AN APPARATUS FOR SIZING PARTICULATE MATTER IN SOLID ROCKET MOTORS (U) NAVAL POSTGRADUATE SCHOOL MONTEREY CA
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AN APPARATUS FOR SIZING PARTICULATE MATTER IN SOLID ROCKET MOTORS

by

Robert Kelly Harris

June 1984

Thesis Advisor: D. W. Netzer

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**Title:** An Apparatus for Sizing Particulate Matter in Solid Rocket Motors

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**Abstract:** A light scattering apparatus to measure particle size \(D_{2\delta}\) in a solid rocket motor was improved. Multiple consecutive scans of two photodiode arrays were accomplished with a pacing circuit and added memory. The device was calibrated using various suspended particle samples and found to make accurate measurements.
An Apparatus for Sizing Particulate Matter in Solid Rocket Motors

by

Robert Kelly Harris
B.S., Central Washington University, 1979

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN AERONAUTICAL ENGINEERING

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ABSTRACT

A light scattering apparatus to measure particle size ($D_{32}$) in a solid rocket motor was improved. Multiple consecutive scans of two photodiode arrays were accomplished with a pacing circuit and added memory. The device was calibrated using various suspended particle samples and found to make accurate measurements.
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I. INTRODUCTION

Performance prediction codes for solid rocket motors model two phase flow losses as functions of particle size. In addition, particle size within the grain port strongly affects the damping of combustion pressure oscillations. At present these models are based on particle size data from collected exhaust samples [Ref. 1]. However, particle size varies with position in the motor and other parameters (pressure, propellant formulation, nozzle design, etc.). Therefore, experiments to determine how particle size varies in the actual flow environment of the motor (i.e., across the nozzle) are needed to validate the models for two phase flow losses. Cramer [Ref. 2] and Karagounis [Ref. 3] provide a good summary of the subject and the Naval Postgraduate School Combustion Laboratory effort to obtain particle size data across the exhaust nozzle of a solid rocket motor.

The method used in this continuing effort was the diffractively scattered light technique. The diffraction patterns of light scattered by particles are analyzed to determine the volume to surface mean diameter [Refs. 4 through 11]. This method has the disadvantages that size distributions cannot be easily determined and particles larger than some threshold size will not be detected due to the exceedingly small angles as which they scatter light. However, it has the advantage
that it is non-intrusive and in theory can be used in the internal motor environment.

Use of this method for particle sizing in solid rocket motors at the Naval Postgraduate School Combustion Laboratory was begun by Karagounis [Ref. 3]. The apparatus was subsequently redesigned and the data acquisition equipment upgraded with the introduction of the Hewlett Packard 3054A data acquisition system with an HP 85 as the controlling computer [Ref. 12]. The investigation by Cramer and Hansen followed and showed that propellant composition can limit the application of the technique. Large particulate combustion products in the flow made particle size data difficult to obtain. This was especially true if only one measurement of the scattering profile was made during a test firing.

To address this problem in the present study several improvements were made. A cleaner burning propellant was obtained to reduce char agglomerates in the exhaust products. A more statistically valid data sample (multiple measurements during a single test) was made possible with added memory in the data acquisition equipment and a pacing circuit which allowed full use of this memory. Data reduction was also improved with a Hewlett Packard 9836S computer combined with a more recently developed approach to particle sizing presented by Buchele [Ref. 13]. This method is discussed later in depth.
The focus of this thesis project was the following:

1. Implement the HP 9836S as the system controller.
2. Expand the multiprogrammer memory in order to obtain up to eight consecutive scans of the diode arrays during a test firing.
3. Improve data reduction techniques by the method of Buchele [Ref. 13].
4. Modify the apparatus and experimental procedures to improve the angular resolution and to reduce extraneous light.
5. Certify the proper functioning and accuracy of the apparatus prior to actual motor testing.
II. THEORETICAL BACKGROUND

A. GENERAL DISCUSSION

The completely general theory of scattering was developed by Mie and is presented by Van de Hulst [Ref. 14]. The light scattering characteristics for spherical particles of any size are fully described in a mathematical format. The Mie scattering functions contain Legendre polynomials and spherical Bessel functions and fully treat the phenomena of reflection, refraction, diffraction, and extinction. The full theory is most often applied when particle size is approximately the same as the wavelength of the incident light. Van de Hulst [Ref. 14] calls this the regime of Anomalous Scattering.

For particle sizes much smaller than the wavelength of light the Mie equations simplify to a form which is more dependent on the index of refraction of the particles and less dependent on particle size. This is called Rayleigh Scattering.

The study of particle size behavior in solid propellant rockets mainly covers sizes much greater than the wavelength of light. Scattering by large particles such as these is described adequately by Fraunhofer diffraction.
B. APPLICATION TO LARGER PARTICLES

The ringed diffraction pattern generated by a hole in a mask, or a number of particles of the same size is described by the equation:

\[ I(\theta) = \frac{2J_1(\alpha\theta)^2}{\alpha\theta} \]

where:

- \( I(\theta) \) describes the relative intensity of the scattered light at an angle \( \theta \)
- \( J_1(\alpha\theta) \) is the Bessel function of the first kind
- \( \alpha = \frac{\pi D}{\lambda} \) is the particle size parameter for diameter
- \( D \) and wavelength of light \( \lambda \).

Measuring the particle size for a monodispersion can be accomplished by measuring the angular position of a dark or bright ring in the diffraction pattern. For a dark ring the zero of the Bessel function corresponding to the ring is set equal to \( (\alpha\theta) \) and particle size is determined directly [Ref. 5]. For bright rings one sets \( (\alpha\theta) \) equal to the corresponding maximum of the Bessel function and solves for the diameter.

The above method is not used for polydispersions since the discrete rings are not observed. However, Dobbins, et al. [Ref. 5] introduced a significant improvement in the diffractively scattered light method of particle sizing. They found that although the method was not directly able to
determine distributions of sizes, the volume to surface mean diameter defined by

\[
D_{32} = \frac{\int_0^D N_r(D) D^3 dD}{\int_0^D N_r(D) D^2 dD}
\]

(1)

where:

\(N_r(D)\) is a distribution function describing the proportion of particles with diameter \((D)\) in the sample, could be accurately measured.

A curve for sizing polydispersions was presented which was used by Cramer and Hansen [Refs. 2, 12].

Two phase flow losses are often calculated in terms of \(D_{43}\). If the distribution of sizes in the polydispersion is well behaved then \(D_{32}\) and other diameters such as \(D_{43}\) can be easily related [Ref. 15]. Reference 5 reported that very small particles in the distribution have a minor influence on the scattering profile. This makes the measurement technique promising for the two phase flow loss study since very small particles do not contribute significantly to these losses and so are of less interest.

Roberts and Webb [Ref. 6] essentially confirmed the conclusions of Reference 5 and presented a similar curve for use in sizing.

More recently, Buchele [Ref. 13] gives a good summary of experimental techniques for particle sizing by measuring
diffracted light. One point of interest in his report is that he represents the scattering profile of a polydispersion with a function which closely approximates the curves of References 5 and 6.

\[ I_n(\theta) = \exp(-0.57a \theta)^2 \]

This function from Reference 13 and the curve from Reference 5 were both used in the present study to evaluate the apparatus to be used with solid propellant rocket motors.

An additional detail of measuring scattering profiles is covered by Van de Hulst [Ref. 14]. The wavelength of light used in the scattering calculations depends on the index of refraction of the medium containing the particles. The wavelength used in all calculations must be:

\[ \lambda = \frac{\lambda_0}{M} \]

where:

\( \lambda_0 \) is the wavelength of light in a vacuum and,

\( M \) is the refractive index of the medium with respect to a vacuum.

Thus, the size parameter (\( \alpha \)) becomes:

\[ \alpha = \frac{\pi DM}{\lambda_0} \]

and the beam spread parameter becomes:
Another consideration is presented by Gumprecht and Sliepcevich [Ref. 4]. Light scattered by particles in a medium is refracted as it crosses each interface of the container holding the medium. This is discussed further in the section on calibration and evaluation of the apparatus.

Additional complications arise with the full treatment of the index of refraction of the particles with respect to the medium. But, for Fraunhofer diffraction alone this aspect can be neglected.

C. RESTRICTIONS AND SOURCES OF ERROR

Some restrictions on use of the method are described by Dobbins, et al. [Ref. 5] and were satisfied as described by Cramer [Ref. 2]. These are related to the size of particles, the distance to the detector, and some phenomenon covered in the rigorous Mie theory.

One must keep in mind also that the curves developed for polydispersions are based on the Upper Limit Distribution Function of Mugele and Evans [Ref. 7]. This means that no particles with size greater than approximately ten times the mean should be in the sample [Ref. 13]. This appears to be a mild restriction. Van de Hulst [Ref. 14] describes the criteria for single scattering and a simple test to verify
it. In general, as long as the scattered intensity is proportional to the number of particles the mathematics remain simple.

Sources of error of the diffractively scattered light method are covered by Buchele [Ref. 13] and are presented here.

(1) Inaccuracy of angular measurement or the limited ability to resolve small angles and,

(2) Inaccuracy of the intensity measurement due to extraneous light.

Extraneous light includes all light other than scattered light from the particles. Some examples are scattering from an aperture or dirty test section windows. Refraction of the beam due to gas density gradients and image point broadening from turbulence are others. Laser speckle is also extraneous light.

The sources of error addressed in this investigation are discussed in the related portions of the paper.
III. EXPERIMENTAL APPARATUS

A photograph of the apparatus is presented in Figure 1. A schematic is presented in Figure 2. The light scattering equipment was mounted on two optical benches. Components for measurements in the exhaust plane were mounted on one bench. The other bench held the equipment associated with the motor cavity. The light source was an eight (8) milliwatt Helium Neon laser mounted on the exhaust bench. A collimated beam was required so a spatial filter/collimator was used. A modification to this collimator is discussed later in this section. The collimated beam passed through a cube beam splitter and the second beam was diverted to a 90 degree prism on the other bench. The original beam continued through the motor exhaust plane. The other beam was routed through the nitrogen-purged glass windows in the motor housing.

Each beam was then intercepted by a physical stop located in front of its set of receiving optics. The further the stop was placed from the test section, the smaller the angle at which scattered light could be measured. In this apparatus, the stops were placed approximately 30.5 centimeters from the exit plane of the test section. This allowed a minimum angle of approximately .008 radians to be measured. Light scattered at angles greater than this was
not intercepted and continued past the edges of the stop. The stop served to keep the transmitted beam out of the measuring optics and thus reduce extraneous light. The stops also improved optics alignment. This is discussed under calibration and evaluation of the apparatus.

