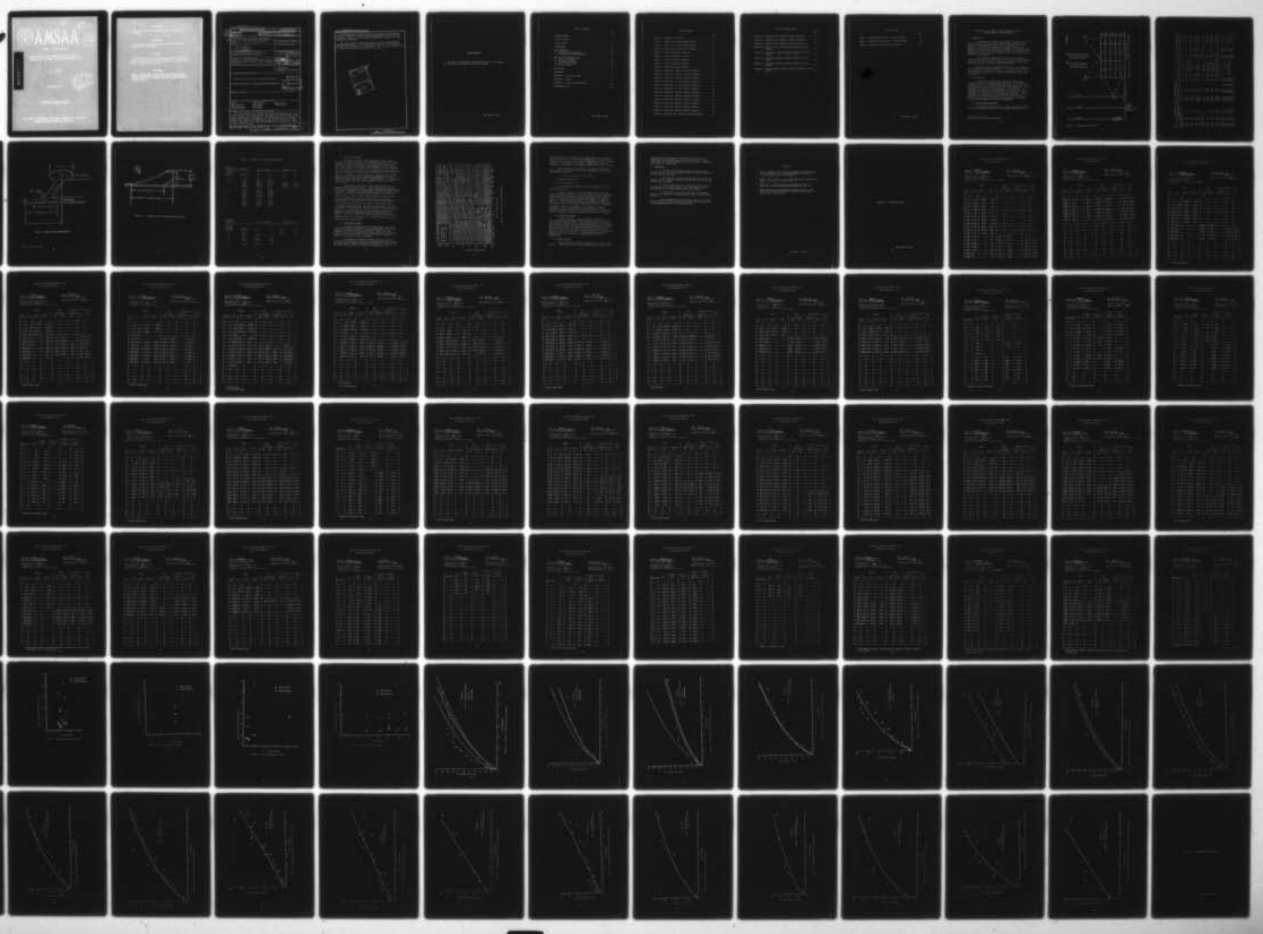
AD-A045 874 ARMY MATERIEL SYSTEMS ANALYSIS ACTIVITY ABERDEEN PROV--ETC F/G 19/1
AN ANALYSIS OF THE SMOKE CLOUD DATA FROM THE AUGUST, 1975 JEFFE--ETC(U)
SEP 77 T J DOLCE, D F METZ

UNCLASSIFIED AMSAA-TR-201 NL

1 OF 2
ADA045874



AMSAA

TECHNICAL REPORT NO. [illegible]

AN ANALYSIS OF THE [illegible]
[illegible], 1975 JEFFERSON PROVING GROUND [illegible]

[illegible]
[illegible]

SEPTEMBER 1977

U.S. ARMY MATERIEL SYSTEMS ANALYSIS ACTIVITY
ABERDEEN PROVING GROUND, MARYLAND

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: AMSAA TR-201	2. GOVT ACCESSION NO. (9) Technical rept. 2
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): (6) An Analysis of the Smoke Cloud Data from the August, 1975 Jefferson Proving Ground Smoke Test.	5. TYPE OF REPORT & PERIOD COVERED
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): (10) T. J. Dolce, D. F. Metz	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: US Army Materiel Systems Analysis Activity, Aberdeen Proving Ground, MD 21005	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: DA Project No. 1R765706M541 (16)
11. CONTROLLING OFFICE NAME AND ADDRESS: Commander, US Army Materiel Development and Readiness Command, 5001 Eisenhower Avenue, Alexandria, VA 22333	12. REPORT DATE: (11) Sept [redacted] 1977
	13. NUMBER OF PAGES: ~~108~~ (12) 99 p.
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): UNCLASSIFIED
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

DDC RECEIVED NOV 2 1977 F

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

smoke	smoke modelling	105mm howitzer
smoke munitions	60mm mortar	155mm howitzer
white phosphorus	81mm mortar	
hexachloroethane	4.2" mortar	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

In order to gather data on smoke cloud growth and characteristics, a test of artillery and mortar smoke munitions was conducted at the Jefferson Proving Ground, Indiana, on 19-21 August 1975. Ten rounds of each of the following WP and HC smoke munitions were dynamically fired in single-round fire missions: 155mm M110 WP; 105mm M60 WP; 4.2" M328 WP; 81mm M375 WP; 60mm M302 WP; 155mm M116 HC; 105mm M84 HC. The series also included a static firing of one round of each of these munitions.

4.2 IN.

(See Reverse)

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

403910

Data extraction, discussed in Section 2, was limited to meteorlogical data and to 16mm films of the clouds from three ground locations, as shown in Figure 1. Measures of cloud growth and other cloud characteristics were extracted from the films.

The data analysis, presented in Section 3, is to support the JTCG/ME Smoke Obscuration Model. It is therefore restricted to: cloud dimensions at early times; rate of rise of the WP plume. The time period of each analysis is limited by the filming time of each fire mission.

ACKNOWLEDGMENTS

The authors acknowledge Mr. Mike Carroll and Mr. Mark Kronman who assisted in the analysis of the JPG test data.

Next page is blank

TABLE OF CONTENTS

Next page is blank

LIST OF FIGURES

LIST OF FIGURES (CONT)

LIST OF TABLES

Next page is blank

AN ANALYSIS OF THE SMOKE CLOUD DATA FROM THE AUGUST 1975 JEFFERSON PROVING GROUND SMOKE TEST

1. INTRODUCTION

To gather data on smoke cloud growth and characteristics, a test of artillery and mortar smoke munitions was conducted at the Jefferson Proving Ground, Indiana, on 19-21 August 1975.[1] Ten rounds of each of the following WP and HC smoke munitions were dynamically fired in single-round fire missions: 155mm M110 WP; 105mm M60 WP; 4.2-inch M328 WP; 81mm M375 WP; 60mm M302 WP; 155mm M116 HC; 105mm M84 HC. The series also included a static firing of one round of each of these munitions.

Data extraction, discussed in Section 2, was limited to meteorological data and to 16mm films of the clouds from three ground locations, as shown in Figure 1. Measures of cloud growth and other cloud characteristics were extracted from the films.

The data analysis, presented in Section 3, is to support the JTCG/ME Smoke Obscuration Model.[2] It is therefore restricted to: cloud dimensions at early times; rate of rise of the WP plume. The time period of each analysis is limited by the filming time of each fire mission.

2. DATA EXTRACTION

Extensive measurements were made of WP and HC cloud characteristics from the ground-based 16mm films. The graduated reference markers in the field appeared with the clouds in the films, and provided a scale with which to extract linear dimensions. Time estimates were based on the filming speed of 24 frames/sec. An adjustment was applied to the measurements to account for the angle between the film plane* and the direction of cloud travel. This adjustment has been made to the data reported in Appendix A. The location of the smoke sources relative to the impact area were derived by use of the grid markings on the ground, which appeared in the 16mm photographic coverage from helicopters.

2.1 Meterological Conditions

The meteorological conditions of wind, atmospheric stability, and relative humidity are crucial to the growth and transport of a

*Cameras were in a fixed orientation

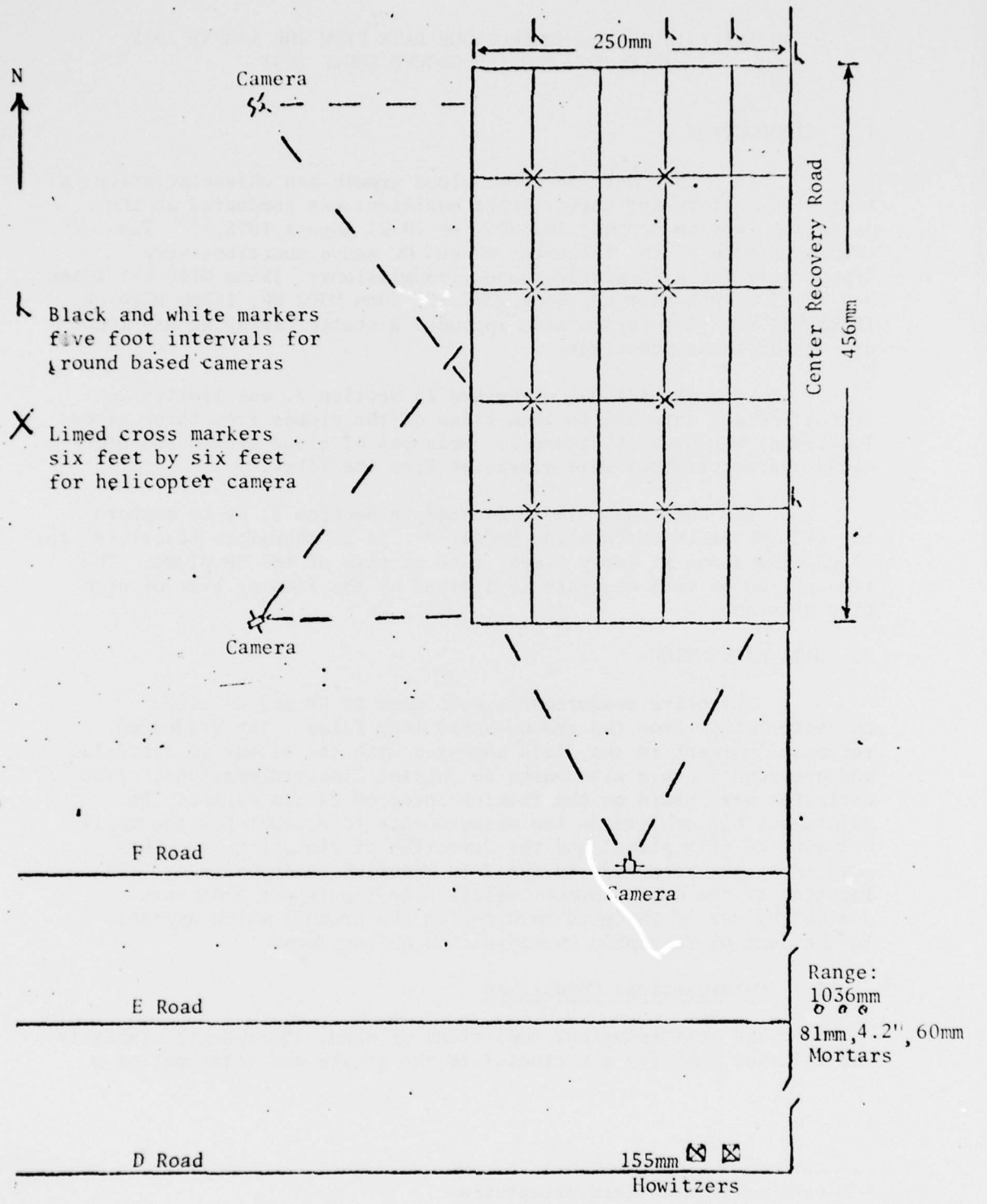


Figure 1. Diagram of Test Setup (1)

TABLE 1. JPG METEROLOGICAL DATA - SURFACE READINGS[1]

Time	Wind Data Dir.	Vel. (Knots)	Bar. Pres. Corrected	Temp °F XXX	Wet	RH	Den.	Viaibility	Precip.	Weather	Cloud Coverage
Date: 19 Aug 75											
0800	190	3	29.150	71.0		95	96.1	100% cld cover less than 1/2 mi.	None	Hazy-cldy	Ovc 7500'M
0900	270	0-2	29.170	72.0		91	95.9	"	Trace	" "	Ovc 4000'E
1000	120	2	29.180	73.0		91	95.7	100% cld cover less than 3/4 mi.	None	" "	Bkn 15000'
1100	255	4	29.180	79.0		75	94.6	No clouds, 2 mi.	None	Sunny	Unlimited
1200	280	2-4	29.178	82.0		69	94.1	Sct clds, 3 mi. 50%	None	Hazy-cldy	Bkn 8000'
1300	330	2	29.167	82.0		65	94.1	"	None	Hazy-PC	Bkn 8000'
1400	270	3	29.150	85.0		57	93.7	Cldy 80%, 5 mi.	None	Cldy	Bkn 5000'
1500	Calm	Calm	29.140	84.0		62	93.7	Cldy 90%, 4 mi.	Trace	Ptly Cldy	Bkn 4500'
1600	320	2	29.130	84.0		62	93.7	Cldy 90%, 4 mi.	None	"	Bkn 4500'
Date: 20 Aug 75									.020" overnite		
0800	90	6	29.242	72.0		91	96.1	No clouds, fog, 1/2 mile	None	Humid	Unlimited
0900	95	6	29.260	75.0		82	95.8	25% cumulus,1 mi.	None	"	Unlimited
1000	95	2	29.265	77.0		82	95.3	10% cumulus, 1 1/2 mile	None	"	Unlimited
1100	85	2	29.275	84.0		66	94.0	30% cumulus,2 mi.	None	PC, humid	Unlimited
1200	180	3	29.260	83.0		62	94.3	30% cumulus, 2 1/2 mile	None	" "	Sct 15000'
1300	250	4-8	29.258	86.0		57	93.7	50% cover,2 1/2 mi.	None	" "	Sct 15000'
1400	090	6	29.250	86.0		53	93.7	75% cover,2 1/2 mi.	None	" "	Bkn 10000'
1500	180	2-6	29.230	87.0		54	93.5	75% cover,2 1/2 mi.	None	Ptly Cldy	Sct 10000'
Date: 21 Aug 75											
0800	190	5-9	29.285	75.0	87	95.9		No clds, 1/2 mile	None	Clear	Haze 20000'
0900	210	4-10	29.270	79.0	87	94.9		" "	None	Clear	Haze 20000'
1000	210	6-13	29.260	82.0	65	94.4		" 1 1/2 mile	None	Clear	Unlimited
1100	210	5-12	29.255	85.0	63	93.8		" 3 mile	None	Clear	Unlimited
1200	220	6-15	29.268	87.0	55	93.5		30% cld cumulus,3 mi.	None	PC	Sct 15000'E
1300	245	8-14	29.260	89.0	55	93.0		50% cld cumulus,3 mi.	None	Cldy	Bkn 15000'E
1400	250	12-14	29.240	90.0	49	92.8		" "	None	Cldy	Bkn 15000'E
1500	260	8-12	29.220	90.0	52	92.8		" "	None	Cldy	Bkn 15000'E

TABLE 2. AMSAA METEOROLOGICAL DATA - SURFACE READINGS (1)

Time	Wind Data Dir.	Vel. (Knots)	Temp C Low	High	Dry	Wet	Ground Surface
Date: 19 Aug 75 - JPG Thermometers							
1412	North	2	27.1	26.6	27.8	24.7	31.4
1535	NW	2	28.7	27.9	28.3	24.4	31.0
1603	NW	3-4	26.0	24.4	25.0	23.1	25.0
1645	NW	3-4	24.6	23.8	27.3	24.2	
Date: 20 Aug 75 - AMSAA Thermometers							
1027	SSE	2-5	26.7	28.2	27.4	24.5	31.9
1103	SSE	.5-1	27.4	29.4	28.2	23.9	34.8
1140	SSE	3-4	28.2	30.1	29.2	33.8	35.3
1155	NNW	0-1	29.2	31.2	29.8	23.2	36.6
1252	E	2	30.0	32.0	31.2	25.7	37.7
1318	N	1-2	30.1	32.6			37.8
1355	NW	1-2.4	31.0	32.6			38.4
1430	SE	4-7	29.5	30.8			33.2
1500	NE	4-6	30.2	31.7	30.8	25.0	36.2
1530	NE	3-5	31.8	33.3			36.0
1600	NE	5-6	30.0	31.7	30.6	24.7	34.7
1635	NE	1.2	29.8	31.7			33.2
1705	SE	5-6	29.7	30.9			31.9
1735	NE	2-3	28.7	30.2	29.7	24.7	29.8
1800	E	3	28.4	29.9			28.6
1825	SE	2.2-2.6	27.0	28.4	28.1	24.3	27.5
Date: 21 Aug 75 - AMSAA Thermometers							
0930	SW	6-8	27.4	28.0	28.9	29.7	28.6
1030	SW	6-8	29.2	29.8	30.1	24.8	31.6
1115	SW	6-8	30.2	30.2	30.8	24.8	33.3
1135	SW	6-8	31.0	31.1	32.0	25.0	34.4
1215	SW	2-3	29.8	30.8	30.9	24.7	31.7
1255	SW	4-8	30.7	31.8			34.5
1328	SW	4-6	32.0	32.7	32.6	25.0	34.5
1355	WSW	4-6	32.0	32.6			35.3
1430	NNW	5-8	32.7	33.0	32.6	24.7	35.1
1500	WSW	4-6	31.8	32.3			34.0
1530	WSW	4-8	32.5	32.9	32.3	24.5	33.3
1555	WSW	2-4	31.8	32.7	32.0	25.0	33.2
1635	WSW	3-6	31.2	32.0	32.6	24.8	32.2
1710	WNW	2-4	30.9	31.8			31.2
1733	WNW	2-3	30.0	31.0	31.1	24.7	29.9

smoke cloud. The meteorological data gathered during the JPG test are presented in Tables 1 and 2, and may be related to the individual cloud data records in Appendix A.

An assessment was made of the Pasquill category of atmospheric stability for each fire mission. Pasquill categories of atmospheric stability[4] are identified by percent cloud cover and wind speed. The parameters defining each category may be used to predict the growth of a smoke cloud with a Gaussian distribution of mass. Small corrections to these groupings of the cloud measurements were made by comparing the measured heights of the WP plume centroid versus time for each munition. The need for such an adjustment probably reflects short-lived, localized variations in the meteorological conditions during the cloud development.

2.2 WP and HC Cloud Characteristics

A summary of WP and HC cloud characteristics for which measurements were made is given in Figures 2 and 3, respectively. This reflects the difference in nature of the WP and HC sources: conventional WP is a bursting munition which exhibits a pillaring effect due to the high heat flux generated by the rapid burning of the WP; HC burns in its component canisters over a 2 to 2.5 minute period. The clouds from the individual canisters quickly merge to form a single cloud which generally has the approximate shape of a right angle triangle. Because of its far simpler shape, fewer measurements were required of the HC clouds than of the WP clouds at each time. The measured cloud dimensions would allow a rough picture of the cloud to be constructed at each of the given times. The particular cloud dimensions exploited in this analysis, for use in the JTCG/ME Smoke Obscuration Model, are discussed in Section 3.

3. APPLICATION OF MEASURED DATA

The measurements of cloud characteristics presented in Appendix A were used for the following:

a. To obtain the height and width of the WP cloud just after the weapon phase, as a function of munition fill weight. The end of the "weapon phase" is the time when the glowing orange hemisphere becomes a white cloud, which is generally about one second after burst.

b. To calculate parameters for a function giving the height of the centroid of the WP plume as a function of time; a similar study was made of the farthest downwind portion of HC clouds, as this is the portion of the cloud where separation from the ground surface occurs. These parameters are given in Table 3.

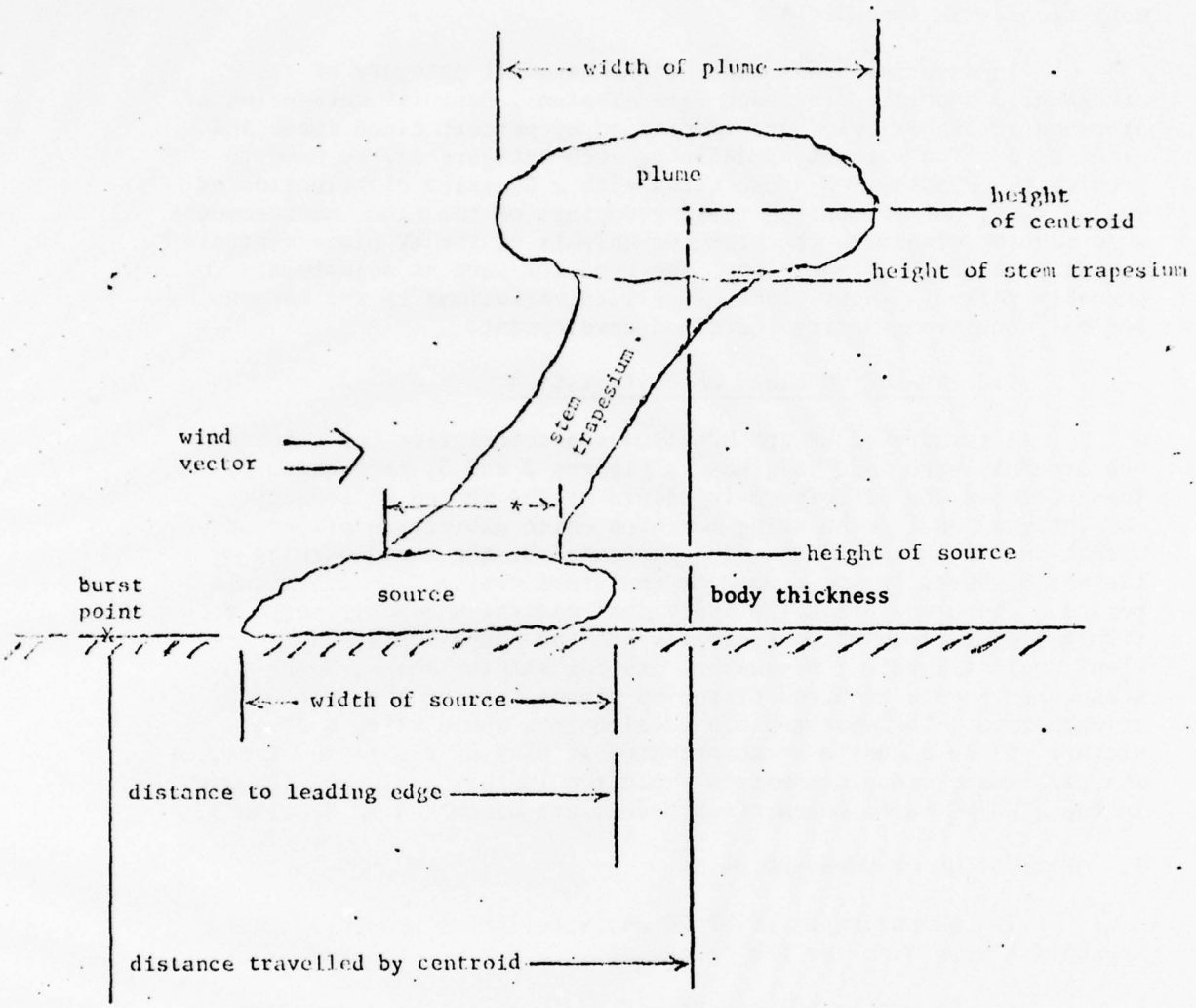


Figure 2. Summary WP Cloud Characteristics

*base of stem trapesium.

