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EXPERIMENTAL STATION
RESEARCH AND DEVELOPMENT DIVISION TECHNICAL REPORT
CHEMICALS, DYES AND PIGMENTS DEPARTMENT
E. I. DU PONT DE NEMOURS & COMPANY

COANDA-FLOW CLASSIFICATION OF TiO_2

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Patent Situation Approved By:	J. W. Heberling	Date:	11/8/79
Previous Related Reports:	PTD-SA-78-2B		
Project Code:	7053-182088		
Type Technical Work:	IEB		
Period Covered:	Sept., 1978 to Oct., 1979		
Notebook Nos.:	E16067, E19622		
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ABSTRACT

Coanda-flow classification has been shown to effectively handle TiO_2. Present applications include removal of TiO_2 scrub solids grit and fine-cut (1-3 μm) separations. Potential energy benefits (primarily micronizer steam savings) from such classifications are now being studied. Removal of 7-8 wt. % + 325 mesh grit has already been shown to significantly reduce grinding energy requirements. Fine-cut separations are still being evaluated. In conjunction with the experimental program, a mathematical model of the Coanda-flow separation technique was formulated. The resulting cut-size predictions were in good agreement with the experimental results. This mathematical model was further used to analyze larger slot dimensions, etc. which would be more amenable to plant-scale operation.

COANDA-FLOW CLASSIFICATION OF TiO_2

INTRODUCTION

Size classification of TiO_2 is being investigated as a means of reducing energy consumption in the micronizer. The micronizer is the primary energy consumer in the plant, using ~1/3 of the total energy, and the particle size distribution of its feed is thought to affect its grinding efficiency. In particular, the presence of 5 to 10 wt. % scrub solids grit (+325 mesh) has been shown to significantly increase the micronizer steam consumption. In the present program Coanda-flow classification has been studied and shown to be effective in removing such grit. This same Coanda-flow technique is also being used to make fine-cut classifications. If the micronizer feed can be separated into two fractions, one of which is very fine, these two fractions could be micronized separately and thus avoid any overgrinding of the fines. Since TiO_2 is particularly sticky and hard to handle, past classification techniques have had difficulty with TiO_2, and none have been able to make a fine enough cut-size to accomplish the above goal. The present technique shows the greatest promise for success. It has been shown to handle TiO_2 well and to make a cut as low as 2-3 μm.

OBJECTIVES

- Assess the feasibility of classifying TiO_2 in a Coanda-flow classifier.
- Determine the micronizer energy usage and pigment quality resulting from such size classification.

PATENT SITUATION

Patent Protection:	None
Filing Action:	None contemplated.

PROGRAM

A laboratory model based on Coanda-Flow principle is being constructed at the Engg. Test Center. Experimentation is planned for this Boundary-Layer classifier to determine what if any flow-balance problems may occur with the exit streams and to determine potential energy savings.

PUBLICATION STATUS

No plans for paper(s) at this time.

SPECIAL SAFETY PRECAUTIONS

Ear protection necessary.

ENVIRONMENTAL CONSIDERATIONS

None.

ACKNOWLEDGEMENTS

George Schurr had the original idea of using the Coanda-flow principle for scrub solids classification and has actively participated in the experimental programs discussed in this report. Phil Muhlmichl is responsible for the design of the laboratory apparatus. Professor Löffler and K. Mali (University of Karlsruhe, West Germany) are responsible for running our TiO_2 samples on their Uternal Jet classifier.

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SUMMARY AND CONCLUSIONS

The initial stage of this study included the design, construction, and testing of a laboratory Coanda-flow classifier for separating out TiO_2 scrub solids grit. (In the plant TiO_2 scrub solids, when used, constitute 4 to 8 wt. % of the TiO_2.) This technique was shown to be an effective way to make such a separation and the resulting decrease in grinding energy usage was significant. In conjunction with the laboratory experiments, this classification technique was analyzed theoretically. Particle trajectories were mathematically modeled. By comparing the trajectories for different-sized particles, it was possible to predict the separation for different classifier conditions. The results were in good agreement with the experimental results, indicating that the model could be used to predict cut sizes under scaled-up conditions.

In the second part of this study fine-cut classifications were made on micronizer feed. A German Uternal Jet classifier (also based on the Coanda-flow principle) was used for these tests. The results were particularly good. The classifier effectively separated the TiO_2 and produced a very fine cut size (2-3 µm diameter top size). This is in agreement with the theoretical predictions. The investigation of energy usage and pigment quality is not completed yet, but some of the unmicronized fine fractions behaved very closely to standard grade pigments.

Plant-scale implementation has also been considered. Potential problem areas were identified and some of them were considered in detail. In particular, dimension changes were evaluated theoretically to determine whether the desired separations could still be made. The results suggest that such plant-scale separations are possible.

DISCUSSION

I. Description of Coanda-flow Separation Principle

Coanda flow occurs when a high velocity stream attaches itself to a solid and flows along the surface. In such case, the surface may be curved, irregular, etc., and the stream will deflect and follow the surface curvature rather than continue in a straight pathway. This principle can easily be adapted to produce a particle-size separation by using a convexly-curved surface, the resulting centrifugal force throwing the larger particles away from the surface while the fine particles are carried with the gas stream (Figure LSW-1)

II. Classifier Design

A. TiO_2 Scrub Solids Classification

To separate out TiO_2 scrub solids grit, a laboratory classifier based on the Coanda flow principle was designed and constructed (Figure LSW-2). To aid in the design, a theoretical analysis was made of the behavior of various size particles subjected to different gas velocities and radii of curvature. (This will be discussed in a later section.) The results of this analysis were used in selecting the dimensions for the laboratory model. They include: slot = 1/8" x 4"; radius of curvature = 4"; wedge + 3" from surface and displaced 60° from start of curvature. The fine fraction was collected by means of a bag filter while the coarse fraction was either collected by cyclone or allowed to fall by gravitation into a cotton bag. Both of these methods were satisfactory.

The ideal location for such a classifier in the plant would be at the end of the flue legs (i.e. after the pigment has been formed and cooled, and after the scrub solids have served their purpose of keeping the pipe walls clean and free of sticky pigment). At this point the pigment is dispersed in chlorine gas and is traveling at a velocity of ~100 ft/sec. The gas (air) used in the laboratory experiments differs only slightly in physical properties from the higher temperature (~150°C) chlorine in the flues. Also the air velocity used in the experiments (at the slot exit) was ~100 ft/sec to match that in the flues.

B. Classification of Micronizer Feed

To make a fine cut on micronizer feed, a German-made Uternal-Jet classifier was used. This required shipping the pigment samples to the University of Karlsruhe for the tests. George Schurr (ESD) observed some of these tests, and returned with a diagram of the classifier (Figure LSW-3). This classifier is also based on the Coanda-flow principle but has some slight differences (as compared to the scrub solids classifier) which give more control over the boundary layer flow of the gas. Thus it can produce a finer separation. The velocity was 100 m/sec and the radius of curvature was 3/4". Also, a secondary gas stream flows at the same velocity as the pigment/gas mixture, and a curved section confines this stream as it flows ~30 to 40° around the Coanda surface. Thus a high velocity is maintained (i.e., the gas stream is not allowed to expand) while much of the pigment separation is occurring. Some expansion of the gas occurs as it proceeds farther around the Coanda surface, but surface suction is used to help keep the stream attached.

III. Theoretical Analysis

To predict cut size for a Coanda-flow classifier, a mathematical model was developed to compute particle trajectories for different-sized particles. For each individual particle a force balance was made. Since the particle is generally traveling in a direction different from the surrounding gas stream, the particle velocity was broken down into components - one in the direction of the gas flow; the other perpendicular to it. The gas velocity in this perpendicular direction was assumed to be zero.

Force Balances:

In the direction of gas flow:

drag force = acceleration

$$1/2\ \rho_p \pi r^2 (v_g - v_{pg})^2 C_D = +(4/3)\pi r^3 \rho_p \left(\frac{dv_{pg}}{dt}\right)$$

In perpendicular direction:

drag force = deceleration

$$1/2\ \rho_p \pi r^2 (v_{pp})^2 C_D = -(4/3)\pi r^3 \rho_p \left(\frac{dv_{pp}}{dt}\right)$$

where r = particle radius (cm)

ρ_p = particle density (gm/cm^3)

v_{pg} = particle velocity in direction of gas flow (cm/sec)

ρ_g = gas density (gm/cm^3)

v_{pp} = particle velocity in direction perpendicular to gas flow (cm/sec)

C_D = drag coefficient

v_g = gas velocity (cm/sec)

(Note: All particles are assumed spherical and gravity has been neglected.)

If the particle is large and manages to escape the flowing gas stream, the force balance reduces to a single expression for the direction of particle travel.

Drag Force = deceleration

$$1/2\ \rho_p \pi r^2 (v_p)^2 C_D = -(4/3)\pi r^3 \rho_p \left(\frac{dv_p}{dt}\right)$$

Where v_p = particle velocity (cm/sec)

The drag coefficient, and more importantly its functionality, vary with Reynolds number ($Re = 2\rho_g vr/\mu_g$ and v = particle velocity, μ_g = gas viscosity). However, the Reynolds number can be broken down into several ranges for which the resulting functionalities are all fairly simple (the commonly known relation for Stokes drag is $C_D = 24/Re$).

However, solution of these two force balances is complicated by the constantly changing direction of movement (and consequently the direction of the forces). Solution must therefore be done in small incremental time steps. At each time step, the differential equations can be solved analytically. The particle is then assumed to travel $v\Delta t$ in the appropriate direction and the procedure is repeated. A computer program was written to perform these calculations and to plot the resulting particle trajectories (Appendix).

Knowledge of the gas velocity profile is also necessary for this analysis. For the initial calculations (for the scrub solids classifier) a gradually expanding box-like profile was assumed (Figure LSW-4). No boundary layer (i.e., velocity dropping to zero) at the Coanda surface was included, as it was assumed to be so small that it would not play a role in the separation. Estimation of the boundary layer thickness based on boundary layer theory (Schlichting, 1968, p.26) confirms this. The calculated value at 1 cm from the slot exit is $\approx 10^{-5}$ cm, i.e., less than the diameter of a particle.

Actual velocity profiles were measured using a pitot tube and are shown in Figure LSW-5. The minimum distance from the surface at which a measurement could be made was 1/16". The surface boundary layer thickness was always less than 1/16", and therefore was never actually measured. Thus, the boundary layer as shown is not intended to be accurate in its indicated thickness, but rather to emphasize that such a boundary layer does exist.

These measured profiles are similar to those reported in the literature, but such profiles were not used in the theoretical calculations because they were too complex, and no correlation based on the slot exit velocity was available. More important, however, was the fact that the measured expansion rate of the gas stream was in fair agreement with the assumed rate, as this rate may affect the sharpness of the cut as well as the cut size.

The results of this mathematical analysis for a set of conditions similar to those in the flues (i.e., chlorine gas @ 150 C with a gas exit velocity of 100 ft/sec) and a Coanda surface radius of curvature of 10 cm with a 1/8" slot width are shown in Figure LSW-6.

These calculated trajectories indicate that the small particles (<10μm diameter) follow the gas stream around the Coanda surface. Slightly larger particles (10 to 50 μm) have sufficient inertia to escape the flowing gas stream, but are then decelerated by the surrounding quiescent gas. The trajectory end points shown do indeed represent stopping points, but once the particle slows down (or stops), gravity will soon take over, causing it to fall back into the gas stream, and likely continue to move with the edge of this stream. The larger particles (> 50 μm) escape the gas stream immediately and continue for long distances (>10") before gravity has any effect.

The easiest way to separate the grit will therefore be to place the separating wedge so that all of the gas flows along with the fine fraction. The expected cut size will then be ~50 μm. Based on this information the laboratory scrub solids classifier was set up with the wedge about 3" from the surface at ~60° around. A typical experimental run gave the following results

Wet screen analysis of feed	
+80 mesh	6.53 wt.%
-80 +325 mesh	1.32 wt.%
Classified - Fine fraction	
+80 mesh	0.30 wt.%
-80 +325 mesh	0.42 wt.%

This indicates that the cut was near 325 mesh as predicted. (Although it appears that only ~2/3 of the 80 to 325 mesh was classified out, the actual value is probably higher (possibly as high as 80%). This is due to a small loss of fines when running small samples in the present system.

The accuracy of the mathematical model was further demonstrated when it was used to predict the cut size for the Uternal Jet classifier. (A non-expanding gas profile was assumed for these calculations.) In this case the separating wedge actually splits the gas flow, and the sharpness of the cut will depend more strongly on the height of the slot. For instance, if a sharp cut between 2 and 3 μm is desired, a 3 μm particle exiting next to the surface (Fig. LSW-7) must be separable from a 2 μm particle exiting from the top of the slot (Fig. LSW-8). Based on the particle trajectories a reasonable separation can be made as low as 1 to 2 μm, but a really sharp separation is probably possible only at ~5 μm. For the present location of the separator (1/4" from the surface and ~120° around), the predicted cut is between 1 and 2 μm with top size of ~1.5 μm, and indeed the resulting fine fraction had a top size of 2 to 3 μm. The coarse fraction, as expected, did contain some of the fine particles, but only a small percentage of the original sample.

EXPERIMENTATION

Samples of R900 and R960 dryer discharge (micronizer feed) were classified in the Coanda-flow scrub solids classifier. The "as is" R900 DD contained ~8 wt.% +325 mesh grit. Almost all of this grit was in the size range 20 to 40 mesh. The R960 DD, on the other hand, contained <1 wt.% grit (apparently it had been produced using salt scrubs). For testing purposes ~7 wt.% grit (20 to 40 mesh) was added to it. The Coanda classifier effectively separated out the grit in both of these samples. However, pigment stickiness and ease of deagglomeration are important. A sample of R101 containing 6 wt.% grit could not be classified well because much of the fine pigment remained agglomerated in the injector and thus behaved like grit during classification (i.e., much of the fine pigment was collected in the coarse fraction).

To determine grinding energy requirements, samples were classified and micronized at various steam/pigment levels in the Edge Moor 8" micronizer. They were then compared to unclassified samples similarly micronized. Since gloss is the property most strongly affected by the grinding energy level, all samples were analyzed for gloss in both alkyd and aqueous formulations. The results (Figs. LSW-9 and 10) show reduced grinding energy requirements for grit-free samples. The actual energy requirements of the large plant micronizers may, however, differ somewhat from those of the 8" experimental micronizer, but the present results do suggest that significant grinding energy reductions may be possible.

