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TRANSPORT AND DIFFUSION SOLUTIONS FOR OBSCURATION USING THE XM--ETC(U)

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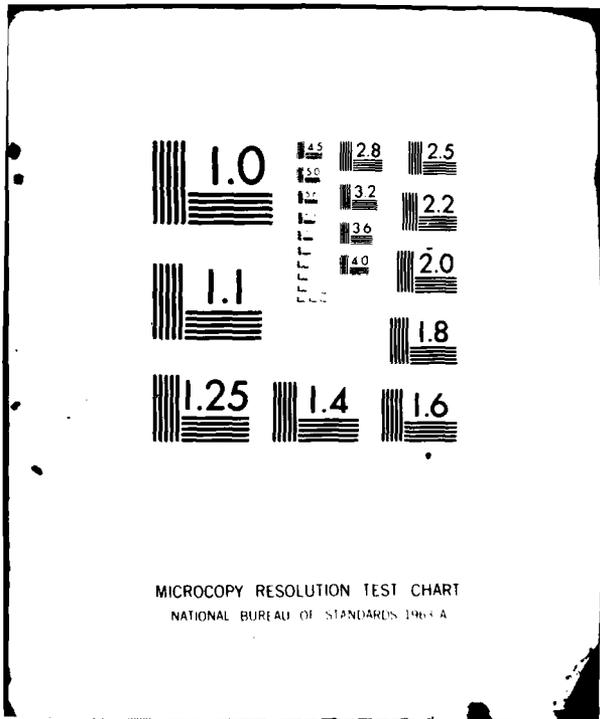
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**TRANSPORT AND DIFFUSION SOLUTIONS FOR OBSCURATION  
USING THE XM-825 SMOKE MUNITION**

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NOVEMBER 1981

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By

Stephen L. Cohn

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US Army Electronics Research and Development Command

**Atmospheric Sciences Laboratory**

White Sands Missile Range, NM 88002

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Thermal diffusion	Smoke area source									
Turbulent diffusion	Smoke screen									
Smoke	Munition expenditure									
20. ABSTRACT (Continue on reverse side if necessary and identify by block number)										
<p>The practical problem of downwind transport and diffusion of smoke from an array of sources with an arbitrary distribution of positions and emission strengths may be dealt with by integrating the distributions from the individual point sources. Identifying the effects of a number of continuous emissions may be carried out algebraically by superimposing the alongwind concentrations from successive sources to determine the cumulative contributions at some finite distance downwind. The transport and diffusion area</p>										

20. ABSTRACT (cont)

source characteristics of the candidate smoke projectile XM-825 have been studied, and the resultant attributes of the multipoint-source, chemically generated smoke have been modeled. Three schemes are considered and compared to experimental data with respect to the integrated line of sight concentrations and crosswind integrated concentrations downwind of the resultant area source.

## CONTENTS

LIST OF TABLES.....	4
LIST OF FIGURES.....	4
INTRODUCTION.....	5
THEORETICAL CONSIDERATIONS.....	5
The XM-825 Candidate Smoke Munition.....	5
The Pseudopoint Solution.....	6
The Infinite Line Source.....	7
Algebraic Integration Method.....	7
MODEL RESULTS AND EVALUATIONS.....	9
CONCLUSIONS.....	10
TABLE.....	12
FIGURES.....	13
REFERENCES.....	18

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LIST OF TABLES

1. Summary of Test Conditions..... 12

LIST OF FIGURES

1. Circular representation of XM-825 area source and source strength strips..... 13

2. Test grid for XM-825 FWWP smoke munition..... 14

3. CWIC for XM-825 FWWP smoke munition, Test G1-A2..... 15

4. CWIC for XM-825 FWWP smoke munition, Test G2-A1..... 16

5. CWIC for XM-825 FWWP smoke munition, Test G4-A1..... 17

## INTRODUCTION

Military requirements for more efficient smoke munitions have led to the development of the XM-825 felt wedge white phosphorus (FWWP) 155-mm projectile. The basic goals of the XM-825 were to provide a smoke munition that nearly eliminated the exothermic and the quasi-instantaneous source characteristics associated with bulk-filled white phosphorus (WP). The XM-825 projectile accomplishes this by using 92 phosphorous-impregnated felt wedges\* that provide an area smoke source of a continuous nature with little or no exothermic effect when dispersed.

