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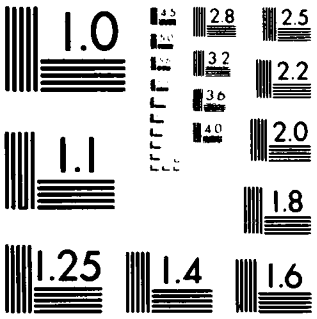
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A PARAMETRIC MODEL FOR THE EFFECT OF WHITE PHOSPHORUS SMOKE ON TARGET DETECTION I: MODEL DEVELOPMENT

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Advanced Systems Concepts Office

18 October 1979

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The development of a parametric model for target acquisition in white phosphorus smoke is described. Parameters include wind speed and direction, stability category, and munition size. The model depicts critical cloud dimensions that prohibit target acquisition. Use of the model in simulations is described.

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SUMMARY

In this report, the work begun on the effects of WP smoke on target detection is extended. A parametric model for LOS blockage by WP smoke in the visual region of the spectrum was developed from the SEMM.

A second volume of this report is planned, describing uses of the model. In particular, the use of the model for calculating artillery firing patterns and in conflict simulations will be reported.

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I. INTRODUCTION

This investigation is an extension of the work on munition White Phosphorus (WP) smoke reported in "Do Gaussian Plumes Have Sharp Edges?" [1] and "An Investigation of the Effect of White Phosphorus Smoke on Target Detection." [2] These reports were concerned with quantifying the effect of WP smoke on the acquisition of targets by various sensors.

This report documents the development of a simple, parametric model of the effect of WP smoke on target acquisition in the visual region of the spectra. This model is a derivative of the Smoke Effectiveness Manual Model [3] (SEMM) developed for the production of the Smoke Effectiveness Manual, FM 101-61-8. [4]

The SEMM, while a good model, is limited in its usefulness to operational problems by its large size and long execution time. These limitations are common to most smoke models in existence. To satisfy the need to address operational problems, a smaller, quicker model was needed. That model is described here.

This investigation is part of an on-going examination of the effect of battlefield obscuration on the performance of missile (and certain selected non-missile) weapons systems as part of the Concepts Analysis and Validation work area of the A214 Missile Technology Program. The results of this examination will be used in the formulation, analysis, and evaluation of present and conceptual missile weapon systems.

II. SMOKE EFFECTIVENESS MANUAL MODEL.

The smoke cloud concentration model used in this investigation was from the SEMM. [3] This model was developed to perform the calculations for the Joint Technical Coordinating Group/Munition Effective (JTCG/ME) Smoke Effectiveness Manual. [4] The total SEMM calculates munition impact points, Concentration Pathlength (CL) along angle varied observer position specified line-of-sight (LOS)'s, and transmission in addition to concentration.

The SEMM concentration model is a gaussian plume of the form,

$$C = \frac{2}{(2\Pi)^{3/2}} \sum_{\text{CLOUDS}} \frac{Q \lambda \Omega}{\sigma_x \sigma_y \sigma_z} \exp \left\{ -\frac{1}{2} \left[\frac{(x - ut)^2}{\sigma_x^{\,2}} + \frac{Y^2}{\sigma_x^{\,2}} + \frac{(Z - Z(t))^2}{\sigma_z^{\,2}} \right] \right\} \tag{1}$$

where:

Q = weight of smoke material (g),

λ = munition efficiency,

Ω = yield factor,

$\sigma_s, \sigma_x, \sigma_z$ = concentration standard deviations along the three cartesian axes,

x, y, z = cartesian coordinates,

u = wind speed

t = time

$z(t)$ = cloud centroid rise function.

As is usual in such models, the munition is assumed to impact and the cloud to form at the coordinate system origin at $t=0$. Additionally, the wind blows uniformly along the X axis with speed u. The z coordinate is altitude. Thus at time t the centroid of the cloud is at $(ut, o, z(t))$.

The SEMM model uses an approximation of cloud rise by setting $z(t)$ to be zero and adjusting Q and Ω as a function of meteorology. These values are given in Table 1. The smoke producing material in each round is assumed to be completely consumed (efficiency is one).

TABLE 1. FILL WEIGHTS

Munition	Fill wt (lb)	Effective fill wt (lb) Lapse	Neutral	Inversion
155mm	15.60	1.56	1.56	4.68
105mm	3.83	0.38	0.38	1.15
4.2in	7.50	3.00	3.00	4.50
81mm	1.75	0.175	0.175	0.53

The yield factor used in SEMM has a value of 5.2 for a 50% humidity.

The smoke cloud standard deviations have the form,

$$\sigma_x = 0.1522 \left[ut + A\right]^{0.9294}, \tag{2}$$

$$\sigma_y = 3.41 \left[\frac{ut + B}{100}\right]^{\alpha} \tag{3}$$

$$\sigma_z = 1.35 \left[\frac{ut + C}{20}\right]^{\beta} \tag{4}$$

when the parameters for the initial cloud, A, B, and C are given by

$$A = \left[\frac{\sigma_{xo}}{.1522}\right]^{1/.9294}, \tag{5}$$

$$B = 100 \left[\frac{\sigma_{yo}}{3.41}\right]^{1/\alpha}, \tag{6}$$

$$C = 20 \left[\frac{\sigma_{zo}}{1.35}\right]^{1/\beta}. \tag{7}$$

The initial cloud standard deviations, σ_{xo}, σ_{yo}, and σ_{zo} are functions of munition and meteorology. These are given in Table 2.

The diffusion coefficients α and β are functions only of meteorology, and are:

Meteorology	α=β
Lapse	1.50
Neutral	0.88
Inverison	0.70

TABLE 2. INITIAL CLOUD STANDARD DEVIATIONS

	$\sigma_x = \sigma_y$ (m)			σ_z (m)		
MUNITION	LAPSE	NEUTRAL	INVERSION	LAPSE	NEUTRAL	INVERSION
155mm	4.13	4.13	5.62	1.37	1.37	1.87
105mm	2.79	2.79	3.79	0.93	0.93	1.26
4.2in	4.96	4.96	5.56	1.65	1.65	1.87
81mm	2.24	2.24	3.05	0.74	0.74	1.01

The wind conditions favorable to smoke are also functions only of the meteorology, and are

Meteorology	Wind Speeds (knots)
Lapse	5
Neutral	5,10,15
Inversion	5

Additionally, three wind directions are considered relative to the observer-target LOS:

- Cross, perpendicular to the LOS
- Head, along the LOS;
- Quartering, 45° off the LOS.

These conditions represent the variations in the WP smoke considered:

- Four munitions.

- Three meteorologies.
- Up to three wind speeds.
- Three wind directions.