The purpose of classifying the micronizer feed (dryer discharge) with the Uternal Jet was to split it into two fractions which when micronized separately would require less grinding energy. This would occur if the present process overgrinds the fines or if a narrower particle size distribution is more efficiently ground. Samples of R900 and R931 DD were sent to Germany for classification in the Uternal Jet. Upon return, both coarse and fine fractions were micronized at various S/P levels and compared to unclassified samples similarly micronized. Analyses of the samples included particle size distribution for the original R900 DD and R931 DD and the classified samples. (Figures LSW 11 and 12)
Accoridng to the sedigraph results the mass does not balance. At the present time we do not know why, but further study is planned once the Engineering Department completes their own boundary layer classifier. Paint formulations were used to determine gloss

for the R900 samples and hiding power for the R931 samples. The results are plotted in Fig. LSW-13. The most significant result was the high hiding power for the unmicronized R931 fine fraction - this sample was just below standard pigment quality in its behavior. Attempts to determine the grinding energy requirement for this fine fraction, however, have been inconclusive. The 8" micronizer could not be run at a S/P ratio low enough to distinguish between the classified and the unclassified (i.e., both samples had good hiding power at this lowest S/P). A low energy hammermill was subsequently tried, but its grinding energy level may have been too low as there was no improvement in the R931 fine fraction.

Problems were also encountered with the R900 samples. One of the R900 fine fractions had an impressively high gloss value, but was irreproducible - the initial measurement gave 77 and several repetitions gave 42. The micronization tests were again inconclusive. This particular sample of R900 micronizer feed was so good that even at the lowest S/P (on the 8" micronizer) a very high gloss pigment resulted. Thus differences in energy requirements between classified and unclassified pigment could not be determined. A further test was made using sandmilling, a lower energy type of grinding. The resulting slurries, however, produced very poor gritty paint films. (It is not certain whether the slurry preparation technique had any effect on this or whether it was solely due to poor pigment quality.) To resolve the question of energy usage, a poorer (more normal) quality R900 micronizer feed will be used in future tests.

To determine overall energy requirements, the coarse fractions must also be evaluated. Some micronization tests have already been done on the R900 coarse fraction. The results suggest that more grinding energy is required (as compared to an unclassified sample), but the observed gloss differences were within the accuracy limits of the measurement and thus inconclusive. The R931 coarse fraction has not been evaluated, as the original sample pelletized in transit to Germany. These pellets were removed before classification so it is uncertain whether the resulting coarse fraction (and possibly even the fine fraction) are representative of fresh plant samples. Further experimental work with fresh pigment is planned.

SCALE-UP CONSIDERATIONS

For scrub solids grit classification either the laboratory model or the Uternal Jet design could be used. However, the laboratory Coanda model would likely use the least amount of extra gas. If such a classifier is to be used at the end of the flues, the pigment would be in a chlorine atmosphere and additional gas would have to be chlorine as well. Thus large quantities may be undesirable. On the other hand, the controlled boundary layer flow of the Uternal Jet would undoubtedly insure a sharper cut at 325 mesh. The Uternal Jet could also be used to make a dual separation (grit elimination plus fine-cut classification) after the pigment has been collected in the cyclone. This would require an air stream to disperse the pigment,whereas for classification in the flues we would assume that the pigment is already dispersed (i.e., deagglomerated). However, logistically it may be difficult for the plant to handle two separate streams (the fine and coarse fractions) through the remainder of the process, i.e. wet treatment, filtration, drying, and micronization.

I. Scrub Solids Classification

For the present analysis we will first consider the laboratory Coanda design. For scrub solids classification at the end of the flues, the slot height must be large enough to avoid pluggage. Also the JV plant cannot tolerate an in-line pressure drop; i.e. orifice flow must be avoided or additional blowers will be necessary to inject the pigment. Orifice flow can be avoided by maintaining the same cross-sectional area going from the flues into the slot. For example, the flues end with a 12" diameter pipe, thus having a cross-sectional area of 112 in^2. To maintain this area, a slot of height 1" would have to be 112" long. A more reasonable size would be either 2" x 56" or 3" x 37". Thus the major scale-up considerations (assuming gas velocity and pigment concentrations are kept the same) will be:

1) how large (height) a slot can be used without sacrificing cut sharpness.
2) how long will the stream stay attached to the Coanda surface if a large slot is used.
3) how much additional gas is needed for mixing as the boundary layer expands.

A correlation for detachment angle was given in the literature (B. G. Newman, 1961).

$$\Theta_{sep} = 245 - \frac{391(b/a)}{1 + (9/8)(b/a)}$$

(See Figure LSW-14 for Newman's Coanda configuration)

where Θ_{sep} = detachment angle (degrees); the angle refers to the angular displacement around the Coanda surface

b = slot height
a = radius of curvature

This expression, however, is only valid for Reynolds numbers (where Re is defined as $[(P - P_\infty)\ ba/\rho\nu^2]^{1/2}$) greater than some limiting value. Newman's experimental results gave a limiting value of Re $\approx$ 4 x 10^4, but the b/a values which he studied were quite low (0.0067 to 0.04). He further states, that the Re value should deviate less than 5% for b/a up to 1 and that the value (4 x 10^4) is not known to that accuracy. (His data suggest an accuracy of $\pm$10%.)

The following three cases (for the original Coanda-flow design) were selected to represent the range of practical plant-scale conditions:

1) 6 in. radius of curvature; 2" x 56" slot
2) 8 in. radius of curvature; 2" x 56" slot
3) 8 in. radius of curvature; 3" x 37" slot

To determine whether these conditions would still give the desired separation, the above correlation was used along with a computer analysis of the particle trajectories. The accuracy of Newman's correlation is not known for the desired range of b/a $\geq$0.25 but Newman expects it to be reasonably accurate for b/a $\leq$1.0. The expression was, therefore, used only to obtain an estimate. If the original scrub solids classifier design were used, we would need the gas stream to remain attached at least 90°. However, to obtain an estimate a value of 150° was used to include a margin of safety. This resulted in a b/a value of $\approx$1/3.

As a check on the usefulness of the Newman expression the slot Reynolds number was calculated for the following conditions:

$ab = 12\ (2\text{x}6)\ \text{in}^2$ where $\rho = 0.004$ (Cl_2 @ 150°C)

$(P-p)_\infty = \frac{1}{2}\rho v^2$ $v = 3000$ cm/sec

$\nu = \mu/\rho$ $\mu = 0.0002$ poise (Cl_2 @ 150°C)

The resulting value was $1.5\text{x}10^5$ which is above the desired minimum.

Another consideration is the slot aspect ratio (length/height). In the literature, one study (McGlaughlin and Greber, 1967) was reported in which aspect ratios of 0.8 to 2.4 were used, and the gas streams detached much earlier than predicted by the above expression. Newman's experiments, on the other hand, were in the range of 200 to 1200. It is not known how large the aspect ratio must be to avoid problems, but probably 10 to 20 would be a good guess. In the laboratory scrub solids classifier, a value of ~30 was used. In the Uternal Jet the ratio was 11. In the three selected cases, the aspect ratio is $\geq$12.

The computer results for the three cases are shown in Figs. LSW-15 16 and 17. In general, the use of such large slot widths causes a considerable sacrifice in the sharpness of the cut, and the exact location of the separating wedge will be much more critical than it was in the laboratory model. This effect is shown quite clearly in Fig. LSW-18, which gives particle trajectories for particles exiting from different locations in the slot. If the separator is carefully placed, a separation at ~40μm could be made. The cut would not be as sharp as in the lab model, but probably sharp enough. However, this requires the separator to be in the middle of the gas stream and would require gas flow balance and control on the exiting streams. If on the other hand, the separator is placed outside of the gas flow, all of the gas will be associated with the fine fraction and gas handling would be much easier. However, the cut size will be considerably greater, ranging from 70 to 150 μm. Of the three cases, the 2" slot with the 6" radius of curvature gives the finest cut. The case of the 8" radius of curvature with the 2" slot is similar to the previous case, but the gas flow is more expanded. This will cause an even greater loss in the cut sharpness and possibly some increase in cut size. The third case is the worst and would certainly not be recommended. In fact, in general, the smaller the slot height, the better will be the cut sharpness. Also, a smaller radius of curvature will be possible, which in turn will decrease the cut size. Based on this information, the first case (2" x 56" slot height, with 6" radius of curvature) would be recommended. An even smaller slot height, such as 1½ (length = 75") or 1-3/4" (length = 65") would be better, if the slot length does not pose a problem in design and construction.

Another consideration for plant-scale feasibility is the amount of surrounding gas which becomes entrained in the pigment/gas jet as it flows around the Coanda surface. No exact correlation was available for the present configuration. However, Giles et al (1965) reported an approximate formula for a logarithmic spiral surface.

$$V_E \approx 1/2\; U\; (Y_{m/2}/s)$$

where V_E = entrainment velocity

$$\text{or } \frac{\text{(vol. entrained)}}{\text{(dist. traveled around surface)(slot length)(time)}}$$

U = maximum velocity for any given distance around surface

$Y_{m/2}$ = half jet thickness (see Fig. LSW-8)

s = distance around surface (i.e., travel distance from slot exit)

This formula was used to obtain an order-of-magnitude estimate for the laboratory Coanda-flow classifier design. For a circular Coanda surface, $Y_{m/2}/s$ is not constant along the surface. Therefore, an average value was used, and based on the experimentally determined velocities, a value of 0.2 was selected. U also varies as the stream progresses. Again, an average value was used - in this case, one-half of the exit velocity. The resulting value of V_E was 150 cm/sec. For the previously-mentioned case of a 2" x 56" slot with a 6" radius of curvature, the gas flow rate through the slot would be $\approx$ 78 ft^3/sec, while the total entrainment would be $\approx$18 ft^3/sec or $\approx$ 1/5 of the jet flow rate. To avoid undue turbulence in the plant classifier, it may, therefore, be necessary to have a bleed stream of this magnitude situated above the slot.

If the Uternal Jet design were used for scrub solids classification at the end of the flues we would still want a large slot for the pigment feed. Thus we would probably want to change some of the other dimensions such as the radius of curvature. For instance, the radius of curvature could be 4", the pigment slot 1 1/2" and the additional gas slot 2 1/2". θ_{sep} for these conditions is ~60° (see next section on Uternal Jet fine cut classification for further explanation). The predicted cut size for this was ~5μm (Figs. 19 & 20).

Regardless of the classifier design, the state of pigment agglomeration will be important. If the pigment is not well-dispersed at the end of the flues, a sharp separation cannot be obtained without supplying extra energy to break up the agglomerates. A separate study (W. E. Stevens) is already underway to determine the degree of dispersion at other points along the flues, and we have requested that he also include a measurement at the end. This information will then be used in our assessment of plant-scale feasibility.

II. Classification of Micronizer Feed

Scale-up of the Uternal Jet for use as a fine-cut classifier would primarily consist of making the total slot length great enough to handle the pigment rate in the plant. Otherwise, there would be no change in dimensions. Analysis of the design, however, did clarify the operation of such a classifier. The slot height (in Newman's expression) is actually the combined heights of the pigment feed slot and the additional air slot totalling ~1.25 in. Therefore

$$\theta_{sep} = 245 - \frac{391(1.25/0.75)}{1 + (9/8)(1.25/0.75)}$$

$$= 18.3°$$

(The "Re" was calculated for these conditions and is above the minimum value.)

This angular distance is quite small, but much of the separation is actually produced within the air slot (i.e., after the pigment exits but within the region of controlled flow). Also the suction on the Coanda surface may be very important in keeping the stream attached. A small pigment feed slot will be important to maintain good cut sharpness, but increasing it from 1/4" to 1/2" may be all right. Some idea of the required length can be determined from the experimental feed rates. If one production line makes 100,000 tons/yr. (10,300 kg/hr.) and the feed rate is twice the experimental (because the slot height has been doubled), - 2x200 = <100 kg/hr., the needed length is

$$\frac{10,300}{400} \text{ (8 cm)} = 206 \text{ cm.} = 82.5 \text{ in.}$$

This total length could be provided by using several classifiers; for instance 4 classifiers each having $\sim$20" long slot.

A possible disadvantage of this unit, however, is the need to balance the flows of exiting gas streams. It is not known how critical this will be, but further studies are planned to determine this.

Other Applications

The Coanda-flow classification principle can also be used to separate particles of different density.

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INDEXING TERMS

Boundary Layer Classifier
Classification
Coanda-flow
Titanium Dioxide
Uternal Jet

