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An Introduction to Basic Characteristics

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SYMBOLS

R	Reynolds number	
ρ_a	Air density	kg/m^3
ρ_d	Droplet density	kg/m^3
v	Droplet speed relative to the surrounding air	cm/sec
v_s	Sedimentation speed	m/sec
v_o	Initial droplet speed relative to the air	m/sec
d	Droplet diameter	m
$\overline{d}$	Droplet diameter	Microns
μ_a	Viscosity of air	$kg/msec$
D	Drag of droplet	Newtons
g	Acceleration due to gravity	$9.81 m/sec^2$
m	mass of droplet	kg
q	Droplet charge	coulombs
E	Impaction efficiency	
E_F	Electric field flux	$volts/m$
γ	Surface tensions	kg/sec^2
ε_o	Permittivity of freespace	$\frac{amp^2 sec^4}{kgm^3}$
s	distance or stop distance	metres
t	time	seconds

SPRAY IMPACTION, RETENTION AND ADHESION

AN INTRODUCTION TO BASIC CHARACTERISTICS

1. Synopsis

Droplets falling under gravity through air which is not moving relative to the target will impact on any object in their path whilst charged droplets will be drawn to objects of earth potential along paths normal to the lines of equipotential which, near the catching surface, means they move directly towards it. If the air is moving relative to the target it will tend to move the droplets with it. The greater the drag to mass ratio of a droplet the more rapidly will any initial motion it has through the air cease and it will move through the air only very slowly under the effects of gravity and any electro-magnetic potential. Air flowing past an object is able to change its path rapidly, but droplets moving with the air are less able to do this. Their ability to avoid impact increases with decrease in droplet size and wind speed and increase in the size of the catching surface. Thus small smooth stems catch big droplets in a high wind efficiently whilst large smooth branches in a light wind will not catch many small droplets. Artificial cylinders and ribbons are poorer at catching droplets than natural surfaces which are rarely smooth and often hairy. Hairs or spikes on a surface greatly increase the catch efficiency of droplets being carried in the wind.

A droplet several hundred microns in diameter is so dominated by gravity that it will fall in a near vertical path even in a moderate wind. impacting on any horizontal surface which obstructs its path. Its chances of reaching a vertical stem are negligible unless it runs off or splashes from a near horizontal surface. Conversely, a small droplet will be carried almost horizontally in any wind and is most likely to impact on vertical surfaces, or flapping leaves. It has a much greater chance of getting inside the canopy without being caught since most leaves are near horizontal, and once there must rely on the turbulence induced by the wind for transport and impaction on under -surfaces or hairs. Since turbulence reduces as the droplet nears the ground it is very difficult to catch droplets on the lower parts of the crop within the canopy.

To bounce a droplet must have enough kinetic energy surplus to rebound clear of the surface, allowing for the energy losses in deforming the droplet in the bounce process, and the surface must not be significantly wetted by the drop. Thus the droplet must be moderate to large in size and must be moving rapidly relative to the surface, and have a high surface tension to contain it as a droplet even at its extreme deformation. Surface condition is of great importance, hairs and type of roughness affect the probability of maintaining an air film between the surface and droplet. In general droplets below 150μm are unlikely to bounce whilst adding small amounts of surfactant to the droplet formulation can increase this size by several times. Any one plant leaf can vary considerably over its area because of age, abrasion and local surface shape. A film of water on a wet surface ensures an airfilm is maintained and the droplet will bounce.

2. PARTICLES MOVING RELATIVE TO THE SURROUNDING AIR

2.1 Sedimentation

A particle moving relative to the air which surrounds it experiences a force, resisting its motion, generally called its aerodynamic drag. This drag depends not only on the shape and size of the particle but also upon the ratio of the kinetic energy per unit volume of air to the shear stress arising from the air moving round the droplet, that is the Reynolds number.

$$\text{Reynolds number } R = \frac{\rho_a v d}{\mu_a} \tag{1}$$

where ρ_a is the air density

μ_a is the air viscosity

v is the air velocity relative to the particle

d is a typical length, for example, the diameter if the particle is spherical.

A particle 80μm. in diameter, travelling at 0.16 m/sec. through air, has a Reynolds number of about 1 and viscous effects dominate. However for a 500μm. particle travelling at 2.5 m/sec. through air, corresponding to a Reynolds number of about 100, the inertia effects considerably influence the pressure distribution over the surface of the particle and its drag. The biggest changes in pressure occur near the lateral circumference as suctions which tend to increase the diameter of the droplet in the plane normal to the direction of movement. Thus a droplet moving through the air tends to be flattened fore and aft and present a greater frontal area than that of a sphere of the same volume. The extent to which this happens increases with increase in Reynolds number and speed and decreases with increase in the surface tension which gives cohesion to the droplet. If the speed is sufficiently high the pressure induced will cause the droplet to shatter.