The continuous area source has introduced some complexities to the diffusion modeling associated with this candidate munition. However, several area source approaches to the downwind dispersion of windborne material are available. Notable among these hypotheses are a pseudopoint model advocated by Turner,<sup>1</sup> an infinite line solution also suggested by Turner, and the algebraic integration method suggested by Pasquill.<sup>2</sup>

The three approaches to area source diffusion were investigated within the framework of the KWIK smoke algorithm.<sup>3</sup> Results obtained during evaluation of the three methods using data from Dugway Proving Ground<sup>4</sup> were encouraging.

## THEORETICAL CONSIDERATIONS

### The XM-825 Candidate Smoke Munition

The XM-825 is a 155-mm projectile designed to disperse 92 phosphorous-saturated felt wedges\* which will produce a screening smoke for 5 to 10 min. The total warhead payload is 7.48 kg, consisting of 1.13 kg of felt wedges and 6.35 kg ( $\pm 0.10$  kg) of white phosphorus. Preliminary estimates indicate that this configuration is 82 percent efficient by weight and produces effective obscuration in the visible portion of the electromagnetic spectrum for up to 450 s.

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\*Configuration of XM-825 as of March 1980.

<sup>1</sup>Turner, D. B., Workbook of Atmospheric Dispersion Estimates, Public Health Service Publication No. 999-AP-26, Cincinnati, Ohio, Rev. 1969.

<sup>2</sup>Pasquill, F., Atmospheric Diffusion, second edition, Halsted Press Div, John Wiley and Sons, Inc., New York, 429 pp, 1974.

<sup>3</sup>Umstead, R. K., R. Pena, and F. V. Hansen, KWIK: An Algorithm for Calculating Munition Expenditures for Smoke Screening/Observation in Tactical Situations, ASL-TR-0030, 1979.

<sup>4</sup>Dugway Proving Ground, Development Test 1 of 155 mm Smoke Projectiles (XM-803 and XM-825), Defense Technical Information Center, Cameron Station, Alexandria, Virginia, 1979.

### The Pseudopoint Solution

One approach to solving area source diffusion problems is to assume that the area can be represented by a pseudopoint located at some distance  $x_0$  upwind of the center of the area. Thus, the origin of the vertical dispersion parameter  $\sigma_z$  is at the pseudopoint--in this case, the upwind edge of the XM-825 burst pattern. The vertical dispersion parameter (standard deviation) can then be written as:

$$\sigma_z = c(x_0 + x)^d \quad (1)$$

where  $x_0$  is the burst radius and  $x$  the downwind distance. The coefficients and indices  $c$  and  $d$  for equation (1) are dependent upon both surface roughness and the stability of the surface boundary layer according to Pasquill.<sup>2</sup> The obscuration power of a screening smoke is dependent upon the crosswind integrated concentration (CWIC) of the aerosol in an optical path traversing the plume. The integrated concentration through a nonbuoyant continuous plume can be shown to be given by:

$$x_{\text{cwic}} = \left(\frac{2}{\pi}\right)^{1/2} \frac{\lambda \Omega Q}{\sigma_z \bar{V}} \exp \left[ -1/2 \left(\frac{z}{\sigma_z}\right)^{3/2} \right] \quad (2)$$

where  $\lambda$  is a munition efficiency,  $\Omega$  a relative-humidity-dependent yield factor,  $Q$  the source strength in grams per second,  $\bar{V}$  the mean windspeed in meters per second, and  $z$  the height above the surface of the optical path. Equation (2) is an empirically modified version of a Gaussian plume in that a power of 3/2 is used in place of the more conventional second power. This is done to compensate for non-Gaussian effects upon vertical dispersion, based upon experimental results obtained by Pasquill,<sup>2</sup> Huang,<sup>5</sup> and Horst.<sup>6</sup>

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<sup>2</sup>Pasquill, F., Atmospheric Diffusion, second edition, Halsted Press Div, John Wiley and Sons, Inc., New York, 429 pp, 1974.

<sup>5</sup>Huang, C. H., "A Theory of Dispersion in Turbulent Shear Flow," Atmospheric Environ., 13:453, 1979.