III. CONCENTRATION PATHLENGTH CALCULATION

The target-observer geometry used in this investigation is shown in Figure 1. The cloud is always considered in the cloud centroid coordinate systems which have their origin at the centroid of the cloud. The x'-y' coordinate system has its axes parallel to the x-y coordinate system used in Section II. The η-ξ coordinate system is aligned such that the η axis is parallel to the LOS, and the ξ axis is perpendicular to the η axis.

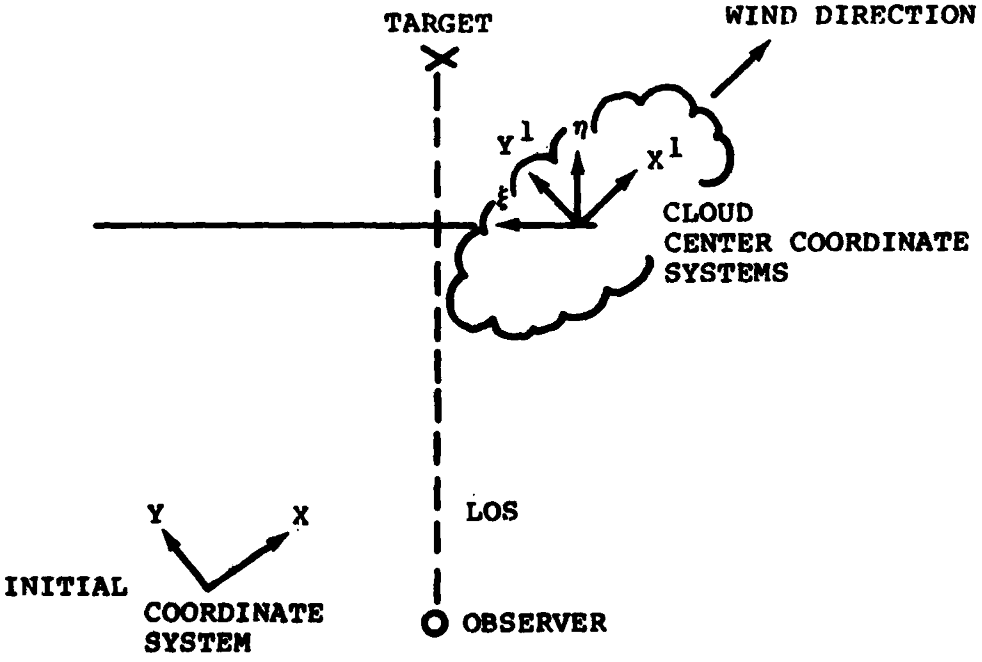

Figure 1. Target-observer geometry.

The z axis is unchanged.

For this case, the concentration model, Equation (1) may be written as

$$C = \frac{2\,Q\,\lambda\,\Omega}{(2\pi)^{3/2}\,\sigma_x\sigma_y\sigma_z}\exp\left[-\frac{1}{2}\left(\frac{x'^2}{\sigma_x^2}+\frac{y'^2}{\sigma_y^2}\right)\right] \cdot \exp\left[-\frac{z^2}{2\sigma_z^2}\right] . \tag{8}$$

The z dependence has been removed since the LOS is assumed to be at ground level in concert with the SEMM approximation for cloud rise.

The x'-y' coordinate system and the η-ξ coordinate system are related by

$$\begin{aligned} x' &= \eta\cos(\phi) + \xi\sin(\phi) \\ y' &= -\eta\sin(\phi) + \xi\cos(\phi) \end{aligned} \tag{9}$$

where ϕ is the angle of the wind direction with the perpendicular to the LOS (complement of wind direction with LOS). Equations (9) may be substituted into Equation (8) to yield

$$\begin{aligned} C = \frac{2\,Q\,\lambda\,\Omega}{(2\Pi)^{3/2}\,\sigma_x\sigma_y\sigma_z}\exp\Bigg\{-\frac{1}{2}\Bigg[\eta^2\left(\frac{\cos^2(\phi)}{\sigma_x^2}\right. & \\ \left. + \frac{\sin^2(\phi)}{\sigma_y^2}\right) + \xi^2\left(\frac{\sin^2(\phi)}{\sigma_x^2}+\frac{\cos^2(\phi)}{\sigma_y^2}\right) & \qquad (10) \\ + 2\,\eta\,\xi\cos(\phi)\sin(\phi)\left(\frac{1}{\sigma_x^2}-\frac{1}{\sigma_y^2}\right)\Bigg]\Bigg\}\exp\left[-\frac{z^2}{2\sigma_z^2}\right]. & \end{aligned}$$

The CL along the LOS is then

$$CL(\xi,z) = \int_{\text{Observer}}^{\text{Target}} C(\eta,\xi,z)\ d\eta\ . \tag{11}$$

An approximation is now introduced; the observer and target are on opposite sides of the cloud, and are far apart compared to the standard deviations σ_x and σ_y. This allows Equation (11) to be rewritten as

$$CL(\xi,z) \simeq \int_{-\infty}^{+\infty} C(\eta,\xi,z)\ d\eta, \tag{12}$$

which may be integrated analytically as

$$CL(\xi) = \frac{Q\ \lambda\ \Omega}{\sqrt{2}\ \Pi\ \sigma_x\sigma_y\sigma_z\ \Sigma}$$

$$\exp\left[-\ \frac{\xi^2}{2}\ \frac{(\cos^2(\phi)\ +\ \sin^2(\phi))^2}{\sigma_y^{\ 2}\ \cos^2(\phi)\ +\ \sigma_x^{\ 2}\sin^2(\phi)}\right]\exp\left(-\ \frac{z^2}{2\sigma_z^{\ 2}}\right),$$

where

$$\Sigma = \sqrt{\frac{1}{2}}\ \left(\frac{\cos^2(\phi)}{\sigma_x^{\ 2}}\ +\ \frac{\sin^2(\phi)}{\sigma_y^{\ 2}}\right)^{\frac{1}{2}}\ . \tag{13}$$

Equation (13) was used in this investigation in the form

$$\xi = \left\{2\left[\ln\left(\frac{Q\ \lambda\ \Omega}{\sqrt{2}\ \Pi\ \sigma_x\sigma_y\sigma_z\ \Sigma}\right) -\ \ln\ (CL)\right]\cdot\right.$$

$$\left.\frac{\sigma_y^{\ 2}\cos^2(\phi)\ +\ \sigma_x^{\ 2}\sin^2(\phi)}{(\cos^2(\phi)\ +\ \sin^2(\phi))^2}\right\}^{\frac{1}{2}},\ z = 0 \tag{14}$$

to calculate the half width of a smoke cloud corresponding to a given CL,

and

$$z = \left\{ 2 \left[\ell n \left(\frac{Q \lambda \Omega}{\sqrt{2}\, \Pi\, \sigma_x \sigma_y \sigma_z\, \Sigma} \right) - \ell n \, (CL) \right] \right\}^{\frac{1}{2}} \sigma_z , \; \xi = 0 \; . \qquad (15)$$

to calculate the height of a smoke cloud corresponding to a given CL.