Stokes showed that the drag of rigid spheres at Reynolds number of the order of unity was given closely by

$$\text{Drag} = D = 3\pi\mu_a v d \tag{2}$$

Green and Lane (1964) (1) show that for Reynolds numbers less than 0.5 the deviation from Stokes's Law is less than 1% . With increase in Reynolds number equation (2) progressively underestimates the drag, If a particle is free to fall under gravity through still air it will accelerate until its drag equals the gravitational force. Using Stokes Law this gives

$$3\pi \mu_a v_s d = \frac{\pi}{6} \rho_d d^3 g$$

or the sedimentation velocity

$$v_s = \frac{\rho_d g d^2}{18\mu_a} \qquad (3)$$

where ρ_d is the density of the particle and g is the acceleration due to gravity. Note that at standard temperature (15°C) and pressure (760 mm.Hg)

$$v_s = 0.003\bar{d}^{\,2} \qquad (4)$$

for water droplets when v_s is measured in cm/sec. and $\bar{d}$ in microons. Thus a 10μm. diameter droplet has a sedimentation velocity of only 0.3cm/sec. and an 80μm. droplet falls through still air at 16 cm/sec. corresponding to a Reynolds number of 1. Equation (3) predicts the sedimentation velocities of small particles well, but above a Reynolds number of unity will tend to overestimate as the particle size increases. This can be seen from the experimental data of Davies (1966)(2) shown in Fig.1. Thus equation (3) is really only accurate for droplets below 70μm. in diameter although it can be used to give an answer within 20% up to 100μm. in size. However, at 500μm. diameter the sedimentation velocity is only about one third of that predicted by equation (3) because the Reynolds number in free fall is about 100.

The kinetic energy of a freely falling particle is one half its mass, m, times the square of its sedimentation velocity. Thus for particles below 70μm. in diameter the

$$\text{kinetic energy} = \frac{1}{2} m v_s^{\,2} = \frac{\pi \rho_d^{\,3} g^2 d^7}{3888 \mu_a^2} \qquad (5)$$

which for water droplets at normal temperature and pressure gives a kinetic energy of $0.236\bar{d}^{\,7}$ Joules, where $\bar{d}$ is the droplet diameter in microns.

2.2 Electro-statics.

Particles can be made to move by giving them an electric charge and creating an electro-magnetic field. The accelerating force they experience is proportional to the product of their charge, q, and the strength of the electrical field, E_F. Thus the acceleration they experience in this way is proportional to their charge to mass ratio times the field strength.

The maximum size of the charge which a droplet can carry is limited by corona discharge or energy equilibrium effects and depends upon its size, the physical characteristics of the fluid and of the surrounding air. As a result the maximum charge per unit mass varies a little with the physical properties for a given size of droplet but reduces rapidly with increase in the droplet size because as this increases the surface area to volume and radius of curvature both decrease.

It is found that Rayleighs prediction of the limiting values given by

$$\left(\frac{q}{m}\right)_{max} = \left(\frac{288\gamma\varepsilon_o}{\rho_d^2 d^3}\right)^{\frac{1}{2}} \qquad (6)$$

agrees reasonably well with experimental results. Thus typically

$$\left(\frac{q}{m}\right)_{max} = \begin{array}{lll} 10^{-2}\text{Coulomb/kg} & \text{for} & d = 60\mu m - 100\mu m. \\ 10^{-3}\text{Coulomb/kg} & \text{for} & d = 280\mu m - 370\mu m. \\ 10^{-4}\text{Coulomb/kg} & \text{for} & d = 1300\mu m - 1800\mu m. \end{array}$$

The lower values correspond to oil based formulations whilst the higher ones correspond more to water based preparations.

In a field strength of 5×10^4 volts per metre the acceleration experienced by a 60μm. droplet of an oily formulation would be $5 \times 10^2 m/sec^2$.

or 50 times the gravitational acceleration. However if the droplet were 1.3mm. in diameter the acceleration it would experience would be only half that due to gravity. Thus the ability of the electro-magnetic field to move droplets against the gravitational field decreases significantly as their size increases.

Once a particle starts to move through the air the drag force will oppose the motion. For droplets moving horizontally they will make a maximum speed when their drag equals the electro-magnetic force on them. For small droplets, behaving as Stokes Law, their maximum speed is given by

$$v_{max} = \frac{q E_F}{3\pi\mu_a d} \qquad (7)$$

or using equation (3)

$$\frac{v_{max}}{v_s} = \frac{E_F}{g}\left(\frac{q}{m}\right) \qquad (8)$$

This again illustrates how much more effective electro-static forces can be on small droplets relative to large ones because their maximum charge/mass ratios are so much greater.

The movement induced on a charged particle by an electrical field is always normal to the lines of equi-potential. Figure 2 shows that this means the droplets are moved along curved paths which become more normal to the target plant's surface as they get closer to it, assuming that gravitational effects are insignificant. The figure also shows why the target is evenly covered if the source cloud of charged droplets is large and of uniform density.

3 PARTICLES MOVING WITH THE AIR THAT SURROUNDS THEM

3.1 Stopping Distances

The equation of motion of an uncharged droplet moving horizontally through air at a speed v is given in equation (9).

$$\text{Drag} = D = m\frac{dv}{dt} = mv\frac{dt}{ds}\cdot\frac{dv}{dt} = mv\frac{dv}{ds} \qquad (9)$$

where s is the distance travelled and t is the elapsed time.

Assuming that the Reynolds number is small enough for Stokes Law to apply then

$$\frac{dv}{ds} = \frac{3\pi\mu d}{m} = \frac{18\mu}{\rho_d\, d^2} = \frac{g}{v_s} \qquad (10)$$

Thus if the particle is travelling at an initial speed V_o to the fluid the horizontal distance it moves before it is stationary relative to the fluid, known as the stop distance, is

$$s = \frac{\rho_d\, d}{18\mu} V_o = \frac{v_s V_o}{g} \qquad (11)$$

v_s decreases rapidly with decrease in droplet diameter and so does the stop distance. It is important to realise how small these stop distances really are. Table 1 shows values calculated assuming Stokes Law applies; the values underlined are over-estimates because the Reynolds number conditions are too high for Stokes Law to be accurate.