The scattered light passed through a narrow pass filter which admitted only light of the Helium Neon frequency. This filter served to reduce extraneous light from the external surroundings.

An objective lens of 50 centimeter focal length was located behind the narrow pass filter. This lens imaged onto a photodiode array the scattering profile of the particles in the test section. The shadow of the beam stop was also imaged since the stop was between the test section and the objective lens. This was a limitation which is discussed under calibration and evaluation.

The photodiode arrays were the same units used by Cramer and Hansen [Refs. 2,12]. Each array contained 1024 silicon photodiodes on a single chip with 25 micron spacing. The accompanying circuits provided a sampled and held output which was essentially analog except for switching transients. At the end of each diode scan there was a delay before the next scan. During this delay the diodes were reset and allowed to measure the intensity of the scattering profile again. The scanning of the diode array repeated continuously. The
actual sampling time of the array was about 34 milliseconds with a delay between scans of about 6 milliseconds.

The 50 centimeter focal length of the objective lens combined with the dimensions of the diode array provided a half angle field of view of about 3 degrees for mediums of refractive index near one. The effective field of view was reduced to about 2.3 degrees for calibrations when the refractive index of a Plexiglas container and water was taken into account.

The laser beam collimator mentioned previously at first produced a beam one centimeter in diameter. A lens in the collimator was changed to reduce the beam diameter for several reasons. Extraneous light would be generated if a large beam impinged on the aperture of the motor test section window. Also, if the aft beam was larger than the motor exhaust jet it would be refracted in the density (and refractive index) gradient between the exhaust and air.

The last part of the apparatus was the rocket motor itself. It was the one used by Cramer and Hansen [Refs. 2, 12] and in the present study served only for aligning the optics.
IV. DATA ACQUISITION SYSTEM

A. NEW CONTROLLER

Hansen [Ref. 12] describes the major components of the Hewlett Packard 3054A data acquisition system. A list of the manuals relevant to this study is in Table 1. The HP 85 computer used by Hansen and Cramer was replaced with an HP 9836S as system controller. This newer computer has far more capability than the HP 85, including a choice of more powerful operating systems. The system used for this study was Basic Extended 2.1.

The data acquisition program written by Hansen needed minor modification to acquire multiple consecutive scans of the photodiodes. Some different I/O commands such as those which transfer data to the disk were also incorporated. The revised version of this program is listed in Appendix A. A general flow chart is presented in Figure 3.

The 9836S has two internal disk drives which were used to store the data after acquisition. The data from both diode arrays was stored in the same file. The eight (8) scans of the motor cavity were first, followed by the four (4) exhaust scans.
B. MODIFICATIONS

The memory capacity of the Multiprogrammer unit was increased so that multiple consecutive scans of the diode arrays could be recorded during a motor firing. This would provide a more statistically valid measurement of particle size. Fluctuations of scattered light intensity for a polydispersion need to be integrated over time or averaged to provide a more appropriate measurement.

In order to fully use the memory added and make data management easier the data acquisition system needed to be modified. The memory consisted of three (3) cards, each with a capacity of 4096 values. The fact that this was a multiple of 1024 (the exact number of photodiodes) meant that the idle period between scans needed to be excluded from the data. If this was not done, one (1) less scan per card would have been acquired and locating the scans in the overall block of memory would have been more difficult.

It was also necessary to chain two of the memory cards together in a way which would allow one card to be filled and then the other. A schematic of the data acquisition system is presented in Figure 4.

C. PACING AND MEMORY CONTROL CIRCUITS

The timing clock and blanking pulse of the photodiode circuitry provided the means for pacing data acquisition.
Specific results of the modifications were:

(1) Memory space was fully utilized and management of the multiple scans made easier.

(2) A/D conversions of the data were made exactly when a diode's output was on line and steady. Thus, the analog filter used in the previous study was no longer needed to suppress the switching spikes on the data line.

The following is a description of the signals and circuits used to modify the data acquisition system. All voltage levels were TTL. A timing diagram in Figure 5 shows the relations between signals. A schematic of the circuit is presented in Figure 6.

The clock pulse was a positive going spike at a frequency of about 30 KHz. This clock controlled all circuits of the photodiodes. It ran continuously, even during the blank period between scans when the diode output was clamped at zero volts.

The blanking pulse was a signal which fell to zero at the beginning of each scan. It then went positive at the end of the scan and remained high until the next scan began.

The clock pulse was used to drive a pulse shaper (monostable multivibrator). This ensured that the voltage levels through the rest of the circuit would not accidentally fall below the TTL threshold. The pulse width of the shaper was adjusted so that the negative going edge of each pulse
would occur after the switching transient on the data line had decayed. This negative going edge would eventually trigger the A/D converter to store the output of each diode.

The blanking pulse was inverted and connected to an AND gate along with the pulse shaper output. The output of this AND gate is shown in Figure 5 as the pulse shaper signal held low between scans of the diode array. This was the basic signal which paced data acquisition.

This basic trigger signal was connected to an AND gate along with the output of the Multiprogrammers Timer Pacer card. In this way the trigger would not reach the A/D until the Timer Pacer output a pulse. This enabling pulse from the Timer Pacer was at least as long as the time for eight scans of a diode array.

The controller programed the Timer Pacer to produce the pulse when the Timer Pacer received a trigger from the blanking pulse. In this way, data acquisition began at the start of a scan and no data was taken during the time between scans.

The circuit to chain the memory cards together was basically an OR gate used as a negative logic AND gate. The end of conversion (EOC) signal of the A/D and the (FULL) signal of one memory card were connected to the gate. When both signals went low the second card was then able to store data from the A/D. This arrangement is shown in the schematic of
the data acquisition system in Figure 4. The automatic lock-out feature of the memory cards when full, and the relatively slow rate of data throughput made it unnecessary to control other handshake lines [memory card manual, Table 1].

The circuit was designed to handle four (4) memory cards, so no modification will be necessary if one more card is added to the system. This would provide an additional four scans of the exhaust beam.
V. DATA REDUCTION

The data reduction programs written by Hansen were not used for this study. The new computer lend itself to another approach. Its memory capacity made it unnecessary to chain programs together and polynomial curve fitting was eliminated in favor of interactive graphics. Avoiding polynomial fits preserved the nature of the raw data so that one had a better feel for the parameters. The data reduction program "RDC" is listed in Appendix A. Figure 7 is a general flow chart for the program.

The following is a description of the program. The user was first prompted for values needed to analyze a given data set. For example, the wavelength of the laser used and the index of refraction of the medium must be known for any data set. Next, one had the choice of reducing raw data scans or reviewing a reduced data file. For raw data one chose either the exhaust or motor cavity beam data.

Raw data was plotted on the CRT and any obviously erroneous scans were excluded from further reduction. The valid scans were averaged to obtain a mean scattering profile. The mean intensity profile taken before particles were introduced was then subtracted from that taken with particles present.
This corrected for the characteristics of individual photodiodes and extraneous light which was independent of the particles.

A symmetric moving-average-type of digital filter was then applied to the profile to achieve some smoothing. This type of digital filter was chosen for simplicity and because it does not have the phase lag of analog filters [Ref. 16]. Preserving the phase of the data was necessary to retain angular resolution. Another advantage of filtering in the software rather than hardware was that raw data files remained unmolested.

The scattering profile was then analyzed using interactive graphics. If earlier, one chosen to review a reduced file, program execution began here.

One had to normalize a scattering profile in order to compare it to the theoretical curves for polydispersions. The scattered intensity on the centerline of the beam was the correct value to use for normalization but was unmeasurable due to the beam's presence.

The other unknown was, of course, the particle size. These two variables (centerline intensity for the measured profile and \( D_{32} \) for the theoretical profile of normalized intensity vs. \( \theta_1 \)) were adjusted using interactive graphics until the curve for polydispersions coincided with the data. In this way the mean diameter of particles was determined.
The second reduction technique used was the direct application of the method presented by Buchele [Ref. 13]. The equation for the polydispersion curve:

\[ I_n(\theta) = \exp\left(-0.57 \alpha \theta\right)^2 \]

was applied at two points of the scattering profile. This gave:

\[ \frac{I_2}{I_1} = \exp\left(-D^2\left(\theta_2^2 - \theta_1^2\right)\left(0.57 \frac{\pi}{\lambda}\right)^2\right) \]

Solving this for the diameter gave:

\[ D = \left[-\ln\left(\frac{I_2}{I_1}\right)\left(\frac{\lambda}{0.57\pi}\right)^2/(\theta_2^2 - \theta_1^2)\right]^{1/2} \]

The computer would sweep through the data using many values of \(\theta_1\) along with several angle ratios to determine \(\theta_2\). The results were presented graphically as particle size vs. \(\theta_1\) for each angle ratio \((\theta_2/\theta_1)\).

In actual practice the range of useable angles depends on the apparatus, and the quality of the data. Therefore, in order to interpret the results one must have previously inspected the data. The interactive graphics routine was well suited to this and provided a hard copy for inspection.

After reducing a set of raw data the mean scattering profile was stored on disk for later review.
VI. CALIBRATION AND EVALUATION

A. IMPROVEMENTS

The geometry of the apparatus used in the investigation by Cramer and Hansen is compared with that of this study in Figure 8. In the previous study the transmitted beam was allowed to enter the receiving optics. The beam was focused off the diode array a few millimeters from the first diode. This was necessary to avoid damaging the diodes but introduced some uncertainty in angle measurements. The intense image of the beam along with scattered light from the receiving optics produced a high level of extraneous light. In the present study, stops were used to intercept the beam before reaching the receiving optics. These stops provided several advantages. A high intensity beam could be used while producing little extraneous light. Optics alignment was also improved. This reduced error in angle measurement. Alignment was accomplished using a neutral density filter to reduce beam intensity and protect the diodes. A schematic of the apparatus is in Figure 2. The laser, collimator, beam splitter and prism were positioned so that the beams passed through the appropriate measurement areas. The narrow pass filter and imaging lens were then positioned so that the beam entered on the centerline. The
photodiode array was then moved using a three-axis micrometer so that the focused beam fell on the first diode. The beam stops were then put in place and the neutral density filter removed. In this way measurements commenced exactly from the optical axis of the beam.

