the average spray density through the spray cloud along the entire length of the truck. Consequently, essentially all field measurements of truck-generated spray made in the past have employed transmissivity measurements, usually employing a laser light source. Because of the highly directive laser beam, relatively low output power is required (about 10 milliwatts) to produce a power level at the receiver which is well above the ambient light level, even with only a few percent transmission through the spray.

Given the transmissivity measure of spray density, it is then desirable to relate the spray density to object contrast (visibility) viewed through the spray. This has been done in previous studies by correlating transmissivity with subjective evaluation of visibility by human observers [1,4]. An alternative procedure, which eliminates the variability of the human observer, is to make contrast measurements from photographs or video recordings. However, this measurement is also affected by veiling luminance, and the uncontrolled veiling luminance in the field situation can have a significant effect on the correlation measure.

3.0 LABORATORY EXPERIMENTS AND RESULTS

3.1 The Expanded Laser Beam Transmissometer

The laser transmissometer method of measuring spray density appears to be the simplest measurement method. Thus, ways of improving this technique were considered. Expanding the laser beam to a larger diameter prior to its passage through the spray and then focusing this collimated beam onto the detector at the receiver appeared to have two potential advantages over use of the narrow raw laser beam: (1) an expanded beam performs spatial averaging, with the result that receiver output fluctuations caused by large water droplets passing through the beam would be smoothed and (2) the expanded beam would provide a measure of spray density through a space along the side of the truck more closely approximating the space through which the driver of a passing vehicle must see to observe oncoming vehicles. The expanded laser beam certainly would give more information than one narrow beam, and possibly as much needed information as multiple narrow beams.

Figure 1 illustrates the geometry of the expanded laser beam experiments performed in the laboratory. Figure 1a shows the raw or unexpanded beam setup for reference. The laser and receiver were about 20 feet apart. The diameter of the raw beam arriving at the detector was slightly larger than the detector, thus a lens was used before the detector to focus the entire beam onto the detector surface. Figure 1b and 1c show lens arrangements producing a two-inch-diameter and a six-inch-diameter collimated beam. A 20-power microscope objective is used to diverge the laser beam. The beam is then collimated by a collimating lens and focused on the detector by the collector lens. The diameter of these lenses must be at least as large as the desired beam diameter. The distance from the microscope objective to the collimating lens and from the collector lens to the detector is the focal length of the lens. The diameter and focal length of the collimating lens must be matched to the beam divergence in order to collimate all the light from the laser. This match was not acheived with the lenses available in the laboratory, but a small loss of light is not critical. Lens quality is not critical because shape focusing is not required. Low cost, plastic fresnel lenses should be