TABLE 1. Stop distances for various droplet sizes for two initial speeds.

Droplet Diameter	microns	10	50	100	300	1000
Stop Distance	Initial speed V_o=1m/sec	0.03	0.75	<u>2.45</u>	<u>12.5</u>	<u>52.0</u>
centimetres	Initial speed V_o=50m/sec	1.50	<u>37.5</u>	<u>123</u>	<u>625</u>	<u>2600</u>

It can be seen that the horizontal distances travelled before the droplet becomes stationary relative to the surrounding air are below 1.25 metres for sizes smaller than 100μm. even when released from an aircraft travelling at 50m/sec.(112m.p.h.) through the air. In a gust of wind in which there is a sudden change in windspeed of 1m/sec. even the largest particles only lag behind the air which surrounded them initially by a few centimetres.

It is interesting to note that the values of v_s given in Figure 1 have the same numerical value as the stop distances, in centimetres, for water droplets released in a wind of 9.81m/sec. or about 10m/sec.

3.2 Conditions for Impact on Smooth Surfaces

Stop distances are a means of calculating the response in behaviour of a particle to a rapid change in the speed of the air enveloping it. A sub-micron diameter particle has a tiny stop distance and consequently in an accelerating flow would accelerate almost as quickly as the air. Thus very small particles will follow almost exactly the curved paths of the air molecules flowing round a body. Conversely big particles with relatively large stop distances will be slow to move from their initial Paths when the air changes directions due to the presence of a body, and they are much more likely to collide with it. In either case the time during which the changes in airspeed due to the presence of most catching bodies of interest occur is sufficiently small for the effects of sedimentation to be ignored when calculating the probability of impact of particles being carried horizontally by a wind past a near vertical object.

Figure 3 shows the paths followed by the air when flowing round a smooth long cylindrical rod with its axis normal to the flow direction and round a long flat plate with its face normal to the flow. They are typical of flow round a smooth, round stem or an absolutely flat smooth leaf in wind-speeds of a few metres per second. At much faster speeds the flat plate pattern would not change significantly but for the cylinder the flow might follow the surface of the cylinder more near its sides reducing the depth of the dead air region by up to 50%. For very small sized objects and very low windspeeds such that the product of windspeed in metres per second and object diameter in millimetres is of the order of 0.01 the Reynolds number of the flow is sufficiently low for the air to flow round the objects without creating any dead air regions. These changes in flow pattern about the body will have some effect upon the degree of impaction but not as much as the stop distance.

The air flow patterns of Figure 3 scale with the size of the diameter or width of the obstacle. Since for a given approach speed the speeds at similar places in the pattern are the same then the greater the width of the obstacle the lower the acceleration experienced by the air molecules in avoiding the obstacle and the more closely will a particle be able to follow them. It follows that the probability of particles carried in an airflow colliding with an obstacle will increase with stop distance and decreases with increase in the width of the catching surface. A catching or impaction parameter, P is often used to assess the probability of particles impinging onto an obstacle, where P is defined as

$$P = \frac{s}{D} \qquad (12)$$

$$= \frac{v_s V_o}{gD} = \frac{\rho_d d^2 V_o}{18 \mu_a D} \text{ if Stokes Law applies}$$

where D is the width or diameter of the obstacle. Impaction efficiency, E, is defined as the ratio of the number of particles caught to the number of particles which would have passed through the cross-sectional area of the object during the time of exposure had the obstacle not been there, expressed as a percentage. The way the impaction efficiency, E, varies with the impaction parameter, P, depends upon the shape of the obstacle, its surface characteristics and whether it is stationary or oscillating in the flow. May and Clifford (1967) (3) are among a large number of experimenters who have evaluated the relationship between E and P for simple, smooth surfaced shapes. Some of their results are shown in Figure 4. These simple shapes all show the same trend, a low catch efficiency for values of P less than 0.1 and a high efficiency for values of P greater than 10. For spheres, cylinders and ribbons or flat plates normal to the flow direction they show that about 55% of the droplets within the swept volume of these obstructions are caught when P is unity. This is a useful point to remember because since the acceleration due to gravity, g, is almost 10 m/sec^2. then for $P = 1$ $v_s \simeq \frac{10D}{V_o}$ and Figure 1 can be used to evaluate the ratio of object width to approach air speed which will give a catch efficiency of about 55% for these catching surfaces.

It is clear that for good catch efficiency the value of P should exceed 10 and this can be achieved by using a small width of catching object. The lower the airspeed and the smaller the particle size the smaller the width of the catching device must be to ensure a high particle capture. For example, to catch droplets 10μm. in diameter being carried past a smooth cylinder used as a sampling device in a wind of 1m/sec. with an efficiency, of at least 85%, the sampling cylinder must be 31μm. in diameter or less, in other words a very fine wire. Anything of greater diameter would have a poorer catch efficiency. This illustrates how difficult it is to sample correctly spray clouds which contain small droplets. Table II gives the maximum diameter of cylinders which can be used to catch efficiently (85%) droplets of various sizes in a 1m/sec. wind.

TABLE II Maximum sizes of cylindrical rods which will catch various sized droplets efficiently in a 1m/sec. wind.

