DOT/FAA/CT-86/10

FAA TECHNICAL CENTER
Atlantic City Airport
N.J. 08405

Quantitative Determination of Engine Water Ingestion

(NASA-CR-180188) QUANTITATIVE DETERMINATION OF ENGINE WATER INGESTION Final Report, May 1984 - Dec. 1985 (Jet Propulsion Lab.) 78 p CSCL 21E G3/07 N87-17702 Unclas 43338

P. Parikh
M. Hernan
V. Sarohia

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California 91109

December 1986

Final Report

This document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161.

U.S. Department of Transportation
Federal Aviation Administration

NOTICE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/CT-86/10		
4. Title and Subtitle QUANTITATIVE DETERMINATION OF ENGINE WATER INGESTION		5. Report Date December 1986
		6. Performing Organization Code
7. Author(s) P. Parikh, M. Hernan and V. Sarohia		8. Performing Organization Report No. JPL Publication No. D-3041
9. Performing Organization Name and Address Jet Propulsion Laboratory California Institute of Technology 4800 Oak Grove Drive Pasadena, CA 91109		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. DTFA03-81-A-00765
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Aviation Administration Technical Center Atlantic City Airport, New Jersey 08405		13. Type of Report and Period Covered Phase I May 84-Dec. 85
		14. Sponsoring Agency Code

15. Supplementary Notes

Project Manager, Tom Rust, Engine/Fuel Safety Branch, Aircraft and Airport Safety Technology Division, FAA Technical Center

16. Abstract

This report describes a non-intrusive optical technique for determination of liquid mass flux in a droplet laden airstream. The technique was developed for quantitative determination of engine water ingestion resulting from heavy rain or wheel spray. Independent measurements of the liquid water content (LWC) of the droplet laden airstream and of the droplet velocities were made at the simulated nacelle inlet plane for the liquid mass flux determination. The liquid water content was measured by illuminating and photographing the droplets contained within a thin slice of the flow field by means of a sheet of light from a pulsed laser. A fluorescent dye introduced in the water enhanced the droplet image definition. The droplet velocities were determined from double exposed photographs of the moving droplet field. The technique was initially applied to a steady spray generated in a wind tunnel. It was found that although the spray was initially steady, the aerodynamic breakup process was inherently unsteady. This resulted in a wide variation of the instantaneous liquid water content of the droplet laden airstream. The standard deviation of ten separate LWC measurements was 31 percent of the average. However, the liquid mass flux calculated from the average LWC and droplet velocities came within 10 percent of the known water ingestion rate.

17. Key Words	18. Distribution Statement
Engine water ingestion wheel spray Two phase flow measurement	This document is available to U.S. Public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified		

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

ACKNOWLEDGEMENTS

This work was sponsored at the Jet Propulsion Laboratory of California Institute of Technology by the U.S. Department of Transportation, Federal Aviation Administration Technical Center through NASA Contract NAS7-918, agreement No. DTFA03-81-A-00765. The authors extend their gratitude to Messrs. T. Rust, F. Howard, and W. T. Westfield of FAA Technical Center for their guidance and suggestions. The assistance of Messrs. W. Bixler and S. Kikkert in fabrication of the apparatus is gratefully acknowledged.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

NOMENCLATURE

A_f	Frontal area of nacelle. (m^2)
D	Droplet Diameter (mm)
LWC	Liquid Water Content (gm/m^3)
$\dot{m}_w$	Mass flow rate of water (gm/sec)
n	Number of drops counted
q_w	Total liquid volume in the measurement volume (cm^3)
$\dot{Q}_w$	Volumetric water ingestion rate (cm^3/sec)
V_a	Airspeed (m/sec)
V_w	Water jet speed at the spray nozzle (m/sec)
V_d	Average water drop speed (m/sec)
x	distance downstream from the spray nozzle (m)

Greek Letters

ρ_w	Water density (gm/cm^3); 1.0 gm/cm^3
δ	Thickness of the Light Sheet (mm)

Subscripts

a	Average spray property
i	Identify $_i$th drop, where $_i$ = 1 to n

EXECUTIVE SUMMARY

Water droplet ingestion into turbine engines resulting from heavy rain and wheel spray generated on a wet runway is of importance. Adverse effects of large quantities of water ingestion can include the compressor stall and combustor flame-out. Engine certification requirements as set forth in FAA regulations call for continued engine operation at takeoff and flight idle conditions while ingesting water at 4 percent by weight of airflow, generated by a spray to simulate rain. There is also a certification requirement on the entire aircraft system which dictates that the system must be designed to prevent hazardous quantities of water from being ingested into the engine during takeoff, landing and taxiing operations on wet runways. The present work was undertaken to develop measurement techniques of two-phase droplet laden airstreams during engine water ingestion. The ultimate objective is to correlate the non-intrusive measurements of the water ingestion rate and droplet size and spatial distribution at the engine inlet with engine performance parameters. Such techniques and data will assist the FAA in evaluating current water ingestion certification tests.

A non-intrusive optical technique was developed for the determination of liquid mass flux in a droplet laden airstream. The technique is also capable of providing information on the droplet size and spatial distribution at the nacelle inlet plane.

Independent measurements of the liquid water content (LWC) of the droplet laden airstream and of the droplet velocities were made at the inlet plane of a simulated nacelle in a wind tunnel for the liquid mass flux determination. The liquid water content was determined by illuminating and photographing the droplets contained within a thin slice of the flow-field by means of a sheet of light from a pulsed laser. Fluorescent dye introduced in the water enhanced the droplet image definition. The droplet velocities were determined from double exposed photographs of the moving droplet field. The technique was initially applied to a steady spray generated in a wind tunnel. It was found that although the spray was initially steady, the aerodynamic breakup process was inherently unsteady. This resulted in a wide variation of the instantaneous liquid water content of the droplet laden airstream. The standard deviation of ten separate LWC measurements was 31 percent of the average. However, the liquid mass flux calculated from the average LWC and droplet velocities came within 10 percent of the known water ingestion rate.

INTRODUCTION

The effects of water droplet ingestion into turbine engines resulting from heavy rain and wheel spray generated on a wet runway is of importance. The effects of water ingestion on engine performance have recently been investigated (reference 1) and a probe for stagnation pressure measurement in a droplet laden airflow was developed (reference 2). The adverse effects of large quantities of water ingestion can include the compressor stall and combustor flame-out (reference 1). Engine certification requirement as set forth in FAA regulations (reference 3) call for continued engine operation at takeoff and flight idle conditions while ingesting water at 4 percent by weight of airflow, generated by a spray to simulate rain. There is also a certification requirement on the entire aircraft system which dictates that the system must be designed to prevent hazardous quantities of water from being ingested into the engine during takeoff, landing, and taxiing operations, (reference 4).

The criteria for both water ingestion certification tests are somewhat arbitrary. The 4 percent by weight water ingestion test for engine certification does not address such issues as droplet size and their spatial distribution over the frontal area of the nacelle. For performance on a wet runway, the criterion is even more arbitrary in that it does not specify what constitutes a hazardous quantity of water ingestion.

The present work was undertaken to develop measurement techniques in two-phase droplet laden airstreams to better quantify the engine water ingestion. The ultimate objective is to correlate non-intrusive measurements of the water ingestion rate and droplet size and spatial distribution at the engine inlet with engine performance parameters. Such techniques and data will assist the FAA in evaluating current water ingestion certification tests.

REVIEW OF APPLICABLE MEASUREMENT TECHNIQUES

A review of available measurement techniques for sprays was undertaken to determine the applicability of the existing techniques to quantitative determination of water ingestion into an engine. The quantities that need to be determined are:

a) Drop size distribution together with spatial distribution of drops at the nacelle inlet.

b) The mass flow rate of water crossing the nacelle inlet plane at any instant.

Extensive work on measurements of wheel sprays generated by aircraft under-carriages was carried out by Barrett (reference 5). A spray intensity probe was developed to measure mean local dynamic pressure generated by moving droplets. However, all of Barrett's measurements were in the near field of the wheel generating the spray and the technique used only provided time averaged <u>local</u> measurements in the spray.

Several mechanical, electrical, and optical methods are available for droplet size determination in fuel sprays as surveyed in review articles by Jones (reference 6) and, McCreath and Beer (reference 7). None of the techniques surveyed would be capable, in their existing form, of satisfying the second requirement above. It was considered possible that the requirement could be met by some modification of the existing techniques.

The first trial approach was an extension of the charged wire probe technique described by Gardiner (reference 8) for drop size determination in water sprays. In that technique, the electrical pulse generated in a circuit containing a charged electrode when a drop impacts the electrode is measured by a pulse height analyzer. The probe is initially calibrated using known size drops impacting the electrode. A relationship is established between the pulse height and the drop size. In practice, the drop size characteristics are derived from the pulse height statistics stored in a pulse height analyzer. The technique as described by Gardiner (reference 8) thus provides the local drop size distribution in a spray. In the present work, a modification of the technique was considered. Instead of a single electrode probe, a charged grid was considered. A copper wire mesh with wire spacing of approximately 1 mm was charged to 2000 volts by a high voltage DC power supply. The idea was to install the screen at the nacelle inlet plane so that all drops larger than the mesh size would be intercepted by the screen. The charge transfer between the screen and the impacting drops would set up a current in the circuit supplying the grid. The current would be proportional to the total surface area of the drops impacting per unit time. Then if the size distribution were to be determined by an independent optical technique, the volume flow rate of water would be proportional to the product of the Sauter Mean Diameter (SMD) of the spray and the current supplied to the grid.

In practice, however, several difficulties were encountered with this technique.

1) The charge distribution on the screen was non-uniform, resulting in different pulse characteristics for different impact locations on the screen for the same size drop.

2) Wetting of the screen altered the initial charge distribution.

3) Water film on the support set up a conduction path from the screen to the ground, causing a leakage current.

Because of these difficulties and the fact that an optical technique was still needed in conjunction with the charged screen for water flow determination, this approach was abandoned in favor of a purely optical non-intrusive technique.

PRESENT TECHNIQUE

A non-intrusive optical technique was developed for the determination of drop sizes, spatial distribution of drops at the nacelle inlet plane and instantaneous mass flow rate of liquid water entering the nacelle. The liquid water mass flow rate is determined by independent measurements of the liquid water content of the droplet laden airstream and the droplet velocity at the nacelle inlet plane.

For liquid water content (LWC) determination, a thin cross-section of the flow close to the nacelle inlet plane is illuminated by a pulsed laser light sheet. The drops contained within this light sheet are photographed by a camera placed with its axis nearly normal to the plane of the light sheet (figure 1). The duration of illumination of drops by the laser pulse is extremely short, about 10 nano second. Therefore, the motion of the drops is frozen in the photographs. The thickness of the laser sheet is controlled by a beam expander and a slit. The slit was of 9 mm width while the initial beam width was 14 mm. The slit thus allowed only the intense central portion of the expanded beam to pass through, cutting off the less intense outer portions.

The depth of field of the camera is set to be larger than the light sheet thickness by proper selection of aperture and magnification. This assures that all illuminated drops (contained within the light sheet) appear in the photographs with a sharp edge definition. The measurement volume is defined by the product of the projected frontal area of the nacelle and the light sheet thickness. Information on drop sizes and spatial distribution is also obtained from this photograph.

When drops are photographed using the optical set up as shown in figure 1, with proper focusing and depth of field selection, the droplet edge definitions in the resulting photographic images are still far from ideal as shown in figure 2. This is caused by two effects:

1) The illumination of individual drops is not uniform, resulting in poor image definition of larger drops.

2) Scattering and diffraction around smaller drops causes a "halo" effect around the drop boundary, causing the image to appear much larger than the actual size.

An improved version of this technique utilizes laser induced fluorescence of a small quantity (less than 10 ppm) of dye (Rhodamine 6G or Fluorescene) introduced in the water. The fluorescence spectrum of the dye lies in a wavelength range longer than that of the incident light, therefore, the incident light scattered from the drops can be filtered out and only the fluoresced light is photographed. Shott colored glass filters are ideally suited for this purpose. This technique results in much better edge definition of droplets in the photographic images and a nearly uniform illumination of droplet interior (see figure 3).

An automated digital image processing system was developed to analyze the photographic images. The image processing algorithm detected drop edges, defined droplet boundaries, calculated the area of the drop images and an equivalent drop diameter based on this area. Droplet size distributions were constructed once statistics on a sufficient number of drops were available. The liquid water content was determined from the total volume of drops contained within the projected area of the nacelle, together with the knowledge of the incident light sheet thickness. A description of the image processing system is presented later in this report.

For the determination of instantaneous mass flow rate of airborne liquid water, a measurement of drop velocities is needed in addition to the LWC measurement. This may be accomplished non-intrusively by laser double pulse photography of the moving droplet field. Two images of each drop appear in the photograph (see figure 4) and the drop velocity may be determined by the measurement of