FIGURE LSW-1

COANDA CLASSIFIER

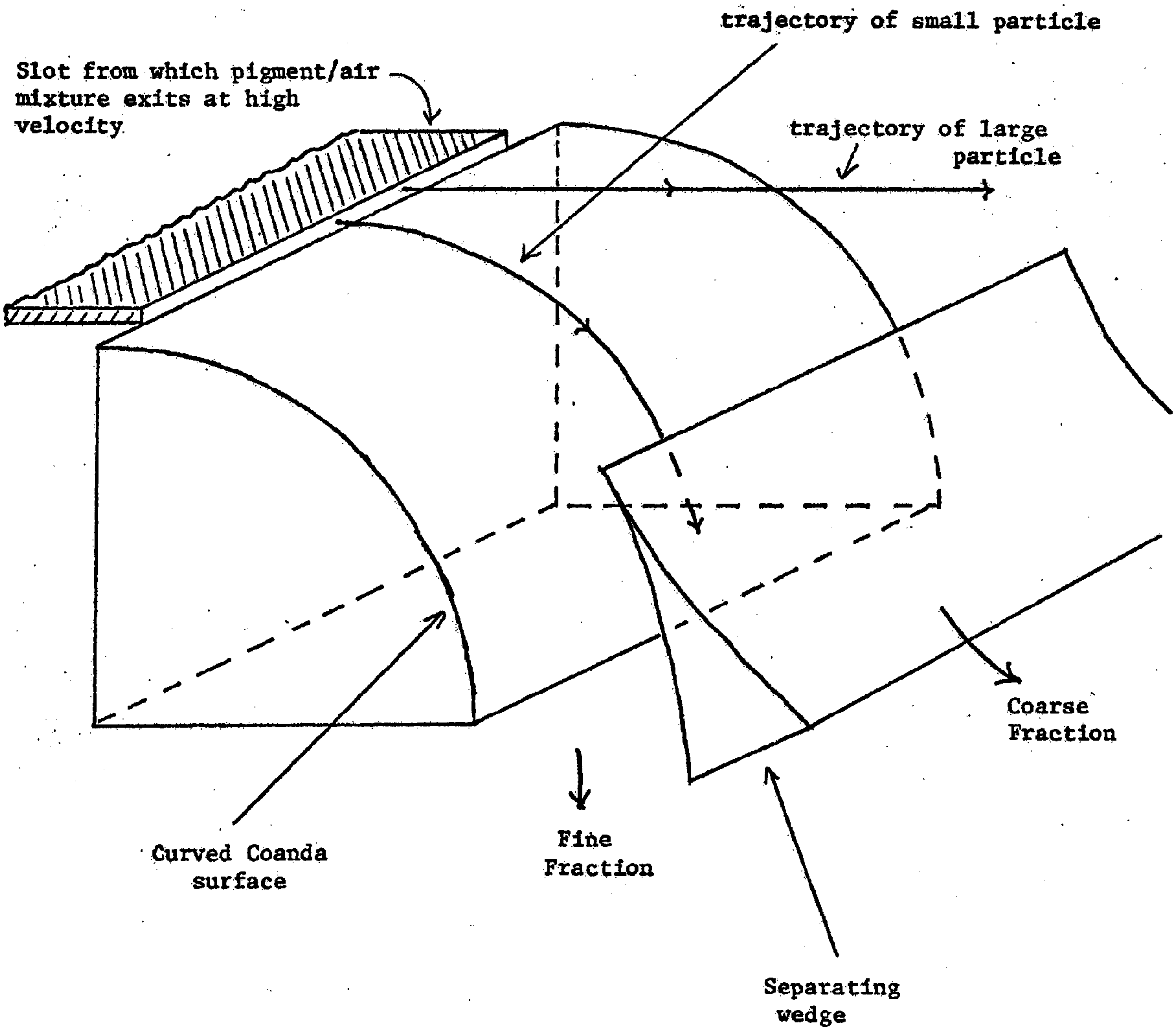


FIGURE LSW-2

LABORATORY APPARATUS

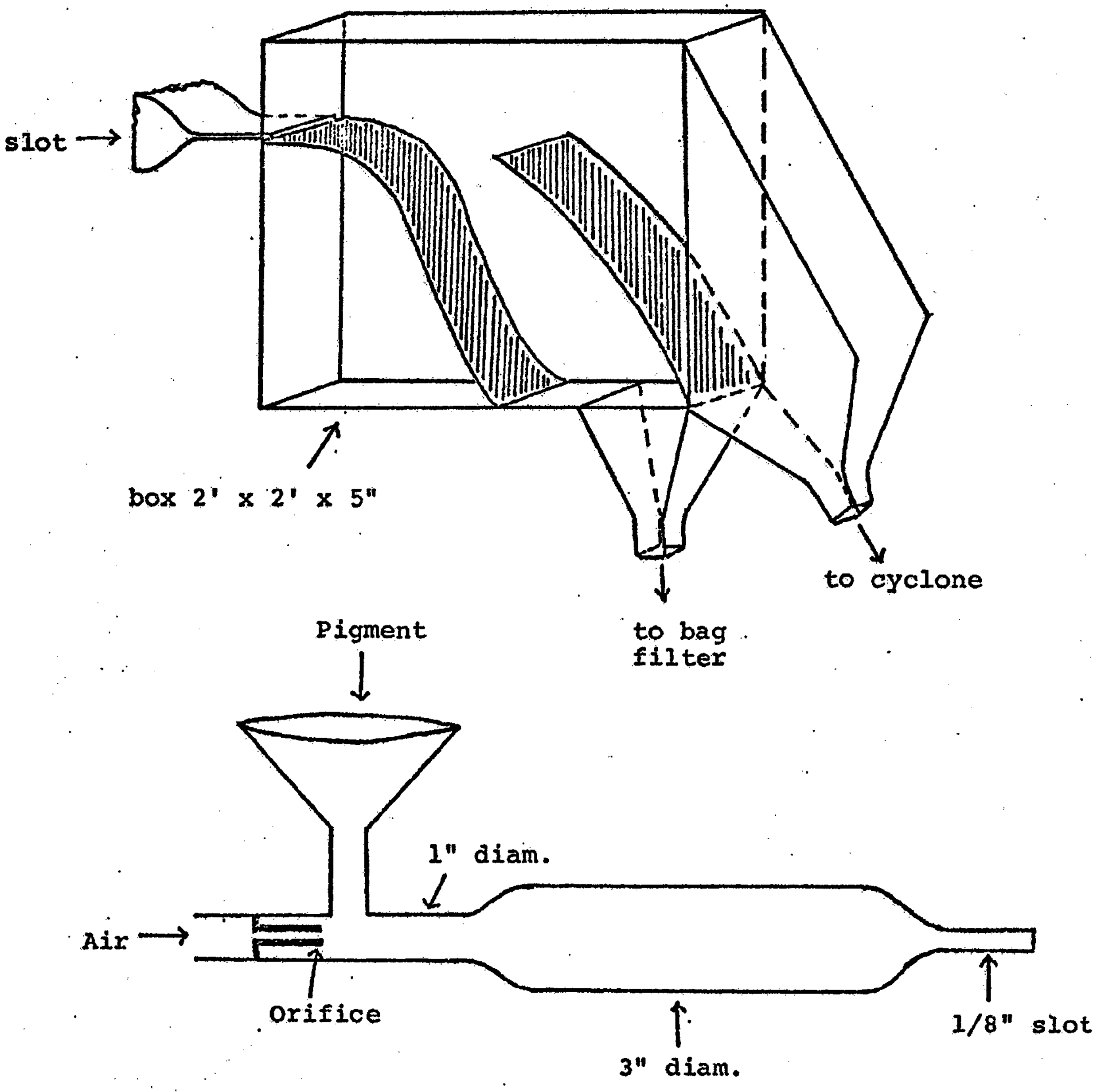


Figure LSW-3

UJERNAL CLASSIFIER

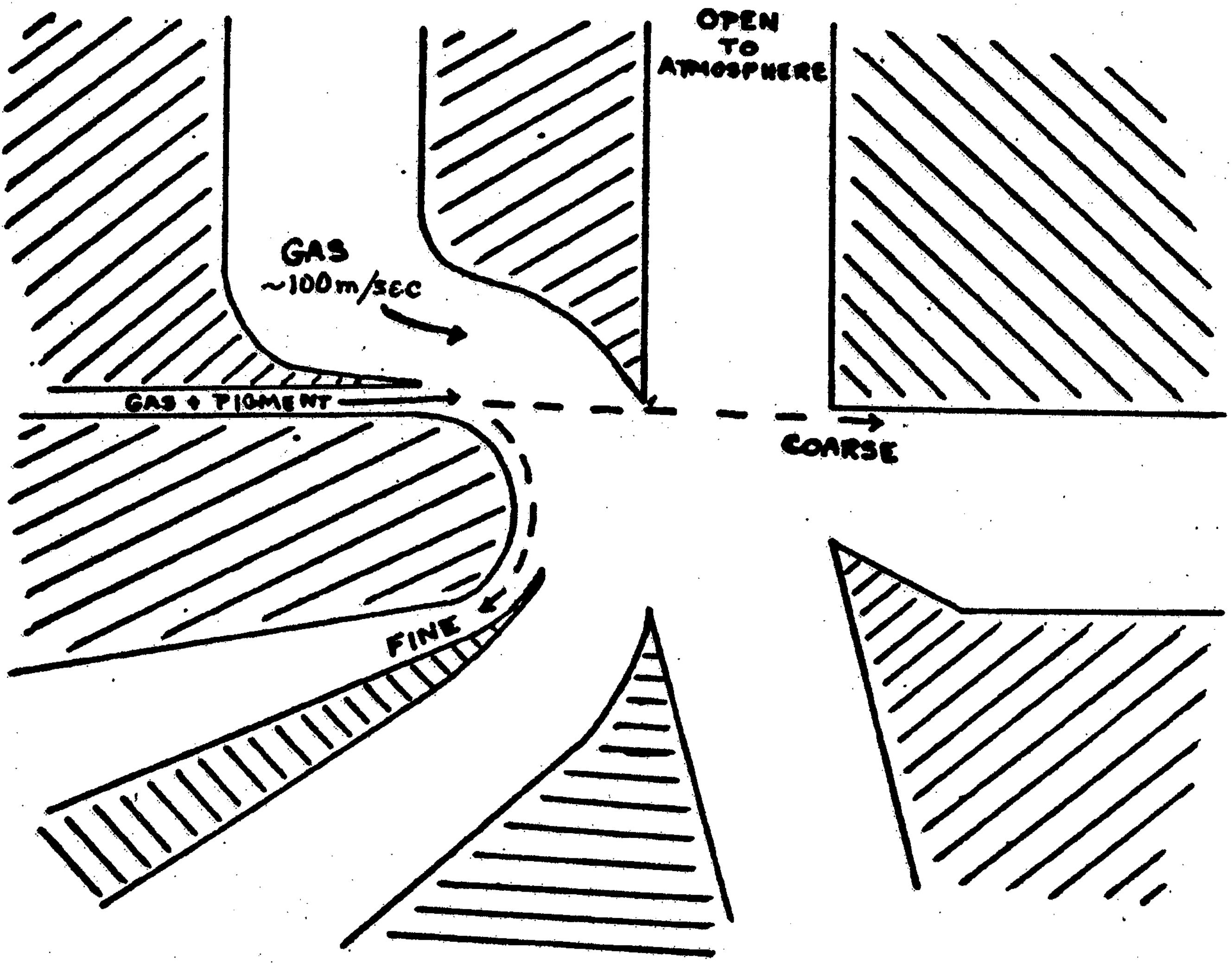
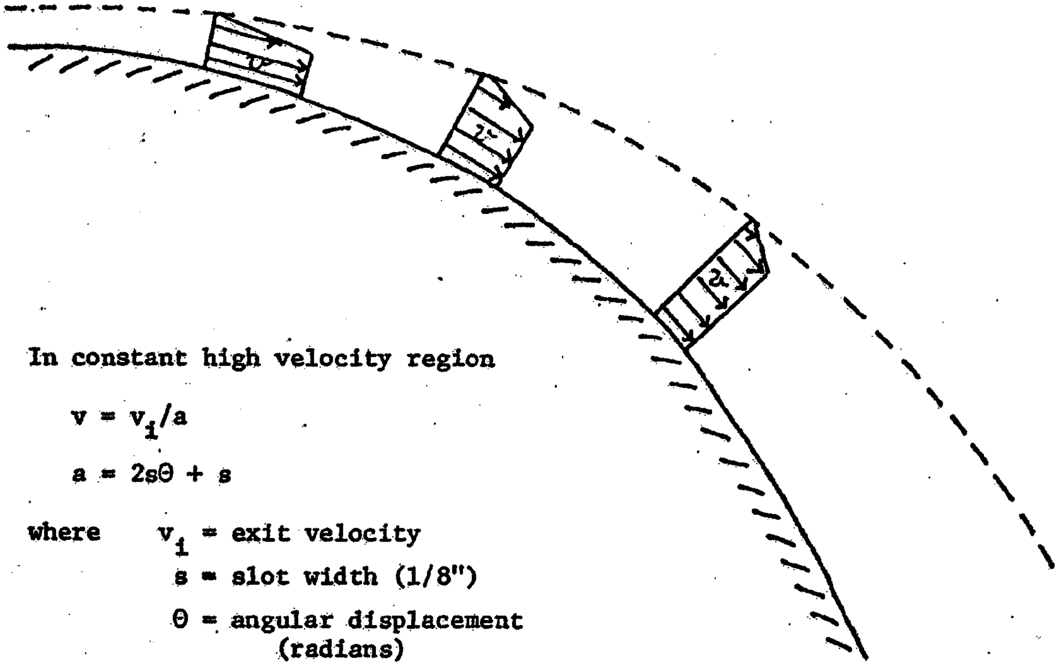


FIGURE LSW-4

ASSUMED GAS VELOCITY PROFILES



In constant high velocity region

$v = v_i/a$

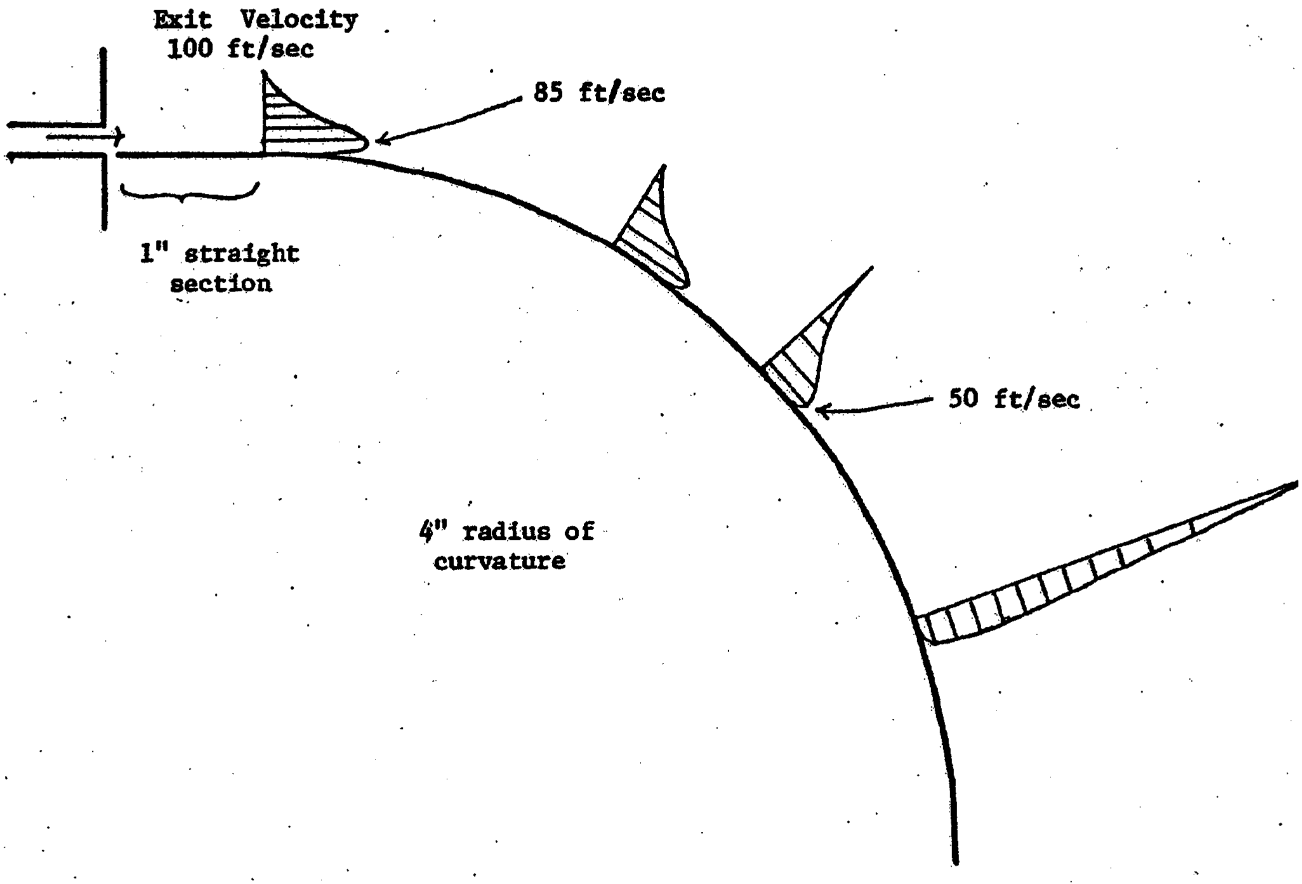
$a = 2s\Theta + s$

where v_i = exit velocity
s = slot width (1/8")
Θ = angular displacement (radians)

Note - No initial straight section was assumed, however the actual surface did include one (see Figure LSW-2). This figure is not drawn to scale.