Droplet size microns	10	50	100	200
Maximum cylinder dia. for 85% catch efficiency in a 1m/sec.wind millimetres	0.031	0.7	2.5	7.1

It is apparent that the small sizes involved make the sample rods difficult to examine. Larger sizes can be used by moving them through the air to increase their relative velocity to the droplets.

3.3 Particle capture by natural surfaces

Plant and insect surfaces differ from smooth simple artificial surfaces such as cylinders and plates in having far rougher surfaces of more complex shape, often with spikes or hairs protruding from the surfaces. The effect of roughness and surface protuberances is to greatly increase their capture efficiency when air carries droplets towards them. Imagine that the cylinder shown in Figure 3 a) had a small spike or hair protruding from the surface about 50^{o} from the most upstream point. The small effective width of this protuberance would give it a very high impaction parameter especially as the local speed there is well in excess of the speed the air is approaching the cylinder. Thus such a spike or hair would capture almost all the particles passing close to the surface at that point. However, if the spike or hair were at the most upstream point, the local velocity would be well below the air approach speed and their capture efficiency would be low. However, the particles not caught here would move round to the 60^{o} position and be caught easily. It follows that even quite a moderate degree of roughness or hair cover will give the cylinder a catch efficiency of nearly 100% even under quite low impaction parameters based on air approach speed and cylinder diameter The protuberances towards the lateral sides of the cylinder making the big difference in catch efficiency.

A leaf face on to the wind might look like Figure 3b) but any serrations or hairs near the lateral edges will readily catch even small particles because of the high local velocities and small size of local catching surface. Any irregularities or curling of the leaf surface will change the general flow pattern and change the catching efficiency of the surface.

In general a squaring of the cylinder shape or a concave cupping of the forward face of the leaf will increase the catch efficiency, shifting the curves of Figure 4 towards the left. A flattening of the lateral dimension of the cylinder or a convex cupping of the leaf would slightly reduce the capture efficiency.. However these effects are often dwarfed by the effects at very local places of high curvature caused by such things as leaf veins, surface ridges and rapid local changes in surface shape. The small scale and rapid changes in slopes at these places make it difficult for even the smaller particles to follow the path of the air and they tend to be caught on such exposed peaks and ridges.

The extent of the increase in the capture efficiency of droplets moving in a wind past a natural surface compared to a smooth artifical surface depends tremendously on the roughness of its shape, the extent of the hair cover, its orientation to the path of the droplet and whether the effective catching speed is increased due to its fluttering in the wind. A smooth birch twig would behave very much as an artifical cylinder but the hairy rough stem of a nettle would have a very much higher catch efficiency. The variation in individual leaf and stem surfaces and their orientation make it certain that there will be a wide variation in capture efficiency, particularly when the droplets are small. Exposed branch tips are likely to catch far more droplets per unit area than the lowest or central branches because of the lower local airspeeds and because they are sheltered by the other growth. Variation in the number of droplets caught per unit area of leaf can be as much as 1000:1 over trees in a forest. Considerably less variation is found when insects fly through a cloud of spray. Large horizontal flat leaves do not catch a large number of small wind-carried droplets per unit area, but may catch more droplets than the plant stems because of their much greater surface area.

4. DROPLET CAPTURE

4.1 Effect of a wind

In very still air, that is with no wind or significant turbulence the only motion of a droplet is downwards due to sedimentation and the catch efficiency on horizontal or nearly horizontal surfaces is 100% if the droplets do not bounce. However if there is a wind the droplets will follow a slanting path, which is more nearly horizontal as the size of the droplet decreases. Table III shows how significant this effect is.

TABLE III. The effects of drop size and wind on the fall path of droplets.

Droplet size μm		10	50	100	300	1000
Angle to the Horizontal	Wind of 0.1m/sec	1.8°	35.6°	67.8°	85.3°	88.9°
	Wind of 1m/sec.	0.18°	4.1°	13.8°	50.4°	78.9°
	Wind of 5m/sec.	0.04°	0.82°	2.8°	13.6°	45.6°

It is clear that small droplets are more likely to be caught on vertical surfaces than horizontal where their capture depends upon the factors discussed in the previous section. With crops like grass, nearly mature cereals and coniferous trees where the main catching surfaces are mainly vertical only extremely large droplets are likely to penetrate to the lower parts of the crop and most of the spray will be caught near the top of the crop. With crops such as cotton with essentially horizontal leaves the big droplets will be caught by the leaves at the top of the canopy and most of the smaller droplets in the upper parts of the canopy. However, if the wind is sufficiently high to create significant turbulence this will not decrease with proximity to the canopy to anything like the same degree as the mean windspeed and some of the smaller droplets may be carried into the lower regions of the crop and be caught there due to the turbulent fluctuations of the air. Clearly the fraction of the total number of small droplets arriving at the canopy which do this will be small but can be significant in some crop protection systems. Certainly there is clear experimental evidence which shows that the only droplets reaching the lower horizontal leaves are small ones which deposit on fine hairs or ridges.

When charged droplets are used in still air conditions extremely good cover over the target surface is obtained due to the earth potential of the crop surfaces. However, this cover becomes less uniform with increase in the wind strength as, on the lea side of the plant, the electro-magnetic attraction has to pull the droplets through the air towards the plant. The porosity of the canopy to the air must be a significant factor. An open plant will have a noticeable wind component on its lea side whilst a dense plant will have almost still air. Charged droplets will reach the lea-side lower regions of plants more readily when the plants are well spaced apart.