Procedures were also refined to account for the bending of light rays as they passed through the walls of the particle container. As noted earlier, the index of refraction of the container and the medium containing particles affects scattering measurements. A Plexiglas box held the particle samples and a magnetic stirrer kept the samples suspended in water. The index of refraction of the Plexiglas and water combination was measured using a simple technique. A microscope was used to measure the ratio of actual depth to apparent depth for Plexiglas and water. The index of refraction was determined to be 1.39. This value was applied to the data to convert the measured scattering profile to that actually produced in the medium containing the particles.

B. RESULTS

Calibration results are summarized in Table 2. Initial tests were done with two samples which were basically monodispersions of large particles. Figure 9 shows the measured profile of scattered light for glass spheres ranging from...
37 to 44 microns in diameter. This profile was obtained by placing the focused beam just far enough from the first diode to avoid saturation with no particles present. The diodes located at angles less than about .01 radians saturated. The first bright ring for particles of about 40 micron diameter was visible near .02 radians. Figure 10 shows a profile for the same particles, illustrating use of the beam stops to avoid diode saturation and improve angle measurements. In this case, the first diode was located exactly on the centerline of the beam as discussed above.

Results for a sample of 53 to 63 micron glass spheres are shown in Figure 11. The center lobe was nearly completely missed but the first two bright rings were seen near .014 and .022 radians. The first two dark rings near .01 and .019 radians were also seen. The method described earlier of setting the beam spread parameter ($\alpha\theta$) equal to the zeroes and maximums of $J_1(\alpha\theta)$ was used to calculate a size of about 58 microns. Also shown in Figure 11 is the theoretical profile for a polydispersion with $D_{32} = 54$ microns.

Various polydispersions of either glass spheres or aluminum oxide powder were then tested. These polydispersions consisted of fairly large particles. Results are shown in Figures 12 through 17. These tests showed that the apparatus
had two distinct modes of operation. If the particle concentration was very high, or if large particles dominated the polydispersion, many of the diodes at the smaller angles would saturate. This left only the data at larger angles useable. When many diodes saturated, the theoretical curve given by Dobbins, et al., was used to determine size. This was done because this curve was valid for the larger angles and lower relative intensities. The curve from Buchele [Ref. 13] was not valid for values of the beam spread parameter greater than three (3).

For low particle concentrations and/or small particles the data proved more accurate at the smaller angles. If no diodes were seen to saturate then one knew the measurement was in the higher intensity part of the center lobe. Here the curve given by Buchele was quite satisfactory for sizing.

The smallest particles tested were five, ten, and twenty micron polystyrene spheres. The bright rings for these particles occurred at angles too large for the apparatus to measure. For these samples the diodes did not saturate. Both the Gaussian curve fit and the two angle method were used to obtain $D_{32}$. These results were especially consistent. It should be noted that the two-angle method uses the equation for the Gaussian. If the measured profile matched the Gaussian exactly, then $D_{32}$ would be the same for any $(\theta_1)$ and angle ratio $(\theta_2/\theta_1)$ employed. Some variations in
calculated $D_{32}$ due to the imperfect fit are obvious in Figures 19, 21 and 23.

A scanning electron microscope was used to photograph the types of particles tested. These photographs are shown in Figures 24 through 27. Equation (1) was used along with these photographs to calculate some of the values of $D_{32}$ in Table II. Calculations of $D_{32}$ for the polystyrene were arrived at using the manufacturers data on size distributions. The photographs generally confirm the validity of the technique.
VII. CONCLUSIONS AND RECOMMENDATIONS

The results of the calibration tests showed that the apparatus is capable of accurately measuring mean particle size for a broad range of mean diameters. It was found that the technique was most accurate if the theoretical profile fit or the two-angle method were applied at the smallest possible scattering angles.

The rocket exhaust is likely to attenuate the beam somewhat, reducing the problems related to diode saturation at small scattering angles. Thus, measurements should be possible using the high intensity part of the center lobe. This should make data reduction less ambiguous. Actual testing should begin with measurements at the exhaust plane of the motor. These should be compared with collected exhaust samples to validate the use of the apparatus in an actual motor environment. Measurements in the motor cavity would then be interpreted based on the correlation between exhaust samples and exhaust measurements.

It is also recommended that the index of refraction of the combustion gases be investigated. A literature search for an estimate of the index of refraction would probably be satisfactory.
<table>
<thead>
<tr>
<th>No.</th>
<th>Manual Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>HP Memory Cards Model 6970B Operating Manual</td>
</tr>
<tr>
<td>2.</td>
<td>HP Timer Pacer Card Model 69737A Operating Manual</td>
</tr>
<tr>
<td>3.</td>
<td>HP Analog to Digital Converter Card Model 69736A Operating Manual</td>
</tr>
<tr>
<td>4.</td>
<td>HP Users Guide, &quot;Using the 9826 and 9836 Computers with the 6942A Multiprogrammer&quot;</td>
</tr>
<tr>
<td>5.</td>
<td>Basic Language Reference Guide with Extensions 2.0 for Series 200 Computers</td>
</tr>
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### TABLE II. CALIBRATION RESULTS

<table>
<thead>
<tr>
<th>Particle Material</th>
<th>Particle Size microns</th>
<th>Equation (1) Calculated $D_{32}$ microns</th>
<th>Scattering Measurement $D_{32}$ microns</th>
<th>Error microns</th>
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<tbody>
<tr>
<td>Polystyrene</td>
<td>3 to 6</td>
<td>4.7 **</td>
<td>4.5</td>
<td>.5</td>
</tr>
<tr>
<td>Polystyrene</td>
<td>6 to 16</td>
<td>10.2 **</td>
<td>7.9</td>
<td>2.3</td>
</tr>
<tr>
<td>Polystyrene</td>
<td>15 to 30</td>
<td>21.6 **</td>
<td>21</td>
<td>.6</td>
</tr>
<tr>
<td>Glass</td>
<td>37 to 44</td>
<td>38. *</td>
<td>40</td>
<td>2.</td>
</tr>
<tr>
<td>Glass</td>
<td>53 to 63</td>
<td>54. *</td>
<td>54 to 58</td>
<td>0 to 4</td>
</tr>
<tr>
<td>Glass</td>
<td>1 to 37</td>
<td>25. *</td>
<td>28 to 30</td>
<td>3 to 5</td>
</tr>
<tr>
<td>Aluminum Oxide</td>
<td>≥ 25</td>
<td>see Fig. 24</td>
<td>28</td>
<td>-----</td>
</tr>
<tr>
<td>Aluminum Oxide</td>
<td>≥ 50</td>
<td>see Fig. 24</td>
<td>45</td>
<td>-----</td>
</tr>
</tbody>
</table>

* From SEM Photos  ** From Manufacturers Data
Figure 1. Photographs of Light Scattering Apparatus
Figure 2. Schematic of Light Scattering Apparatus.
Figure 3. Flow Chart for Program "ACQDTA".
Figure 4. Schematic of Data Acquisition System.
Figure 5. Timing Diagram for Data Acquisition.
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Figure 7. (Continued) Flow Chart for Program "RDC".

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Figure 7. Flow Chart for Program "RDC".
Figure 7. (Continued) Flow Chart for Program "RDC".
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Figure 9. 37-44 Micron Glass Spheres Using No Beam Stop.
Figure 10. 37-44 Micron Glass Spheres Using Beam Stop.
Figure 11. 53-63 Micron Glass Spheres Showing Diffraction Rings.
Figure 12. 1-37 Micron Glass Spheres, High Concentration.
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Figure 14. 50 Micron Aluminum Oxide, High Concentration.
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CURVE FIT RESULTS
INTENSITY vs. THETA

Mean Diameter 28 Microns
Theoretical Polydispersion Profile (Ref. 5) for $D_{32}=28$ microns

Measured Profile

Figure 16. 25 Micron Aluminum Oxide, High Concentration.
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Figure 18. 5 Micron Polystyrene, Curve Fit.
Figure 19. 5 Micron Polystyrene, Two Angle Method [Ref. 13].
Figure 20. 10 Micron Polystyrene, Curve Fit.
Figure 21. 10 Micron Polystyrene, Two Angle Method [Ref. 13].
CURVE FIT RESULTS
INTENSITY vs. THETA

Mean Diameter 21 Microns

Gaussian
(Ref. 13)
for
$D_{32}=21$ microns

Figure 22. 20 Micron Polystyrene, Curve Fit.
Figure 23. 20 Micron Polystyrene, Two Angle Method [Ref. 131].
Figure 24. SEM Photographs of Aluminum Oxide.
Figure 25. SEM Photographs of Glass Spheres.

37 to 44 micron Glass
$D_{32} = 38$

1 to 37 micron Glass
$D_{32} = 25$
Figure 26. SEM Photographs of Glass and Polystyrene Spheres.

53 to 63 micron Glass
D_{52} = 54

600-800, 15KU, 15KU

Micron Polystyrene
D_{32} = 4.7
**APPENDIX A**

**PROGRAM LISTINGS**

```plaintext
10 !*********** ACQDTA : FOR 9365
20 !*********** ACQUIRES MULTIPLE SCANS OF BOTH DIODE ARRAYS ***********
30 !*********** AND STORES THEM ON DISK ***********
40 !*********** BERT HANSEN, KEN GRAHAM, KELLY HARRIS 1984 ***********
50 OPTION BASE 1
60 COM Q1%[12],Q2%[12],T1%[20],D1%[12],D2%[12],Address(4),E(4096)
70 COM A(1024) BUFFER,B(4096) BUFFER,C(4096) BUFFER,D(4096) BUFFER
80 OUTPUT 799,"AR",!ANALOG RESET
90 ASSIGN @multil O TO 72310 !CLEAR THE WAKE-UP SERVICE REQUEST
100 ENTER @multil O;Qq1,Qq2,Qq3,Qq4,Qq5,Qq6 !OF THE MULTIPROGRAMMER
110 MAT Address= (0)
120 ENABLE INTR 7
130 CLEAR 722
140 PRINT USING "3/
150 PRINT "ENTER THE FILENAMES OF THE DATA FILES TO BE CREATED (e.g. RAW1,RAW2)
160 PRINT "12 CHARACTERS MAXIMUM, EACH"
170 PRINT USING "/
180 PRINT "AN EMPTY DISK MUST BE IN THE LEFT DISK DRIVE"
190 PRINT "*
200 PRINT "THE DATA FILES WILL NEARLY FILL A DISK"
210 PRINT USING "/
220 MASS STORAGE IS ":INTERNAL,4,0" !CHANGE THIS LATER IF NECESSARY
230 INPUT " 
240 INPUT FILE NAMES NOW - (FILENAME1,FILENAME2) ",D1$,D2$
250 M5=1024
260 CREATE BDAT D1%Z$,6144,16 !12 SCANS OF 1024 * 8=8 BYTES PER RECORD
270 CREATE BDAT D2%Z$,6144,16 !1024*12/2=NUMBER OF RECORDS=6144)
280 PRINT USING "/
290 PRINT "DATA WILL BE STORED ON DISKETTE WITH FOLLOWING FILE NAMES:
300 PRINT USING "/
310 PRINT "NO PARTICLES ---- FILENAME = " ;D1$
320 PRINT "PARTICLES ------ FILENAME = " ;D2$
330 PRINT USING "/
340 PRINT "IS THIS A CALIBRATION? ENTER 'Y' IF YES 
350 PRINT "ANYTHING ELSE IF NO 
360 INPUT R$
370 PRINT USING "/
380 PRINT "BE SURE LASER IS ON"
390 PRINT "PRESS [CONTINUE] WHEN READY"
400 PAUSE
```