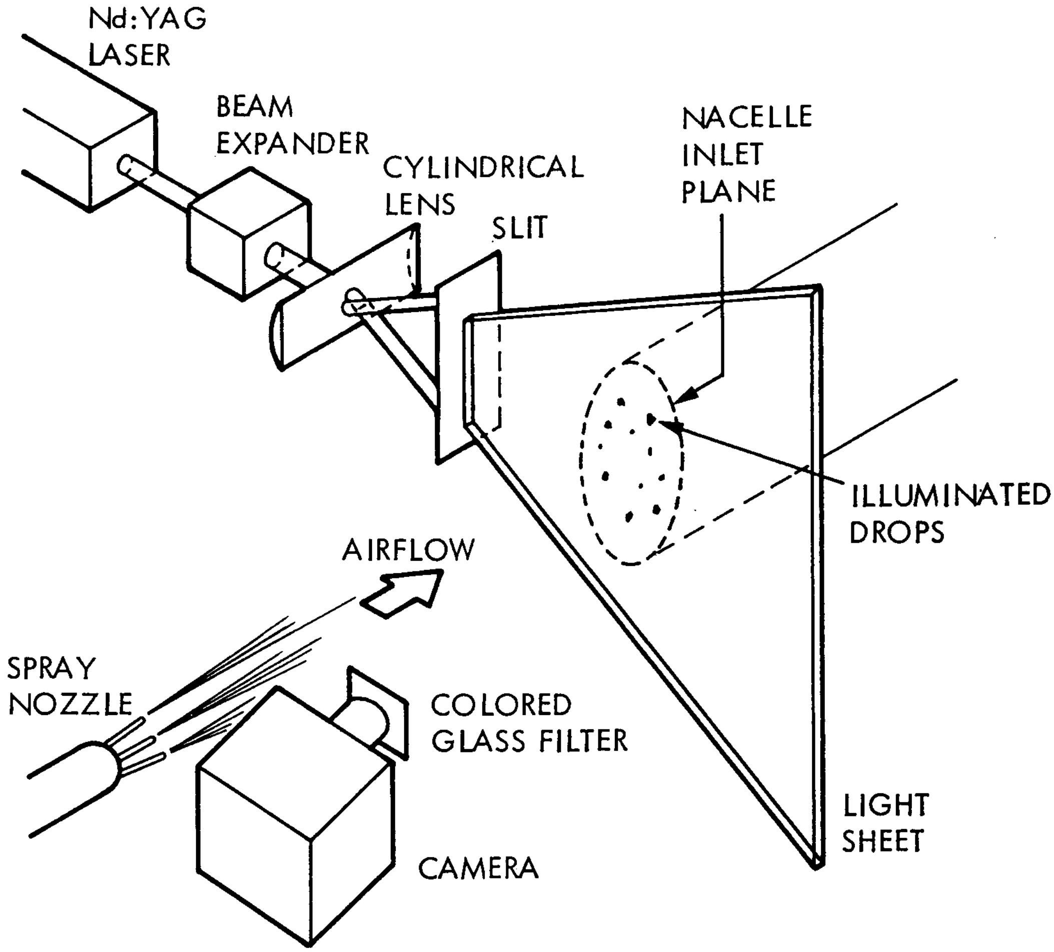

Figure 1. Droplet Illumination and Photographic System

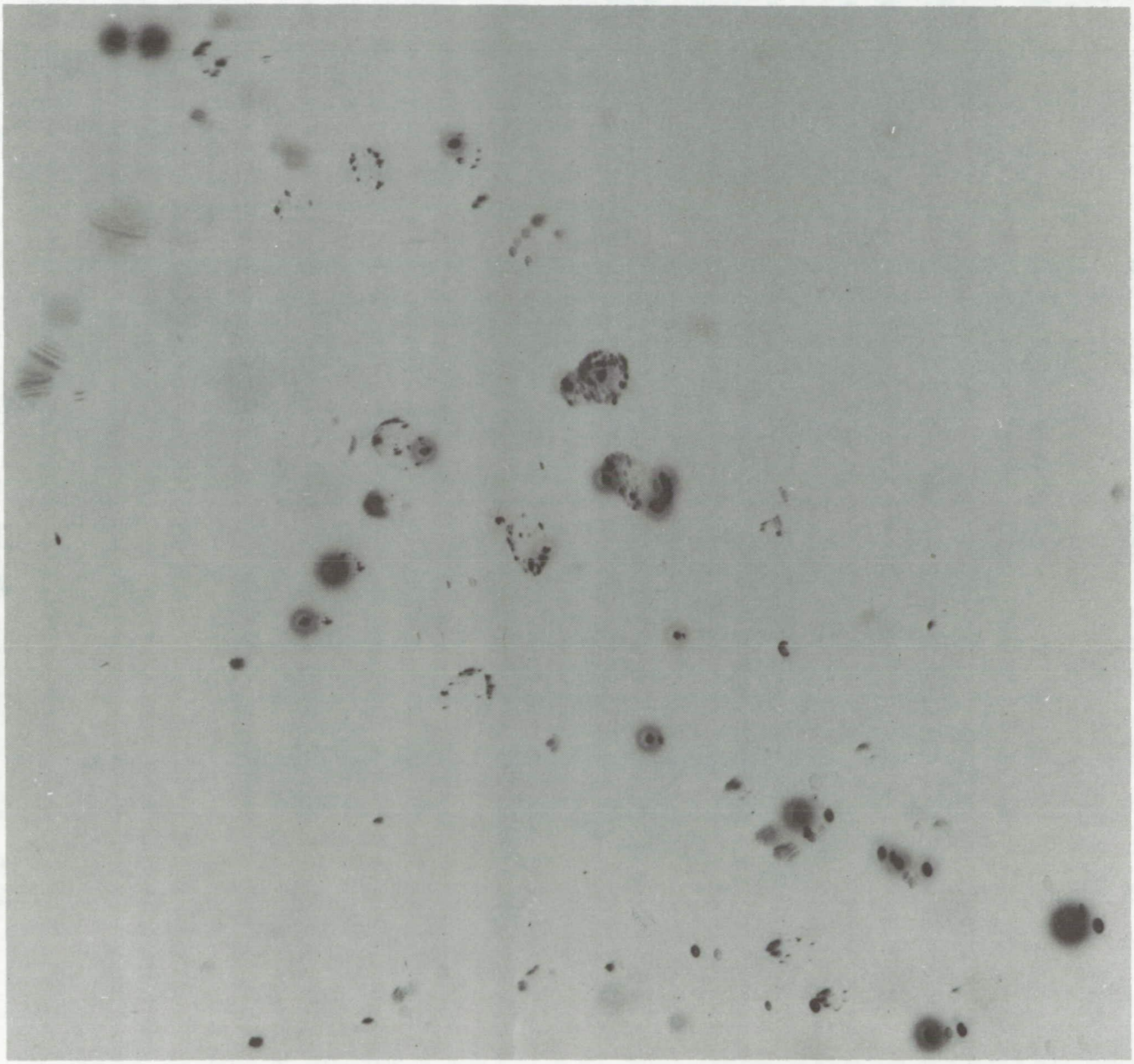

Figure 2. Droplet Photograph Without Fluorescent Dye in the Water

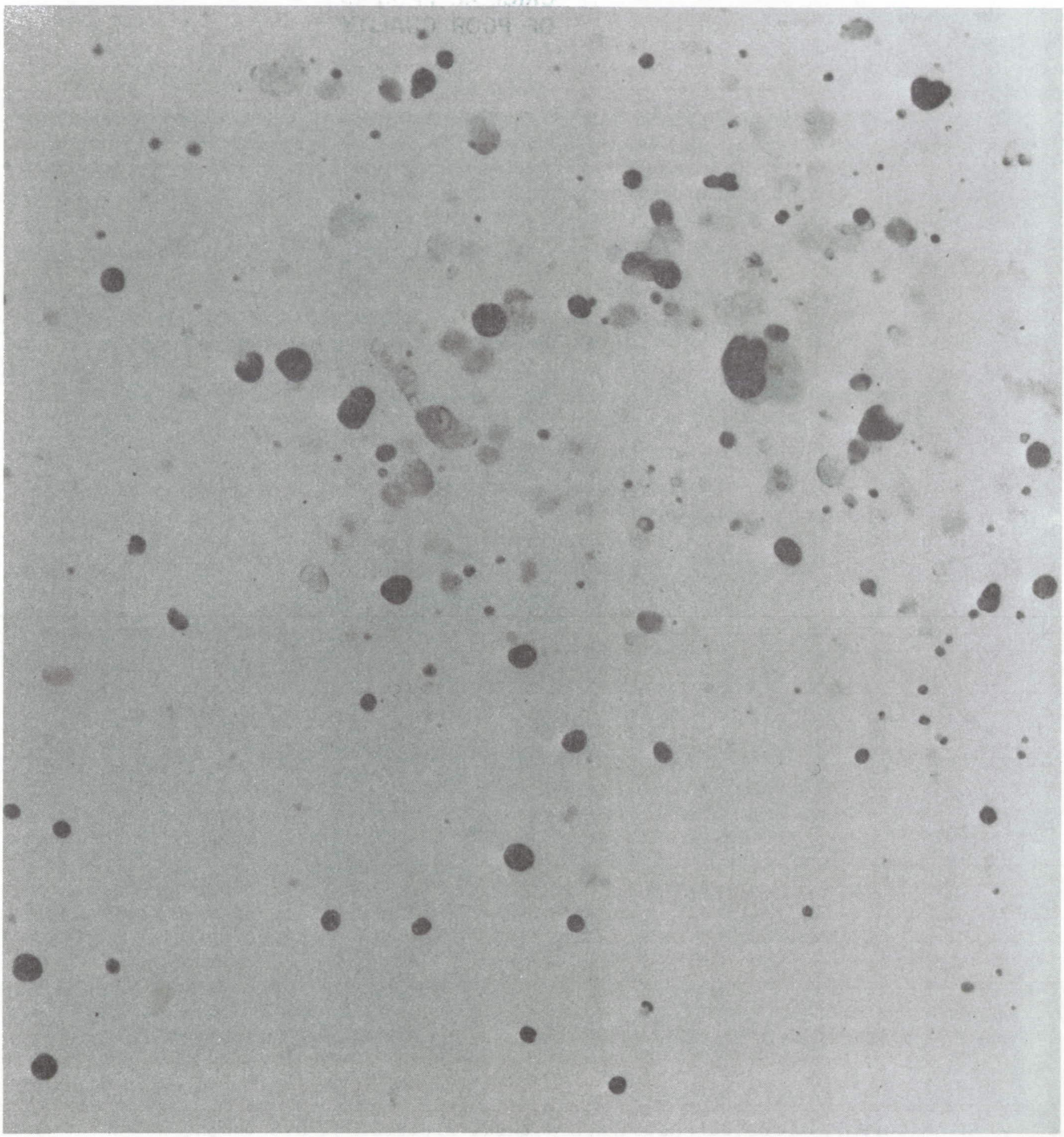

Figure 3. Droplet Photograph With Fluorescent Dye in the Water

ORIGINAL PAGE IS
OF POOR QUALITY

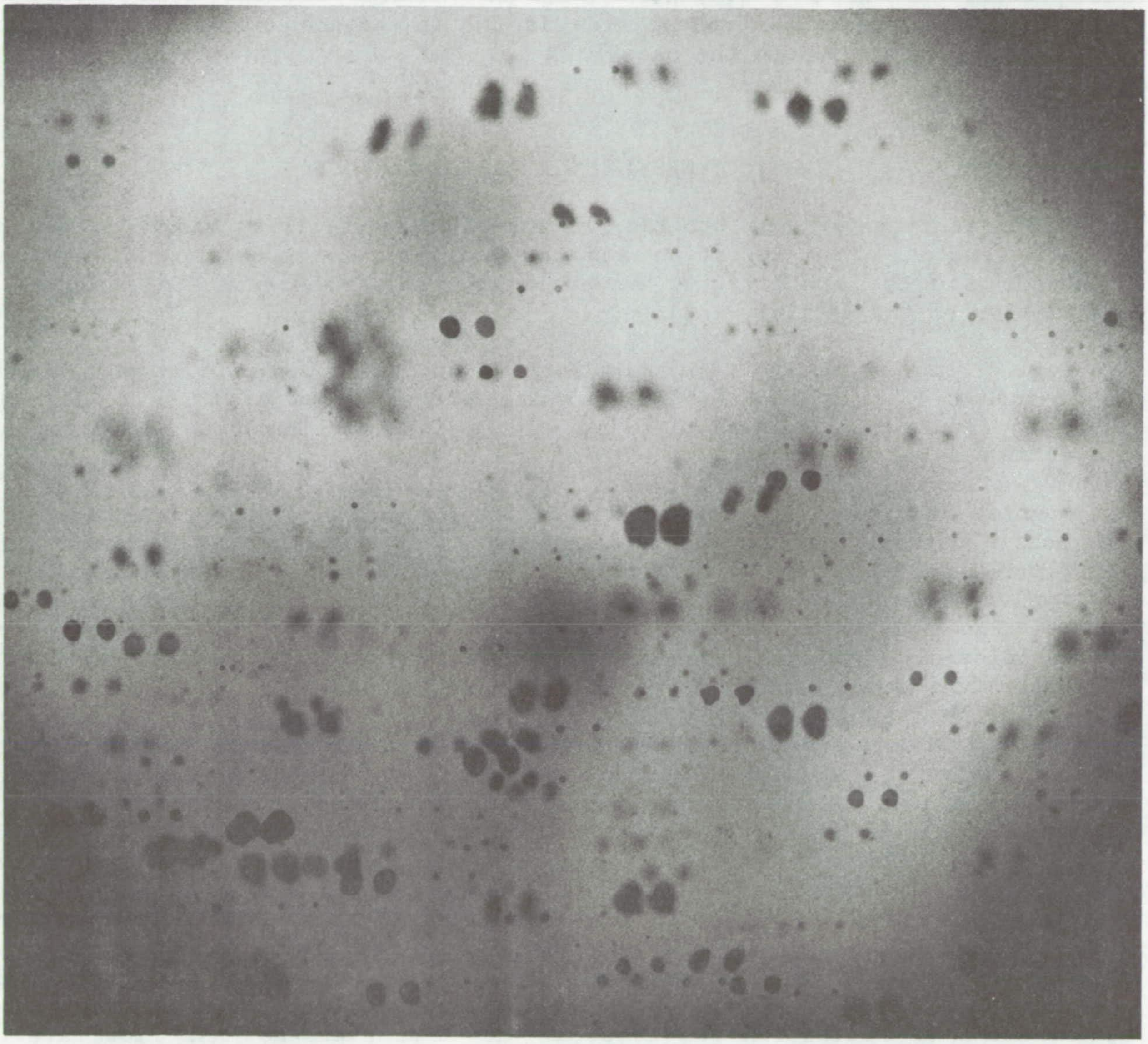

Figure 4. Double Pulse Photograph of Droplets in a Moving Air Stream

the distance translated in a known time interval. Solid-state lasers such as Ruby or Neodymium: yttrium aluminum garnet (Nd:YAG) lasers may be operated in the double pulse mode, wherein the Q-switch is opened twice in rapid succession to split the energy of the flash tube between two intense pulses. The time interval between the two pulses may be adjusted in the range of 50 to 200 μs.

The product of the LWC evaluated over the nacelle frontal area, the drop velocity and the nacelle frontal area is the instantaneous mass flow rate of airborne liquid water into the nacelle.

WATER INGESTION SIMULATION FACILITY

In the first phase of the program, an experimental facility was developed to simulate engine water ingestion and to calibrate the non-intrusive optical technique for the quantitative measurements of engine water ingestion. A description of the facility follows.

The engine water ingestion simulation was set up in an open circuit wind tunnel of 18-inch x 18-inch test section. A schematic diagram of this facility is shown in figure 5. Air was supplied to the test section by a high capacity blower via a settling chamber, screens and a nozzle contraction. The blower output was adjusted by a damper vane ring at the inlet. A water spray nozzle was mounted on a streamlined sting support at the entrance to the test section. The nozzle consisted of seven 2 cm long tubes of 1.6 mm inside diameter. The water was supplied to the nozzle from a pressurized tank via a flowmeter and a ball valve. The individual tubes of the spray nozzle were adjusted such that most of the spray water entered the simulated nacelle with the tunnel running. The droplet-air mixture entering the simulated nacelle passed through a separator box which contained a series of baffle plates. The baffle plates subjected the flow to a series of sharp turns, thereby separating the droplets from the airstream and collecting them in a water film on the plate surfaces. Most of the water entering the nacelle in the form of droplets was collected at the bottom of the separator box. The air was evacuated from the separator box by means of the suction provided by the inlet of a secondary blower. The air from the exit side of the secondary blower was dumped back into the tunnel, downstream of the nacelle location. Calibration checks were made to determine the carry over loss of water in the form of fine drops. For the spray flow rate employed (300 cc/sec), the carry over loss was about 5 percent, with 95 percent of the water sprayed into the nacelle being collected at the bottom of the separator. With a steady spray, the total mass of water collected, divided by the time of collection was close to the time averaged mass flow rate of water entering the nacelle in the droplet-air mixture.

The optical set up is shown in figure 1. The laser sheet of 9 mm thickness was produced in front of the nacelle inlet plane approximately 2 mm from the inlet plane to avoid illuminating the water film on the rounded nacelle entrance. The illuminated droplet field was viewed through the side of the tunnel. The camera axis formed an angle of approximately 20 degrees with the nacelle axis. In viewing the droplet field through the plexiglas wall of the tunnel at such a shallow angle, multiple reflections of illuminated drops were encountered within the plexiglas wall. To alleviate this problem, a window extension was mounted on the tunnel side wall at a 20 degree angle, such that the camera line of sight was normal to the window at the end of the extension.

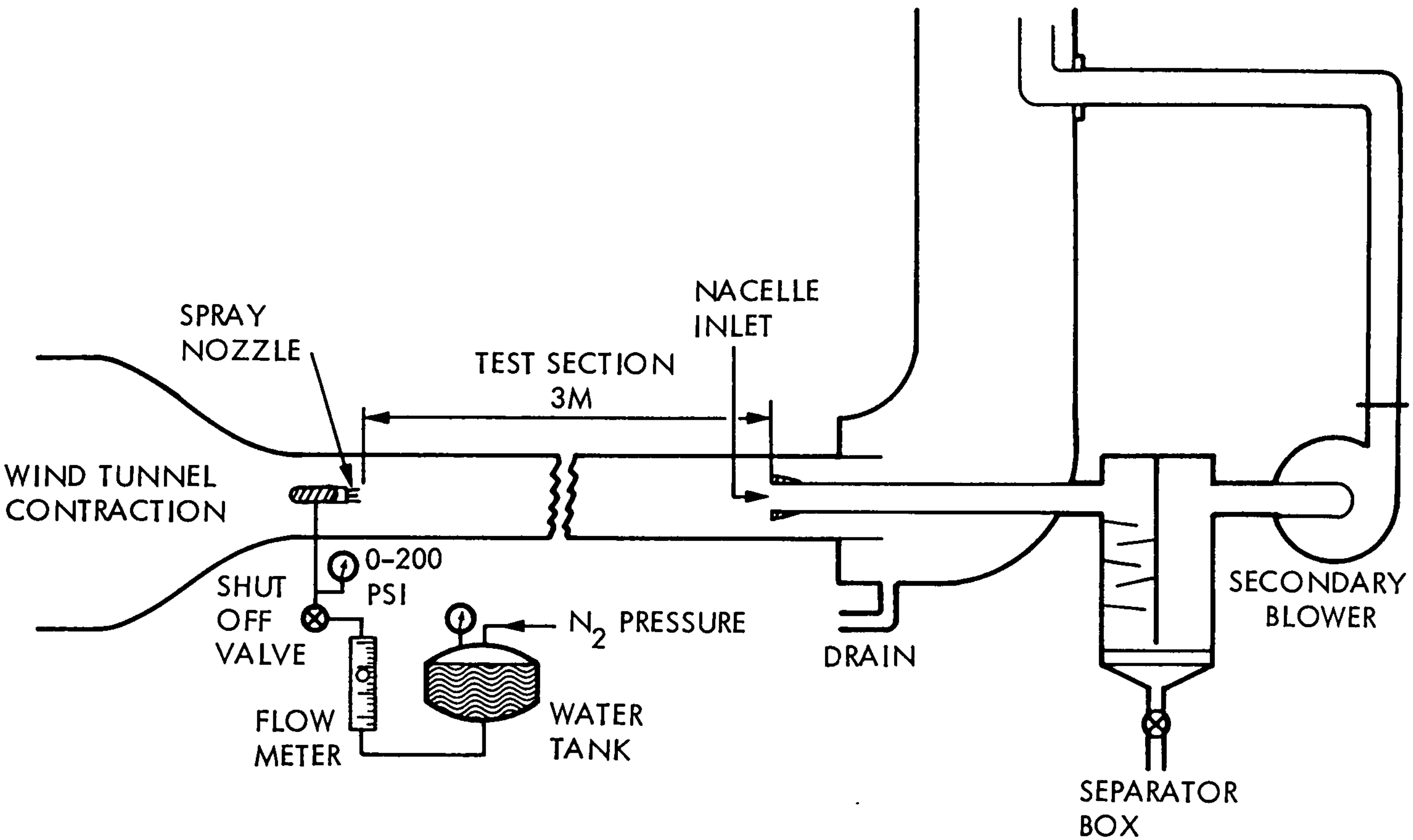

Figure 5. Schematic Diagram of Engine Water Ingestion Simulation Facility

The objective of the experiments was to compare the instantaneous water flow rate into the nacelle as determined by the present non-intrusive optical technique with the known time averaged water flow rate. Ten photographs were taken for a fixed spray rate and airspeed to yield a set of ten successive LWC measurements in a steady spray. The variation in the drop velocities within a given double exposed photograph or between two photographs at fixed tunnel speed and water injection pressure was found to be less than 5 percent. Therefore, a single drop velocity was used for water mass flow rate determination. A sample photograph of droplet field is shown in figure 6. The nacelle boundary was photographed separately and superimposed onto the droplet photograph in figure 6. Notice that the drops within the light sheet are uniformly illuminated and appear with sharp boundaries. Unfortunately, due to light scattered from drops contained in the light sheet and that from the beam dump and the transmitting side plexiglas window, some of the drops outside the laser sheet appear with faint images. During image processing of the photographic negatives, these faint drops, which are present outside the light sheet may easily be eliminated by setting proper threshold criteria.

IMAGE PROCESSING SYSTEM DESCRIPTION

Processing system architecture is depicted in figure 7. Image acquisition, display and processing was accomplished using a De-Anza ID-5400 image processing system. The hardware package incorporates a vidicon and power supply for analog image formation, three image refresh random access memory channels, RAM, digital video array processor, and color video display. The analogue signal from the video camera can be digitized by an A/D converter and fed directly to the array processor which in turn controls the data flow and writes the data into one of the memory planes at a rate of 30 frames/sec. The digitization process converts each picture into 512*512 matrix element (pixels). Each pixel is one byte number (256 resolution level) representing the average optical density in an elementary cell, the size of which dictates the spatial resolution of the system. While digitization can proceed at video rates of 30 frames per second, a program is used which creates one digital frame from the average of 64 consecutive digitized frames. Thus, the image formed has a low level of random noise caused by the vidicon and the digitizer electronics. The digitized image information is then stored on a mass-storage device for further off-line processing.

Software residing in the host computer (PDP 11/34) operates through a direct memory access (DMA), interface through which the PDP-11 sends and receives information from the video processor registers or from the RAM channels via a driver program. The vidicon image digitization, averaging and storage capability is part of this (DMA) interface software.

To study a droplet picture, the negative is taped on to a transparency containing a 1 cm x 1 cm grid formed by fine lines. The grid lines are carefully oriented with respect to the droplet images on the negative such that none of the drop images is intersected by the grid lines. The negative, together with the grid lines, is then mounted on a flat light-table. The vidicon is focused on the plane of the background illuminated negative by means of a macro lens. The magnification on to the vidicon is adjusted such that a 1 cm^2 area of the negative enclosed by the superposed grid lines nearly fills a video frame containing the 512 x 512 pixel array. After accounting for the photographic magnification of the image on the negative and a specification of

