1062

Water Jet/Spray Measurement Analysis

Final Report on Contract H - 78743B

G. Garland Lala
Atmospheric Sciences Research Center
State University of New York at Albany
1400 Washington Avenue
Albany, NY 12222

(NASA-CR-178802) WATER JET/SPRAY MEASUREMENT ANALYSIS Final Report (State Univ. of New York) 12 p HC A02/MF A01 CSCL 20D

N86-24930

Unclas G3/34 42917

January, 1986

Prepared for:

George C. Marshall Space Flight Center
Marshall Space Flight Center, AL 35812

1.0 Introduction

The objective of this study was to provide analysis of data obtained under a previous contract entitled "Characterization of Drop Spectra from High Volume Flow Water Jets." Under this previous contract measurements of drop spectra were obtained in the spray resulting from the breakup of high volume flow water jets from a variety of nozzle types. The drop spectra measurements were obtained from two drop spectrometers covering a range from 10 microns to 12 millimeters diameter. These tests were conducted at the Marshall Space Flight Center during October, 1984. The task addressed was to select representative spectra from the individual tests and provide analyses in both numerical and graphical formats as outlined in the proposal. The intended application of these results is an evaluation of the feasibility of fog clearing by high volume water sprays.

During the tests, a fog event occurred making it possible to test the concept of fog clearing. Visual range data and fog drop spectra were analyzed, with particular emphasis placed on the modification of these parameters due to the water spray.

This report summarizes the analysis methods used for the reduction of the data from the drop spectrometers and documents the analysis provided under this contract.

2.0 Description of the Data Set

The measurement system for droplet distribution employed in the study consisted of four particle/drop spectrometers manufactured by Particle Measuring Systems (Table 1) connected to a central data acquisiton system (PDS-400).

Table 1

Particle/Drop Spectrometers

Probe		Size Range
1.	ASASP-X	0.12 μm - 6 μm
2.	FSSP-100	0.5 μm - 47 μm
3.	OAP-230X	10.0 μm - 310 μm
4.	GBPP-100	0.2 μm - 12.4 mm

Each spectrometer sizes individual particles and reports the encoded binary size data to the data system which accumulates multi-channel spectra for each probe. At the end of a sample interval (controlled by the PDS-400), a report of measured counts in each size channel for each probe is recorded on a cartridge tape system. For these tests, a one-minute sample interval was used. Thus, for each of the nozzle tests, many spectra from the individual probes were recorded. After the conclusion of a test, the raw data was transferred to a computer system for analysis. Because the data recorded were in the form of particle counts in a prescribed size range, additional analysis was necessary to incorporate the specific operating characteristics of the probes and produce spectra in terms of volume concentrations. The details of this data reduction scheme and analysis procedure are reported here.

3.0 Sample Volume Analysis

3.1 Scattering Probes (ASASP-X, FSSP-100)

Reduction of ASASP-X data to volume concentration is easily accomplished because the sample volume depends only on the sample flow rate which is preset to a constant value. Particle counts were scaled to particle concentration by dividing by the product of the sample flow rate (10 cm^3 sec^{-1}) and the sample time. Similar procedures were applied to the FSSP-100 data set using the sample flow rate of 9.04 cm^3 sec^{-1} provided by the manufacturer's calibration.

3.2 Imaging Probes (OAP-230X, GBPP-100)

Imaging probes determine a drop's diameter by measuring the size of the image formed on a discrete element photodiode array during its transit through the spectrometer beam. The size calibration is fixed by the size of the diodes and the overall optical magnification. Diodes at either end of the array are used to detect droplets which are partially outside the sample volume. These measurements are rejected. This edge rejection scheme leads to an effective sample volume which is dependent on the particle size. Besides limitations on the beam width imposed by the edge rejection system, the sample volume is constrained by the depth of field of the optical system for resolving small drops. For larger drops the depth of field is the mechanical limit of the probe which determines the volume for these drops.

3.2.1 Sample Volume Calculations: OAP-230X

The sample volume for the OAP-230X is given by the following equation.

$$V = DOF * EAW * u * t$$

where V = the sample volume

DOF = the depth of field for small drops or the mechanical limit (6.1 cm) for large drops

EAW = 0.31 - D(mm) = the effective array width as a function of drop size (D)

u = the velocity of the drops passing through the sample volume. For the OAP-230X, this is the aspirator air speed of 13.45 m sec^{-1}

t = sample time (which was typically 60 seconds during these tests)

Thus, to convert particle counts to concentration this equation is evaluated for each size channel to calculate the volume sampled.