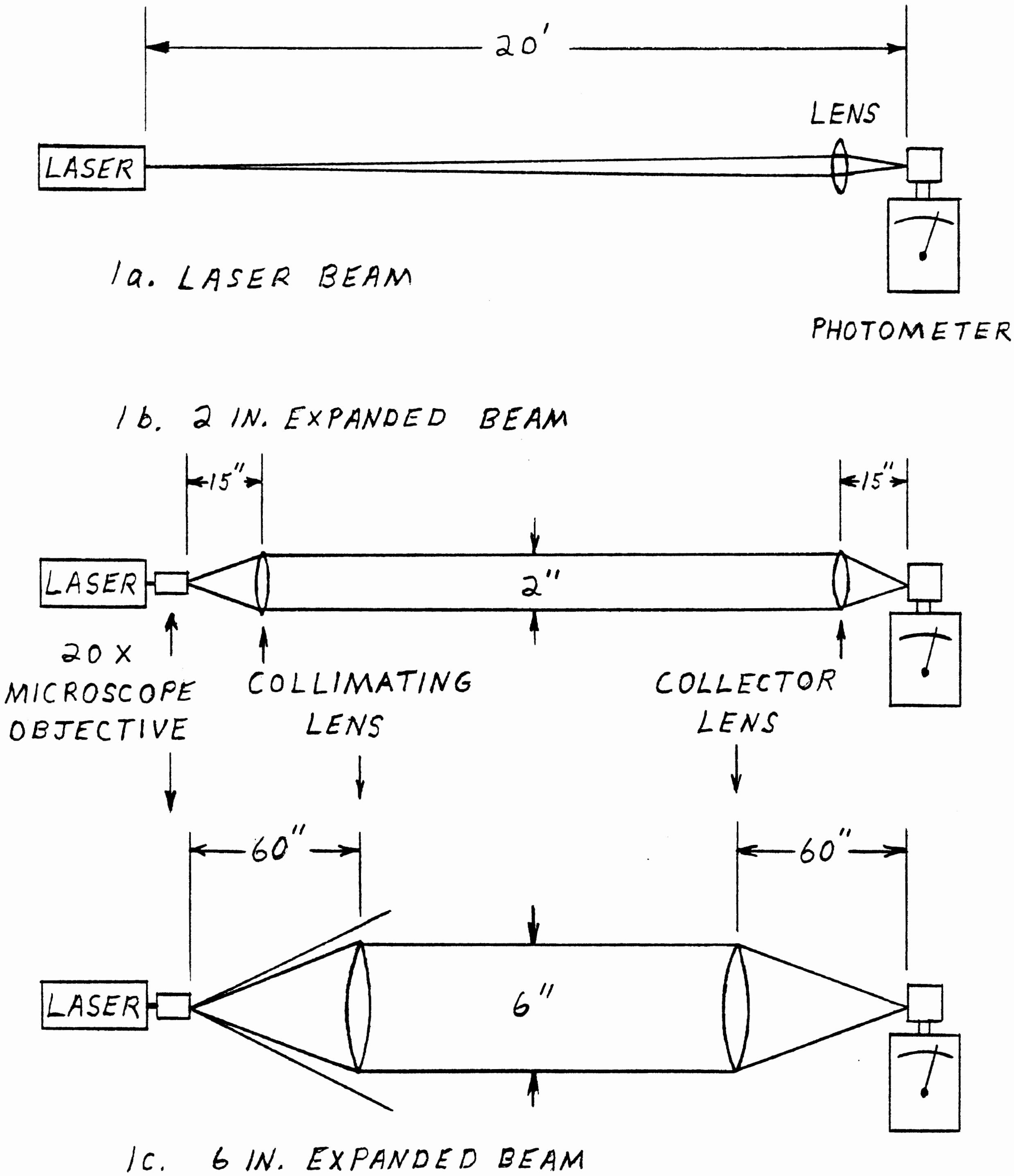


Figure 1. Geometry of the expanded beam setups used in the laboratory test.

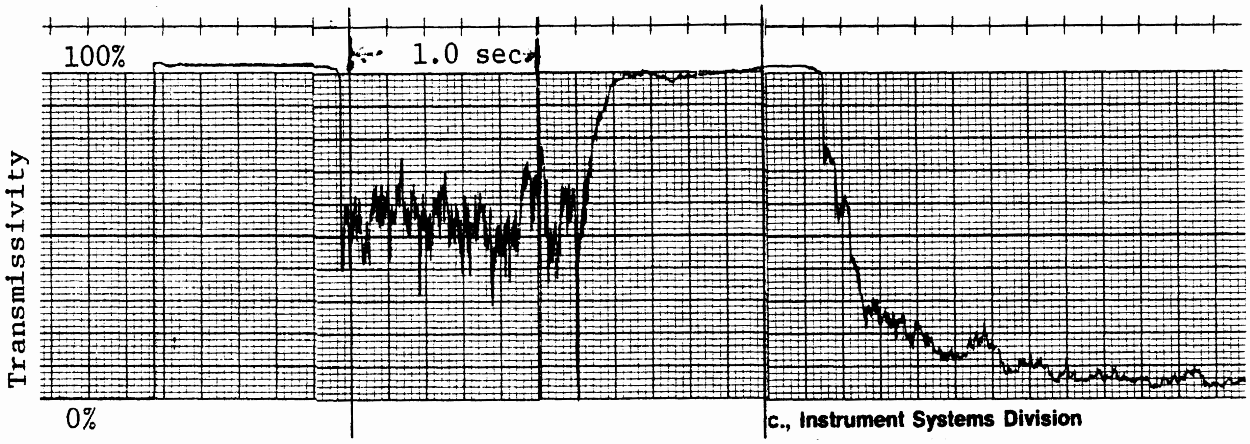
adequate, but they were not tried. The length of the setup can be minimized by using lenses with a short focal length. Fresnel lenses up to 15 inches in diameter with focal lengths as short as eight inches inches are readily available. The receiver was a model 45-230 photometer made by Metrologic. Although the laser (Metrologic Model ML-855) was new, it failed after only two hours of operation. A similar laser, which was available in the laboratory, was used to complete the tests.