<sup>6</sup>Horst, T. W., "Lagrangian Similarity Modeling of Vertical Diffusion From a Ground-Level Source," J Appl Meteorol., 18:733, 1979.

### The Infinite Line Source

Turner<sup>1</sup> suggests that area sources may be treated by considering the area as a line source by compressing all of the sources into an infinite line running through the axis of the burst pattern. Concentrations at a given distance downwind may then be calculated from:

$$x = \frac{2qA\Omega}{\sin \phi \sqrt{2\pi} \sigma_z \bar{V}} \exp \left[ -1/2 \left( \frac{z}{\sigma_z} \right)^{3/2} \right] \quad (3)$$

where  $\phi$  is the angle between the wind direction and the line source, and  $q = Q/L$  with  $L$  being the diameter of the burst. Equation (3) is not valid when  $\phi$  is less than  $45^\circ$ . The vertical standard deviation  $\sigma_z$  is calculated in the same fashion as in the pseudopoint model. The horizontal standard deviation  $\sigma_y$  is required to calculate CWIC and is determined from:

$$\sigma_y = ax^b \quad (4)$$

where the coefficient  $a$  and index  $b$  are functions of the Pasquill Stability Category. CWIC can then be calculated from the following:

$$x_{\text{CWIC}} = x(L + 4.3 \sigma_y) \quad (5)$$

The factor 4.3 is included to delineate the visible edge of the plume, where the concentration decreases to 10 percent of the centerline value.

A comparison was made between the infinite line source and a finite line source, which is basically the same equation with an edge effect error function. The difference in downwind concentrations at screening distances were found to be insignificant.

### Algebraic Integration Method

The pseudopoint and infinite line source models are very simplistic models based on unrealistic geometrics of the burst pattern. They are only capable of predicting an average value for CWIC. A more sophisticated approach would be to model the geometry of the burst to give a more realistic answer. The algebraic integration approach of Pasquill<sup>2</sup> attempts to model the geometry with a circular burst pattern, as shown in figure 1. The circular pattern is

<sup>1</sup>Turner, D. B., Workbook of Atmospheric Dispersion Estimates, Public Health Service Publication No. 999-AP-26, Cincinnati, Ohio, Rev. 1969.

<sup>2</sup>Pasquill, F., Atmospheric Diffusion, second edition, Halsted Press Div, John Wiley and Sons, Inc., New York, 429 pp, 1974.

divided into crosswind strips of equal downwind lengths  $\Delta x$ . The strips are of varying widths, with the submunitions of the XM-825 spread uniformly throughout the pattern. A weighting factor  $W$  is used to represent the relative importance of the separate contributions from each strip and is given by:

$$W = n^{(1-d)} - (n - 1)^{(1-d)} \quad (6)$$

where  $n$  is the number of the strip (the first strip being farthest downwind). The index  $d$  is identical with that of equation (1). A sample of the weights for six strips for a surface roughness length of 10 cm and a Pasquill Stability Category of "B" is as follows:

$n =$	1	2	3	4	5	6
weighting factor =	1.0	0.11	0.07	0.05	0.04	0.04

Eighty-five percent of the source is contained in the first two strips due to the rapid decline in the contribution of the more distant strips.

The contribution to the downwind concentration of a given strip  $n$  is:

$$x = W A q_n (1-d)^{-1} \left[ \frac{(j^{1-d})^{n\Delta x}}{(n-1)\Delta x} \right] \quad (7)$$

where  $A = \frac{\lambda\Omega}{\sin \phi \pi \sigma_z V}$ ,  $q_n$  is the source strength of strip  $n$  in grams per

meter per second and  $j$  is a dummy variable. Calculating the total CWIC at some downwind sampling distance requires that concentrations first be calculated for each separate strip and then be summed over the six strips, using the appropriate weighting factors. In addition,  $\sigma_z$  must be calculated separately for each strip, since the successive strips are farther upwind by a distance of  $\Delta x$ . CWIC is then evaluated from:

$$x_{\text{cwic}} = x(L_s + 4.3 \sigma_y) \quad (8)$$

assuming that  $L_s$  is the width of the source strips.