3.2.2 Sample Volume Calculations: GBPP-100

The sample volume for the GBPP is given by the following equation:

$$V = DOF * EAW * V_s * t$$

where DOF = the depth of field for small drops or the mechanical limit (50 cm) for large drops

EAW = 12.3 - D(mm) = the effective array width as a function of drop size (D) in millimeters

V = the velocity of drops passing through the sample volume. For the GBPP this velocity is usually assumed to be the the terminal fall speed of the drops which is a function of drop diameter

t = the sample time (which was typically 60 seconds for these tests)

Under typical operating conditions, particle counts are converted to concentration using the equation above for the sample volume. The influence of the unusual conditions during these tests on this procedure will be considered in a subsequent section.

4.0 Correction of GBPP-100 drop spectra for drop flattening

Drops larger than one millimeter diameter become distorted into oblate ellipsoids by a combination of aerodynamic and surface tension forces. Thus, the diameter measured by the GBPP-100 is the dimension of the largest axis of the ellipsoidal drop. Drop size distributions are commonly reported in terms of the equivalent spherical diameter of the drops which makes it necessary to adjust the measured spectra. The basis of this correction is an equation relating the dimension of the largest drop axis to the equivalent spherical diameter given by Beard (1976) as

$$D_o = 18.02 + 18.52\ (0.9467 + 0.108\ Dm)^{1/2} \qquad (1)$$

where D_o = equivalent spherical diameter

Dm = measured length of the major axis

Two approaches to the correction problem are possible. The simplest method is to redefine the instrument channels in terms of the equivalent diameter. This has the disadvantage of producing spectra with unequal channel widths which can be difficult to analyze. The alternative to this approach is to redistribute the droplet counts by linear interpolation in a way that allows the instrument channels to be interpreted as equivalent spherical sizes rather than major axis dimensions. This latter approach has been used in this analysis.

The interpolation of drop spectra from the measured size concentration to the equivalent spherical size can be summarized as follows. In the measurement coordinate system, the channel size bounds are D_j and D_{j+1} with the corresponding concentration in this channel of N_j. Similarly, in the spherical drop coordinate system, channel size bounds are d_i and d_{i+1} with a concentration of n_i. By means of the equation (1) the channel bounds D_j and D_{j+1} are transformed into equivalent spherical sizes of D_L, D_H respectively. The conditions for the interpolation from the measurement system to the equivalent spherical diameter are as follows:

$$D_L > d_i \text{ and } D_H < d_{i+1} \; ; \; n_i = n_i + N_j$$

$$D_L < \text{ and } D_H < d_{i+1} \; ; \; n_i + N_j \, (D_H - d_i / D_H - D_L)$$

$$D_L > d_i \text{ and } D_H > d_{i+1} \; ; \; n_i = n_i + N_j \, (d_{i+1} - D_L / D_H - D_L)$$

By means of this algorithm, spectra are transformed from one coordinate system to the other while preserving the total concentration.

Correction of the drop spectra for equilibrium droplet distortion is only an approximate correction for drop shape variations. It is well known that larger drops exhibit complicated modes of oscillation which may be excited by collisions, drop breakup or turbulence. The transit time for droplets falling through the sample area of the GBPP is less than the period of oscillation which will cause drops of a given size to be distributed over several size channels. Due to the complexity of this problem, at this time the best approach is to correct for the average shape while remaining aware that the spectral measurements are subject to spreading by oscillations. The influence of the artificial broadening will be most apparent in distribution of the higher moments such as the crossectional area and volume of the drops.

5.0 Other External Sources of Error in the GBPP-100

As noted in an earlier section, the calculation of the sample volume for precipitation drops depends on the value assumed for their fall velocity. In this analysis, Beard's (1976) equation for the terminal fall velocity of raindrops, which is a reasonable assumption for natural rainfall, has been used. In some of the spray tests, breakup processes were observed throughout the spray column. When drops were breaking up above the GBPP-100 the actual fall speeds of the drops may have been different than their theoretical terminal fall speeds because insufficient time was available for acceleration or deceleration. Because of the unsteady nature of the water spray breakup, it is not feasible to try to correct for this effect.

Because of its geometry, the GBPP-100 is sensitive to the direction of drop trajectories. Components of velocity perpendicular to the probe axis can lead to overestimation of the size of drops. In the spray tests, the probe was aligned to minimize this effect but the potential for sizing errors was still present.

6.0 Water Spary Tests - Data Selection and Analysis

From the large number of spectra measured during the nozzle tests, spectra representative of specific nozzle types and operating conditions were selected for analysis. Representativeness was judged by inspecting the moments of the size distribution as well as total water content and drop concentration. Spectra selected for analysis were chosen from the middle of a sequence of measurements exhibiting stable characteristics which is indicative of nearly constant test conditions. Appendix 1 summarizes the spectra selected as well as operating conditions for the tests. A detailed summary of the analysis provided in terms of plots of spectra as well as numerical listings is provided in Appendix 2.