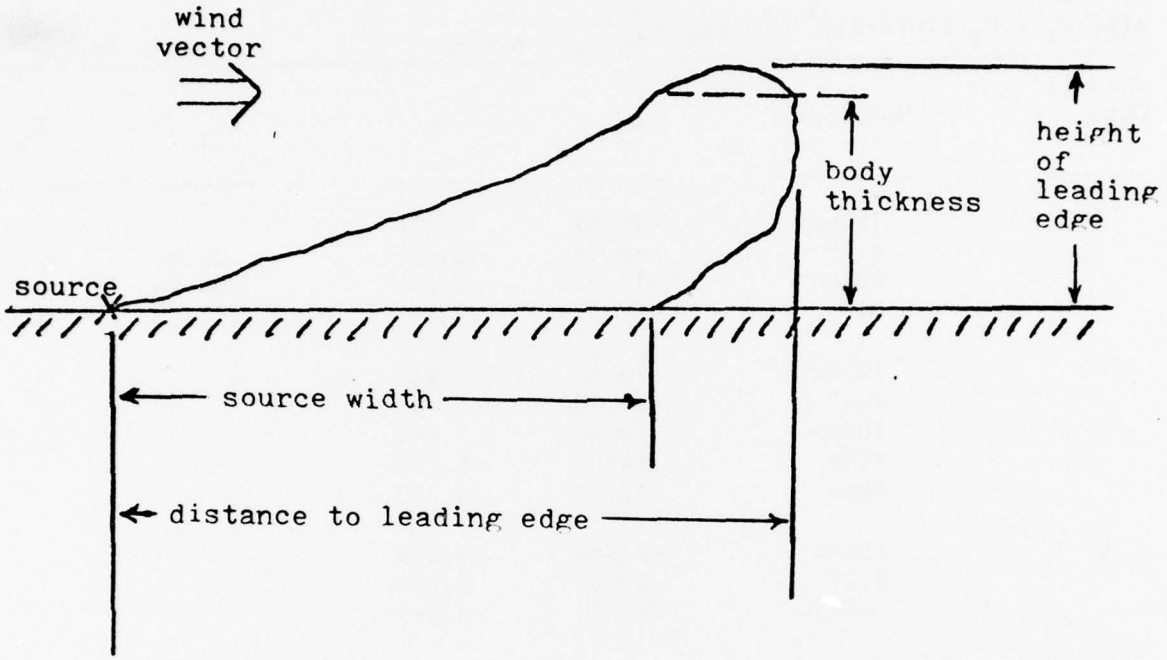


Figure 3. Summary of HC Cloud Characteristics

TABLE 3. PARAMETERS FOR CLOUD RISE FUNCTIONS

WP Smoke:
$z(t) = C_1 + C_2 (\ln(t+5))^2$

Pasquill Category	Munition	Dynamic Firing C_1	Dynamic Firing C_2	Static Firing C_1	Static Firing C_2
A	155mm	-23.07	9.428		
	4.2"	-30.34	12.15	-31.44	12.57
	105mm	-17.91	7.27	-23.88	8.862
	81mm	-27.33	10.91	-9.674	4.097
B	155mm	-18.03	7.482		
	4.2"	-16.80	6.919		
	105mm	-9.052	3.842		
	81mm	-14.07	5.795		
	60mm	-10.48	4.272		
C	155mm	-9.968	4.369		
	4.2"	-5.922	2.720		
	105mm	-5.909	2.636		

HC Smoke:
$z(t) = m.t + b$

Pasquill Category	Munition	Dynamic Firing m	Dynamic Firing b	Static Firing m	Static Firing b
A	155mm			0.129	1.4
	105mm	0.650	1.5		
B	155mm	0.555	1.5		
	105mm	0.237	1.35		
C	155mm	0.173	1.6		

3.1 Source Description

The Smoke Obscuration Model represents a smoke cloud as a Gaussian distribution of agent. To initiate the growth of the cloud, a measure of the base diameter and the height of the cloud at the time of its formation are needed. These measures are referred to as the "source sigmas" of the distribution, where $4\sigma_{xs}$ ($=4\sigma_{ys}$) represent the base diameter in the windward and crosswind directions, respectively, and $4\sigma_{zs}$ represents the height, wherein more than 99% of the cloud material is contained. The existing values, represented by the solid lines in Figure 4, are based on numerous experimental data points for mortar rounds compiled from the literature by Mr. M. C. Johnson.[1] Some of the points had been crudely measured hence the need for verification.

Measurements of the source sigmas from the JPG test are given in Figure 4 as circled dots. They were averaged for each WP munition, independent of meteorological conditions and other factors which were considered to be non-influential at such early times. The measured σ_{ys} values for both mortar and artillery lie fairly close to the solid σ_{ys} curve. However, their consistently greater value than the existing values may indicate that the curve should be adjusted upward. The measured σ_{zs} values for the mortar rounds lie close to the existing curve for σ_{zs}, but, as noted above, their consistently higher values may indicate that the existing curve for σ_{zs} should be adjusted upward. The test values for the σ_{zs} artillery rounds are so much higher than those for the mortar rounds that a separate curve may be indicated, as shown by the dashed line in Figure 4. If the σ_{zs} values for artillery and mortar rounds may be lumped together, as in the case of σ_{ys}, then the existing σ_{zs} curve should still be adjusted upward.

3.2 WP Plume Rise Models

The smoke cloud produced by the conventional, bulk-filled WP munitions generally exhibits a strong pluming effect, due to the high heat flux from the burning smoke agent. Because the plume generally contains a high percentage of the original fill weight, and because of its tactical value, its influence must be considered in certain calculations of smoke obscuration.

Two mathematical forms which predict the height of the centroid of the plume were considered for application to the JPG data: the Joules model,[3] which was developed from a consideration of basic principles of the growth of the plume (see Appendix C), and was

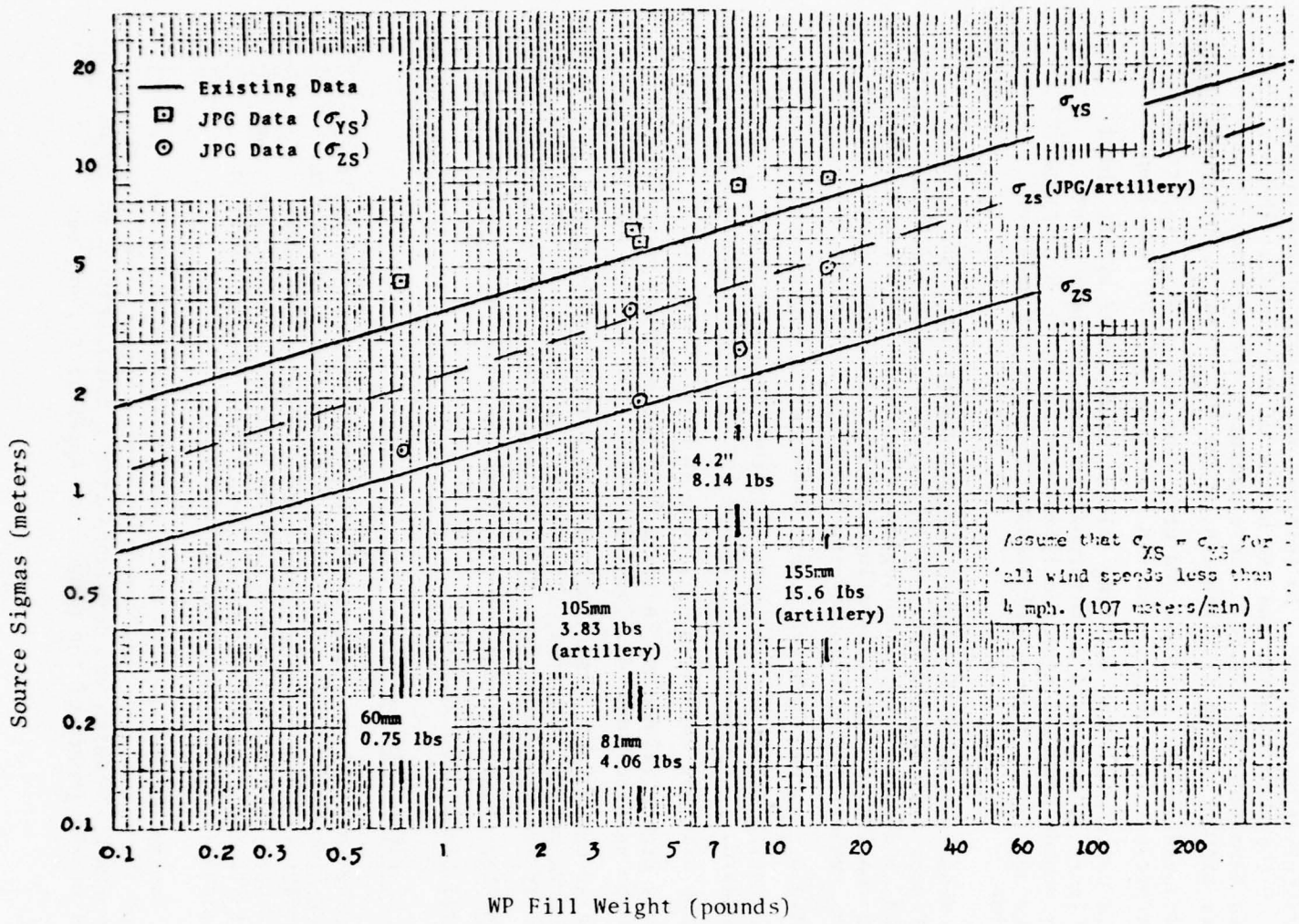


Figure 4. Source Sigmas vs WP Fill Weights

intended primarily as a research tool; and a modified logarithmic function which was an accurate and convenient curve fit of the data. Because of its explicit use of several interesting variables, an effort was made to implement the Joules model. However, for reasons of expediency, this attempt was abandoned in favor of the curve fit form.

The expression, given, below, is a function of time only, and is implicitly a function of munition, wind speed, and condition of atmospheric stability:

$$Z(t)=C_1 + C_2 (\ln (t + 5))^2, \text{ where}$$

z = height of centroid (m)

t = time after burst (sec.)

C_1, C_2 are constants determined by a least squares fit of the function to the data.

Figures 9 through 11 give the height of centroid for the 155mm WP, Pasquill categories, A, B and C, respectively, as generated by the Joules function (based on Yuma Proving Ground data) and the curve fit (based on Jefferson Proving Ground data). The "adjusted curve fit," which appears in several of the figures, is simply the curve fit to the given data points which was translated vertically to conform to the initial size of the cloud (σ_z) at t=0. Considering the numerous sources of discrepancy, the comparison is quite reasonable. Graphs of the height of rise data and their fitted functions for other WP munitions are given in Figures 12 through 20. Table 3 contains the values of C_1 and C_2 for all of the curve fits.

3.3 HC Cloud Rise Model

Without a separate, explicit cloud rise function, the Smoke Obscuration Model permits the centroid of a cloud to rise only as a result of cloud expansion. Based on observations of HC clouds, this assumption seemed to be questionable when applied to the leading portion of an HC cloud. For this reason data describing the rate of rise of the centroid of the leading portion of HC clouds were extracted from the JPG test results. A linear function was successfully applied to curve fit these cases. Their graphs and curve fitted parameters are given in Figures 21 through 24 and in Table 1, respectively.

3.4 Static Firings

Cloud characteristics were also measured for several static firings. A comparison with the rise functions for the dynamic shots

would indicate the influence of the motion of the projectile, entrenchment of smoke agent particles in the earth, etc. These graphs and curve fitted parameters are given in Figures 25 through 29 and in Table 1, respectively.

4. CONCLUSIONS

a. The JPG test data indicate that the source sigmas currently used in the Smoke Obscuration Model may be about 45 percent low for artillery munitions.

b. The test data indicate that separate functions for the initial vertical component of cloud growth for artillery and mortar munitions may be needed.

c. The test data and curve fit function for the rise of the centroid of the 155mm WP plume closely approximate for predictions by the more sophisticated Joules rise function.

d. The height of rise of the centroid of the downwind portion of HC clouds may be represented by a simple linear function of time.

It is recommended that each of these aspects of data and extraction and analysis be separated with other smoke tests, and the results amalgamated with those presented herein.

REFERENCES

1. Ford, B., Support Test of Artillery and Mortar Smoke Munitions, Final Report; USA Jefferson Proving Ground, Test Report No. 75-1789, September 1975. UNCLASSIFIED.

2. Johnson, M.C., and Forney, P. D., The Effectiveness of Obscuring Smokes, (Unpublished). UNCLASSIFIED

3. Joules, R. G., Vertical Rise of a Heated Plume; ARMCOM Methodology Division Memorandum for Record, 28 April 1975.

4. Progress Report on the Development of a BCW Forecast System; Booze-Allen Applied Research Inc., Report No. 141-2-16-R7, October 1963. UNCLASSIFIED.

Next page is blank

APPENDIX A. CLOUD DATA SHEETS

Next page is blank

JEFFERSON PROVING GROUND SMOKE TEST

CLOUD CHARACTERISTICS

Munition 60mm WP
Shot Number A-1 S looking E

Date Aug. 19
Time of Firing 1557

Wind Speed (kts) 3-4
% Cloud Cover 90
Particle Dispersion Width (m)

Wind Direction (^{O}TN) 315

	Source			Stem		Plume Centroid		Width of Plume (m)
				Trapesium				
Frame No.	Time (Sec)	Width (m)	Thickness (m)	Base (m)	Height (m)	Distance Travelled (m)	Height (m)	
1	0	12.9	4.57					
3	.125	15.1	4.57					
8	.333	15.1	5.33					
11	.458	16.2	6.1					
18	.75	20.5	6.1					
25	1.04	23.7	6.86					
33	1.38	24.8	8.38					
48	2.00	30.2	8.38					
57	2.38	32.3	24.4					
64	2.67	32.3	25.9					
76	3.17	32.3	27.4					
88	3.67		13.7	30.2	10.7			
118	4.92		10.7	32.3	12.2		11.4	18.1
141	5.88		13.0	32.3	10.7		12.2	21.6
165	6.88		15.2	32.3	10.7		12.2	21.6
199	8.29		16.8	28.0	9.14		14.5	25.9
240	10.		15.2	15.1	10.7		19.1	28.0
288	12.		18.3	19.4	9.14		21.3	30.2

JEFFERSON PROVING GROUND SMOKE TEST

CLOUD CHARACTERISTICS

Munition 60mm WP
Shot Number A-1 (Cont)

Date Aug. 19
Time of Firing 1557

Wind Speed (kts) 3-4
% Cloud Cover 90
Particle Dispersion Width (m) _____

Wind Direction (^{O}TN) 315

		Source		Stem		Plume Centroid		Width of Plume (m)
				Trapesium				
Frame No.	Time (Sec)	Width (m)	Thickness (m)	Base (m)	Height (m)	Distance Travelled (m)	Height (m)	
360	15		22.9	19.4	9.14		22.9	32.3
480	20		28.2	25.9	12.2		30.5	38.8
605	25.2		32.0	28.0	12.2		36.6	41.0
720	30		36.6	36.6	12.2		41.2	45.3
840	35		41.2	38.8	12.2		44.2	49.6
960	40		33.5	38.8	12.2		48.8	49.6
1010	42.1		33.5	41.0	12.2		50.3	45.3

JEFFERSON PROVING GROUND SMOKE TEST

CLOUD CHARACTERISTICS

Munition 155mm WP
Shot Number A-5 S looking E

Date Aug. 19
Time of Firing 1640

Wind Speed (kts) 3-4
% Cloud Cover 90
Particle Dispersion Width (m) 182

Wind Direction (^{O}TN) 340

	Source			Stem		Plume Centroid		Width of Plume
				Trapesium		Distance		
Frame No.	Time (Sec)	Width (m)	Thickness (m)	Base (m)	Height (m)	Travelled (m)	Height (m)	(m)
1	0	10.8	4.35					
5	.208	18.5	10.2					
10	.417	21.6	13.1					
30	1.25	30.8	20.3					
55	2.29	38.5	20.3					
76 +	3.17	46.2	23.2					
108	4.5	53.9	23.2					
173	7.21			55.4	16.0			
397	16.5			52.4	34.8		43.5	52.4
563	23.5			58.5	26.1		47.9	69.3
852	35.5			58.5	29.0		53.7	93.9
1292	53.8			61.6	43.5		59.5	120.

+ end of weapon phase

JEFFERSON PROVING GROUND SMOKE TEST

CLOUD CHARACTERISTICS

Munition 155mm WP
Shot Number E-5 S looking E

Date Aug. 20
Time of Firing 1650

Wind Speed (kts) 3-3.5
% Cloud Cover 75
Particle Dispersion Width (m) _____

Wind Direction (^{O}TN) 161

	Source			Stem		Plume Centroid		
				Trapesium		Distance		Width
Frame No.	Time (Sec)	Width (m)	Thickness (m)	Base (m)	Height (m)	Travelled (m)	Height (m)	of Plume (m)
	0	11.6	2.22					
	.250	63.2	9.97					
	.625	76.4	14.4					
	1.46+	106	16.6					
	4.42	123	27.7					16.6
	9.04	106	22.2	149	33.5		31.0	49.7
	16.6	159	38.8	216	39.9		52.1	106
	25.8	183	48.5	278	59.6		72.0	183
	35.3	208	58.2	332	80.4		91.4	266
	41.5	237	69.3	365	88.7		108	320
	71.6*							

* still burning
\+ end of weapon phase

JEFFERSON PROVING GROUND SMOKE TEST

CLOUD CHARACTERISTICS

Munition 4.2" WP
Shot Number B-3 S looking N

Date Aug. 20
Time of Firing 1320

Wind Speed (kts) 1-2
% Cloud Cover 60
Particle Dispersion Width (m) _____

Wind Direction (^{o}TN) 25

	Source			Stem		Plume Centroid		
				Trapesium				Width of Plume (m)
Frame No.	Time (Sec)	Width (m)	Thickness (m)	Base (m)	Height (m)	Distance Travelled (m)	Height (m)	
	.042	26.9	8.13					
	.33	24.6	11.2					
	.92	60.5	10.2					
	2.38	58.2	22.4					
	4.71	51.6	30.5	67.3	31.4		26.4	
	6.5	53.8	38.6	67.8	29.2		34.5	
	8.42	51.6	48.8	67.3			46.7	
	11.0	67.3	50.8	62.8	40.4		58.9	
	17.5	76.2	71.1	53.8	31.3		83.3	
	24.4	101.	77.2	38.1	29.2		108.	
	32.5	130.	79.3	40.4			128	

JEFFERSON PROVING GROUND SMOKE TEST

CLOUD CHARACTERISTICS

Munition 4.2" WP
Shot Number C-3 S looking N

Date Aug. 20
Time of Firing 1325

Wind Speed (kts) 1-2
% Cloud Cover 60
Particle Dispersion Width (m) _____

Wind Direction (^{O}TN) 280

		Source		Stem		Plume Centroid		
				Trapesium				
Frame No.	Time (Sec)	Width (m)	Thickness (m)	Base (m)	Height (m)	Distance Travelled (m)	Height (m)	Width of Plume (m)
1	0	7.43	4.9					
1	.042	32.2	12.2					
13+	.54	66.9	13.4					
32	1.33	89.1	19.5					
72	3.0		24.4	111	21.8		24.4	54.5
119	4.96		36.6	114	24.8		31.0	61.9
177	7.38		43.9	111	24.8	139	56.1	84.2
298	12.4		65.0	173	26.7	149	80.5	117
515	21.5		92.7	198	91.6	198	117	117
761	31.7		132	223	86.6	223	154	131
985	41.0		146				201	142

+ end of weapon phase

JEFFERSON PROVING GROUND SMOKE TEST

CLOUD CHARACTERISTICS

Munition 4.2" WP
Shot Number D-3 S looking E

Date Aug. 20
Time of Firing 1618

Wind Speed (kts) 3
% Cloud Cover 75
Particle Dispersion Width (m) _____

Wind Direction (^{o}TN) 20

		Source		Stem		Plume Centroid		Width of Plume (m)
Frame No.	Time (Sec)	Width (m)	Thickness (m)	Trapesium Base (m)	Trapesium Height (m)	Distance Travelled (m)	Height (m)	
1	0	15.1	5.08					
4	.167	24.9	5.59					
15	.625	34.6	6.1					
27 +	1.13							
76	3.17			19.5	10.8		9.14	
190	7.92	29.2	22.4	46.5	10.8		20.3	
325	13.5	35.7	30.5	50.8	25.9		35.6	
478	19.9	49.7	40.6	51.9	35.7		43.7	
623	26.0	54.1	45.7	45.4	43.1		54.9	
841	35.0	73.0	58.4	43.2	54.1		67.3	
1058	44.1	90.6	68.5	46.5	64.9		81.3	
1318	54.9	118.9	76.2	45.4	83.8		109.	