## MODEL RESULTS AND EVALUATIONS

The three area sources postulates were used to evaluate seven sets of experimental data extracted from data reports published by Dugway Proving Ground.<sup>4</sup> Of the seven examples, three were chosen for inclusion in this report. The remainder were eliminated because of apparent improper burning characteristics, unfavorable wind direction, or a combination of both. A summary of test conditions is listed in table 1 and the test grid is illustrated in figure 2.

The integrated concentration values of the pseudopoint, infinite line, and algebraic integration models are as follows:

Test	Pseudopoint	Infinite Line	Algebraic Integration	
			Peak	Mean
G1-A2	0.66 g m <sup>-2</sup>	1.62 g m <sup>-2</sup>	2.19 g m <sup>-2</sup>	1.40 g m <sup>-2</sup>
G2-A1	0.50 g m <sup>-2</sup>	1.24 g m <sup>-2</sup>	1.99 g m <sup>-2</sup>	1.34 g m <sup>-2</sup>
G4-A1	0.49 g m <sup>-2</sup>	1.20 g m <sup>-2</sup>	2.11 g m <sup>-2</sup>	1.38 g m <sup>-2</sup>

The pseudopoint model generates average integrated concentrations which are consistently the lowest of the three models. It underpredicts the measured values, as shown in figures 3, 4, and 5. This is not surprising, due to the simplifying assumptions in the model.

The infinite line model does better than the pseudopoint model in giving average integrated concentrations that are closer to the measured values, as shown in figures 3, 4, and 5. However, during the final 150 s of burn time the model overpredicts. For test G4-A1, the results are slightly high for the entire burn.

The algebraic integration model (which will be called the circle model due to the shape of the modeled burst) gives the best results of the three. This model generates both a peak and a geometric mean value for CWIC. The peak value is the highest CWIC that is expected for the given meteorological conditions and the distance from the optical line of sight. The threshold value of smoke which will obscure the visible wavelengths is calculated from:

$$CL = \frac{\ln T_{smk}}{-\alpha} \quad (9)$$

<sup>4</sup>Dugway Proving Ground, Development Test 1 of 155 mm Smoke Projectiles (XM-803 and XM-825), Defense Technical Information Center, Cameron Station, Alexandria, Virginia, 1979.

where CL is the concentration,  $T_{smk}$  the transmittance, and  $\alpha$  the extinction coefficient. The threshold concentration is calculated to be  $0.7 \text{ g m}^{-2}$ . This value occurs at an average burn time of 450 s. By assuming the peak value occurs at the beginning of the burn, an estimate of the emission rate curve of the XM-825 can be made. The results are labeled "circle" in figures 3, 4, and 5. The actual emission characteristics curve, as reported by Carter,<sup>7</sup> indicates that the emission rate of the XM-825 decreases with time after its initial buildup time. This is due to the peculiarities of the burn characteristics of the phosphorous-impregnated felt submunitions. (The geometric mean value is listed with the model results shown previously.)

The overestimation of CWIC by this model for the first 75 s of the burn--which is evident in figures 3, 4, and 5--is a function of the buildup time, the time required for the smoke plume to reach the measuring line, and the percentage of the cloud that actually drifts through the optical line of sight. As with the infinite line model there is a slight overestimation of CWIC in test G4-A1. Both of these overestimates could be caused by the failure of some of the submunitions to burn properly, thus giving lower concentrations than would normally be expected.

The preliminary center-to-center impact separations can be computed based on the weighted circular model. The equation to compute the separation is a variation of equation (7), which is as follows:

$$x = \left[ \frac{\sum_{n=1}^n (W_n q_n) \Omega \lambda}{\pi \bar{V} c x_{cwic}} \Delta x (1-d) \right]^d \quad (10)$$

For stability category C the impact separation is 132 m, and for category B the impact separation is 121 m.

#### CONCLUSIONS

The pseudopoint model underpredicts the average integrated concentrations in all cases investigated. Therefore, this model would overpredict the number of munitions necessary to screen and would not be an acceptable model. The infinite line model, although better than the pseudopoint model still overpredicts the final 150 s of the burn. This would cause too few munitions to be expended, risking the deterioration of the screen. The circle model appears to be the best fit to the experimental data. It gives a fairly good

<sup>7</sup>Dugway Proving Ground, Basic Smoke Characterization Test, TECOM-DPG-TP-77-311, Dugway Proving Ground, Utah, 1979.

estimate of the emission curve, as shown in figures 3, 4, and 5. The over-estimation of the concentrations in the model only occurs during the first 75 s of the burn, which is the buildup time of the smoke generated by this munition. This model has the promise of giving good expenditure estimates, and it deserves further investigation.