FIGURE LSW-5

MEASURED VELOCITY PROFILES

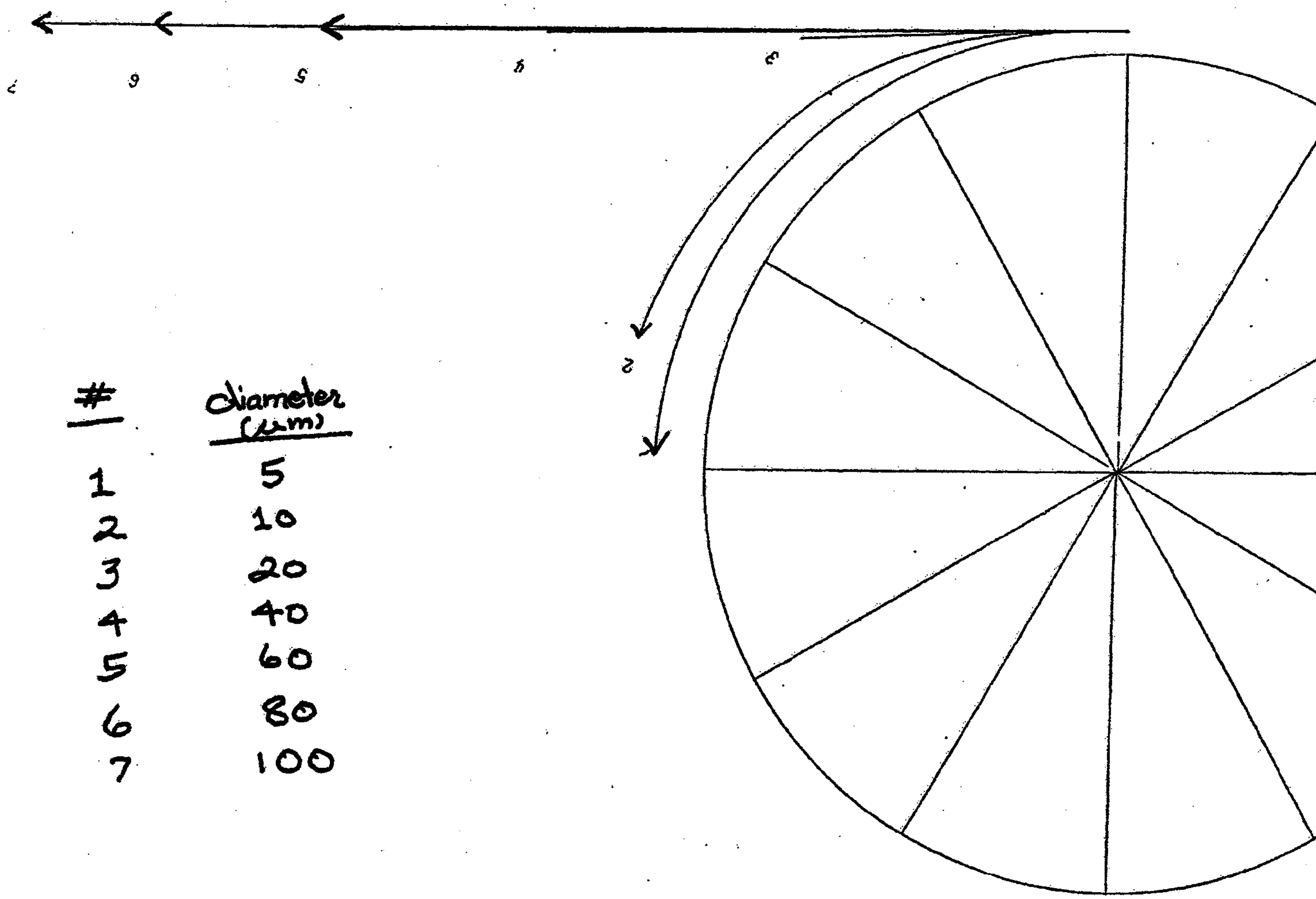


(Drawn to scale)

Figure LSW-6

Particle Trajectories in a Coanda Classifier

4" Radius of Curvature

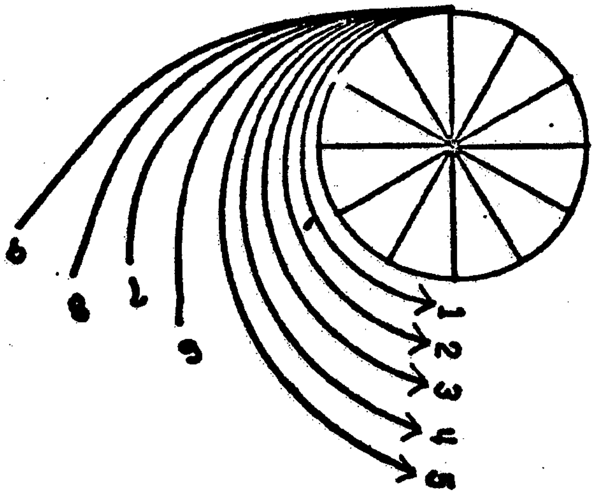


#	diameter (µm)
1	5
2	10
3	20
4	40
5	60
6	80
7	100

Figure LSW-7

PARTICLE TRAJECTORIES

CONDITIONS: AIR, Rm. Temp.
V = 3000 CM/SEC,
PART. DENS = 4.0 G/CM^3



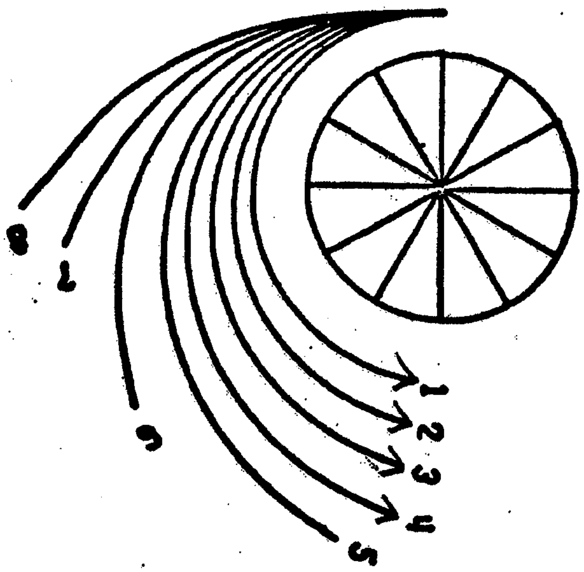
DIAMETERS

1 - 1 µm
2 - 2 µm
3 - 3 µm
4 - 4 µm
5 - 5 µm
6 - 7 µm
7 - 9 µm
8 - 12 µm
9 - 15 µm

Figure LSW-8

PARTICLE TRAJECTORIES

(Same as Figure LSW-7
but Exiting from Top
of Slot)