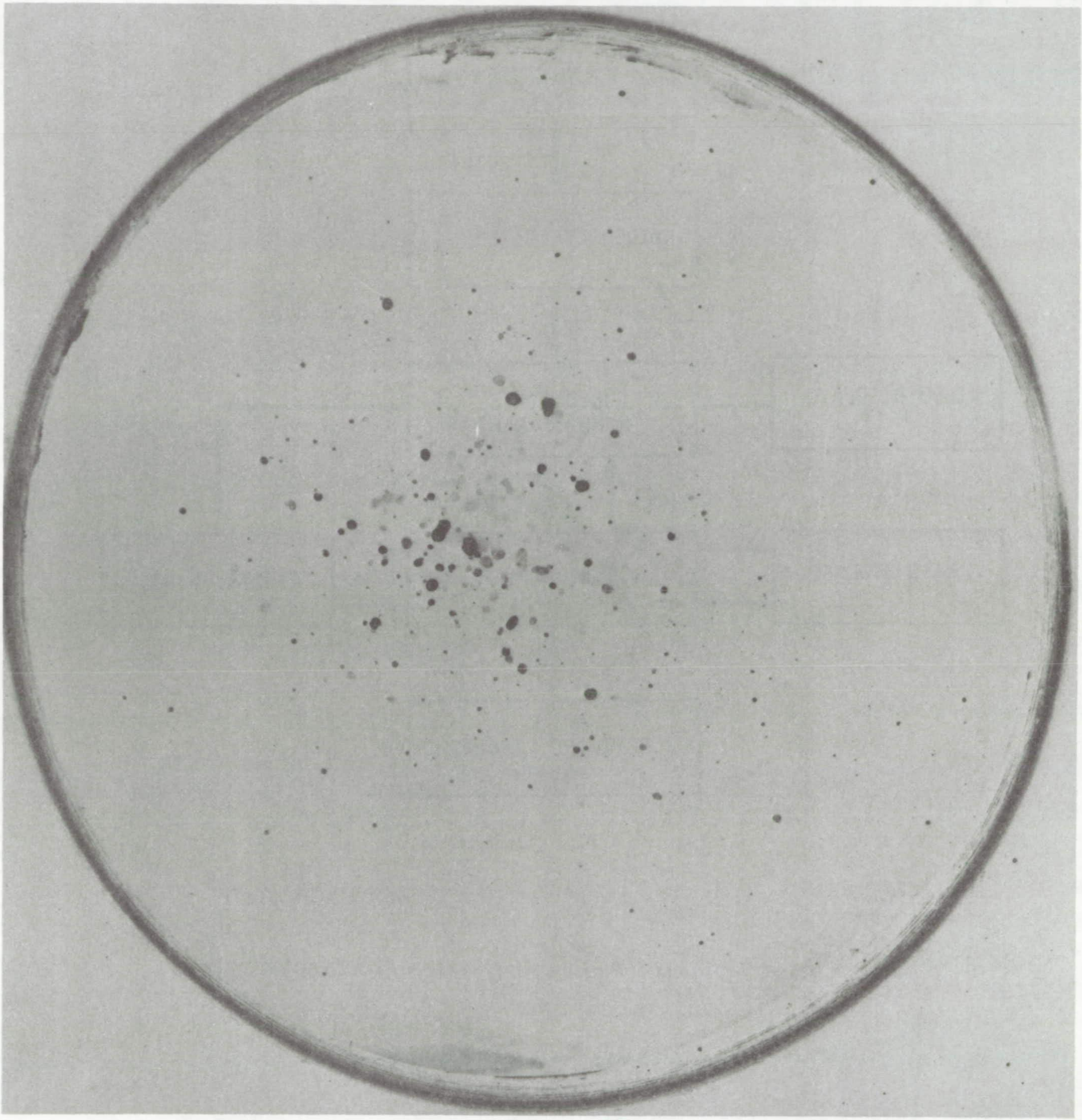

Figure 6. Typical Photograph of the Droplet Field at the Nacelle inlet plane

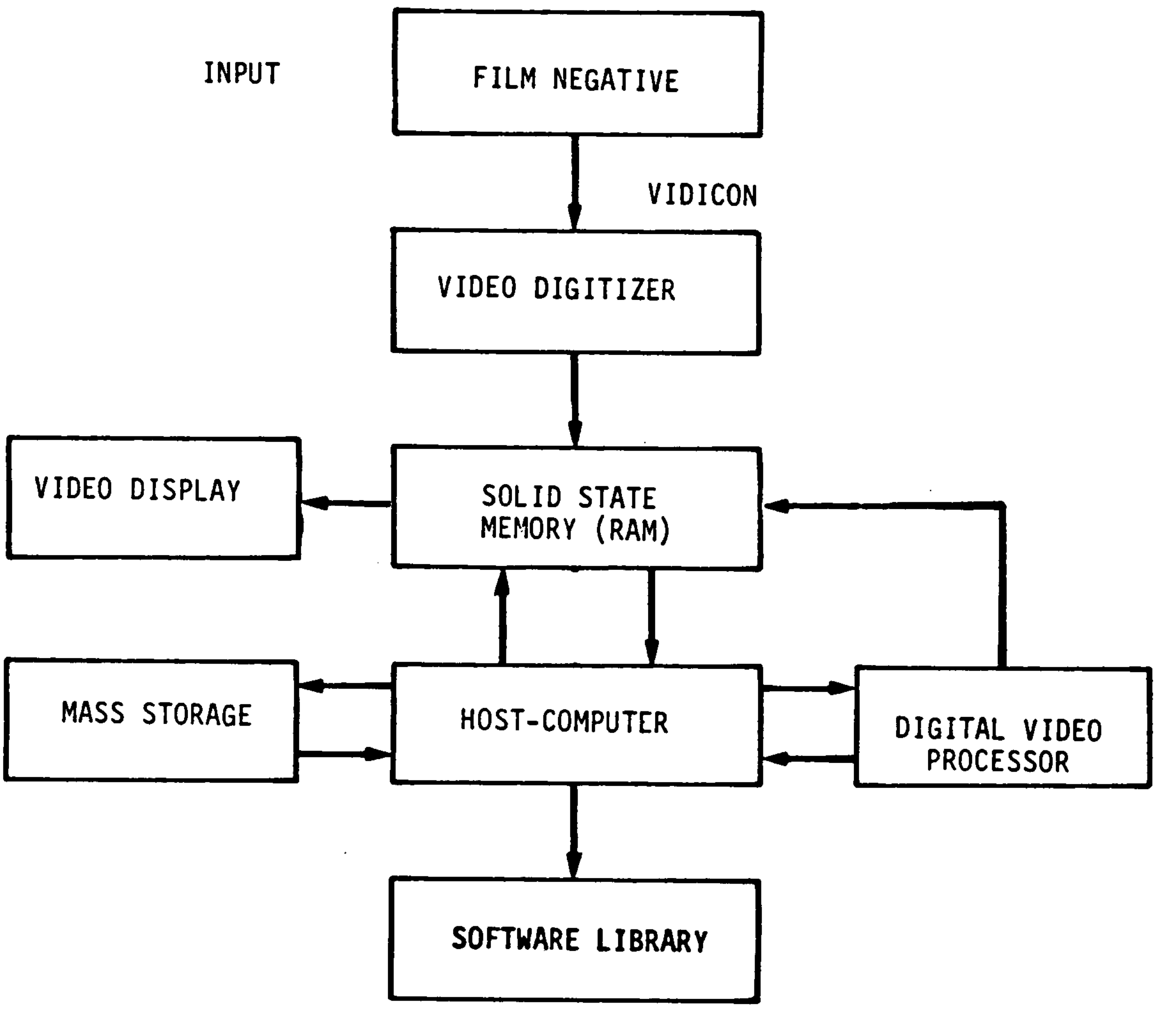

Figure 7. Image Processing System Architecture

4 pixels for the minimum size drop accepted, an overall resolution of 0.1 mm was estimated for the diameter of the smallest drop measured.

The negative was scanned, one grid square at a time over the projected frontal area of the nacelle. The calculated drop volumes were then added up for all the squares to evaluate the liquid water content over the projected frontal area of the nacelle. This procedure ensured that every drop is accounted for and is counted only once. An example of a digital subimage representing one grid square is shown in figure 8. An enhanced image with defined droplet boundaries is shown in figure 9.

Image processing software was developed to detect drop edges, define droplet boundaries, and calculate the area of drop images. The excellent contrast between the images of drops within the light sheet and the background allowed a simple thresholding criterion to define regions containing drop images.

The various image processing programs along with computer program needed for droplet statistics determination are attached under Appendices A and B, respectively.

RESULTS AND DISCUSSION

Results are presented here for fixed values of spray flow rate and airspeed in the wheel spray simulation tunnel. The flow rate through the spray nozzle was maintained constant at 0.3 liters/sec, which resulted in a water jet velocity of 22 m/s based on the total flow area of the seven tubes in the spray nozzle. As discussed later, this flow rate was chosen to simulate extreme cases of engine water ingestion resulting from wheel spray. The airspeed was maintained at 61 m/s. The large difference between the speeds of the air and the water jets caused an aerodynamic breakup of the water jets into small drops, which accelerated along the flow direction to approach the airspeed. The measurement station was located 3 m downstream of the spray nozzle and immediately upstream of the simulated nacelle inlet.

The droplet velocities were determined from a double exposed photograph of the moving droplet field as shown in figure 4. A 100 μs time interval between the two pulses was employed. The droplet velocities were found to be within 5 percent for a large number of droplet pairs. Furthermore, within this small variation of droplet velocities, no correlation was found between the drop velocity and size. A single average value of velocity was assigned to all droplets. This average value was found to be only 41 m/s, i.e., 67 percent of the airspeed. Thus, the 3 m distance between the spray nozzle and the measurement station was insufficient to accelerate the drops to the tunnel airspeed.

A series of ten photographs was taken during the period January-February 1986 for the liquid water content determination. The width of the light sheet was maintained at 9 mm. The photographic negatives were analyzed by the image processing technique discussed in this report. The volume of a drop was calculated as the volume of a spherical drop having the same equivalent diameter. The equivalent diameter was calculated from the image area of each drop. For a non-spherical drop this procedure leads to a higher value of the calculated drop volume. The percentage error introduced therefore depends upon the how different the drop is as compared to the spherical shape.

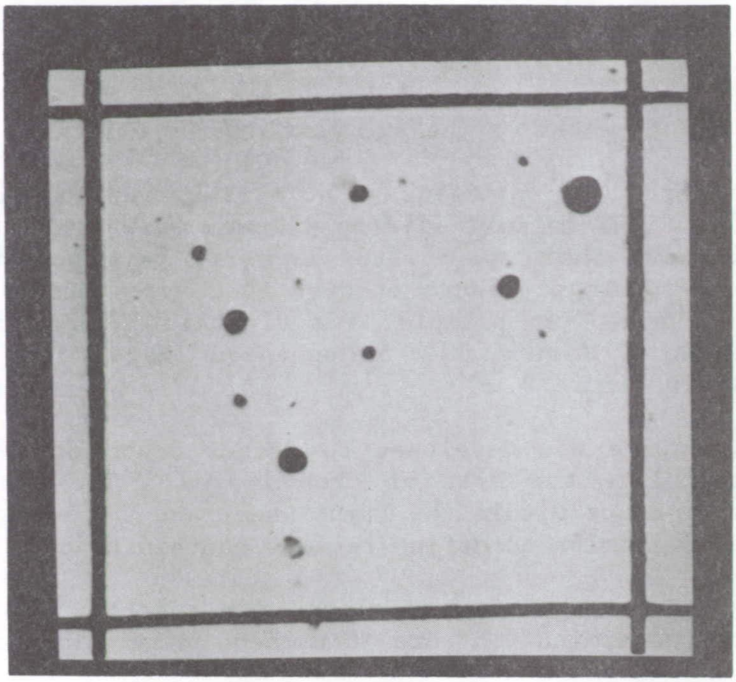

Figure 8. Digital Subimage Representing One Grid Square

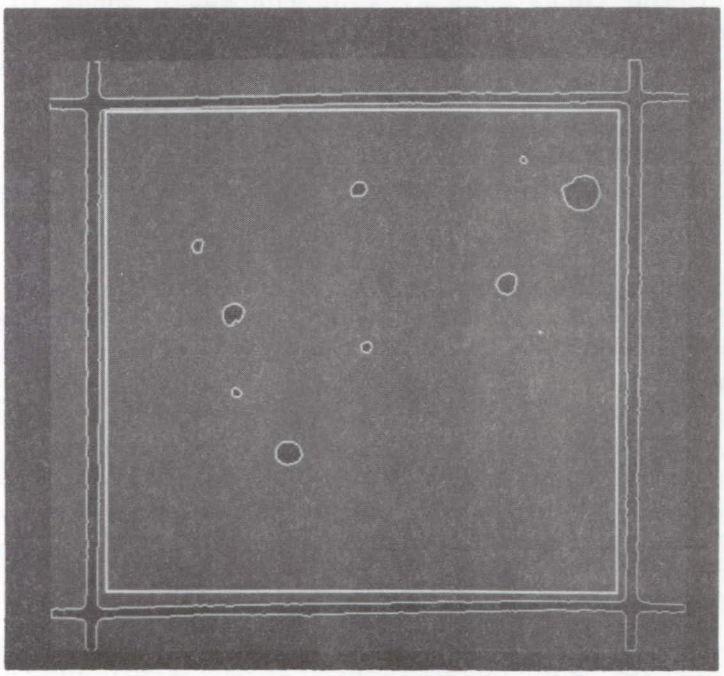

Figure 9. Enhanced Version of Digital Subimage Shown in Figure 8

The results of the image processing analysis are shown in table I. The raw droplet data has been shown under Appendix C. For each of the ten droplet pictures analyzed, the total number of drops counted over the nacelle frontal area, the mean droplet diameter, the volume weighted mean diameter and the total liquid volume are presented. The standard deviation of the mean and volume weighted mean droplet diameters as calculated from the ten pictures was in the range of 7 to 8 percent of the average. This indicated that the picture-to-picture variation of the calculated mean diameter was relatively small. The picture-to-picture variation of the total liquid volume was larger: the standard deviation of the ten measurements was 31 percent of the average. The average value of the total liquid volume from the ten pictures was used to calculate the average liquid water content, i.e.,

$$(LWC)_a = \frac{\rho_w q_w}{A_f . \delta} = 450 \text{ gm/m}^3; \text{ where } \rho_w = 1.0 \text{ gm/cm}^3$$

The average mass flow rate of water was then calculated as

$$\dot{m}_w = (LWC)_a . A_f . V_d$$

$$= 332.5 \text{ gm/sec}$$

The average mass flow rate of water in the moving droplet-air mixture as measured by the present non-intrusive optical technique thus indicates a flow rate approximately 10 percent higher than the actual value of 0.3 l/s. Reasons for this discrepancy between the measured and the actual mass flow rates are discussed below. It should be noted however, that there is a significant picture-to-picture variation in the instantaneous water mass flow rate determinations caused by measured variations in the instantaneous LWC values. The test droplet spray was quite dense in comparison with the certification requirement of 4 percent by weight of liquid water in the airstream. The present 0.3 l/s water ingestion rate in a 61 m/s airstream over the frontal area of the 15.24 cm diameter nacelle translates to a water flow rate/airflow rate ratio of 22.5 percent. Such a high water spray rate was used to simulate extreme cases of engine water ingestion resulting from wheel spray.

There are three factors that affect the accuracy of LWC measurement by the present technique:

1) Droplets largely outside the light sheet but at the boundary are partially grazed by the light sheet and show up on photographs, thus increasing the LWC measured.

2) The procedure for calculation of drop volume from its non-spherical images on the photograph relies on an equivalent diameter which is calculated from the enclosed area of the image. This procedure tends to over-predict the volume of the non-spherical drop and hence leads to a higher value of measured LWC.

3) The illuminated drops contained in the light sheet are viewed by the camera through a dense spray. Therefore, there is a possibility of some illuminated drops being masked by droplets present in the view path of the camera. This masking will result in a lower value of the measured LWC.

TABLE I

Summary of Data Photographs

V_a = 61 m/s; V_w = 21.7 m/s; Q_w = 300 cm^3/sec; x = 3 m; A_f = 182.4 cm^2;
δ = 9 mm

Negative No.	No. of Drops -	Mean Dia. mm	Vol. Mean Dia. mm	Total Liquid Vol. mm^3
1	267	0.55	0.89	97.4
2	207	0.58	0.86	68.2
3	256	0.51	0.87	89.0
4	155	0.58	0.86	52.3
5	179	0.63	0.92	88.0
6	212	0.56	0.88	75.0
7	243	0.59	0.91	95.7
8	128	0.50	0.68	21.5
9	337	0.53	0.80	91.8
10	169	0.60	0.87	57.8
	Average:	0.56	0.85	73.7
	Standard Deviation:	0.04	0.066	23.0
	Std Dev. percent of Mean:	7.0	7.8	31.0

NOTE: Mean Dia. $= \frac{\Sigma n_i D_i}{\Sigma n_i}$; Vol. Mean Dia. $= \frac{\Sigma n_i D_i{}^4}{\Sigma n_i D_i{}^3}$

Total Liquid Vol. $= \Sigma n_i \frac{\pi}{6} D_i{}^3$

Despite these three sources of errors, the present non-intrusive technique is still considered a good method for measurement of the liquid water flow rate in a moving droplet-laden airstream.

The droplet size distribution determined from the more than 2000 drops counted in the ten pictures is shown in figure 10.

CONCLUDING REMARKS

1) A non-intrusive optical technique has been developed for quantitative determination of instantaneous liquid water mass flow rate in a droplet laden airstream. The technique is generally applicable to the problem of water ingestion into an engine resulting in up to 22% water by weight (rain or wheel spray).

2) The technique yields instantaneous spatial distribution of droplets at the nacelle inlet plane as well as the droplet size distribution.

3) Significant variation in the instantaneous values of the liquid water content was encountered in a droplet laden airstream produced by injection of a steady water spray in a steady airstream. The standard deviation among ten separate instantaneous determinations of the LWC was 31 percent of the average LWC.

4) The average liquid water flow rate as determined from the average LWC and drop velocity measurements was approximately 10 percent higher than the actual spray flow rate.

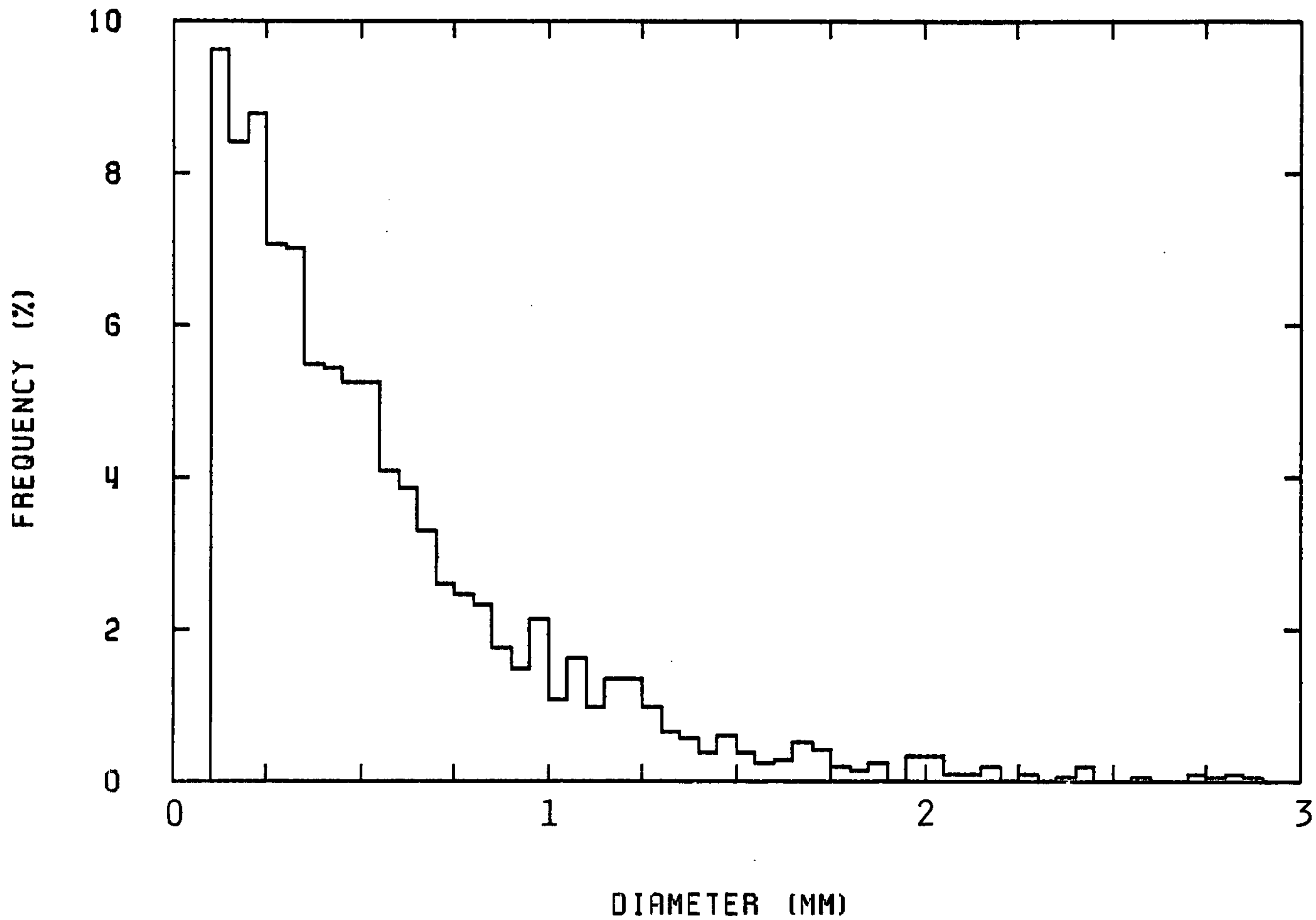

Figure 10. Droplet Size Distribution at the Nacelle Inlet Plane

REFERENCES

1. Murthy, S.N.B. and C.M. Ehresman: Effects of Water Ingestion into Jet Engine. AIAA paper No. 84-0542 presented at the Airbreathing Propulsion Session of the 22nd Aerospace Sciences Meeting, January 1984.

2. Murthy, S.N.B. et.al.: A Stagnation Pressure Probe for Droplet-laden Air Flow. AIAA paper No. 85-0330 presented at the Airbreathing Propulsion Session of the 23rd Aerospace Sciences Meeting, January 1985.

3. Code of Federal Regulations, Title 14-Aeronautics and Space, Chapter 1-Federal Aviation Administration, Article 33.77, paragraphs (c) and (f). January 1980.

4. Code of Federal Regulations, Title 14-Aeronautics and Space, Chapter 1-Federal Aviation Administration, Article 25.1091, paragraph (d)(2). January 1980.

5. Barrett, R.V.: Spray From Aircraft Undercarriages at High Speed - a Model Investigation. The Aeronautical Journal, Royal Aeronautical Society, May 1977.

6. Jones, A.R.: A Review of Drop Size Measurement - The Application of Techniques to Dense Fuel Sprays. Progress in Energy and Combustion Science. Vol. 3. 1977.

7. McCreath, C.G. and J.M. Beer: A Review of Drop Size Measurement in Fuel Sprays. Applied Energy, Vol. 2. 1976.

8. Gardiner, J.A.: Measurement of the Drop Size Distribution in Water Sprays by an Electrical Method. Instrument Practice. April 1964.