TABLE 1. SUMMARY OF TEST CONDITIONS

<u>Test</u>	<u>G1-A2</u>	<u>G2-A1</u>	<u>G4-A1</u>
Date - Time	8 Aug 78 - 1020	8 Aug 78 - 1228	8 Sep 78 - 1219
Wind direction (8 m)	339°	338°	330°
Windspeed (8 m)	3.8 m/s	3.8 m/s	3.8 m/s
Relative humidity (4 m)	16%	14%	11%
Temperature (8 m)	29.3°C	30.8°C	31.7°C
Visibility (km)	48	48	48
Cloud cover	0%	0%	10%
Stability category	C	B	B
Entry angle	15.9°	15.9°	15.9°
Burst altitude (m)	102	103	101
Time to obscuration (s)	9.5	11	13

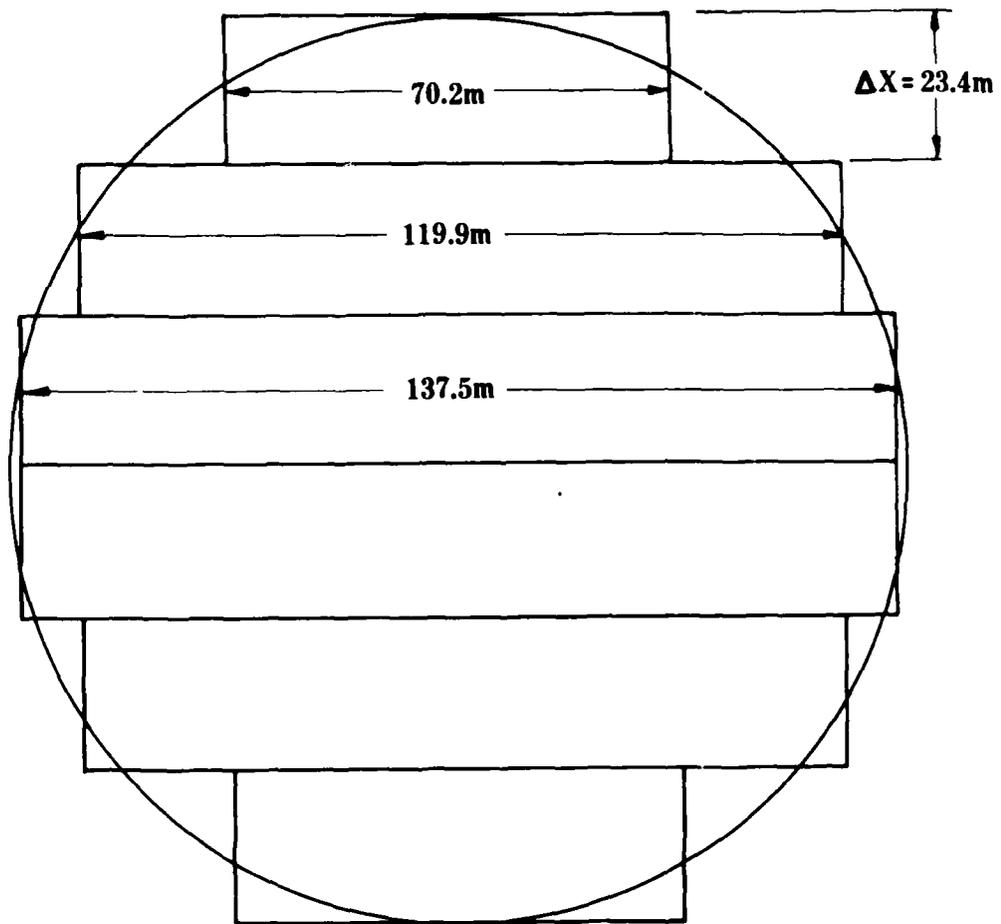
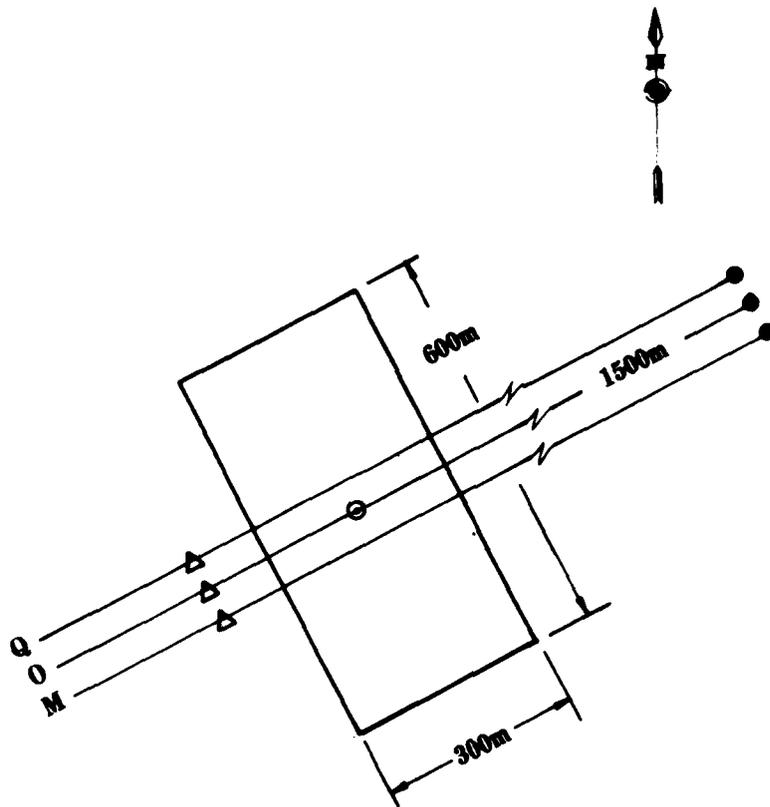