An airless paint sprayer was used to simulate the spray generated by a truck. Spray was injected into the laser beam (with the sprayer oriented perpendicular to the beam) from a distance of about two feet, producing a visible spray about ten inches wide in the beam. Similarly, with the sprayer positioned about one foot from the beam and aimed along the beam, a visible spray about six feet along the beam was obtained.

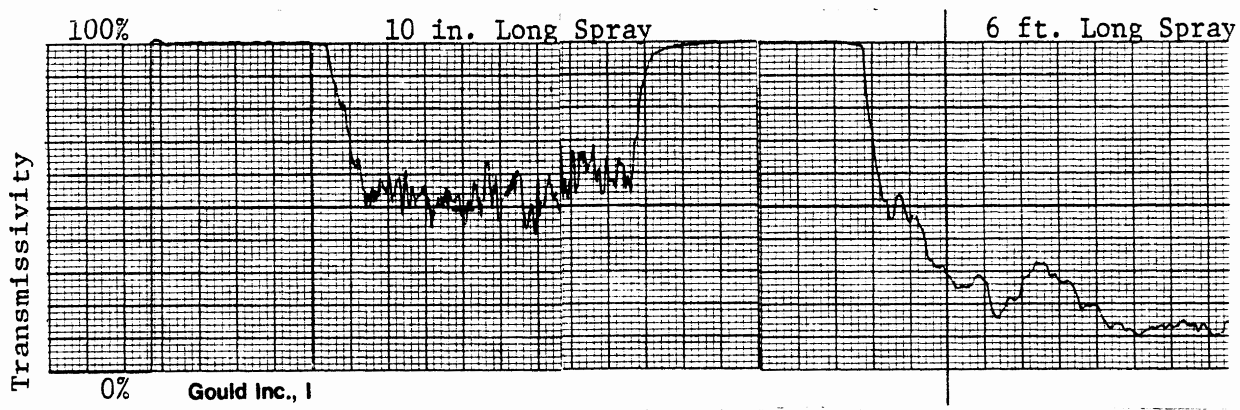
Figure 2 contains a composite of strip-chart recordings made of the photometer output for the three beam diameters illustrated in Figure 1 and for the ten-inch and the six-foot spray patterns. The zero to full-scale step at the left side in the figure is the blocked beam and full beam photometer outputs giving a 0% to 100% transmissivity calibration for the recordings. The ten-inch-long spray pattern is seen to have a transmissivity of 50% to 60% with all three beam configurations, and the six-foot-long spray pattern has a transmissivity of 10% to 20%. These values are in the same range of transmissivity values that have been reported for spray along the entire side of semitrailers, thus this simulated spray appears to be somewhat denser than typical truck-generated spray. Signal smoothing resulting from spatial averaging in the expanded beams is clearly evident, especially in the recordings for the short, ten-inch spray pattern. The frequency and amplitude of the noise in the signal decreases as the beam diameter is increased.

3.2 Laser Beam Scattering and Reflectance Measurements

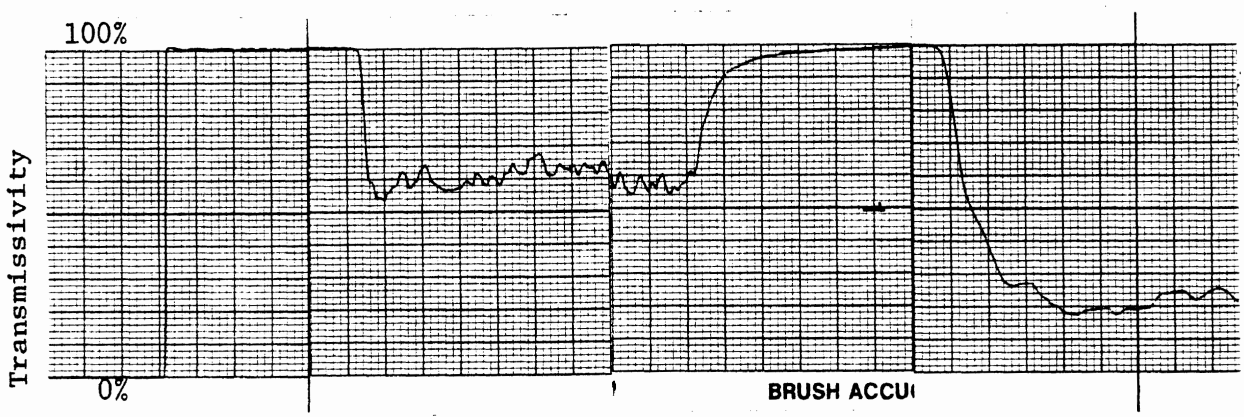
Both the transmissivity and scattering of light by water spray are a function of spray density, thus either can be measured to determine spray density. However, scattering measurements have two major disadvantages compared with transmissivity measurements for the purpose of evaluating the