APPENDIX A

IMAGE ANALYSIS PROGRAMS

```
0001            PROGRAM DROPS
          C
          C     Drops analysis based on averaged maximum gradient
          C
0002            LOGICAL*1 ANSA,ANSO
0003            BYTE ZERO
0004            REAL*8 HIST(0:255),DMAXO
0005            BYTE BUPIC(512),BUGRA(512)
0006            BYTE PIXEL(512,16)
0007            COMMON/PINTA/PIXEL
0008            INTEGER*2 IVLT(256)
0009            INTEGER*2 ARMIN
0010            INTEGER*2 IBUFO(8)! Basic data processing parameters
0011            EQUIVALENCE (IBUFO(1),KREDC)
0012            EQUIVALENCE (IBUFO(2),SCALE)
0013            EQUIVALENCE (IBUFO(4),ARMIN)
0014            EQUIVALENCE (IBUFO(5),ICORTA)
0015            INTEGER*2 SL,SS,NL,NS
0016            REAL*4 ABUF(200),PBUF(200)
0017            INTEGER*2 LIMIT(4,200)
0018            COMMON/MINARE/AMINAR
0019            INTEGER*2 IBUFE(8),PL,PC,CL,CC
0020            REAL*4 AREA,PERIM
0021            EQUIVALENCE (IBUFE(1),PL)
0022            EQUIVALENCE (IBUFE(2),PC)
0023            EQUIVALENCE (IBUFE(3),CL)
0024            EQUIVALENCE (IBUFE(4),CC)
0025            EQUIVALENCE (IBUFE(5),AREA)
0026            EQUIVALENCE (IBUFE(7),PERIM)
          C
          C
          C     Open data file
          C
0027            OPEN (UNIT=3,NAME='SY:[300,300]RAIN.DAT',TYPE='OLD',
                1 DISP='KEEP',ACCESS='DIRECT',RECORDSIZE=4,FORM='UNFORMATTED')
0028            READ(3'1) IBUFO
0029            IF (KREDC.NE.0) GO TO 900
0030            KREDC=1! Initial record for parameters storage,no data
0031            ARMIN=5! Default min area
0032            ICORTA=5
0033            SCALE=1
0034            TYPE *,' Processing parameters initialization, defaults are:'
0035            TYPE *,' Min area 5 Sq. pixels, Scale 1 mm/pixel; Change (Y/N)!'
0036            ACCEPT 101,ANSA
0037            IF (ANSA.NE.'Y') GO TO 111
0038            TYPE *,' Enter Min area (Sq. pix) and Scale (mm/pix)'
0039            ACCEPT *,ARMIN,SCALE
0040            GO TO 111
0041      900   TYPE *,' File has already data, Stops execution (Y/N)'
0042            ACCEPT 101,ANSA
0043            IF (ANSA.EQ.'Y') GO TO 950

          C
          C     First detector
          C
0044      111   TYPE *,' Begin coarse detection'
```

ORIGINAL PAGE IS
OF POOR QUALITY


```
                CALL SETUP
                TYPE *,' Smoothing before compute gradient (Y/N)'
                ACCEPT 101,ANSA
                IF (ANSA.EQ.'N') GO TO 4
                CALL SMOOTH
                GO TO 5
        4       DO 3 K=1,256
        3       IVLT(K)=K/2
                CALL VLTCOR(1,IVLT)
        C
        C       Save original picture
        C
        5       CALL SETUP
                OPEN (UNIT=7,TYPE='SCRATCH',ACCESS='DIRECT',INITIALSIZE=512,
                1RECORDSIZE=128)
                NBLK=1
                DO 10 K=1,32
                LIN=(K-1)*16+1
                ICOD=IMAGE(0,LIN,16,'R',PIXEL)
                ISTAT=JESC(7,PIXEL,NBLK,4096,1,NBLK)
        10      CONTINUE
        C
        C       Transfer smooth picture to channel 0
        C
                CALL SETUP
                CALL INSEL(2,8,0)
                CALL OUTNBL(1)
                CALL FMOPER
        C
        C       Compute gradient
        C
                CALL SETUP
                CALL GRADIE
        C
        C       Restore original picture
        C
                CALL SETUP
                NBLK=1
                DO 20 K=1,32
                LIN=(K-1)*16+1
                ISTAT=JLEE(7,PIXEL,NBLK,4096,1,NBLK)
                ICOD=IMAGE(0,LIN,16,'W',PIXEL)
        20      CONTINUE
        C
        C       Threshold gradient picture
        C
                CALL SETUP
                CALL INSEL(1,8,0)
                CALL OUTNBL(4)
                CALL FMOPER
                CALL SETUP
        50      TYPE *,' Threshold gradient image',ICORTA
                CALL SETUP
                DO 51 JLT=1,ICORTA
        51      IVLT(JLT)=0
                DO 52 JLT=ICORTA+1,256
```

```
52      IVLT(JLT)=255
        CALL VIDTHR(1,IVLT)
        TYPE *,' Accept threshold (y/n)'
        ACCEPT 1Ø1,ANSA
        IF (ANSA.NE.'N') GO TO 6Ø
        TYPE *,' Enter gradient image threshold'
        ACCEPT *,ICORTA
        GO TO 5Ø
1Ø1     FORMAT(A1)
6Ø      CALL SETUP
        DO 7Ø JLT=ICORTA+1,256
7Ø      IVLT(JLT)=JLT-1
        CALL VLTCOR(1,IVLT)
        CALL SETUP
C
C       Save gradient picture
C
        NBLK=1
        DO 8Ø K=1,32
        LIN=(K-1)*16+1
        ICOD=IMAGE(1,LIN,16,'R',PIXEL)
        ISTAT=JESC(7,PIXEL,NBLK,4Ø96,1,NBLK)
8Ø      CONTINUE
C
C       Remove background variations
C
        TYPE *,' Remove background variations (Y/N)'
        ACCEPT 1Ø1,ANSO
        IF (ANSO.NE.'N') GO TO 85
        CALL INSEL(2,8,Ø)
        CALL OUTNBL(4)
        CALL FMOPER
        CALL SETUP
        CALL INSEL(1,8,Ø)
        CALL OUTNBL(2)
        CALL FMOPER
        CALL SETUP
        GO TO 88
85      ISD=1ØØ ! Variations scale
        CALL HIGPAS(ISD,1,Ø)
        CALL SETUP
C
C       Restore gradient picture
C
        NBLK=1
        DO 12Ø K=1,32
        LIN=(K-1)*16+1
        ISTAT=JLEE(7,PIXEL,NBLK,4Ø96,1,NBLK)
        ICOD=IMAGE(2,LIN,16,'W',PIXEL)
12Ø     CONTINUE
C
C       Compute Histogram
C
88      ZERO=*Ø
        TYPE *,' Computing modified PDF'
        DO 9Ø K=Ø,255
```

```
      90     HIST(K)=0.
             DO 150 K=10,500
             ICOD=IMAGE(1,K,1,'R',BUPIC)
             ICOD=IMAGE(2,K,1,'R',BUGRA)
             DO 150 J=10,500
             IF (BUGRA(J).EQ.ZERO) GO TO 150
             A=IV(BUGRA(J))
             II=IV(BUPIC(J))
             HIST(II)=HIST(II)+II*A
     150     CONTINUE
     C
     C       Display histogram and threshold determination
     C
             DMAXO=0.
             DO 180 K=0,255
             IF (HIST(K).GT.DMAXO) DMAXO=HIST(K)
     180     CONTINUE
             DO 182 K=0,255
             HIST(K)=HIST(K)/DMAXO
     182     CONTINUE
             CALL INSEL(1,8,0)
             CALL OUTNBL(4)
             CALL FMOPER
             CALL SETUP
             DO 160 K=1,256
     160     IVLT(K)=0
             CALL VIDTHR(1,IVLT)
             ITHR=0
             CALL DISHIS(HIST,ITHR)
             TYPE *,' Enter (1) simple, (2) bimodal distribution'
             ACCEPT *,IMODES
             CALL SEUISO(HIST,ITHR,IMODES)
     300     TYPE *,' Estimated threshold',ITHR
             CALL SETUP
             DO 301 JLT=1,ITHR
     301     IVLT(JLT)=0
             DO 302 JLT=ITHR+1,256
     302     IVLT(JLT)=255
             CALL VLTCOR(1,IVLT)
             CALL SETUP
             IVLT(1)=0
             IVLT(256)=1
             CALL VLTCOR(1,IVLT)
             CALL SETUP
             CALL BORDEA(IVLT)
             CALL SETUP
             CALL DISHIS(HIST,ITHR)
             TYPE *,' Accept threshold (Y/N)'
             ACCEPT 101,ANSA
             IF (ANSA.NE.'N') GO TO 350
             TYPE *,' Enter threshold'
             ACCEPT *,ITHR
             IF (ANSO.NE.'N') GO TO 320
             CALL INSEL(1,8,0)
             CALL OUTNBL(2)
             CALL FMOPER
```

```
              CALL SETUP
              GO TO 300
      320     CALL HIGPAS(ISD,1,0)
              CALL SETUP
              GO TO 300
      350     TYPE *,' Default region the entire picture; change (Y/N)'
              ACCEPT 101,ANSA
              IF (ANSA.EQ.'Y') GO TO 400
              SL=1
              SS=1
              NL=510
              NS=510
              GO TO 450
      400     TYPE *,' Use cursor to define region/push white key'
              CALL REGIO(SL,SS,NL,NS)
C
      450     AMINAR=ARMIN
              TYPE *,' Region definition SL=',SL,' SS=',SS,' NL=',NL,' NS=',NS
              IVLT(1)=0
              IVLT(2)=255
              IVLT(256)=255
              CALL VLTCOR(1,IVLT)
              CALL SETUP
              TYPE *,' Computing drops size'
              CALL GOTAS(1,SL,SS,NL,NS,ABUF,PBUF,LIMIT,NUMOBJ)
              IVLT(1)=0
              IVLT(256)=1
              CALL VLTCOR(1,IVLT)
              CALL BORDEA(IVLT)
              CALL SETUP
              TYPE *,' End coarse detector'
      800     CLOSE(UNIT=7)
C
C             Save results on disk
C
      2000    NUMDR=0
              SCALE2=SCALE*SCALE
              TYPE *,' DATABASE: Initial element',KREDC
              DO 2001 K=1,NUMOBJ
              NUMDR=NUMDR+1
              KREDC=KREDC+1
              PL=LIMIT(1,K)
              PC=LIMIT(2,K)
              CL=LIMIT(3,K)
              CC=LIMIT(4,K)
              AREA=ABUF(K)*SCALE2
              PERIM=PBUF(K)*SCALE
              WRITE(3'KREDC) IBUFE
              IF (KREDC.EQ.1201) GO TO 2025
      2001    CONTINUE
      2025    TYPE *,' DATABASE: Final element',KREDC-1
              TYPE *,' Number of objects in this frame',NUMDR
              WRITE(3'1) IBUF0!Update general information record
      950     CLOSE(UNIT=3)
              END
```

```
      SUBROUTINE GOTAS(CHAN,SL,SS,NL,NS,ABUF,PBUF,LIMIT,NUMOBJ)
C
C     Drops geometrical caracterization
C
      INTEGER*2 CHAN,SL,SS,NL,NS
      BYTE PIXEL(512,16)
      COMMON /PINTA/PIXEL
      INTEGER*2 FLAG(512,2),ID(30)
      INTEGER*2 ISLS(90),ISSS(90),EL(90),ES(90)
      INTEGER*2 CNTR(90,2),BEGIN(90,2),IEND(90,2)
      INTEGER*2 OLDID,NEWID
      INTEGER*4 NPIXS(90)
      REAL*4 RPER(90)
      REAL*4 ABUF(1),PBUF(1)
      INTEGER*2 LIMIT(4,1)
C
C      Initializa
C
      CALL ZIA(FLAG(1,1),1024)
      CALL ZIA(RPER,180)
      CALL ZIA(NPIXS,180)
      CALL ZIA(EL,90)
      CALL ZIA(ES,90)
      CALL ZIA(CNTR(1,1),180)
      CALL ZIA(BEGIN(1,1),180)
      CALL ZIA(IEND(1,1),180)
      CALL ITIA(32000,ISLS,90)
      CALL ITIA(32000,ISSS,90)
      NUMOBJ=0
      ISW=1
      NEWC=0
      NOLC=0
      OLDID=1
      NSS=SS+NS
      NSL=SL-1
      NLL=NSL+NL
C
C        Main loop
C
      DO 100 L=1,NL,16
      IBLOCK=MIN0(16,NL-L)
      LINE=L+NSL
      ICOD=IMAGE(CHAN,LINE,IBLOCK,'R',PIXEL)
      DO 100 KK=1,16
      N1=SS
      LINIA=LINE+KK-1
      NEWC=0  ! Start searching for an object gt 0
105   DO 110 J=N1,NSS ! look for left edge
      IF (PIXEL(J,KK)) GO TO 120
110   CONTINUE
C       No more edges on this line
      GO TO 103
120   N1=J ! Left edge
      DO 130 J=N1,NSS !  Look righ edge
      IF (.NOT.PIXEL(J,KK)) GO TO 140
130   CONTINUE
```

```
                J=NSS+1 ! Righ edge is the picture boundary
      140       N2=J-1
      C
      C           Find ID of this object from previous flag line
      C
                CALL MATCH(FLAG(1,3-ISW),N1,N2,NUM,ID,NSS)
                NEWID=ID(1)
                IF (NUM.LT.2) GO TO 101
      C
      C           If many ID condense them into one
                CALL CONID(RPER,NPIXS,ISLS,ISSS,EL,ES,NUM,ID)
                GO TO 102
      101       IF (NUM.NE.0) GO TO 102
      C
      C           If threre is not ID them creates one
                CALL FIND(90,NEWID,NPIXS,OLDID)
      C
      C         begin counting perimeter new object
                RPER(NEWID)=N2-N1+2
      C
      C         And update flag buffer and counters
      102       CALL ITIA(NEWID,FLAG(N1,ISW),N2-N1+1)
                NEWC=NEWC+1
                CNTR(NEWC,ISW)=NEWID
                BEGIN(NEWC,ISW)=N1
                IEND(NEWC,ISW)=N2
      C
      C         Update statistics buffer
                NPIXS(NEWID)=NPIXS(NEWID)+N2-N1+1
                IF (ISLS(NEWID).GT.LINIA) ISLS(NEWID)=LINIA
                IF (ISSS(NEWID).GT.N1) ISSS(NEWID)=N1
                IF (ES(NEWID).LT.N2) ES(NEWID)=N2
                EL(NEWID)=LINIA
                CALL PERIM(NOLC,NEWC,CNTR(1,ISW),NEWID,RPER,BEGIN(1,3-ISW),
                1 BEGIN(1,ISW),IEND(1,3-ISW),IEND(1,ISW))
      C
      C          Send back for more data on the same line
                N1=N2+2
                IF (N1.LE.NSS) GO TO 105
      C
      C          Search buffers for terminated drops
      C
      103       CALL ENOFLI(RPER,NPIXS,ISLS,ISSS,EL,ES,NLL,LINIA,CNTR(1,3-ISW),
                1       CNTR(1,ISW),NOLC,NEWC,NUMOBJ,BEGIN(1,3-ISW),BEGIN(1,ISW),
                2         IEND(1,3-ISW),IEND(1,ISW),ABUF,PBUF,LIMIT)
                CALL ZIA(FLAG(1,3-ISW),512) ! Zero flag line
                ISW=3-ISW  ! Switch the flag
                NOLC=NEWC
      100       CONTINUE ! Close main loop
                RETURN
                END
```

```
FORTRAN IV-P        V02-51          19:01:30     04-APR-85              P      1
MATCH.FTN           /TR:BLOCKS/WR

            SUBROUTINE MATCH(FLAG,N1,N2,NUM,ID,NS)
C
C     RETURN I.D. OF OBJECT FOUND ON PREVIOUS LINE
C     FLAG = OLD FLAG BUFFER
C     N1 = BEGIN, N2 = END  OF OBJECT
C     NUM = NUMBER OF OBJECTS LOCATED
C     ID = I.D. OF OBJECTS LOCATED
            INTEGER FLAG(1)
            INTEGER*4 ID(1)
            M1 = N1 - 1
            M2 = N2 + 1
            IF (M1.LT.1) M1 = 1
            IF (M2.GT.NS) M2=NS
            NUM = 0
            K = 0
C
C     FIND ALL FLAGS
C
            DO 10 J=M1,M2
            IF (FLAG(J).EQ.K) GO TO 10
            IF (FLAG(J).EQ.0) GO TO 10
            K = FLAG(J)
            NUM = NUM + 1
            ID(NUM) = K
   10       CONTINUE
            IF (NUM.LT.2) RETURN
C
C     REJECT DUPLICATES
C
            CALL CORSRT(ID,ID,NUM)
            N = 1
            K = ID(1)
            DO 20 J=2,NUM
            IF (K.EQ.ID(J)) GO TO 20
            N = N + 1
            ID(N) = ID(J)
   20       CONTINUE
            NUM = N
            RETURN
            END
```

ORIGINAL PAGE IS
OF POOR QUALITY

```
FORTRAN IV-P        V02-51            19:01:04      04-APR-86              P     1
PERIM.FTN           /TR:BLOCKS/WR

                    SUBROUTINE PERIM(NOLC,NEWC,NECNTR,NEWID,RPER,OBEGIN,NBEGIN,
                    1     OEND,NEND)
        C
        C   THIS SUBROUTINE ACCUMULATES PERIMETER MEASUREMENTS FOR THE 'OLD'
        C        LINE BETWEEN N1 AND N2 OF THE 'NEW' LINE.
        C
                    INTEGER NECNTR(1),OBEGIN(1),NBEGIN(1),OEND(1),NEND(1)
                    REAL*4 RPER(1)
                    IF (NOLC.EQ.0) RETURN
        C
        C   SEARCH 'OLD' LINE FOR MATCHING OBJECT SEGMENTS.
        C
                    L1 = 0
                    DO 100 J=1,NOLC
                    IF (OEND(J).GE.NBEGIN(NEWC)-1.AND.
                    1      OBEGIN(J).LE.NEND(NEWC)+1) GO TO 101
                    GO TO 100
               101  ONEWC = NEWC - 1
                    IF (ONEWC.LT.1) GO TO 301
                    IF (NEWID.EQ.NECNTR(ONEWC).AND.OEND(L2).GE.NBEGIN(NEWC))
                    1     GO TO 302
                    GO TO 301
        C
        C   IF PERIMETER HAS BEEN ADDED FOR PREVIOUS PARTICLE SEGMENT ON
        C       'NEW' LINE WITH SAME I.D. AND THE 'OLD' MATCHING SEGMENT
        C         OVERLAPS BOTH 'NEW' SEGMENTS, THEN THE OVERLAP IN THE
        C           CURRENT SEGMENT IS SUBTRACTED FROM THE PERIMETER VALUE.
        C
               302  RPER(NEWID) = RPER(NEWID) - SQRT((OEND(L2)
                    1    - FLOAT(NEND(ONEWC)))**2 + 1.) + NBEGIN(NEWC) - NEND(ONEWC)
                    GO TO 303
               301  RPER(NEWID) = RPER(NEWID) + SQRT((NBEGIN(NEWC)
                    1       - FLOAT(OBEGIN(J)))**2 + 1.)
               303  L1 = J
                    K = J + 1
                    GO TO 102
               100  CONTINUE
               102  IF (L1.EQ.0) RETURN
                    L2 = 0
                    IF (K.GT.NOLC) GO TO 200
                    DO 103 J=K,NOLC
                    IF (OEND(J).GE.NBEGIN(NEWC)-1.AND.
                    1      OBEGIN(J).LE.NEND(NEWC)+1) GO TO 104
                    GO TO 103
               104  RPER(NEWID) = RPER(NEWID) + (OBEGIN(J) - OEND(J-1))
                    L2 = J
               103  CONTINUE
               200  IF (L2.EQ.0) L2 = L1
                    RPER(NEWID) = RPER(NEWID) + SQRT((NEND(NEWC)
                    1      - FLOAT(OEND(L2)))**2 + 1.)
                    RETURN
                    END
```

```
0001          SUBROUTINE CONID(RPER,NPIXS,ISLS,ISSS,EL,ES,NUM,ID)
        C
        C     USED TO CONCATINATE MANY I.D.'S
        C
0002          INTEGER OLDID,ISLS(1),ISSS(1),EL(1),ES(1)
0003          INTEGER*4 NPIXS(1),ID(1)
0004          REAL*4 RPER(1)
0005          NEWID = ID(1)
0006          DO 10 J=2,NUM
0007          OLDID = ID(J)
0008          RPER(NEWID) = RPER(NEWID) + RPER(OLDID)
0009          RPER(OLDID) = 0.
0010          NPIXS(NEWID) = NPIXS(NEWID) + NPIXS(OLDID)
0011          NPIXS(OLDID) = 0
0012          IF (ISLS(NEWID).GT.ISLS(OLDID)) ISLS(NEWID) = ISLS(OLDID)
0013          ISLS(OLDID) = 32000
0014          IF (ISSS(NEWID).GT.ISSS(OLDID)) ISSS(NEWID) = ISSS(OLDID)
0015          ISSS(OLDID) = 32000
0016          IF (EL(NEWID).LT.EL(OLDID)) EL(NEWID) = EL(OLDID)
0017          EL(OLDID) = 0
0018          IF (ES(NEWID).LT.ES(OLDID)) ES(NEWID) = ES(OLDID)
0019    10    ES(OLDID) = 0
0020          RETURN
0021          END
```

```
0001            SUBROUTINE PCNCAT(NCEN,PCNTR,BEGIN,END,NEWID,RPER)
          C
          C   THIS SUBROUTINE CONCATINATES ALL ENDING PERIMETER VALUES FOR EACH
          C        I.D. ON AN ENDING LINE.
          C
0002            INTEGER PCNTR(1),BEGIN(1),END(1)
0003            REAL*4 RPER(1)
0004            DO 100 J=1,NCEN
0005            IF (NEWID.EQ.PCNTR(J)) GO TO 101
0006            GO TO 100
0007      101   RPER(NEWID) = RPER(NEWID) + END(J) - BEGIN(J) + 2.
0008      100   CONTINUE
0009            RETURN
0010            END
```

```
0001              SUBROUTINE FIND(NBIN,NEWID,NPIXS,OLDID)
          C
          C   USED TO FIND A NEW BIN POSITION
          C   NBIN = LENGTH OF BIN BUFFERS
          C   NEWID = NEW BIN VALUE RETURNED
          C   NPIXS = SUM OF PIXELS BUFFER
          C   OLDID = LAST FOUND I.D.
0002              INTEGER OLDID
0003              INTEGER*4 NPIXS(1)
0004              DO 100 J=OLDID,NBIN
0005              IF (NPIXS(J).EQ.0) GO TO 200
0006      100     CONTINUE
0007              DO 150 J=1,OLDID
0008              IF (NPIXS(J).EQ.0) GO TO 200
0009      150     CONTINUE
0010              TYPE *,' All bins filled'
0011              STOP
0012      200     NEWID=J
0013              OLDID=J
0014              RETURN
0015              END
```