65
INPUT "ENTER THE THRESHOLD PRESSURE TO TRIGGER THE DEVICES (psi)", S8
INPUT "ENTER TIME DELAY FROM THRESHOLD PRESSURE (sec)", T8

VO=S8/151.5

D3=D14

PRINT USING "ENTER THE THRESHOLD PRESSURE TO TRIGGER THE DEVICES (psi)", S8
PRINT USING "ENTER TIME DELAY FROM THRESHOLD PRESSURE (sec)", T8

TIMES ARE INTERPRETED BY THE COMPUTER IN SECONDS DOWN TO .001

VO=S8/151.5

D3=D14

D3S=D3S

NO-PARTICLES STRING NAME

GOSUB Multiprog
GOSUB Storedata

IF R$="Y" THEN 1100

CONTINUITY CHECK:

OUTPUT 709;"AC20*
LOCAL LOCKOUT 7
R7=225

OUTPUT 722;"HSMO02SW2SO1LISOF4#173QX1"

RESISTANCE MEASUREMENT

H SETS SERVICE REQUEST MASK WHERE 002 IS OCTAL REP. OF
THE SERIAL POLL MASK BYTE;SW2 TELLS WHICH TERMINAL SWITCH IS USED;SO1
SYSTEM OUTPUT MODE ON - WAITS FOR CONTROLLER TO HANDSHAKE;L1 LOAD
INTERNAL MEMORY ON;SO-FUNCTION SHIFT OFF;FA-TWO WIRE CONNECTION TO DVM
R1-AUTORANGING;T3-SINGLE TRIGGER;Q-LOAD INTERNAL MEMORY OFF;X1-EXECUTE
STORED PROGRAM.
GOSUB Reading
R8=U

IF R8>R7 THEN GOTO 0k

CONTINUITY CHECK

PRINT USING "*
PRINT "CONTINUITY CHECK BAD!!!"

PRINT "RECHECK BEFORE PROCEEDING. WHEN CHECKED, PRESS [CONTINUE]"

BEER 3000,3
WAIT .1
BEER 100,1.0
PAUSE
GOTO Contcheck

CONTINUITY CHECK IS O.K.

PRINT USING "*
PRINT "BE SURE NITROGEN IS ON"
OUTPUT 709;"AC21*
PRINT "DVM CONNECTED TO FIRE SWITCH"
PRINT USING "*
PRINT "BE SURE VISICOUS IS SET UP TO RUN ON PROPER SCALE WITH LAMP ON"
PRINT USING "*
OUTPUT 722;"HSMO02SW2SO1LISOF4#173QX1"

VOLTAGE ON IGNITER

DISP "STANDING BY FOR IGNITION"
PRINT "STANDING BY FOR IGNITION"

BEER 2000,1
OUTPUT 722;"X1*
GOSUB Reading
R9=ABS(V)

IF R9<R7 THEN GOTO 870

12 VOLTS ON IGNITOR
910 DB=TIME:DATE       ! USES COMPUTER CLOCK TO GET ELAPSED TIMES
920 OUTPUT 729;"AC22"   ! CONNECT PRESSURE SENSER TO DUM
930 OUTPUT 722;"x1"     ! TRIGGER VOLTMETER
940 GOSUB Reading
950 RP=ABS(V)
960 IF RP(100 THEN GOTO 930   ! THRESHOLD PRESSURE
970 WAIT 10       ! TIME DELAY
980 Q1=TIME:DATE
990 IF R$"1" THEN 1060   ! IF ACTUAL RUN THEN SKIP SOME LINES
1000 ! FOR CALIBRATIONS INTRODUCE PARTICLES AND THEN CONTINUE
1010 PRINT CHR$(12)
1020 PRINT USING 1130  ! TAKE PARTICLE DATA
1030 PRINT *
1040 ON KEY 9 LABEL 1060  ! IF ACTUAL RUN THEN SKIP SOME LINES
1050 Standby: GOTO Standby
1060 GOSUB Multiprog   ! TAKE PARTICLE DATA
1070 LOCAL 7
1080 D3=D2$   ! PARTICLE DATA FILE NAME
1090 GOSUB Steredata
1100 PRINT "ELAPSED TIME: FIRE TO MULTIPROGRAME CALL = ":01-00
1110 PRINT "ELAPSED TIME: FIRE TO MEMORY INTERRUPT = :02-00
1120 PRINT "DATA STORED ON DISK WITH FILENAMES (*.D15;") AND (*.D25;")
1130 GOTO End
1140 Multiprog:
1150 OUTPUT 723;"CC,2,3,12,13T"
1160 OUTPUT 723;"CC,5,6,9,10T"  ! CLEARSA THE ARM,BUSY AND EOF OF MEMORY CARDS
1170 OUTPUT 723;"CC,1,4,11T"   ! CLEAR SAME FOR A TO D'S AND TIMER PACER
1180 OUTPUT 723;"SF,2,3,1,001,12,1T"  ! THE (1) IS 2'S COMPLIMENT BINARY
1190 OUTPUT 723;"SF,5,3,1,001,12,1T"  ! THE .001 IS THE LEAST SIGNIFICANT BIT
1200 OUTPUT 723;"SF,9,3,1,001,12,1T"  ! THE 12 IS FOR 12 BIT WORD SIZE
1210 OUTPUT 723;"SF,12,3,1,001,12,1T"  ! SINCE THE A TO D IS 12 BIT
1220 OUTPUT 723;"WF,3,1023T,WF,6,4095T"
1230 OUTPUT 723;"WF,10,4095T,WF,13,4095T"
1240 ! SETS REFERENCE WORD FOR WHEN TO STOP TAKING DATA AND GENERATE INTERRUPT
1250 OUTPUT 723;"WF,2,1,1T,WF,5,1,1T,WF,9,1,1T,WF,12,1,1T"  ! SETS FIFO MODE
1260 OUTPUT 723;"WF,3,1,0T,WF,5,2,0T,WF,6,3,0T,WF,10,1,0T,WF,10,2,0T,WF,10,3,0T"
1270 OUTPUT 723;"WF,6,1,0T,WF,6,2,0T,WF,6,3,0T,WF,10,1,0T,WF,10,2,0T,WF,10,3,0T"
1280 ! SETS COUNTER AND POINTERS OF 2ND MEMORY CARD IN EACH PAIR TO 0
1290 OUTPUT 723;"AC,3T,AC,6T,AC,10T,AC,13T"! ARMS CARDS WHICH GENERATE INTERRUPT
1300 OUTPUT 723;"WF,4,2,0T,WF,4,15T"  ! TIMER PACER GIVES 1 PULSE OF 1 SEC WHEN
1310 ! TRIGGERED BY THE BLANKING PULSE (PLEN'T OF TIME FOR 0 SCANS)
1320 WAIT 2
1330 K=SPOLL(723)       ! WAIT FOR MEM INTERRUPT
1340 IF K(64) THEN GOTO 1330
1350 OUTPUT 723;"WF,4,2,1T"  ! MAY BE UNNECESSARY TO ALTER TIMER PACER SINCE
1360 ! MEMORY CARDS HAVE AUTOMATIC LOCKOUT BUT FOR NOW WE WILL DO IT
1370 Q2=TIME:DATE
1380 ON ERROR GOTO Err_trap ! NEEDED TO READ ARMED CARD INTERRUPT LIST
1390 SEND 7;UNL MLA TALK 23 SEC 12  ! SPECIFICALLY ASKS FOR INTERRUPT LIST
1400 \textbf{Var, read: ENTER \$/Address(*)} \textbf{READ WHICH CARDS INTERRUPTED}
1410 \textbf{Memcards: PRINT \* MEMORY CARDS WHICH GENERATED INTERRUPTS ARE *}
1420 \textbf{PRINT \* SLOTS$ = \$/Address(*)}
1430 \textbf{MAT Address = (0) OFF ERROR}
1440 \textbf{OUTPUT 723;\string"DC,3,6,13,10T\string" IDISSARM MEM CARDS}
1450 \textbf{OUTPUT 723;\string"MI,2,1024T\string" SET UP CARD TO BE READ}
1460 \textbf{ENTER 72305;A(*)! GETS DATA FROM 1024 MEMORY BOARD}
1470 \textbf{OUTPUT 723;\string"MI,5,4096T\string"! GETS DATA FROM 4096 MEMORY BOARD}
1480 \textbf{PRINT SLOTS* EXHAUST DATA ENTERED''}
1490 \textbf{OUTPUT 723;\string"MI,12,4096T\string"! SET UP CARD TO BE READ}
1500 \textbf{PRINT SLOTS* EXHAUST DATA ENTERED''}
1510 \textbf{OUTPUT 72305;B(*)! GETS DATA FROM 4096 MEMORY BOARD}
1520 \textbf{OUTPUT 72305;C(*)! GETS DATA FROM 4096 MEMORY BOARD}
1530 \textbf{OUTPUT 72305;D(*)! GETS DATA FROM 4096 MEMORY BOARD}
1540 \textbf{PRINT \* EXHAUST DATA ENTERED''}
1550 \textbf{PRINT \* MOTOR DATA ENTERED''}
1560 \textbf{MAT A = (-1)*A! THE 1024 CARD IS INCLUDED BUT NOT SAVED, IT DIDN'T PERFORM WELL. COULD BE REPLACED BY A 4096 CARD.}
1570 \textbf{MAT B = (-1)*B! PERFORM WELL. COULD BE REPLACED BY A 4096 CARD.}
1580 \textbf{MAT C = (-1)*C}
1590 \textbf{MAT D = (-1)*D! DIODE VOLTAGES ARE NEGATIVE SO SIGNS ARE CHANGED}
1600 \textbf{RETURN}
1610 \textbf{Storedata:!}
1620 \textbf{RETURN}
1630 \textbf{ASSIGN \#Diskfile TO D34&Zz! MOTOR CAVITY 4 SCANS}
1640 \textbf{ASSIGN \#Buff1 TO BUFFER C(*)! MOTOR CAVITY 4 SCANS}
1650 \textbf{ASSIGN \#Buff2 TO BUFFER D(*)! MOTOR CAVITY 4 SCANS}
1660 \textbf{ASSIGN \#Buff3 TO BUFFER B(*)! EXHAUST 4 SCANS}
1670 \textbf{CONTROL \#Buff1,3;1,32768,1!SETS BUFFER POINTERS TO FULL}
1680 \textbf{CONTROL \#Buff2,3;1,32767,1!INTERFACE REGISTERS SECTION OF LANGUAGE MANUAL}
1690 \textbf{CONTROL \#Buff3,3;1,32767,1}
1700 \textbf{TRANSFER \#Buff1 TO \#Diskfile! ORDER OF DATA ON THE DISK IS}
1710 \textbf{TRANSFER \#Buff2 TO \#Diskfile! MOTOR CAVITY 4 SCANS}
1720 \textbf{TRANSFER \#Buff3 TO \#Diskfile! INTERFACE REGISTERS SECTION OF LANGUAGE MANUAL}
1730 \textbf{TRANSFER \#Buff4 TO \#Diskfile! ORDER OF DATA ON THE DISK IS}
1740 \textbf{TRANSFER \#Buff5 TO \#Diskfile! INTERFACE REGISTERS SECTION OF LANGUAGE MANUAL}
1750 \textbf{TRANSFER \#Buff6 TO \#Diskfile! INTERFACE REGISTERS SECTION OF LANGUAGE MANUAL}
1760 \textbf{TRANSFER \#Buff7 TO \#Diskfile! INTERFACE REGISTERS SECTION OF LANGUAGE MANUAL}
1770 \textbf{TRANSFER \#Buff8 TO \#Diskfile! INTERFACE REGISTERS SECTION OF LANGUAGE MANUAL}
1780 \textbf{TRANSFER \#Buff9 TO \#Diskfile! INTERFACE REGISTERS SECTION OF LANGUAGE MANUAL}
1790 \textbf{TRANSFER \#Buff10 TO \#Diskfile! INTERFACE REGISTERS SECTION OF LANGUAGE MANUAL}
1800 \textbf{RETURN}
1810 \textbf{Reading:!}
1820 \textbf{STATUS 7,1;A8! CHECKING STATUS BEFORE READING}
1830 \textbf{ENTER 722;V! VOLTMETER IS A FORMALITY TO}
1840 \textbf{ENABLE INTR 7;B! CLEAR THE SERVICE REQUEST}
1850 \textbf{RETURN}
1860 \textbf{Err_trap: IF ERRN=159 AND ERRL(Var_read) THEN Memcards}
1870 \textbf{PRINT ERm$! EVEN IF THE ERROR WAS NOT THE ONE PLANNED}
1880 \textbf{GOTO Memcards! FOR PROGRAM EXECUTION CONTINUES}
1890 \textbf{End: END}