2a. Raw laser beam (see Fig. 1a)



2b. 2 in. expanded laser beam (see Fig. 1b)



2c. 6 in. expanded laser beam (see Fig. 1c)

Figure 2. Composite strip chart recordings of the photometer outputs from the expanded laser beam experiments.

effectiveness of spray suppression devices in improving visibility along the side of heavy trucks. First, the transmissivity measurement gives a measure of the average spray density through the full length of the spray field along the side of the vehicle, whereas the scattering measurement gives a measure of the spray density in a localized volume of the spray field determined by the light acceptance angle of the collector lens at the receiver and the direction the receiver is aimed relative to the scattering elements in the spray. Second, the light level arriving at the receiver due to scattering of light by the spray is on the order of one millionth of that received in transmission measurements. Consequently, a modulated light source and a sensitive bandpass amplifier photometer are required to detect the low-level signal separately from the ambient light.

There are, however, measurements of truck spray which may be useful and which are best made by scattered light measurements. Two such measurements are illustrated in Figures 3 and 4. Figure 3 shows an arrangement for measuring spray at a local area alongside of the vehicle as it travels on the highway. The spray is illuminated by a modulated light source and scattered or reflected light is detected by a bandpass amplifier photometer focused on an area in the spray cloud. Figure 4 illustrates a scheme to measure the distribution of spray density along the side of a vehicle on the test track. A collimated beam from a modulated light source is directed along the side of the passing vehicle. A bandpass amplifier photometer is focused on the beam from a position approximately perpendicular to the beam. The scattered light detected by the photometer is a function of the spray density along the truck as the truck passes. This measurement could also be accomplished with the transmission measurement setup with the laser and photometer moved closer together, that is, only a few feet apart, but the instruments would have to be well shielded from the spray by streamlined covers to protect them from the water while not disturbing the airflow in the area of the measurement.

In order to define the receiver sensitivity required for scattering measurements, some simple scattering measurements were conducted in the laboratory. The setup used is illustrated in Figure 5. The two-inch-diameter expanded laser beam described above was used for the illumination source. The spray cloud was generated with the airless sprayer. Measurements were made with a United Detector Technology Model 80K photometer,

