College of Aeronautics Report 8207

December 1982

Atomisers for the Aerial Application of Herbicides

– Ideal and Available

by John Spillman

College of Aeronautics
Cranfield Institute of Technology
Cranfield, Bedford, UK

College of Aeronautics Report 8207
December 1982

Atomisers for the Aerial Application of Herbicides
– Ideal and Available

by John Spillman

College of Aeronautics
Cranfield Institute of Technology
Cranfield, Bedford, UK

ISBN 0 902937 69 3

£7.50

ATOMISERS FOR THE AERIAL APPLICATION OF HERBICIDES

- IDEAL AND AVAILABLE

John Spillman, Professor of Applied Aerodynamics
Cranfield Institute of TEchnology
Cranfield
Bedford Mk43OAL

ABSTRACT

Reduction of spray drift is essential when herbicide sprays are applied from aircraft, so sprays with a narrow spectrum and a volume median diameter of about 225µm. are required. Analysis of the performance of currently available atomisers suggest that one of the best is a flat fan hydraulic nozzle (8005) set at 45° downwards and backwards relative to the flight direction. This atomises about 33% of the volume emitted within 25% of this desired size. A new 50mm. diameter windmill disc atomiser produced 70% of the volume emitted in this size range with less than 5% in droplets smaller than 150µm. This is achieved by having far greater control over the actual atomising condition ensuring ligament formation even at flow rates approaching one litre per minute. A strong radial airflow at the atomising edges is found to be extremely beneficial.

INTRODUCTION

Aerial application of herbicides has been very restricted because of the fear of downwind drift of droplets onto susceptible crops. Ideally small droplets are needed to achieve good coverage of foliage but in current practice much larger droplets than those required for biological and economical efficiency are used to ensure that the spray falls rapidly into the target area. However, large numbers of small droplets are often generated at the same time. The fall velocity of small droplets is so low that their movement is almost that of the pocket of air which surrounds them. The wind blowing over the ground creates fluctuations in the airspeed which are called gusts, eddies or turbulence depending on their scale and these fluctuations increase in magnitude with increase in the windspeed and the roughness of the ground cover. Thus in a high wind over forests the level of turbulence is very large whilst in light winds over flat, open grassland or arable land the turbulence is low.

Although these fluctuations occur in a random order, so that at any instant the pocket of air carrying the droplet may move in any direction, the overall effect is to cause a cloud of small droplets to spread out in all directions as well as to gradually fall. Those drops which reach the ground are likely to be caught by the crop or ground unless they are minute, whilst those which have moved up are likely to be moved downwards again a moment later. The net result is that in highly turbulent conditions most small droplets are brought to ground level and captured more rapidly than they would have been in still air, in spite of the random up and down motions en route. Consequently they reach the ground nearer their release point than if there had been no turbulence and they had fallen under their own weight in a steady wind of the same speed. This is the reason why most cases of serious damage due to the drift of a herbicide off-target are in cases of low wind and therefore of low turbulence - often under temperature inversion conditions when the vertical turbulence is particularly low. One should not spray herbicides under these conditions! Figure 1. taken from Spillman (1980), illustrates this clearly. In a light wind the small droplets remain in a concentrated cloud because of the low turbulence and are blown a long distance before reaching the ground, particularly if the temperature variation with height makes the air carrying them more buoyant.

In a high wind, in spite of the high turbulence, the smaller droplets may be carried off the target area in such numbers as to be unacceptable. To minimise this effect the aircraft must fly quite close to the ground to reduce the droplet fall time. However, it should not fly so close to the ground that the local velocities caused by the aircraft itself become dominant. This suggests that the aircraft should not fly lower than about one-fifth of its span, typically two metres above the ground. Care should be taken to avoid spraying droplets into the tip vortices of the wings since if they are caught in this swirling flow they can be thrown several metres above the aircraft and as a consequence can be blown off target. It has been found by Parkin and Spillman, (1980) that if wing-tip sails are fitted to the aircraft this effect is very significantly reduced.

Figure 2 shows the most probable distribution over the ground of the various constituent sizes of droplets of a spray emitted by an aircraft flying at a height of two metres in a crosswind of eight metres per second (15 knots) over an open field with no crop or one newly emerged. The calculations have used the predictions of Bache and Sayers (1975) as described by Lawson (1978) and allow for both sedimentation and wind turbulence effects. The effect of turbulence can be seen from the fact that without it the 250µm. droplets would be blown 16.8m. downwind, whilst the 50µm. droplets would all be blown 222m. downwind. Clearly the turbulence is bringing the smaller droplets down faster on average although a few will be blown much further than 222 metres.

2 OPTIMUM SIZES FOR HERBICIDE DROPLETS

Whilst it is unlikely that a pilot would apply a herbicide in a crosswind of eight metres per second it has been used as a limiting condition to try to estimate what is the minimum acceptable size of droplet to be used. Figure 3 shows how droplet size affects the most probable downwind distances from emission point to the peak deposit and to where the deposit drops to only 10% of the peak deposit. It has been assumed for this extreme condition that not more than 10% of the deposit of the most probable droplet size produced by the atomiser should be more than 30 metres from the peak deposit. Thus from figure 3 the most probable size of droplet generated should be 225µm. in diameter. An acceptable tolerance on this optimum size is thought to be ± 25% and droplets outside this range are considered inefficient. Since figure 3 shows that droplets less than 150µm. in diameter will be carried in significant numbers further downwind than 30 metres, it is desirable that less than five per cent of the total volume emitted should be less than 150µm. in diameter. In wind speeds less than eight metres per second the droplets will not be blown so far downwind, particularly the large droplets. However for the same ratio of mean turbulence velocity to wind velocity the smallest droplets will travel almost as far and therefore it is important to limit the minimum size of droplets if the limit in downwind distance suggested is to be adopted.

3. Performance of Existing Atomisers

Windtunnel tests, reported by Parkin Wyatt and Wanner (1980) have measured the droplet size spectra of various atomisers spraying water at simulated aircraft flying speeds. Their results are presented in figures 4,5 and 6, in a way aimed at indicating the relative efficiency of the atomisers in producing droplets of the desired size. For a selected size, called the specified droplet diameter, the percentage of the total volume emitted in droplets sizes within ±25% of that size has been plotted. The results show that the maximum percentage is only about 40% and this can be obtained over a wide range of sizes greater than about 200µm. by varying the type and orientation of the atomisers.