EFFECT OF GRIT REMOVAL ON R900

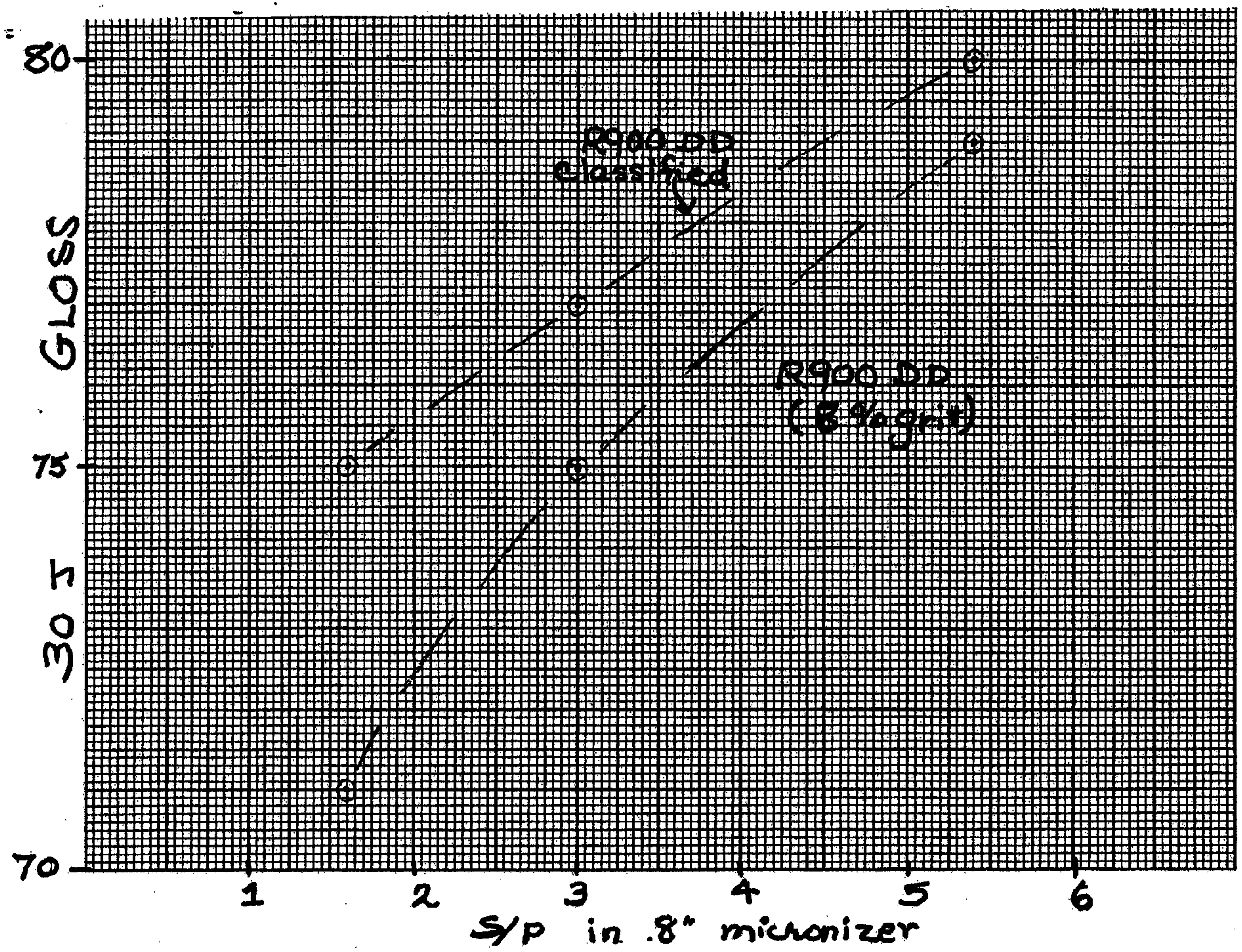


Figure LSW-10

EFFECT OF GRIT REMOVAL ON R960

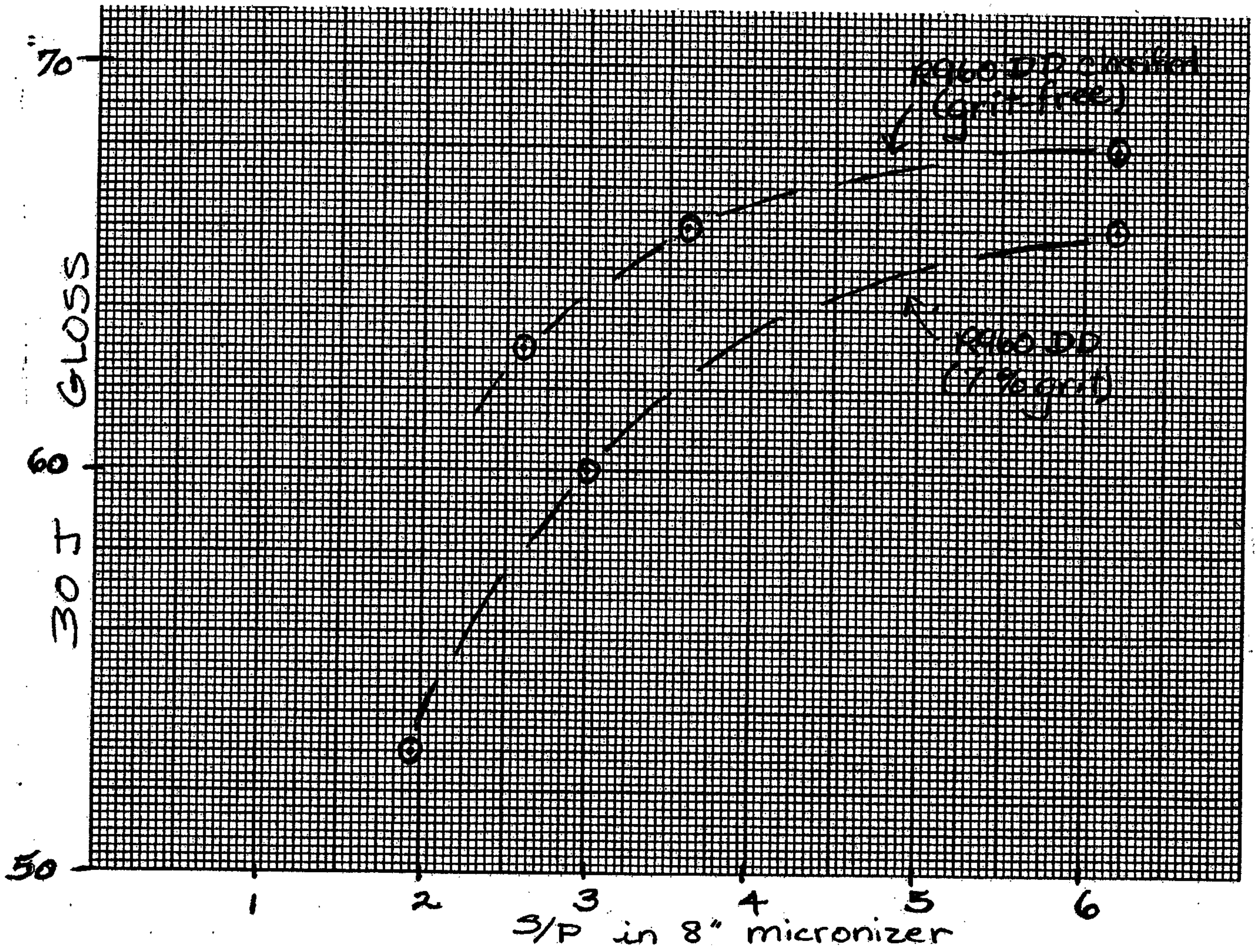


Figure LSW-11

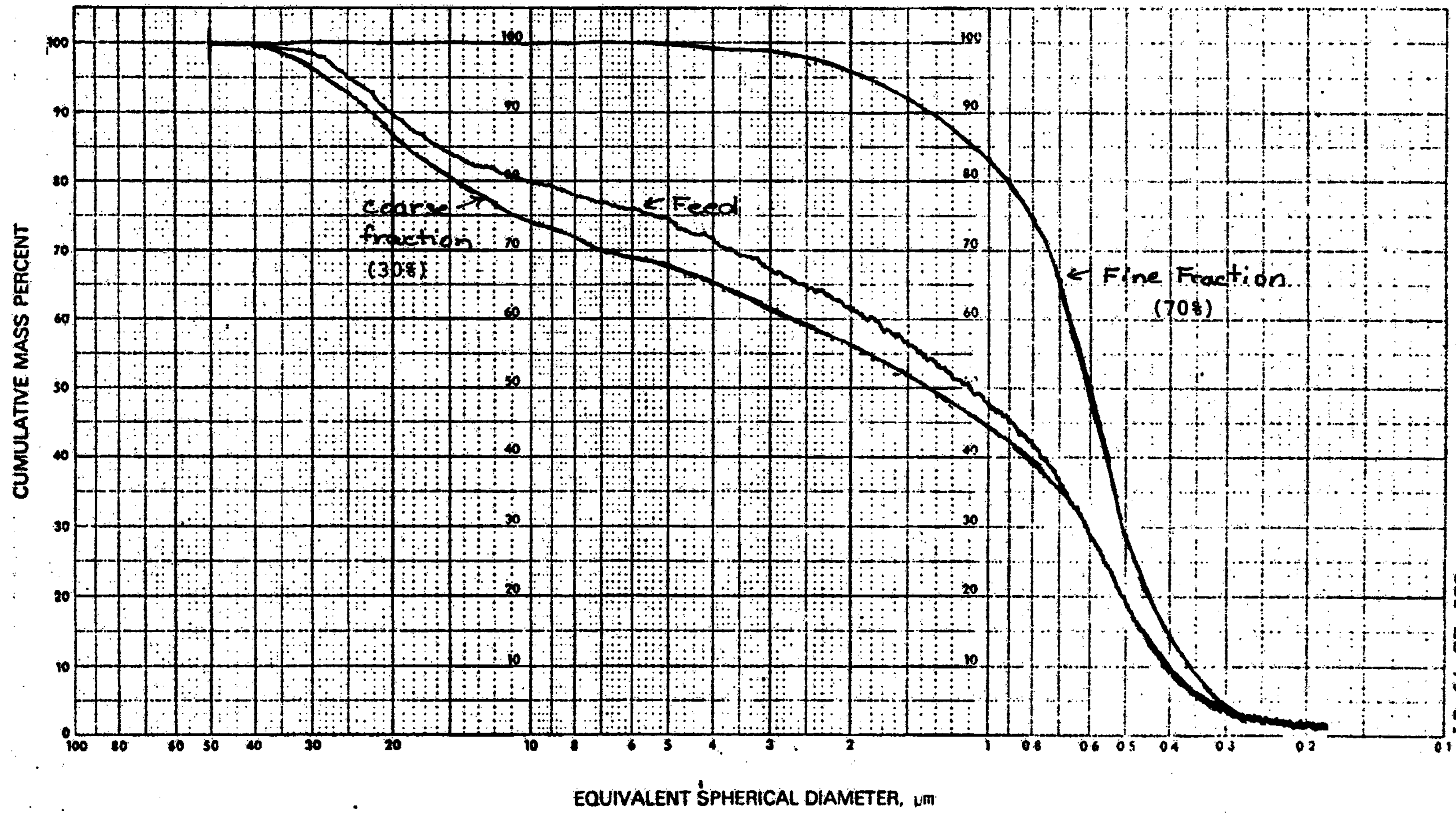
PARTICLE SIZE DISTRIBUTION

SAMPLE IDENTIFICATION Uternal Jet Classification of R900 LSW DATE 11-29-78 ③

Density 4.11 g cc LIQUID H₂O-TMPP Density 0.9954 g/cc Viscosity 0.7840 cp BY CLB TS

Preparation c Std. Classified at 200 kg/hr. TEMPERATURE 31 C

RATE 215 START DIA 50



micromeritics®
instrument corporation
5680 goshen springs road • norcross, georgia 30093

Figure LSW-12

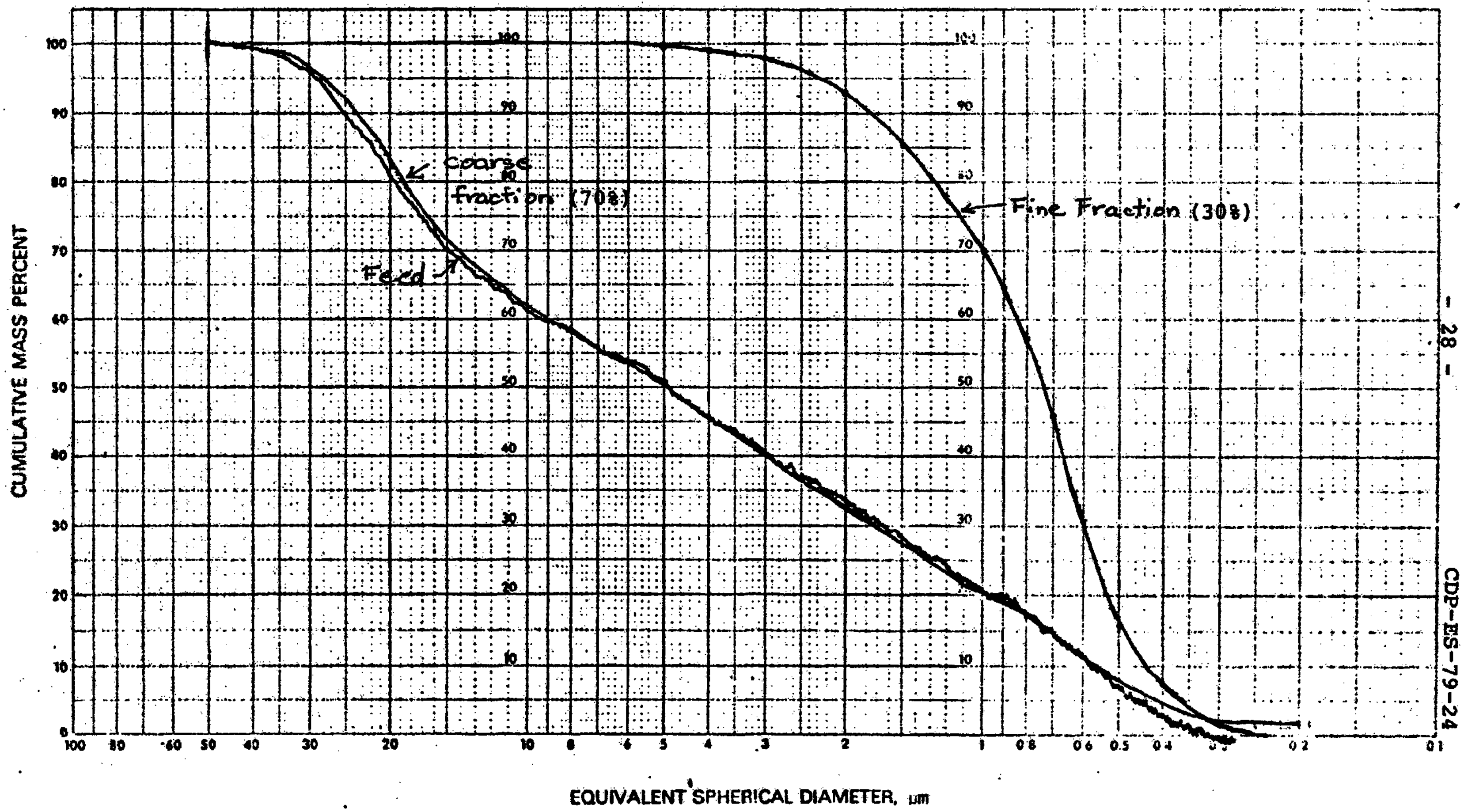
PARTICLE SIZE DISTRIBUTION

SAMPLE IDENTIFICATION **GC. 4** Uternal Jet Classification of R931 **LSW** DATE **12-1-78** ③

Density **3.86** g/cc LIQUID **H2O-TKPP P** Density **0.9954** g cc Viscosity **0.7840** cp BY **CRB** **TS**

Preparation **Std.** Classified at 360 kg/hr. TEMPERATURE **31** C

RATE **198** START DIA **50**



micromeritics
instrument corporation

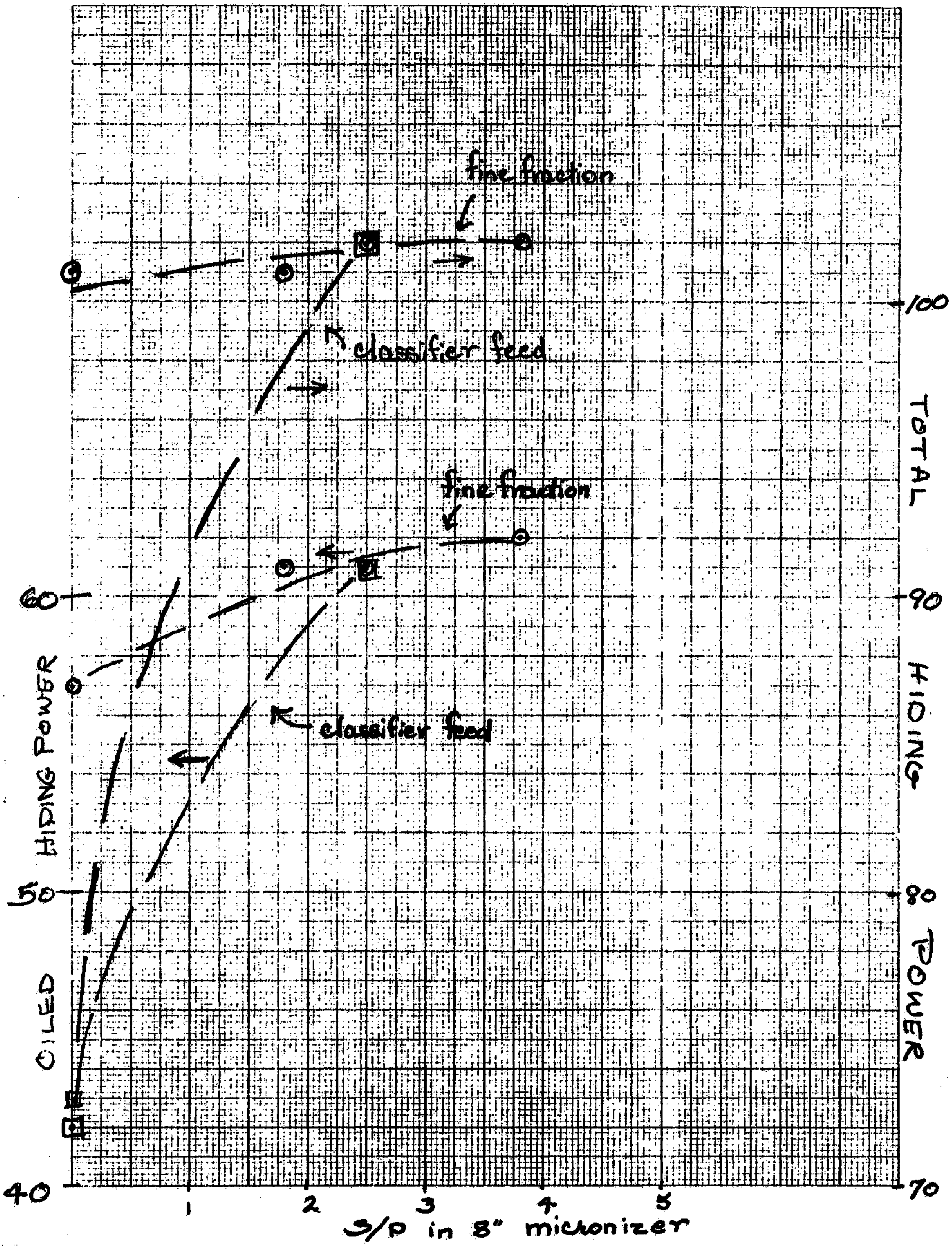

fine fraction
classifier feed
fine fraction
classifier feed
OILED HIDING POWER
TOTAL HIDING POWER
40
50
60
70
80
90
100
1
2
3
4
5
S/P in 8" micronizer