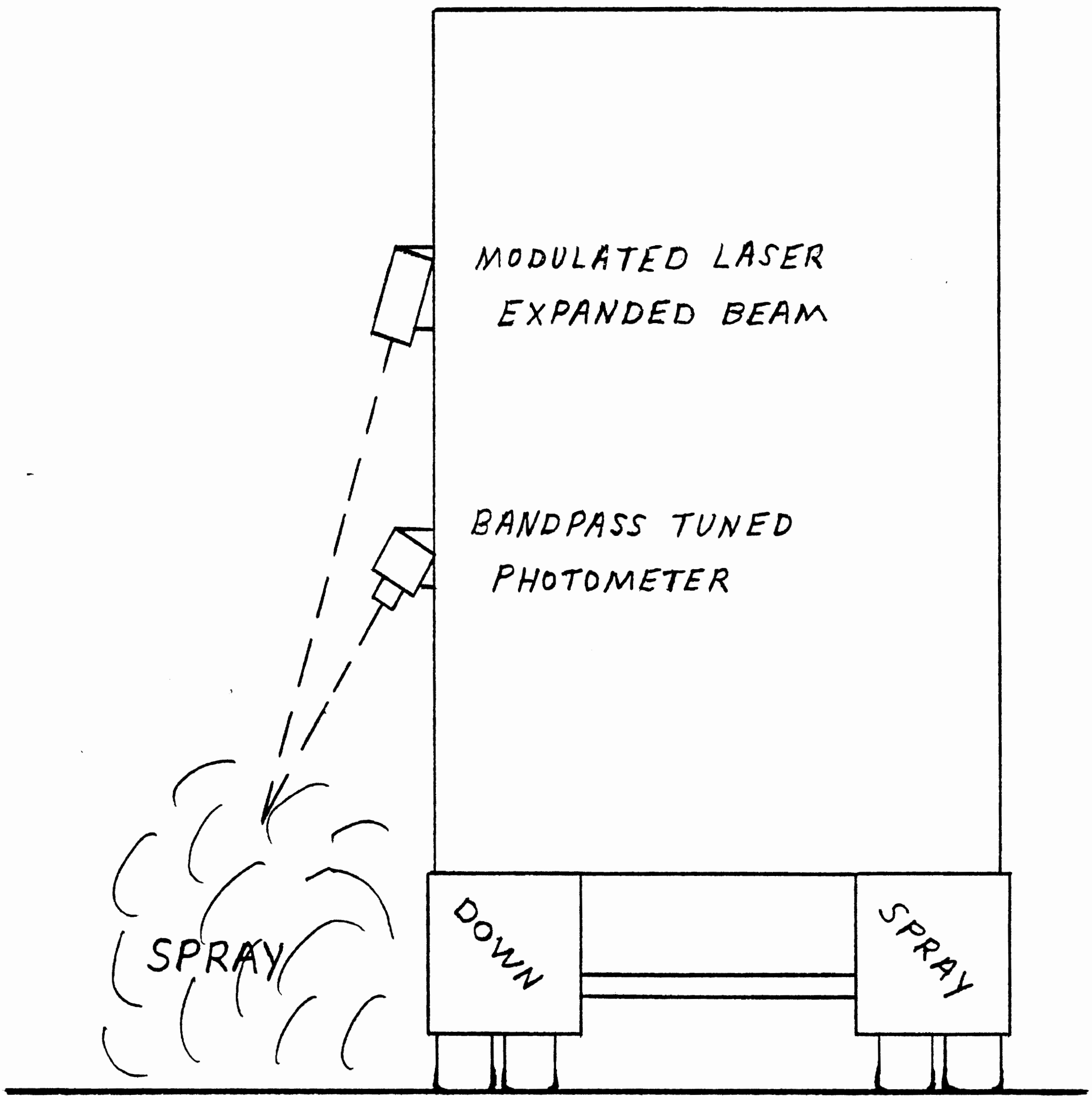


Figure 3. Modulated laser photometer system mounted on a truck to measure spray density at a fixed location along the side of the truck while on the highway.