Figure 4 shows that a greater percentage is achieved at the higher flight speeds, presumably because the very big droplets shatter in the airflow. Figure 5 shows the importance of selecting the right orientation of the nozzle to the airflow direction whilst figure 6 shows the importance of blade setting and hence rotational speed on the characteristics of rotating cage devices. The Rotanet is a new form of rotating cage atomiser using a metal foam dispenser which was first reported by Parkin (1980).

The results shown in these figures are for water and are only a selection from the large number of atomisers which are available. However, they are representative and show that all currently available atomisers emit wide spectra of droplet sizes and consequently are likely to be far from ideal when spraying a herbicide formulation. The most effective appears to be the flat fan hydraulic nozzle 8005 set at 117^{o} to 135^{o} to the oncoming airflow, that is downwards and backwards. The best angle depends upon the acceptable number of droplets below 100μm. Whilst 117^{o} will give a maximum percentage of the spray within ±25% of 225μm. of about 45%, the number of small droplets would be rather large and a setting of 135^{o} may be more acceptable even though only 39% of the spray is in the required size band. The rotating cage atomisers appear to be inferior to the hydraulic nozzles at the flow rate chosen.

4. THE WINDMILL-DISC ATOMISER

Byass J.B. and Frost A.R. (1977), Bals E.J. (1978) and Frost A.R. and Green R. (1978) have tested various spinning discs in still air and have found that they give a narrow spectrum of sizes with few droplets below 150μm. in diameter as shown in Figure 7. However, their flow rates are generally too low for practical use on aircraft where a flow rate of at least 0.5ℓ/min. and preferably over 1.0ℓ/min. is needed at flight speeds of 40 to 60m/sec. These results show that in order to achieve a narrow spectrum of droplet sizes the fluid must be accelerated to form a very thin sheet at the emitting edge and the break up of that sheet into ligaments and then droplets must be carefully controlled. If the flow rate is increased to give a sheet mode of atomisation there is an unacceptable increase in the size range of droplets. In the search for a better atomiser for aircraft it has been found that by providing a radially outward airflow at the peripheral edge of a disc the maximum flow rate for which ligament mode atomisation can be maintained is increased dramatically.

A new disc windmill atomiser is currently being developed at Cranfield. The disc has its periphery divided evenly into 8 or more sections by radial cuts. The tip region of each section is twisted to turn the disc into a windmill. Fluid is fed from the hollow shaft onto the disc via specially shaped front and rear bodies. When this disc windmill is placed in an airflow it rotates rapidly. The 50mm.dia. disc windmill tested to date spins freely at over 14,000r.p.m. with zero flow rate in an airstream of 47 knots (24m/sec.). Its performance when fluid is flowing is shown in figure 9. It can be seen that even at this early stage of development the device is producing very high percentages of the total volume emitted in specific size classes, the size determined by the windspeed, blade setting angle, and flow rate. The lower peak value for the smaller flow rate is a direct result of the fact that the range of sizes included decreases with decrease in specified drop size because the acceptable band is taken as ±25% of that size. The performance with a flow rate of 400 mℓ/min. of water gives a value of 75% of total volume in the prescribed class of 225µm. and a peak value of almost 80%, with less than five per cent of the volume in sizes less than 150µm. in diameter. At a higher windspeed the same disc at the same flow rate would give a peak at a smaller specified size, or at the same specified size with a larger flow rate. It is hoped that when the present series of tests are completed it will be possible to design and produce very cheaply disc windmill atomisers which will replace hydraulic nozzles on standard spray booms.

Whilst the percentage of the total volume emitted in a given size range is a useful indication of the effectiveness of an atomiser it is not really a measure of its efficiency since droplets too large to be included are still likely to fall in the target area and contribute to the biological objective. If one assumes that all droplets greater than three quarters of the most desired size, which in this case is taken as 169µm. (0.75 x 225µm.) make an equal contribution to the biological effectiveness of the application, then the ratio of the number of droplets above 169µm. produced per litre of spray to the number which would be produced if all the spray were in 225µm. diameter droplets is a measure of the efficiency of the atomiser for herbicides. Table 1 shows the results for some of the atomisers discussed earlier. It should be noted that by taking 169µm. as the lowest acceptable size, a theoretical maximum efficiency of $\left(\frac{225}{169}\right)^3$ or 232% is possible, corresponding to all the liquid being atomised into droplets of 169µm. in diameter.

The absolute values of these efficiencies are not particularly valuable but their relative values are. They suggest that, of the currently available atomisers discussed in this note, the best one is the 8005 flat fan nozzle at 1.8 min. flow rate (2.5 bar or 37 p.s.i.) orientated at 135° i.e. downwards and backwards to the airflow. Whilst the 90° orientation gives a slightly higher efficiency the number of droplets smaller than 150µm. is too large to justify its use. D6/45 nozzles orientated backwards, operating at the same flow rate (2.2. bar or 32 p.s.i.) gives a slightly poorer result. **Table I shows the marked superiority of the disc windmill atomiser.**

5 CONCLUSION

These results suggest that by using 8005 fan jets at 135° orientation the total application rate per hectare of the formulation could be reduced to 70% of that for 8005 fan jets at 180° orientation and to 45% of that required by a D6/45 raindrop nozzle at the same flow rate. The new disc windmill atomisers promise even lower application rates, almost halving those of the 135° flat fan. Such reductions reduce directly the cost of the chemicals and indirectly the cost of the aircraft operation. These benefits, large as they are, may well be dwarfed in the long term by those associated with the lower ecological damage which must result, not only from the lower dosage rates but also from fewer small droplets.

TABLE I.

ATOMISER	FLOW RATE ml/min	AIRSPEED knots	EFFICIENCY %
D6/45 RAINDROP 180^{o} orientation	1800	90	19.7%
8005 FLAT FAN 180^{o} orientation	1800	90	31.2%
D6/45 180^{o} orientation	1800	90	39.1%
8005 FLAT FAN 135^{o} orientation	1800	90	44.5%
8005 FLAT FAN 90^{o} orientation	1800	90	46.0%
DISC WINDMILL PROTOTYPE AD/0870/17	400	47	81.3%

6. REFERENCES.

Bache D.H. and Sayer W.J.D. (1975) 'Transport of Aerial Spray'. I. A Model of Aerial Dispersion. Agricultural Meterology. 15 pp.257-271

Bals E.J. (1978) 'Reduction of Active Ingredient Dosage by Selecting Appropriate Droplet Size for the Target.' British Crop Protection Council Monograph 22 11 101-106.