It may be noted that the approximation of infinite limits on Equation (11) is not necessary if the exact locations of target and observer are known. This introduces two new parameters, and a closed-form solution of the type as Equation (14) is not possible since Equation (11) develops into the sum (or difference) of two error functions. For these reasons, the approximation is used throughout this investigation. From the standpoint of sensitivity, the approximation maximizes the effect of the smoke on the sensor since the integral, Equation (12), calculates the total CL along an infinitely long LOS. In practice, as long as both target and observer are not in the smoke cloud, the approximation is quite good.

IV. DEVELOPMENT OF THE PARAMETRIC MODEL

During the course of the work that is reported in Reference 2, a functional relationship was noted that led to this parametric model. In that work, probabilities of detection were associated with CLs. These CLs were used to generate cloud half-widths (using Equation (14)) as a function of time. An example of this is shown in Figure 2. It may be noted that the half-width of the cloud is approximately quadratic or cubic in time.

This observation is the key to the parametric model. By accepting the approximations extant in Reference 2: that all LOS are approximately parallel to the ground, that the cloud is entirely between the target and the observer, and that the model described in Sections II and III is

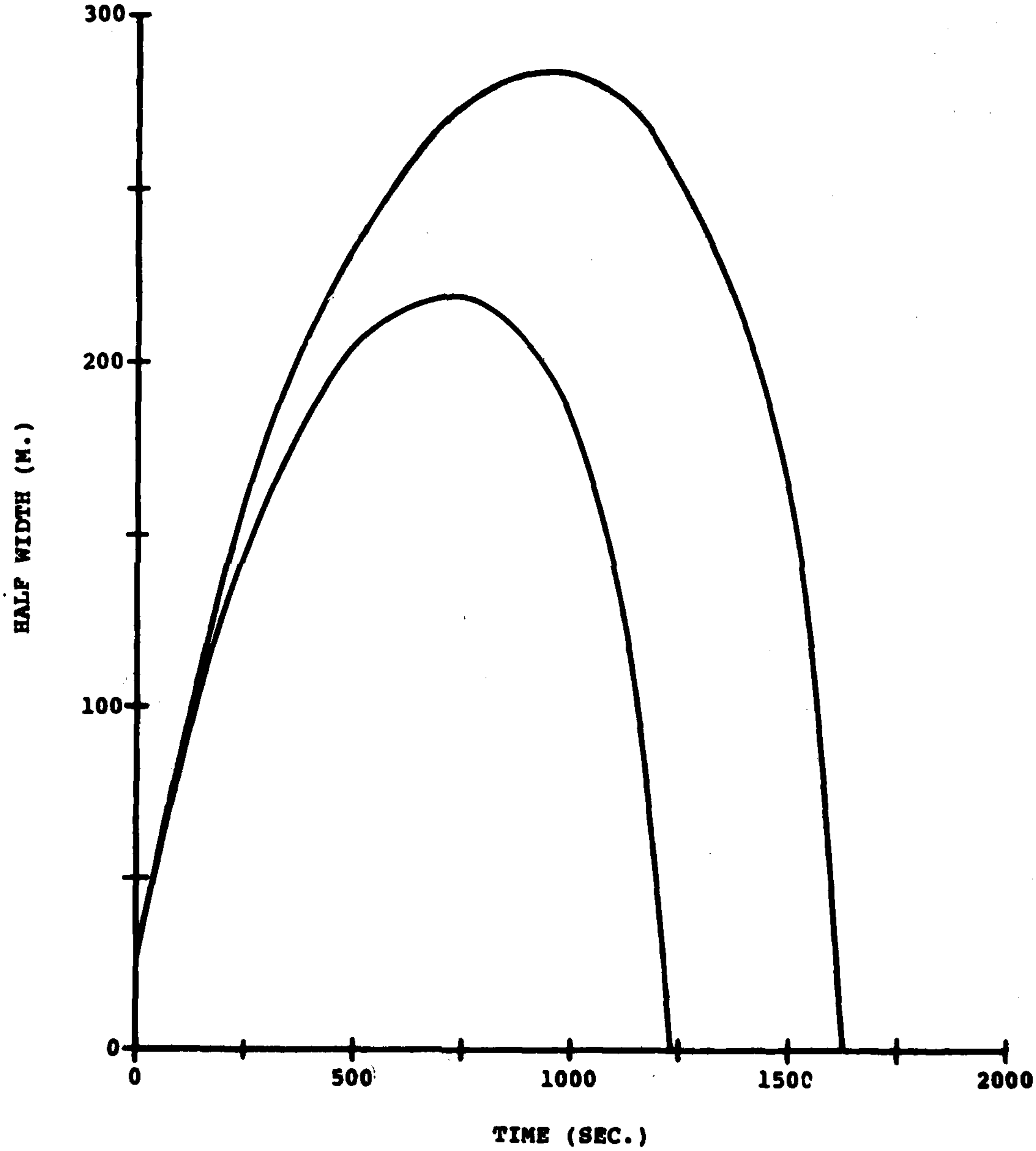

Figure 2. Half-width versus time.

sufficiently accurate, a simple model for cloud half-width may be developed.

In developing this model, the LOS defeat criterion used in Developing FM 101-61-8 was used. This is an attenuation of 90% in the visual region of the spectrum, which corresponds to a CL of 0.6936 g/m^2. This criterion was chosen for two reasons; first, the resulting model would correlate with the FM, and second, the resulting model would be unclassified. For users desiring a more rigorous model, or a model for other spectral regions, the techniques developed here may be applied for other CLs.

This CL of 0.6936 g/m^2 was used with Equation (14) to generate the volumes of the half-width of the cloud, $W_{\frac{1}{2}}$ as a function of time during the lifetime of the cloud. These half-widths and times were then fitted to functions of the form

$$W_{\frac{1}{2}} = \sum_{i=0}^{I} \alpha(i)\, t^{i} \qquad (16)$$

where $I = 2$ for a quadratic, and $I = 3$ for a cubic, using a linear regression code added to the smoke model code. These $a(i)$ are given in <u>Tables 3-17</u> for the various meteorologies, wind conditions, and wind directions described in Section II. Assuming the CL calculated from SEMM to be exact, an average standard deviation of error for all quadratic fits was 1.4245 m with a maximum error for all quadratic fits of 7.5%. The fits for the neutral condition were more accurate, and for inversion condition less accurate.

The cubic fits were only slightly more accurate than the quadratic, having an average standard deviation of error of approximately 1.2 m.