FIGURE LSW-14

B. G. NEWMAN'S COANDA-FLOW CONFIGURATION

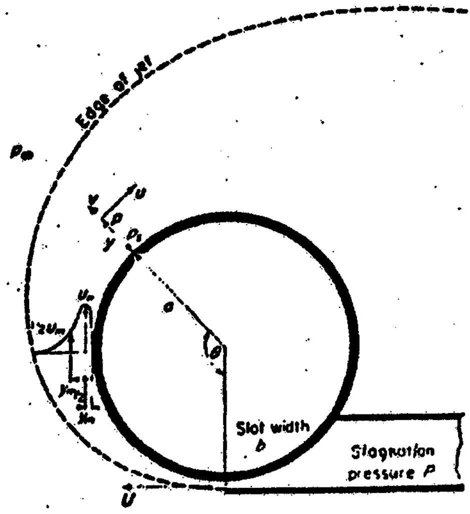
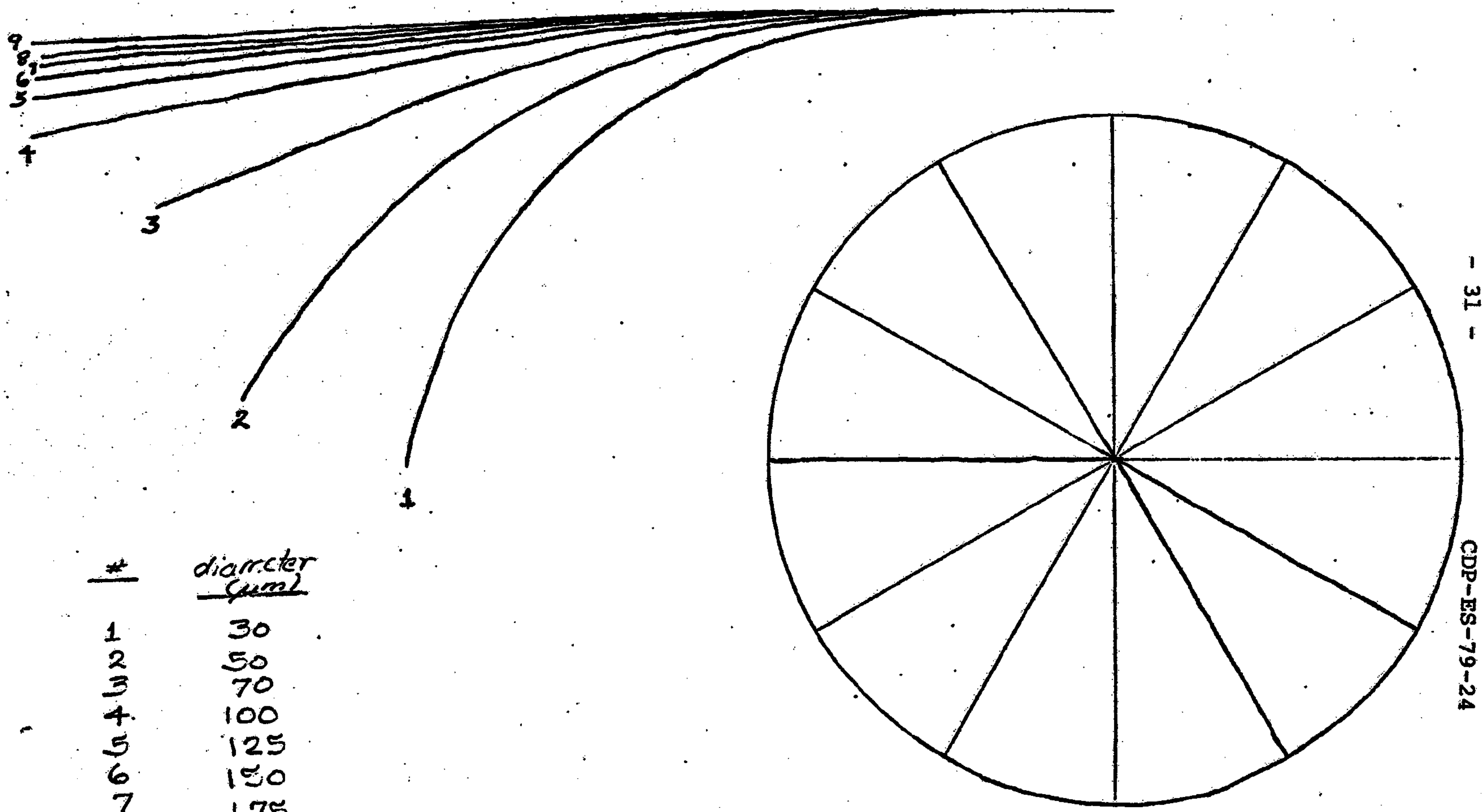


Figure LSW-15
PARTICLE TRAJECTORIES

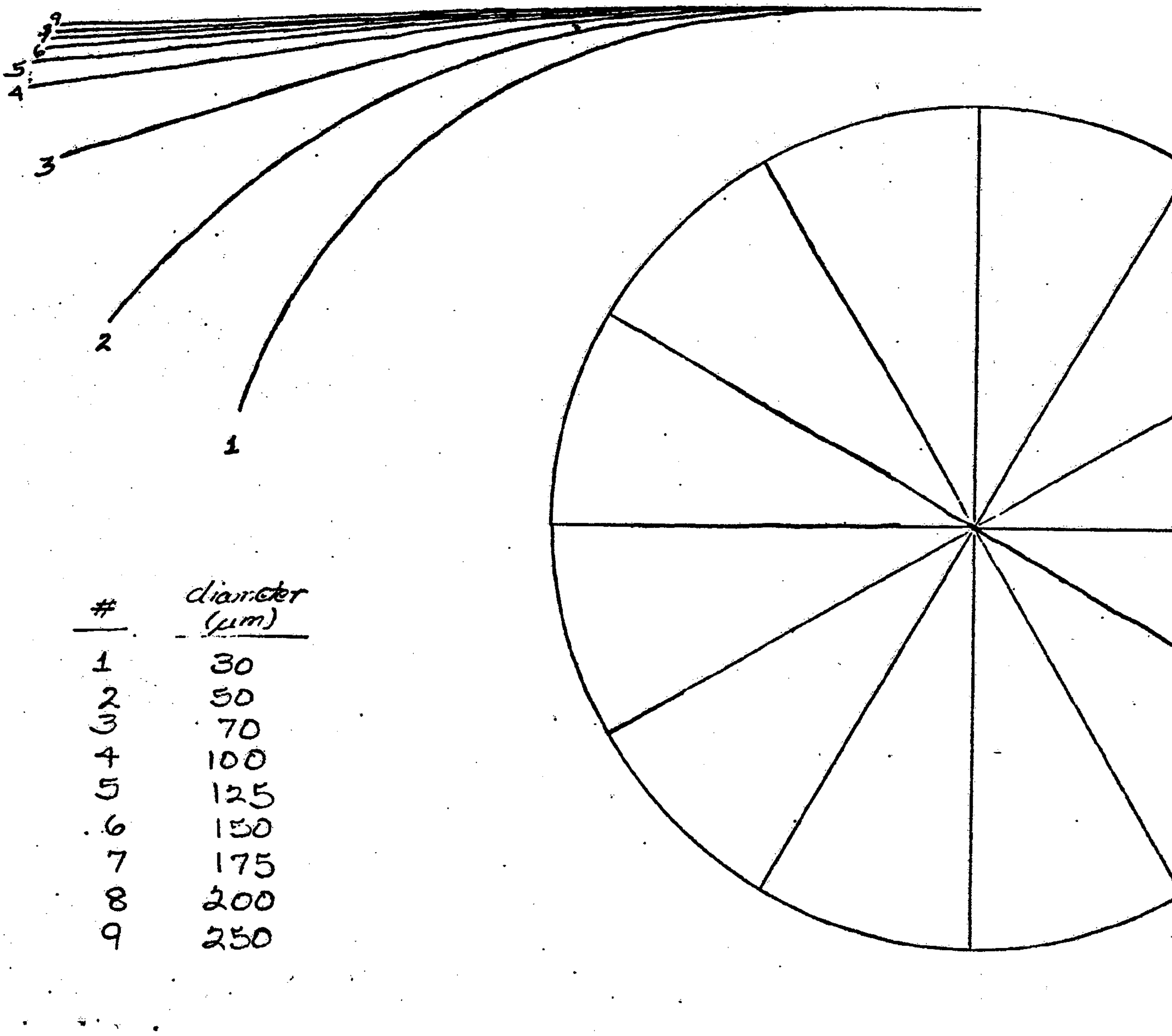
6" Radius of Curvature

2" Slot Height



#	diameter (µm)
1	30
2	50
3	70
4	100
5	125
6	150
7	175
8	200
9	250

Figure LSW-16
PARTICLE TRAJECTORIES
8" Radius of Curvature, 2" Slot Height



#	diameter (μm)
1	30
2	50
3	70
4	100
5	125
6	150
7	175
8	200
9	250

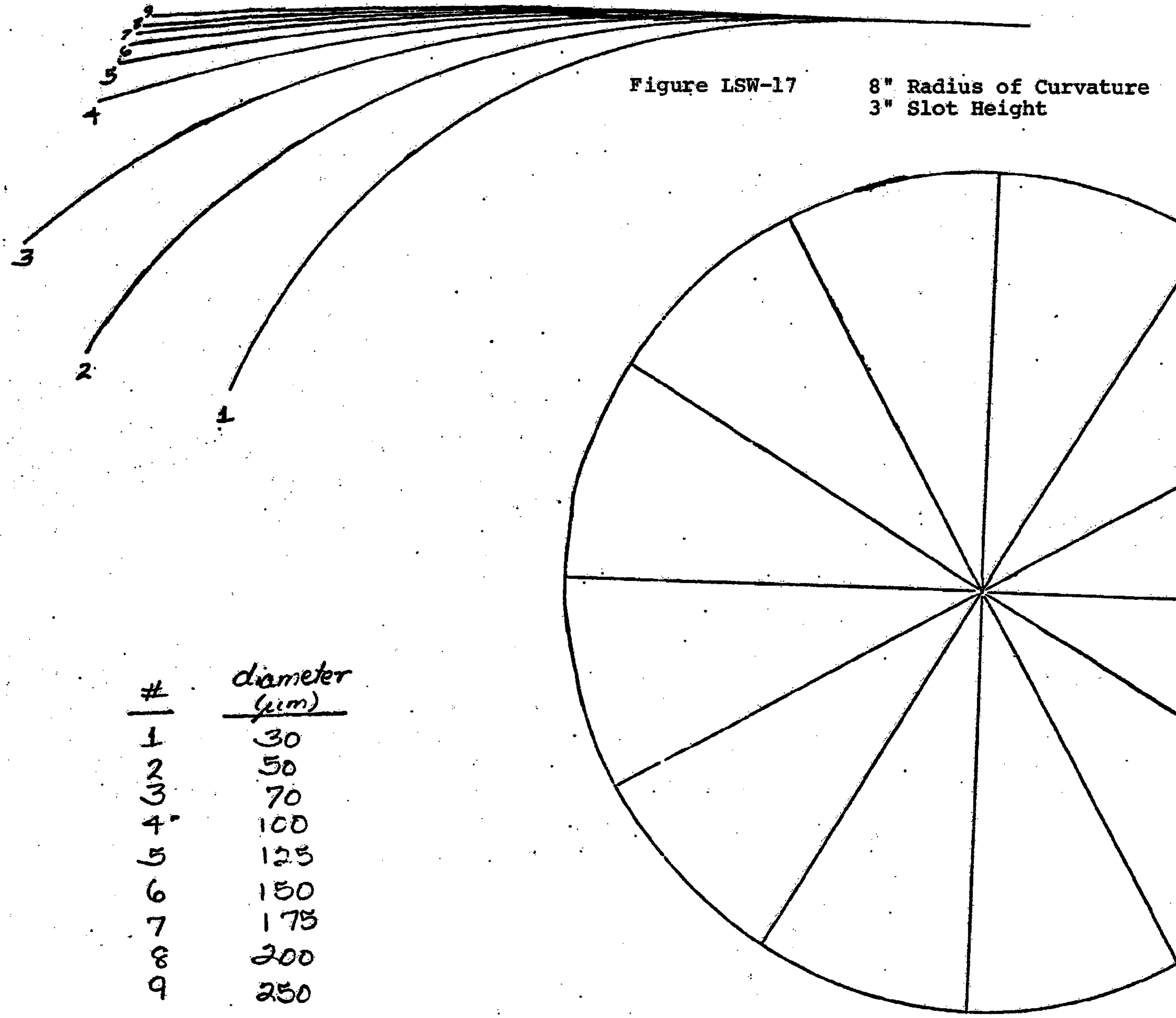
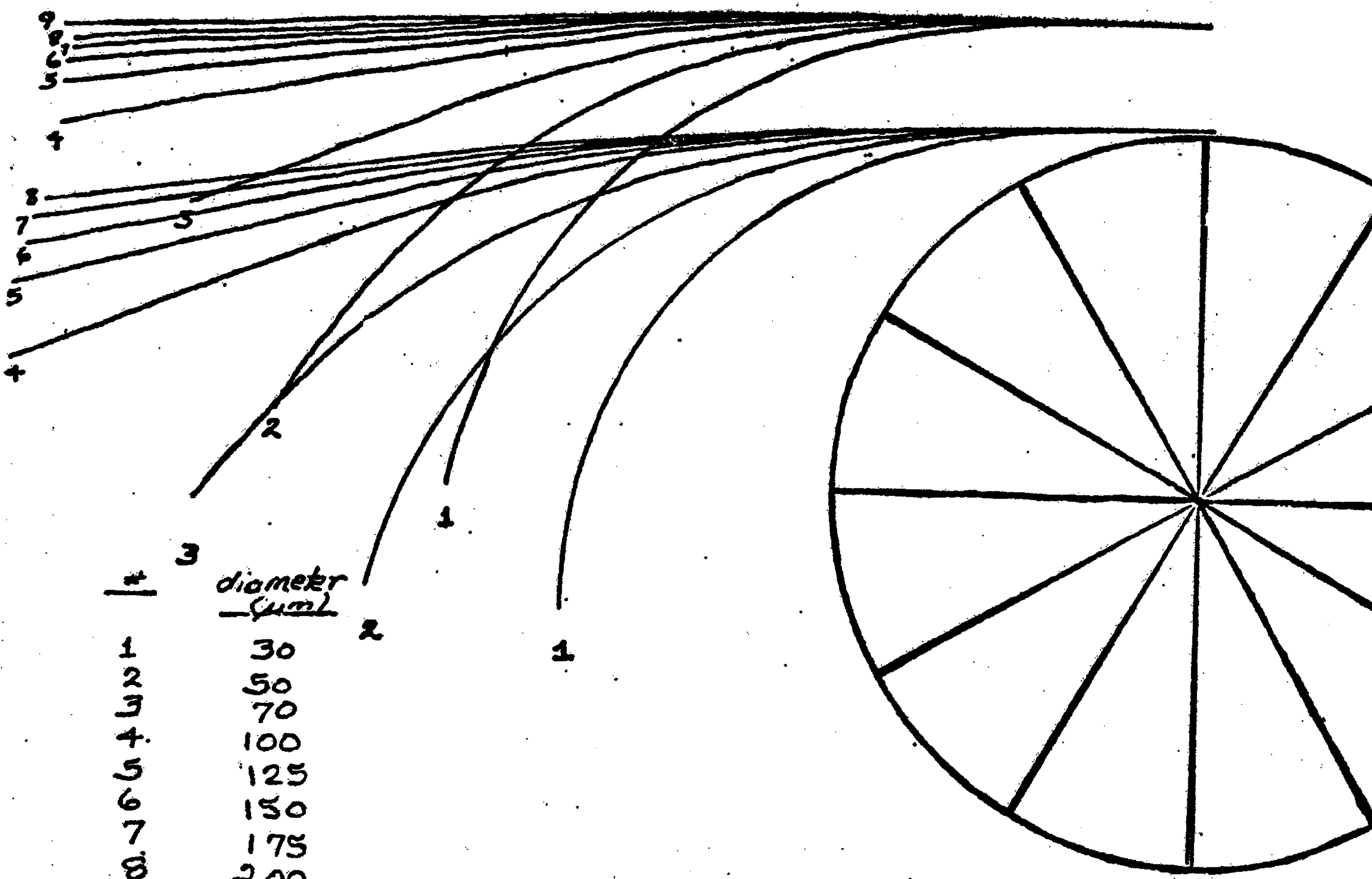