Byass J.B. and Frost A.R.(1977) 'The Physics of Droplet Production.' 'Aerial Application of Pesticides' Short Course. Cranfield Institute of Technology, September, 1977.

Frost A.R. and Green R. (1978) 'Drop Size Spectra and Spray Distribution from a Micron Battleship Disc.' Proceedings of the 1978 British Crop Protection Conference - Weeds.

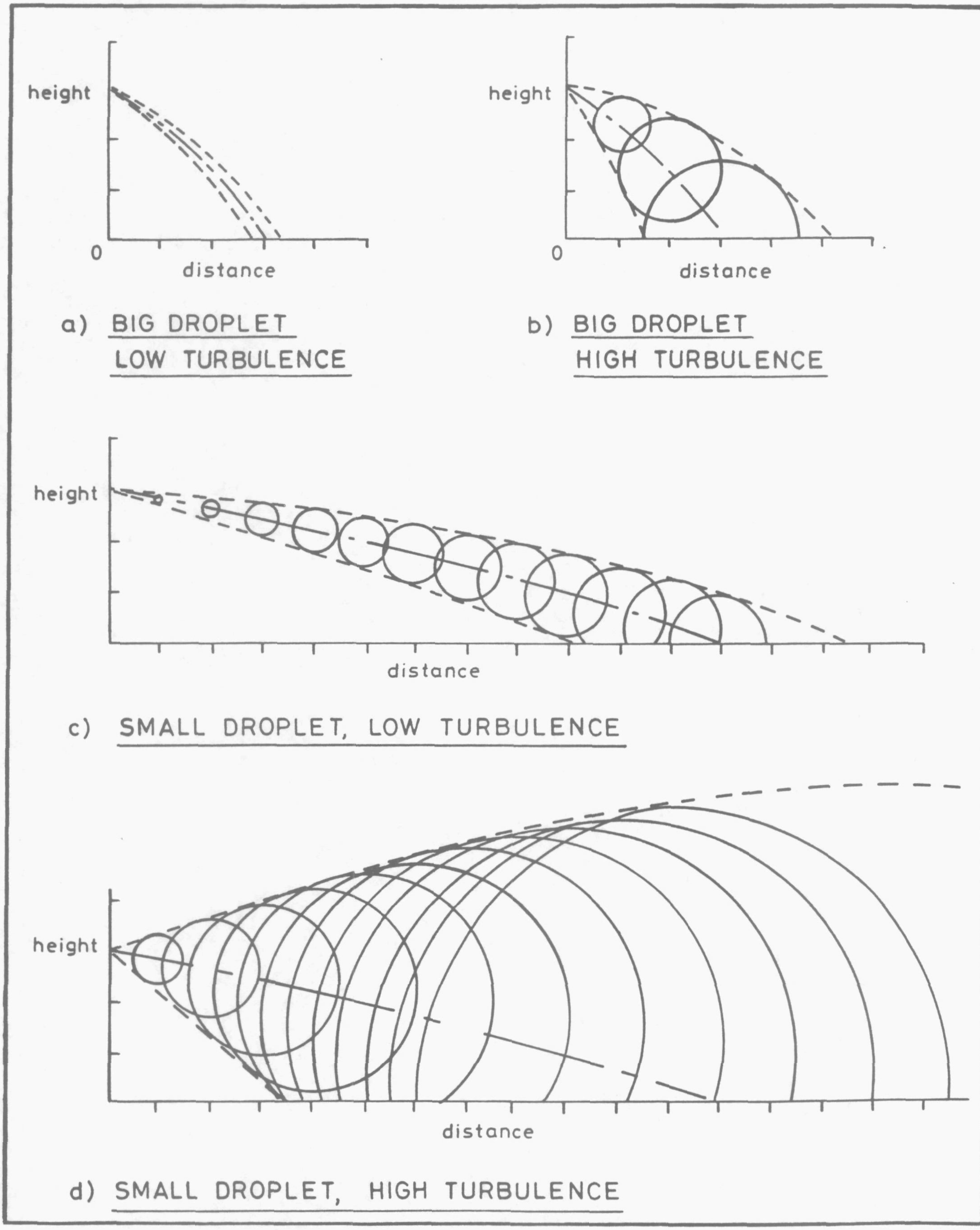
Lawson T (1978) 'Particle Transmission and Distribution in Relation to the Crop.' Notes of the Cranfield Short Course 'Aerial Application of Pesticides.'

Parkin C.S. (1980) 'A high Performance Rotating Atomiser.' Proceedings of the Vlth International Agricultural Aviation Congress,Turin, September 19 1980 (In print).

Parkin C.S. and Spillman J (1980) 'The Use of Wing-Tip Sails on a Spraying Aircraft to Reduce the Amount of Material Carried Off-Target by a Crosswind.' Journal of Agricultural Engineering Resources (1980) 25pp 65 - 74

