Technical Comments

Comments on "Particle Size Analysis of Ammonium Perchlorate by Liquid Sedimentation"

V. S. de Marchi*
Aerojet-General Corporation, Sacramento, Calif.

Introduction

Bastress, Hall, and Summerfield[1] have concluded from their studies that the liquid sedimentation analysis technique "is superior in speed, precision, and first cost" to the air sedimentation method. "The superiority in precision" is not in accord with the prior art, because wet sedimentation gives consistently coarser distributions than the Micromerograph when analyzing environmentally sensitive powders. My own analysis of their reported distributions is in agreement with the results reported in the literature rather than those reported by Bastress, Hall, and Summerfield.[1] Both techniques have advantages and disadvantages.[2]

Technical Discussion

The particle size distributions of the "fine grind" powder obtained by Bastress, Hall, and Summerfield[1] on the Micromerograph at laboratories *A* and *B*, presented in their Fig. 3, show striking similarity to some of the particle size distributions that have been encountered at Aerojet-General Corporation and reported in Fig. 1. In this graph are represented the distributions of agglomerates of lead, aluminum, and "fine grind" ammonium perchlorate, as contrasted to that of experimental coarse grind ammonium perchlorate that does not show agglomeration. The curves representing the particle size distributions of the agglomerated powders show a characteristic higher than normal percentage of coarse particles.

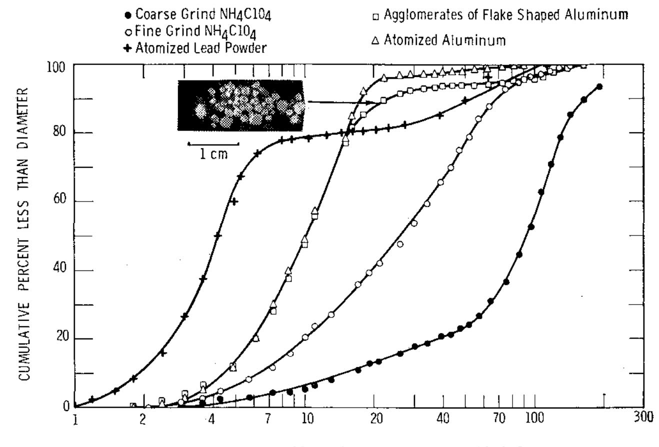

Fig. 1 Particle size distribution of various powders and agglomerated particles.

The presence in these powders of strongly bonded agglomerated fine particles has been observed under the microscope, as shown in Fig. 2 for atomized aluminum, where some of the small particles are clustered together and others are either attached to or welded to the larger particles.

To show the subtle differences that are not evident in the semilog plot of Fig. 1, the data have been replotted on arithmetic probability paper as suggested by Herdan.[3] Figure 3 shows such a graph for powdered metal data of Fig. 1, and Fig. 4 shows the ammonium perchlorate data of Fig. 1, together with the three sets of "coarse grind" data given by Bastress, Hall, and Summerfield. Their "fine grind" data do not fit the arithmetic probability plot, but do fit the log probability scale as shown in Fig. 5. Of the distributions shown, only that for atomized lead fits both probability plots of Figs. 3 and 5 as is the case for the distribution of ground rock presented by Hatch and Coate.[4]

In general, deviation from a straight line on a probability plot indicates a corresponding deviation of the particle size distribution from the normal.[5] The shift away from normality at the very fine end of the curve has been shown by Doeglas[6] to be caused by removal of the fine fractions. Such a removal may be caused by losses through the collecting system or during the various handling and mechanical operations, by the formation of agglomerates, or by the inability of either the mill to grind the powder in the submicron range, or the measuring methods to determine particles less than 2μ. The deviation from normality at the coarse end of the plot is believed caused by the presence of strongly held particles-agglomerates, as shown by Phelps[7] in analyzing Georgia sedimentary kaolin and by the writer in working with flake shaped aluminum powder.[8]