Figure 1. Circular representation of XM-825 area source and source strength strips.



- △ MID IR TRANSMITTERS
- MID IR RECEIVERS
- ⊙ GRID CENTER

Figure 2. Test grid for XM-825 FWP smoke munition.

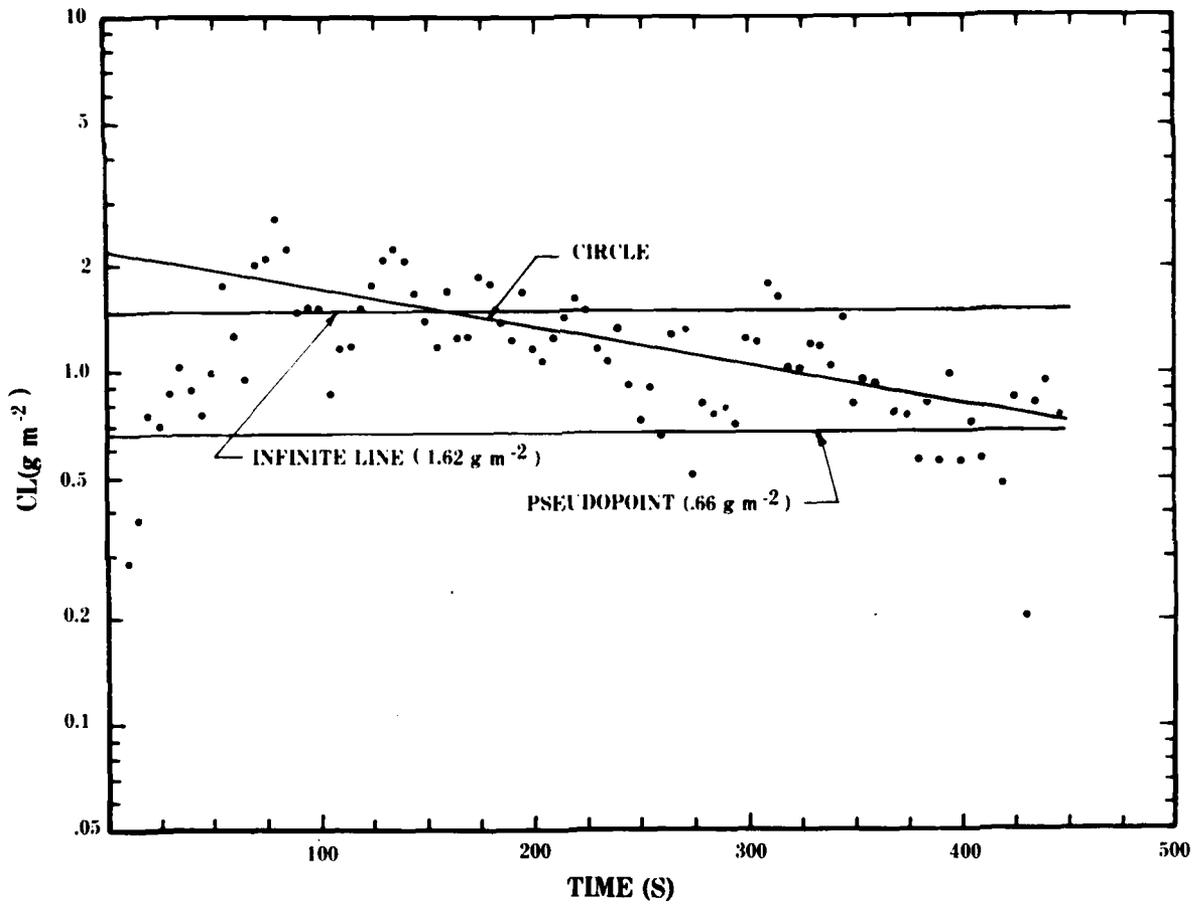


Figure 3. CWIC for XM-825 FWP smoke munition, Test G1-A2.