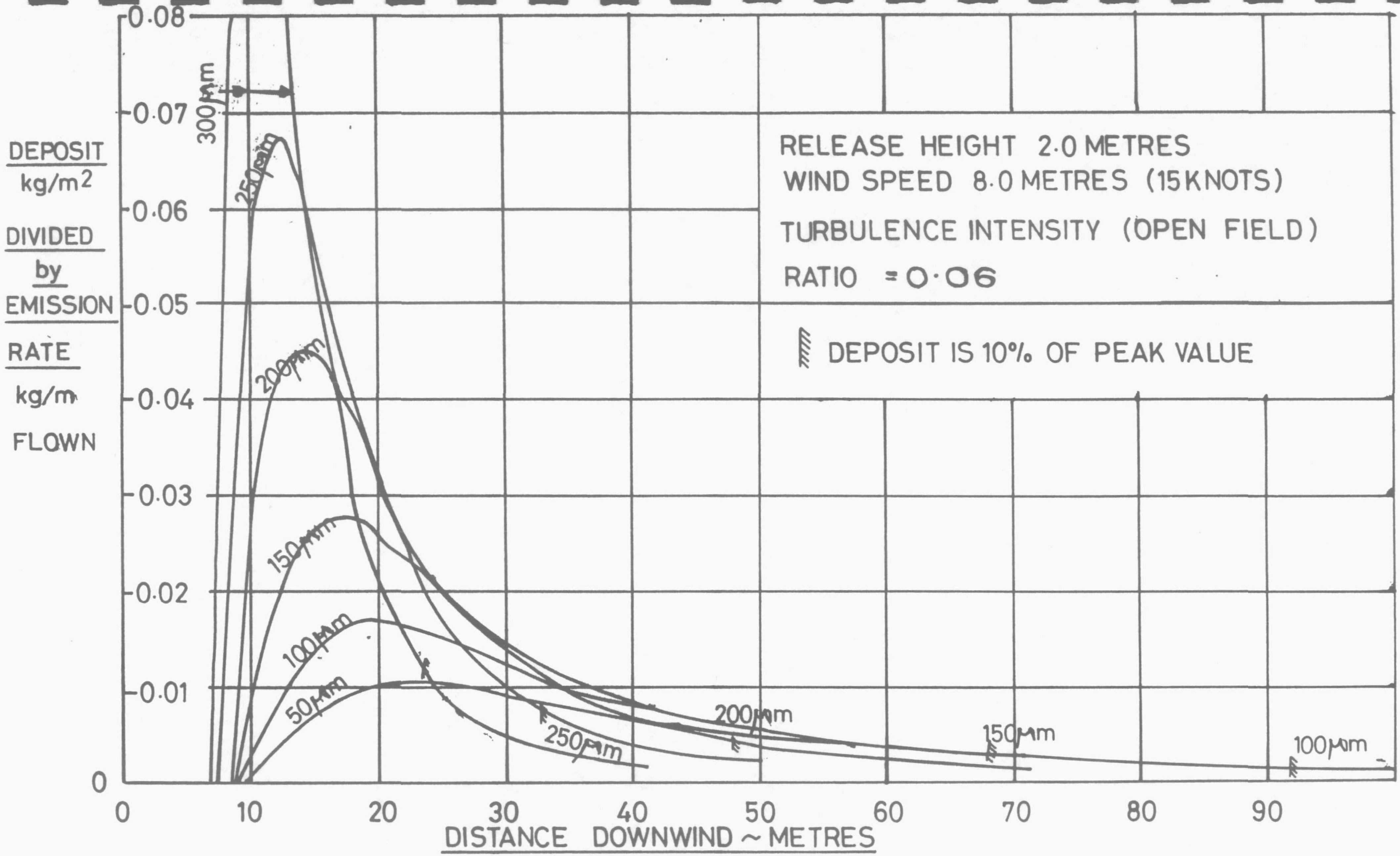
Parkin C.S., Wyatt J. and Wanner R (1980) 'The Measurement of Drop Spectra in Agricultural Sprays Using a Particle measuring Systems Optical Array Spectrometer.' British Crop Protection Council 'Symposium on Spraying Systems for the 1980's.' Egham. March 1980 and further private communication.

Spillman J, (1980) 'The Efficiency of Aerial Spraying.' The Aeronautical Journal, Royal Aeronautical Society. Vol.84 No.830.pp60-6 February, 1980.