The log-normal distributions, as represented by the "fine ground" ammonium perchlorate from the Micromerograph at both laboratories *A* and *B*, definitely show the presence of agglomerated particles. The dispersing operation is insufficient to break down agglomerates, and this may be the main reason why the mining safety appliance (MSA) analyzer gives a coarser distribution than does the Micromerograph. Actually, according to Marstiller,[9] for particles less than 2μ, the MSA analyzer is more accurate and faster than the Micromerograph. This is confirmed by the fact that the distribution of the "fine grind" ammonium perchlorate obtained with the MSA analyzer shows, at the fine end, a better fit of the normal curve than those obtained with the Micromerograph.

Only the distributions obtained by means of the MSA analyzer show deviation to the left of the normal curve, indicating deficiency of coarse material.[5, 6] This may indicate

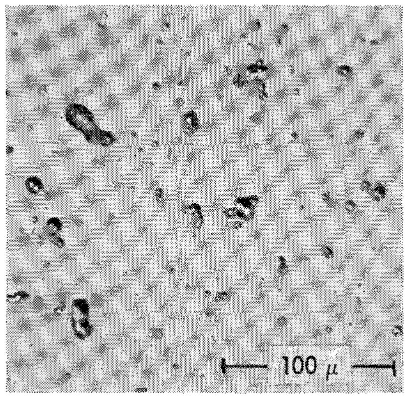

Fig. 2 X-250 atomized aluminum showing agglomerated particles.

Received January 16, 1964.

* Technical Specialist, Propellant Ballistics Department.

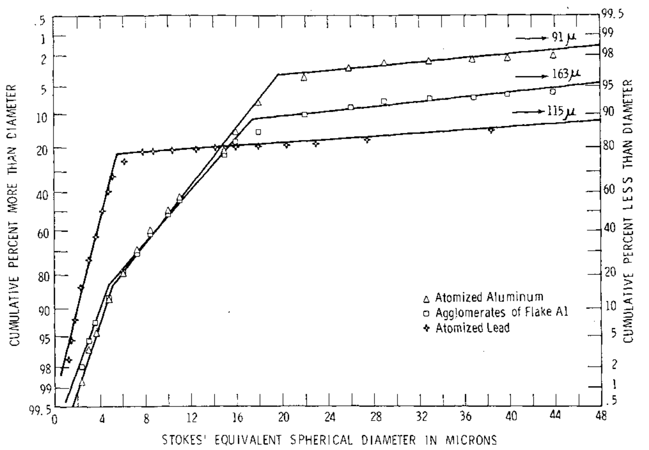

Fig. 3 Particle size distribution of various powders (probability plot).

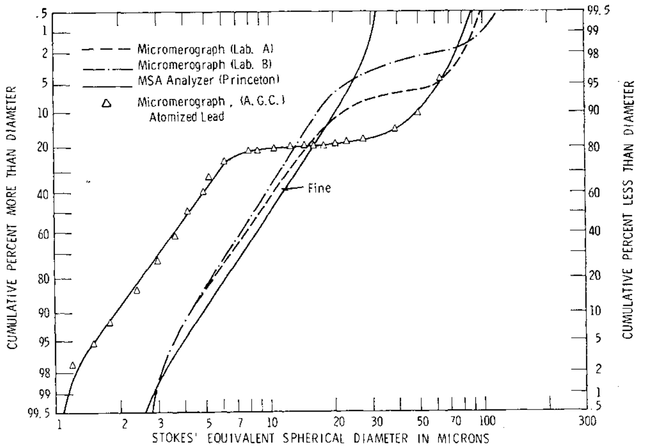

Fig. 5 Particle size distribution of ammonium perchlorate replotted from Ref. 1 and atomized lead.

that the eye dropper missed some of the coarser particles in transferring the samples from the beaker, where the suspension is prepared, to the "feeding chamber."