In addition to the half-widths, it was necessary to examine the height of the cloud above the centroid. This curve is not a polynomial, but rather approximately

TABLE 3. CLOUD PARAMETERS LAPSE CONDITIONS, 5 KNOT CROSS WIND

MUNITION		HALF-WIDTH			HEIGHT
		CUBIC	QUADRATIC		
155mm	a(0)	15.0742	12.9759	Zo	4.6251
	a(1)	0.4080	0.6967	A	0.9210
	a(2)	-5.5211(-7)	-7.9903(-3)	a	0.7754
	a(3)	-5.9051(-5)		b	0.0409
				c	-5.0737(-4)
105mm	a(0)	9.4381	8.2582	Zo	2.9603
	a(1)	0.4044	0.7011	A	1.0015
	a(2)	6.5841(-7)	-0.0152	a	0.8554
	a(3)	-2.0706(-4)		b	-8.8419(-3)
				c	7.2794(-6)
4.2"	a(0)	18.6366	15.8237	Zo	5.7079
	a(1)	0.4147	0.7037	A	1.0012
	a(2)	8.7511(-9)	-6.0550(-3)	a	0.7804
	a(3)	-3.3653(-3)		b	-8.6622(-3)
				c	7.2794(-6)
81mm	a(0)	7.2837	6.4522	Zo	2.2781
	a(1)	0.3973	0.6930	A	1.0019
	a(2)	2.7368(-7)	-0.0214	a	0.7351
	a(3)	-4.1064(-4)		b	-5.4805(-3)
				c	2.5706(-6)

TABLE 4. CLOUD PARAMETERS LAPSE CONDITIONS, 5 KNOT QUARTERING WIND

MUNITION		HALF-WIDTH			HEIGHT
		CUBIC	QUADRATIC		
155mm	a(0)	14.2758	12.4465	Zo	4.6251
	a(1)	0.3465	0.5860	A	0.9959
	a(2)	2.4557(-6)	-6.3978(-3)	a	0.7354
	a(3)	-4.5372(-5)		b	-6.7251(-3)
				c	4.8881(-6)
105mm	a(0)	9.0391	8.0379	Zo	2.9603
	a(1)	0.3100	0.5438	A	0.9938
	a(2)	4.9494(-6)	-0.0111	a	0.7301
	a(3)	-1.4061(-4)		b	-5.9094(-3)
				c	3.8603(-6)
4.2"	a(0)	17.5485	15.0867	Zo	5.7079
	a(1)	0.3683	0.6159	A	0.9958
	a(2)	2.2596(-6)	-5.0775(-3)	a	0.7367
	a(3)	-2.7650(-5)		b	-6.6171(-3)
				c	4.8938(-6)
81mm	a(0)	7.0109	6.3126	Zo	2.2781
	a(1)	0.2896	0.5163	A	0.9940
	a(2)	6.0126(-6)	-0.0150	a	0.7205
	a(3)	-2.6326(-4)		b	-5.2252(-3)
				c	3.0342(-6)

TABLE 5. CLOUD PARAMETERS LAPSE CONDITIONS, 5 KNOT HEAD WIND

MUNITION		HALF-WIDTH		HEIGHT	
		CUBIC	QUADRATIC		
155mm	a(0)	13.2287	11.6939	Zo	4.6251
	a(1)	0.2795	0.4705	A	0.9930
	a(2)	6.6774(-6)	-4.8396(-3)	a	0.7375
	a(3)	-3.2638(-5)		b	-6.1838(-3)
				c	4.2680(-6)
105mm	a(0)	8.4941	7.7104	Zo	2.9603
	a(1)	0.2031	0.3673	A	0.9766
	a(2)	1.0791(-5)	-7.0074(-3)	a	0.6992
	a(3)	-7.9587(-5)		b	-3.4031(-3)
				c	1.2439(-6)
4.2"	a(0)	16.1142	13.9458	Zo	5.7079
	a(1)	0.3243	0.5363	A	0.9783
	a(2)	6.0236(-6)	-4.2187(-3)	a	0.7074
	a(3)	-2.2342(-5)		b	-3.7061(-3)
				c	1.3788(-6)
81mm	a(0)	6.6538	6.1425	Zo	2.2781
	a(1)	0.1617	0.3060	A	0.9739
	a(2)	1.2156(-5)	-8.3009(-3)	a	0.6946
	a(3)	-1.2700(-4)		b	-2.8446(-3)
				c	9.8795(-7)

TABLE 6. CLOUD PARAMETERS NEUTRAL CONDITIONS, 5 KNOT CROSS WIND

MUNITION		HALF-WIDTH			HEIGHT
		CUBIC	QUADRATIC		
155mm	a(0)	18.0139	13.4267	Zo	4.6251
	a(1)	0.4041	0.6495	A	1.0187
	a(2)	-1.2223(-6)	-2.6792(-3)	a	0.8953
	a(3)	-7.7538(-6)		b	-3.9462(-3)
				c	-4.5645(-5)
105mm	a(0)	10.4483	8.2599	Zo	2.9603
	a(1)	0.4047	0.6639	A	0.9955
	a(2)	-1.3995(-6)	-6.2689(-3)	a	0.7641
	a(3)	-4.0200(-5)		b	-6.9639(-3)
				c	4.5728(-6)
4.2"	a(0)	23.2792	16.7302	Zo	5.7079
	a(1)	0.4029	0.6450	A	1.0021
	a(2)	-8.8592(-7)	-1.8274(-3)	a	0.7674
	a(3)	-3.6552(-6)		b	-7.3225(-3)
				c	5.1038(-6)
81mm	a(0)	7.8416	6.4475	Zo	2.2781
	a(1)	0.3974	0.6559	A	1.0033
	a(2)	-2.3930(-6)	-9.7793(-3)	a	0.6843
	a(3)	-9.8067(-5)		b	-3.8628(-3)
				c	7.0907(-7)

TABLE 7. CLOUD PARAMETERS NEUTRAL CONDITIONS, 5 KNOT QUARTERING WIND

MUNITION		HALF-WIDTH			HEIGHT
		CUBIC	QUADRATIC		
155mm	a(0)	16.6033	12.6753	Zo	4.6251
	a(1)	0.2854	0.4618	A	0.9974
	a(2)	-4.9697(-7)	-1.6158(-3)	a	0.7365
	a(3)	-3.9253(-6)		b	-6.7172(-3)
				c	4.8016(-6)
105mm	a(0)	9.7727	7.9023	Zo	2.9603
	a(1)	0.2830	0.4691	A	0.9933
	a(2)	-4.9701(-8)	-3.7798(-3)	a	0.7238
	a(3)	-2.0364(-5)		b	-5.9464(-3)
				c	5.0425(-6)
4.2"	a(0)	21.3696	15.8269	Zo	5.7079
	a(1)	0.2848	0.4571	A	0.9955
	a(2)	-4.4667(-7)	-1.0943(-3)	a	0.7302
	a(3)	-1.8417(-6)		b	-5.9394(-3)
				c	3.9380(-6)
81mm	a(0)	7.3938	6.1996	Zo	2.2781
	a(1)	0.2752	0.4609	A	0.9939
	a(2)	3.5373(-8)	-5.8917(-3)	a	0.7076
	a(3)	-4.9598(-5)		b	-4.8952(-3)
				c	2.7323(-6)