ORIGINAL PAGE IS
OF POOR QUALITY


```
      SUBROUTINE CORSRT(KEY,PTR,LEN)
C
C  IN CORE SORT ROUTINE.  SORTS THE VECTORS KEY AND PTR INTO ASCENDING ORDER OF
C  KEY.  THE VALUES IN KEY ARE TREATED AS LOGICAL QUANTITIES HENCE SIGN BITS
C  MUST BE TREATED ACCORDINGLY.  ALPHABETIC RECORDS MAY BE SORTED SINCE
C  CHARACTER CODES ARE IN LOGICAL ORDER.  THE PTR ARRAY CAN THEN BE USED TO MOV
C  RECORDS IN A DISK FILE.
C
      IMPLICIT INTEGER(A-Z)
      INTEGER*4 IMSK,JMSK,SM(32),PTR(1),TEMP
      LOGICAL*4 IMSL,JMSL,KEY(1),LTEMP
      DIMENSION BDRY(3,32),CBD(32)
      EQUIVALENCE (IMSK,IMSL),(JMSK,JMSL)
      DATA SM(1),SM(2),SM(17)/02ØØØØØØØØØØ,01ØØØØØØØØØØ;01ØØØØØ/
C
      DO 1 I=3,16
    1 SM(I) = SM(I-1)/2
      DO 2 I=18,32
    2 SM(I) = SM(I-1)/2
      LEV = 1
      BDRY(2,LEV) = 1
      BDRY(3,LEV) = LEN
      CBD(LEV) = 2
   72 CB = CBD(LEV)
      PL = BDRY(CB,LEV)
      PU = BDRY(CB+1,LEV)
      IF (PL.GE.PU) GO TO 75
      IMSK = SM(LEV)
   81 JMSL = KEY(PL).AND.IMSL
      IF (JMSK.NE.Ø) GO TO 85
      PL = PL + 1
      IF (PL.EQ.PU) GO TO 73
      GO TO 81
   85 JMSL = KEY(PU).AND.IMSL
      IF (JMSK.NE.Ø) GO TO 86
      LTEMP = KEY(PL)
      TEMP = PTR(PL)
      KEY(PL) = KEY(PU)
      PTR(PL) = PTR(PU)
      KEY(PU) = LTEMP
      PTR(PU) = TEMP
      GO TO 81
   86 PU = PU - 1
      IF (PU.NE.PL) GO TO 85
   73 JMSL = KEY(PL).AND.IMSL
      IF (JMSK.NE.Ø) PL = PL - 1
      IF (LEV.GE.32) GO TO 75
      CB = CBD(LEV)
      LEV = LEV + 1
      CBD(LEV) = 1
      BDRY(1,LEV) = BDRY(CB,LEV-1)
      BDRY(2,LEV) = PL
      BDRY(3,LEV) = BDRY(CB+1,LEV-1)
      GO TO 72
   75 IF (CBD(LEV).EQ.2) GO TO 76
      CBD(LEV) = 2
```

```
0049          BDRY(2,LEV) = BDRY(2,LEV) + 1
0050          GO TO 72
0051    76    LEV = LEV - 1
0052          IF (LEV.GT.0) GO TO 75
0053          RETURN
0054          END
```

```
                SUBROUTINE ENOFLI(RPER,NPIXS,ISLS,ISSS,EL,ES,NL,LINE,
                1    OLCNTR,NECNTR,NOLC,NEWC,NUM,OBEGIN,NBEGIN,
                2    OEND,NEND,ABUF,PBUF,LIMIT)
      C
      C   SEARCH FOR FINISHED OBJECTS
      C
                INTEGER*4 NPIXS(1)
                INTEGER OLCNTR(1),NECNTR(1),OBEGIN(1),NBEGIN(1),OEND(1),NEND(1)
                INTEGER ISLS(1),ISSS(1),EL(1),ES(1)
                REAL*4 RPER(1),ABUF(1),PBUF(1)
                INTEGER*2 LIMIT(4,1)
      C
      C   SEARCH OLCNTR FOR I.D.'S NOT IN NECNTR
      C
                IF (LINE.EQ.NL) GO TO 52
                IF (NOLC.EQ.0) RETURN
                IF (NEWC.EQ.0) GO TO 51
                DO 10 J=1,NOLC
                NEWID = OLCNTR(J)
                DO 20 K=1,NEWC
                IF (NEWID.EQ.NECNTR(K)) GO TO 10
         20     CONTINUE
      C
      C   DROPLET NOT CONTINUED
      C
                CALL PCNCAT(NOLC,OLCNTR,OBEGIN,OEND,NEWID,RPER)
                CALL FINAL(NEWID,RPER,NPIXS,ISLS,ISSS,EL,ES,NUM,ABUF,
                1       PBUF,LIMIT)
         10     CONTINUE
                RETURN
      C
      C   FINISH OFF EVERYTHING
      C
         51     DO 50 J=1,NOLC
                NEWID = OLCNTR(J)
                CALL PCNCAT(NOLC,OLCNTR,OBEGIN,OEND,NEWID,RPER)
                CALL FINAL(NEWID,RPER,NPIXS,ISLS,ISSS,EL,ES,NUM,ABUF,
                1        PBUF,LIMIT)
         50     CONTINUE
                RETURN
         52     IF (NOLC.EQ.0) GO TO 60
                IF (NEWC.EQ.0) GO TO 51
                DO 80 J=1,NOLC
                NEWID = OLCNTR(J)
                DO 90 K=1,NEWC
                IF (NEWID.EQ.NECNTR(K)) GO TO 100
         90     CONTINUE
                CALL PCNCAT(NOLC,OLCNTR,OBEGIN,OEND,NEWID,RPER)
                CALL FINAL(NEWID,RPER,NPIXS,ISLS,ISSS,EL,ES,NUM,ABUF,
                1        PBUF,LIMIT)
                GO TO 80
        100     CALL PCNCAT(NEWC,NECNTR,NBEGIN,NEND,NEWID,RPER)
                CALL FINAL(NEWID,RPER,NPIXS,ISLS,ISSS,EL,ES,NUM,ABUF,
                1        PBUF,LIMIT)
         80     CONTINUE
                RETURN
```

```
0039      60     IF (NEWC.EQ.0) RETURN
0040             DO 70 J=1,NEWC
0041             NEWID = NECNTR(J)
0042             CALL PCNCAT(NEWC,NECNTR,NBEGIN,NEND,NEWID,RPER)
0043             CALL FINAL(NEWID,RPER,NPIXS,ISLS,ISSS,EL,ES,NUM,ABUF,
                 1          PBUF,LIMIT)
0044      70     CONTINUE
0045             RETURN
0046             END
```

```
      SUBROUTINE FINAL(NEWID,RPER,NPIXS,ISLS,ISSS,EL,ES,NUM,ABUF,
     1                 PBUF,LIMIT)
C
C   TO TERMINATE AN OBJECT
C
      INTEGER*4 NPIXS(1)
      INTEGER*2 LIMIT(4,1)
      INTEGER ISLS(1),ISSS(1),EL(1),ES(1)
      REAL*4 RPER(1),ABUF(1),PBUF(1)
      BYTE ORIGA(512)
      COMMON /MINARE/ AMINAR
      IF (NPIXS(NEWID).EQ.0) RETURN
      NUM = NUM + 1
      IF (NUM.LT.201) GO TO 5
      TYPE *,' Number of spots gt buffer space available'
      STOP
C
C   ACCUMULATE DROPLET STATISTICS
C
    5 ABUF(NUM) = NPIXS(NEWID)
      PBUF(NUM) = RPER(NEWID)
      LIMIT(1,NUM) = ISLS(NEWID)
      LIMIT(2,NUM) = ISSS(NEWID)
      LIMIT(3,NUM) = EL(NEWID) - ISLS(NEWID) + 1
      LIMIT(4,NUM) = ES(NEWID) - ISSS(NEWID) + 1
C   CLEAR OUT BINS
      IF (ABUF(NUM).GT.AMINAR) GO TO 10
      CALL BORRAR(1,LIMIT(1,NUM),LIMIT(2,NUM),LIMIT(3,NUM),LIMIT(4,NUM))
      NUM=NUM-1
C
   10 NPIXS(NEWID) = 0
      RPER(NEWID) = 0.
      ISLS(NEWID) = 32000
      ISSS(NEWID) = 32000
      EL(NEWID) = 0
      ES(NEWID) = 0
      RETURN
      END
```

APPENDIX B

DROPLET STATISTICS PROGRAM

ORIGINAL PAGE IS
OF POOR QUALITY

```
FORTRAN IV-P       V02-51            10:50:30     23-FEB-84            P     1
RAINST.FTN         /TR:BLOCKS/WR

                   PROGRAM RAINST
          C
          C         Read droplets' data file and compute general statistic
          C
          C          Programer: Miguel A. Hernan
          C
                   REAL*4 DBUF(1200),VOBUF(1200),ESFER(1200)
                   REAL*8 SHD3,SHD2,DTOT,ESTOT,SHD4,COMOD
                   INTEGER*2 NUME
                   LOGICAL*1 ANSA
                   REAL*4 VOLHIS(0:79),FREHIS(0:79)
                   REAL*4 AREA,PERIM,D3,D2,D,D4
                   LOGICAL*1 NOZOD(12),NOZIN(68),NOZID(80)
                   EQUIVALENCE(NOZOD(1),NOZID(1))
                   EQUIVALENCE(NOZIN(1),NOZID(13))
                   INTEGER*2 OPEPLO
                   LOGICAL*1 FILENA(22)
                   INTEGER*2 IBUFER(8),SL,SS,NL,NS
                   EQUIVALENCE(IBUFER(1),SL)
                   EQUIVALENCE(IBUFER(2),SS)
                   EQUIVALENCE(IBUFER(3),NL)
                   EQUIVALENCE(IBUFER(4),NS)
                   EQUIVALENCE(IBUFER(5),AREA)
                   EQUIVALENCE(IBUFER(7),PERIM)
                   DATA VOLHIS/80*0./,FREHIS/80*0./
                   DATA NOZOD /'N','O','Z','Z','L','E',' ','I','D',':',' ',' '/
          C
          C         Open data file
          451      FORMAT(Q,22A1)
                   TYPE *,' Enter filename'
                   ACCEPT 451,LONGO,(FILENA(I),I=1,LONGO)
          C
                   OPEN(UNIT=3,NAME=FILENA,TYPE='OLD',
                   1DISP='KEEP',ACCESS='DIRECT',RECORDSIZE=4,FORM='UNFORMATTED')
                   READ(3'1) IBUFER
                   NUME=IBUFER(1)
                   ICONT=0
                   SHD4=0.
                   SHD3=0.
                   SHD2=0.
                   DTOT=0.
                   ESTOT=0.
                   PI=3.14159
                   QI=4./(3.*SQRT(PI))
          C
          C           Main loop
                   DO 100 K=2,NUME
                   READ(3'K) IBUFER
                   IF (IBUFER(1).EQ.0) GO TO 200
                   ICONT=ICONT+1
                   D2=(4.*AREA)/PI
                   D=SQRT(D2)
                   D3=D2*D
                   D4=D2*D2
                   ESFER(ICONT)=(PERIM*PERIM)/(AREA*4.*PI)
                   DBUF(ICONT)=D
```

```
              VOBUF(ICONT)=QI*(AREA**1.5)
              SHD4=SHD4+D4
              SHD3=SHD3+D3
              SHD2=SHD2+D2
              DTOT=DTOT+D
              ESTOT=ESTOT+ESFER(ICONT)
              II=10*D
              II=MIN0(79,II)
              FREHIS(II)=FREHIS(II)+1
              VOLHIS(II)=VOLHIS(II)+D3
      100     CONTINUE
              CLOSE (UNIT=3)
              GO TO 300
      200     CLOSE(UNIT=3)
              TYPE *,' File records counter error'
              CALL EXIT
      C
      C         Begin general statistic
      C
      300     TYPE *,' Enter nozzle code'
              ACCEPT 750,ITEX,(NOZIN(I),I=1,ITEX)
      750     FORMAT(Q,68A1)
              TYPE *,' Enter water pressure (psi)'
              ACCEPT *,WATP
              TYPE *,' Enter wind tunnel speed (ft/sec)'
              ACCEPT *,WTS
              TYPE *,' Enter downstream coordinate (inch)'
              ACCEPT *,DOWL
              PRINT 4,NOZOD,(NOZIN(I),I=1,ITEX)
              PRINT 5,WATP
              PRINT 6,WTS
              PRINT 7,DOWL
              PRINT 11,ICONT
      4       FORMAT(X,12A1,68A1)
      5       FORMAT(' Water pressure =',F6.2,' psi')
      6       FORMAT(' Wind tunnel speed =',F6.2,' ft/sec')
      7       FORMAT(' Downstream location =',F6.2,' inch')
      11      FORMAT(' Number of Drops =',I5)
              PRINT 12
      12      FORMAT(' Length diameter (D10)')
              NAMO=ICONT
              CALL STATS(NAMO,DBUF,DTOT)
              PRINT 13,SQRT(SHD2/FLOAT(ICONT))
      13      FORMAT(' Area mean diameter (D20)=',F15.6)
              COMOD=SHD3*PI/6.
              PRINT 17,COMOD
      17      FORMAT(' Drops total volume=',F15.6)
              NAMO=ICONT
              CALL STATS(NAMO,VOBUF,COMOD)
              VOLMED=SHD3/FLOAT(ICONT)
              VOLMED=VOLMED**(1./3.)
              PRINT 14,VOLMED
      14      FORMAT(' Volume mean diameter (D30)=',F15.6)
              PRINT 16,SHD3/SHD2
      16      FORMAT(' Sauter mean diameter (D32)=',F15.6)
              PRINT 30,SHD4/SHD3
```

```
 3Ø      FORMAT(' Volume distribution mean diameter (D43)=',F15.6)
         PRINT 31
 31      FORMAT(' Circularity (perimeter**2/area*4pi)')
         NAMO=ICONT
         CALL STATS(NAMO,ESFER,ESTOT)
         TYPE *,' Plot the distributions (Y/N)'
         ACCEPT 8Ø8,ANSA
 8Ø8     FORMAT(A1)
         IF (ANSA.NE.'Y') GO TO 8ØØ
         OPEPLO=Ø
         SAMP=FLOAT(ICONT)/1ØØ.
         SMD3=SMD3/1ØØ.
         DO 5ØØ K=Ø,79
         VOLHIS(K)=VOLHIS(K)/SMD3
         FREHIS(K)=FREHIS(K)/SAMP
 5ØØ     CONTINUE
         TYPE *,' Frequency distribution (Y/N)'
         ACCEPT 8Ø8,ANSA
         IF (ANSA.NE.'Y') GO TO 6ØØ
         CALL RAINHI(FREHIS,OPEPLO,Ø.,.1)
         IF (OPEPLO.EQ.Ø) GO TO 6ØØ
         OPEPLO=-OPEPLO
         CALL SYMBOL(-4.3,1.15,.1,'DROPS DIAMETER FREQUENCY DISTRIBUTION',
        1            9Ø.,37)
         CALL SYMBOL(-1.35,-.75,.1,'FREQUENCY (%)',1ØØ.,13)
         GO TO 4ØØ
 6ØØ     TYPE *,' Cumulative volume distribution (Y/N)'
         ACCEPT 8Ø8,ANSA
         IF (ANSA.NE.'Y') GO TO 65Ø
         CALL RAINHI(VOLHIS,OPEPLO,Ø.,.1)
         IF (OPEPLO.GE.Ø) GO TO 65Ø
         CALL SYMBOL(-4.3,1.45,.1,'VOLUME CONTRIBUTION VS DIAMETER',9Ø.,31)
         CALL SYMBOL(-.85,-.75,.1,'VOLUME CONTRIBUTION (%)',1ØØ.,23)
 4ØØ     CALL SYMBOL(.7,2.35,.1,'DIAMETER (MM)',9Ø.,13)
         CALL SYMBOL(-5.5,Ø.,.1,NOZID,9Ø.,ITEX+12)
         CALL SYMBOL(-5.25,Ø.,.1,'WATER PRESSURE (PSI)',9Ø.,2Ø)
         CALL NUMBER(-5.25,2.25,.1,WATP,9Ø.,-1)
         CALL SYMBOL(-5.Ø,Ø.,.1,'WIND TUNNEL SPEED (FT/SEC)',9Ø.,26)
         CALL NUMBER(-5.Ø,2.85,.1,WTS,9Ø.,-1)
         CALL SYMBOL(-4.75,Ø.,.1,'DOWNSTREAM STATION (INCH)',9Ø.,25)
         CALL NUMBER(-4.75,2.75,.1,DOWL,9Ø.,-1)
         IF (OPEPLO.GT.Ø) GO TO 6ØØ
 65Ø     IF (OPEPLO.NE.Ø) CALL PLOT(Ø.,Ø.,999)
 8ØØ     CALL EXIT
         END
```

APPENDIX C

DROPLET DATA

DROPLET DATA FOR NEGATIVE 1

Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)
1	0.5243418	36	1.180004	71	0.6642479	106	0.2157810	141	0.6872163
2	0.1561709	37	0.1412618	72	0.3766983	107	1.201418	142	0.5862319
3	0.1631151	38	0.2864208	73	1.752381	108	0.4589501	143	2.744425
4	0.2258227	39	0.6317422	74	0.1631151	109	0.3296110	144	0.7907299
5	0.5670060	40	0.1245812	75	0.1697756	110	1.016475	145	1.626387
6	0.1489031	41	0.3395512	76	0.5993233	111	0.1153398	146	0.5728415
7	0.2745637	42	0.5179601	77	0.2157810	112	0.2940600	147	1.310009
8	0.3939605	43	0.6387230	78	0.5591305	113	0.4565282	148	2.814229
9	0.1331829	44	0.8436380	79	0.9661503	114	0.2785721	149	0.2052487
10	0.4685126	45	0.6103209	80	0.6211239	115	0.4211615	150	0.1412618
11	0.5937480	46	0.5766991	81	0.3262303	116	1.182819	151	1.342607
12	0.1883491	47	0.7794333	82	0.1331829	117	1.805354	152	0.4185209
13	0.4613593	48	0.7949249	83	0.7094414	118	0.7460029	153	1.160107
14	0.6524605	49	0.1631151	84	0.2535728	119	0.9865882	154	0.3428006
15	0.2354364	50	0.5571443	85	0.2446727	120	0.8317273	155	1.217004
16	0.1489031	51	0.1883491	86	0.6774681	121	1.021913	156	1.093196
17	0.1245812	52	0.4755583	87	0.2621709	122	0.1331829	157	1.231492
18	0.3707657	53	0.1631151	88	0.1823683	123	0.1412618	158	0.1489031
19	0.1245812	54	0.5222232	89	0.6936390	124	1.678713	159	0.5611097
20	0.4893454	55	0.9832113	90	0.1489031	125	0.4825011	160	0.2535728
21	0.3193615	56	0.3967645	91	0.1489031	126	0.5689578	161	0.2446727
22	0.1697756	57	0.4661403	92	0.2825237	127	0.1153398	162	1.889368
23	0.1489031	58	0.7935290	93	0.5551509	128	0.1761845	163	0.5243418
24	0.1245812	59	0.5093269	94	0.4050601	129	0.2306796	164	1.015383
25	0.1489031	60	0.1489031	95	0.7548665	130	0.4589501	165	0.7949249
26	0.8656892	61	0.1489031	96	0.5591305	131	0.6524605	166	0.2306796
27	0.2663659	62	0.2902655	97	0.2535728	132	0.3123417	167	0.5805310
28	0.7047380	63	0.2825237	98	0.3087720	133	0.2400990	168	1.517058
29	0.1561709	64	0.2902655	99	0.1153398	134	0.1941458	169	0.1823683
30	0.6904351	65	0.4637560	100	0.3228141	135	1.315076	170	0.1631151
31	0.1823683	66	0.3492087	101	0.6121347	136	0.1245812	171	1.431329
32	1.167727	67	1.727532	102	0.1761845	137	0.4732214	172	0.9820831
33	0.1823683	68	0.1561709	103	0.4131892	138	0.3395512	173	1.015383
34	0.1941458	69	1.462741	104	0.6387230	139	0.7264272	174	0.2825237
35	0.4104974	70	0.1561709	105	0.3967645	140	0.4237855	175	0.5974706