+ end of weapon phase

JEFFERSON PROVING GROUND SMOKE TEST

CLOUD CHARACTERISTICS

Munition 4.2" WP
Shot Number E-3 S looking E

Date Aug. 20
Time of Firing 1635

Wind Speed (kts) 1.2
% Cloud Cover 75
Particle Dispersion Width (m) _____

Wind Direction (^{O}TN) 161

	Source			Stem		Plume Centroid		
				Trapesium				Width of
Frame No.	Time (Sec)	Width (m)	Thickness (m)	Base (m)	Height (m)	Distance Travelled (m)	Height (m)	Plume (m)
	0	26.6	4.43					
	.25	66.5	5.54					
	.75	83.0	6.65					
	1.04 +							
	1.42	106.	9.98					
	3.58	133.	21.1					
	7.71	79.7	17.7	176	20.0		26.6	
	12.7	83.0	23.3	179	28.8	53.1	37.7	53.1
	19.8	146	44.3	133	27.7	106.	41.0	106.
	26.6	79.7	52.1	163	33.3	166.	54.0	166.
	36.3	199	66.5	179	38.8	220.	66.5	220.
	46.1	224	88.7	216	58.2	286.	81.7	286.
	68.3*							

* still burning
\+ end of weapon phase

JEFFERSON PROVING GROUND SMOKE TEST

CLOUD CHARACTERISTICS

Munition 4.2" WP
Shot Number F-3 S looking E

Date Aug. 20
Time of Firing 1815

Wind Speed (kts) 2.5
% Cloud Cover 75
Particle Dispersion Width (m)

Wind Direction (^{O}TN) 160

	Source			Stem		Plume Centroid		
Frame No.	Time (Sec)	Width (m)	Thickness (m)	Trapesium Base (m)	Trapesium Height (m)	Distance Travelled (m)	Height (m)	Width of Plume (m)
	0	9.41	5.54					
	.208	28.2	5.54					
	.625	38.8	7.76					
	1.21+							
	1.29	52.9	7.76					
	2.21	58.8	12.2					
	4.92	23.6	15.5	60.3	11.1		16.6	7.05
	10.7	43.5	27.7	64.7	22.2		34.5	23.6
	17.9	55.8	38.8	64.7	38.8		52.6	43.5
	29.7	61.7	55.4	75.0	52.6		80.4	80.8
	40.3*	75.0	72.0	99.9	69.3		119	121

* still burning

+ end of weapon phase

JEFFERSON PROVING GROUND SMOKE TEST

CLOUD CHARACTERISTICS

Munition 105mm WP
Shot Number C-4 S looking E

Date Aug. 20
Time of Firing 1445

Wind Speed (kts) 4-6.5
% Cloud Cover 75
Particle Dispersion Width (m) _____

Wind Direction (°TN) 161

	Source			Stem		Plume Centroid		Width of Plume (m)
				Trapesium		Distance		
Frame No.	Time (Sec)	Width (m)	Thickness (m)	Base (m)	Height (m)	Travelled (m)	Height (m)	
20	.83		6.1					
86	3.58		12.2					
136	5.67		18.3					
236	9.83	25.9	14.6	19.4	15.8		13.4	
348	14.5	32.4	24.4	11.6	6.1		15.8	
401	16.7	33.6	28.0	6.47	9.8		15.8	
544	22.7	54.3	34.1	12.9	10.9		24.4	
679	28.3	55.7	36.6		12.2		28.0	

JEFFERSON PROVING GROUND SMOKE TEST

CLOUD CHARACTERISTICS

Munition 81mm WP
Shot Number C-2 S looking N

Date Aug. 20
Time of Firing 1345

Wind Speed (kts) 1-2.3
% Cloud Cover 75
Particle Dispersion Width (m) _____

Wind Direction (°TN) 20

	Source			Stem		Plume Centroid		
				Trapesium		Distance		Width
Frame No.	Time (Sec)	Width (m)	Thickness (m)	Base (m)	Height (m)	Travelled (m)	Height (m)	of Plume (m)
1	0	8.7	4.05					
3	.083	18.4	6.1					
7	.292 +	25.9	7.4					
36	1.46	34.6	12.2					
58	2.38	35.8	36.6					
88	3.63	25.9	16.3	19.5	17.3		16.3	
119	4.92	28.1	16.3	64.9	19.5		22.3	
167	6.88	34.6	23.4	69.2	21.6		27.4	
402	16.7	54.1	36.6	130.	19.5		43.8	
659	27.4	54.1	63.0	186.	19.5		67.1	
874	36.4	61.0	238	238.	17.3		77.2	

+ end of weapon phase

JEFFERSON PROVING GROUND SMOKE TEST

CLOUD CHARACTERISTICS

Munition 81mm WP
Shot Number F-2 S looking E

Date Aug. 20
Time of Firing 1822

Wind Speed (kts) 2.4
% Cloud Cover 75
Particle Dispersion Width (m) _____

Wind Direction (^{O}TN) 165

	Source			Stem		Plume Centroid		
				Trapesium				
Frame No.	Time (Sec)	Width (m)	Thickness (m)	Base (m)	Height (m)	Distance Travelled (m)	Height (m)	Width of Plume (m)
	0	8.03	3.88					
	.458 +	18.4	6.65					
	2.63	31.0	11.1					
	4.04	16.1	9.98	36.7	6.88		11.1	
	4.67	18.4	11.1	34.4	8.03		12.2	
	6.5	23.0	13.3	34.4	10.3		14.4	5.74
	9.25	24.1	14.4	28.2	14.9		18.8	10.3
	14.9	32.1	18.8	35.9	23.0		27.7	16.1
	23.4	29.8	22.2	37.9	32.1		42.1	29.8
	35.4	31.0	29.9	40.2	41.3		54.3	52.8
	46.0	44.8	43.2	55.1	47.0		61.0	77.5

+ end of weapon

JEFFERSON PROVING GROUND SMOKE TEST

CLOUD CHARACTERISTICS

Munition 60mm WP
Shot Number C-1 S looking N

Date Aug. 20
Time of Firing 1343

Wind Speed (kts) 1-2.2
% Cloud Cover 75
Particle Dispersion Width (m) _____

Wind Direction (^{O}TN) 295

	Source			Stem		Plume Centroid		
				Trapesium				
Frame No.	Time (Sec)	Width (m)	Thickness (m)	Base (m)	Height (m)	Distance Travelled (m)	Height (m)	Width of Plume (m)
58	0	8.77	5.08					
64	0.25 +	17.9	4.05					
88	1.25	31.4	12.2					
119	2.54			26.9	11.5		15.2	13.5
167	4.54			33.6	15.7		17.3	22.4
402	14.3			126	13.5		39.6	47.1
659	25.0			200	29.2		50.8	55.7
874	34.0			296	56.1		50.8	87.4

+ end of weapon phase

JEFFERSON PROVING GROUND SMOKE TEST

CLOUD CHARACTERISTICS

Munition 60mm WP
Shot Number F-1 S looking E

Date Aug. 20
Time of Firing 1822

Wind Speed (kts) 2.2 - 2.6
% Cloud Cover 75
Particle Dispersion Width (m)

Wind Direction (^{o}TN) 200

	Source			Stem		Plume Centroid		Width of Plume (m)
Frame No.	Time (Sec)	Width (m)	Thickness (m)	Trapesium Base (m)	Trapesium Height (m)	Distance Travelled (m)	Height (m)	
1	.042	9.20	4.43					
15 +	.625	21.2	5.52					
59	2.46	27.0	11.1					
125	5.21	11.8	7.76	34.1	14.4		16.6	4.7
260	10.8	16.5	11.1	37.6	23.2		27.7	16.5
465	19.4	29.4	17.7	41.2	32.1		41.0	35.3
753	31.4	38.8	33.3	49.4	41.0		55.4	57.6
1008	42.0	48.5	44.3	58.8	41.6		61.0	88.2

+ end of weapon phase

JEFFERSON PROVING GROUND SMOKE TEST

CLOUD CHARACTERISTICS

Munition 155mm HC
Shot Number A-7 S looking N

Date Aug. 20
Time of Firing 1140

Wind Speed (kts) 3-4
% Cloud Cover 30
Cannister Dispersion (m)

Wind Direction (^{o}TN) 157
Burn Time (sec)

Canister	Time (sec)	Source Width (m)	Body Thickness (m)	Distance To Leading Edge (m)	Height of Leading Edge (m)
1	1.08	19.9	6.1		
2	1.08	15.9	4.6		
3	1.08	9.93	3.05		
1, 2	2.0	35.9	9.9		
3	2.0	12.0	9.6		
3	3.54			51.7	12.2
3	3.54			13.9	6.1
3	6.04				
	8.46*				
	17.0	215		243	24.4
	29.5	319		350	36.6
	37.8	370		418	51.4
	46.2	398		458	61.0
	54.5	408		513	68.6
	63.1	438		533	91.4
	71.3	403		488	113
	84.8	433		508	133

* merger of individual clouds

JEFFERSON PROVING GROUND SMOKE TEST

CLOUD CHARACTERISTICS

Munition 155mm HC
Shot Number B-7 S looking N

Date Aug. 20
Time of Firing 1145

Wind Speed (kts) 2-3
% Cloud Cover 30
Cannister Dispersion (m)

Wind Direction (°TN)
Burn Time (sec) 202

Canister	Time (sec)	Source Width (m)	Body Thickness (m)	Distance To Leading Edge (m)	Height of Leading Edge (m)
1	5.63	17.6		22.0	8.13
2	5.63	17.6		13.2	6.10
3	5.63	17.6		11.0	8.13
4	5.63	7.70		11.0	5.08
1	13.4	35.2	9.14	39.6	
2	13.4	17.6	19.3	26.4	
3	13.4	39.6	16.3	48.4	
1	21.6	41.8		61.6	26.4
2	21.6	41.8		57.2	24.4
1	29.9	48.4	26.4	70.4	
2	29.9	61.6	30.5	72.6	
	38.5*	108		126	36.6
	59.1	137		165	55.9
	66.7	159		176	66.0

* merger of individual clouds

JEFFERSON PROVING GROUND SMOKE TEST

CLOUD CHARACTERISTICS

Munition 155mm HC
Shot Number E-7 S looking E

Date Aug. 20
Time of Firing 1746

Wind Speed (kts) 2.5-3
% Cloud Cover 75
Cannister Dispersion (m)

Wind Direction (^{o}TN) 71
Burn Time (sec)

Canister	Time (sec)	Source Width (m)	Body Thickness (m)	Distance To Leading Edge (m)	Height of Leading Edge (m)
1	.042	23.3	5.54	33.2	
2	.042	16.6	3.33	33.2	
3	.042	9.98		9.98	
1	1.13	33.2	5.54	43.2	
2	1.13	19.3	3.33	39.8	
3	1.13	13.3	4.43	13.3	
1, 2	4.08	73.1		73.1	3.33
3	4.08	21.6		21.6	6.64
	10.6*	120		133	9.97
	19.4	154		179	13.3
	29.4	203		245	13.3
	41.5	266		332	16.6
	53.8	349		419	22.2
	66.6	415		498	27.7

* merger of individual clouds

JEFFERSON PROVING GROUND SMOKE TEST

CLOUD CHARACTERISTICS

Munition 155mm HC
Shot Number F-7 S looking E

Date Aug. 20
Time of Firing 1754

Wind Speed (kts) 2.5-3
% Cloud Cover 75
Cannister Dispersion (m)

Wind Direction (^{o}TN) 65
Burn Time (sec)

Canister	Time (sec)	Source Width (m)	Body Thickness (m)	Distance To Leading Edge (m)	Height of Leading Edge (m)
	.042	48.1		48.1	6.10
	4.67	117.		117	3.66
	10.8	136		136	4.88
	17.0	149		149	6.10
	26.8	195		195	7.32
	40.1	216		241	17.1
	52.5	276		305	24.4
	62.0	340		375	24.4
	69.2	361		432	24.4
	84.8	425		566	24.4

JEFFERSON PROVING GROUND SMOKE TEST

CLOUD CHARACTERISTICS

Munition 105mm HC
Shot Number B-6 S looking N

Date Aug. 20
Time of Firing 1152

Wind Speed (kts) 0-1
% Cloud Cover 30
Cannister Dispersion (m) 24.4

Wind Direction (^{o}TN) 157
Burn Time (sec) 91-100

Canister	Time (sec)	Source Width (m)	Body Thickness (m)	Distance To Leading Edge (m)	Height of Leading Edge (m)
1	0	15.9	4.88		
1	0	19.1	3.66		
2	2.21	31.9	7.32		
2	2.21	35.0	6.10		
	5.92*	51.0	12.2	70.0	
	6.25	63.7	13.4	82.8	
	12.3	172		210	19.5
	22.5	280		338	36.6
	35.0	420		542	41.5
	46.6	534		574	57.9
	81.3				

* merger of individual clouds

JEFFERSON PROVING GROUND SMOKE TEST

CLOUD CHARACTERISTICS

Munition 105mm HC
Shot Number C-6 S looking E

Date Aug. 20
Time of Firing 1507

Wind Speed (kts) 4-6
% Cloud Cover 75
Cannister Dispersion (m) 104

Wind Direction (°TN) 71
Burn Time (sec) _____

Canister	Time (sec)	Source Width (m)	Body Thickness (m)	Distance To Leading Edge (m)	Height of Leading Edge (m)
1	.83	18.2			2.4
2	.83	7.31			3.7
3	.83	11.0			3.0
1	5.29	47.3		47.3	2.4
2	5.29	18.3		25.5	8.5
3	5.29	18.3		25.5	6.1
1	12.8	110.		110.	6.1
2	12.8	47.3		62.0	14.6
3	12.8	58.4		76.7	8.5
	21.1*			283.	9.1
	29.6	288.		329.	14.6
	38.3	332		374.	17.1
	50.9	402		475	28.0
	63.8	475		534	24.4
	83.9	612		685	29.3
	84.6	717		795	45.1

* merger of individual clouds

JEFFERSON PROVING GROUND SMOKE TEST
CLOUD CHARACTERISTICS

Munition 155mm WP
Shot Number G-5 S looking N

Date Aug. 21
Time of Firing 1103

Wind Speed (kts) 6-8
% Cloud Cover 0
Particle Dispersion Width (m) _____

Wind Direction (°TN) 210

	Source			Stem		Plume Centroid		Width of Plume (m)
Frame No.	Time (Sec)	Width (m)	Thickness (m)	Trapesium Base (m)	Height (m)	Distance Travelled (m)	Height (m)	
	0	30.4	7.62					
	.208	76.2	27.4					
	.75	131	41.1					
	1.0 +	152	45.7					
	2.0	236	45.7					
	5.0	293	68.6					
	10.0	328	15.2			91.4	48.8	152
	15.0	343	19.8	67.0	48.8	91.4	77.7	165
	20.0	373	22.9	91.4	54.9	110	76.2	198
	25.0	366	22.9	85.4	57.9	122	87.6	244
	30.0	358	24.4	122	54.9	122	91.4	229
	35.0	351	25.9	152	61.0	152	101	168

+ end of weapon phase

JEFFERSON PROVING GROUND SMOKE TEST

CLOUD CHARACTERISTICS

Munition 155mm WP
Shot Number H-5 S looking N

Date Aug. 21
Time of Firing 1240

Wind Speed (kts) 3-6
% Cloud Cover 50
Particle Dispersion Width (m) _____

Wind Direction (^{o}TN) 245

		Source		Stem		Plume Centroid		
				Trapesium				Width
Frame No.	Time (Sec)	Width (m)	Thickness (m)	Base (m)	Height (m)	Distance Travelled (m)	Height (m)	of Plume (m)
1	0	18.5	5.57					
2	.083	24.6	8.36					
5	.208	24.6	9.75					
16	.67 +	35.4	20.9					
24	1.0	49.2	23.7					
42	1.75	72.3	30.7			7.70		
57	2.38	99.9	36.2			15.1		
75	3.13	99.9	22.3	99.9	23.7	18.5	33.4	27.7
99	4.13	138	26.5	26.1	33.4	24.6	46.0	33.8
146	6.08	154	39.0	23.1	44.6	38.4	57.1	46.1
198	8.25	158	44.6	33.8	51.6	50.7	65.5	61.5
243	10.1	165	55.7	30.7	58.5	66.1	76.6	69.2
292	12.2	174	62.7	38.4	65.5	80.0	80.8	83.0
388	16.2	177	62.7	53.8	69.7	115	90.6	111
446	18.6	191	61.3	76.9	65.5	131	90.6	115

+ end of weapon phase

JEFFERSON PROVING GROUND SMOKE TEST

CLOUD CHARACTERISTICS

Munition 105mm HC
Shot Number D-6 S looking E

Date Aug. 20
Time of Firing 1528

Wind Speed (kts) 3-5
% Cloud Cover 75
Cannister Dispersion (m)

Wind Direction (^{O}TN) 71
Burn Time (sec)

Canister	Time (sec)	Source Width (m)	Body Thickness (m)	Distance To Leading Edge (m)	Height of Leading Edge (m)
1	1.04	11.0	2.44		
2	1.04	11.7	3.90		
3	1.04	11.0	3.66		
1	3.21	29.2	3.66		
2	3.21	11.0	4.88		
3	3.21	14.6			
1	8.75	51.1		58.5	4.27
2	8.75	21.9		32.9	10.4
3	8.75	40.2		47.5	6.71
1	14.9	87.7		102.	6.71
2	14.9	47.5		65.8	15.9
3	14.9	58.5		76.7	9.75
	20.5*	256		270	11.0
	30.9	292		329	15.9
	42.8	358		402	19.5
	59.2	449		493	20.7
	76.4	544		621	34.1
	88.3	636		712	36.6
	99.0	712		794	48.8

* merger of individual clouds

JEFFERSON PROVING GROUND SMOKE TEST

CLOUD CHARACTERISTICS

Munition 155mm WP
Shot Number I-5 S looking N

Date Aug. 21
Time of Firing 1416

Wind Speed (kts) 4-6
% Cloud Cover 50
Particle Dispersion Width (m) _____

Wind Direction (^{o}TN) 250

	Source			Stem		Plume Centroid		
				Trapesium				Width
Frame No.	Time (Sec)	Width (m)	Thickness (m)	Base (m)	Height (m)	Distance Travelled (m)	Height (m)	of Plume (m)
1	0	9.73	4.57					
13 +	54	25.9	13.7					
72	3.0	35.7	22.9					
120	5.0	45.4	3.05			32.4	15.2	37.3
168	7.0	48.1	22.9			48.7	30.5	27.6
216	9.0	81.1	27.4			66.5	38.1	32.4
360	15.0	122	30.5	21.1	38.1	101	45.7	45.4
482	20.1	157	30.5	40.6	42.7	127	57.9	50.3
600	25.0	190	38.1	35.7	53.3	154	67.1	58.4
721	30.0	216	41.2	48.7	54.9	177	68.6	58.4
953	39.7	227	41.2	48.7	61.0	235	76.2	87.6

+ end of weapon phase

JEFFERSON PROVING GROUND SMOKE TEST

CLOUD CHARACTERISTICS

Munition 155mm WP
Shot Number J-5 S looking N

Date Aug. 21
Time of Firing 1505

Wind Speed (kts) 4-6
% Cloud Cover 50
Particle Dispersion Width (m) _____

Wind Direction (^{O}TN) 260

		Source		Stem		Plume Centroid		
				Trapesium				Width
Frame No.	Time (Sec)	Width (m)	Thickness (m)	Base (m)	Height (m)	Distance Travelled (m)	Height (m)	of Plume (m)
1	0	16.5	8.13					
3	.125	28.9	12.2					
7	.29	35.1	18.3					
15	.63	41.3	22.4					
19	.79	41.3	24.4					
24	1.0	47.5	28.5					
48	2.0	76.4	32.5					
96	4.0	99.0	20.3			31.0	38.6	35.1
148	6.17	134	32.5			51.6	52.8	47.5
216	9.0	161	46.7			86.7	67.1	74.3
241	10.0	161	50.8			94.9	71.1	74.3
360	15.0	206	52.8			144	81.3	108
480	20.0	268	61.0			1.98	87.4	124
562	23.4	310	67.1			239	87.4	129
724	30.2	361	71.1			315	102	134

JEFFERSON PROVING GROUND SMOKE TEST

CLOUD CHARACTERISTICS

Munition 4.2" WP
Shot Number G-3 S looking N

Date Aug. 21
Time of Firing 1052

Wind Speed (kts) 6-8
% Cloud Cover 0
Particle Dispersion Width (m) _____

Wind Direction (^{O}TN) 225

	Source			Stem		Plume Centroid		
				Trapesium				
Frame No.	Time (Sec)	Width (m)	Thickness (m)	Base (m)	Height (m)	Distance Travelled (m)	Height (m)	Width of Plume (m)
	0	41.7	9.14					
	.292	71.8	12.2					
	.708	106 +	18.3					
	3.0	167	26.4					
	5.0	175	42.7					
	10.0	194	16.3			69.0	36.6	83.3
	15.0	204	20.3			101	50.8	77.6
	20.0	207	20.3			132	54.9	94.9
	25.0	218	24.4	54.6	86.2	161	81.3	115
	30.0	194	24.4	71.8	91.9	180	89.4	126
	35.1	216	24.4	69.0	86.2	194	89.4	138
	40.0	223	30.5	71.8	94.9	208	93.5	158
	45.0	237	52.8			233	91.4	144
	50.1	266	61.0			252	96.5	129
	55.0	287	52.8			266	91.4	138

+ end of weapon phase

JEFFERSON PROVING GROUND SMOKE TEST

CLOUD CHARACTERISTICS

Munition 4.2" WP
Shot Number H-3 S looking N

Date Aug. 21
Time of Firing 1303

Wind Speed (kts) 4-8
% Cloud Cover 50
Particle Dispersion Width (m) _____

Wind Direction (^{O}TN) 245

	Source			Stem		Plume Centroid		
				Trapesium				
Frame No.	Time (Sec)	Width (m)	Thickness (m)	Base (m)	Height (m)	Distance Travelled (m)	Height (m)	Width of Plume (m)
1	0	15.7	6.1					
14 +	.58	33.6	10.2					
24	1.0	49.3	10.2					
48	2.0	58.3	16.3					
72	3.0	67.3	20.3					
96	4.0	80.7	24.4					
120	5.0	83.0	28.5					
170	7.08	89.7	36.6					
192	8.0	91.9	40.6					
240	10.0	89.7	46.7					
360	15.0	117	12.2			98.6	34.6	80.7
480	20.0	168	16.3			135	36.6	101
600	25.0	202	20.3			168	46.7	123
720	30.0	235	26.4			202	50.8	135
770	32.1	247	24.4			213	54.9	140
837	34.1	247	28.5			247	56.9	139

+ end of weapon phase

JEFFERSON PROVING GROUND SMOKE TEST

CLOUD CHARACTERISTICS

Munition 4.2" WP
Shot Number J-3 S looking N

Date Aug. 21
Time of Firing 1533

Wind Speed (kts) 3-6
% Cloud Cover 50
Particle Dispersion Width (m) _____

Wind Direction (^{O}TN) 260

	Source			Stem		Plume Centroid		
				Trapesium				Width
Frame No.	Time (Sec)	Width (m)	Thickness (m)	Base (m)	Height (m)	Distance Travelled (m)	Height (m)	of Plume (m)
	.417	51.6	12.2					
	.833	51.6+	14.2					
	1.0	66.0	16.3					
	2.0	86.6	18.3					
	4.0	103.2	14.2			14.4	26.4	37.2
	5.0	109.4	18.3			20.6	30.5	45.4
	8.0	103.2	24.4			28.8	46.7	57.8
	10.0	113.5	34.5			36.2	56.9	61.9
	15.0	121.8	44.7			53.6	79.3	78.4
	20.0	118.6	54.9			72.2	89.4	92.3
	25.0	123.8	65.0			87.7	105.7	103
	30.0	134.2	67.1			103	111.8	124
	35.0	146.5	67.1			107	130.1	128
	40.0	156.8	71.1			129	137.2	124
	45.0	158.9	86.4			150	146.3	144
	50.0	170.2	91.4			173	150.4	144
	62.5	185.7	93.5			229	162.6	136

+ end of weapon phase

JEFFERSON PROVING GROUND SMOKE TEST

CLOUD CHARACTERISTICS

Munition 105mm WP
Shot Number H-4 S looking N

Date Aug. 21
Time of Firing 1255

Wind Speed (kts) 4-8
% Cloud Cover 50
Particle Dispersion Width (m) _____

Wind Direction (^{O}TN) 245

	Source			Stem		Plume Centroid		
				Trapesium				Width of Plume (m)
Frame No.	Time (Sec)	Width (m)	Thickness (m)	Base (m)	Height (m)	Distance Travelled (m)	Height (m)	
1	0	6.73	3.66					
3	.125	16.1	4.88					
13	.54	24.2	11.0					
50	2.08	47.1	14.6					
99	4.13	56.5	28.0			16.1		
151	6.29	67.3	15.9	14.8	29.6	24.2	31.7	20.2
229	9.54	69.9	29.3	18.8	40.4	37.7	43.9	29.6
313	13.0	80.7	24.4	22.9	49.8	56.5	56.1	33.6
401	16.7	87.4	28.0	26.9	57.9	74.0	67.1	37.7
495	20.6	101	24.4	26.9	69.8	90.8	81.7	43.0