TABLE 8. CLOUD PARAMETERS NEUTRAL CONDITIONS, 10 KNOT CROSS WIND

MUNITION		HALF-WIDTH		HEIGHT	
		CUBIC	QUADRATIC		
155mm	a(0)	18.0054	13.4153	Zo	4.6251
	a(1)	0.8085	1.2997	A	1.0004
	a(2)	-4.8703(-6)	-1.0700(-2)	a	0.6896
	a(3)	-6.2069(-5)		b	-5.3227(-3)
				c	3.3138(-6)
105mm	a(0)	10.4959	8.3739	Zo	2.9603
	a(1)	0.8036	1.3100	A	0.9985
	a(2)	-8.5601(-6)	-2.4600(-2)	a	0.6830
	a(3)	-3.1789(-4)		b	-5.1321(-3)
				c	3.1205(-6)
4.2"	a(0)	23.2791	16.7302	Zo	5.7079
	a(1)	0.8058	1.3118	A	1.0001
	a(2)	-3.5565(-6)	-7.3094(-3)	a	0.6984
	a(3)	-2.9241(-5)		b	-5.5664(-3)
				c	3.5634(-6)
81mm	a(0)	7.8416	6.4475	Zo	2.2781
	a(1)	0.7947	1.3118	A	1.0018
	a(2)	-9.7499(-6)	-3.9100(-2)	a	0.6807
	a(3)	-7.8453(-4)		b	-4.8774(-3)
				c	2.6726(-6)

TABLE 9. CLOUD PARAMETERS NEUTRAL CONDITIONS, 5 KNOT HEAD WIND

MUNITION		HALF-WIDTH		HEIGHT	
		CUBIC	QUADRATIC		
155mm	a(0)	15.2709	12.9831	Zo	4.6251
	a(1)	0.0883	0.1488	A	0.9921
	a(2)	-9.2724(-8)	-3.2698(-4)	a	0.7302
	a(3)	-4.6827(-7)		b	-5.5019(-3)
				c	3.3816(-6)
105mm	a(0)	9.2379	8.1718	Zo	2.9603
	a(1)	0.0853	0.1498	A	0.9766
	a(2)	-8.1191(-9)	-7.9600(-3)	a	0.6979
	a(3)	-2.6059(-6)		b	-3.4197(-3)
				c	1.2556(-6)
4.2"	a(0)	19.3395	16.0374	Zo	5.7079
	a(1)	0.0887	0.1482	A	0.9789
	a(2)	-6.9627(-8)	-2.1907(-4)	a	0.7047
	a(3)	-2.1375(-7)		b	-3.4229(-3)
				c	1.2454(-6)
81mm	a(0)	7.0330	6.3406	Zo	2.2781
	a(1)	0.0814	0.1477	A	0.9738
	a(2)	1.8019(-7)	-1.2935(-3)	a	0.6906
	a(3)	-6.7019(-6)		b	-2.8025(-3)
				c	9.7512(-7)

TABLE 10. CLOUD PARAMETERS NEUTRAL CONDITIONS, 10 KNOT QUARTERING WIND

MUNITION		HALF-WIDTH		HEIGHT	
		CUBIC	QUADRATIC		
155mm	a(0)	16.6033	12.6753	Zo	4.6251
	a(1)	0.5708	0.9236	A	0.9941
	a(2)	-1.9966(-6)	-6.4632(-3)	a	0.7127
	a(3)	-3.1402(-5)		b	-5.5444(-3)
				c	3.6732(-6)
105mm	a(0)	9.7974	7.9560	Zo	2.9603
	a(1)	0.5635	0.9313	A	0.9933
	a(2)	-1.1664(-6)	-1.5000(-2)	a	0.7110
	a(3)	-1.6179(-4)		b	-5.5148(-3)
				c	3.6616(-6)
4.2"	a(0)	21.3696	15.8269	Zo	5.7079
	a(1)	0.5695	0.9142	A	0.9944
	a(2)	-1.7921(-6)	-4.3771(-3)	a	0.7160
	a(3)	-1.4733(-5)		b	-5.5668(-3)
				c	3.6495(-6)
81mm	a(0)	7.3938	6.1996	Zo	2.2781
	a(1)	0.5504	0.9218	A	0.9944
	a(2)	1.4369(-7)	-2.3600(-2)	a	0.7098
	a(3)	-3.9679(-4)		b	-5.3546(-3)
				c	3.4170(-6)

TABLE 11. CLOUD PARAMETERS NEUTRAL CONDITIONS, 10 KNOT HEAD WIND

MUNITION		HALF-WIDTH			HEIGHT
		CUBIC	QUADRATIC		
155mm	a(0)	15.2691	12.9806	Zo	4.6251
	a(1)	0.1766	0.2977	A	0.9754
	a(2)	-3.6880(-7)	-1.3085(-3)	a	0.6943
	a(3)	-3.7473(-6)		b	-2.9562(-3)
				c	1.0432(-6)
105mm	a(0)	9.2379	8.1718	Zo	2.9603
	a(1)	0.1706	0.2996	A	0.9751
	a(2)	-3.2669(-8)	-3.1840(-3)	a	0.6949
	a(3)	-2.0848(-5)		b	-2.9729(-3)
				c	1.0507(-6)
4.2"	a(0)	19.3395	16.0374	Zo	5.7079
	a(1)	0.1774	0.2965	A	0.9769
	a(2)	-2.7900(-7)	-8.7628(-4)	a	0.6980
	a(3)	-1.7100(-6)		b	-2.9716(-3)
				c	1.0425(-6)
81mm	a(0)	7.0330	6.3406	Zo	2.2781
	a(1)	0.1628	0.2954	A	0.9742
	a(2)	7.2755(-7)	-5.1740(-3)	a	0.6910
	a(3)	-5.3615(-5)		b	-2.9147(-3)
				c	1.0295(-6)