DROPLET DATA FOR NEGATIVE 1 (cont'd)

Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)
176	0.1941458	211	0.3296110	246	0.1823683				
177	0.9684424	212	1.373626	247	1.751115				
178	0.4565282	213	0.3825389	248	0.5805310				
179	0.6507592	214	0.8087506	249	0.1489031				
180	0.4960953	215	0.1153398	250	0.2157810				
181	0.5900019	216	0.6642479	251	0.2704958				
182	0.4708728	217	1.852632	252	0.6575381				
183	0.2258227	218	0.1761845	253	0.1412618				
184	0.3262303	219	0.5264518	254	0.1245812				
185	1.063381	220	0.2825237	255	0.3939605				
186	0.1941458	221	0.5786182	256	0.2902655				
187	1.131075	222	0.2864208	257	0.3647365				
188	0.2579077	223	0.3123417	258	0.4315621				
189	0.1561709	224	0.5430371	259	0.5049549				
190	0.5027546	225	0.1823683	260	0.6103209				
191	0.5786182	226	0.5071455	261	0.1412618				
192	0.6541575	227	0.3296110	262	0.7822727				
193	0.3262303	228	0.3616843	263	1.276578				
194	1.575138	229	0.5591305	264	0.2354364				
195	0.1245812	230	0.1331829	265	0.7031631				
196	0.5571443	231	0.4825011	266	0.8410058				
197	0.2354364	232	0.1941458	267	0.5450747				
198	0.5974706	233	0.2306796						
199	1.077877	234	0.5551509						
200	0.3555012	235	0.3428006						
201	0.2258227	236	0.1412618						
202	0.4467092	237	0.1331829						
203	2.063262	238	0.7233686						
204	0.2785721	239	0.5709030						
205	0.3825389	240	0.2400990						
206	2.363294	241	0.1697756						
207	0.3586060	242	0.2208589						
208	0.4801979	243	0.5264518						
209	1.219733	244	0.2208589						
210	0.4516453	245	0.5974706						

DROPLET DATA FOR NEGATIVE 2

Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)
1	0.1331829	36	0.8488781	71	0.4392009	106	0.4755583	141	0.3123417
2	0.7533965	37	0.6952354	72	0.3586060	107	1.302370	142	1.726248
3	0.6984173	38	0.6121347	73	0.4847932	108	0.3329574	143	0.9752867
4	0.4516453	39	0.1761845	74	0.1153398	109	0.1561709	144	2.713552
5	0.2864208	40	1.190294	75	0.4938556	110	0.1823683	145	0.4211615
6	0.4847932	41	1.405538	76	0.3395512	111	0.9008328	146	0.6807330
7	0.4801979	42	0.3193615	77	0.2105807	112	1.164875	147	0.1245812
8	0.4392009	43	1.278314	78	0.3523690	113	0.5531504	148	0.2208589
9	0.6456283	44	0.1561709	79	0.5093269	114	0.2354364	149	0.2208589
10	0.2745637	45	0.5114988	80	0.2306796	115	1.724963	150	0.2105807
11	0.1489031	46	0.3123417	81	0.3737437	116	0.8566780	151	1.266114
12	0.7665254	47	0.7294731	82	1.057107	117	1.191225	152	1.673421
13	0.7015847	48	0.7294731	83	0.3737437	118	0.8656892	153	1.363907
14	0.5264518	49	0.7822727	84	0.7294731	119	0.2940600	154	1.805968
15	0.1697756	50	0.8896880	85	0.6456283	120	0.3296110	155	0.1489031
16	0.2785721	51	1.473313	86	0.8462621	121	0.3296110	156	0.7851019
17	0.1883491	52	0.9638526	87	0.5805310	122	0.4613593	157	0.1997744
18	0.2704958	53	0.5049549	88	0.1941458	123	0.3939605	158	0.4237855
19	0.7309912	54	0.8290572	89	0.3296110	124	0.2902655	159	0.3492087
20	0.2491625	55	0.3586060	90	0.5049549	125	0.1331829	160	0.7865127
21	0.1997744	56	1.278314	91	0.2535728	126	0.2052487	161	1.122219
22	0.3939605	57	0.3428006	92	0.2208589	127	0.9546068	162	0.2535728
23	0.2978061	58	0.5179601	93	0.4540933	128	1.173409	163	0.1561709
24	0.2306796	59	1.052904	94	0.5918780	129	0.2579077	164	0.6473432
25	0.5368776	60	1.296398	95	0.5862319	130	0.6575381	165	0.7694125
26	0.1245812	61	0.1245812	96	0.4289856	131	1.224269	166	0.1631151
27	0.1561709	62	1.161062	97	0.3193615	132	0.5551509	167	0.1489031
28	0.1245812	63	0.9592409	98	0.6659148	133	0.1631151	168	0.4211615
29	0.4613593	64	1.345906	99	0.2306796	134	2.012671	169	0.3193615
30	0.8859419	65	1.190294	100	0.6030114	135	0.5430371	170	0.6175439
31	0.4983250	66	0.8169339	101	0.3766983	136	0.2745637	171	0.1331829
32	0.8317273	67	1.261728	102	0.1331829	137	0.9008328	172	0.3586060
33	0.8707965	68	0.2446727	103	0.2621709	138	0.2306796	173	1.098255
34	0.1561709	69	0.4050601	104	0.9251183	139	1.197721	174	0.6282227
35	0.9752867	70	0.4825011	105	0.1761845	140	0.3460194	175	1.071688

DROPLET DATA FOR NEGATIVE 2 (cont'd)

Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)
176	1.120242								
177	0.2258227								
178	0.8644077								
179	0.1245812								
180	0.2052487								
181	1.320964								
182	0.2157810								
183	0.6839823								
184	0.1331829								
185	0.1331829								
186	0.2052487								
187	0.3825389								
188	0.1941458								
189	0.3492087								
190	0.1412618								
191	0.3796298								
192	0.2704958								
193	0.4661403								
194	0.2978061								
195	0.2400990								
196	0.4938556								
197	1.672096								
198	0.2400990								
199	0.1153398								
200	0.3395512								
201	0.5071455								
202	0.4847932								
203	0.3586060								
204	1.110302								
205	0.1883491								
206	0.6352422								
207	0.2579077								

DROPLET DATA FOR NEGATIVE 3

Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)
1	0.2052487	36	0.4916057	71	0.3854260	106	0.4315621	141	0.4870746
2	0.5709030	37	0.1631151	72	0.1883491	107	0.1631151	142	0.3911363
3	0.1561709	38	0.3882917	73	0.4104974	108	0.2105807	143	1.618871
4	0.7294731	39	0.5158154	74	0.2400990	109	0.9650021	144	0.4392009
5	0.3329574	40	0.2579077	75	0.3158711	110	0.4315621	145	0.2306796
6	0.1245812	41	0.2354364	76	0.1331829	111	0.1697756	146	0.4589501
7	0.3882917	42	0.1561709	77	0.2208589	112	0.1245812	147	0.8114876
8	0.4050601	43	0.5136616	78	0.8087506	113	1.204183	148	0.2745637
9	0.5071455	44	0.2208589	79	0.3296110	114	1.467281	149	0.2052487
10	0.2446727	45	0.2940600	80	1.197721	115	0.1761845	150	0.3262303
11	0.1153398	46	0.1245812	81	0.2105807	116	0.1331829	151	0.1631151
12	0.1997744	47	0.5264518	82	0.3882917	117	0.6011702	152	0.3051605
13	0.9322807	48	0.1631151	83	0.4050601	118	0.2400990	153	0.1761845
14	1.322641	49	0.2258227	84	0.1823683	119	3.194656	154	0.7094414
15	0.2902655	50	0.9298993	85	0.2491625	120	1.217914	155	0.7125599
16	0.4392009	51	0.1489031	86	0.2258227	121	0.2745637	156	0.4392009
17	0.1245812	52	0.4916057	87	0.4870746	122	0.5862319	157	0.1561709
18	0.1331829	53	0.1697756	88	0.3647365	123	0.2825237	158	0.3939605
19	0.3123417	54	0.2663659	89	0.1997744	124	0.2258227	159	0.5900019
20	0.3015057	55	0.6609015	90	0.1631151	125	0.2157810	160	0.1331829
21	0.6609015	56	0.7851019	91	0.1997744	126	0.3911363	161	0.9405677
22	0.1489031	57	0.7519236	92	0.3362705	127	1.526529	162	0.1697756
23	0.6524605	58	0.2940600	93	0.7990977	128	0.3523690	163	0.6642479
24	0.2052487	59	1.053956	94	0.2491625	129	1.961342	164	1.213354
25	0.6229062	60	0.4491840	95	0.3677634	130	1.411834	165	0.6592219
26	0.5114988	61	0.7650778	96	0.6888276	131	0.4732214	166	1.418883
27	0.1245812	62	0.3395512	97	1.017565	132	0.4637560	167	0.1331829
28	0.1941458	63	0.4237855	98	0.1697756	133	0.2354364	168	0.6741873
29	0.6524605	64	1.192155	99	0.2105807	134	2.418930	169	0.7851019
30	0.3362705	65	0.3677634	100	0.4131892	135	1.812096	170	0.2491625
31	0.3228141	66	0.2825237	101	0.1412618	136	0.1153398	171	0.1153398
32	0.3796298	67	2.182332	102	2.134566	137	0.1153398	172	0.6968281
33	0.2785721	68	1.173409	103	0.2208589	138	0.4825011	173	0.6264555
34	0.6334946	69	0.2785721	104	1.887607	139	0.1561709	174	0.8449511
35	0.9370251	70	0.3647365	105	0.5571443	140	0.2052487	175	1.965295

DROPLET DATA FOR NEGATIVE 3 (cont'd)

Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)
176	0.2446727	211	0.7607183	246	0.2157810				
177	0.9695865	212	0.2902655	247	0.5650474				
178	0.1697756	213	0.6439089	248	0.5179601				
179	0.2208589	214	0.9730106	249	0.1245812				
180	0.2663659	215	0.4237855	250	0.7708520				
181	1.068581	216	0.1997744	251	0.5264518				
182	0.7340181	217	0.3262303	252	0.8884411				
183	0.5956123	218	0.4637560	253	0.2306796				
184	0.1245812	219	0.1331829	254	0.3123417				
185	0.5285534	220	0.1697756	255	0.9684424				
186	0.4755583	221	0.2052487	256	0.1997744				
187	0.2621709	222	0.1412618						
188	0.2864208	223	0.7935290						
189	0.1697756	224	0.2745637						
190	0.1331829	225	0.5974706						
191	0.7340181	226	0.3707657						
192	0.8236910	227	0.4708728						
193	0.4131892	228	0.6936390						
194	0.1331829	229	0.1883491						
195	0.3796298	230	0.3677634						
196	0.1245812	231	0.8182897						
197	1.225175	232	0.5862319						
198	0.3586060	233	0.2663659						
199	0.1631151	234	0.6299849						
200	0.1697756	235	0.3586060						
201	0.1153398	236	0.1489031						
202	0.1941458	237	0.9130563						
203	0.1331829	238	0.2258227						
204	0.5805310	239	0.5005447						
205	1.020828	240	0.7031631						
206	1.968113	241	0.4185209						
207	0.1761845	242	0.5114988						
208	0.1561709	243	0.2621709						
209	1.074787	244	0.9775574						
210	0.1412618	245	0.8410058						

DROPLET DATA FOR NEGATIVE 4

Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)
1	0.5709030	36	0.9499502	71	0.7636274	106	0.2208589	141	0.6456283
2	0.8707965	37	0.6558500	72	0.3228141	107	0.6524605	142	0.4366695
3	0.3707657	38	2.033495	73	0.2579077	108	1.117269	143	0.2400990
4	0.3766983	39	0.9603959	74	0.1245812	109	0.1331829	144	0.1697756
5	0.5766991	40	0.2354364	75	0.4366695	110	0.1412618	145	0.4211615
6	0.1561709	41	0.7765834	76	0.5071455	111	0.1489031	146	0.4050601
7	0.2978061	42	0.4185209	77	0.3329574	112	0.6103209	147	0.5179601
8	0.1697756	43	0.9166915	78	0.5136616	113	0.4185209	148	0.1561709
9	0.2157810	44	0.3707657	79	1.669442	114	0.8644077	149	0.2105807
10	0.5747736	45	0.5918780	80	0.6317422	115	1.376850	150	0.8032488
11	1.004406	46	1.460465	81	0.3015057	116	0.2446727	151	0.6369849
12	0.2052487	47	0.7694125	82	1.760586	117	0.3737437	152	0.1883491
13	0.4315621	48	0.4778837	83	1.650743	118	0.7141140	153	0.1631151
14	0.3586060	49	0.1761845	84	0.8707965	119	0.8746075	154	0.1631151
15	0.9944228	50	0.5327318	85	1.136941	120	0.6473432	155	0.4211615
16	0.3523690	51	0.3939605	86	0.2785721	121	1.266989		
17	0.2354364	52	0.6246834	87	0.8317273	122	0.5049549		
18	0.9786908	53	0.9057420	88	1.728174	123	0.2940600		
19	0.7851019	54	0.3460194	89	2.441738	124	0.6659148		
20	0.2579077	55	0.4131892	90	0.8004838	125	1.347552		
21	0.3087720	56	0.3616843	91	0.6085018	126	0.5049549		
22	0.3677634	57	0.5005447	92	0.5650474	127	0.2052487		
23	0.1153398	58	0.2157810	93	0.1489031	128	0.3428006		
24	1.345082	59	0.1331829	94	0.1631151	129	0.1245812		
25	0.6725409	60	0.7355269	95	0.5491273	130	0.8370419		
26	0.3329574	61	0.7577981	96	0.1245812	131	0.2258227		
27	1.102285	62	0.4131892	97	0.1997744	132	0.2400990		
28	0.2157810	63	0.2208589	98	0.2258227	133	0.5709030		
29	1.245812	64	0.1631151	99	0.1823683	134	0.8846897		
30	1.881725	65	0.5670060	100	0.1883491	135	0.1153398		
31	0.3911363	66	0.6741873	101	1.226983	136	0.2491625		
32	1.237778	67	0.8983681	102	0.3158711	137	0.6421849		
33	0.1761845	68	0.7415313	103	0.8018675	138	0.3492087		
34	1.422005	69	0.6473432	104	0.4516453	139	0.4613593		
35	0.3995488	70	0.1761845	105	0.5900019	140	0.3051605		

DROPLET DATA FOR NEGATIVE 5

Droplet No.	Diameter (mm)
1	0.5348087
2	0.2825237
3	0.1489031
4	0.4237855
5	0.4211615
6	0.2535728
7	0.2978061
8	0.4825011
9	0.2940600
10	0.1245812
11	0.7548665
12	0.1761845
13	0.8169339
14	0.1997744
15	0.1697756
16	0.5285534
17	0.4366695
18	0.9557675
19	0.9843382
20	0.5179601
21	0.5243418
22	0.7679704
23	0.1823683
24	0.6456283
25	0.9382074
26	0.5766991
27	0.7172121
28	0.1997744
29	0.7430248
30	2.168061
31	0.4825011
32	1.548162
33	1.087094
34	1.122219
35	1.032705
36	1.156278
37	2.265579
38	0.8771389
39	0.8784019
40	0.1631151
41	0.1697756
42	0.7665254
43	0.2157810
44	0.3939605
45	1.881725
46	0.4289856
47	1.646709
48	0.3228141
49	0.9999814
50	1.391268
51	0.7325062
52	0.1331829
53	0.3911363
54	0.1631151
55	0.7294731
56	1.098255
57	0.2902655
58	0.5409917
59	0.2940600
60	0.6030114
61	0.2306796
62	0.2354364
63	0.5993233
64	1.044446
65	0.1331829
66	0.2400990
67	0.7325062
68	0.3616843
69	0.6066772
70	0.2306796
71	1.072722
72	0.3362705
73	0.2621709
74	1.262607
75	0.3296110
76	0.1823683
77	0.1412618
78	0.4847932
79	0.1761845
80	0.7279517
81	1.188429
82	1.027323
83	0.6175439
84	1.994412
85	0.8357164
86	0.1489031
87	0.4211615
88	3.548145
89	1.033778
90	0.1331829
91	0.5611097
92	0.2446727
93	0.2535728
94	0.6558500
95	0.6952354
96	2.299094
97	0.1412618
98	0.1489031
99	0.1331829
100	0.3158711
101	0.2208589
102	0.4801979
103	0.3737437
104	0.6369849
105	0.5491273
106	0.2446727
107	0.8223441
108	0.5843378
109	0.3825389
110	0.4960953
111	0.1489031
112	0.4755583
113	0.9106247
114	6.326891
115	0.4516453
116	0.2579077
117	0.3228141
118	1.006611
119	0.2864208
120	1.354936
121	0.1489031
122	0.3362705
123	2.172148
124	0.9429221
125	1.215180
126	0.4315621
127	0.3555012
128	0.5430371
129	0.6352422
130	0.2208589
131	0.7794333
132	1.495716
133	0.2258227
134	0.5918780
135	0.1153398
136	0.5285534
137	0.2400990
138	0.5306467
139	0.4263935
140	0.8605515
141	0.3428006
142	0.3015057
143	0.4613593
144	0.5591305
145	0.4104974
146	1.127148
147	1.347552
148	0.1153398
149	0.2785721
150	0.4366695
151	0.1697756
152	0.5862319
153	0.3228141
154	0.2825237
155	0.3523690
156	0.2306796
157	1.028402
158	0.1331829
159	0.2621709
160	0.4870746
161	0.2306796
162	0.2663659
163	0.3555012
164	0.8357164
165	0.7708520
166	0.4847932
167	0.5114988
168	0.3460194
169	0.7694125
170	0.1153398
171	0.1697756
172	0.2825237
173	0.5591305
174	0.2105807
175	0.1412618
176	0.6246834
177	0.4637560
178	0.3296110
179	0.9786908

DROPLET DATA FOR NEGATIVE 6

Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)
1	0.3395512	36	0.4732214	71	0.5200961	106	0.2258227	141	0.8343887
2	0.6299849	37	0.6904351	72	0.4366695	107	0.4185209	142	0.1153398
3	0.2354364	38	0.5368776	73	0.1489031	108	0.2258227	143	0.2258227
4	0.4185209	39	0.4104974	74	0.6524605	109	0.1489031	144	0.7047380
5	0.6439089	40	0.8004838	75	1.357388	110	0.5027546	145	0.8644077
6	0.3523690	41	0.6872163	76	0.1245812	111	0.8087506	146	0.2491625
7	0.4565282	42	0.4685126	77	0.4237855	112	2.016524	147	0.5285534
8	0.1489031	43	0.1331829	78	0.2354364	113	0.2105807	148	0.2208589
9	0.5974706	44	0.7963182	79	0.2704958	114	0.4104974	149	1.598889
10	0.4341233	45	0.6246834	80	0.6404563	115	0.3015057	150	0.8423229
11	0.3395512	46	0.2400990	81	0.2745637	116	1.681352	151	0.4893454
12	0.5786182	47	0.3586060	82	0.7031631	117	2.049785	152	1.063381
13	0.1245812	48	1.109303	83	0.6317422	118	0.1153398	153	0.3395512
14	0.4131892	49	0.4613593	84	0.1412618	119	0.5747736	154	0.1823683
15	0.3193615	50	0.3492087	85	0.6968281	120	0.9534448	155	0.1883491
16	0.2208589	51	0.9627018	86	0.6085018	121	0.4104974	156	1.217004
17	0.4158636	52	0.3707657	87	0.8330591	122	0.4613593	157	0.4708728
18	0.4417179	53	0.2978061	88	0.4050601	123	0.2579077	158	0.7489691
19	0.2940600	54	0.2940600	89	0.3939605	124	1.502372	159	2.133007
20	0.6791024	55	0.3586060	90	0.2864208	125	0.4708728	160	1.120242
21	0.1412618	56	0.6473432	91	1.097245	126	0.1412618	161	0.9786908
22	0.1883491	57	0.3555012	92	1.731378	127	0.1153398	162	1.370394
23	0.3228141	58	1.387278	93	2.829158	128	0.3555012	163	0.3329574
24	0.2306796	59	0.2354364	94	0.4467092	129	2.176737	164	0.2864208
25	0.2902655	60	0.9008328	95	0.7607183	130	1.996079	165	0.3193615
26	0.3911363	61	0.6541575	96	0.1823683	131	0.5136616	166	0.5158154
27	0.2306796	62	0.3123417	97	0.3911363	132	0.3967645	167	0.3015057
28	0.6421849	63	0.2902655	98	0.8032488	133	0.4938556	168	1.685304
29	0.3158711	64	0.3677634	99	0.1697756	134	0.3193615	169	0.6692361
30	0.5409917	65	0.9865882	100	0.5881200	135	1.280913	170	0.1331829
31	0.4732214	66	1.689246	101	0.1245812	136	1.041257	171	0.3766983
32	0.4417179	67	0.6030114	102	0.1245812	137	1.163923	172	0.6473432
33	0.9346558	68	0.1331829	103	0.2306796	138	0.4893454	173	0.2052487
34	0.5389386	69	0.1153398	104	0.2446727	139	0.5285534	174	0.1631151
35	0.5179601	70	0.4392009	105	0.9358413	140	0.2978061	175	0.5179601