JEFFERSON PROVING GROUND SMOKE TEST

CLOUD CHARACTERISTICS

Munition 105mm WP
Shot Number I-4

Date Aug. 21
Time of Firing 1410

Wind Speed (kts) 4-6
% Cloud Cover
Particle Dispersion Width (m)

Wind Direction (^{O}TN) 250

	Source			Stem		Plume Centroid		
Frame No.	Time (Sec)	Width (m)	Thickness (m)	Trapesium Base (m)	Trapesium Height (m)	Distance Travelled (m)	Height (m)	Width of Plume (m)
1	0	13.0	4.57					
8	.33	32.4	12.2					
24	1.0	43.8	15.2					
49	2.04	48.7	18.3					
96	4.0	48.7	7.62				13.7	32.4
169	7.04	64.9	10.7			42.2	22.9	35.7
242	10.1	69.7	15.2			58.4	25.9	40.5
363	15.1	101	15.2			86.0	35.1	48.7
480	20.0	115	12.2	24.3	24.3	109	35.1	56.8
600	25.0	131	16.8	27.6	24.3	136	39.6	56.8
720	30.0	148	15.2	24.3	25.9	161	41.2	55.1
840	35.0	164		32.4	32.4	185	45.7	58.4
1,011	42.1	178		32.4	40.5	211	53.3	68.1

JEFFERSON PROVING GROUND SMOKE TEST

CLOUD CHARACTERISTICS

Munition 105mm WP
Shot Number J-4 S looking N

Date Aug. 21
Time of Firing 1507

Wind Speed (kts) 4-6
% Cloud Cover 50
Particle Dispersion Width (m) _____

Wind Direction (^{O}TN) 260

		Source		Stem		Plume Centroid		Width of Plume (m)
Frame No.	Time (Sec)	Width (m)	Thickness (m)	Trapesium Base (m)	Trapesium Height (m)	Distance Travelled (m)	Height (m)	
	0	4.12	3.05					
	.208	24.8	12.2					
	.542 +	26.8	18.3					
	.75	33.0	20.3					
	1.0	35.1	22.4					
	2.04	47.5	26.4					
	4.0	66.0	36.6					
	6.0	66.0	20.3			47.7	30.5	45.4
	8.0	88.7	20.3			64.0	32.5	47.4
	10.0	92.9	24.4			78.4	38.6	45.4
	15.0	126	10.2	26.8	31.0	120	50.8	45.4
	20.0	150	10.2	37.1	41.3	165	67.1	57.8
	25.0	186	12.2	33.0	49.5	206	69.1	68.1
	30.0	212	14.2	37.1	55.7	243	77.2	72.2
	35.0	253	20.3	47.5	51.6	277	77.2	86.6
	40.0	294	12.2	61.9	51.6	325	75.2	103

+ end of weapon phase

JEFFERSON PROVING GROUND SMOKE TEST

CLOUD CHARACTERISTICS

Munition 81mm WP
Shot Number G-2 S looking N

Date Aug. 21
Time of Firing 1047

Wind Speed (kts) 6-8
% Cloud Cover 0
Particle Dispersion Width (m) _____

Wind Direction (^{O}TN) 210

	Source			Stem		Plume Centroid		
				Trapesium*				
Frame No.	Time (Sec)	Width (m)	Thickness (m)	Base (m)	Height (m)	Distance Travelled (m)	Height (m)	Width of Plume (m)
	0	24.4	6.10					
	.208	36.6	6.10					
	1.0 +	56.8	10.2					
	2.0	81.2	13.2					
	3.08	93.4	19.3					
	3.83	89.4	20.3					
	5.0	142	26.4					
	10.0	159	10.2			16.3	20.3	40.6
	15.0	142	10.2			24.4	30.5	102
	20.0	146	10.2			40.6	34.5	122
	25.0	146	34.5			61.0	56.9	134
	30.0	173	38.6			81.2	58.9	114
	35.0	195	40.6			102	65.0	122
	40.0	203	52.8			114	71.1	114
	45.0	183	54.9			138	71.1	122
	50.0	175	50.8			150	73.2	138

* Plume was situated directly atop source, hence no stem.

+ end of weapon phase

JEFFERSON PROVING GROUND SMOKE TEST

CLOUD CHARACTERISTICS

Munition 81mm WP
Shot Number H-2 S looking N

Date Aug. 21
Time of Firing 1309

Wind Speed (kts) 4-8
% Cloud Cover 50
Particle Dispersion Width (m) _____

Wind Direction (°TN) 245

	Source			Stem		Plume Centroid		
				Trapesium				
Frame No.	Time (Sec)	Width (m)	Thickness (m)	Base (m)	Height (m)	Distance Travelled (m)	Height (m)	Width of Plume (m)
1	0	6.7	3.8					
12	0.5+	26.9	6.9					
24	1.0	31.9	7.62					
48	2.0	33.6	13.7					
68	2.83	28.6	4.57			10.1	9.14	16.8
77	3.21	28.6	4.57			11.8	10.7	16.8
126	5.25	28.6	6.09			21.9	19.8	20.1
168	7.0	33.6	7.62			28.6	22.9	23.5
216	9.0	40.4	3.80	16.8	16.8	37.0	33.5	25.2
270	11.3	47.1	7.62	25.2	23.5	43.7	44.2	30.3
360	15.0	55.5	15.2	18.5	42.0	63.9	57.9	35.3
480	20.0	70.6	10.7	20.2	62.2	89.1	78.2	43.7
600	25.0	80.1	15.2	21.8	95.9	118	96.0	53.8
720	30.0	103	15.2	25.2	92.5	136	111	58.9

+ end of weapon phase

JEFFERSON PROVING GROUND SMOKE TEST

CLOUD CHARACTERISTICS

Munition 81mm WP
Shot Number I-2 S looking N

Date Aug 21
Time of Firing 1315

Wind Speed (kts) 4-7
% Cloud Cover 50
Particle Dispersion Width (m) _____

Wind Direction (^{o}TN) 245

		Source		Stem		Plume Centroid		
				Trapesium				
Frame No.	Time (Sec)	Width (m)	Thickness (m)	Base (m)	Height (m)	Distance Travelled (m)	Height (m)	Width of Plume (m)
		*						
1	0		1.52					
5	.208		6.09					
14	.58		7.62					
24	1.0		10.7					
48	2.0		13.7					
77	3.21		19.8					
101	4.21		27.4					
221	9.21			16.8	37.0	67.3	35.1	23.6
341	14.2			50.5	42.0	79.9	50.3	33.6
461	19.2			42.0	47.1	109.	57.9	37.0
581	24.2			42.0	55.5	139.	67.1	42.0
801	33.4			50.5	66.1	202.	83.8	42.0

* Source Width could not be measured because its separation from the nearly-simultaneous case I-1 was not clear.

JLFFERSON PROVING GROUND SMOKE TEST

CLOUD CHARACTERISTICS

Munition 60mm WP
Shot Number H-1 S looking N

Date Aug. 21
Time of Firing 1309

Wind Speed (kts) 4-8
% Cloud Cover 50
Particle Dispersion Width (m) _____

Wind Direction (^{O}TN) 245

	Source			Stem		Plume Centroid		
				Trapesium				Width of Plume (m)
Frame No.	Time (Sec)	Width (m)	Thickness (m)	Base (m)	Height (m)	Distance Travelled (m)	Height (m)	
1	0	10.1	4.57					
9	.375	16.8	4.57					
58	2.42	32.0	12.2					
100	4.17	38.7	4.57			26.9	9.14	15.1
148	6.17	40.4	7.62			41.9	13.7	18.5
202	8.42	58.9	7.62			58.9	19.8	21.9
292	12.2	75.7	9.14	16.8		85.8	27.4	30.3
412	17.2	113	13.7	16.8		118	38.1	37.0
532	22.2	118	15.2	25.2		163	61.0	58.9

JEFFERSON PROVING GROUND SMOKE TEST

CLOUD CHARACTERISTICS

Munition 60mm WP
Shot Number 1-1

Date Aug. 21
Time of Firing 1315

Wind Speed (kts) 4-7
% Cloud Cover 50
Particle Dispersion Width (m) _____

Wind Direction (°TN) 245

	Source			Stem		Plume Centroid		
Frame No.	Time (Sec)	Width (m)	Thickness (m)	Trapesium Base (m)	Trapesium Height (m)	Distance Travelled (m)	Height (m)	Width of Plume (m)
1	0	5.04	3.05					
11	.458+	20.2	7.62					
24	1.0	23.6	7.62					
144	6.0	75.7	22.9					
264	11.0	127.	7.62	21.9	20.2	123.	24.4	30.9
384	16.0	181.	18.3				29.0	37.0
504	21.0	230.	18.3				30.5	45.4
605	25.2	252	18.3				36.6	67.3

+ end of weapon phase

JEFFERSON PROVING GROUND SMOKE TEST

CLOUD CHARACTERISTICS

Munition 155mm HC
Shot Number I 7 S looking N

Date Aug 21
Time of Firing 1428

Wind Speed (kts) 5-8
% Cloud Cover 50
Cannister Dispersion (m)

Wind Direction (^{o}TN) 328
Burn Time (sec)

Canister	Time (sec)	Source Width (m)	Body Thickness (m)	Distance To Leading Edge (m)	Height of Leading Edge (m)
1	3.0	35.9	3.05		
2	3.0	11.9	1.52		
3, 4	3.0	47.8	4.57		
1	7.67	75.7	6.09		
2	7.67	47.8	6.09		
3	7.67	83.6	4.57		
1, 2	15.0	159.	15.2	159	
3, 4	15.0	159.	9.14	159	
1, 2	20.0	187	25.9	187	
3, 4	20.0	199	10.7	199	
1, 2	25.0	239	33.5	239	
3, 4	25.0	243	12.2	243	
1, 2	30.0	287	45.7	189	
3, 4	30.0	319	16.8	299	
1, 2	35.0	339	53.3	207	
3, 4	35.0	358	25.9	269	
	40.0	538	61.0	508	
	45.0	569	61.0	526	

JEFFERSON PROVING GROUND SMOKE TEST

CLOUD CHARACTERISTICS

Munition 155mm HC
Shot Number I-7 (Cont)

Date Aug. 21
Time of Firing 1428

Wind Speed (kts) 5-8
% Cloud Cover 50
Cannister Dispersion (m) _____

Wind Direction (^{o}TN) _____
Burn Time (sec) _____

Canister	Time (sec)	Source Width (m)	Body Thickness (m)	Distance To Leading Edge (m)	Height of Leading Edge (m)
	50.0	617	61.0	528	
	55.0	597	61.0	498	
	65.0	567	68.6	458	
	70.0	637	68.6	548	
	75.0	647		717	

JEFFERSON PROVING GROUND SMOKE TEST

CLOUD CHARACTERISTICS

Munition 105mm HC
Shot Number I-6 S looking N

Date Aug. 21
Time of Firing 1422

Wind Speed (kts) 5-8
% Cloud Cover 50
Cannister Dispersion (m)

Wind Direction (^{O}TN) 315
Burn Time (sec)

Canister	Time (sec)	Source Width (m)	Body Thickness (m)	Distance To Leading Edge (m)	Height of Leading Edge (m)
1	1.75	17.2	2.03		
2	1.75	23.0	4.06		
3	1.75	8.61	8.13		
1	4.0	23.0	4.06	23.0	
2	4.0	43.1	8.31	43.1	
3	4.0	28.7	10.2	28.7	
1	6.0	34.5	6.09	34.5	
2	6.0	54.6	8.13	54.6	
3	6.0	46.0	16.3	46.0	
1	10.0	48.9	12.2	48.9	
2	10.0	71.8	12.2	71.8	
3	10.0	71.8	16.3	51.7	
1	15.0	94.8	16.3	94.8	
2	15.0	112	12.2	112.	
3	15.0	115	20.3	54.6	
2	20.0	109	10.2	109.	
3	20.0	172	10.2	97.7	
	25.0*	330	36.6	244	

* Merger of individual clouds.

JEFFERSON PROVING GROUND SMOKE TEST

CLOUD CHARACTERISTICS

Munition 105mm HC
Shot Number I-6 (Cont)

Date Aug. 21
Time of Firing 1422

Wind Speed (kts) 5-8
% Cloud Cover 50
Cannister Dispersion (m)

Wind Direction (^{o}TN) 315
Burn Time (sec)

Canister	Time (sec)	Source Width (m)	Body Thickness (m)	Distance To Leading Edge (m)	Height of Leading Edge (m)
	30.0	330.	40.6	273	
	35.0	345.	38.6	316	
1, 2	40.0	150.9	16.3	150.9	
3	40.0	215.5	30.5	172.4	
1, 2	45.0	172.4	20.3	172.4	
3	45.0	229.9	30.5	172.4	
1, 2	50.0	194	24.4	194	
3	50.0	229.9	28.5	201.2	
1, 2	55.0	115.7	18.3	115.7	
3	55.0	184.1	32.5	157.8	
1, 2	60.0	121.0	20.3	73.6	
3	60.0	178.8	40.6	168.3	
1, 2	65.0	126.2	20.3	126.2	
3	65.0	231.4	44.7	189.3	
1, 2	70.0	136.7	26.4	110.4	
3	70.0	226.2	44.7	189.3	
1, 2	75.0	131.5	26.3	131.5	
3	75.0	226.2	30.5	184.1	

JEFFERSON PROVING GROUND SMOKE TEST

CLOUD CHARACTERISTICS

Munition 105mm HC
Shot Number I-6 (Cont)

Date Aug 21
Time of Firing 1422

Wind Speed (kts) 5-8
% Cloud Cover 50
Cannister Dispersion (m)

Wind Direction (^{O}TN) 315
Burn Time (sec)

Canister	Time (sec)	Source Width (m)	Body Thickness (m)	Distance To Leading Edge (m)	Height of Leading Edge (m)
1, 2	80.0	147.3	24.4	147.3	
3	80.0	199.9	36.6	126.2	
*	90.0	336.6	44.7	257.3	
	100.0	347.1	61.0	263.0	

* Merger of individual clouds.

JEFFERSON PROVING GROUND SMOKE TEST

CLOUD CHARACTERISTICS

Munition 105mm WP
Shot Number Static

Date Aug. 21
Time of Firing 1704

Wind Speed (kts) 2-4
% Cloud Cover 50
Particle Dispersion Width (m) 61.0

Wind Direction (^{O}TN) 293

	Source			Stem		Plume Centroid		
				Trapesium				
Frame No.	Time (Sec)	Width (m)	Thickness (m)	Base (m)	Height (m)	Distance Travelled (m)	Height (m)	Width of Plume (m)
1	0			13.0	6.1			
4	.17			24.0	11.0			
8	.33			27.2	10.5			
22	.92			29.5	15.5			
38	1.58	29.4	9.97	34.3	21.1		18.8	
68	2.83	37.8	24.4	33.1	20.0		24.4	
100	4.17	36.6	37.7	31.9	16.6		33.3	
128	5.33	44.9	45.4	29.5	15.0		41.0	
165	6.88	52.0	54.3	28.4	15.5		49.7	
327	13.6	66.5	72.0	33.1	25.5		62.4	
479	20.0	70.9	74.8	38.4	30.5		66.5	

* True plume not formed; "Centroid Height" refers to the upper structure of the cloud.

JEFFERSON PROVING GROUND SMOKE TEST

CLOUD CHARACTERISTICS

Munition 81mm WP
Shot Number Static S looking N

Date Aug. 21
Time of Firing 1732

Wind Speed (kts) 2-3
% Cloud Cover 50
Particle Dispersion Width (m) 15.9-62.5

Wind Direction (^{O}TN) 293

	Source			Stem		Plume Centroid*		
Frame No.	Time (Sec)	Width (m)	Thickness (m)	Trapesium Base (m)	Trapesium Height (m)	Distance Travelled (m)	Height (m)	Width of Plume (m)
1	.04			10.4	6.10			
3	.125			22.1	11.0			
9	.375			28.6	15.9			
14+	.58			32.5	18.3			
28	1.17			42.8	20.7			
81	3.38			54.6	36.6			
143	5.96			62.4	54.9			
305	12.7			52.0	82.3			
475	19.8			103.9	94.5			
633	26.4			110.9	97.5			
748	31.2			118.3	100.			
766	31.9			103.9	101.			
828	34.5			108.7	100.			
901	37.5			108.7	91.4			

* Cloud rose to rapidly to show a well-defined plume and a separate source.

+ end of weapon phase

JEFFERSON PROVING GROUND SMOKE TEST

CLOUD CHARACTERISTICS

Munition 60mm WP
Shot Number Static

Date Aug. 21
Time of Firing 1732

Wind Speed (kts) 2-3
% Cloud Cover 50
Particle Dispersion Width (m) _____

Wind Direction (^{o}TN) 293

		Source		Stem		Plume Centroid		Width of Plume (m)
Frame No.	Time (Sec)	Width (m)	Thickness (m)	Trapesium Base (m)	Trapesium Height (m)	Distance Travelled (m)	Height (m) *	
1	0			19.49	5.49			
3	.125			15.6	7.32			
11	.46			16.9	8.53			
80	3.33			21.4	9.75			
153	6.38	39.0	26.8	31.2	34.1		32.9	
357	14.9	59.8	42.7	28.6	30.5		48.8	
454	18.9	70.2	43.9	38.9	32.9		53.6	
648	27.0	71.5	53.6	38.9	40.2		51.8	
762	31.8	74.1	57.3	58.5	45.1		61.0	
828	34.5	81.9	61.0	62.4	34.1		67.1	
924	38.5							

* True plume not formed: "Centroid Height" refers to the upper structure of the cloud.

JEFFERSON PROVING GROUND SMOKE TEST

CLOUD CHARACTERISTICS

Munition 155mm HC
Shot Number Static S looking N

Date Aug. 21
Time of Firing 1617

Wind Speed (kts) 2.5-5
% Cloud Cover 70.7
Cannister Dispersion (m)

Wind Direction (^{o}TN) 248
Burn Time (sec)

Canister	Time (sec)	Source Width (m)	Body Thickness (m)	Distance To Leading Edge (m)	Height of Leading Edge (m)
1	1.54	11.7	2.6		
2	1.54	3.9	3.9		
3	1.54	5.2	3.9		
1	3.21	6.5	3.3		
2	3.21	8.4	3.3		
3	3.21	11.7	4.6		
1	5.46	7.8	3.9		
2	5.46	13.0	5.2		
3	5.46	22.1	5.2		
1	8.63	7.8	4.6		
2	8.63	16.9		20.1	9.1
3	8.63	26.0		28.6	7.1
2	17.0	32.5		42.8	14.3
3	17.0	29.8		40.3	12.4
	25.4*	78.0		103.9	13.0
	34.2*	90.9		126.8	14.9
	44.9*	97.4		154.6	16.2
	55.5*	179		179.1	18.2
	72.4*	173.7		182.3	19.5

*merger of individual clouds

Next page is blank.