Most droplets will be caught on the upper exposed surfaces when the canopy is continuous and dense.

4.2 Best conditions for capture.

The best conditions for good droplet capture depend upon the positions of the target surface. If penetration to the ground or cover of the top surfaces of the large horizontal leaves of a canopy is required then droplets 250μm. in diameter or greater are required, preferably sprayed in low wind conditions. If cover of vertical surfaces or the stems and undersides of leaves particularly in the lower parts of a crop is required then small droplets of 20μm.- 50μm. in diameter sprayed with a wind of at least 3m/sec. is most likely to give the best results. Charging the droplets enhances their capture under low wind conditions.

5. RETENSION AND ADHESION.

5.1 The dynamics at impact.

Once a droplet impacts on a surface it may remain on the surface or bounce and the factors which influence this are varied and complex.

On impact the kinetic energy of a droplet will cause it to spread out laterally over the catching surface. The major restraining influence on this effect is the surface tension of the fluid. As the droplet flattens so its surface area increases and the kinetic energy is changed into potential energy stored in the liquid air surface. The maximum lateral spread is reached when all the available kinetic energy is stored. Subsequently the surface tends to return towards its minimum energy state of uniform curvature and the fluid is accelerated back to the central point of impact. If the loss of energy due to friction associated with the movement of the fluid over the surface is low, the surface tension will cause the fluid to rebound to the centre where the pressure can build up sufficiently to push the fluid off the surface and the droplet will have bounced. If the surface is such that it is not wetted by the fluid then the loss of energy in the process can only be due to frictional losses. If the surface is not wetted there must be a layer of air trapped between it and the liquid and th friction can only occur due to isolated areas of contact such as hairs or ridges and friction within the liquid. In such a case the energy losses are small and the droplet will bounce. If the surface comes into direct contact with the fluid and is wetted then the surface tension bond between it and the liquid will oppose both the lateral expansion and contractions and this will absorb a lot of the kinetic energy leaving insufficient for the subsequent tendency to bounce to be effective and the droplet will be retained.

This dynamic process depends considerably on the values of kinetic energy and surface tension. If the kinetic energy of the droplet relative to the catching surface is low then it will be retained as the energy losses in surface friction and within the droplet during the intense distortion of the droplet on impact will absorb all this energy. Thus droplets below 100μm. in diameter will almost certainly be retained on impact almost irrespective of other factors. By reducing the value of surface tension by adding a small amount of surfactant the maximum spread of a droplet is increased giving it a better chance of wetting the surface and hence being retained. Thus retention can be dramatically enhanced by reducing surface tension by adding no more than one percent of a suitable surfactant. It is worth noting that surfactants take a finite time to reach the surface of a droplet and the true surface tension is not got immediately after droplet formation.. Increasing the amount of surfactant beyond a small amount is unlikely to further increase the retention characteristics. Since the kinetic energy of a droplet falling at its terminal velocity varies as the seventh power of its diameter it is virtually impossible to retain a very big droplet. Very often the process of rebounding causes it to shatter into an uneven group of smaller droplets.

Experiments seem to indicate that the angle between the flight path and the droplet is relatively unimportant on its probability of being retained. In such experiments it is important to account for every droplet released rather than just count the droplets per unit area since for the same source the droplet flux per unit leaf area depends on the leaf orientation.

5.2 Surface Effects

The major factor is the detailed shape of the catching surface rather than the material of the surface. Thus 300μm. droplets will bounce readily from new pea leaves but not from bean leaves, will bounce from carbon blacked glass or magnesium oxide coated slides but not from waxy paper as R.C.Amsden has shown. Droplets are more likely to bounce from a smooth surface than one which has roughness, particularly if that roughness forms pockets in which air can be trapped during the impaction process. Thus new pea leaves grown in a glass-house will have small wax crystals of about 1μm. in size all over their surfaces and all but the smallest of droplets will bounce off them. However, if the leaves are squeezed between finger and thumb or exposed to effective sand blasting from wind carried particles or allowed to rub against one another they become retentive. Thus old leaves are more retentive than new.

Considerable variations between different kinds of plants and indeed between different varieties of the same species can occur and these differences can be exploited. Thus at the one and a half leaf stage of growth wild oats can be killed whilst wheat is not because of the difference in herbicide droplet retention. At a later stage in their growth both will retain most of the droplets. It is possible for a previous chemical application to the soil to change the characteristics of a plant such that it becomes rententive so

it is essential to check the crop and weed characteristics before spraying.

Some plants have areas which are generally retentive and other areas which are not. The ribs and extreme edges of banana leaves are highly retentive but other parts of the leaves are reflective. On most plants hairs tend to retain droplets even though the surface between them might be reflective.

One sure way of ensuring that a surface is reflective is to thoroughly wet it. As a droplet is about to impact on a wet surface the local pressure field causes the water on the surface to distort and as a consequence there is always an air film between droplet and surface liquid. This can be shown by bouncing a clear liquid off the surface of one dyed and catching the drop on blotting paper: it will show no trace of dye. It follows that dew and rain can considerably reduce the retention qualities of crops.