Figure LSW-17 8" Radius of Curvature
3" Slot Height

#	diameter (μm)
1	30
2	50
3	70
4	100
5	125
6	150
7	175
8	200
9	250

Figure LSW-18
6" Radius of Curvature

2" Slot Height



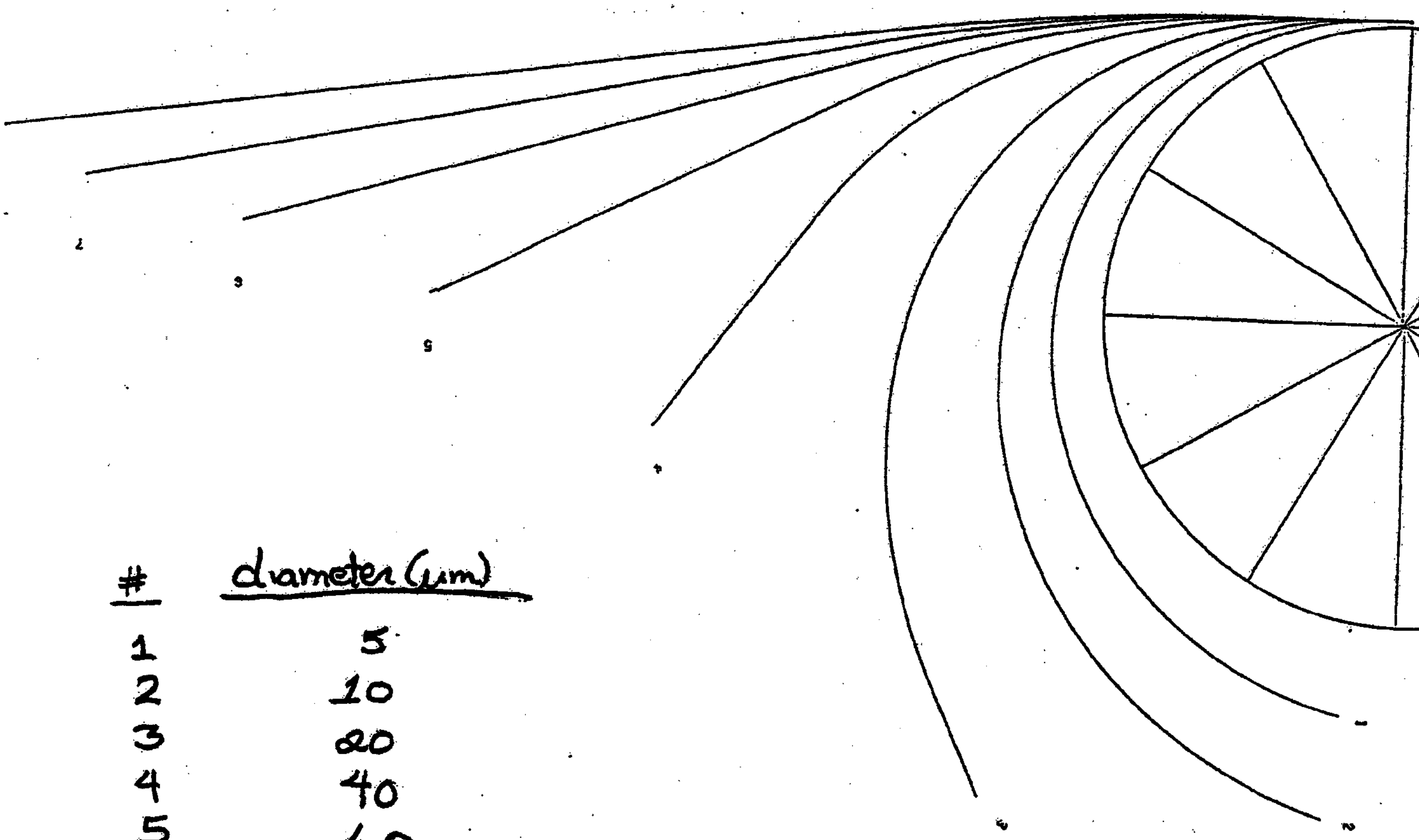
#	diameter (µm)
1	30
2	50
3	70
4.	100
5	125
6	150
7	175
8	200
9	250

Figure LSW-19

UTERNAL JET DESIGN

4" Radius of Curvature

2" Feed Slot



#	diameter (μm)
1	5
2	10
3	20
4	40
5	60
6	80
7	100
8	125

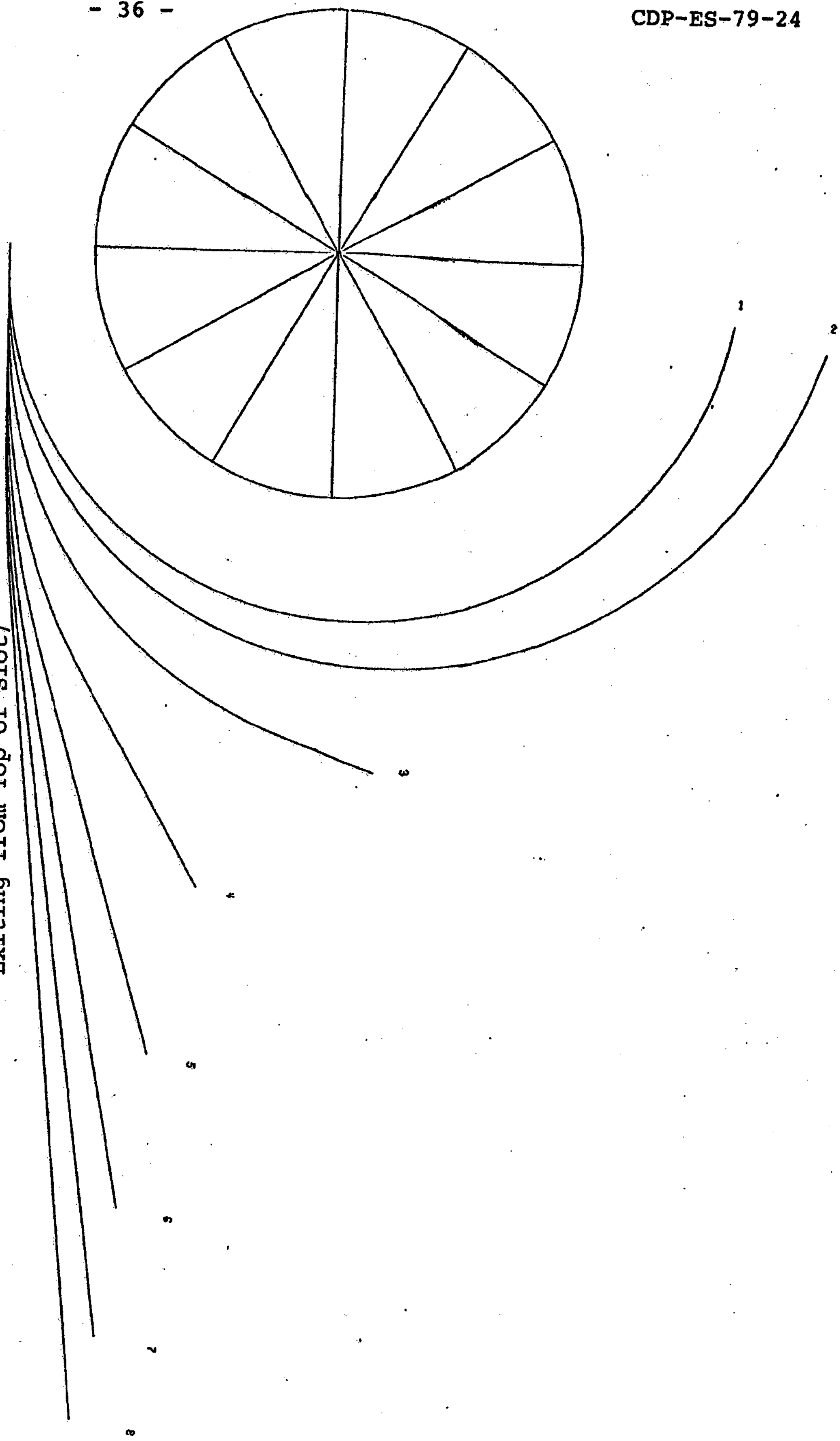


Figure LSW-20

UTERNAL JET

(Same as Figure LSW-19 Except Exiting from Top of Slot)