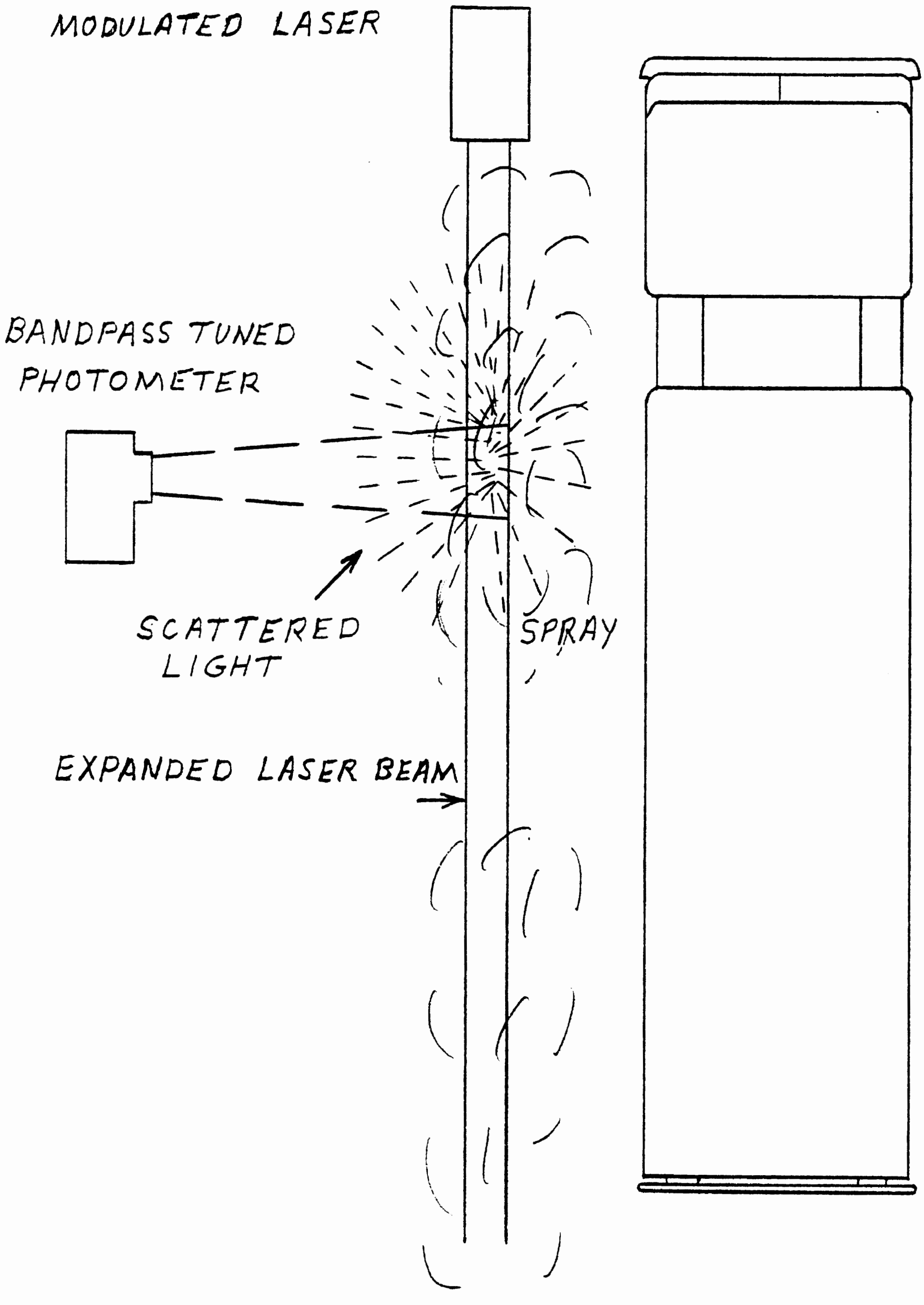


Figure 4. Modulated laser photometer system arranged to measure the distribution of spray along the side of a truck.