APPENDIX B. GRAPHS

Next page is blank

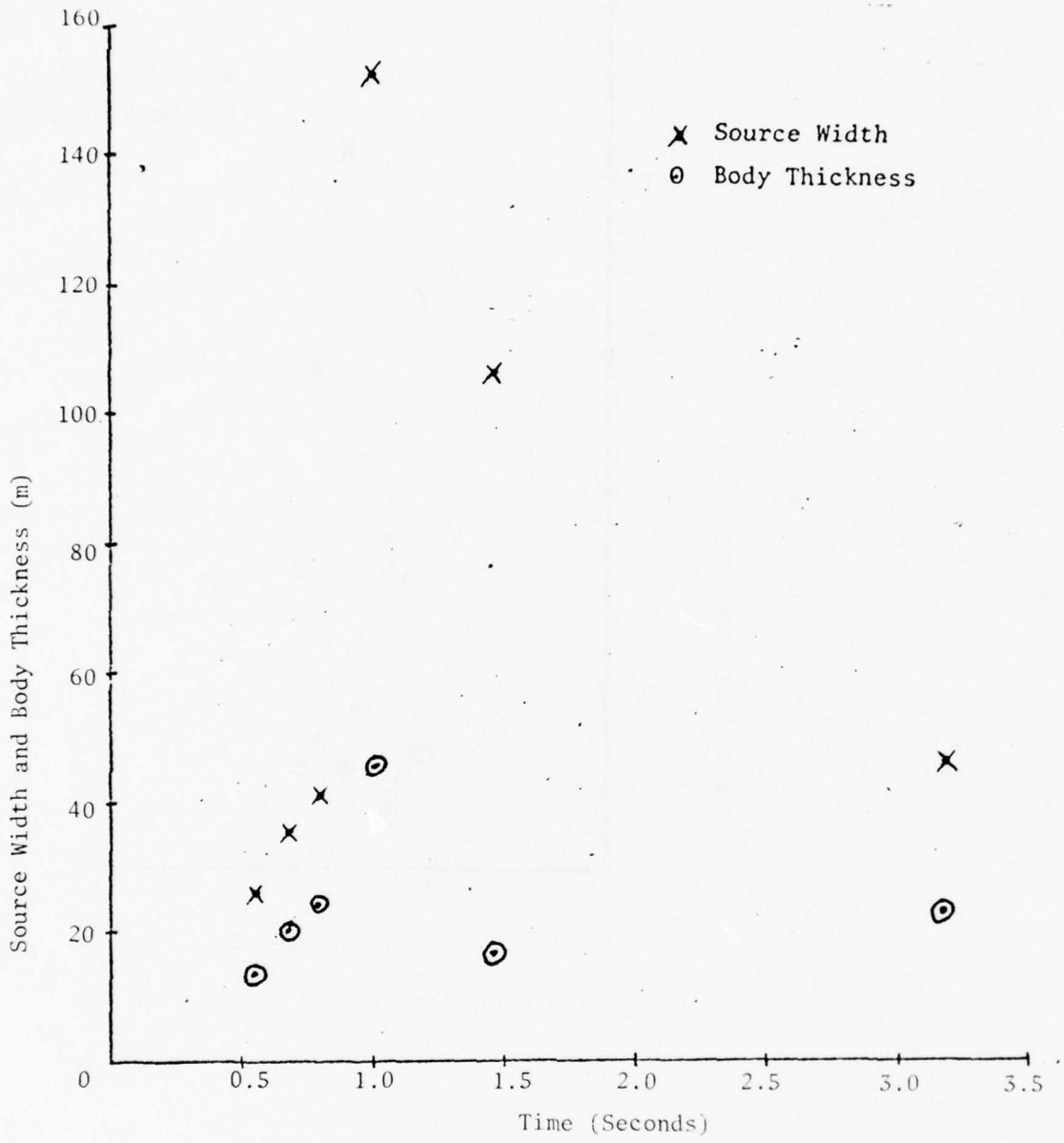


Figure 5. Source Description, 155mm WP

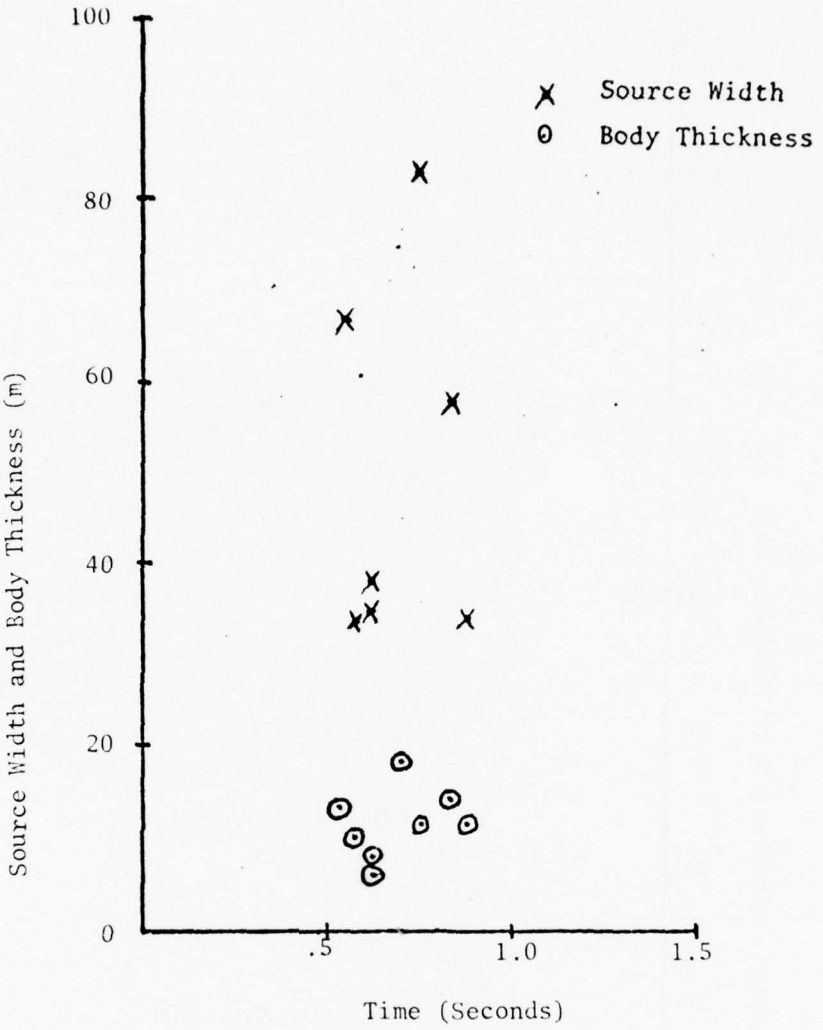


Figure 6. Source Description, 4.2" WP

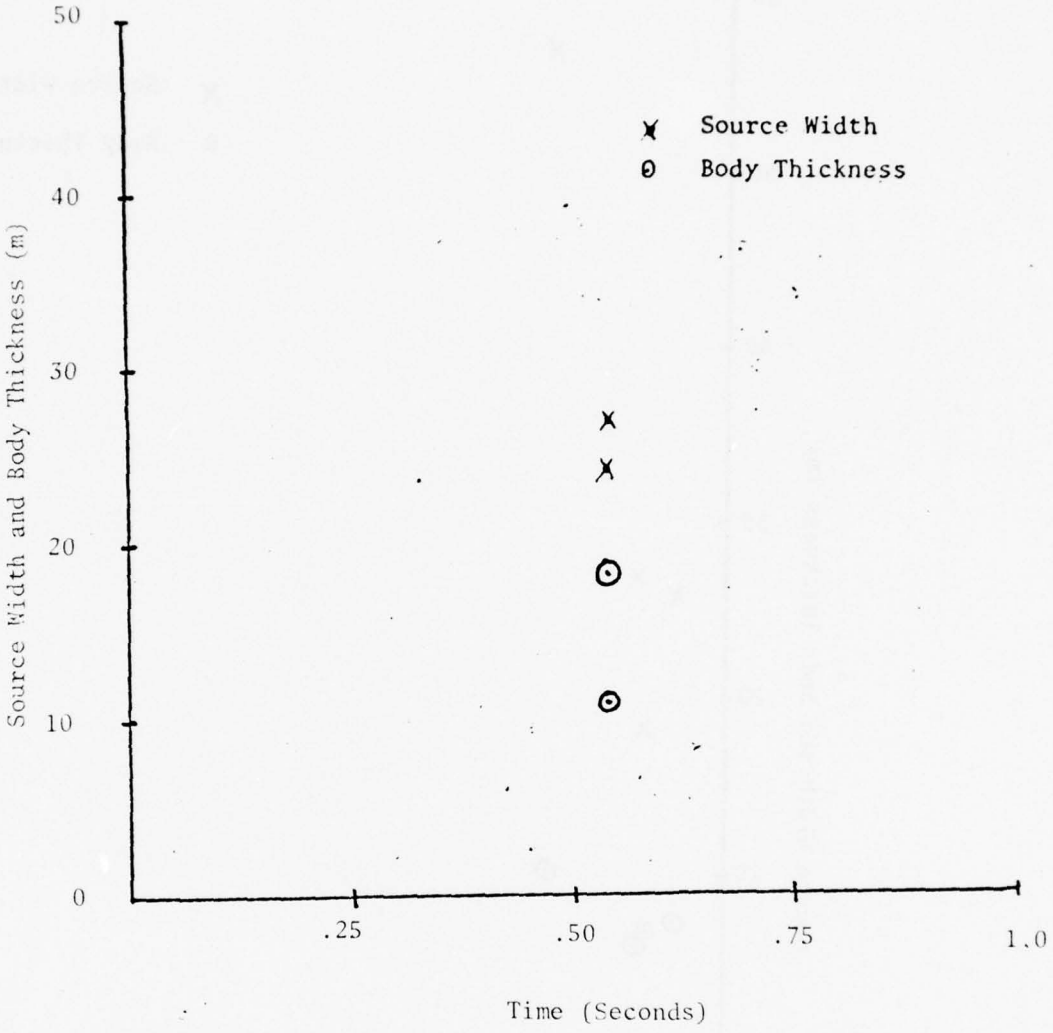


Figure 7. Source Description, 105mm WP

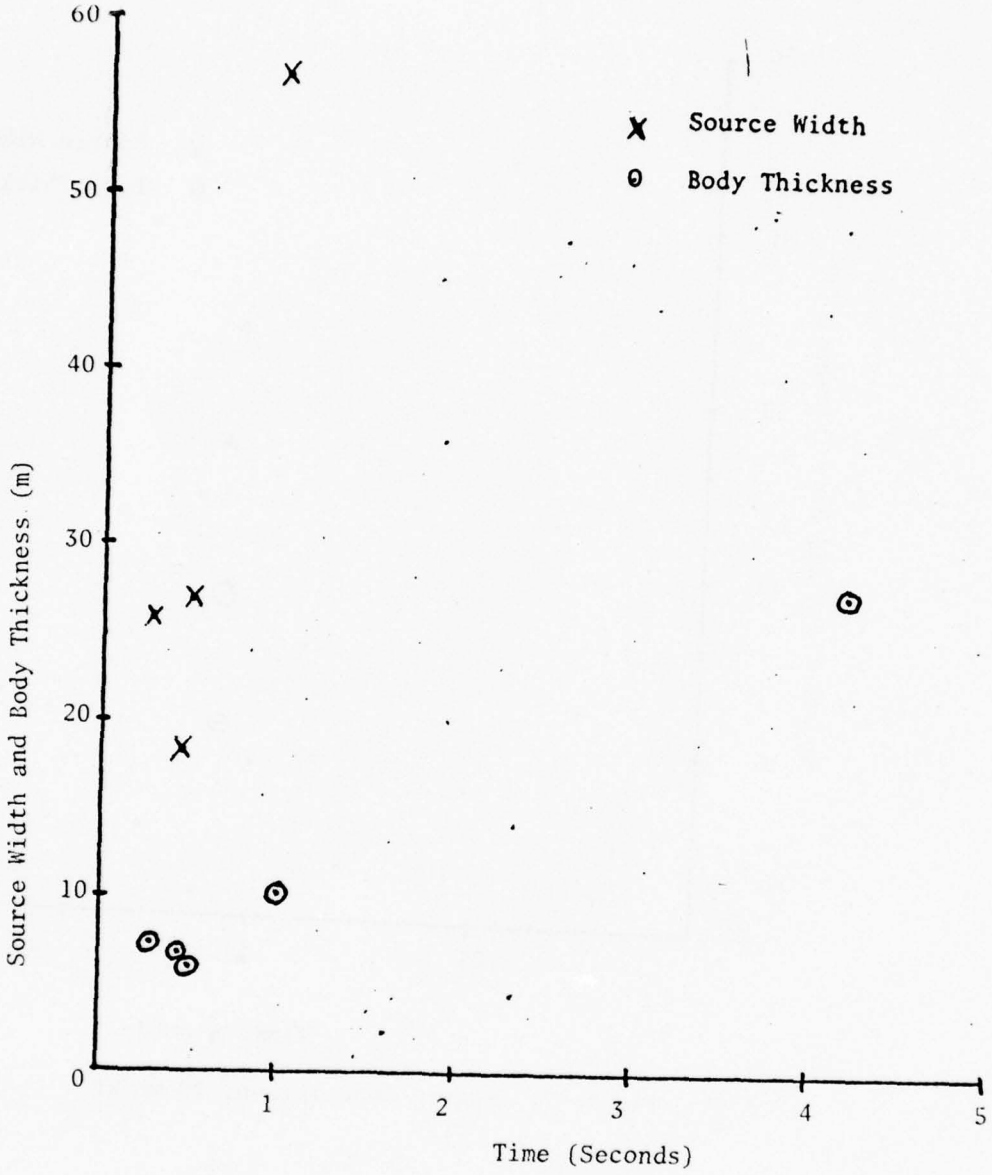


Figure 8. Source Description, 81mm WP

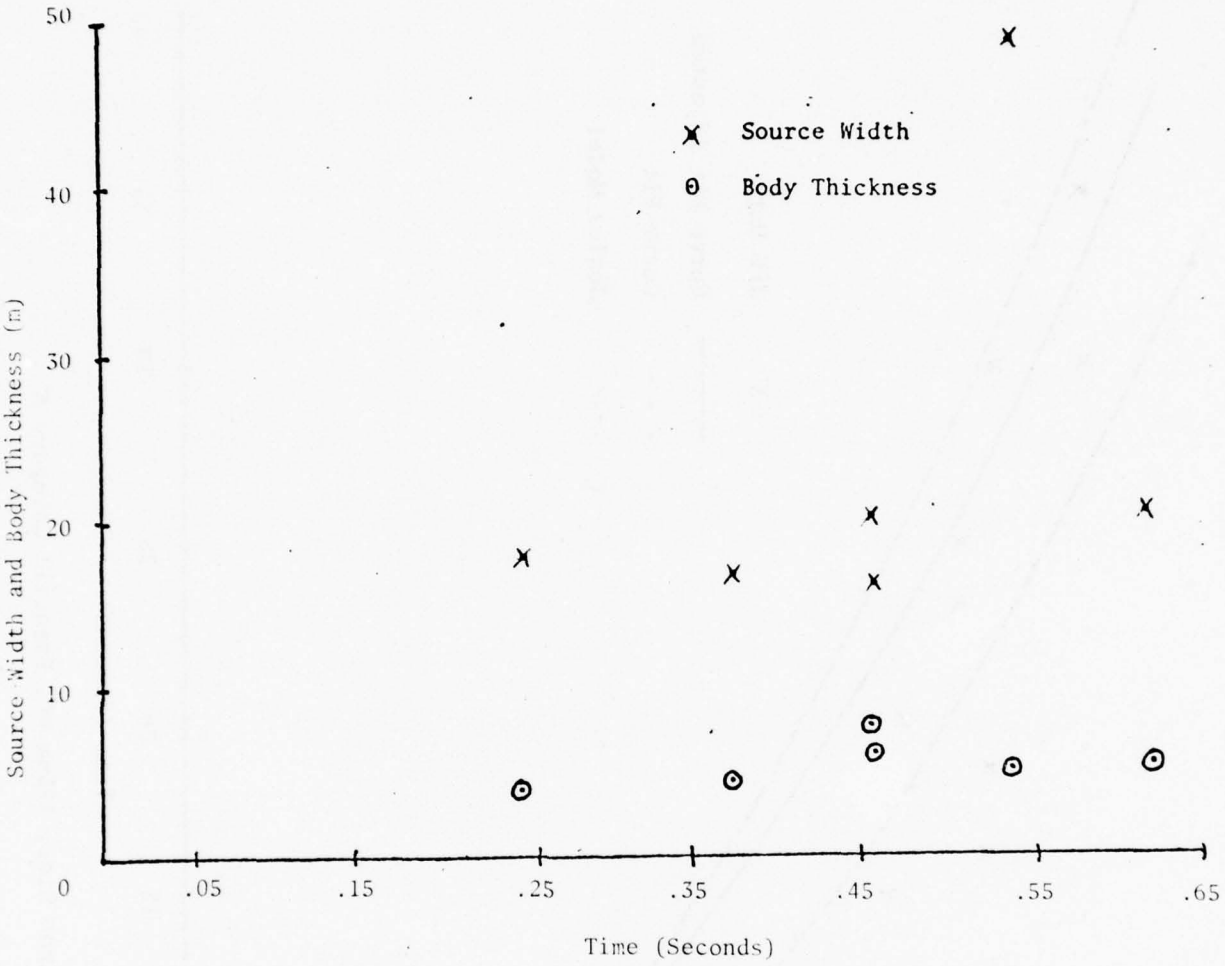


Figure 9. Source Description, 60mm WP

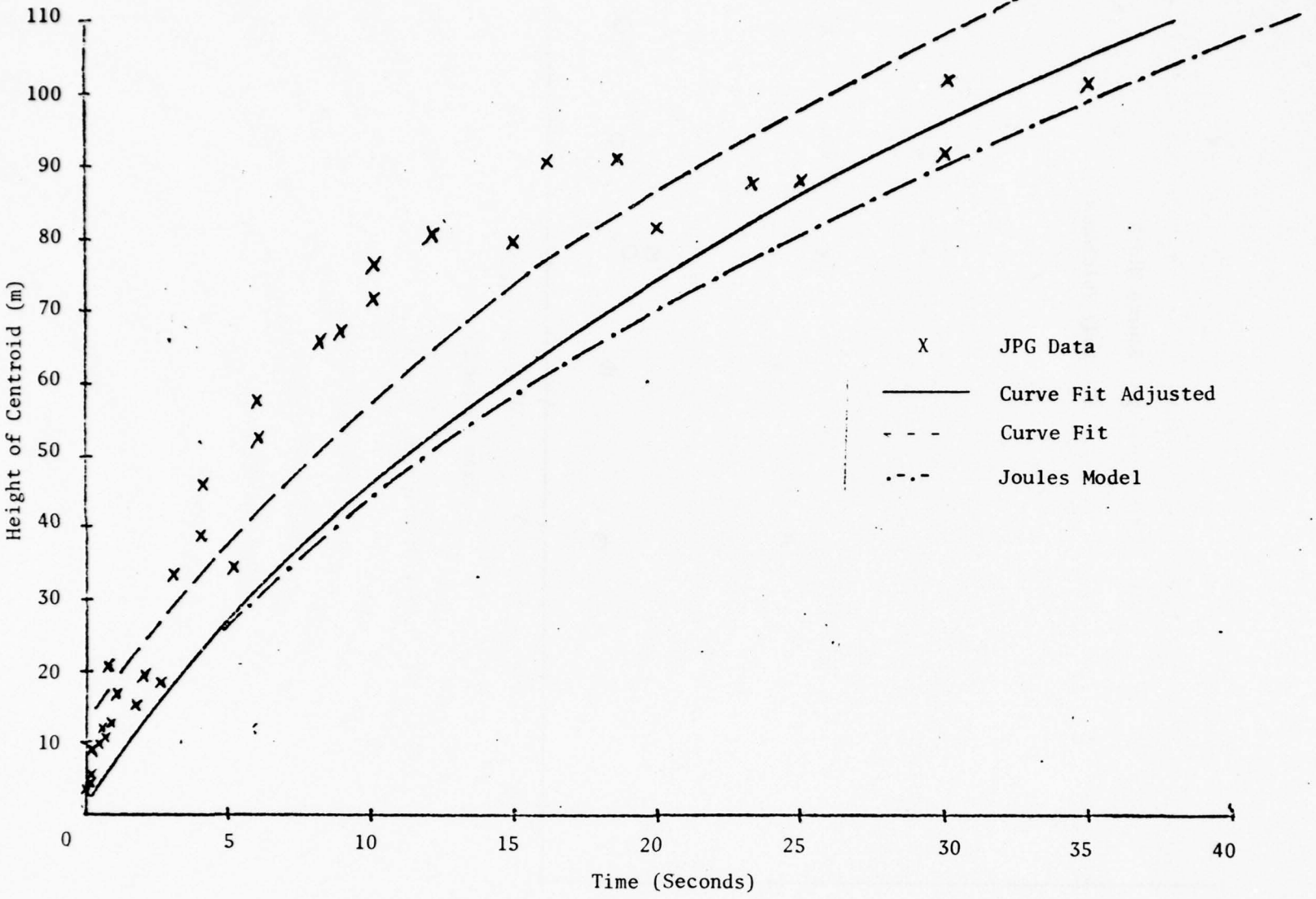


Figure 10. Plume Rise, 155mm WP, Pasquill Category A

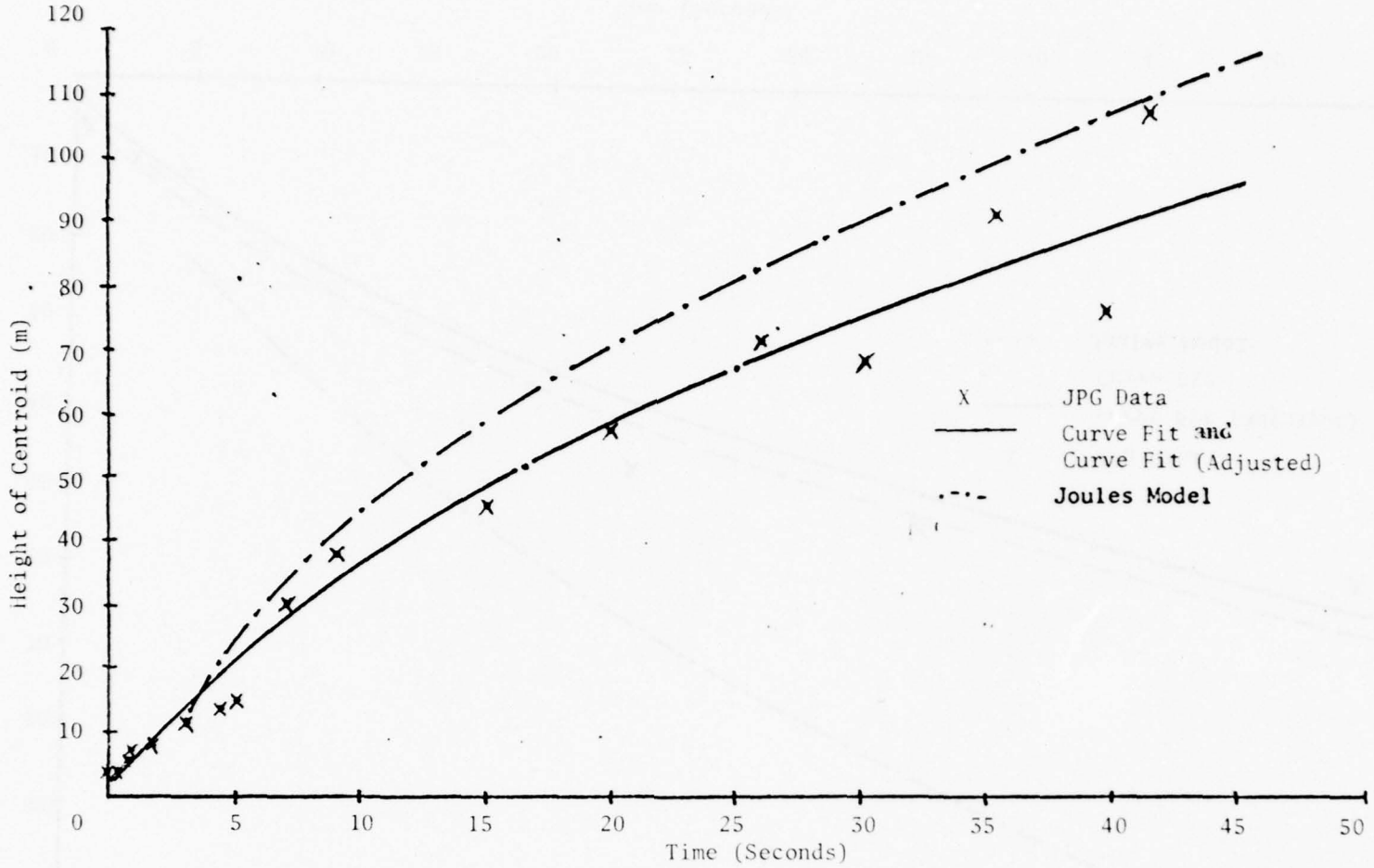


Figure 11. Plume Rise, 155mm WP, Pasquill Category B

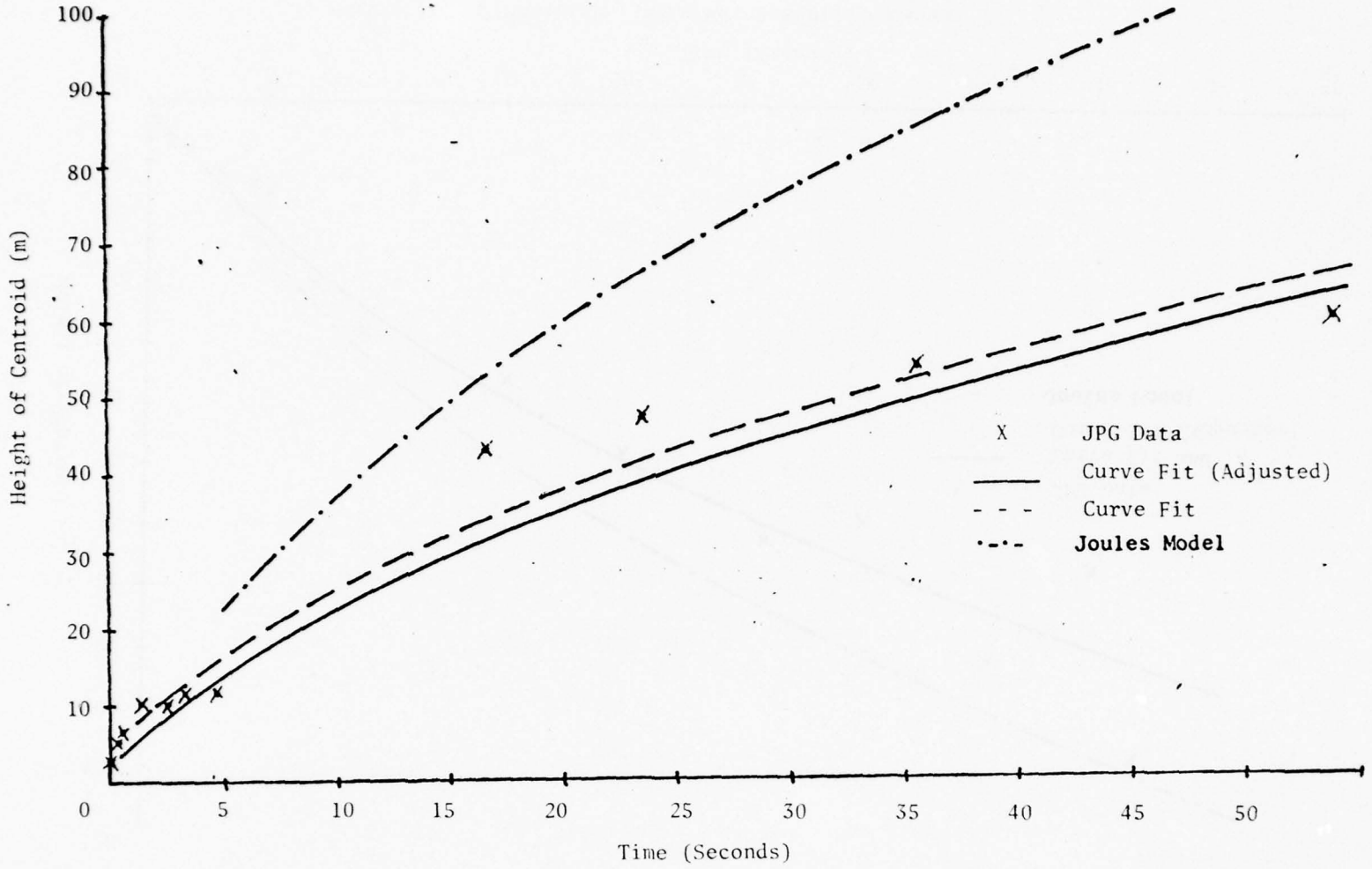


Figure 12. Plume Rise, 155mm WP, Pasquill Category C

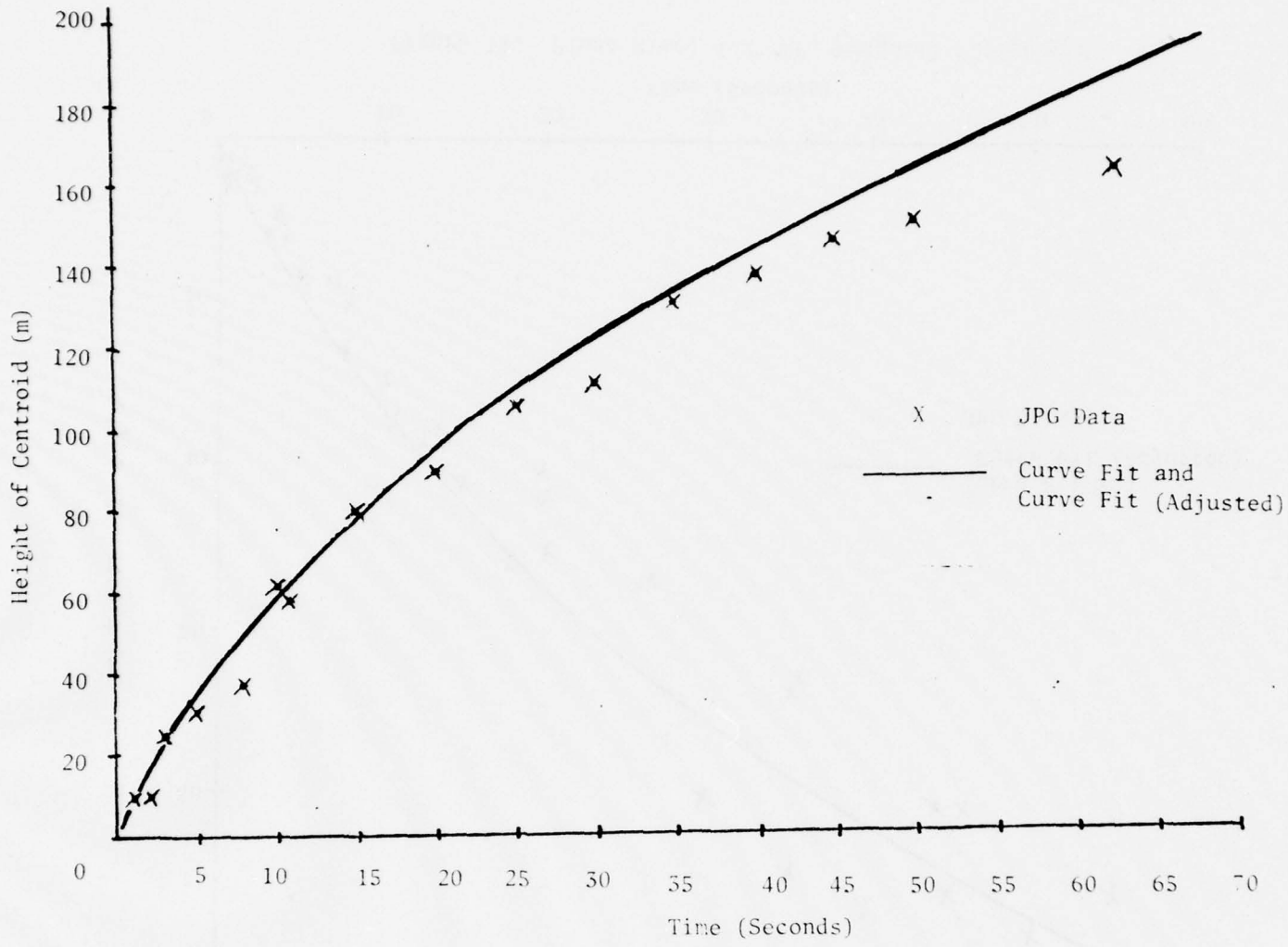


Figure 13. Plume Rise, 4.2" WP, Pasquill Category A

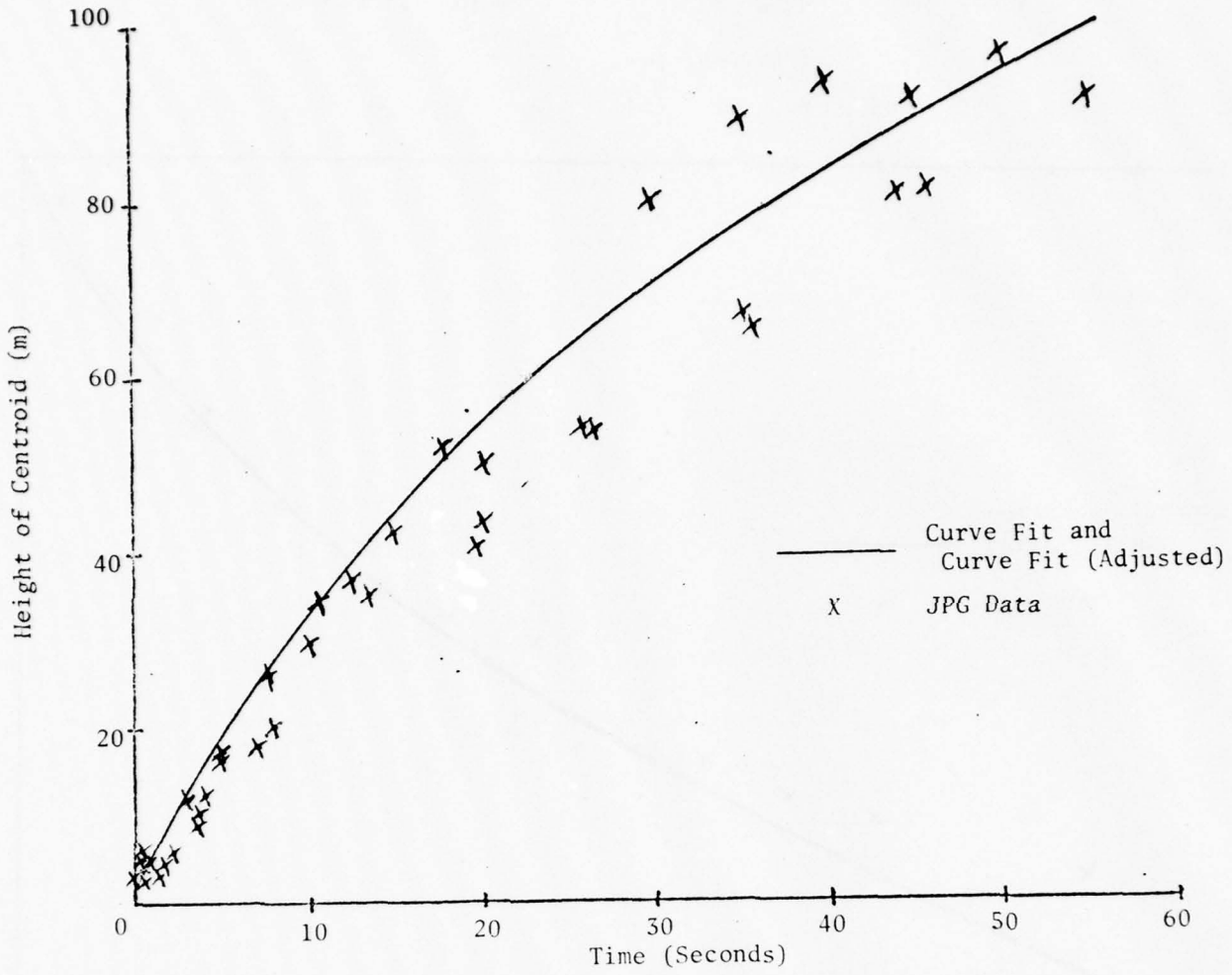


Figure 14. Plume Rise, 4.2" WP, Pasquill Category B

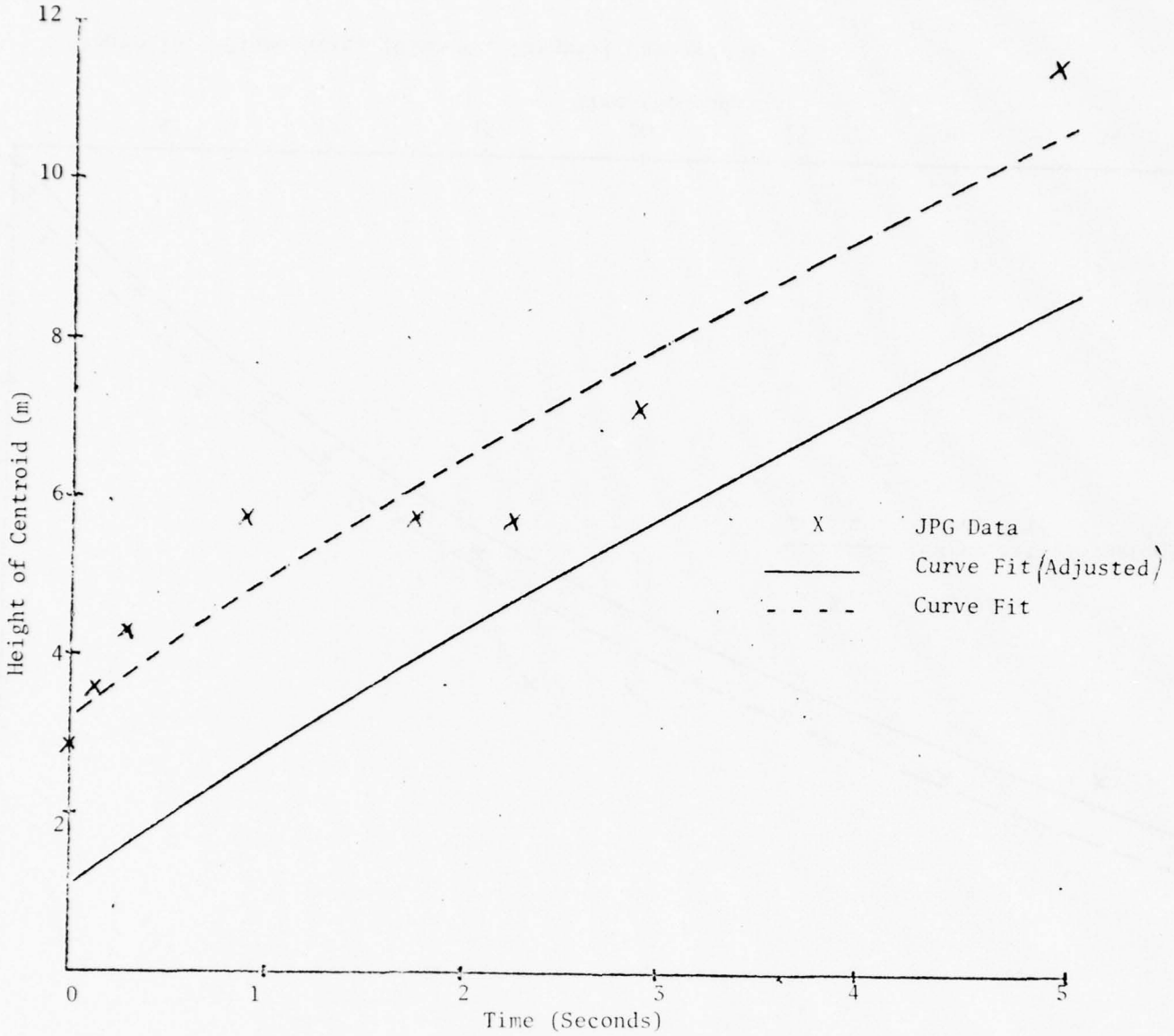


Figure 15. Plume Rise, 4.2" WP, Pasquill Category C

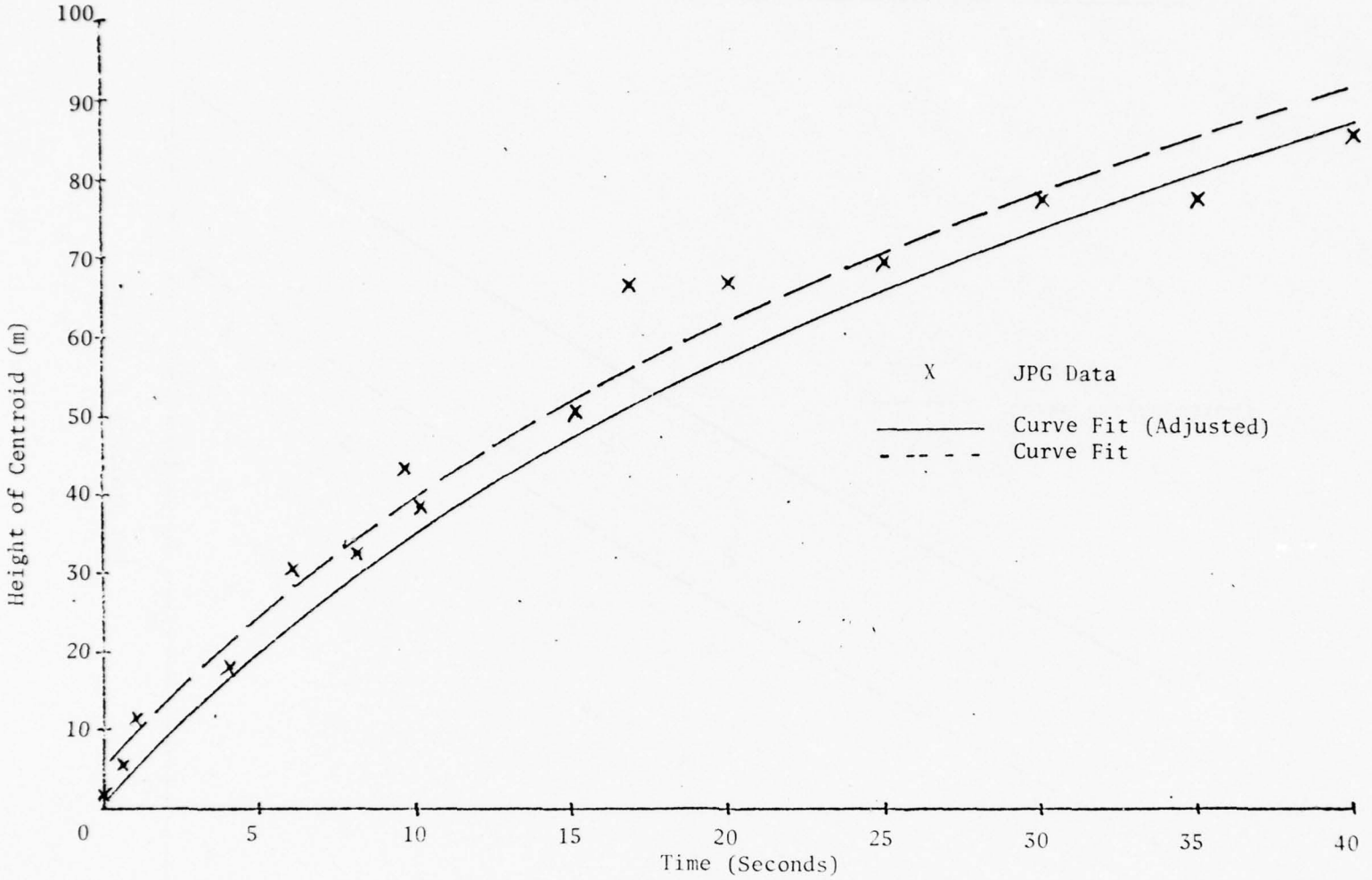


Figure 16. Plume Rise, 105mm WP, Pasquill Category A

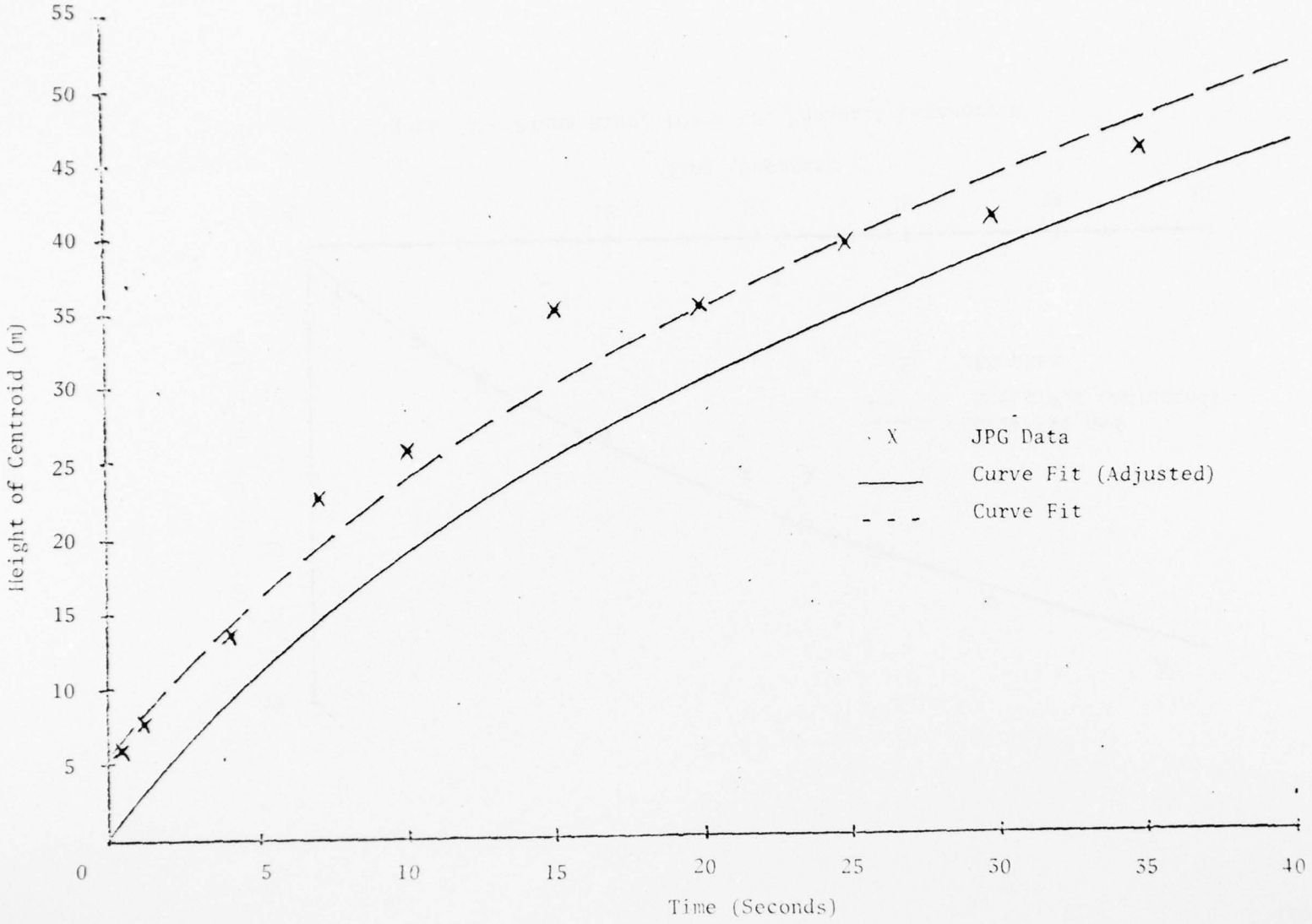