TABLE 12. CLOUD PARAMETERS NEUTRAL CONDITIONS, 15 KNOT CROSS WIND

MUNITION		HALF-WIDTH			HEIGHT
		CUBIC	QUADRATIC		
155mm	a(0)	18.0054	13.4153	Zo	4.6251
	a(1)	1.2128	1.9496	A	0.9982
	a(2)	-1.1016(-5)	-2.4100(-2)	a	0.6981
	a(3)	-2.0948(-4)		b	-5.6130(-3)
				c	3.6677(-6)
105mm	a(0)	10.4483	8.2599	Zo	2.9603
	a(1)	1.2140	1.9918	A	0.9937
	a(2)	-1.2895(-5)	-5.6400(-2)	a	0.6986
	a(3)	-1.0854(-3)		b	-5.6496(-3)
				c	3.7460(-6)
4.2"	a(0)	23.1568	16.4661	Zo	5.7079
	a(1)	1.2152	1.9544	A	0.9942
	a(2)	-6.5553(-6)	-1.6700(-2)	a	0.7165
	a(3)	-9.9584(-5)		b	-6.2591(-3)
				c	4.4716(-6)
81mm	a(0)	7.8188	6.4049	Zo	2.2781
	a(1)	1.1979	1.9837	A	0.9926
	a(2)	-1.6490(-5)	-8.8900(-2)	a	0.7110
	a(3)	-2.6672(-3)		b	-6.0428(-3)
				c	4.1836(-6)

TABLE 13. CLOUD PARAMETERS NEUTRAL CONDITIONS, 15 KNOT QUARTERING WIND

MUNITION		HALF-WIDTH			HEIGHT
		CUBIC	QUADRATIC		
155mm	a(0)	16.6442	12.7767	Zo	4.6251
	a(1)	0.8535	1.3763	A	0.9937
	a(2)	-5.3143(-6)	-1.4400(-2)	a	0.7174
	a(3)	-1.0541(-4)		b	-5.6278(-3)
				c	3.7275(-6)
105mm	a(0)	9.8398	8.0541	Zo	2.9603
	a(1)	0.8389	1.3776	A	0.9920
	a(2)	-6.4712(-6)	-3.3100(-2)	a	0.7191
	a(3)	-5.3951(-4)		b	-5.6974(-3)
				c	3.8164(-6)
4.2"	a(0)	21.3220	15.7219	Zo	5.7079
	a(1)	0.8564	1.3779	A	0.9925
	a(2)	-3.6453(-6)	-9.9103(-3)	a	0.7272
	a(3)	-4.9930(-5)		b	-5.9293(-3)
				c	4.0444(-6)
81mm	a(0)	7.3956	6.2125	Zo	2.2781
	a(1)	0.8249	1.3793	A	0.9914
	a(2)	-7.1869(-7)	-5.2900(-2)	a	0.7254
	a(3)	-1.3371(-3)		b	-5.8617(-3)
				c	3.9688(-6)

TABLE 14. CLOUD PARAMETERS NEUTRAL CONDITIONS, 15 KNOT HEAD WIND

MUNITION		HALF-WIDTH			HEIGHT
		CUBIC	QUADRATIC		
155mm	a(0)	15.2691	12.9806	Zo	4.6251
	a(1)	0.2649	0.4466	A	0.9770
	a(2)	-8.3195(-7)	-2.9442(-3)	a	0.7014
	a(3)	-1.2647(-5)		b	-3.0258(-3)
				c	1.0630(-6)
105mm	a(0)	9.2379	8.1718	Zo	2.9603
	a(1)	0.2559	0.4494	A	0.9759
	a(2)	-7.3943(-8)	-7.1640(-3)	a	0.7034
	a(3)	-7.0360(-5)		b	-3.0634(-3)
				c	1.0783(-6)
4.2"	a(0)	19.3395	16.0374	Zo	5.7079
	a(1)	0.2661	0.4447	A	0.9772
	a(2)	-6.2884(-7)	-1.9716(-3)	a	0.7081
	a(3)	-5.7713(-6)		b	-3.1148(-3)
				c	1.0937(-6)
81mm	a(0)	7.0064	6.2875	Zo	2.2781
	a(1)	0.2480	0.4532	A	0.9762
	a(2)	3.5100(-6)	-1.1940(-1)	a	0.7088
	a(3)	-1.8436(-4)		b	-3.1257(-3)
				c	1.0984(-6)

TABLE 15. CLOUD PARAMETERS INVERSION CONDITIONS, 5 KNOT CROSS WIND

MUNITION		HALF-WIDTH			HEIGHT
		CUBIC	QUADRATIC		
155mm	a(0)	32.2101	20.8043	Zo	4.6251
	a(1)	0.3845	0.6098	A	0.9939
	a(2)	-4.7982(-7)	-8.3530(-4)	a	0.8749
	a(3)	-8.2077(-7)		b	-9.3787(-3)
				c	6.5356(-6)
105mm	a(0)	13.2475	10.5662	Zo	2.9603
	a(1)	0.3724	0.6106	A	0.9917
	a(2)	-1.0995(-6)	-4.3206(-3)	a	0.7013
	a(3)	-2.0779(-5)		b	-6.8707(-3)
				c	5.7946(-6)
4.2"	a(0)	32.4832	20.2144	Zo	5.7079
	a(1)	0.3859	0.6137	A	0.9981
	a(2)	-4.4602(-7)	-8.6342(-4)	a	0.7417
	a(3)	-8.6745(-7)		b	-5.6807(-3)
				c	2.8064(-6)
81mm	a(0)	12.8445	9.4311	Zo	2.2781
	a(1)	0.3948	0.6358	A	1.0012
	a(2)	-1.4131(-6)	-3.4702(-3)	a	0.6745
	a(3)	-1.3249(-5)		b	-4.6460(-3)
				c	2.3906(-6)

TABLE 16. CLOUD PARAMETERS INVERSION CONDITIONS, 5 KNOT QUARTERING WIND

MUNITION		HALF-WIDTH			HEIGHT
		CUBIC	QUADRATIC		
155mm	a(0)	29.7281	19.0165	Zo	4.6251
	a(1)	0.2677	0.4254	A	0.9937
	a(2)	-2.4278(-7)	-4.7393(-4)	a	0.7211
	a(3)	-3.7753(-7)		b	-5.5747(-3)
				c	3.4717(-6)
105mm	a(0)	12.3185	9.9664	Zo	2.9603
	a(1)	0.2552	0.4242	A	0.9924
	a(2)	1.4095(-7)	-2.4761(-3)	a	0.7176
	a(3)	-9.6277(-6)		b	-6.2729(-3)
				c	4.6952(-6)
4.2"	a(0)	29.1813	18.6868	Zo	5.7079
	a(1)	0.2681	0.4263	A	0.9932
	a(2)	-2.4215(-7)	-4.8710(-4)	a	0.7196
	a(3)	-3.9744(-7)		b	-5.1768(-3)
				c	2.9731(-6)
81mm	a(0)	11.7616	8.7430	Zo	2.2781
	a(1)	0.2752	0.4477	A	0.9937
	a(2)	-3.1982(-7)	-2.0110(-3)	a	0.7074
	a(3)	-6.2188(-6)		b	-5.3353(-3)
				c	3.4332(-6)