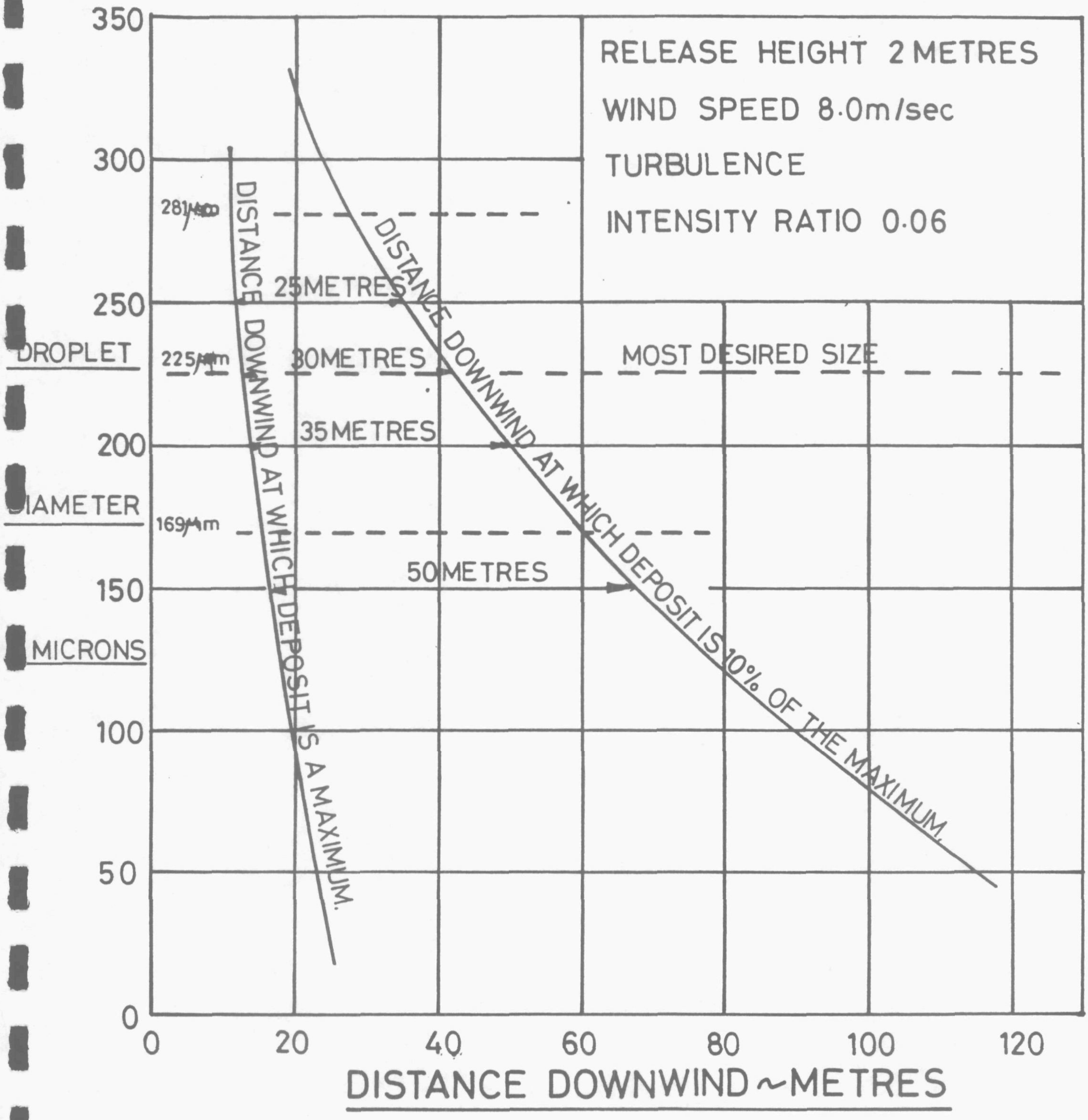
EFFECT OF DROPLET SIZE AND TURBULENCE LEVEL ON GROUND DEPOSIT

FIGURE 1



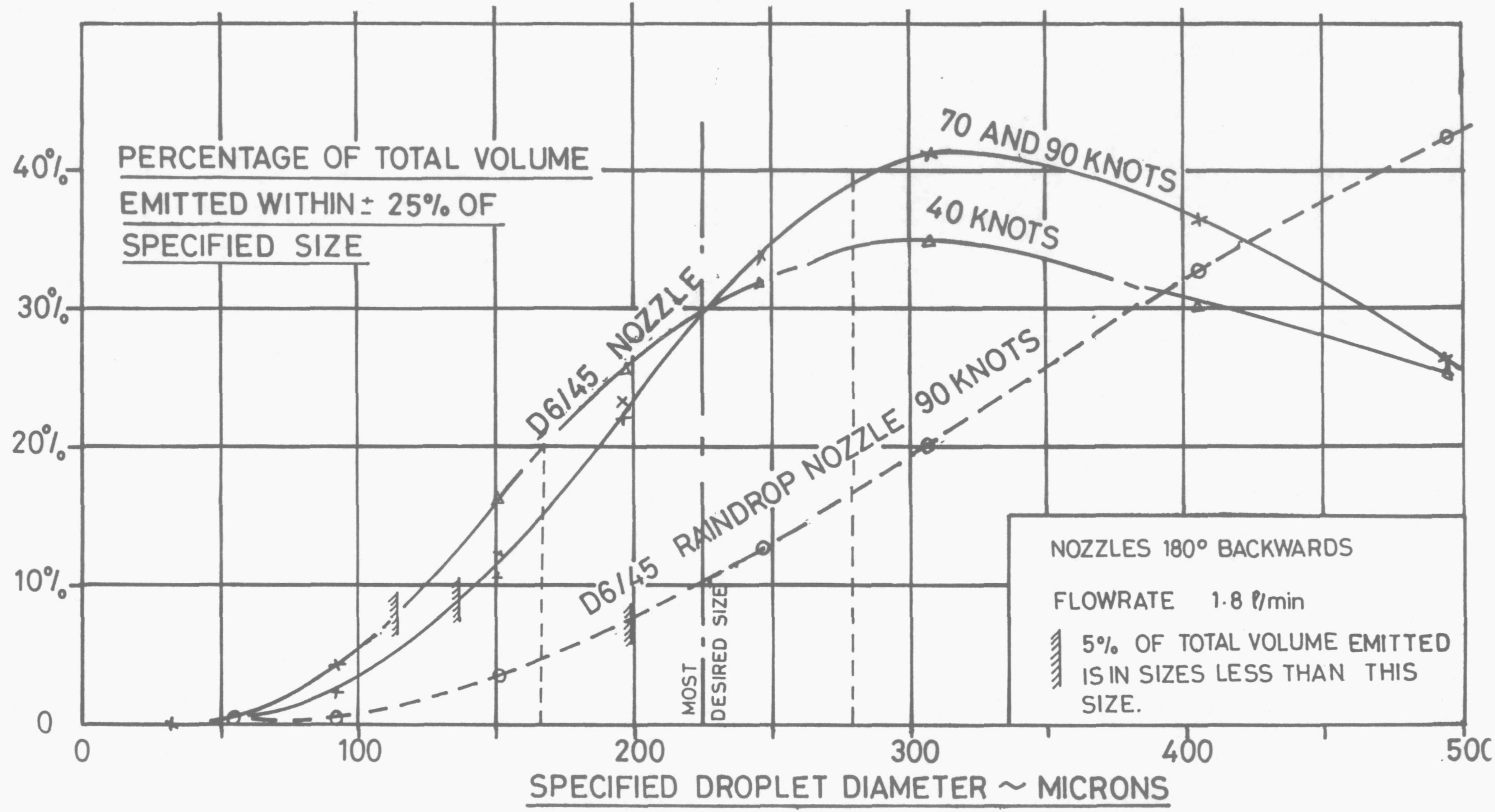
DOWNWIND DEPOSIT DISTRIBUTION

FIG. 2