Figure 17. Plume Rise, 105mm WP, Pasquill Category B

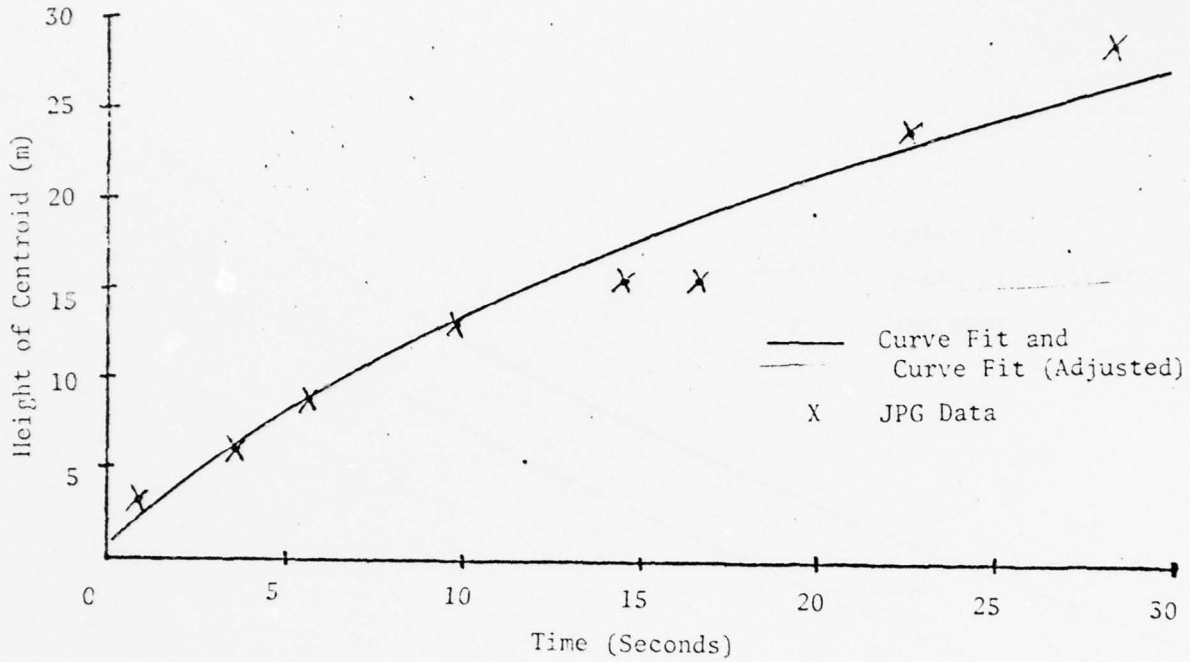


Figure 18. Plume Rise, 105mm HP, Pasquill Category C

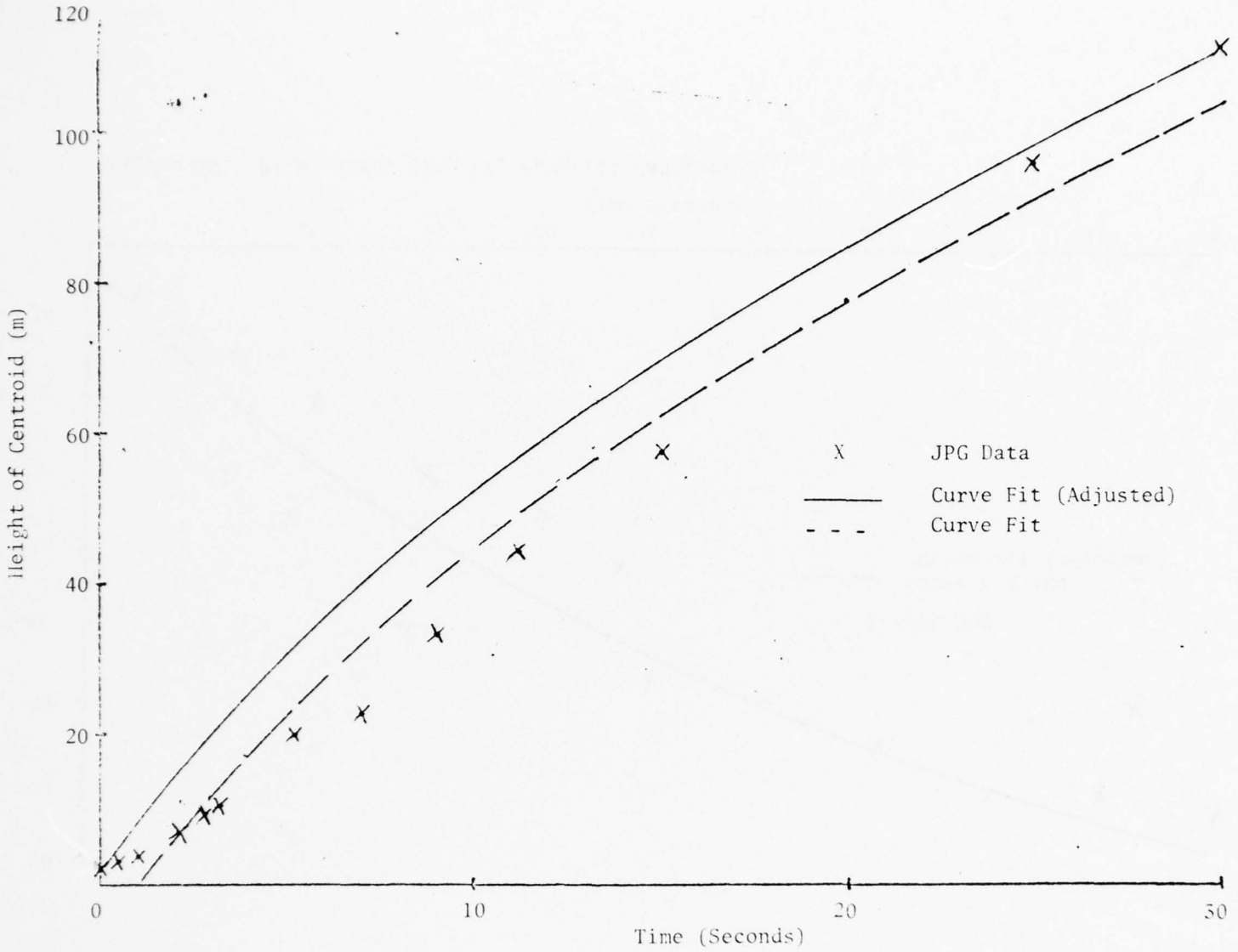


Figure 19. Plume Rise, 81mm WP, Pasquill Category A

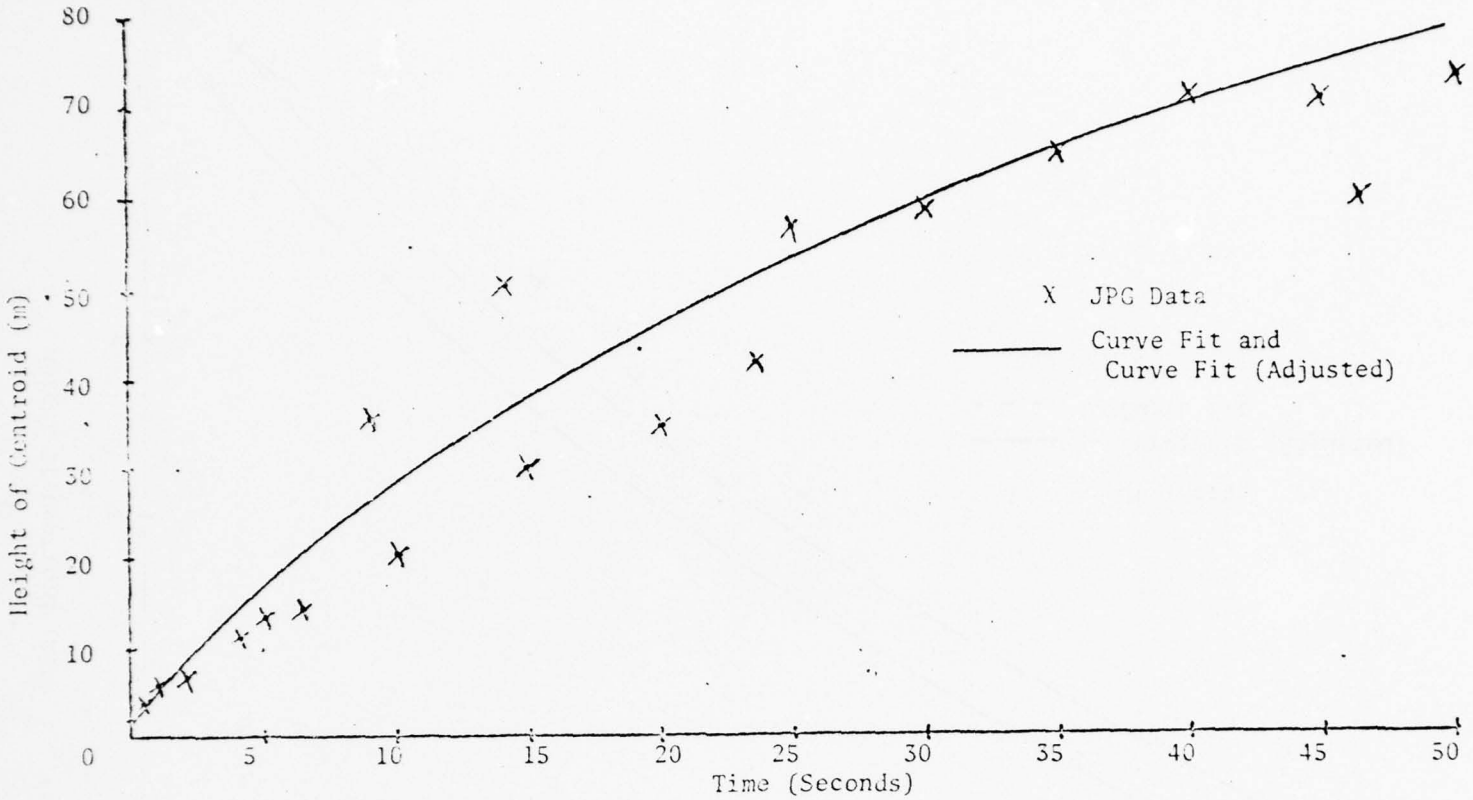


Figure 20. Plume Rise, 81mm WP, Pasquill Category B

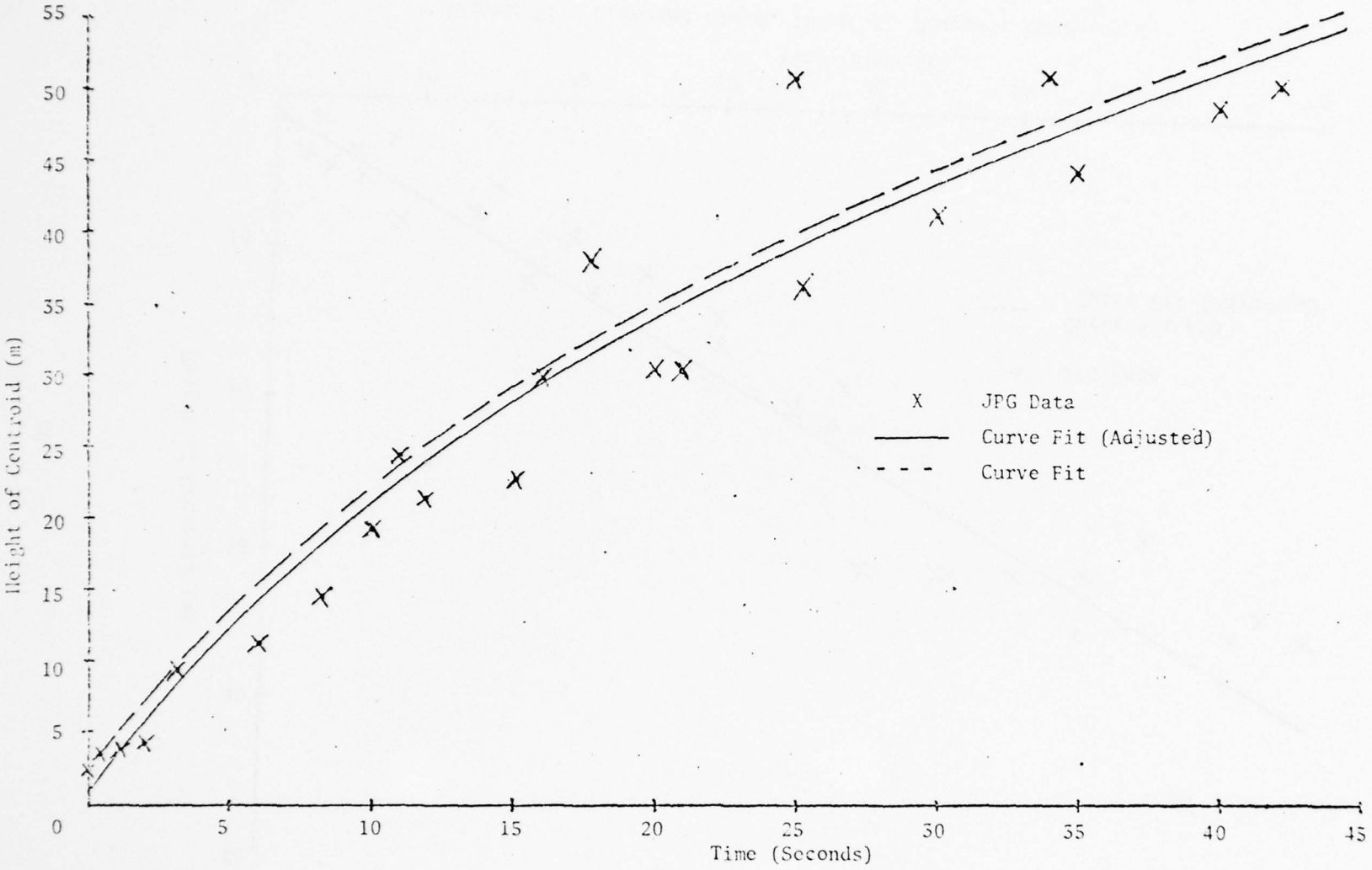


Figure 21. Plume Rise, 60mm WP, Pasquill Category B

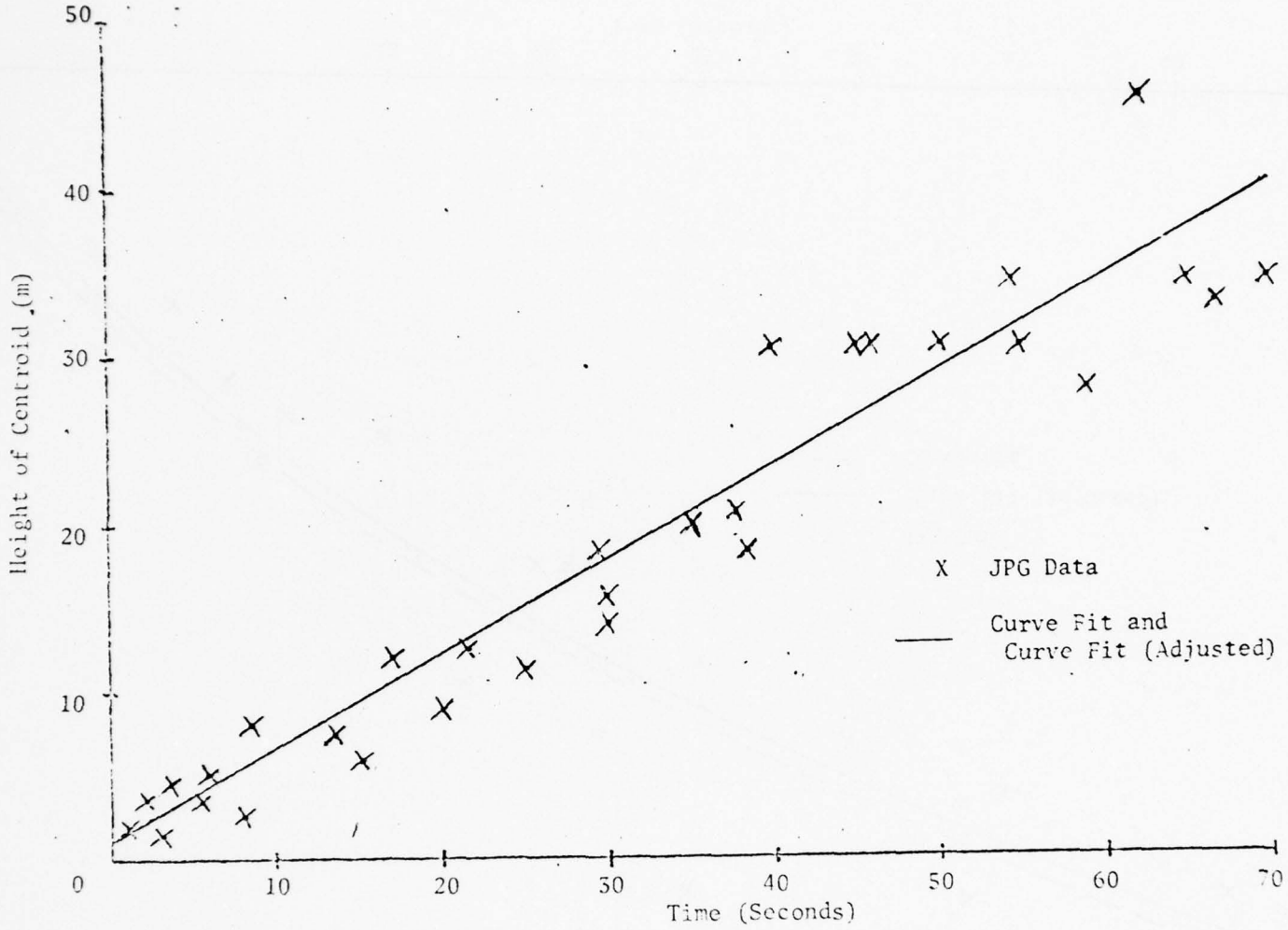


Figure 22. Downwind Cloud, 155mm HC, Pasquill Category 3

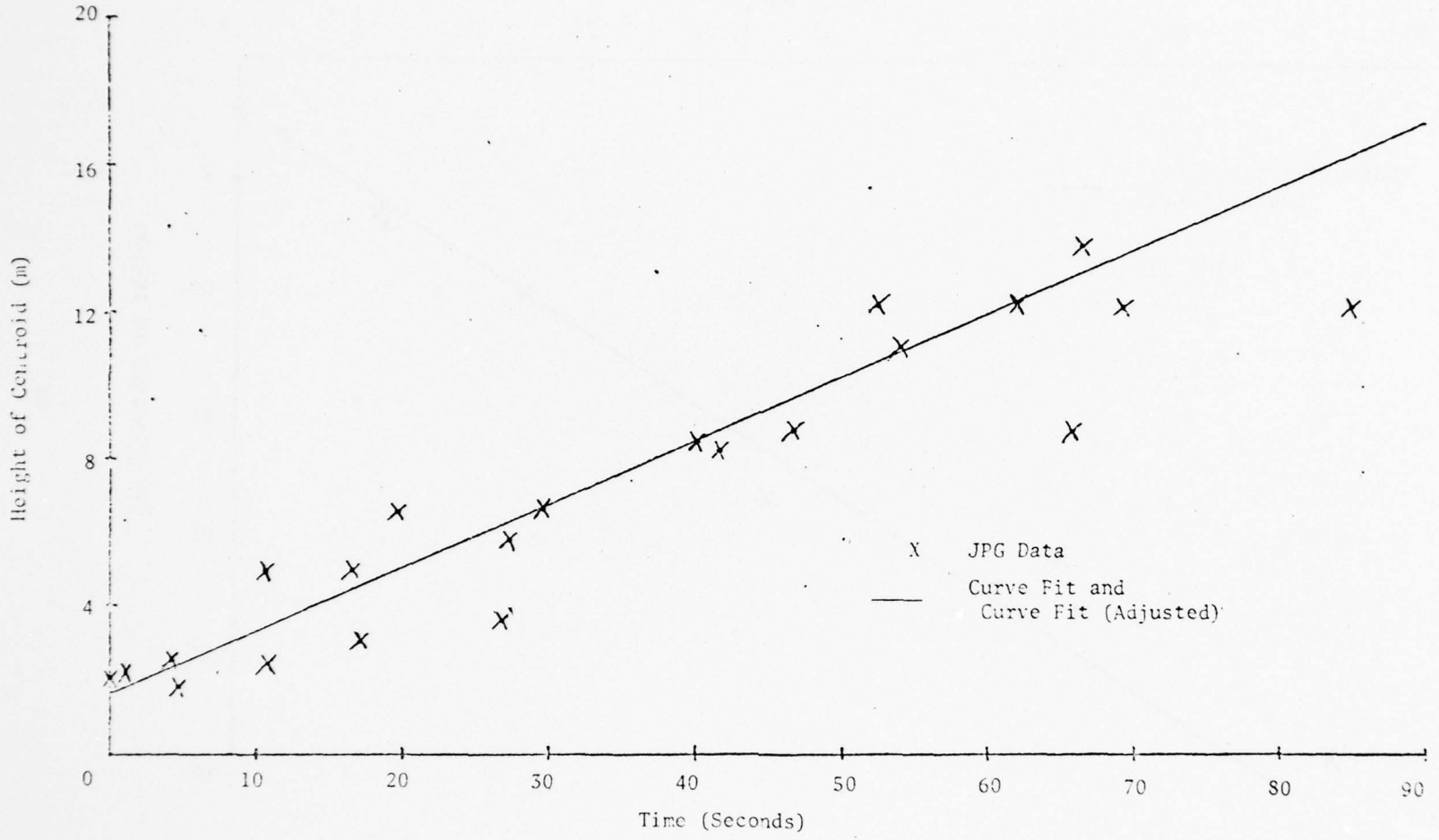


Figure 23. Downwind Cloud, 155mm HC, Pasquill Category C

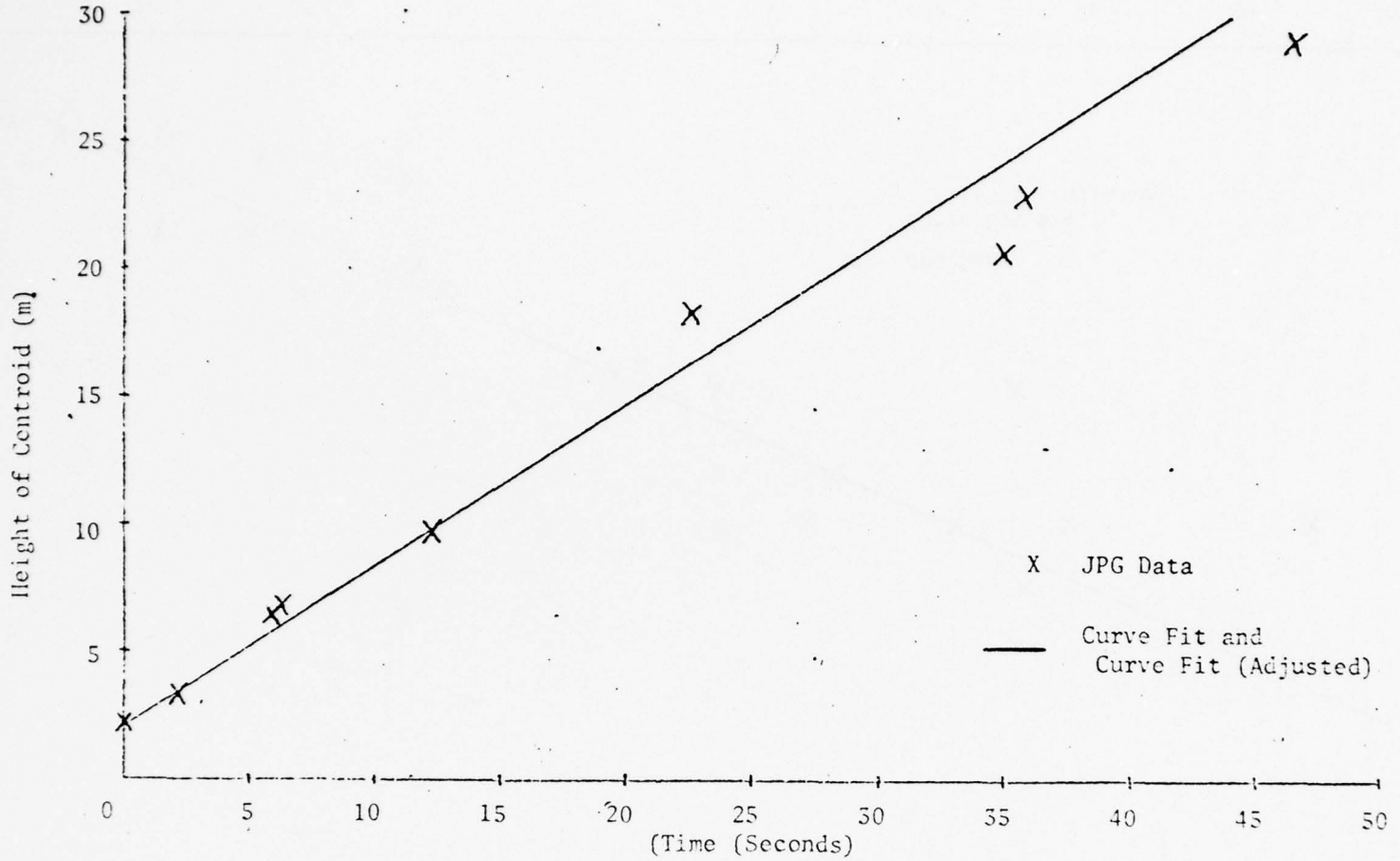


Figure 24. Downwind Cloud, 105mm HC, Pasquill Category A

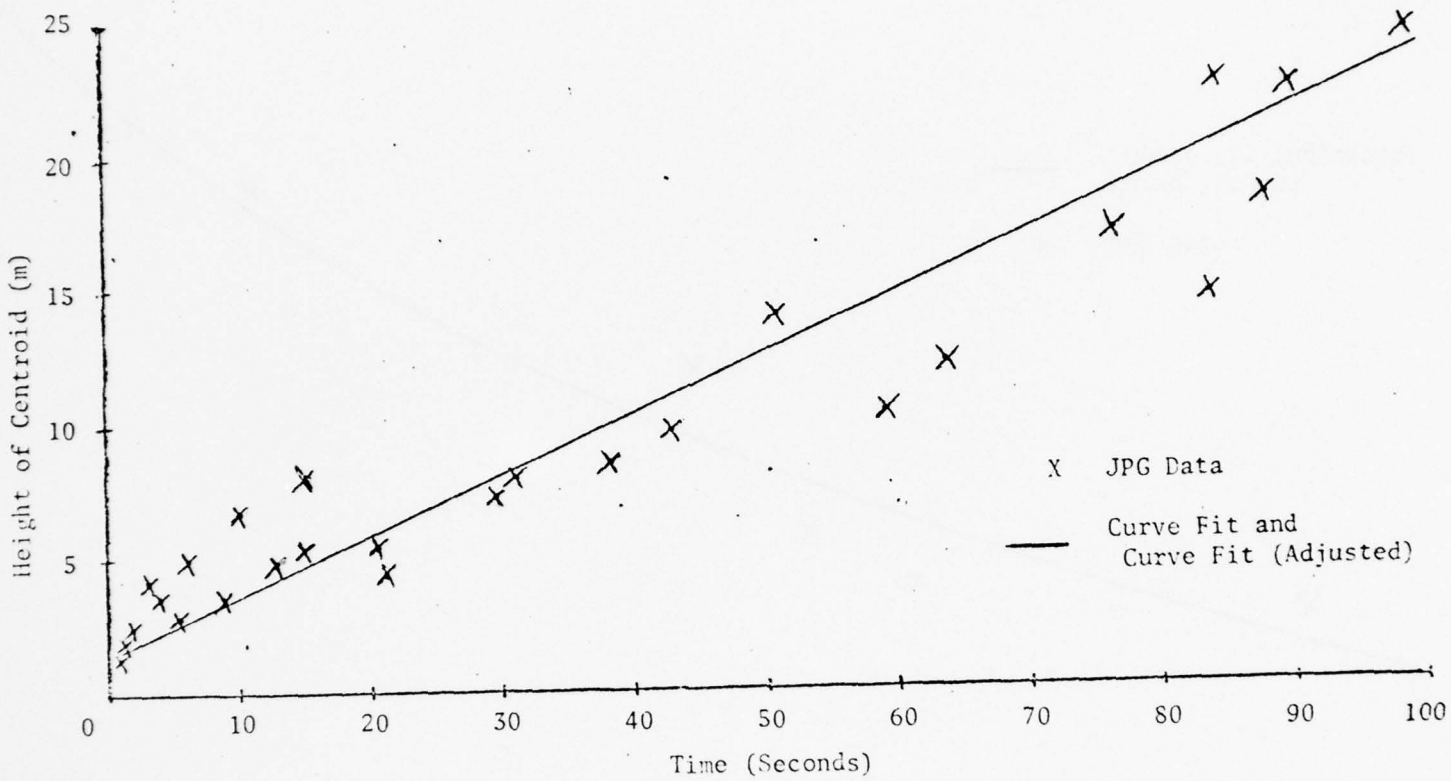


Figure 25. Downwind Cloud, 105mm, Pasquill Category B

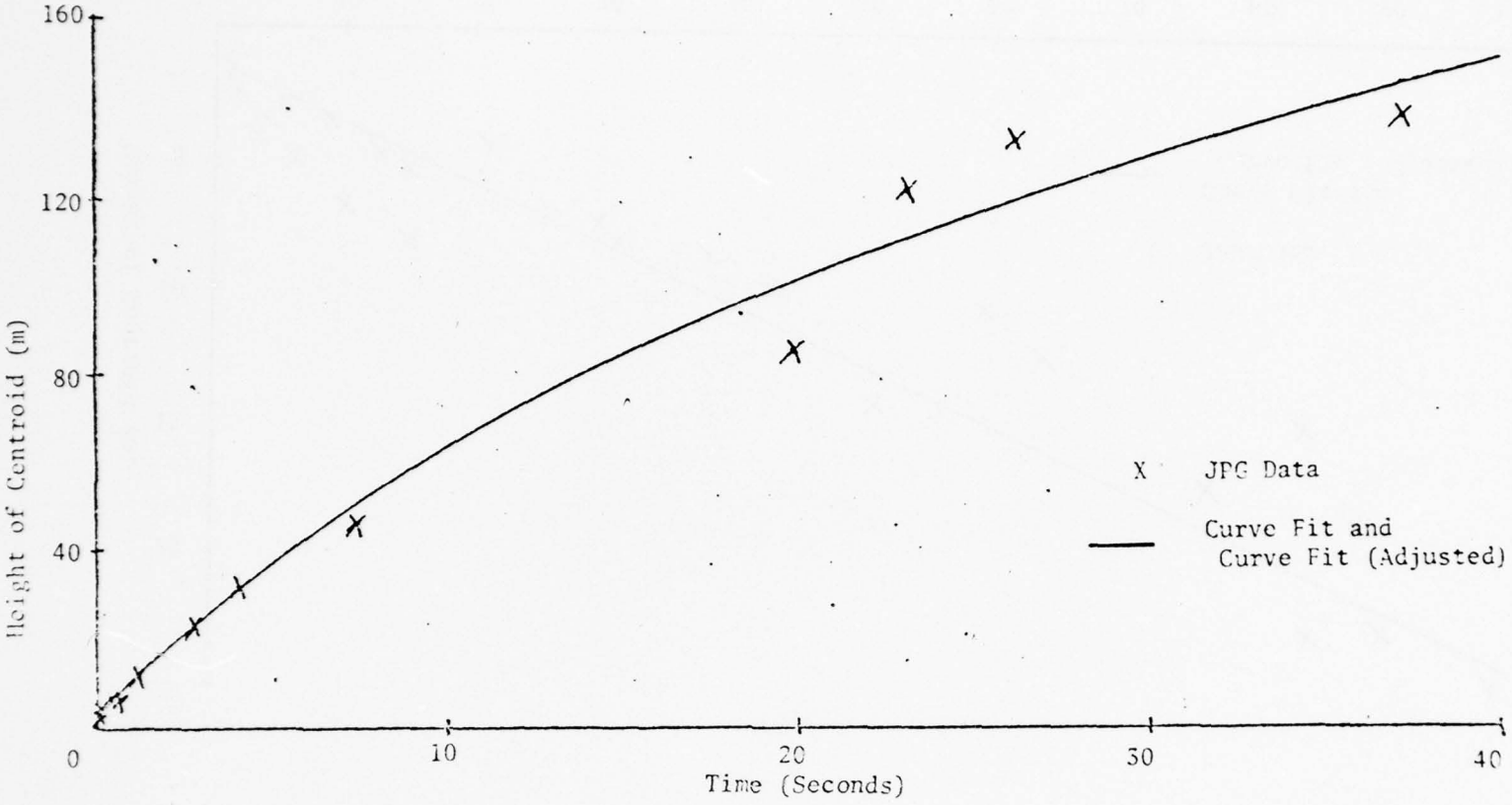


Figure 26. Plume Rise, 4.2" WP, Static Firing

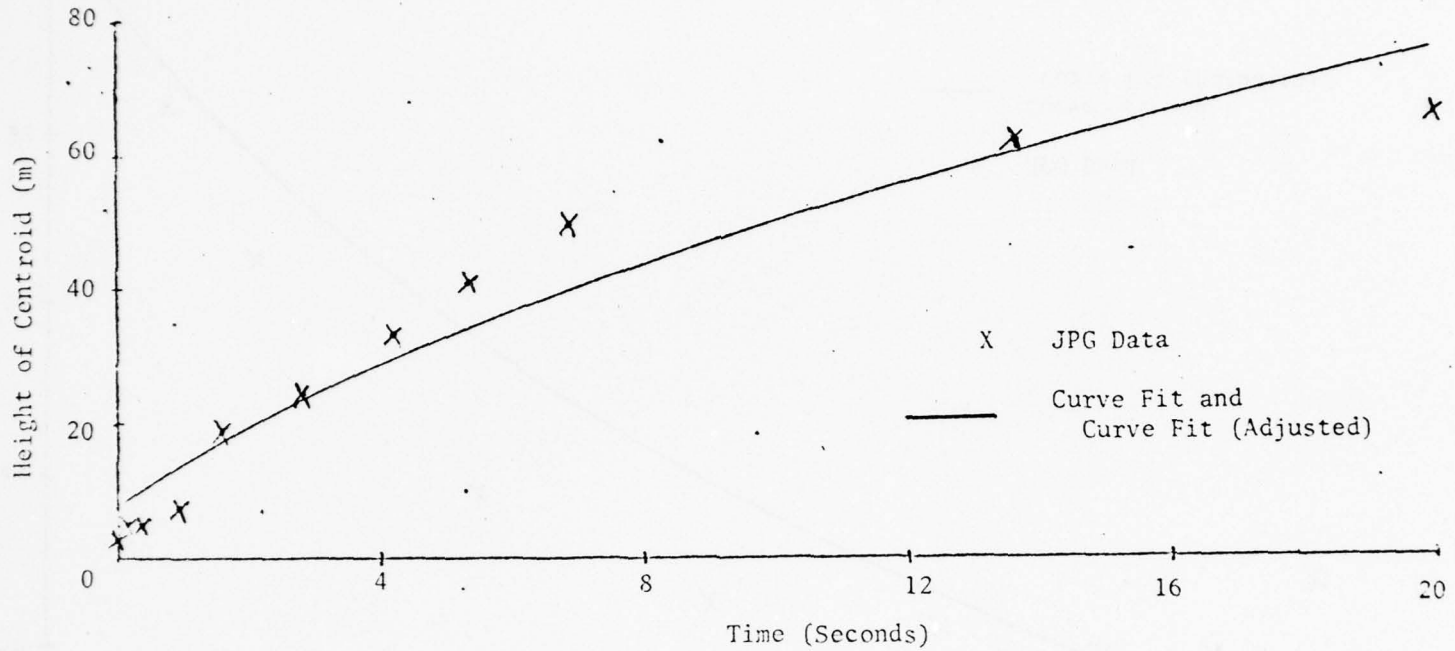


Figure 27. Plume Rise, 105mm WP, Static Firing

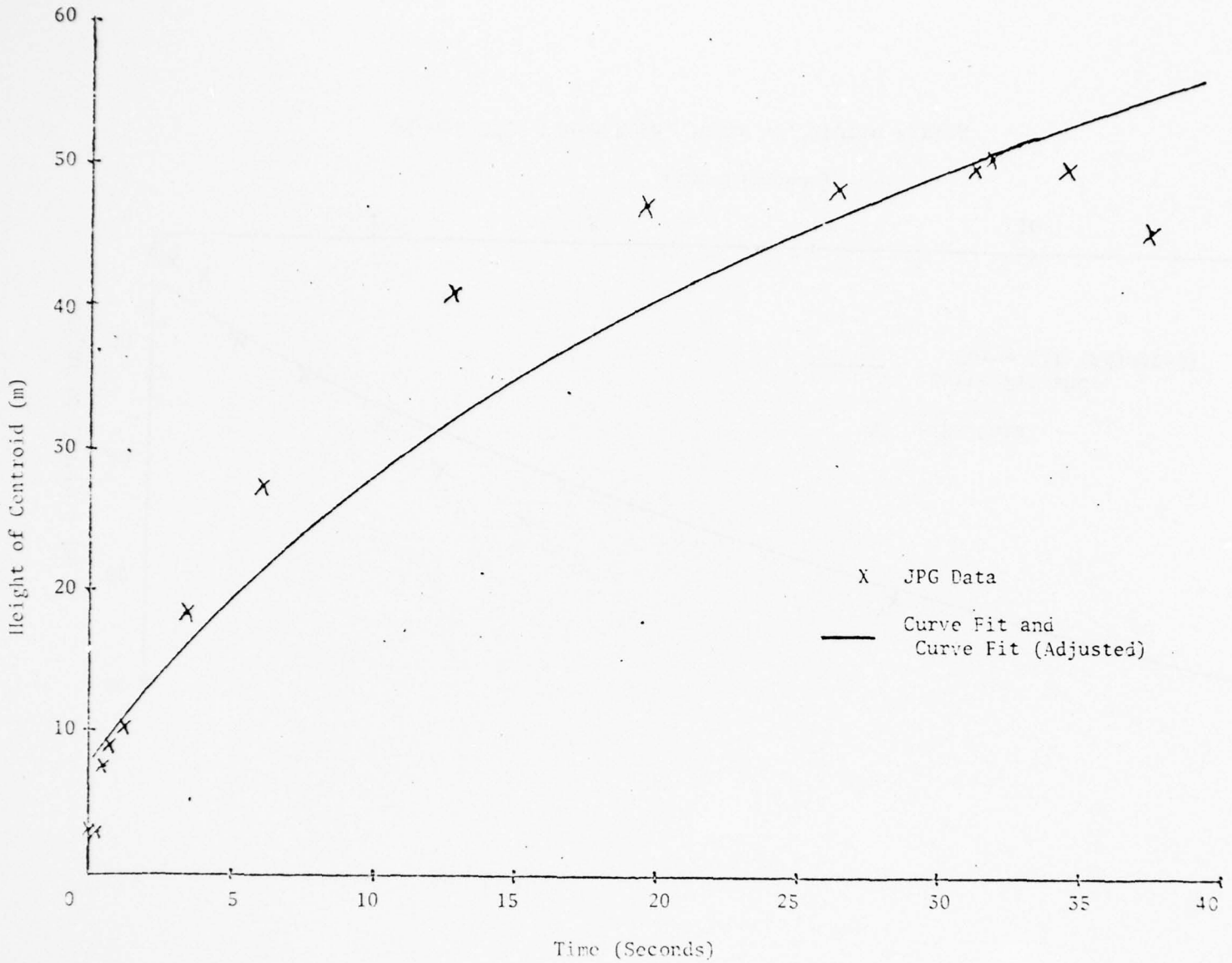


Figure 28. Plume Rise, 81mm WP, Static Firing

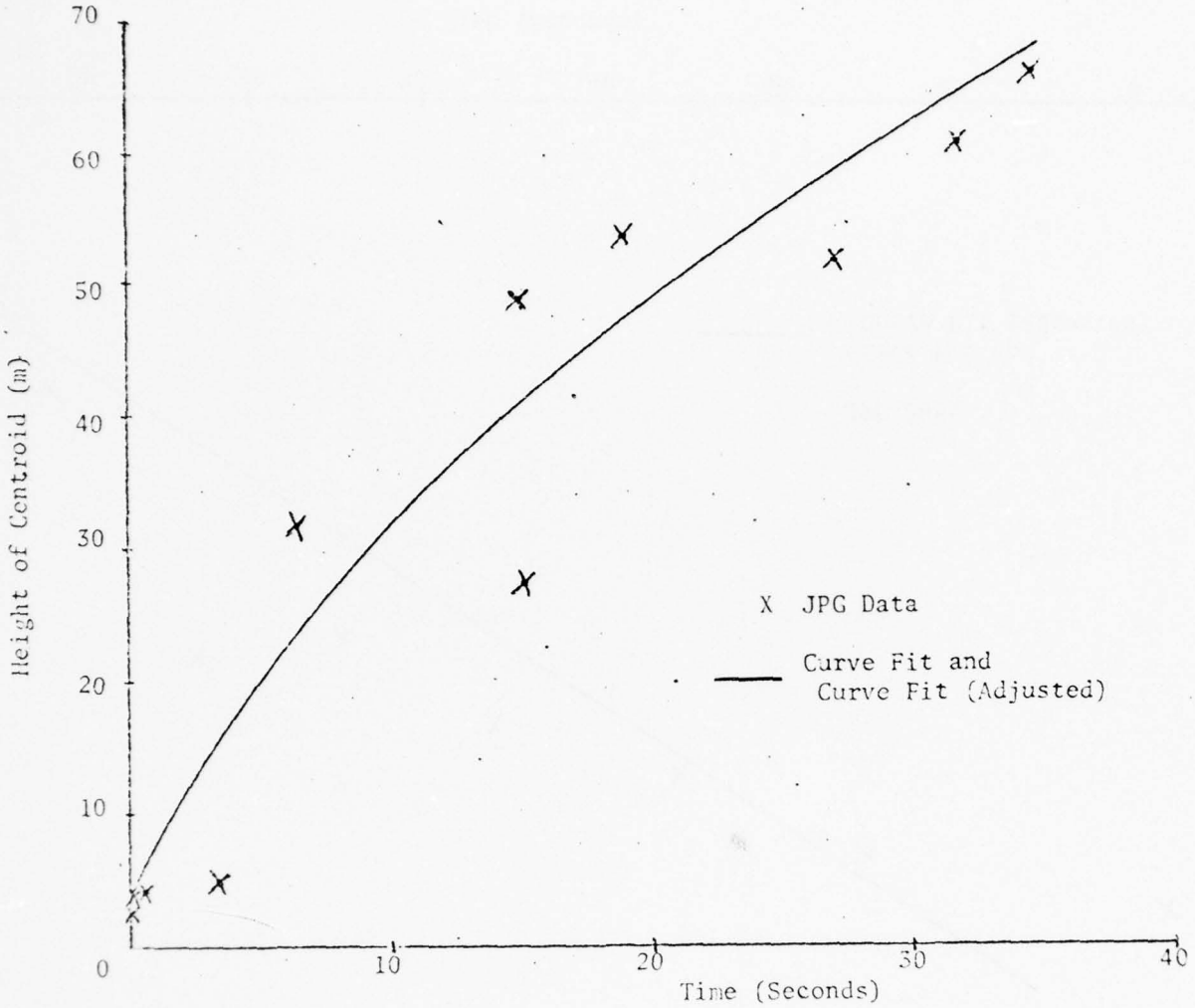


Figure 29. Plume Rise, 60mm WP, Pasquill Category Static Firing