7.0 Fog Tests

One episode of fog occurred during the test period providing an opportunity to measure the effects of the water spray curtain on fog drop size distribution and visibility. During this test, the water spray curtain was periodically turned on providing data on fog drop spectra under natural conditions as well as with spray curtain operation. Spectra used for analysis were selected from the observations near the midpoints of the test intervals. These times, as well as the analysis performed, are summarized in Appendices 1 and 2. A variety of time series plots of visual range, both from the visibility meter and integration of drop spectra, of liquid water content calculated from drop spectra, and of number concentration in selected size channels were also provided.

APPENDIX 1

Summary of Selected Spectra

1. Nozzle Tests

Spectrum #	Date mo/da/yr	Time hr:mn:sc	Exp ID	Nozzle	Pressure (psi)
1	10/23/84	17:32:27	F	1 1/4	100
2	10/23/84	17:22:55	F	1 1/4	120
3	10/23/84	17:39:47	F	1 1/4	145
4	10/23/84	17:08:13	F	1 1/4	200
5	10/25/84	12:10:53	I	1 3/8	125
6	10/19/84	13:14:15	D	Fixed teeth	195
7	10/19/84	13:51:14	D	Fixed teeth	205
8	10/22/84	18:10:43	E	Spin teeth	125
9	10/22/84	17:25:57	E	Spin teeth	145
10	10/22/84	18:15:23	E	Spin teeth	175
11	10/22/84	17:44:03	E	Spin teeth	195
12	10/23/84	09:50:34	F	Spin teeth	172
13	10/23/84	12:02:41	F	Spin teeth	185
*14	10/16/84	14:54:29	A	1 3/8	138
15	10/24/84	12:32:33	H	1 3/4	145
16	10/24/84	14:47:21	H	1 3/4 curtain	153
17	10/23/84	17:48:09	F	1 1/4 st bore	n/a
18	10/23/84	13:29:25	F	1	145
*19	10/18/84	14:05:42	C	1	190
20	10/24/84	16:06:28	H	2 streams	n/a

* No GBPP hood modification

2. Fog Tests

Spectrum #	Date mo/da/yr	Time hr:mn:sc	Exp ID	Nozzle	Pressure (psi)
1	10/24/84	07:53:45	G	spray on - road array	
2	10/24/84	08:02:09	G	spray off - road array	
3	10/24/84	08:09:34	G	spray on - road array	
4	10/24/84	08:22:50	G	spray off - road array	
5	10/24/84	08:27:58	G	spray on - road array	
6	10/24/84	08:35:19	G	spray off - road array	

Summary of Graphics

1. Nozzle Tests

Plot Type	X-Axis Parameter [units]	Y-Axis Parameter [units]
OAP	Linear D [mm]	Log dN/dD [m^-3 mm^-1]
OAP	Linear D [mm]	Log dS/dD [mm^2 m^-3 mm^-1]
OAP	Linear D [mm]	Log dM/dD [g m^-3 mm^-1]
GBPP	Linear D [mm]	Log dN/dD [m^-3 mm^-1]
GBPP	Linear D [mm]	Log dS/dD [mm^2 m^-3 mm^-1]
GBPP	Linear D [mm]	Log dM/dD [g m^-3 mm^-1]
OAP,GBPP	Log D [mm]	Log dN/dlogD [m^-3]
OAP,GBPP	Log D [mm]	Linear dN/dlogD [m^-3]
OAP,GBPP	Log D [mm]	Log dS/dlogD [mm^2 m^-3]
OAP,GBPP	Log D [mm]	Linear dS/dlogD [mm^2 m^-3]
OAP,GBPP	Log D [mm]	Log dM/dlogD [g m^-3]
OAP,GBPP	Log D [mm]	Linear dM/dlogD [g m^-3]

2. Fog Tests

Plot Type	X-Axis Parameter [units]	Y-Axis Parameter [units]
FSSP	Linear D [um]	Log dN/dD [cm^-3 um^-1]
FSSP	Linear D [um]	Log dS/dD [um^2 cm^-3 um^-1]
FSSP	Linear D [um]	Log dM/dD [g m^-3 um^-1]
OAP	Linear D [um]	Log dN/dD [cm^-3 um^-1]
OAP	Linear D [um]	Log dS/dD [um^2 cm^-3 um^-1]
OAP	Linear D [um]	Log dM/dD [g m^-3 um^-1]
FSSP,OAP	Log D [um]	Log dN/dlogD [cm^-3]
FSSP,OAP	Log D [um]	Linear dN/dlogD [cm^-3]
FSSP,OAP	Log D [um]	Log dS/dlogD [um^2 cm^-3]
FSSP,OAP	Log D [um]	Linear dS/dlogD [um^2 cm^-3]
FSSP,OAP	Log D [um]	Log dM/dlogD [g m^-3]
FSSP,OAP	Log D [um]	Linear dM/dlogD [g m^-3]

References

Beard, K.V., 1976: Terminal velocity and shape of cloud and precipitation drops aloft. J. Atmos. Sci., 33, 851-863.