DISTANCES DOWNWIND BETWEEN MAXIMUM DEPOSIT AND 10% OF MAXIMUM DEPOSIT

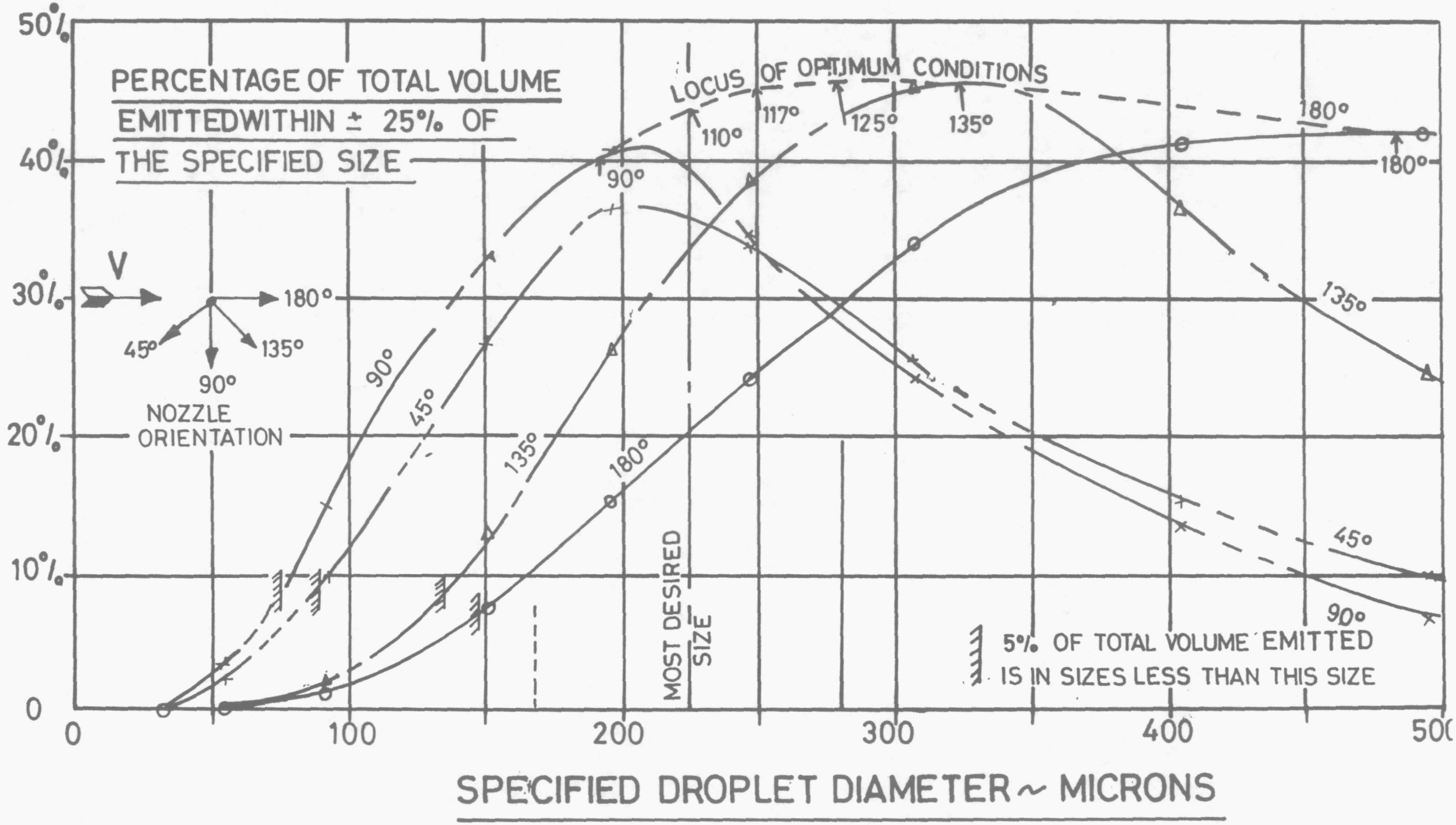
FIG.3



EFFICIENCY OF SIZE CONTROL ~ D6/45 HYDRAULIC NOZZLE

AT 1·8ℓ/min AT 40 KNOTS TO 90 KNOTS

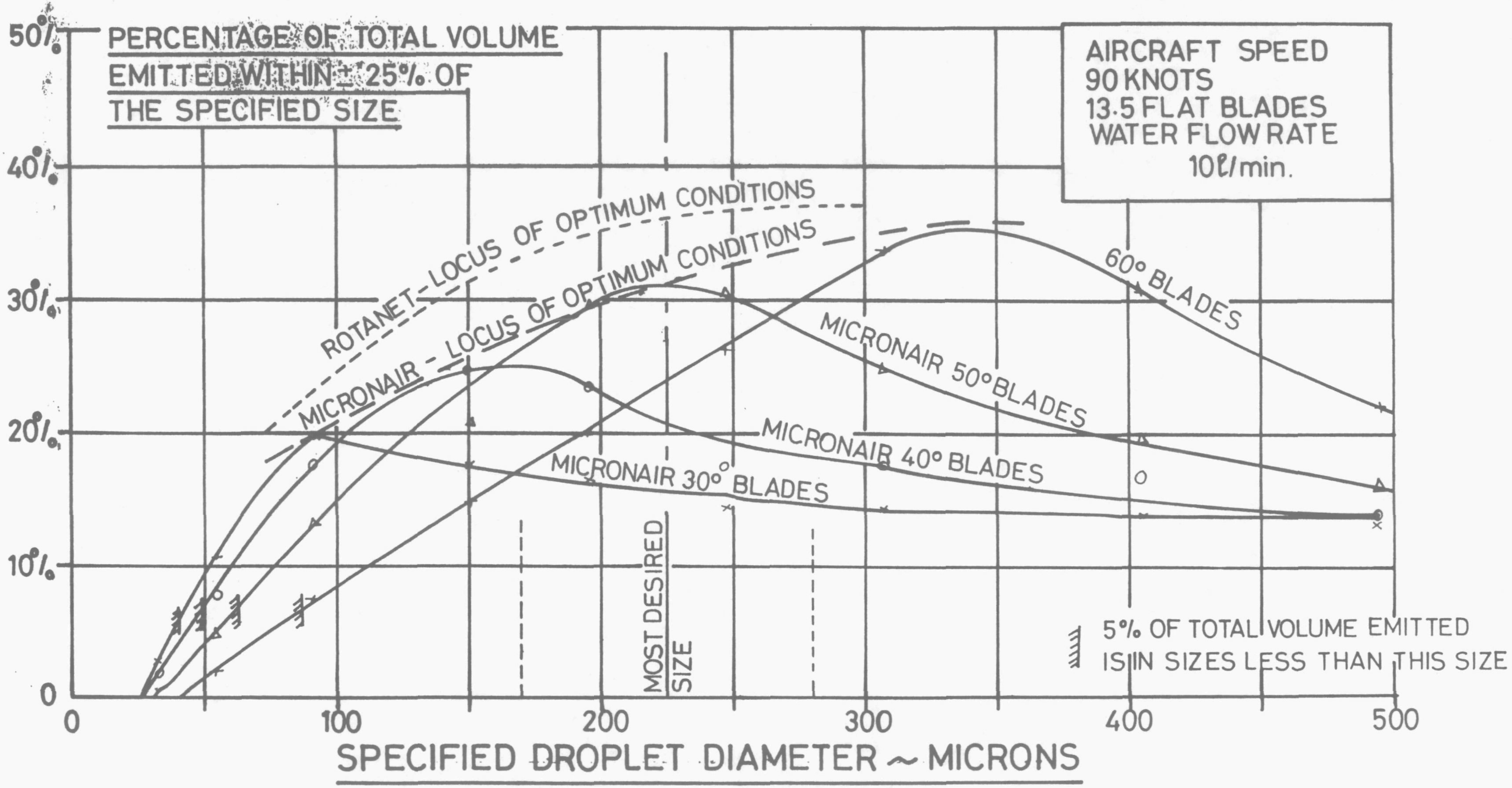
FIG. 4