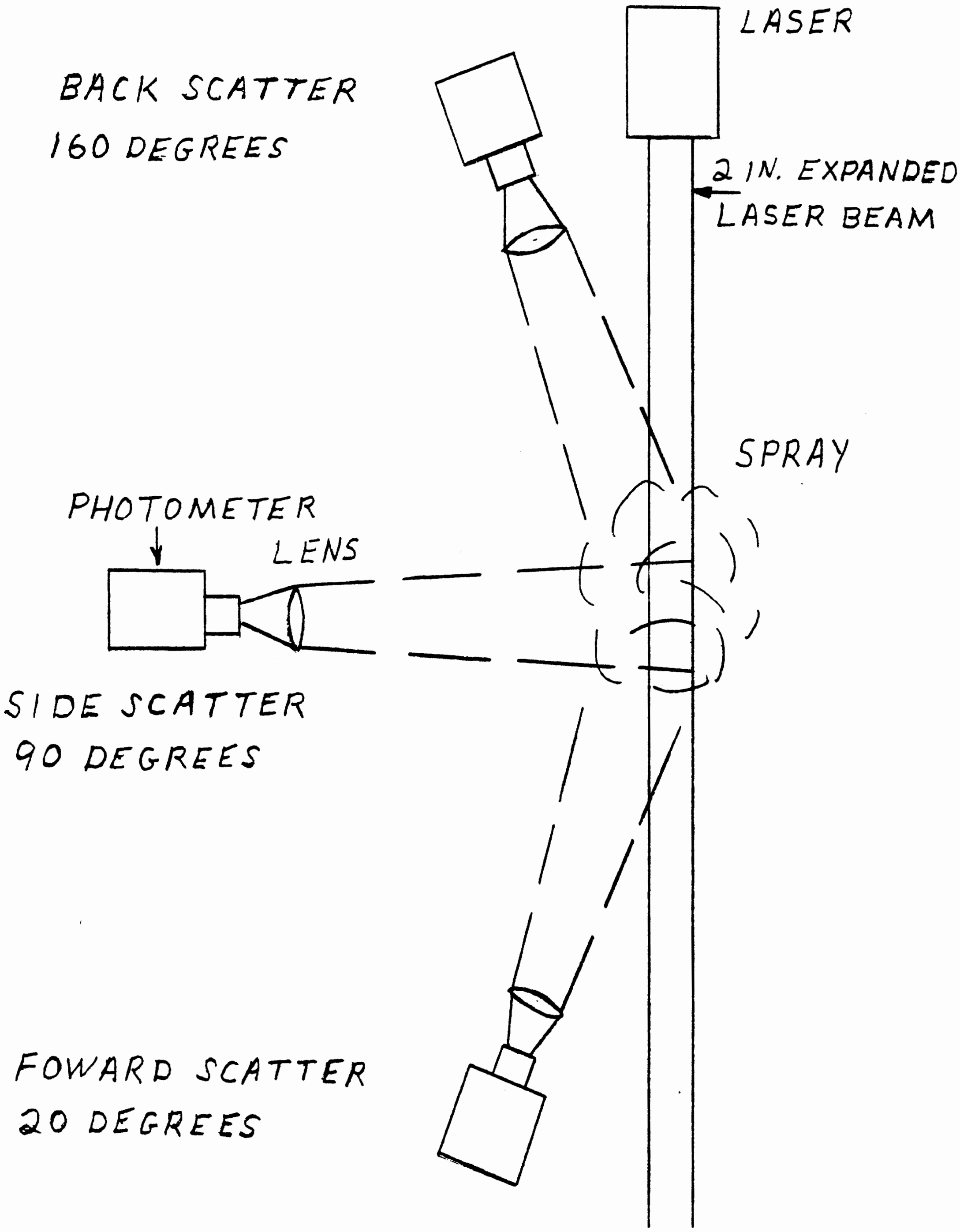


Figure 5. Laboratory setup used to measure the power received at various angles (forward scatter, side scatter, and back scatter) from a laser beam scattered by a water spray cloud.

which has a sensitivity of one picowatt. This is a DC instrument which responds only to constant and very slowly changing light intensities, with a step response of about two seconds. The measurements were made in a dark room since any ambient light would have obscured the desired measurements. The photometer was placed five feet from the point in the spray field to be measured. A two-inch-diameter collector lens was placed in front of the photometer. A piece of frosted glass was placed in the beam at the measurement point to scatter light toward the photometer while the position of the collector lens was adjusted to focus this point on the photometer detector. The photometer output was then recorded while the spray was injected into the laser beam with the spray gun located about two feet from the measurement point. Scattering measurements were made with the detector located at 20 degrees (forward scatter), 90 degrees (side scatter), and 160 degrees (back scatter), with respect to the laser beam, as shown in Figure 5. Our consultant, Professor Leith, indicated that forward scatter should be considerably greater than side or back scatter. The measurements resulted in a forward scatter about ten times that of side and back scatter. Specifically, the measured power was: 50 nanowatts at 20 degrees; 2 nanowatts at 90 degress; and 5 nanowatts at 160 degrees. A larger collecting lens provides optical gain by gathering more of the scattered light. An eleven-inch-square fresnel lens, replacing the two-inch lens, increased the received power in the backscatter measurement (160 degrees) from 5 nanowatts to 80 nanowatts.

Assuming that the density of the simulated spray used in these laboratory measurements is approximately equal to the maximum density of truck-generated spray, and assuming that spray density at least one one-hundredth of this level must be detectable in field test measurements, the photometer sensitivity required is determined to be at least 5/100 nanowatts or 50 picowatts. Of course, lower receiver sensitivity would be required if a higher powered light source were employed.