APPENDIX: COMPUTER PROGRAM

```
00 R 001677 VNER        0000 R 001671 VNET        0000 R 001702 VNU        0000 R 00170
00 R 001637 VRET        0000 R 001653 XB          0000 R 001663 XC         0000 R 00164
00 R 001703 XXX         0000 R 000000 Y           0000 R 001720 YY         0000 R 00170
```

```
      COMMON INT,AT,BT,CT,DT,KAY1,KAY2,KAY3,KAY4
      DIMENSION Y(3),RR(300),THETA(300),V(300),ITR(9)
      REAL KAY1,KAY2,KAY3,KAY4
      DATA ITR/'1','2','3','4','5','6','7','8','9'/
C        VIN    =   INITIAL PARTICLE VELOCITY (CM/SEC)
C        DM     =   PARTICLE DIAMETER (MICRONS)
C        TM     =   GAS TEMPERATURE (C)
C        VISC   =   GAS VISCOSITY (POISE)
C        RHOP   =   DENSITY OF PARTICLE (GM/CM3)
C        RHOG   =   DENSITY OF GAS (GM/CM3)
C        RIN    =   RADIUS OF CURVATURE OF COANDA SURFACE (CM)
C        VRET   =   TANGENTIAL VELOCITY OF PARTICLE (CM/SEC)
C        SLOT   =   PIGMENT FEED SLOT HEIGHT (CM)
C        TDEL   =   TIME STEP FOR CALCULATIONS (SEC)
C        PST    =   STARTING LOCATION OF PARTICLE IN SLOT (0.0 TO 1.0,
C                   0.0 SETS PARTICLE AT SURFACE, 1.0 SETS PARTICLE AT
C                   TOP OF SLOT)
      NUM = 0
C     DRAW COANDA SURFACE
      CALL PLOTS(0,0,0)
      CALL PLOT(2.0,2.0,3)
      CALL ORIGIN (8.0,8.0,-1)
      CALL SCALF (0.394,0.394,1)
C     ADD SPOKES TO INDICATE ANGLES
      READ (5,100) SLOT,VIN,VISC,TM,RHOG,RIN,TDEL,PST
      CALL POL(0.,0.,PIN,12,1,0)
  100 FORMAT (8F10.0)
  102 READ(5,100) DM,PHOP
      IF (DM) 999,999,150
  150 WRITE (6,104) SLOT,VIN,DM,VISC,TM
  104 FORMAT (1H1//10X,'SLOT =',F8.2,5X,'VIN =',F8.2,5X,'DM =',
     1  F6.2,5X,'VISC =',F7.4,5X,'TM =',F5.0)
      WRITE (6,105) RHOP,PHOG,RIN,TDEL
  105 FORMAT (9X,'RHOP =',F5.1,5X,'PHOG =',F6.3,5X,'RIN =',F6.2,5X,
     1 'TDEL =',F8.5)
C     SET INITIAL POSITION OF PARTICLE
      RR(1) = RIN + PST*SLOT
      VGAS = VIN
      TT = 0.0
      Y(1) = 0.0
      Y(2) = PR(1)
      Y(3) = 0.
      V(1) = Y(1)
      THETA(1) = Y(3)
      RAD = DM/2.
      VRER = 0.
      VPFT = VIN
      T1 = 0.375*PHOG
      T2 = RAD*PHOP*1.E-4
      RER = RHOG*DM*1.E-4/VISC
      J = 1
```

```
      INT = 1
C     DETERMINE GAS VELOCITY AT PRESENT PARTICLE POSITION
  200 CALL AGAST (RR(J),THETA(J),VIN,VGAS)
      IF (VGAS.LE.1.0) GO TO 500
      RE = RER*ABS(VRET - VGAS)
      J = J + 1
      VAN = SQRT(VRET*VRET + VRER*VRER)
      XV = VAN*TDEL
      TH = ATAN(VRER/VRET)
      RR(J) = SQRT(XV*XV + RR(J-1)*RR(J-1) - 2.0*XV*RR(J-1)*COS(1.57+TH
     1 )
      THA = ASIN(XV*SIN(1.57+TH)/RR(J))
      THETA(J) = THA + THETA(J-1)
C     CALCULATE DRAG COEFFICIENT
  201 IF (DM.LE.1.3.OR.RE.LE.0.1) CD=24./RER
      IF (DM.GT.1.3.AND.RE.GT.0.1) GO TO 204
      IF (DM.GT.1.3) GO TO 202
      CUNN = 1.0 + (.0002*TM/DM)*(2.79+0.894*EXP(-2.47E3*DM/TM))
      CD = CD/CUNN
  202 XB = T1*CD/T2
      IF (XB*TT.LT.50.0) GO TO 203
      IF (INT.EQ.2) GO TO 302
      GO TO 301
  203 BT = XB
      CT = VGAS
      AT = (VRET - CT)/EXP(-BT*TT)
C     EQUATION FORM V=A*EXP(-B*T) + C
      GO TO 300
  204 IF (RE.GT.3.0) GO TO 206
      C1 = 0.0
      C2 = 24./RER
      C3 = 2.4
      GO TO 208
  206 IF (RE.GT.100.) GO TO 207
      C1 = -17.5/RER/RER
      C2 = 34.6/RER
      C3 = 0.815
      GO TO 208
  207 C1 = 0.0
      C2 = 75./RER
      C3 = 0.4
  208 TN1 = (T1*C1 - T1*C2*VGAS + T1*C3*VGAS*VGAS)/T2
      TN2 = (T1*C2 - 2.*T1*C3*VGAS)/T2
      TN3 = (T1*C3)/T2
      Q = TN2*TN2 - 4.*TN1*TN3
C     EQUATION FORM V = A/(1. - B*EXP(-CT)) + D
      XC = SQRT(Q)
      IF (XC*TT.GE.50.0) GO TO 345
      DT = -(TN2 + SQRT(Q))/TN3/2.0
      AT = SQRT(Q)/TN3
      CT = XC
      BT = (1.0 - AT/(VRET - DT))/EXP(-CT*TT)
      IF (INT.EQ.2) GO TO 210
      ATA = AT
      BTB = BT
      CTC = CT
      DTD = DT
  341 TW = TT + TDEL
```

```
      VNET = ATA/(1.0 - BTB*EXP(-CTC*TW)) + DTD
      INT = 2
      GV = VGAS
      VGAS = 0.0
      VRET = VRER
      RE = RER*VRER
      GO TO 201
  345 IF (INT.EQ.2) GO TO 343
      GO TO 341
  210 ATT = AT
      BTT = BT
      CTT = CT
      DTT = DT
  343 TT = TW
      VNER = ATT/(1.0 - BTT*EXP(-CTT*TT)) + DTT
      INT = 1
      GO TO 350
  300 IF (INT.EQ.2) GO TO 340
      ATA = AT
      BTB = BT
      CTC = CT
  301 TW = TT + TDEL
      VNET = ATA*EXP(-BTB*TW) + CTC
      INT = 2
      GV = VGAS
      VRET = VRER
      VGAS = 0.0
      RE = RER*VRER
      GO TO 201
  340 ATT = AT
      BTT = BT
      CTT = CT
  302 TT = TW
      VNER = ATT*EXP(-BTT*TT) + CTT
      INT = 1
  350 VN1 = SQRT(VNET*VNET + VNER*VNER)
      TH2 = ATAN(VNER/VNET)
      VRET = VN1*COS(TH2 + THA)
      VRER = VN1*SIN(TH2 + THA)
      V(J) = VN1
      IF (THETA(J).GE.3.0.OR.RR(J).GE.50.0) GO TO 400
      IF (J.EQ.300) GO TO 400
      IF (V(J).LE.10.0) GO TO 400
      GO TO 200
C     DETERMINE TRAJECTORIES FOR PARTICLES WHICH HAVE ESCAPED HIGH-
C     VELOCITY GAS STREAM
  500 VNU = SQRT(VRET*VRET + VRER*VRER)
      XXX = RR(J)*SIN(THETA(J))
      YYY = RR(J)*COS(THETA(J))
      PHI = ATAN(VRER/VRET)
      PSI = THETA(J) - PHI
  501 RE = RER*VNU
C     CALCULATE DRAG COEFFICIENT
      IF (DM.LE.1.3.OR.RE.LE.0.1) CD = 24./REP
      IF (DM.GT.1.3.AND.RE.GT.0.1) GO TO 504
      IF (DM.GT.1.3) GO TO 502
      CUNN = 1.0 + (.0002*TM/DM)*(2.79+0.894*EXP(-2.47E3*DM/TM))
      CD = CD/CUNN
```

```
  502 XB = T1*CD/T2
      IF (XB*TT.GE.50.0) GO TO 550
      BT = XB
      CT = 0.0
      AT = (VNU - CT)/EXP(-BT*TT)
  550 T = TT
      TT = TT + TDEL
      VNU = AT*EXP(-BT*TT) + CT
      AA = -AT*COS(PSI)/BT
      BB = BT
      CC = CT*COS(PSI)
      DD = XXX-AA*EXP(-BB*T) - CC*T
      XXX = AA*EXP(-BB*TT) + CC*TT + DD
      AA = AT*SIN(PSI)/BT
      CC = -CT*SIN(PSI)
      DD = YYY - AA*EXP(-BB*T) - CC*T
      YYY = AA*EXP(-BB*TT) + CC*TT + DD
      J = J + 1
      RR(J) = SQRT(XXX*XXX + YYY*YYY)
      THETA(J) = ATAN(XXX/YYY)
      IF (THETA(J).LT.0.0) THETA(J) = THETA(J) + 3.14
      V(J) = VNU
      IF (THETA(J).GE.3.0.OR.RR(J).GE.50.0) GO TO 400
      IF (J.EQ.300) GO TO 400
      IF (V(J).LE.10.0) GO TO 400
      GO TO 501
  504 IF (RE.GT.3.0) GO TO 506
      C1 = 0.0
      C2 = 24.0/RER
      C3 = 2.4
      GO TO 508
  506 IF (RE.GT.100.) GO TO 507
      C1 = -17.5/RER/RER
      C2 = 34.6/RER
      C3 = 0.815
      GO TO 508
  507 C1 = 0.0
      C2 = 75.0/RER
      C3 = 0.4
  508 TN1 = T1*C1/T2
      TN2 = T1*C2/T2
      TN3 = (T1*C3)/T2
      Q = TN2*TN2 - 4.*TN1*TN3
      XC = SQRT(Q)
      IF (XC*TT.GE.50.0) GO TO 552
      DT = -(TN2 + SQRT(Q))/TN3/2.0
      AT = SQRT(Q)/TN3
      CT = XC
      BT = (1.0 - AT/(VNU - DT))/EXP(-CT*TT)
  552 T = TT
      TT = TT + TDEL
      VNU = AT/(1.0 - BT*EXP(-CT*TT)) + DT
      AA = AT*COS(PSI) + DT*COS(PSI)
      BB = AT*COS(PSI)/CT
      CC = XXX - AA*T - BB*ALOG(1.0 - BT*EXP(-CT*T))
      XXX = AA*TT + BB*ALOG(1.0 - BT*EXP(-CT*TT)) + CC
      AA = -AT*SIN(PSI) - DT*SIN(PSI)
      BB = -AT*SIN(PSI)/CT
```

```
                CC = YYY - AA*T - BB*ALOG(1.0 - BT*EXP(-CT*T))
                YYY = AA*TT + BB*ALOG(1.0 - BT*EXP(-CT*TT)) + CC
                J = J + 1
                RR(J) = SORT(XXX*XXX + YYY*YYY)
                THETA(J) = ATAN(XXX/YYY)
                IF (THETA(J).LT.0.0) THETA(J) = THETA(J) + 3.14
                V(J) = VNU
                IF (THETA(J).GE.3.0.OR.RR(J).GE.50.0) GO TO 400
                IF (J.EQ.300) GO TO 400
                IF (V(J).LE.10.0) GO TO 400
                GO TO 501
            400 NPT = J
          C     PLOT TRAJECTORY
                CALL POLAR(RR,THETA,NPT,1,0,1H*,0.,0.394)
                NUM = NUM + 1
                LAB = ITR(NUM)
                TEND = THETA(NPT) + 0.05
                XX = RR(NPT)*COS(TEND)
                YY = RR(NPT)*SIN(TEND)
                CALL CHAR(XX,YY,TEND,0.125,LAB,1)
                WRITE (6,106) (V(I),RR(I),THETA(I),I=1,NPT)
          106   FORMAT(1H1,(10X,F8.2,5X,F8.2,5X,F8.2))
                GO TO 102
            999 CALL PLOT(0.0,0.0,999)
                STOP
                END

END OF COMPILATION:       NO  DIAGNOSTICS.


A.
27R3A      E35 SL73R1 11/27/79 13:48:52

S*COANDA(1) ELEMENT TABLE

E          VERSION       TYPE        DATE        TIME      SEQ #  SIZE-PRE,TEXT
B                        FOR SYMB    30 DEC 77   11:11:30     1              19
S                        FOR SYMB    05 JAN 78   09:07:10     2               7
S                        FOR SYMB    10 JAN 78   11:00:57     3               4
                         FOR SYMB    10 JAN 78   16:03:42     4               3
                         FOR SYMB    10 JAN 78   16:03:49     5               3
                         RELOCATABLE 11 JAN 78   09:49:51     6      1        3
                         RELOCATABLE 11 JAN 78   09:49:54     7      1        3
B                        RELOCATABLE 11 JAN 78   09:49:59     8      1       23
S                        RELOCATABLE 11 JAN 78   09:50:02     9      1        4
S                        RELOCATABLE 11 JAN 78   09:50:05    10      1       10
ST                       FOR SYMB    21 NOV 79   11:21:01    11               2
ST                       RELOCATABLE 21 NOV 79   11:21:06    12      1        2
NDA                      FOR SYMB    26 NOV 79   13:03:44    13              61
NDA                      RELOCATABLE 26 NOV 79   13:03:50    14      3       79
NDA                      FOR SYMB    27 NOV 79   13:48:50    15              63
NDA                      RELOCATABLE 27 NOV 79   13:48:52    16      3       76
VAILABLE LOCATION-

LER PROCEDURE TABLE EMPTY

PROCEDURE TABLE EMPTY
```

```
COPE*GRAPH.POL,TPF$.POL
4R1   T -08/23/79-14:24:19 (1,)

ROUTINE POL        ENTRY POINT 000253

RAGE USED: CODE(1) 000303; DATA(0) 000065; BLANK COMMON(2) 000000

ERNAL REFERENCES (BLOCK, NAME)

03    PLOT
04    PLTLN
05    NUMPLT
06    ELIPS
07    RMATH$
10    COS$
11    SIN$

RAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

01      000073 123G       0001    000213 147G       0001    000133 2L          0001    00017
00  R  000012 BS          0000 R  000011 BY         0000 R  000002 C           0000 R  00001
00  R  000017 D           0000 R  000013 DS         0000    000023 DYNS        0000 I  00001
00  R  000006 RX          0000 R  000007 RY         0000 R  000003 S           0000 R  00001
00  R  000004 XS          0000 R  000020 XX         0000 R  000005 YS          0000 R  00002


        SUBROUTINE POL(X,Y,R,NR,NC,IOP)
        T = 360.0/NR
        RA = .0174533
        C = COS(RA*T)
        S = SIN(RA*T)
        CALL PLOT (XS,YS,4)
        XS = 1.0
        YS = 1.0
        RX = R*XS
        RY = R*YS
        AX = RX/NC
        BY = RY/NC
        BS = .12
        DS = R + .05
        CC = C
        SS = S
        DO 4 I = 1,NR
        CALL PLTLN(X,Y,X+RX*CC,Y+RY*SS)
        IF(IOP .EQ. 0) GO TO 3
        D = T*I-90
        IF(D-90.0) 2,2,1
      1 DS = R + .13
        D = D + 180
        BS = -.12
      2 XX = X + (DS*CC+BS*SS)*XS
        YY = Y + (DS*SS-BS*CC)*YS
```

```
      CALL NUMPLT(XX,YY,RA*D,-.08,T*I,-1)
    3 CT = C*CC - S*SS
      SS = S*CC + C*SS
    4 CC = CT
      DO 5 I = 1,NC
    5 CALL ELIPS (X+AX*I,Y,AX*I,BY*I,0.,0.,0.,3)
      RETURN
      END

END OF COMPILATION:         NO  DIAGNOSTICS.
```

```
S A.AGAS,A.AGAS
OT3-01/11/76-09:49:59 (2,)

BROUTINE AGAS      ENTRY POINT 000050

ORAGE USED: CODE(1) 000062; DATA(0) 00001C; BLANK COMMON(2) 000000

ORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

001   000037 150L       0001   000044 152L       0001   000045 999L       0000 R 00000
000 R 000001 VH



                SUBROUTINE AGAS(R,TH,SLW,RAD,VI,VG)
                IF (TH.EQ.0.0) GO TO 999
                ALEN = 2.0*SLW*TH + SLW
                IF (R-RAD.LE.ALEN) GO TO 150
                IF (R-RAD.GE.1.25*ALEN) GO TO 152
                VH = VI*SLW/ALEN
                VG = -4.0*VH*(R-RAD-ALEN)/ALEN + VH
                GO TO 999
            150 VG = VI*SLW/ALEN
                GO TO 999
            152 VG = 0.0
            999 RETURN
                END

 END OF COMPILATION:        NO  DIAGNOSTICS.
```

```
IS A.AGAST,.AGAST
0T3-03/20/79-14:11:49 (,0)

BROUTINE AGAST     ENTRY POINT 000015

ORAGE USED: CODE(1) 000024; DATA(0) 000003; BLANK COMMON(2) 000000

ORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

001   000010 150L      0001   000012 999L       0000    000000 DYNS


      1*             SUBROUTINE AGAST(R,TH,VI,VG)
      2*             IF (TH.EQ.0.0) GO TO 999
      3*             IF (R.LE.5.08) GO TO 150
      4*             VG = 0.0
      5*             GO TO 999
      6*         150 VG = VI
      7*         999 RETURN
      8*             END

 END OF COMPILATION:        NO  DIAGNOSTICS.

T A.
R 27R3-1     E35 SL73R1 03/20/79 14:11:52

NS*COANDA(1) ELEMENT TABLE

ME           VERSION            TYPE        DATE         TIME       SEQ #  SIZE-PRE,TEXT
AB                            FOR SYMB     30 DEC 77    11:11:30       1             19
AS                            FOR SYMB     05 JAN 78    09:07:10       2              7
AS                            FOR SYMB     10 JAN 78    11:00:57       3              4
                              FOR SYMB     10 JAN 78    16:03:42       4              3
                              FOR SYMB     10 JAN 78    16:03:49       5              3
                              RELOCATABLE  11 JAN 78    09:49:51       6       1      3
                              RELOCATABLE  11 JAN 78    09:49:54       7       1      3
AB                            RELOCATABLE  11 JAN 78    09:49:59       8       1     23
AS                            RELOCATABLE  11 JAN 78    09:50:02       9       1      4
AS                            RELOCATABLE  11 JAN 78    09:50:05      10       1     10
ANDA                          FOR SYMB     28 JUN 78    14:17:36      11             55
ANDA                          RELOCATABLE  28 JUN 78    14:17:54      12       3     76
ANDA                          FOR SYMB     20 MAR 79    14:11:47      13             56
ANDA                          RELOCATABLE  20 MAR 79    14:11:49      14       3     76
AST                           FOR SYMB     20 MAR 79    14:11:50      15              2
AST                           RELOCATABLE  20 MAR 79    14:11:51      16       1      2
AVAILABLE LOCATION-

BLER PROCEDURE TABLE EMPTY

 PROCEDURE TABLE EMPTY
```

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