68
I unkonw 10

RDC 20
PLTS RAW DATA 30
AVERAGES 40
FILTERS 50
DETERMINES MEAN DIAMETER 60
BY INTERACTIVE GRAPICS 70
AND THE TWO-ANGLE METHOD 80
Robert Kelly Harris 90
1984 100

OPTION BASE 1 120
COM /Hrdgaus/ Av2(1024) 130
COM /Gauss/ T1(1024),G(1024),L 140
COM /Max/ H7,H5,Xt,Yt,Xm,Ym 150
COM /Readata/ B,P,H,Q3201,0441201,2z41201,Y1(8192) BUFFER,Y2(8192) BUFFER 160

DIM Scans(8),X(1024) 180
DIM Graf(1:12480) BUFFER 190

Choose: PRINT CHR$(12) 210
Old=0 220
PRINT * TO LOOK AT ANY DATA FILE THE PROGRAM NEEDS SOME STARTING INFORMATION 230
PRINT ** 240
PRINT * TO ACCOUNT FOR THE CHANGE IN WAVELENGTH IN THE MEDIUM 250
PRINT ** 260
PRINT * ENTER THE INDEX OF REFRACTION OF THE MEDIUM 270
PRINT ** 280
PRINT * WATER = 1.33 290
PRINT * AIR = 1.0 300
PRINT * ESTIMATE OF EXHAUST = 1.1 310
BEEP 320
INPUT * THIS VALUE ADJUSTS THE COMPARISON CURVE TO THE MEDIUM,H1 330
PRINT CHR$(12) 340
PRINT * TO ACCOUNT FOR REFRACTION OF LIGHT AT BOUNDARIES BETWEEN 350
PRINT ** 360
PRINT ** 370
PRINT * THE MEDIUM AND AIR YOU MUST ENTER THE INDEX OF REFRACTION 380
PRINT **
300 PRINT "OF THE COMBINATION OF THE MEDIUM AND ITS BOUNDARY"
400 PRINT "" THIS VALUE IS APPLIED DIRECTLY TO THE DATA"
410 PRINT " AIR=1.0 PLEXIGLASS & WATER = 1.39"
420 PRINT **
430 PRINT "ESTIMATE OF MOTOR CAVITY COMBUSTION PRODUCTS & WINDOW = 1.22"
440 PRINT **
450 PRINT "ESTIMATE OF ROCKET EXHAUST = 1.1 OR 1.0"
460 INPUT M
470 PRINT " ENTER LASER WAVELENGTH (HeNe=.6328,Ar=.488)*,L"
480 INPUT " ENTER THE DESIRED PLOTTING INTERVAL OF DIODE ARRAY (2,4,6)*,H"
490 PRINT CHR$(12)
500 PRINT " ENTER THE FOCAL LENGTH OF OBJECTIVE LENS" F=460
510 PRINT " DIODE SPACING MAY BE .03"
520 FOR I=0 TO 1093
530 X(I+1)=I+1
540 T(I+1)=(I*Diod)/(F*M)
550 NEXT I
560 PRINT CHR$(12) !JUST PRINTS INITIAL REMARKS ON CRT
570 IF Old THEN CALL Review(Avr(*)) !THESE TWO LINES ALLOW FOR
580 IF Old THEN GOTO Gauss !REVIEWING REDUCED DATA FILES
590 BEEP
600 INPUT " ENTER TWO FILENAMES NOW (NO-PART, 03, Q48)"
610 INPUT " ENTER '1' FOR MOTOR '2' FOR EXHAUST",P
620 ZzS="INTERNAL,4,1" ! USES LEFT DISK DRIVE FOR RAW DATA FILES
630 CALL Readata
640 CALL Shift
650 BEEP
660 Screen: ! CLEAR SCREEN
670 PRINT CHR$(12)
680 P1$="VOLTAGE"
690 P2$="DIODE NUMBER" ! STRINGS FOR PLOTS
700 P3$="VOLTAGE vs. DIODE"
710 P4$="RAW DATA"
720 MS=1024
730 X=.44
740 Y=.04
750 Xm=4
760 Ym=5
770 CALL Plot(Y2(*)) ! DRAWS AXES, ETC...
780 GSTORE Graf(*)
790 CALL Dataplot(B,Y1(*),H) ! PLOT NO-PARTICLES DATA
800 IF Old THEN GOTO Gauss
810 PRINT " HOW MANY SCANS SEEM TO BE GOOD ?"
PRINT "WHICH SCANS ARE GOOD?...i.e. 1,2,4,5,7. INCLUDE LAST COMMA"

INPUT Scans(*)
PRINT CHR$(12)
PRINT USING "'/'/'/'",
PRINT USING "AVERAGING THE SELECTED SCANS"
CALL Average(J,Scans(*),Y1(*),Av1(*))
PRINT USING "'/'/'
GLOAD Graf(*) !LOADS GRAPHICS ARRAY RATHER THAN WASTE TIME RE-DRAWING
GRAPHICS ON
CALL Result(Av1(*),X(*),H) ! PLOTS 1024 ELEMENT ARRAYS
PRINT USING "'/'
PRINT "AVERAGE INTENSITY NO-PARTICLES"
ON KEY 0 LABEL "AVERAGE1" GOTO Screen
ON KEY 1 LABEL "PLOT-PARTICLES" GOTO 1060
PRINT "PRESS KEY # 0 TO RE-AVERAGE OR # 1 TO CONTINUE"
Standby: ! MANUAL CALLS THIS INTERRUPT DRIVEN PROGRAMMING
GOTO Standby ! LOOPS, WAITING FOR USER TO DECIDE
PRINT USING "'/'
OFF KEY 1 ! HELPS AVOID CONFUSION BY CLEARING THAT BOX
CALL Dataplot(B,Y2(*),H) ! PLOTS PARTICLES DATA
PRINT USING "'/'
PRINT "PARTICLE DATA PLOTTED"
PRINT "FOR A HARD COPY OF THIS RAW DATA PRESS KEY # 6"
PRINT "OR TO CONTINUE PRESS KEY # 1"
ON KEY 6 LABEL "HARD & RAW" GOTO Raw
ON KEY 1 LABEL "CONTINUE " GOTO Select
GOTO Standby
Raw: CALL Plot(Y2(*),1) ! THE ONE (1) IS AN OPTIONAL PARAMETER
CALL Dataplot(B,Y2(*),H) ! WHICH IS USED TO GET HARD COPIES
Select:
OFF KEY 6
OFF KEY 1
PRINT CHR$(12)
PRINT USING "'/'/'
PRINT "HOW MANY SCANS SEEM TO BE GOOD?" 
INPUT J
PRINT "WHICH SCANS ARE GOOD?...i.e. 1,2,4,5,7. INCLUDE LAST COMMA"
INPUT Scans(*)
PRINT CHR$(12)
PRINT USING "'/'/'
PRINT USING "AVERAGING THE SELECTED SCANS"
CALL Average(J,Scans(*),Y2(*),Av2(*))
P4$="AVERAGED SCANS"
1350 CALL Plot(Av2())
1360 GRAPHICS ON
1370 GSTORE Graf(*)
1380 CALL Result(Av2(*),X(*),H)
1390 PRINT USING "/**" Average Scattered Intensity
1400 PRINT "HIT KEY 2 TO RE-AVERAGE OR KEY 3 TO
1410 KEY 1 TO CONTINUE"
1420 GOTO Standby
1430 PRINT "HIT KEY 2 TO RE-AVERAGE OR KEY 3 TO
1440 KEY 1 TO CONTINUE"
1450 PRINT "HIT KEY 2 TO RE-AVERAGE OR KEY 3 TO
1460 KEY 1 TO CONTINUE"
1470 MAT Av1= Av2-Av1
1480 CLOAD Graf(*)
1490 CALL Result(Av1(*),X(*),H)
1500 PRINT USING "///" Plot of the Difference Between Particles and N
1510 PRINT "HIT KEY 2 TO RE-AVERAGE OR KEY 3 TO
1520 KEY 1 TO CONTINUE"
1530 PRINT "HIT KEY 2 TO RE-AVERAGE OR KEY 3 TO
1540 KEY 1 TO CONTINUE"
1550 ON KEY 2 LABEL "HARD AVERAGE" GOTO 1570
1560 ON KEY 3 LABEL "FILTER" GOTO 1580
1570 GOTO Standby
1580 CALL Plot(Av1(*),1)
1590 CALL Result(Av1(*),X(*),H)
1600 PLOTTER IS 3,"INTERNAL"
1610 PRINT USING "///" ENTER THE NUMBER OF TIMES YOU WISH TO APPLY
1620 PRINT "THE DIGITAL FILTER FOR SMOOTHING"
1630 PRINT "EXAMPLE******* 10"
1640 PRINT "TAKES ABOUT 1.5 MINUTES"
1650 INPUT "ZERO IS ALSO ACCEPTABLE",Fil
1660 IF Fil=0 THEN Gauss
1670 P4$="FILTERED DATA"
1680 CALL Filter(Av1(*),Fil)
1690 PRINT CHR$(12)
1700 CALL Plot(Av1(*))
1710 IF Did THEN MAT X= T1
1720 CALL Result(Av1(*),X(*),H)
1730 PRINT "Plot of the Difference Between Particles and N
1740 PRINT "AFTER APPLICATION OF A DIGITAL FIL
1750 PRINT "TER"
1760 PRINT "PREPARE the PLOTTER and"
1770 PRINT "PRESS KEY # 8"
1780 PRINT "OR"
1790 PRINT "PRESS KEY # 9 TO NORMALIZE"
1800 ON KEY 8 LABEL "HARD FILTERED" GOTO 1830
1810 ON KEY 9 LABEL "NORMALIZE" GOTO Gauss