Consideration was given to the possibility of implementing a bandpass amplified photometer measurement system using the Metrologic laser and photometer equipment on hand and available laboratory amplifiers and filters. In such an arrangement the laser could be modulated at a frequency of about 200 Hz with a mechanical beam chopper, and the metrologic photometer output would be amplified by a high-gain bandpass amplifier tuned to 200 Hz. A Rockland Laboratories tunable filter with a gain of 100 is available at UMTRI. If required, additional gain could be obtained with a simple operational amplifier, and a sychronous detector to convert the AC signal to DC could be easily added. The sensitivity of this "throw together" system would be limited by the noise generated in the Metrologic photometer front end, which is simply a 741 operational amplifier connected in a current-to-voltage-converter configuration with adjustable gain. This noise level was measured by connecting the Rockland Labs filter to the output of the Metrologic photometer and measuring the noise at the filter output with a Hewlett-Packard Model 3582A spectrum analyzer. The filter was adjusted to a gain of 100, a bandwidth of 50 Hz centered at 200 Hz, with 24 db per octave out-of-band attenuation. The noise amplitude measured in the bandpass, with the photometer detector covered, was equivalent to 30 picowatts of received light power. The equivalent of 70 picowatts was observed at 60 Hz and 300 Hz which was determined to be from power line pick-up in the Metrologic detector leads. These results indicate that this throw together system should be usable in field tests to evaluate scattered light measurements.

4.0 CONCLUSIONS

The visibility of an object, viewed through a cloud of water spray, is determined by the apparent contrast of the object which is dependent on the spray density. The direct measurement of apparent contrast requires relatively complicated equipment, compared to the simple laser transmissometer, which has proved to be very effective for measuring the transimissivity of the spray cloud along the full length of a truck generating heavy spray. Furthermore, transmissivity is known to be highly correlated with spray density. Development of the equipment to measure apparent contrast is beyond the scope of the present contract, and the development effort is not justifiable unless it can be shown to have a high probability of providing a significantly better measure of spray suppressor effectiveness than that obtained from simple transmissivity measures.

Veiling luminance, resulting from the scattering of ambient light in the test area, may be the predominant factor affecting contrast or visibility of an object viewed through the spray cloud. Thus, attempts to evaluate transmissivity as a measure of visibility, by correlating transmissivity with subjective visibility estimates made by human observers or with objective contrast measurements derived from densitometer measurements of photographs or video recordings, should be carried out only with careful consideration being given to the variations in ambient lighting conditions which occur during tests used to obtain the correlation factor.

The generation and use of an expanded laser beam up to six inches in diameter was shown to be simple and straightforward. Beams 12 inches to 15 inches in diameter should also be easy to generate and apply. By virtue of averaging over a larger area of the spray field, the expanded laser beam arrangement may provide a useful enhancement of the laser transmissometer scheme. Thus, field evaluation of the expanded laser beam transmissometer appears worthwhile.

Photometer measurements of the light scattered as a beam of light passes through the spray field do not appear to have practical application for measuring the visibility through the entire spray field along the side of a vehicle. A photometer focused on the beam would receive power from only a small area of the spray field. However, such measurements could provide a useful measurement of local spray density. For example, with the light source and the photometer mounted on the truck, the spray density could be measured in one area along the side of a truck as it traveled on actual roads during a rainfall. Also, with a ground-mounted system, the variation in spray density could be monitored in a fixed area as a truck passed so as to measure the distribution of spray density along the length of the truck.

In a scattered light measuring system, the light level received by the photometer is several orders of magnitude less than that received in a transmissivity measuring system. Consequently, a modulated light source and a sensitive bandpass-tuned photometer must be used to detect the scattered light separately from the ambient light. Using a 10 milliwatt laser light source, with 100 percent modulation, a tuned photometer with a sensitivity of at least 50 picowatts is required. Of course, a less sensitive photometer would be adequate with a proportionately higher powered light source, and the light source does not have to be a laser. A brief search of literature on hand indicated that bandpass-tuned photometers are not readily available as standard test instruments. Although the design of such a photometer is straightforward, this task was beyond the scope of this contract.

REFERENCES

1. Weir, D.H., Strange, J.F., and Heffley, R.K. "Reduction of Adverse Aerodynamic Effects of Large Trucks." Final Report, Contract No. DOT-FH-11-9165, Systems Technology, Hawthorne, CA., September 1978.

2. Allan, J.W. and Lilley, G.M. "The Reduction of Water Spray from Heavy Road Vehicles." Int. J. of Vehicle Design, Technological Advances in Vehicle Design Series, SP3, Impact of Aerodynamics on Vehicle Design, 1983, pp. 270-307.

3. Sandberg, U. "Spray Protectors Testing of Efficiency." National Road and Traffic Research Institute, Linkoping, Sweden, Rept. No. NR171A, 1978.

4. Sandberg, U. "Efficiency of Spray Protectors, Test 1979." National Road and Traffic Research Institute, Linkoping, Sweden, Rept. No. NR199A, 1980.