For both the "fine" and "coarse grind," the MSA analyzer consistently indicates a coarser distribution than the Micromerograph, even in the submicron size, where it is most useful. Simons,[10] in comparing the results obtained from the Micromerograph and from a liquid sedimentation balance analyzer, reports similar results, and he adds that the difference between the two distribution curves is most pronounced by those powders that contain readily distinguishable agglomerates in the as-received condition. The coarser distribution is caused by agglomerated fines.[11] Thornton[12] has evaluated two wet sedimentation techniques including a complex recording sedimentometer and the dry sedimentation method, Micromerograph. The results show that the data obtained by each method are reproducible, but the results may not be comparable from method to method.

If the "fine grind" ammonium perchlorate behaves in the Micromerograph in the same manner as the glass spheres, platelets, and other contaminants, as shown in Fig. 5 of Ref. 13, then the MSA analyzer sees still fewer (about 10%) very coarse particles than the Micromerograph. The latter, when using spherical particles, gives practically the same distribution as the Coulter counter.[14]

It is very difficult to make comparative studies at different laboratories, when using powders environmentally sensitive, even when packed with a desiccant, as suggested by Reynolds and Clapper,[15] and having a very wide spread in the particle size range, because storage conditions affect the distribution, and shipping and handling affect the homogeneity of the sample. This may explain the difference in the distribution, obtained by means of the Micromerograph at laboratories *A* and *B*. The shape of the distribution curve obtained at the former laboratory shows that considerable agglomeration of the powder has occurred, whereas the good fit obtained at the latter laboratory indicates that no caking is present.

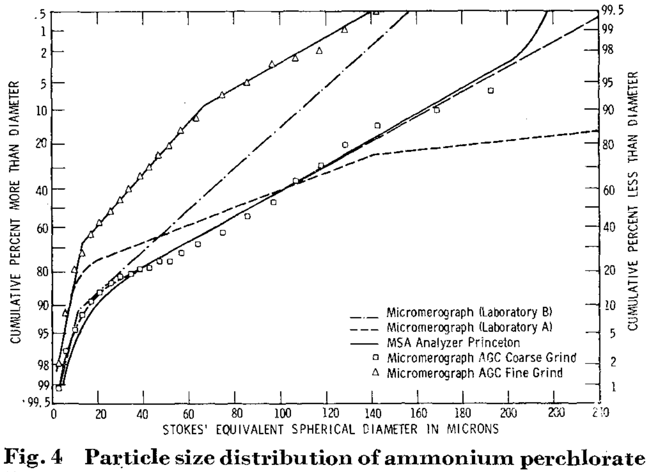

Fig. 4 Particle size distribution of ammonium perchlorate "coarse grind" as reported in Ref. 1 and Aerojet-General Corporation experimental grinds.

Actually, the method to be used in the determination of the particle size distribution of the ammonium perchlorate depends on how the material is transported and fed to the mixer, i.e., if the powder is transported in a hopper and dumped from there into the mixer, then the MSA analyzer would give the more realistic distribution because the agglomerates, if any, would not be disturbed; if the powder is conveyed by means of a fluidized system, then the Micromerograph would represent the distribution more faithfully, because some of the less strongly held agglomerates, if any, would be separated by the shear forces generated in the dispersed system. The foregoing may be expressed more briefly in paraphrasing Stairmand[16]; once it is clearly known which parameter is important, how the material is handled, and how it is processed, it is possible to select a size analysis apparatus that will measure it to the required degree of accuracy.

References

[1] Bastress, E. K., Hall, K. P., and Summerfield, M., "Particle size analysis of ammonium perchlorate by liquid sedimentation," AIAA J. **1**, 1182–1185 (1963).

[2] Irani, R. R. and Callis, C. F., *Particle Size Measurement Interpretation and Application* (John Wiley and Sons, New York, 1963), Chap. 5.

[3] Herdan, G., *Small Particle Statistics* (Academic Press Inc., New York, 1960), 2nd ed., p. 96.