5.3 Adhesion

Once a droplet has been retained after impaction it is likely to stay in that place unless either the surface is accelerated strongly causing the droplet to be thrown off, as might happen in a high wind, or a large number of droplets impact in the same area and the surface becomes saturated and run-off occurs. This happens when the contact areas of the droplets overlap. The rougher the surface and the higher the surface tension of the liquid the smaller the contact area for a given volume of droplets. The larger the droplet the smaller the contact area per unit volume. The larger the droplet and the smaller its contact area the more readily can it be removed by a rapid acceleration. The lower the surface tension the more readily will the droplets spread and the fewer needed to cause run-off.

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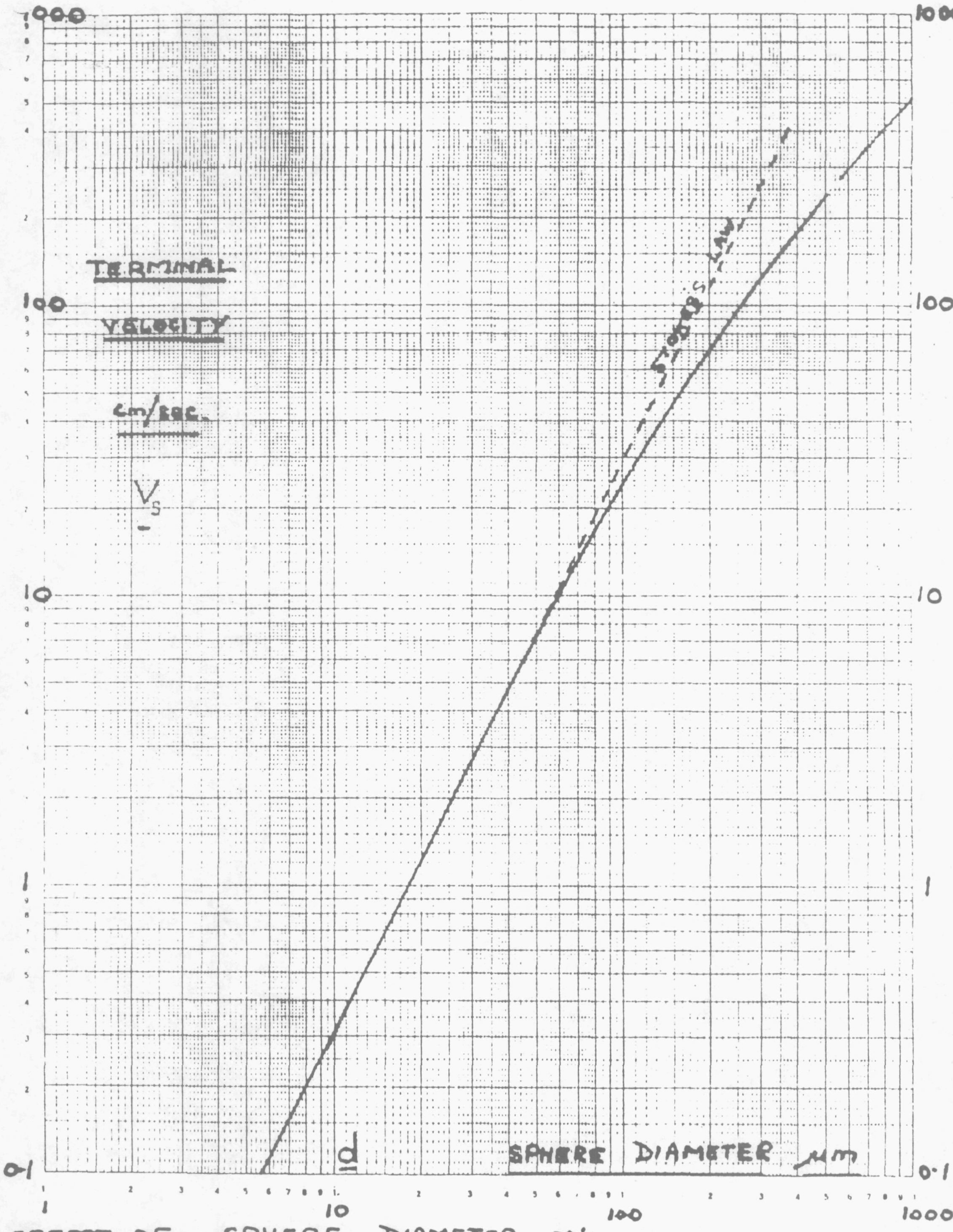
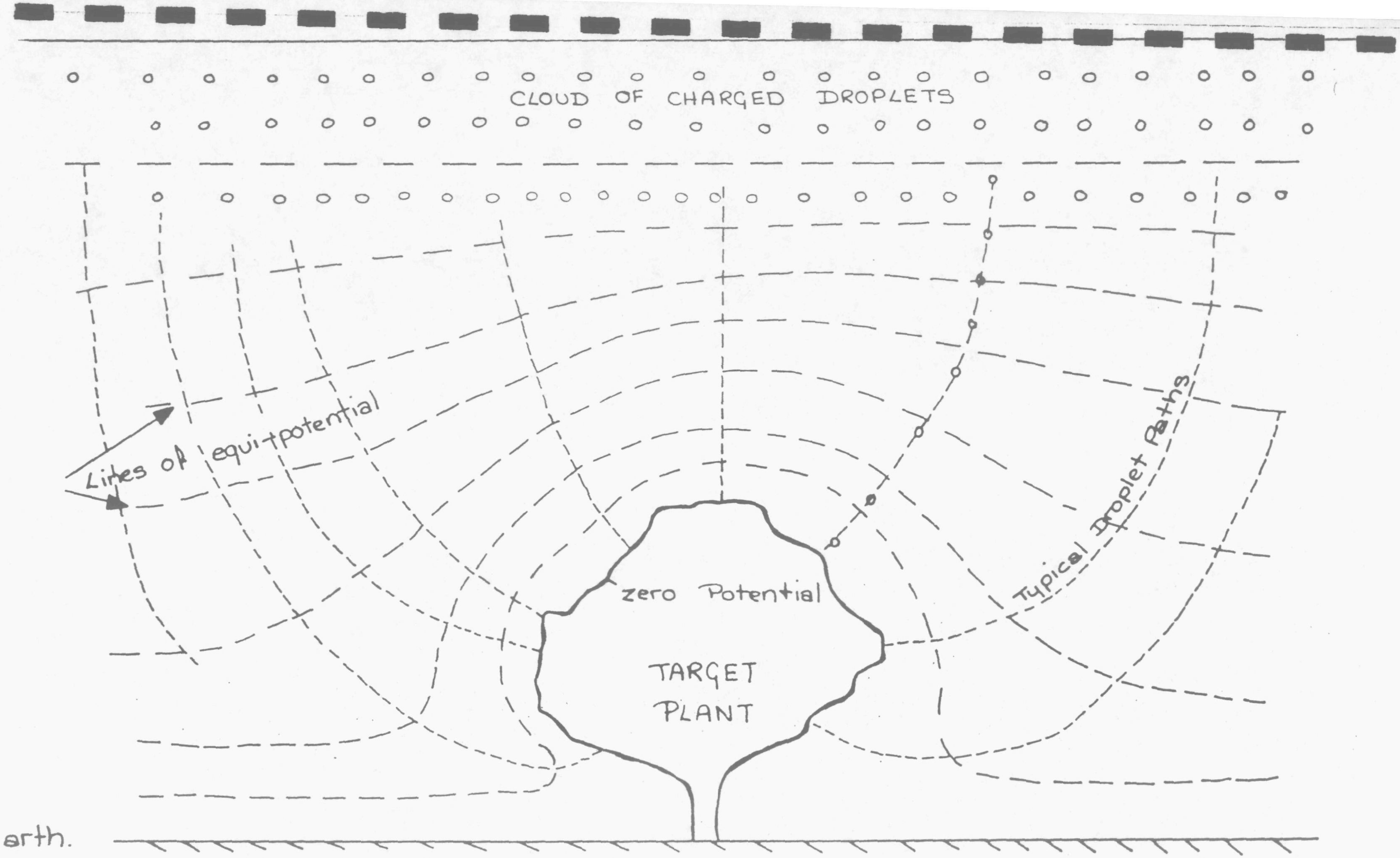