72
GOTO Stancv.
CALL Plot(Av1(*),1)
CALL Result(Av1(*),X(*),H)
OFF KEY 8
Gauss: OFF KEY 2
ON KEY 1 LABEL "FILTER" GOTO 1600
!KEY 1 OPTION IS STILL VALID
OFF KEY 8
ON KEY 1 LABEL "GOTO 1600"
WHEN REVIEWING REJECTED FILES
PRINT CHR$(12)
Av2 Array is Normalized BUT Av1(*) is Still Saved For Re-work if Needed
MAT Av2= Av1
TO BEGIN WITH THE ARRAY IS ASSUMED TO BE NORMALIZED
AND THE USER CHANGES THIS WITH INTERACTIVE GRAPHICS
!IN THE SUBROUTINE "Compare"
P1$="NORMALIZED INTENSITY"
P2$="THETA (rad)"
P3$="INTENSITY vs. THETA"
P4$="CURVE FIT RESULTS"
MS=.85
Xt=0.004
Yt=1
Xm=2
Ym=2
CALL Plot(Av2(*))
CALL Result(Av2(*),T1(*),H)
GSTORE Graf(*)
PLOT OF NORMALIZED INTENSITY vs. THETA
CALL Compare(Av1(*),H,M,M1,Graf(*))
GRAPHICS OFF
ON KEY 4 LABEL "OTHER ARRAY" GOTO Choose
ON KEY 5 LABEL "TWO-ANGLE" GOTO Bucbele
ON KEY 9 LABEL "NORMALIZE" GOTO Gauss
ON KEY 6 LABEL "STORE DATA" GOTO Storedata
ON KEY 7 LABEL "QUIT" GOTO Quit
CALL Menuel
GOTO Standby
Bucbele:
CALL Twiangle
CALL Menuel
GOTO Standby
Storedata:
CALL Store
CALL Menuel
GOTO Standby
Quit:
END
SUB Average(I,Scans(*),Y(*),Av(*))
MAT Av= (0)
FOR I=1 TO J STEP 1
K=(Scans(I)-1)*1024+1
L=Scans(I)*1024
FOR II=K TO L
!OF 1024 IN THE OVERALL DATA
I = I - X + 1
A(I) = 4v(I) + Y(I)

NEXT I

MAT Av = Av(I)

*****THE AVERAGE*****

SUB datplot(B, Y(*), H)

COM /Max/ M7, M5, X1, Y1, Xn, Ym

LDIX 0

LONG 4

FOR J = 1 TO B

LABEL J;

HELPS KEEP TRACK OF EACH SCAN AS IT APPEARS

LINE TYPE 1

K = (J - 1) * 1024 + 1

L = J * 1024

MOVE 1, Y(I)

FOR I = K TO L STEP H

X = I - K + 1

PLOT X, Y(I)

NEXT I

NEXT J

PENUP

SUBEND

SUB Result(Iav(*), D(*), H)

THE AVERAGE INTENSITY IS PLOTTED

CLIP ON

MOVE D(I), Iav(I)

FOR I = 1 TO 1024 STEP H

DRAW D(I), Iav(I)

NEXT I

PENUP

SUBEND

SUB Plot(Y(*), OPTIONAL Hard)

IF THE OPTIONAL(Hard) IS RECEIVED

COM /Max/ M7, M5, X1, Y1, Xn, Ym

COM /Plots/ P41(20), P25(20), P35(20), P45(20)

M7 = MAX(Y(*) * 1.1

M6 = 1 * M7

PRINT **

GINIT

WHERE YOU ARE BEGINNING

Select NPAR

IF IT COULD BE DONE WITH IF THEN LOGIC

PLOTTER IS J,"INTERNAL"

BUT IS PRESENTED FOR FAMILIARIZATION

PLOTTER IS 705,"HPGL"