TABLE 17. CLOUD PARAMETERS INVERSION CONDITIONS, 5 KNOT HEAD WIND

MUNITION		HALF-WIDTH		HEIGHT	
		CUBIC	QUADRATIC		
155mm	a(0)	28.3846	23.6635	Zo	4.6251
	a(1)	0.0329	0.0560	A	0.9770
	a(2)	-3.0803(-8)	-2.3137(-5)	a	0.6950
	a(3)	-3.7753(-7)		b	-3.3235(-3)
				c	1.2121(-6)
105mm	a(0)	12.0711	10.9484	Zo	2.9603
	a(1)	0.0387	0.0731	A	0.9765
	a(2)	-9.7019(-8)	-2.1623(-4)	a	0.6973
	a(3)	-3.5940(-7)		b	-3.5530(-3)
				c	1.3237(-6)
4.2"	a(0)	27.9121	23.2819	Zo	5.7079
	a(1)	0.0331	0.0565	A	0.9738
	a(2)	-3.1667(-8)	-2.3995(-5)	a	0.6930
	a(3)	-6.5339(-9)		b	-2.8140(-3)
				c	9.7566(-7)
81mm	a(0)	11.6227	10.1170	Zo	2.2781
	a(1)	0.0454	0.0807	A	0.9742
	a(2)	-1.3508(-7)	-1.6939(-3)	a	0.6911
	a(3)	-2.1508(-7)		b	-2.9147(-3)
				c	1.0295(-6)

$$h \cong z_o + A\,t^a \exp\,(bt + ct^2) \qquad (17)$$

where the parameters Z_O, A, a, b, and c were also calculated using linear regression using cloud height versus time values calculated from Equation (15). These parameters are also given in Tables 3-17.

These cloud height fits have a much larger average standard deviation of error (10.2726 m). This error is not without a qualifier however. Most of the errors are due to the long time behavior of Equation (17) when the height of the cloud is overestimated. This error is thus mitigated by the accuracy of the half-width model.

Having modeled the cloud half-width at ground level, and the cloud height above cloud centroid, the nature of the parametric model may now be considered. For any given line-of-sight, there is an angle between the LOS and the wind direction. This angle determines whether the wind is head, quartering, or crossing with respect to the LOS.. Combined with the wind speed, meteorological state (lapse, neutral, or inversion) and the munition type, the half-width and height of the cloud may be calculated as a function of time since impact.

Additionally, the position of the centroid of the cloud may be calculated from the impact point position, the wind velocity, and the time since impact. It is then a simple matter to calculate the point on the observer-target ground line closest to the centroid. If this point falls on the ground projection of the LOS, the LOS may be blocked by the cloud. (This satisfies the condition that the cloud is between the observer and the target.)

To see how the LOS may be blocked, now consider Equation (13). For a given CL, the logarithm of Equation (13) is an ellipse centered at the centroid whose semimajor and semiminor axes are the half-width and height of the cloud. This half ellipse (the half above ground) represents an area in a vertical plane perpendicular to the LOS and

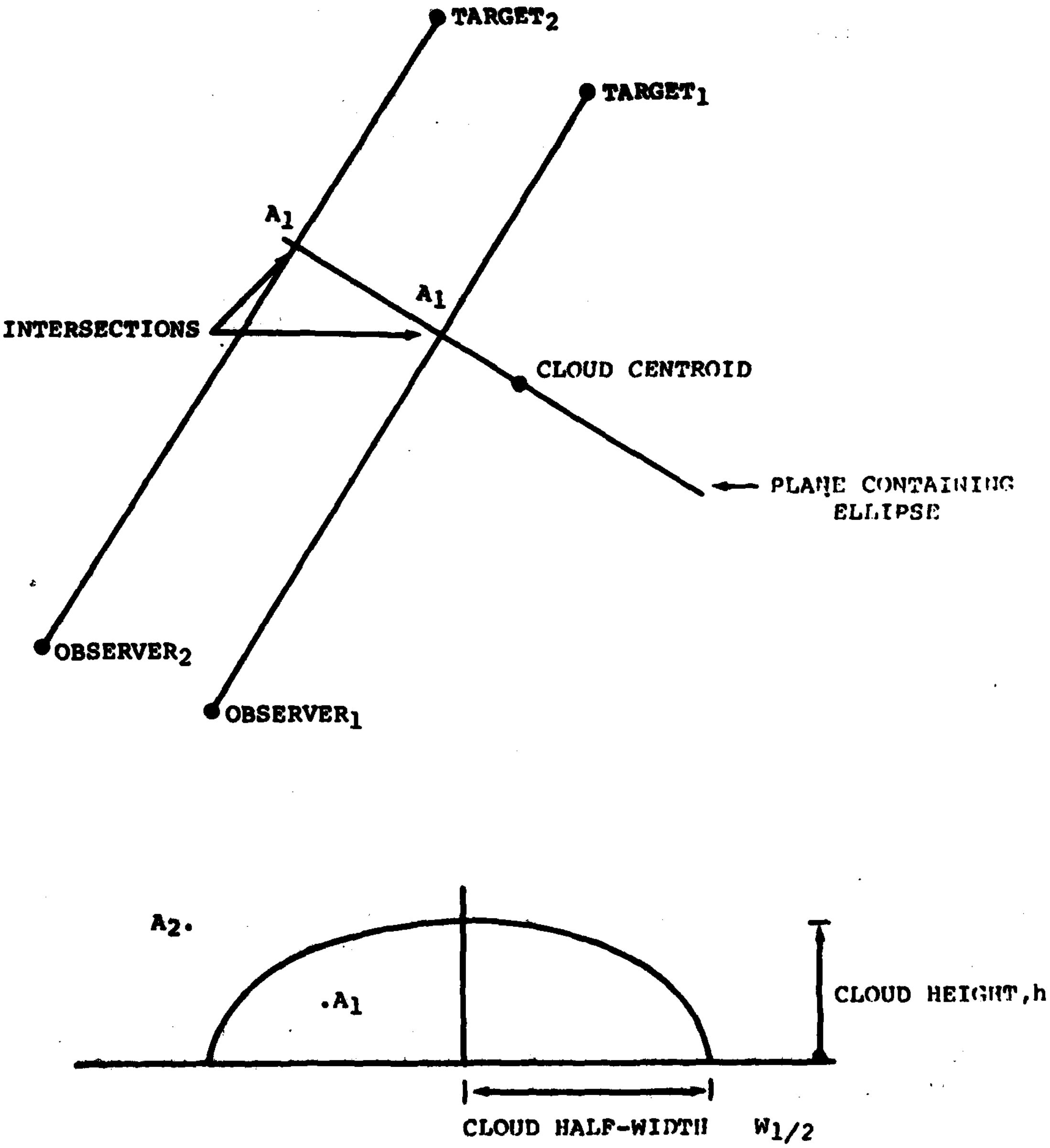

Figure 3. Parametric model operation.

passing through the cloud centroid. All LOS intersecting the plane inside the half ellipse are blocked. This is shown in Figure 3.