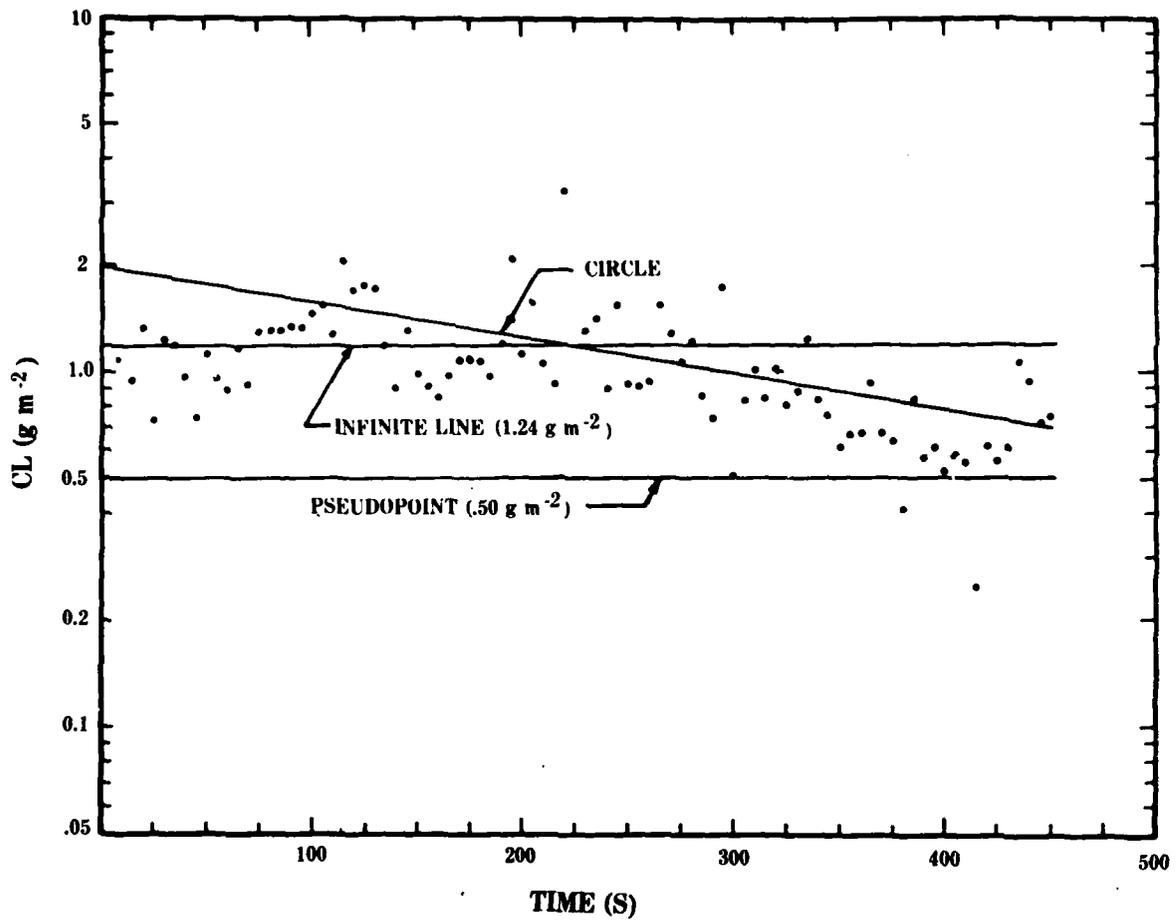


Figure 4. CWIC for XM-825 FWP smoke munition, Test G2-A1..

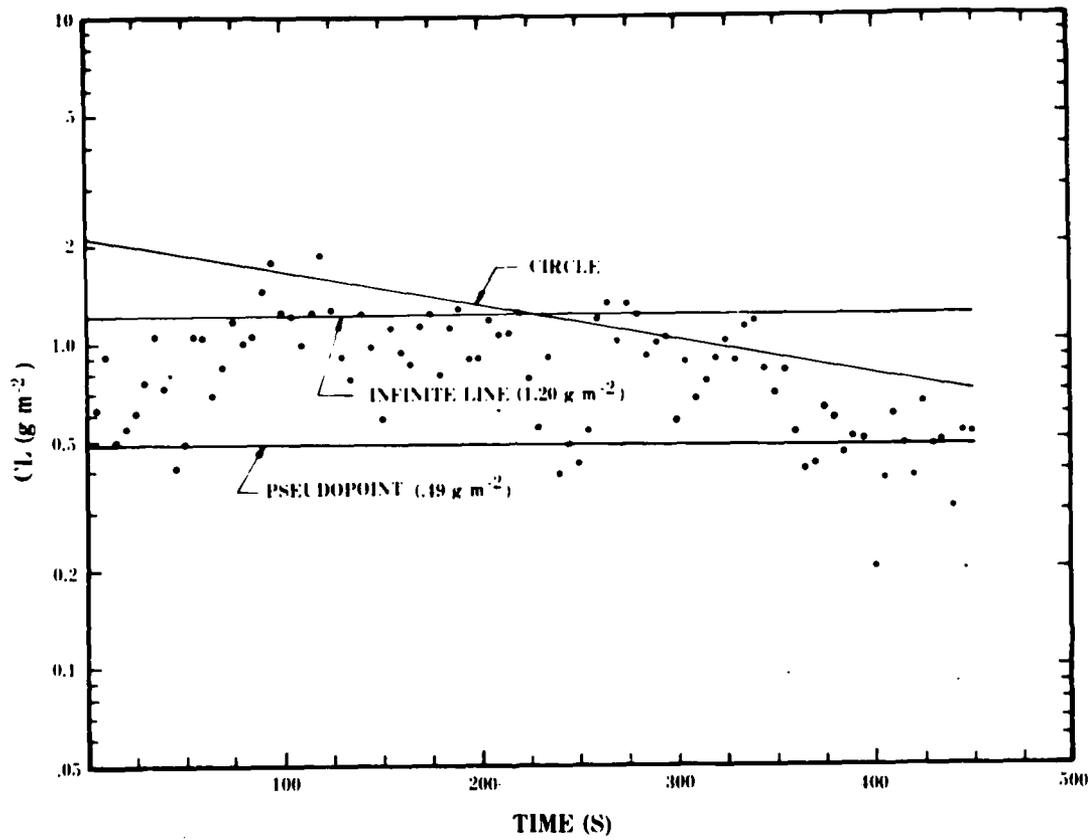


Figure 5. CWIC for XM-825 FWNP smoke munition, Test G4-A1.

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5. Huang, C. H., "A Theory of Dispersion in Turbulent Shear Flow," Atmospheric Environ, 13:453, 1979.
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