DROPLET DATA FOR NEGATIVE 6 (cont'd)

Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)
176	0.1489031								
177	0.4289856								
178	0.6952354								
179	0.1697756								
180	0.4613593								
181	0.4870746								
182	1.185627								
183	0.4185209								
184	0.2785721								
185	0.4613593								
186	0.6439089								
187	0.5348087								
188	0.2785721								
189	0.2621709								
190	0.4050601								
191	0.6264555								
192	0.8859419								
193	0.2491625								
194	0.8527870								
195	0.1997744								
196	0.1761845								
197	0.1412618								
198	0.6334946								
199	0.6229062								
200	0.3647365								
201	0.3460194								
202	0.1941458								
203	0.3523690								
204	0.6066772								
205	0.5824375								
206	0.3395512								
207	0.1489031								
208	0.5843378								
209	0.3395512								
210	0.1761845								
211	0.1823683								
212	0.3262303								

DROPLET DATA FOR NEGATIVE 7

Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)
1	0.6558500	36	0.3087720	71	0.6952354	106	0.3087720	141	0.2785721
2	0.1331829	37	1.098255	72	0.2446727	107	0.6541575	142	2.024206
3	0.4366695	38	0.3677634	73	0.6282227	108	0.2579077	143	0.2258227
4	0.2208589	39	1.165826	74	1.206942	109	1.068581	144	0.8846897
5	0.4263935	40	0.1761845	75	0.1245812	110	1.762474	145	1.250254
6	0.1489031	41	0.3523690	76	0.2785721	111	0.2621709	146	0.3262303
7	0.7607183	42	0.9615495	77	0.5071455	112	0.5027546	147	1.154359
8	0.8475711	43	0.3492087	78	0.3051605	113	0.3051605	148	0.3395512
9	0.2491625	44	0.3616843	79	0.2208589	114	0.5049549	149	0.6968281
10	0.3616843	45	0.2902655	80	0.6659148	115	1.515596	150	0.5158154
11	0.1153398	46	0.3766983	81	0.5306467	116	0.1823683	151	0.5430371
12	0.2940600	47	0.6659148	82	0.3329574	117	0.4467092	152	0.1631151
13	0.8004838	48	0.1245812	83	1.243140	118	0.9672971	153	0.1489031
14	1.097245	49	0.6157461	84	0.1697756	119	0.9921906	154	1.252026
15	0.1245812	50	0.8196434	85	0.1489031	120	0.7751545	155	0.5179601
16	0.1412618	51	0.4778837	86	0.3051605	121	1.159151	156	1.382475
17	0.1631151	52	0.3296110	87	0.1697756	122	0.1245812	157	0.1412618
18	0.1245812	53	0.5471048	88	1.733298	123	1.106301	158	0.3428006
19	0.2621709	54	0.3262303	89	0.8209949	124	0.2052487	159	0.1153398
20	0.4708728	55	1.220642	90	0.4685126	125	0.1153398	160	0.9215163
21	0.5591305	56	0.1245812	91	0.1941458	126	1.738407	161	0.2663659
22	0.4916057	57	0.3586060	92	0.4263935	127	0.3228141	162	1.273099
23	0.3329574	58	0.1883491	93	0.3616843	128	2.043827	163	1.241355
24	0.1153398	59	0.6592219	94	0.4893454	129	1.695142	164	0.2446727
25	0.3158711	60	0.9592409	95	0.5993233	130	2.414802	165	0.6774681
26	0.1997744	61	0.2105807	96	0.1489031	131	0.9820831	166	0.5368776
27	0.6193365	62	0.8644077	97	0.4685126	132	1.233291	167	0.4315621
28	0.5158154	63	0.2105807	98	0.4077878	133	2.761740	168	0.7000028
29	0.3995488	64	0.6490534	99	0.3087720	134	0.1412618	169	0.5471048
30	0.7836886	65	1.463498	100	0.1761845	135	0.2491625	170	0.7822727
31	0.4077878	66	0.3051605	101	0.2785721	136	0.3051605	171	0.4131892
32	0.4801979	67	0.4565282	102	0.5709030	137	0.2446727	172	1.323479
33	0.4077878	68	0.2052487	103	0.8983681	138	0.4023139	173	0.4366695
34	0.9142697	69	1.272228	104	0.4708728	139	1.986615	174	0.1941458
35	0.2400990	70	0.2940600	105	0.2052487	140	0.4589501	175	0.8142152

ORIGINAL PAGE IS OF POOR QUALITY

DROPLET DATA FOR NEGATIVE 7 (cont'd)

Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)
176	0.7047380	211	0.1489031						
177	0.2535728	212	0.5049549						
178	1.665453	213	0.7047380						
179	1.950573	214	0.4442205						
180	0.1489031	215	0.2208589						
181	0.3262303	216	0.3492087						
182	1.212440	217	0.1631151						
183	0.4023139	218	0.2902655						
184	1.044446	219	0.5591305						
185	0.5285534	220	1.570204						
186	0.8250359	221	0.3193615						
187	0.2535728	222	0.3123417						
188	0.3428006	223	0.3193615						
189	0.1697756	224	0.2258227						
190	0.7218344	225	0.2663659						
191	0.3766983	226	1.280047						
192	0.2704958	227	0.1153398						
193	0.8758741	228	0.3995488						
194	0.8087506	229	1.194941						
195	0.1489031	230	1.175297						
196	1.123207	231	0.4211615						
197	0.4516453	232	0.7000028						
198	0.7460029	233	0.2940600						
199	0.2105807	234	0.3737437						
200	0.4825011	235	0.2157810						
201	0.2579077	236	0.2306796						
202	0.8317273	237	0.6856012						
203	0.5348087	238	0.4341233						
204	1.044446	239	0.2157810						
205	1.444436	240	0.7031631						
206	0.2208589	241	0.6507592						
207	0.5974706	242	0.4392009						
208	0.4263935	243	0.3882917						
209	1.573025								
210	0.4825011								

DROPLET DATA FOR NEGATIVE 8

Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)
1	0.1331829	36	0.1823683	71	0.5114988	106	0.7504478		
2	0.4708728	37	0.5471048	72	0.8656892	107	0.4847932		
3	0.1489031	38	0.3854260	73	0.7340181	108	1.024081		
4	0.4417179	39	0.7694125	74	0.5049549	109	0.3882917		
5	0.8223441	40	0.2105807	75	0.7722889	110	0.2491625		
6	0.3051605	41	0.2306796	76	0.5611097	111	0.1697756		
7	0.8018675	42	1.240462	77	0.1883491	112	0.1631151		
8	0.3616843	43	0.2704958	78	0.2354364	113	0.1331829		
9	0.4158636	44	0.2621709	79	0.5327318	114	0.1941458		
10	0.3707657	45	0.1331829	80	0.9429221	115	0.2621709		
11	0.3647365	46	0.5005447	81	0.7279517	116	0.1245812		
12	0.1941458	47	0.6139430	82	0.5158154	117	0.6404563		
13	0.3766983	48	0.1412618	83	0.3087720	118	0.3123417		
14	1.212440	49	0.2354364	84	0.5993233	119	0.9854638		
15	0.6011702	50	0.6193365	85	0.9933073	120	0.2663659		
16	0.7780096	51	0.3707657	86	1.601660	121	0.3158711		
17	0.2940600	52	0.6575381	87	0.5747736	122	0.2579077		
18	0.4661403	53	0.2400990	88	0.5471048	123	0.1245812		
19	0.2052487	54	0.1489031	89	0.1561709	124	0.7385352		
20	0.3616843	55	0.5531504	90	0.3825389	125	0.4755583		
21	0.8330591	56	1.055007	91	0.2491625	126	0.3395512		
22	1.519979	57	0.2208589	92	0.3854260	127	0.3296110		
23	0.2157810	58	0.8946584	93	0.4077878	128	0.6558500		
24	0.1631151	59	0.5306467	94	0.2621709				
25	0.2978061	60	0.3228141	95	0.7031631				
26	0.5843378	61	0.2052487	96	0.9499502				
27	0.3193615	62	0.4467092	97	0.2208589				
28	0.7078770	63	0.2446727	98	0.4491840				
29	1.204183	64	0.6264555	99	0.9534448				
30	0.2621709	65	0.4341233	100	0.2446727				
31	0.2825237	66	0.4847932	101	0.5728415				
32	1.287818	67	1.195869	102	0.2208589				
33	1.035920	68	1.091166	103	0.1997744				
34	0.4685126	69	1.064423	104	0.2400990				
35	0.8540859	70	0.2258227	105	0.3051605				

DROPLET DATA FOR NEGATIVE 9

Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)
1	0.3796298	36	0.2940600	71	0.3616843	106	0.6282227	141	0.1331829
2	0.3428006	37	0.1331829	72	0.1245812	107	0.2400990	142	0.1331829
3	0.2785721	38	0.5005447	73	0.3460194	108	0.3460194	143	0.7907299
4	0.4417179	39	0.8032488	74	0.6085018	109	1.058155	144	1.116277
5	0.2621709	40	0.8669688	75	0.4417179	110	0.5843378	145	0.1631151
6	0.2535728	41	0.8475711	76	0.6387230	111	0.3158711	146	1.060248
7	0.1153398	42	0.4755583	77	0.1631151	112	0.1941458	147	0.7990977
8	0.4341233	43	0.3051605	78	0.4392009	113	0.5158154	148	0.2663659
9	0.1883491	44	0.3123417	79	0.1761845	114	0.3228141	149	0.8142152
10	0.5285534	45	1.057107	80	0.4801979	115	0.6823596	150	0.1941458
11	0.1631151	46	0.2052487	81	0.1697756	116	0.8809224	151	1.124193
12	0.2400990	47	0.1823683	82	0.3262303	117	0.5389386	152	0.3329574
13	0.1697756	48	0.6642479	83	0.5993233	118	0.1245812	153	0.1489031
14	0.3015057	49	1.034850	84	0.3796298	119	1.280913	154	0.7504478
15	0.2105807	50	0.9695865	85	0.4077878	120	0.2940600	155	0.2400990
16	0.1489031	51	0.8032488	86	1.086074	121	0.1997744	156	1.492006
17	0.5956123	52	1.081983	87	0.1153398	122	0.6936390	157	0.9069651
18	0.5824375	53	0.4708728	88	0.4755583	123	0.2704958	158	0.4685126
19	0.5071455	54	0.3616843	89	0.6264555	124	0.7094414	159	0.5728415
20	0.1153398	55	0.1631151	90	0.9358413	125	0.2785721	160	0.6659148
21	0.9106247	56	0.7650778	91	0.3395512	126	0.2621709	161	0.1489031
22	0.6011702	57	0.2579077	92	0.7187562	127	0.5491273	162	0.7125599
23	0.4870746	58	0.5409917	93	0.3051605	128	0.2052487	163	0.9603959
24	0.6066772	59	0.1412618	94	0.1245812	129	1.457426	164	0.3796298
25	0.1153398	60	0.4540933	95	1.110302	130	1.011007	165	0.1941458
26	0.6139430	61	0.5862319	96	1.254680	131	1.091166	166	0.4158636
27	0.7977092	62	0.3967645	97	1.123207	132	1.500157	167	0.5650474
28	0.1153398	63	1.579355	98	0.3796298	133	0.4442205	168	0.2902655
29	0.2902655	64	0.5027546	99	0.5179601	134	0.1997744	169	0.2579077
30	0.2745637	65	0.5005447	100	0.9877112	135	0.4565282	170	0.1331829
31	0.2157810	66	0.1561709	101	0.2825237	136	0.1245812	171	0.8996013
32	0.5766991	67	0.2535728	102	0.6758296	137	0.1331829	172	1.298107
33	0.7063093	68	0.2208589	103	0.7094414	138	1.454380	173	0.8809224
34	0.9191071	69	0.2704958	104	0.1883491	139	0.8821800	174	0.5409917
35	0.3939605	70	0.8896880	105	1.113293	140	0.9057420	175	1.530156

DROPLET DATA FOR NEGATIVE 9 (cont'd)

Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)
176	0.3395512	211	0.5158154	246	0.1412618	281	0.5728415	316	0.5900019
177	0.5306467	212	1.194013	247	0.2400990	282	0.8682466	317	0.4637560
178	0.6642479	213	0.1697756	248	0.6369849	283	0.1245812	318	0.4131892
179	0.4077878	214	0.2052487	249	0.2535728	284	0.4825011	319	0.4341233
180	0.6404563	215	0.1331829	250	0.2785721	285	0.1412618	320	0.6741873
181	0.1561709	216	0.1245812	251	0.7650778	286	0.6421849	321	0.3523690
182	0.1489031	217	0.3707657	252	1.108303	287	0.6139430	322	0.5900019
183	0.4023139	218	0.1245812	253	0.4392009	288	2.068091	323	0.4263935
184	0.2940600	219	0.9094065	254	0.8060045	289	0.1331829	324	0.5389386
185	0.6264555	220	0.9227185	255	0.2258227	290	1.057107	325	0.9910727
186	0.2354364	221	0.3228141	256	0.2306796	291	0.1245812	326	1.281778
187	0.4732214	222	0.4289856	257	0.1153398	292	0.4263935	327	0.3395512
188	0.3087720	223	0.4417179	258	0.2621709	293	0.4211615	328	0.1631151
189	0.1331829	224	0.1153398	259	0.2354364	294	1.180943	329	0.8656892
190	0.2157810	225	0.1331829	260	0.4050601	295	0.1997744	330	0.2978061
191	0.4916057	226	0.1631151	261	0.4661403	296	0.2354364	331	0.4540933
192	0.2621709	227	0.1245812	262	0.3123417	297	0.2105807	332	0.3087720
193	0.1883491	228	2.887337	263	0.4341233	298	1.730097	333	0.2354364
194	0.2208589	229	0.2535728	264	1.131075	299	0.9298993	334	0.1489031
195	0.1561709	230	1.345082	265	0.6725409	300	0.6030114	335	0.1561709
196	0.5591305	231	0.2157810	266	0.2400990	301	0.6121347	336	0.6791024
197	0.1153398	232	0.1697756	267	0.2535728	302	0.1761845	337	0.6317422
198	0.1245812	233	0.9843382	268	0.7309912	303	0.1331829		
199	0.7141140	234	1.605807	269	0.1245812	304	0.2491625		
200	0.7794333	235	2.434463	270	1.399213	305	1.067543		
201	0.6984173	236	0.1489031	271	0.1823683	306	0.9854638		
202	0.2704958	237	0.2745637	272	0.1823683	307	0.3158711		
203	0.1941458	238	0.4023139	273	0.2978061	308	0.1331829		
204	0.7822727	239	0.2621709	274	0.1153398	309	1.239568		
205	0.7141140	240	1.223364	275	1.281778	310	0.2306796		
206	0.3555012	241	1.495716	276	0.3015057	311	0.3492087		
207	0.2446727	242	0.1823683	277	0.4613593	312	0.1489031		
208	1.408689	243	0.1823683	278	0.2400990	313	0.5389386		
209	0.9820831	244	0.8087506	279	0.6856012	314	0.5571443		
210	0.9638526	245	1.042321	280	0.4732214	315	0.2902655		

DROPLET DATA FOR NEGATIVE 10

Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)	Droplet No.	Diameter (mm)
1	1.206023	36	0.5264518	71	0.4263935	106	0.1153398	141	0.4661403
2	0.9764227	37	0.5709030	72	0.5071455	107	0.7400348	142	0.1561709
3	0.1331829	38	0.2306796	73	0.1489031	108	0.1823683	143	0.2258227
4	0.1331829	39	0.9393883	74	0.6558500	109	1.242248	144	0.3766983
5	0.5937480	40	0.5491273	75	0.3193615	110	1.164875	145	0.2825237
6	0.3051605	41	1.074787	76	0.1245812	111	0.5471048	146	0.3586060
7	0.1883491	42	0.1331829	77	0.3882917	112	1.068581	147	0.2306796
8	0.7202969	43	0.6839823	78	1.052904	113	0.8946584	148	0.3939605
9	0.2978061	44	0.6229062	79	0.8155757	114	0.3087720	149	0.2621709
10	0.2825237	45	0.3296110	80	1.203262	115	0.1941458	150	0.4131892
11	0.8343887	46	0.2354364	81	1.666783	116	0.4104974	151	0.3677634
12	1.474065	47	0.8527870	82	1.376045	117	0.4540933	152	0.1631151
13	0.5071455	48	1.154359	83	0.2052487	118	0.5222232	153	0.5005447
14	0.3428006	49	1.094210	84	0.9287064	119	0.3296110	154	0.6675774
15	0.3123417	50	0.3087720	85	0.3228141	120	0.6807330	155	0.5650474
16	0.7751545	51	0.5200961	86	0.1153398	121	1.601660	156	0.2745637
17	0.6085018	52	0.4565282	87	0.4263935	122	1.374433	157	0.4983250
18	0.2940600	53	0.7233686	88	1.727532	123	0.8462621	158	0.9820831
19	0.7607183	54	1.012103	89	0.7708520	124	0.8958967	159	0.7063093
20	0.5200961	55	0.5306467	90	0.1697756	125	0.3616843	160	0.5368776
21	0.6524605	56	1.093196	91	0.2400990	126	0.6175439	161	0.9499502
22	0.2579077	57	0.2446727	92	0.5611097	127	2.599201	162	0.3523690
23	0.4938556	58	0.4315621	93	0.9718706	128	0.2446727	163	0.1631151
24	0.2052487	59	0.7294731	94	1.055007	129	1.465769	164	0.6299849
25	0.7125599	60	1.226983	95	1.308315	130	0.1153398	165	0.3296110
26	0.3523690	61	1.153398	96	0.5243418	131	0.2621709	166	0.6642479
27	0.5179601	62	0.4263935	97	0.1883491	132	0.9522814	167	0.3939605
28	0.1823683	63	0.1823683	98	0.4417179	133	0.1489031	168	0.5450747
29	0.4685126	64	0.1331829	99	1.127148	134	0.6317422	169	0.3015057
30	0.4442205	65	0.3647365	100	0.1153398	135	1.337644		
31	0.2105807	66	1.449799	101	1.292973	136	0.3087720		
32	0.5306467	67	0.1883491	102	0.4983250	137	0.6121347		
33	0.4960953	68	0.1331829	103	2.009364	138	0.6139430		
34	0.3262303	69	0.3329574	104	1.476320	139	0.2446727		
35	0.7415313	70	1.022998	105	0.2306796	140	0.3123417		

APPENDIX D

DISTRIBUTION LIST

Dr. Frank A. Albini
Northern Forrest Fire Lab
Drawer C
Missoula, MT 59806

Mr. A. Allcock
Department of Industry
Abell House, Room 643
John Islip Street, London
SW14 LN ENGLAND

Mr. Robert D. Anderson, P.E.
Manager of Engineering
Facet/Quantek, Inc.
P.O. Box 50096
Tulsa, OK 74150

Allied Pilot Association
Equipment Evaluation Comm.
P.O. Box 5524
Arlington, TX 76011

Dr. R. L. Altman
NASA ARC
M.S. 234-1
Moffett Field, CA 94035

Dr. S. J. Armour
Defense Research Establishment
Suffield
Ralston, Alberta
CANADA, TOJ 2NO

Mr. Robert Armstrong
B-8414 MS-9W61
Boeing Airplane Company
P.O. Box 3707
Seattle, WA 98124

Mr. Steven L. Baxter
Conoco, Inc.
Chemicals Research Division
P.O. Box 1267
Ponca City, OK 74601

Dr. D. E. Boswell
Quaker Chemical Corporation
Elm Street
Conshohocken, PA 19428

Mr. Lou Brown, AWS-120
FAA National Headquarters
800 Independence Avenue, SW.
Washington, DC 20591