SITUATIONS

END SELECT

GRAPHICS ON

CSIZE 5,.6

DEG

LDIR 0
2820 LORG 5
2830 MOVE 75,95
2840 LABEL USING "X";P4$
2850 MOVE 75,90
2860 LABEL P3$
2870 MOVE 75,20
2880 LABEL P2$
2890 LDIR 90
2900 MOVE 18,60
2910 LDIR P1$
2920 VIEWPORT 30,125,30,85
2930 FRAME
2940 WINDOW 0,M5,-M6,M7
2950 AXES X1,M6,0,0,Xm,1,5
2960 LDIR 0
2970 CSIZE 3,5
2980 LORG 8
2990 CLIP OFF
3000 FOR I=-M6 TO M7 STEP M7/10  !NUMBER THE Y AXIS
3010 MOVE 0,I
3020 LABEL USING "#,#,:MD.DDDD";I
3030 NEXT I
3040 CSIZE 3,.6
3050 LDIR 90
3060 LORG 8
3070 FOR I=0 TO M5 STEP Xt  !NUMBER THE X AXIS
3080 MOVE I,-M6
3090 LABEL USING "#,X";I
3100 NEXT I
3110 PENUP
3120 SUBEND
3130 SUB Compare(Avl(*),HMM1,INTEGER Graf(*))
3140 COM /Gauss/ Tl(*),G(*),L
3150 COM /Hrdqaus/ Av2(*)
3160 COM /Max/ M7,X1,Yt,Xm,Ym
3170 DIM T(1:1124),At(1:17),Dobbins(1:17),Tld(1:17)
3180 DATA 3,3.5,4,4.5,5,5.5,6,6.5,7,7.5,8,8.5,9,9.5,10,10.5,11
3190 DATA .0006,.0006,.0006,.0006,.0006,.0006,.0006,.0006,.0006,.0006,.0006,.0006,.0006,.0006,.0006,.0006
3200 READ At(*)
3210 READ Dobbins(*)
3220 OFF KEY  !GETS RID OF ALL LABELS ON KEYS
3230 ON KEY 3 LABEL "MENUE" GOTO Subexit
3240 PLOTTER IS 3,"INTERNAL"  ! IN CASE A HARD COPY WAS JUST MADE
3250 Hard=0  ! (0) SO ONE DOESN'T EXIT TOO SOON
3260 Centerline=1  ! THE INITIAL NORMALIZING VALUE
3270 D=20.  ! INITIAL PARTICLE MEAN DIAMETER IN MICRONS
3280 Change: CSIZE 4,.6
3290 PRINT USING ""
PRINT "STAND BY FOR CURVE"
MOVE 0,1
CLIP ON
Con=PI*D*M1/L
FOR I=1 TO 1024 STEP H
T(I)=T1(I)*Con
G(I)=EXP(-((.57*T(I))2))
IF T(I)>3.0 THEN 3400
DRAW T(I),G(I)
NEXT I
MAT Tld=At/(Con)
FOR I=1 TO 17
DRAW Tld(I),Dobbins(I)
NEXT I
PENUP
IF Hard THEN SUBEXIT
PRINT USING "---------" USE THE KNOB TO VARY THE PARTICLE SIZE*
PRINT "OR HIT KEY # 6 FOR HARD COPY"*
PRINT "KEY # 9 ALLOWS YOU TO"*
PRINT "RE-NORMALIZE*"
PRINT "HIT KEY # 3 TO GET OUT*"
PRINT USING "---------" ON KEY 8 LABEL "HARD COPY" GOTO Hardgauss
ON KEY 9 LABEL "NORMALIZE" GOTO Divide
ON KNOB .05 GOTO Pulse
(.05) IS TIME INTERVAL IN WHICH PULSES FROM THE KNOB ARE COUNTED AND THIS NUMBER IS USED BY THE INTERACTIVE GRAPHICS TO VARY THE PARTICLE SIZE AND PLOT THE ASSOCIATED GAUSSIAN APPROXIMATIONS OF SCATTERING PROFILES
SLOAD Graf(*)
LDIR 8
LORG B
MOVE M5,.B*7
LABEL Strng1$&VAL(D)&Strng2$
Chanqe
Hardgauss:
PRINT "PREPARE the PLOTTER* PRESS CONTINUE for* HARD COPY"
PRINT
PRINT
PAUSE
Hard=1
CALL Plot(Av2(*),1)
CALL Result(Av2(*),TI(*),H)
3781 PRINT USING "E"
3790 DEC 8
3800 MOVE MS,.B#H7
3810 LDIR 0
3820 LABEL Strng1$_VAL$(D)&Strng2$
3830 MOVE 0,1
3840 GOTO 3150
3850 Divide:
3860 PRINT USING "-1"
3870 FOR I=1 TO 1024 STEP H
3880 DRAW TI(I),Av2(I)
3890 NEXT I
3900 GOTO 3150
3910 PRINT USING "-1"
3920 ON KEY 4 LABEL "-RE-PLLOT" GOTO Replot
3930 ON KEY .55 GOTO Vary
3940 GOTO Wait
3950 Vary:
3960 PRINT CHR$(12)
3970 FOR I=1 TO 1024 STEP H
3980 DRAW TI(I),Av2(I)
3990 NEXT I
4000 PEN 1
4010 C2=KNOBX
4020 Centerline=Centerline+C2/120
4030 PRINT USING "-1"
4040 ON KEY 4 LABEL "-RE-PLLOT" GOTO Replot
4050 ON KEY .55 GOTO Vary
4060 GOTO Wait
4070 Vary:
4080 PRINT CHR$(12)
4090 FOR I=1 TO 1024 STEP H
4100 PRINT USING "-1"
4110 FOR I=1 TO 1024 STEP H
4120 PRINT USING "-1"
4130 PRINT USING "-1"
4140 PRINT USING "-1"
4150 PRINT USING "-1"
4160 PRINT USING "-1"
4170 PRINT USING "-1"
4180 PRINT USING "-1"
4190 PRINT USING "-1"
4200 PRINT USING "-1"
4210 PRINT USING "-1"
4220 PRINT USING "-1"
4230 PRINT USING "-1"
4240 PRINT USING "-1"
4250 PRINT USING "-1"
4260 PRINT USING "-1"
4270 PRINT USING "-1"
4290 PRINT "PRESS KEY # 5" * FOR THE 'TWO-ANGLE' METHOD*  
4300 PRINT "OF PARTICLE SIZING"  
4310 PRINT "*****************************************************************************"  
4320 PRINT "TO STORE THE REDUCED DATA PRESS KEY # 6"  
4330 PRINT "*****************************************************************************"  
4340 PRINT "TO END THIS SESSION PRESS KEY # 7"  
4350 SUBEND  
4360 SUB Display1(Old)  
4370 PRINT "TO REDUCE NEW DATA PRESS KEY # 1"  
4380 PRINT "* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * "  
4390 PRINT "TO REVIEW PREVIOUSLY REDUCED DATA PRESS KEY # 2"  
4400 PRINT "* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * "  
4410 ON KEY 1 LABEL "NEW DATA" GOTO New  
4420 ON KEY 2 LABEL "OLD DATA" GOTO Review  
4430 Wait: GOTO Wait  
4440 New: PRINT CHR$(12)  
4450 PRINT "PUT THE DISK IN THE LEFT DRIVE IF IT IS NOT ALREADY"  
4460 PRINT "* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * "  
4470 PRINT "ENTER THE NAMES OF THE FIRST AND SECOND FILES."  
4480 PRINT "* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * "  
4490 PRINT "EACH FILE HAS DATA FROM BOTH DIODE ARRAYS."  
4500 PRINT "* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * "  
4510 PRINT "FIRST IS NO-PARTICLES & NEXT IS PARTICLES ------D1$, D2$"  
4520 PRINT "* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * "  
4530 Old=0  
4540 SUBEXIT  
4550 Review: Old=1  /* THIS VARIABLE IS PASSED TO THE MAIN PROGRAM TO INDICATE THAT THE DATA TO BE READ IS ONE (1) SCAN AND THAT THE AVERAGING ROUTINES WILL NOT BE USED  
4560 SUBEND  
4570 SUB Readata  
4580 COM /Readata/ B,P,H,Q3$1281,Q4$1201,Z$1281,Y1(*) BUFFER,Y2(*) BUFFER  
4590 Xyz=l  /* FILE POINTER VARIABLE  
4600 B=8  /* NUMBER OF SCANS IN MOTOR DATA  
4610 R1=65536  /* NUMBER OF BYTES OF MOTOR DATA  
4620 IF P=2 THEN Xyz=4097  /* RECORD # WHERE EXHAUST DATA BEGINS  
4630 IF P=2 THEN R1=32768  /* NUMBER OF BYTES OF EXHAUST DATA  
4640 IF P=2 THEN B=4  /* NUMBER OF SCANS IN EXHAUST DATA  
4650 PRINT "* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * "  
4660 PRINT "READING DATA FROM FILE ON DISK"  
4670 Assign @disk1 TO Q3$128$  
4680 Assign @disk2 TO Q4$120$  /OPEN I/O PATHS  
4690 Assign @buff1 TO BUFFER Y1(*)  
4700 Assign @buff2 TO BUFFER Y2(*)  
4710 Control @disk1,5,Xyz  
4720 Transfer @disk1 TO @buff1; Count R1  /* READS NO-PARTICLE DATA  
4730 Wait for EDT @disk1  /* NOT AN OVERLAPPING TRANSFER  
4740 Control @disk2,5,Xyz  /* Xyz SETS DISK FILE POINTER TO EITHER MOTOR OR EXHAUST DATA  
4750 Control @disk2,5,Xyz  
4760 Control @disk2,5,Xyz  
4770 Control @disk2,5,Xyz  
4780 Control @disk2,5,Xyz  
4790
4780  TRANSFER @Disk2 TO @Buff1;COUNT R1  !READS PARTICLE DATA
4790  WAIT FOR EDI @Disk2
4800  ASSIGN @Disk1 TO *
4810  ASSIGN @Disk2 TO *  !JUST GOOD PRACTICE TO CLOSE
4820  ASSIGN @Buff1 TO *
4830  ASSIGN @Buff2 TO *
4840  SUBEND
4850  SUB Plot2(E,D(*)X)
4860  DIM Title$[25],Theta$[20]
4870  GINIT
4880  IF X=1 THEN PLOTTER IS 705,"HPGL"
4890  DEC
4900  GRAPHICS ON
4910  VIEWPORT 35,125,30,85
4920  Max=10*INT((MAX(D(*))+10)/10)
4930  WINDOW D(1,2),D(E,2),0,Max
4940  G=(D(E,2)-D(I,2))/(E-I)*4  !AN X GRID LINE EVERY 4th POINT
4950  F=(INT(E/4)-1)*4
4960  IF F=0 THEN F=4
4970  CLIP D(4,2)-G,D(F,2)+2*G,0,Max  !MAKES GRID UNIFORM
4980  GRID G,5,D(4,2)-G,
4990  CLIP OFF
5000  LORG 8
5010  LDIR 90
5020  CSIZE 4,.5
5030  FOR I=4 TO E STEP 4  !PUTS NUMBERS ON X AXIS
5040    MOVE D(I,2),0
5050    LABEL USING ",,DDDD";D(I,2)
5060    NEXT I
5070  LDIR 0
5080  LORG 8
5090  FOR I=10 TO Max STEP 10  !NUMBER Y AXIS
5100    MOVE D(4,2)-G,I
5110    LABEL USING ",,K";I
5120    NEXT I
5130  CSIZE 6,.6
5140  Title$="TWO-ANGLE METHOD"  !STRINGS FOR PLOTS
5150  Title$="For Various Angle Ratios"
5160  Title$="SIZE (microns)"
5170  Theta$="THETA (rad)"
5180  Sub$="I"
5190  LDIR 90
5200  LORG 5
5210  B=D(4,2)-G-(D(E,2)-D(1,2))/10
5220  MOVE B,Max/2
5230  LABEL Size$  !Size$:
5240  LDIR 0
5250  A=(D(E,2)+D(I,2))/2
5260  MOVE A,-Max/4
5270  LABEL Theta$
5280  LORG 3
5290  MOVE A,-Max/4
5300  LABEL Sub#
5310  LORG 5
5320  MOVE A,Max+1.15
5330  LABEL Title#
5340  CSIZE 4.5
5350  MOVE A,Max+1.05
5360  LABEL Title1#
5370  PENUP
5380  SUBEND
5390  SUB Distribution(D(#),Tratio,E)
5400  LINE TYPE 1
5410  Clip ON
5420  Tratio#=VAL$(Tratio)
5430  MOVE D(1,2),D(1,1)
5440  FOR I=1 TO E
5450  DRAW D(I,2),D(I,1)
5460  NEXT I
5470  LORG 4
5480  LINE TYPE 1
5490  CSIZE 4,.3
5500  MOVE D(I-1,2),D(I-1,1)+2
5510  LABEL TratioS
5520  PENUP
5530  SUBEND
5540  SUB Twoangle
5550  !**************************************************************
5560  !**************************************************************
5570  !**************************************************************
5580  !**************************************************************
5590  !**************************************************************
5600  !**************************************************************
5610  !**************************************************************
5620  OPTION BASE 1
5630  COM /Two/ Avl(1024),M,M1,F
5640  COM /Gauss/ Tl(1024),G(1024),L
5650  !THE GAUSS IS NOT USED HERE
5660  !BUT THE COM BLOCK HAS THETA AND WAVELENGTH
5670  DIM D(200,2)
5680  PRINT CHR$(12)
5690  PRINT USING "//////"
5695  PRINT "THIS SUBPROGRAM USES THE TWO-ANGLE METHOD DESCRIBED BY BUCHELE";
5700  PRINT "";
5710  PRINT "TO CALCULATE PARTICLE SIZE FOR VARIOUS ANGLE RATIOS AND ANGLES.";
5720  PRINT "";
5730  PRINT "IT IS HOPED THAT THE CURVES WHICH RESULT WILL SHOW";
5740  PRINT "";
5750  PRINT "WHICH SIZE IS THE MOST PROBABLE.";
5760  PRINT "";
5770  PRINT "AFTER NOTING FROM THE RAW DATA WHICH ANGLES CONTAIN THE CENTER LOBE";
80
5780 PRINT **
5790 PRINT * ENTER**************THE SMALLEST USEABLE ANGLE,
5800 PRINT * THE SMALLEST ANGLE RATIO AND
5810 PRINT * THE STEP SIZE BETWEEN ANGLE RATIOS
5820 PRINT * YOU WISH TO EXPLORE
5830 PRINT * EXAMPLE************** .012,1.2,.4*
5840 INPUT * ENTER theta1,theta-ratio,theta-step, Q,A,B
5850 OFF KEY
5860 X=0 !GRAPH WILL APPEAR ON SCREEN
5870 Begin: !RUNNING CONTINUES HERE WHEN A HARD
5880 !Van De Hulst and Gumprech & Sleepeich explain that the change in
5890 !wavelength of the beam is accounted for by dividing by the index
5900 !of refraction of the medium. **********L=L/MI **********
5910 C=(L/M1/.57/PI)^2 !---see page 15 of nasa tech paper 2156
5920 FOR N=1 TO 1024 !to see this is a convenient constant
5930 IF Q(TI(N) THEN 5950 !FINDS POSITION OF MINIMUM ANGLE
5940 NEXT N
5950 FOR Tratio=A TO 3 STEP B FOR J=N TO 1010/Tratio STEP 10
5960 !SETS THE RANGE OF POSSIBLE !ANGLES (THETA 1)
5970 FOR I=1 TO J
5980 Thtal=TI(I)
5990 Thtal=TI(J*Tratio)
6000 Deltheta=Theta2^2-Tthta1^2
6010 I1=0
6020 I2=0
6030 FOR I=J-5 TO J+5 !THESE 2 LOOPS AVERAGE A FEW
6040 I1=I1+Av1(I) !INTENSITIES IN THE HOPE
6050 NEXT I !OF A STEADIER CALCULATION
6060 I1=I1/11 !THIS IS A COUNTER FOR THE ARRAY CONTAINING
6070 FOR I=INT(J*Tratio-5) TO INT(J*Tratio+5)
6080 I2=I2+Av(I)
6090 NEXT I !THE GIVEN ANGLE RATIO
6100 I2=I2/11 !THIS IS ANGLE RATIO SINCE THE GAUSSIAN
6110 E=(J-N)/10+1 !PARTICLE SIZE AND THETA1 FOR THE GIVEN
6120 IF I1(12 OR I1=0 OR I2(=0 THEN D1E,1)=0 !ALLOWANCE FOR IF THE DATA
6130 !IS NOT WELL BEHAVED)
6140 IF I1(12 OR I1=0 OR I2(=0 THEN GOTO Xcomp
6150 D(E,1)=SQRT(-C/Deltheta+LOG(12/II)) !TWO ANGLE METHOD
6160 !VALUE OF DIAMETER based on INTENSITY RATIO
6170 !For a given ANGLE RATIO and ANGLE THETA1
6180 Xcomp: D(E,2)=Thtal
6190 Spar=PI*D(E,1)*M1/L !THIS IS PI*D/LAMBDA -- THE SIZE PARAMETER
6200 Tbar=Spar*Tthta2 !THETA BAR FOR THE LARGER ANGLE
6210 IF Tbar(3 THEN J=1010/Tratio !THIS ENDS THE DO LOOP FOR THIS
6220 IF E=1 AND Tbar(3 THEN 6330 !ANGLE RATIO SINCE THE GAUSSIAN
6230 !the above line ends all calculation if !IS NOT VALID WHEN Tbar > 3
6240 !the first element (E=1) failed the test
6250 NEXT J
6260 !FIRST TIME THROUGH-- D HAS THE MOST ELEMENTS IT WILL HAVE
6280 ! S3 SET UP THE GRAPH USING D's PRESENT PARAMETERS
6290 PRINT CHR$(12)
6300 IF Tratio < A THEN CALL Plot2E(D(*),X)
6310 CALL DistributionD(*),Tratio,E)
6320 NEXT Tratio
6330 ON KEY 2 LABEL "HARD COPY" GOTO Hard
6340 ON KEY 3 LABEL 'MENUE' GOTO Sobesit
6350 PRINT USING "\\I-.
6360 PRINT 'YOU CAN GET A HARD COPY BY PRESSING KEY # 2'
6370 PRINT 'OR EXIT THIS ROUTINE BY PRESSING KEY # 3'
6380 Standby:GOTO Standby
6390 Hard:X=I
6400 GOTO Begin
6410 Subexii,GINIT
6420 GRAPHICS OFF
6430 SUBEND
6440 SUB Shift
6450 COM /Readata/ B,F,H,G3$[20],G4$[20],Z$[20],Y1(*),Y2(*) BUFFER
6460 DIM E(1:8192)
6470 PRINT CHR$(12)
6480 PRINT USING "\\I-
6490 PRINT 'RAW DATA IS BEING SHIFTED TO CORRECT FOR SMALL GAPS BETWEEN SCANS'
6500 PRINT "BE PATIENT, IT'S A LONG SET OF DO-LOOPS'
6510 THERE ARE SOME SMALL GAPS BETWEEN SCANS AND THIS SUBROUTINE
6520 ! SHIFTS THE DATA SO THAT THE FIRST DIODE DATA POINT IS MOVED
6530 ! TO THE VERY BEGINNING OF ITS 1024 BLOCK IN THE OVERALL ARRAY
6540 ! THE FIRST SET IS RIGHT ON, THE NEXT IS ONE OFF, THE THIRD IS
6550 ! TWO OFF, SO FORTH. THIS MAY NOT MATTER WITH OUR RESOLUTION
6560 ! AND IS PROBABLY DUE TO THE MEMORY CARD CYCLING AT THE END OF
6570 ! SOME SCANS. SEE THE CIRCUIT TIMING DIAGRAM IN THE THESIS.
6580 SELECT B
6590 CASE 4 !EXHAUST DATA HAS 4 SCANS
6600 M=3
6610 CASE 8 !MOTOR DATA HAS 8 SCANS
6620 M=7
6630 END SELECT
6640 FOR K=1 TO 2
6650 IF K=1 THEN MAT E= Y1 !OPERATES ON NO-PARTICLE AND PARTICLE SETS
6660 IF K=2 THEN MAT E= Y2
6670 FOR J=0 TO M
6680 IF M=7 AND J=3 THEN 6800 !One 4096 Block Doesn't Need Shifting
6690 FOR I=(J+1)*1024 TO (J+1+1)*1024 !BLOCKS OF 1024
6700 IF M=3 THEN L=I+1 !Array B Has the worst
6710 IF M=7 THEN L=I+1 !Problem With Shifting Data
6720 IF M=7 THEN L=I+1 !Array D is Always off by one
6730 IF J=1*1024 THEN L=(J+1)*1024
6740 !JUST TO AVOID PROGRAMMING ERROR AT THE END OF THE ARRAY
6750 E(I)=E(L) !THISshifts THE DATA
6760 !DEPENDING ON 'L', ARRIVED AT
6770 82
BY OBSERVING RAW DATA