EFFICIENCY OF SIZE CONTROL ~ 8005 HYDRAULIC NOZZLE

AT 1·8ℓ/min AT 90 KNOTS

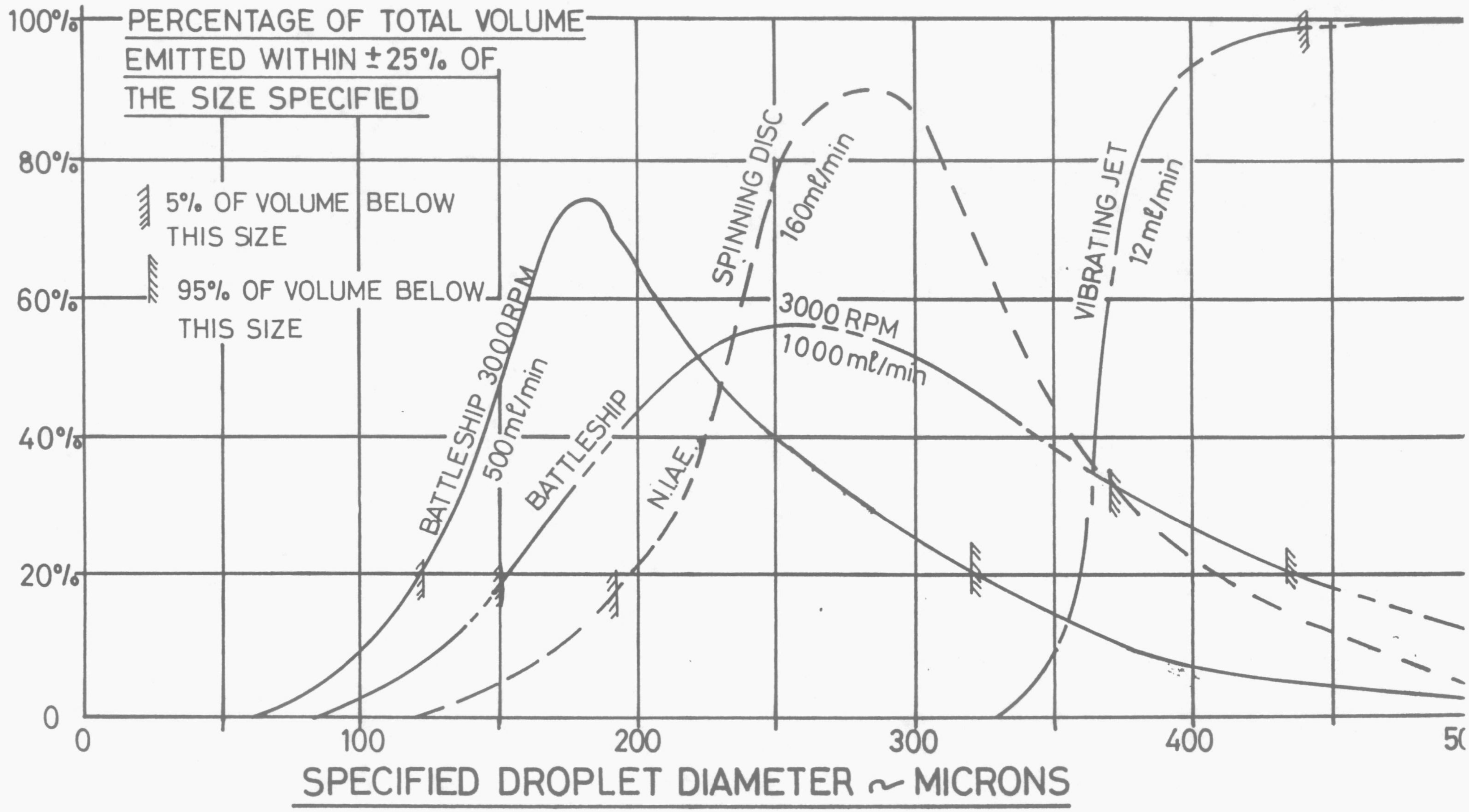
FIG.5



EFFICIENCY OF SIZE CONTROL ~ MICRONAIR AND ROTANET

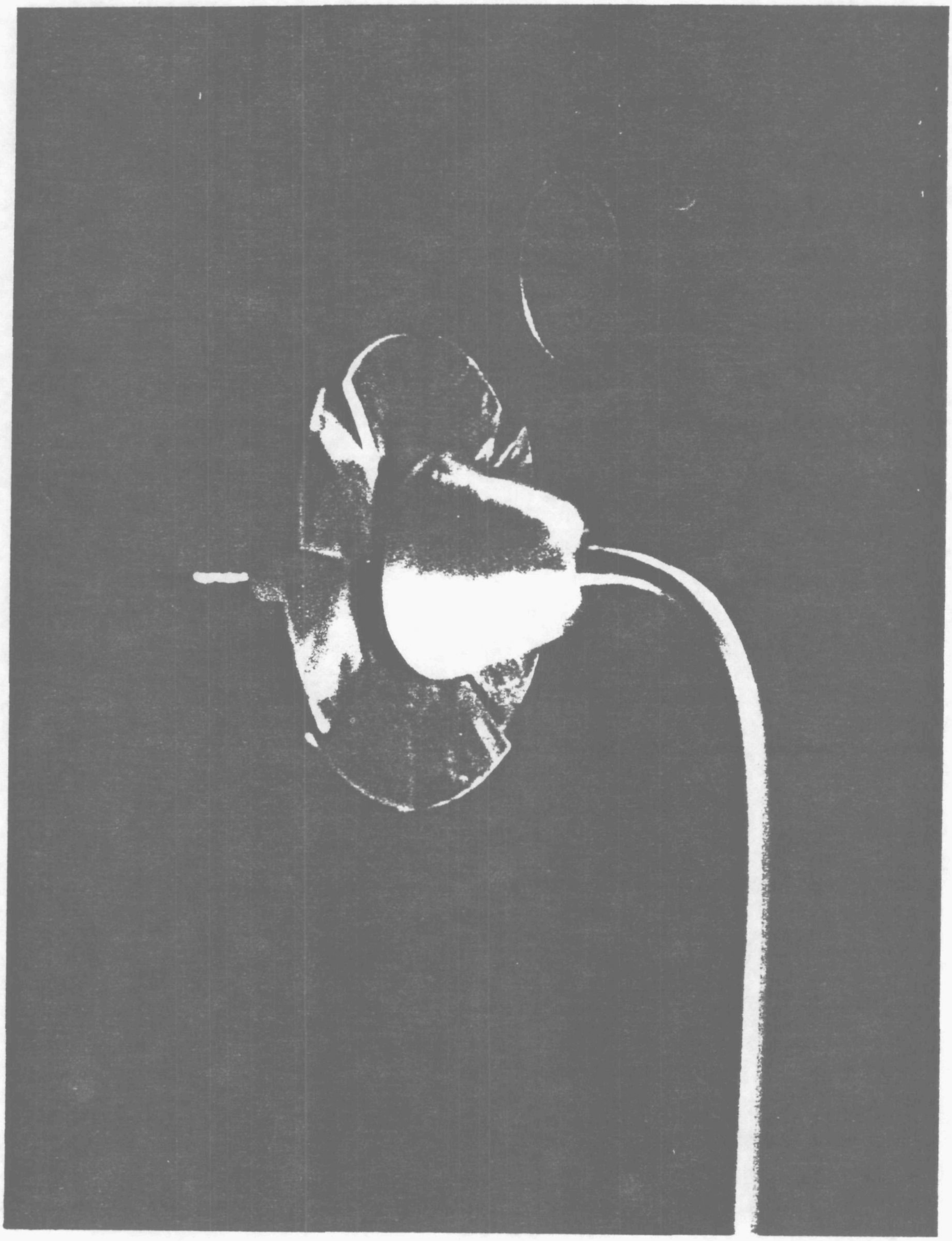