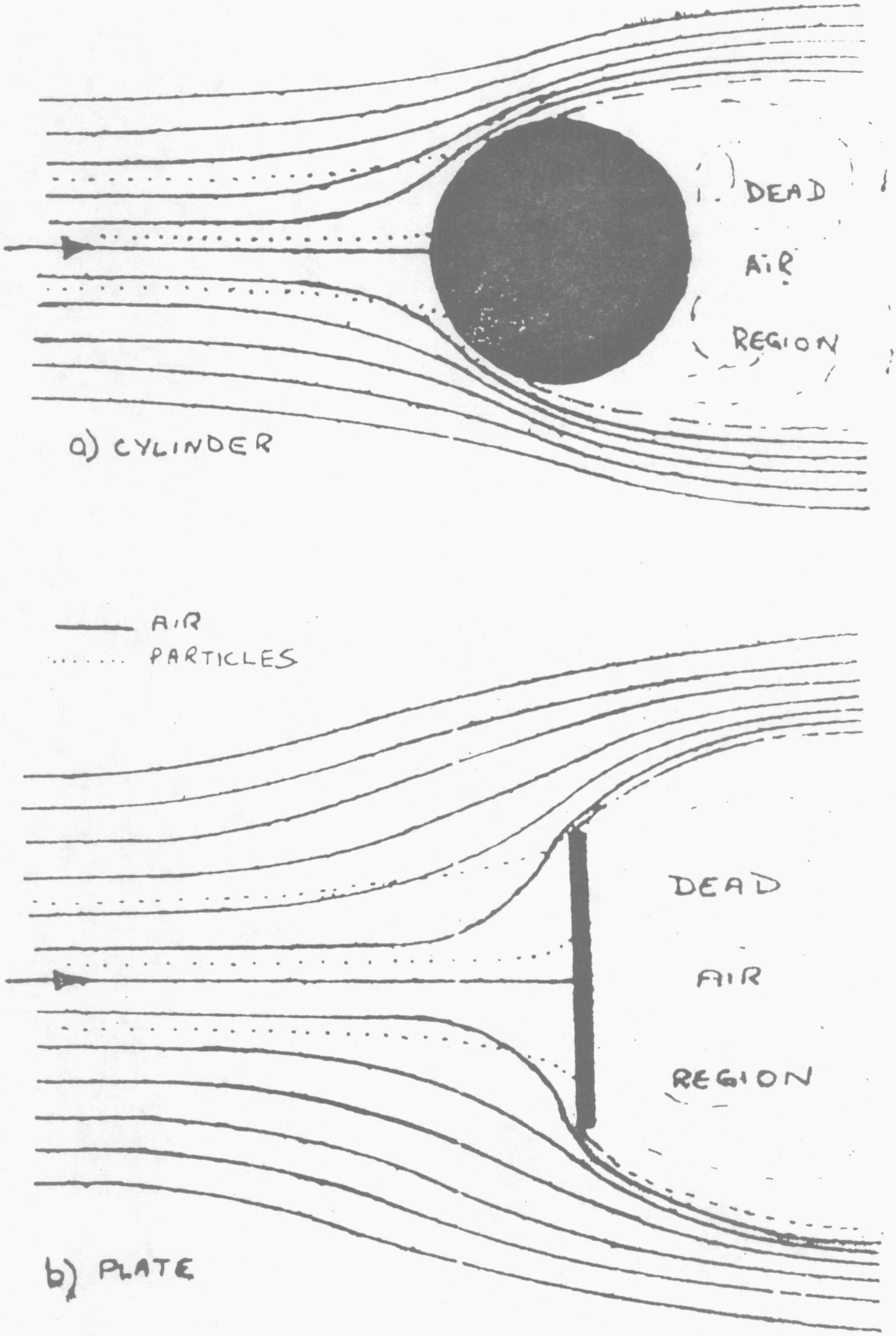
EFFECT OF SPHERE DIAMETER ON TERMINAL VELOCITY OF WATER DROPLETS

FIGURE 1



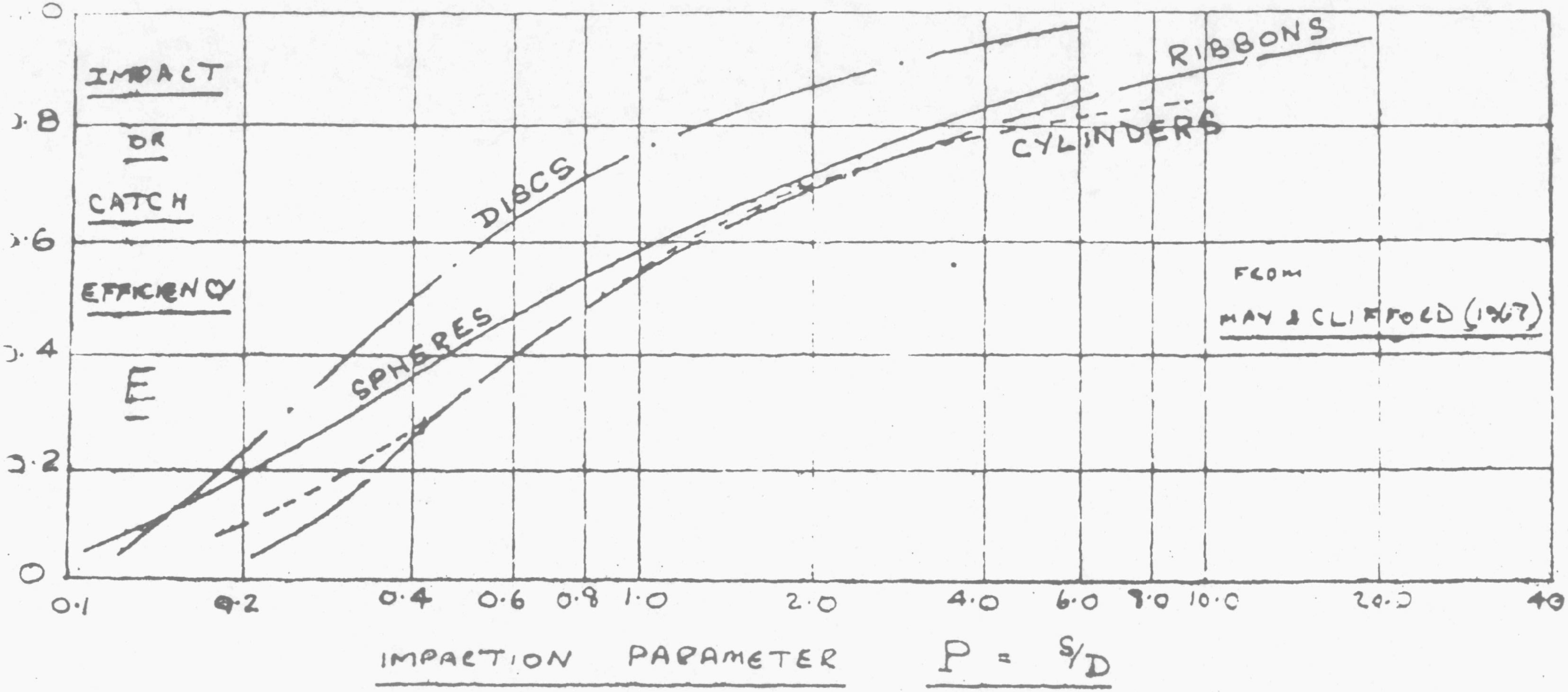
CHARGED DROPLET PATHS IN AN ELECTRO-MAGNETIC FIELD
(WIND AND GRAVITATIONAL EFFECTS IGNORED)

FIGURE 2



FLOW PATHS ABOUT A CYLINDER AND A PLATE.

FIGURE 3



VARIATION IN THE CATCH EFFICIENCY OF WATER DROPLETS WITH IMPACTION PARAMETER FOR DISCS, SPHERES, CYLINDERS AND RIBBONS.

FIGURE 4.