NEXT I

IF K=1 THEN MAT Y1= E

IF K=2 THEN MAT Y2= E

NEXT K

SUBEND

THE LARGE ARRAY CONTAINING MULTIPLE SCANS HAS BEEN REDUCED
TO A MEAN SCATTERING PROFILE BY AVERAGING AND FILTERING. IF
YOU FEEL THAT STORING THIS DATA IS NECESSARY THIS ROUTINE
DOES IT. IT SAVES DISK SPACE TO STORE THE RESULTS THEN
ELIMINATE THE RAW DATA IF YOU FEEL CONFIDENT THAT THE
REDUCTION IS THE BEST THAT CAN BE. IN OTHER WORDS,
DO NOT PURGE A RAW DATA FILE UNLESS YOU ARE ABSOLUTELY SURE
YOU WON'T WANT TO REDUCE IT AGAIN.

COM /Hrdg/Av2(*) !Av2(*) IS THE REDUCED DATA
DIM Data(1:1024) BUFFER !BUFFER USED TO TRANSFER TO DISK
MAT Data= Av2
PRINT CHR$(12)
PRINT USING "IIII"
PRINT "A SUGGESTED METHOD OF NAMING REDUCED DATA FILES IS AS FOLLOWS"*
PRINT "M--------MOTOR BEAM"
PRINT "X--------EXHAUST BEAM"
PRINT "C--------CALIBRATION , IF NO 'C' THEN AN ACTUAL FIRING IS ASSUMED"
PRINT "G--------GLASS BEADS *
PRINT "IF NO 'C' THEN 'G' STANDS FOR 'GAP' PROPELLANT"
PRINT "A--------ALUMINUM OXIDE*
PRINT "PPP------CHAMBER PRESSURE FOR RUN OR OTHER....(NOZZLE TYPE)"
PRINT "*PARTICLE SIZE FOR CALIBRATION"
PRINT "MDD-----MONTH,DAY OF RUN OR CALIBRATION"
PRINT "EXAMPLE: MCA125JN12*
PRINT "EXAMPLE: XG550AU18*
PRINT "PLACE A DISK IN THE RIGHT HAND DRIVE"
PRINT "ENTER THE FILENAME YOU WISH TO USE FOR THIS REDUCED DATA*
INPUT A#
CREATE BDAT $,512,16
ASSIGN #Disk TO A#
ASSIGN #Buff TO BUFFER Data(*)
CONTROL #Buff,31,8192,1 !BUFFER IS FULL
TRANSFER #Buff TO #Disk;COUNT 8192
WAIT FOR EOT #Disk
ASSIGN #Buff TO *
ASSIGN #Disk TO *
SUBEND
SUB Review(Av1(*))
DIM Data(1:1024) BUFFER
PRINT * EACH REDUCED FILE CONTAINS ONE SCAN ONLY. YOU MUST KNOW IF IT*
PRINT * IS EXHAUST, MOTOR CAVITY, OR CALIBRATION DATA.*
PRINT **
PRINT * THE DISK WITH THE REDUCED FILE SHOULD BE IN THE RIGHT-MAND DRIVE*
PRINT **
PRINT * ENTER THE FILENAME OF THE REDEED DATA* TO BE REVIEWED*
PRINT **
INPUT A$
ASSIGN #Disk TO A$
ASSIGN #Buff TO BUFFER Data(*)
CONTROL #Disk,5;1
CONTROL #Buff,3;1,1
TRANSFER #Disk TO #Buff;COUNT 8192
WAIT FOR EOT #Disk
ASSIGN #Disk TO *
ASSIGN #Buff TO *
MAT Avi= Data
SUBEND
SUB Filter(A(*),Fil)
DIM E(1:1024)
PRINT CHR$(12)
PRINT USING 1////"*FILTERING THE SCATTERING PROFILE*
FOR I=1 TO Fil
FOR I=1 TO 1014
B=I+1
C=I+2
D=I+3
F=I+4
G=I+5
H=I+6
K=I+7
L=I+8
N=I+9
P=I+10
E(I)=(A(I)+A(B)+A(C)+A(D)+A(F)+A(G)+A(H)+A(K)+A(L)+A(N)+A(P))/11
NEXT I
NEXT J
SUBEND
LIST OF REFERENCES


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