OPTICAL SCATTERING CHARACTERIZATION FOR THE GLENNAN MICROSYSTEMS MICROSCALE PARTICULATE CLASSIFIER

SUMMARY OF RESEARCH

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Small sensors that are tolerant to mechanically and thermally harsh environments present the possibility for *in-situ* particle characterization in propulsion, industrial, and planetary science applications. Under a continuing grant from the Glennan Microsystems Initiative to the Microgravity Fluids Physics Branch of the NASA-Glenn Research Center, a Microscale Particle Classifier (MiPAC) instrument is being developed. The MiPAC instrument will be capable of determining the size distribution of airborne particles from about $1nm$ to $30\mu m$, and will provide partial information as to the concentration, charge state, shape, and structure of the particles, while being an order of magnitude smaller in size and lighter in weight than presently commercially available instruments. The portion of the instrument that will characterize the *nm*-range particles will employ electrical mobility techniques and is being developed under a separate grant to Prof. David Pui of the University of Minnesota. The portion of the instrument that will characterize the μm-size particles such as dirt, pollens, spores, molds, soot and combustion aerosols will use light scattering techniques. The development of data analysis techniques to be employed in the light scattering portion of the instrument is covered by this grant.

When a laser beam is incident on a single near-spherical particle whose diameter is larger than about $2\mu m$, the near-forward scattered intensity consists of a series of concentric bright and dark roughly circular or elliptical fringes. Since the fringe spacing depends on the particle size, an analysis of the fringes provides an accurate size estimate. As a preliminary test of using near-forward scattered light for particle sizing, flat circular metallic particles on a reticle and single lycopodium spores were illuminated by HeNe laser light, and the near-forward scattered intensity was recorded by a CCD array. The experimental apparatus was assembled from parts in the optics laboratory of Paul Greenberg at NASA-Glenn by Prof. Thomas Taylor of the Physics Department of Cleveland State University under a separate contract. Prof. Taylor also prepared the samples took the experimental data using this apparatus. The reticle particles were guaranteed to be extremely circular and were sized very accurately by the manufacturer. The lycopodium spores are representative of airborne biological allergens. They are not spherical, but are nearly so. They are relatively monodisperse, are opaque, and their refractive index is not known.

When I began to analyze the experimental data taken at NASA-Glenn by Dr. Taylor, I found the intensity maxima to be quite noisy. This was likely due to multiple reflections from the glass substrate of the reticle or the microscope slide upon which the lycopodium spores were placed, or was due to evaporated water residue adjacent to the lycopodium spores. In contrast, the intensity minima were substantially less noisy. As a result, I used the first four intensity minima (labeled $i=1,2,3,4$ below) to determine the particle size. Let a be the particle radius in microns, z be the distance between the particle and the CCD camera in microns (z was mechanically measured to be $185.5mm$ for our apparatus), p be the CCD pixel size in microns ($p=27\mu m/pixel$ quoted by the manufacturer), λ be the wavelength of the illuminating laser beam in microns ($\lambda=0.6328\mu m$ for a HeNe laser), x_i be the pixel number of the i-th intensity minimum, and N_i be the light scattering theory factor of the i-th intensity minimum given below. The particle radius is then given by

$$a = (z\lambda/2\pi p)\,[(N_j-N_i)/(x_j-x_i)] \quad . \tag{1}$$

I used this method of data analysis for *6* sets of scattering intensity minima,

$$\begin{aligned}&i=1, j=2\\&i=1, j=3\\&i=1, j=4\\&i=2, j=3\\&i=2, j=4\\&i=3, j=4 \quad .\end{aligned} \tag{2}$$

For diffraction by a perfectly reflecting circular disk, the Fraunhofer diffraction intensity is

$$I(\theta) = J_1^2(2\pi a\theta/\lambda) \,/\, (2\pi a\theta/\lambda)^2 \tag{3}$$

and N_i are the zeros of the Bessel function $J_1(u)$,

$$\begin{aligned}&N1= 3.832\\&N2= 7.016\\&N3=10.173\\&N4=13.324 \quad .\end{aligned} \tag{4}$$

The data from six flat circular metallic spots on the reticle was analyzed using eqs.(1-4). The results were as follows

Reticle RS40-1** $a=19.14\pm0.09\mu m$
Reticle RS40-2** $a=19.27\pm0.16\mu m$
Reticle RS40-3** $a=19.12\pm0.16\mu m$

The nominal radius quoted by the manufacturer is $a=20.0\mu m$.

Reticle RS60-1** $a=29.04\pm0.39\mu m$
Reticle RS60-2** $a=28.59\pm0.63\mu m$
Reticle RS60-3** $a=28.84\pm0.17\mu m$

The nominal radius quoted by the manufacturer is $a=30.0\mu m$. The rms error in the radius using the analysis of eqs.(1-4) is *1%* or less, and suggests that the measurement of z for our apparatus was probably in error. The nominal radius of the reticle particles is fit quite well by $z=193.26mm$.

Data taken on single lycopodium spores was also analyzed. The analysis is identical to that of the flat circular reticle particles that now for the near-spherical lycopodium spores I used Mie scattering by an absorbing particle to determine the N_i factors of the various near-forward direction intensity minima. Numerical Mie theory computations were performed for a variety of real and imaginary parts of the refractive index of a spherical particle whose radius was in the range $12\mu m$ to $20\mu m$. The numerical computations gave

$$
\begin{aligned}
N1 &= 3.771\\
N2 &= 6.902\\
N3 &= 10.010\\
N4 &= 13.113
\end{aligned}
\tag{5}
$$

The analysis of the lycopodium scattering data using eqs.(1,2,5) with $z=185.5mm$ gave the following results

Lycopodium particle 1 $a=15.91\pm0.74\mu m$
Lycopodium particle 2 $a=15.68\pm0.79\mu m$
Lycopodium particle 5 $a=15.38\pm1.49\mu m$

The mean lycopodium radius given in previous publications is about $16.5\mu m$. The rms error in the radius in this case is always greater than or equal to *5%*, possibly reflecting the degree of non-sphericity of the lycopodium spores. If $z=193.26mm$ rather than $185.5mm$, we obtain $a=16.31\mu m$, in reasonable agreement with the results of previous publications.

In summary, the two tests of the data analysis procedure described here illustrate the utility of near-forward direction light scattering in determining the size of an individual particle of a nearly spherical shape. The next step the development of a general data analysis procedure will be to extend eqs.(1,5) to non-spherical particles, rod-like structures, and to particle agglomerates.