[4] Hatch, T. and Choate, S. P., "Statistical description of the size properties of non-uniform particulate substances," J. Franklin Inst. **207**, 369–387 (1929).

[5] Irani, R. R., "The interpretation of abnormalities in the log-normal, distribution of particle size," J. Phys. Chem. **63**, 1603–1607 (1959).

[6] Doeglas, D. J., "Interpretation of the results of mechanical analysis," J. Sediment. Petrol. **16**, 19–40 (1946).

[7] Phelps, G. W., "Practical grain size analysis of clays. III Log probability data plotting," Am. Ceram. Soc. Bull. **39**, 267–269 (1960).

[8] de Marchi, V. S., "Ageing and storage of flake shaped aluminum powder," Symposium on Dyes and Pigments in Coatings and Plastics, American Chemical Society, New York (September 1963).

[9] Marstiller, C. M., private communication, Alcoa Research Labs., Pittsburgh, Pa. (1962).

[10] Simons, E. L., "How to determine subsieve particle size—Micromerograph," Ceram. Ind. **72**, 88–91 (March 1959).

[11] "Alcoa hydral 700 series," Alcoa Chemical Co., Pittsburgh, Pa. (1962).

[12] Thornton, M. J., "The size analysis of phenothiazine," J. Pharm. Pharmcol. **11**, 127T–138T (1959).

[13] Kaye S. M., Middlebrooks, D. E., and Weingarten, G., "Evaluation of the Sharples Micromerograph for particle size distribution analysis," Feltman Research Labs., Picatinny Arsenal TR FRL-TR-54 (February 1962).

[14] Roby, H., private communication, Aerojet-General Corp., Sacramento, Calif. (1963).

[15] Reynolds, J. E. and Clapper, T. W., "The manufacture of perchlorate part 2," Chem. Eng. Progr. **57**, 94–97 (December 1961).

[16] Stairmand, C. J., in discussing "Methods of production and control" by P. V. Danckwerts, *Powders in Industry* (Society of Chemical Industry, London, 1961), p. 428.

Comments on "Some Effects of Planform Modification on the Skin Friction Drag"

Milton J. Thompson*
The University of Texas, Austin, Texas

IN a recent Technical Note, Hopkins[1] has presented an analysis of the skin friction drag for a "cranked" wing of double trapezoidal planform. The procedure followed includes consideration of the variation in skin friction coefficient with Reynolds number because of changes in wing chord.

It is interesting to note that this same basic concept was employed thirty years ago by Upson and the present writer[2] in a study of the drag of single trapezoidal planforms. The earlier work began with an expression for the profile drag coefficient of a chordwise element of the wing in the form

$$C_{D_0} = h[RN]^n(a_1 + a_2t^2)(1 + a_3C_L{}^3) \tag{1}$$

in which t is the thickness ratio and C_L the section lift coefficient. Definitions of the coefficients h, a_1, a_2, and a_3 are obvious from Eq. (1).

For the case corresponding to Hopkins' analysis, we put $t = 0$ and $C_L = 0$ and obtain

$$C_{D_0} = h[RN]^na_1 \tag{2}$$

with the Reynolds number now given in terms of the local chord y as

$$RN = V_0y/\nu \tag{3}$$

The application of Eq. (2) to the profile drag calculation for the chordwise strip of the wing $y\,\Delta x$ gives

$$C_{D_0} = [RN]_m{}^n\phi a_1 \tag{4}$$

where the Reynolds number is based on the mean chord and

$$\phi = \frac{2^{n+1}h(1 - K_y{}^{n+2})}{(n + 2)(1 + K_y)^{n+1}(1 - K_y)} \tag{5}$$

Changing the notation so that $h = K$ and $K_y = 1/\lambda_2$, Eq. (5) becomes identical with that obtained by application of Hopkins' results in this restricted case.

In connection with Eq. (4) in the Hopkins paper, a slight error is to be noted in that the denominator of the term in the square brackets should read $(1 - \lambda_2)(\lambda_2)^{n+1}$ instead of $(1 - \lambda_2)(\lambda_2)^{n+2}$. This error apparently was not carried over into the computations leading to Figs. 2 and 3 of Ref. 1.