Mr. Don E. Buse
11B12AB
Phillips Petroleum Company
Bartlesville, OK 74004

Mr. William A. Callanan
ARCO Chemicals Company
1500 Market Street
Philadelphia, PA 19101

Mr. Ronald Camp
BASF Wyandotte Corporation
1609 Biddle Avenue
Wyandotte, MI 48192

Mr. Paul Campbell
244 Green Meadow Way
Palo Alto, CA 94306

Mr. Clifford D. Cannon
Transamerica Delaval, Inc.
Wiggins Connectors Division
5000 Triggs Street
Los Angeles, CA 90022

Mr. George A. Cantley
Lear Siegler, Inc.
241 South Abbe Road
P.O. Box 4014
Elyria, OH 44036

Captain Ralph Cantrell
University of Bridgeport
U.S. Army ROTC Department
Bridgeport, CT 06601

Dr. Homer W. Carhart
Naval Research Lab
Code 6180
Washington, DC 20375

Mr. Michael Cass
Sundestrand Corporation
4747 Harrison Avenue
Rockford, IL 61101

Dr. Young I. Cho, Ph.D.
Drexel University
College of Engineering
Philadelphia, PA 19104

Mr. Arthur V. Churchill
AFWAL/POSH
Wright Patterson Air Force Base
Ohio 45433

Mr. J. C. Clerc
Chevron Research Company
P.O. Box 1627
Richmond, CA 94802-0627

Mr. George A. Coffinberry
General Electric Company
1 Neumann Way
Mail Drop E-186
Cincinnati, OH 45215

Mr. Fred W. Cole
Filter Products Division
Facet Enterprises, Inc.
8439 Triad Drive
Greensboro, NC 27409

Mr. J. Donald Collier
Air Transport Association
of America
1709 New York Avenue, NW.
Washington, DC 20006

Captain Ralph Combariati
Port Authority of NY and NJ
JFK International Airport
Jamaica, NY 11430

Mr. Edward Conklin
Sikorsky Aircraft
North Main Street
Straftord, CT 06602

Mr. B. G. Corman
Exxon Research and Engineering
P.O. Box 4255
Baytown, TX 77520

Mr. Dick Coykendall
United Airlines
San Francisco International
Airport
San Francisco, CA 94128

Mr. Gerald A. Cundiff
General Electric Company
3 Penn Center Plaza
Philadelphia, PA 19102

Mr. Rick DeMeis
126 Powers Street
Needham, MA 02192

Mr. Terence Dixon
Boeing Aerospace Corporation
P.O. Box 3999
M/S 8J-93
Seattle, WA 98124

Mr. Thomas F. Donohue
General Electric Company
1 Neumann Way, Mail Drop H-44
P.O. Box 156301
Cincinnati, OH 45215-6301

Mr. William G. Dukek
11 Ridge Road
Summit, NJ 07901

Mr. David W. Eggerding
AMOCO Chemicals Corporation
Research and Development
P.O. Box 400
Naperville, IL 60540

Dr. Thor Eklund, ACT-350
DOT/FAA Technical Center
Atlantic City Airport, NJ 08405

Mr. John H. Enders
Flight Safety Foundation
5510 Columbia Pike
Arlington, VA 22204

Mr. John T. Eschbaugh
Air Maze Incom International
25000 Miles Road
Cleveland, OH 44198

Mr. Anthony Fiorentino
Pratt and Whitney Aircraft
EB2G4
400 Main Street
East Hartford, CT 06108

F. Firth
Lucas Aerospace
Vannonstrand Avenue
Englewood, NJ 07632

Mr. Kent Fisher
Lockheed California Company
Department 70-30, Building 90
P.O. Box 551
Burbank, CA 91520

Mr. David H. Fishman
Technical Planning and Development
United Technologies Inmont
1255 Broad Street
Clifton, NJ 07015

Mr. Ray Fitzpatrick
South African Airways
329 Van Riebeeck Road
Glenn Austin Halfway House, 1685
REPUBLIC OF SOUTH AFRICA

Dr. Kendall Foley
Hercules Inc.
Research Center
Wilmington, DE 19899

Mr. Robert Friedman
NASA Lewis Research Center
M/S 6-9
21000 Brookpark Road
Cleveland, OH 44135

Dr. Allen E. Fuhs
Department of Aeronautics
Naval Post Graduate School
Monterey, CA 93940

Dr. Gerald G. Fuller
Chemical Engineering
Stanford University
Stanford, CA 94305

Y. Funatsu
All Nippon Airways
1-6-6, Tokyo International Airport
Ohta-KU, Tokyo 144
JAPAN

Henry A. Gill
Lockheed California Company
Building 88, B-6
P.O. Box 551
Burbank, CA 91520

Mr. David J. Goldsmith
Eastern Airlines
Miami International Airport
Miami, FL 33148

Mr. Stanley Gray
Mechanical Technology Inc.
968 Albany Shaker Road
Latham, NY 12110

Mr. Ray J. Grill
TRW
1766 Sunset Drive
Richmond Heights, OH 44124

G. Haigh
Air Canada
Air Canada Base, Montreal
International Airport
Quebec, CANADA H4Y 1 C2

Lit S. Han
Ohio State University
206 W. 18th Avenue
Columbus, OH 43210

M. Hardy
United Airlines
SFOEG, MOC
San Francisco International Airport
California 94128

Cyrus P. Henry
E. I. Dupont De Nemours
and Company
Petroleum Lab
Wilmington, DE 19898

R. Hileman
Texaco, Inc.
Box 509
Beacon, NY 12508

W. Hock
Grumman Aerospace Corporation
B 14 035
111 Stewart Avenue
Bethpate, NJ 11714

Arthur Hoffman
American Cynamid
1937 West Main Street
Stamford, CT 06904

LCDR William Holland
Department of the Navy
NAIR 518
Naval Air Systems Command
Washington, DC 20361

Robert L. Hoover
Box 10850 Cave Creek Stage
Phoenix, AZ 85020

Mr. Thomas G. Horeff
Federal Aviation Administration
AEU-101
c/o American Embassy
APO New York 09667-1011

Mr. Gary L. Horton
Chemical Research Division
Conoco, Inc.
P.O. Box 1267
Ponca City, OK 74603

Major Hudson
Air Force Inspection and Safety
SEDM
Norton Air Force Base, CA 92499

Mr. Stephen L. Imbrogno
Pratt and Whitney Aircraft Group
Government Products Division
M/S 711-52
West Palm Beach, FL 33402

Dr. Wolfgang Immel
BASF Aktiengesellschaft
Technologie und Produktionsplanung
6700 Ludwigshafen
WEST GERMANY

M. C. Ingham
Chevron Research Company
P.O. Box 1627
Richmond, CA 94802-0627

G. Jahrstorfer
Chandler Evans, Inc.
Charter Oak Boulevard
West Hartford, CT 06110-0651

Mr. J. P. Jamieson
National Gas Turbine Establishment
Pyestock, Farnborough
Hants GU14 OLS
ENGLAND

Mr. Eric Jevons
Chandler Evans, Inc.
Charter Oak Boulevard
Box 10651
West Hartford, CT 06110-0651

Mr. Stanley Jones
Pan American World Airways
JFK International Airport
New York, NY 11420

R. Kassinger
Exxon International Company
Commercial Department
200 Park Avenue
Florham, NJ 07932

Dr. C. W. Kauffman
The University of Michigan
Gas Dynamics Laboratories
Aerospace Engineering Building
Ann Arbor, MI 48109

Mr. Perry Kirklin
Mobil Research and Development Corporation
Billingsport Road
Paulsboro, NJ 08066

Mr. R. Kirsch, AWS-120
FAA National Headquarters
800 Independence Avenue, SW.
Washington, DC 20591

Mr. John Kirzovensky
Naval Air Propulsion Center
Code PE71
1440 Parkway Avenue
Trenton, NJ 08628

Mr. W. Peter Kochis
FAA Safety Programs Division, ASF-300
800 Independence Avenue, SW.
Washington, DC 20591

Mr. Rob Koller
Rohm and Haas
727 Norristown Road
Spring House, PA 19477

Mr. Robert J. Kostelnik
ARCO Chemical Company
3801 West Chester Pike
Newtown Square, PA 19073

Mr. J. I. Knepper
Petrolite Corporation
369 Marshall Avenue
St. Louis, MO 63119

Dr. John Krynitsky
Fuels and Petroleum Products
4904 Cumberland Avenue
Chevy Chase, MD 20015

Dr. Karl Laden
Carter-Wallace, Inc.
Half Acre Road
Cranbury, NJ 08512

Mr. Thomas P. Lally, Jr.
Senior Marketing Specialist
Aircraft Porous Media, Inc.
Pinellas Park, FL 33565

Dr. R. Landel
Jet Propulsion Lab
4800 Oak Grove Drive
Pasadena, CA 91103

R. Laurens
Rolls-Royce, Inc.
1895 Phoenix Boulevard
Atlanta, GA 30349

Mr. Richard J. Linn
American Airlines
MD 4H14
P.O. Box 61616
Dallas/Fort Worth Airport, TX 75261

P. Longjohn
Clagon Corporation
P.O. Box 1346
Pittsburgh, PA 15230

Mr. Richard R. Lyman
Lear Siegler, Inc.
Energy Products Division
2040 East Dyer Road
Santa Ana, CA 92702

Dr. Richard Mannheimer
Southwest Research Institute
8500 Culebra Road
San Antonio, TX 78284

Captain A. S. Mattox, Jr.
Allied Pilots Association
12723 Brewster Circle
Woodbridge, VA 22191

Mr. James McAbee
ICI Americas, Inc.
Specialty Chemicals Division
Wilmington, DE 19897

Mr. Charles McGuire
Department of Transportation
400 7th Street, SW. (P-5)
Washington, DC 20590

M. L. McMillan
G.M. Research
Fuels and Lubricants Department
Warren, MI 48090

Mr. Peter Meiklem
British Embassy
3100 Massachusetts Avenue, NW
Washington, DC 20008

Mr. G. Chris Meldrum
Texaco Company
P.O. Box 430
Bellaire, TX 77401

Dr. Robert E. Miller
c/o Dr. S. P. Wilford
Royal Aircraft Establishment
Farnborough, Hants
GU146TD, ENGLAND

Mr. Robert J. Moore
Shell Chemical Company
Box 2463
Houston, TX 77001

Mr. Peter D. Moss
American Hoechst Corporation
Route 206 North
Somerville, NJ 08876

Mr. David Nesterok, ACT-2P
DOT/FAA Technical Center
Atlantic City Airport, NJ 08405

Mr. Warren D. Niederhauser
Rohm and Haas Company
727 NOrristown Road
Spring House, PA 19477

J. J. O'Donnell
Airline Pilots Association
1625 Massachusetts Avenue, NW.
Washington, DC 20036

Dean Oliva
Lockheed
Department 7475/Building 229A
P.O. Box 551, Plant 2
Burbank, CA 91520

Dr. Robert C. Oliver
Institute for Defense Analyses
1801 North Bauregard Street
Alexandria, VA 22311

Mr. James H. O'Mara
Rohm and Haas
727 Norristown Road
Spring House, PA 19477

Mr. George Opdyke
AVCO Lycoming Division
550 South Main Street
Stratford, CT 06497

Dr. Robert H. Page
Texas A&M University
College of Engineering
College Station, TX 77884

Chris Papastrat
CEE Electronics, Inc.
8875 Midnight Pass Road
Sarasota, FL 33581

Mr. Roy E. Pardue
Lockheed/Georgia Company
86 South Cubb Drive
Marietta, GA 30063

Mr. Sam Paton
El Paso Products
P.O. Box 3986
Odessa, TX 79760

Mr. Tom Peacock
Douglas Aircraft Company
3855 Lakewood Boulevard
Longbeach, CA 90846

R. D. Pharby
Petro Canada
Sheridan Park
Mississauga, Ontario
CANADA, L5K1A8

Mr. John Pullekins
Air Products and Chemicals
Industrial Chemical Division
P.O. Box 538
Allentown, PA 18105

Dr. Andy Powell
Saudia - CC 836
P.O. Box #167
Jeddah
SAUDI ARABIA

Mr. Horst Rademacher
68 Myrtle Street
Boston, MA 02114

Mr. William Radenbaugh
General Electric Company
Manager, Operational Planning
1000 Western Avenue
Lynn, MA 01910

C. C. Randall, P.E.
Lockheed Georgia Company
D72-47 Zone 418
Marietta, GA 30063

Mr. Richard W. Reiter
National Starch and Chemical
Box 6500
10 Finderne Avenue
Bridgewater, NJ 08807

M. Rippen
Pratt and Whitney Aircraft
Government Products Division
P.O. Box 2691
West Palm Beach, FL 33402

Mr. Charles Rivers
ICI Americas, Inc.
Wilmington, DE 19897

Mr. Russell Rogers
Aeroquip Corporation
Corporate Engineering
Jackson, MI 49203

J. Romans
Hughes Association, Inc.
9111 Louis Avenue
Silver Spring, MD 20910

E. T. Roockey
Northrop Corporation
Aircraft Division
One Northrop Avenue
Hawthorne, CA 90250

Dr. V. Sarohia
Jet Propulsion Lab
M/S 125-214
4800 Oak Grove Drive
Pasadena, CA 91109

Mr. George Savins
Mobil Oil Research and
Development
P.O. Box 819047
Dallas, TX 75381

Dr. Barry Scallet
Annheuser-Busch Corporation
Central Research Inc.
P.O. Box 11841
Clayton, MO 63105

Mr. Forrest W. Schaekel
U.S. Army MERADCOM
Fort Belvoir, VA 22060-5606

Mr. Barry Scott, ADL-31
P.O. Box 25
NASA Ames Research Center
Moffett Field, CA 94035

Professor Valentinas Sernas
Rutgers University
College of Engineering
P.O. Box 909
Piscataway, NJ 08854

Mr. Subhash Shah
Allied Chemical
Syracuse Research Lab
P.O. Box 6
Salisbury, NY 13209

Dr. Hakam Singh, Ph.D.
Product Chemical and Research
Corporation
2920 Empire Avenue
Burbank, CA 91504

Ms. Dana Smith
ARCO Chemical Company
1500 Market Street
32nd Floor
Philadelphia, PA 19101

Mr. H. Daniel Smith
Manager, Research and Development
Engineered Fabrics Division
Goodyear Aerospace Corporation
Akron, OH 44315

S. Sokolsky
Aerospace Corporation
P.O. Box 91957
Los Angeles, CA 90009

Mr. Leo Stamler
Gull Airborne Instruments, Inc.
395 Oser Avenue
Smithtowne, NY

Mr. Barry Stewart
Olin Chemicals
Brandenburg, KY 40108

Dr. Warren C. Strahle
Georgia Institute of Technology
School of Aerospace Engineering
Atlanta, GA 30332

Mr. Peter A. Stranges
1420 16th Street, NW.
Washington, DC 20006

Mr. Kurt H. Strauss
Consultant, Aviation Fuels
116 Hooker Avenue
Poughkeepsie, NY 12601

Mr. Dick Stutz
Sikorsky Aircraft
Engineering Department
Stratford, CT 06602

Mr. A. F. Taylor
Cranfield Institute of Technology
Cranfield, Bedford, MK 43 OAL
ENGLAND

Dr. W. F. Taylor
Exxon Research and Engineering Company
Products Research Division
P.O. Box 51
Linden, NJ 07036

Dr. James Teng, Ph.D.
Annheuser-Busch Corporation
1101 Wyoming Street
St. Louis, MO 63118

Mr. Joseph Thibodeau
Goodyear Aerospace Corporation
1210 Massillon Road
Akron, OH 44315

Mr. Richard G. Thrush
Lear Siegler, Inc.
241 South Abbe Road
P.O. Box 4014
Elyria, OH 44036

Mr. Dick Tobiason
Air Transport Association
1709 New York Avenue, NW.
Washington, DC 20006

Dr. F. F. Tolle
Boeing Military Airplane Company
P.O. Box 3707
M/S 4152
Seattle, WA 98124

Mr. R. Hugh Trask
Southland Corporation
849 Coast Boulevard
LaJolla, CA 93034

M. Trimble
Delta Airlines
DEAT 568
Atlanta International Airport
Atlanta, GA 30320

Mr. T. Ted Tsue
Boeing Aerospace Company
P.O. Box 3999
M/S 45-07
Seattle, WA 98124

Trans World Airlines, Inc.
Kansas City International Airport
2-280
P.O. Box 20126
Kansas City, MO 64195

Mr. Robert Umschied
M.S.E.-6
9709 East Central
Wichita, KS 19328

Mr. Ed Versaw
Lockheed/California Company
P.O. Box 551
Burbank, CA 91520

J. F. Vitkuske
Dow Chemical Company
1702 Building
Midland, MI 48640

Mr. Fred Waite
Imperial Chemical Industries PLC
Paints Division
Wexham Road, Slough SL2 5DS
ENGLAND

Dr. G. J. Walter
Sherwin-Williams Company
501 Murray Road
Cincinnati, OH 45217

H. Weinberg
Exxon Research and
Engineering Company
P.O. Box 45
Linden, NJ 07036

Mr. Paul Weitz
Simmonds Precision Instruments
Panton Road
Vergennes, VT 05491

Mr. John White
National Transportation
Safety Board
800 Independence Avenue, SW.
Washington, DC 20594

Mr. Richard White
Denry White, Inc.
P.O. Box 30088
Cleveland, OH 44130

Dr. S. P. Wilford
Royal Aircraft Establishment
Farnborough, Hants
GU146TD
ENGLAND

R. P. Williams
Phillips Petroleum
107 Catalyst Lab
Bartlesville, OK 74004

R. E. Zalesky
Lockheed California Company
P.O. Box 551
Burbank, CA 91520

Civil Aviation Authority (5)
Aviation House
129 Kingsway
London WC2B 6NN England

Embassy of Australia (1)
Civil Air Attache
1601 Mass. Ave. NW
Washington, DC 20036

Scientific & Tech. Info FAC (1)
ATTN: NASA Rep.
P.O. Box 8757 BWI Airport
Baltimore, MD 21240

Northwestern University (1)
Trisnet Repository
Transportation Center Library
Evanston, ILL 60201

DOT-FAA AEU-500 (5)
American Embassy
APO New York, NY 09667

University of California (1)
Service Dept Institute of
Transportation Standard Lib
412 McLaughlin Hall
Berkely, CA 94720

British Embassy (1)
Civil Air Attache ATS
3100 Mass Ave. NW
Washington, DC 20008

Director DuCentre Exp DE LA (1)
Navigation Aerineene
9141 Orly, France

ANE-40 (2)

ASW-52C4 (2)

APM-13 Nigro (2)

AEA-66.1 (3)

ADL-32 North (1)

AES-3 (1)

ANM-60 (2)

ACT-624 (2)

AAL-62 (2)

M-493.2 (5)
Bldg. 10A

APM-1 (1)

APA-300 (1)

AGL-60 (2)

ASW-53B (2)

AAC-44.4 (2)

ACE-66 (2)

ADL-1 (1)

ALG-300 (1)

ACT-8 (1)

FAA, Chief, Civil Aviation Assistance Group (1)
Madrid, Spain
c/o American Embassy
APO-New York 09285-0001

Al Astorga (1)
Federal Aviation
Administration (CAAG)
American Embassy, Box 38
APO-New York 09285-0001

Dick Tobiason (1)
ATA of America
1709 New York Avenue, NW
Washington, DC 20006

Burton Chesterfield, DMA-603 (1)
DOT Transportation Safety Inst.
6500 South McArthur Blvd.
Oklahoma City, OK 73125

FAA Anchorage ACO
701 C Street, Box 14
Anchorage, Alaska 99513

FAA Atlanta ACO
1075 Inner Loop Road
College Park, Georgia 30337

FAA Boston ACO
12 New England Executive PArk
Burlington, Mass. 01803

FAA Brussels ACO
% American Embassy, APO,
New York, NY 09667

FAA Chicago ACO
2300 E. Devon, Room.232
Des Plains, Illinois 6008

FAA Denver
10455 East 25th Ave., Suite 307
Aurora, Colorado 98168

Frank Taylor
3542 Church Road
Ellicott City, MD 21043

FAA Fort Worth ACO
P.O. Box 1689
Fort Worth, TX 76101

FAA Long Beach ACO
4344 Donald Douglas Drive
Long Beach, CA 90808

FAA Los Angeles ACO
P.O. Box 92007, Worldway Postal Center
Hawthorne, CA 90009

FAA New York ACO
181 So. Frankline Ave., Room 202
Valley Stream, NY 11581

FAA Seattle ACO
17900 Pacific Highway South, C-68966
Seattle, Washington 98168

FAA Wichita ACO
Mid Continent Airport, Room 100 FAA Bldg.
1891 Airport Road
Wichita, KA 67209