AT 10ℓ/min AT 90 KNOTS FLYING SPEED

FIG. 6



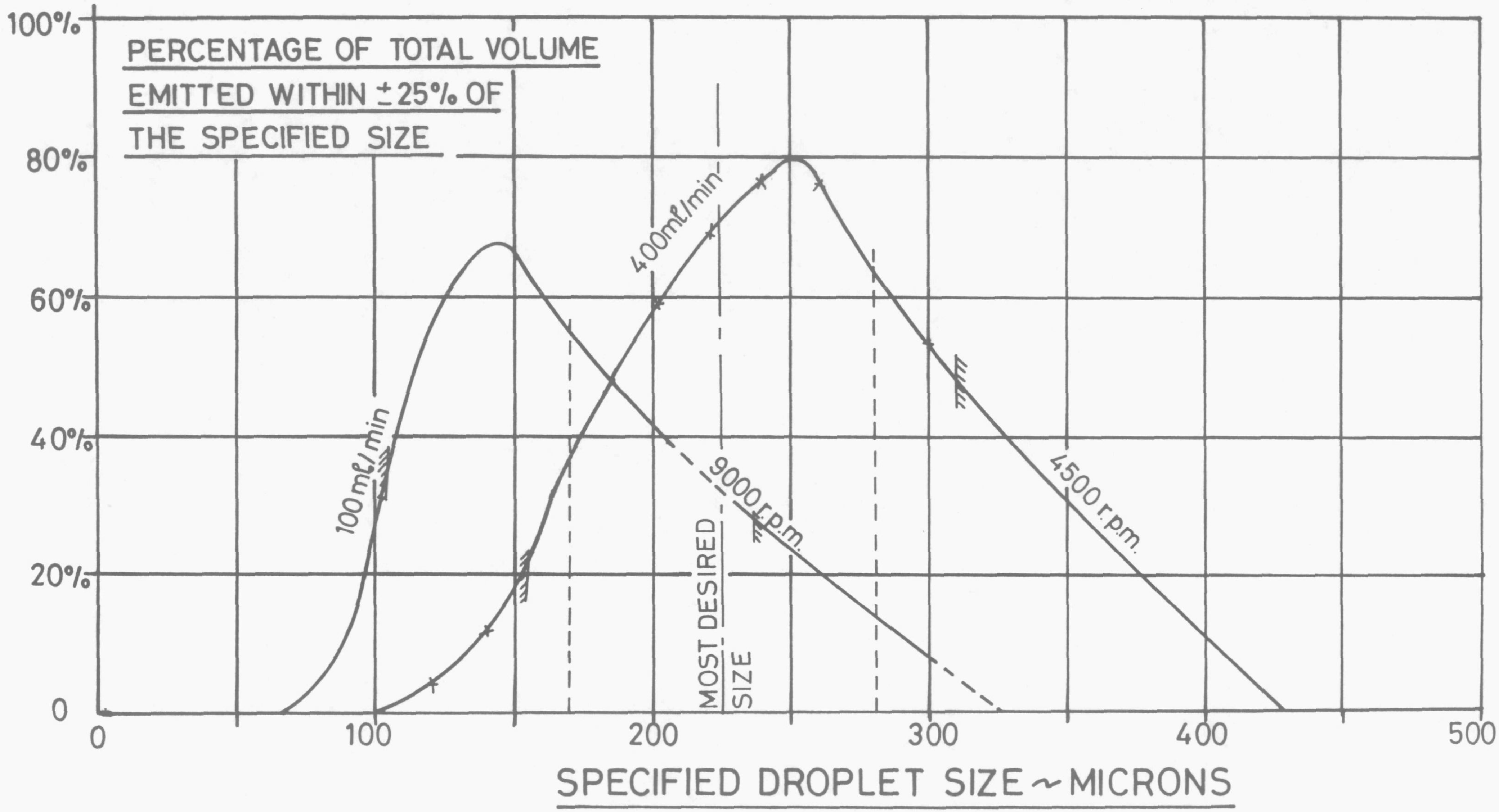
EFFICIENCY OF SIZE CONTROL ~ VARIOUS STATIONARY DEVICES

FIG·7



DISC WINDMILL ATOMISER

FIG.8



EFFICIENCY OF SIZE CONTROL ~ DISC WINDMILL

AT 47 KNOTS

FIG. 9