It may also be of interest to note that the earlier work of Ref. 2 included effects of section thickness ratio and lift coefficient as indicated by Eq. (1). Induced drag was also included in these considerations along with a combined treatment of both aerodynamic and structural factors.

References

[1] Hopkins, E. J., "Some effects of planform modification on the skin friction drag," AIAA J. **2**, 413–414 (1964).

[2] Upson, R. H. and Thompson, M. J., "The drag of tapered cantilevered airfoils," J. Aeronaut. Sci. **1**, 168–177 (1934).

Received October 26, 1964.

* Professor and Chairman, Department of Aerospace Engineering; also Associate Director, Defense Research Laboratory. Associate Fellow Member AIAA.

Comments on "Turbulent Mixing of Coaxial Jets"

George L. Mellor*
Princeton University, Princeton, N. J.

IN the case of incompressible, fully developed, turbulent jet flows, Alpinieri[1] has stated that the conventional eddy viscosity assumption, $\epsilon = \kappa b|u_c - u_e|$ (where b is the jet half-width, u_e the constant external velocity, and u_c the centerline velocity), is only verified experimentally for the case $u_e = 0$, and therefore it is fair game to propose an entirely new assumption when $u_e > 0$. In an attempt to include the effects of variable density, he has apparently selected an assumption out of a set of possibilities all deemed equally probable but one that seems to fit his particular set of data.

However, in the far downstream region there is nothing to distinguish between wakes and jets (where $u_e > 0$, $u_c < u_e$) so that, for the constant density case, we find from the data of Cooper and Lutzky[2] and Carmody[3] that, for large x, $b \sim x^{1/3}$ and $u_e - u_c \sim x^{-2/3}$ which is in agreement with predictions based on the conventional eddy viscosity assumption[4] or on similarity considerations.[2] It follows from this that $\epsilon \sim x^{-1/3}$. Alpinieri's assumption, where in fact ϵ increases with x, is therefore in disagreement with this data.

Both Alpinieri and, in a related paper, Ferri, Libby, and Zakkay[5] object to the fact that, when $u_e = u_c$ and $\rho_e \neq \rho_c$, the conventional assumption leads to zero mixing of scalar quantities such as temperature or concentration. However, in the absence of upstream turbulence or velocity distortions this would, indeed, be evident to an observer travelling with the velocity $u = u_e = u_c$.

The answer seems to be that Refs. 2 and 3 cover a large range of x/d whereas Ref. 1 does not. Thus, Alpinieri is really dealing with the near downstream region with an assumption that, for the most part, involves variables appropriate to the far downstream region. The fact that mixing occurs when $u_e = u_c$ indicates that the turbulence is either present in the upstream flow or is subsequently generated by the velocity profile distortion due to the upstream boundary layers or both.

In the far downstream region where mixing is caused by turbulence generated by the jet or wake velocity profile, it seems evident that $\epsilon = \varkappa b|u_e - u_c|$ where, however, $\varkappa = \varkappa(\rho_c/\rho_e)$ and is still to be determined.†

Received October 22, 1964.

* Associate Professor, Department of Aerospace and Mechanical Sciences. Member AIAA.

† A possible clue might be contained in the analysis of the inviscid stability of a discontinuous jet or cylindrical vortex sheet; one finds that a small disturbance grows like $\exp(\sigma t)$ where $\sigma = [(\rho_e\rho_cf)^{1/2}/(\rho_e + \rho_cf)]k|u_c - u_e|$, k is the disturbance wave number, $f = I_0(kb)K_1(kb)/I_1(kb)K_0(kb)$ (Bessel function notation as used by Hildebrand), and b = jet diameter. The implication is that one might expect $\epsilon \sim \sigma b^2$ where $kb = O(1)$ and $f = O(1)$.