Thus, these two curves, the half-width and the height of the cloud constitute the parametric model. The use of this model is described in the next section.

V. USE OF THE PARAMETRIC MODEL

In the previous sections, the half-width and heights of single munition smoke clouds have been developed. These are given by

$$w_{1/2} = a(0) + a(1)\ t + a(2)\ t^2 + a(3)\ t^3 \tag{18}$$

or

$$w_{1/2} = a(0) + a(1)\ t + a(2)\ t^2 \tag{19}$$

and

$$h = z_o + A\ t^a \exp(bt + ct^2), \tag{20}$$

where t is the time since impact. The parameters a(i), A, a, z_o, b, and c are tabulated. These equations may be used in conflict simulations to determine whether smoke blocks a visual line-of-sight.

The visual line-of-sight is the straight line between an observer and a target. The observer's (target's) position is x_o, y_o, z_o (x_t, y_t, z_t).

The vector $\underset{\sim}{R}$ between the two has components

$$R_x = x_t - x_o \tag{21}$$

$$R_y = y_t - y_o \tag{22}$$

$$R_z = z_t - z_o \tag{23}$$

and the distance between the two, R, is

$$\begin{aligned} R &= \underset{\sim}{R}\cdot\underset{\sim}{R} \\ &= \{(x_t - x_o)^2 + (y_t - y_o)^2 + (z_t - z_o)^2\}^{\frac{1}{2}}. \end{aligned} \tag{24}$$

It is also assumed that there is a wind vector $\underset{\sim}{u}$ with components u_x, u_y, and u_z and magnitude (wind speed) u given by

$$u = (u_x^2 + u_y^2 + u_z^2)^{\frac{1}{2}}. \tag{25}$$

The impact point of a round is x_i, y_i, z_i, and its impact time is t_i. The position of the cloud centroid at time t is

$$x = x_i + u_x(t - t_i) \tag{26}$$

$$y = y_i + u_y(t - t_i) \tag{27}$$

$$z = \text{function of } x \text{ and } y \text{ given by terrain.} \tag{28}$$

The value of z is the terrain height corresponding to the coordinates x and y.

Next, the type of wind must be determined. This is done by use of the dot product. The quantity

$$\cos(\theta) = (R_x u_x + R_y u_y + R_z u_z)^2 / (R^2 u^2) \qquad (29)$$

is calculated. If

$1 \geq \cos(\theta) > .75 \rightarrow$ head wind

$.75 \geq \cos(\theta) > .25 \rightarrow$ quartering wind

$.25 \geq \cos(\theta) > 0 \rightarrow$ cross wind

This determines (with round type, wind speed and meteorology) which set of coefficients to use in calculating the half-width and height of cloud.

If the age of the cloud is greater than the lifetime of the cloud, the LOS is not blocked. This condition occurs if

$$t - t_i \geq \frac{-a(1) - \{a(1)^2 - 4\ a(0)\ a(2)\}^{1/2}}{2\ a(2)}. \qquad (30)$$

The case where Equation (30) is true is that where the cloud has shrunk to zero half-width and need be considered no further. If Equation (30) is not true, then the point on the LOS nearest the cloud centroid's position must be found. The equations of the LOS may be written in terms of the parameter s as

$$x_1 = (x_t + x_o)/2 + (x_t - x_o)\ s\ /2 \qquad (31)$$

$$y_1 = (y_t + y_o)\ /2 + (y_t - y_o)\ s\ /2 \qquad (32)$$

$$z_1 = (z_t + z_o)/2 + (z_t - z_o)\ s\ /2. \qquad (33)$$

The point on the LOS closest to the cloud centroid is x^*, y^*, z^* parametrized by s^* which is given by

$$s^* = \frac{2x(x_t-x_o)+2y(y_t-y_o)+2z(z_t-z_o)-(x_t^2-x_o^2)-(y_t^2-y_o^2)-(z_t^2-z_o^2)}{(x_t-x_o)^2+(y_t-y_o)^2+(z_t-z_o)^2} \tag{34}$$

where x,y, and z are the cloud centroid coordinates. If $|s^*| > 1$, the cloud does not block the line-of-sight because it is beyond the LOS. If $|s^*| \leq 1$, then the cloud may block the line-of-sight. The quantities x^*, y^*, z^* must be calculated by substituting s^* (calculated from Equation (34) into Equations (31)-(33), and the ground plane distance from the point on the LOS to the cloud centroid, d^*, must be calculated,

$$d^* = \{(x^*-x)^2 + (y^* - y)^2\}^{\frac{1}{2}}. \tag{35}$$

If

$$d^* > w_{\frac{1}{2}}, \text{ or } z^* > z + h, \tag{36}$$

the cloud does not block the line-of-sight. If Equation (36) is not satisfied, the final calculation to determine if the LOS is blocked must be made.

If

$$z^* > h(1 + d^{*2}/w_{\frac{1}{2}}^{\;2})^{\frac{1}{2}} + z, \tag{37}$$

the LOS is not blocked. If Equation (37) is not satisfied, the LOS is blocked.

The operation of this algorithm is outlined in Table 18.

Table 18. LOS BLOCKAGE ALGORITHM

Step

1. Calculate the present position of the cloud centroid x, y, z from the impact point, x_i, y_i, and impact time, t_i, the wind velocity components, u_x and u_y, the present time, t, and the terrain representation $f(x,y)$.
2. Calculate the wind direction relative to the LOS, Equation (29).
3. Select the appropriate cloud curves using relative wind direction, wind speed, and meteorology, and calculate $w_{1/2}$ and h, Equations (18)-(20).
4. If age of cloud is greater than lifetime of cloud, Equation (30), go to step 12.
5. Calculate s^*, Equation (17).
6. If $|s^*| > 1$, go to step 12.
7. Calculate x^*, y^*, z^*, d^*, Equations (31)-(33), and (35).
8. If $d^* > w_{1/2}$ or $z^* > z + h$, go to step 12.
9. If $z^* > h(1 + d^{*2}/w_{1/2}^{2})^{1/2} + z$, go to step 12.
10. LOS is blocked.
11. END.
12. LOS is not blocked.
13. END.

References

1. Fowler, B. W., "Do Gaussian Plumes Have Sharp Edges?" Proceedings of the Smoke Symposium III, OPM Smoke/ Obscurants, May 1979.
2. Fowler, B. W., "An Investigation of the Effect of White Phosphorus Smoke on Target Detection, "USAMICOM TR C-79-5, 2 July 1979.
3. Marchetti, R. M., "A Transport and Diffusion Model for Smoke Munitions, " USAMSAA, March 1979.
4. JTCG/ME, "Smoke Effectiveness Manual" FM 101-61-8, 31 May 1979.

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