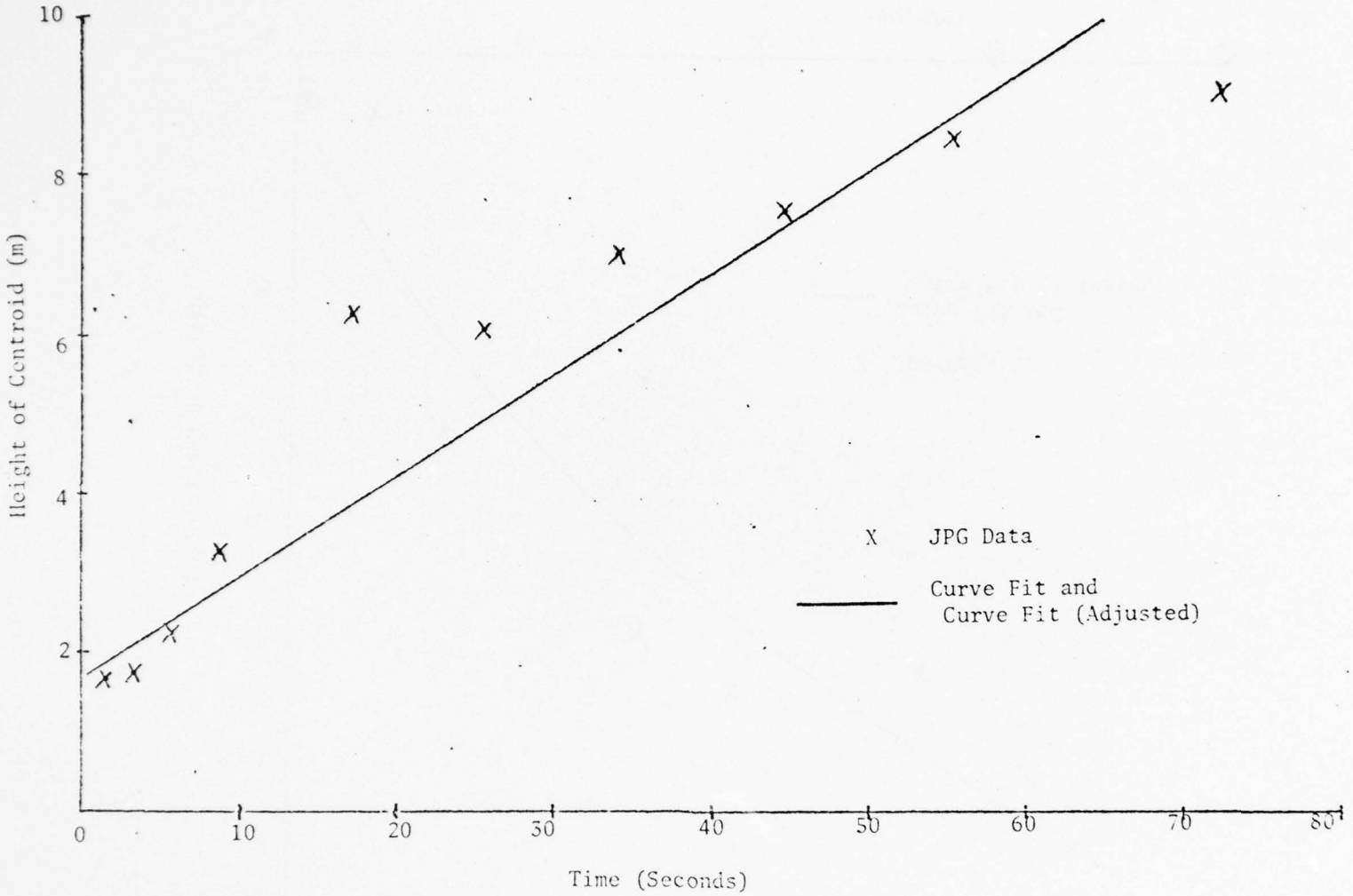


Figure 30. Downwind Cloud, 155mm HC, Pasquill Category, Static Firing

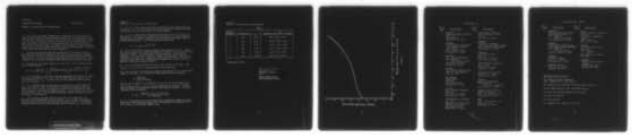
APPENDIX C. JOULES CLOUD RISE MODEL

Next page is blank

AD-A045 874 ARMY MATERIEL SYSTEMS ANALYSIS ACTIVITY ABERDEEN PROV--ETC F/G 19/1
AN ANALYSIS OF THE SMOKE CLOUD DATA FROM THE AUGUST, 1975 JEFFE--ETC(U)
SEP 77 T J DOLCE, D F METZ

UNCLASSIFIED AMSAA-TR-201 NL

2 OF 2
ADA045874



END
DATE FILMED
11-77
DDC

AMSAR-SAM

MEMORANDUM FOR RECORD 28 April 1975

SUBJECT: Vertical Rise of a Heated Plume

1. This "first-generation" methodology for computing the rate-of-rise of a heated plume has been developed from first principles. The assumption is made that the plume resembles an oblate spheriod with a well-defined initial volume. The contents of the plume are "hot", with respect to its surrounding air mass. Thus, the density of the plume is less than the air, and the plume tends to lift because of bouyant forces. As energy is lost through the plume's surface, bouyant forces are reduced and the plume's rate of ascent decreases. Expansion of the plume with time complicates the methodology.

2. Empirical data from the 1971 Yuma Proving Ground surveillance tests of the 155MM, M110 series, WP projectile were used to evaluate certain constants which appear in the model. Because those tests were not intended to provide technical data, certain constants are specified with little confidence. Those constants will be subject to change as more definitive data become available.

3. The height of the plume's centroid, at any time t, may be calculated from the following equation:

$$z(t) = z_o + \left(\frac{\psi t}{n}\right) \lim_{n\to\infty} \sum_{i=1}^{n} \left\{ \frac{(M-1)T_{i-1} + (\tau_{i-1} - T_{i-1}) \, Me^{k\int_{i-1}^{i} f(t)}}{T_{i-1}} \right\}^{0.7}$$

4. z_o is the height of the plume's centroid immediately after munitions impact and smoke dissemination (i.e., t=o). For WP ammunition the volume at z_o is calculated from $z_o = 3\sigma_{zs}$. In particular, for the 155MM WP round the value of z_o is 7.0 meters.

5. ψ is a constant which has been derived, empirically, from the Yuma test data. Its numerical value is believed to depend upon atmospheric stability conditions, only. However, that assumption remains to be validated by tests of WP ammunition other than the 155MM projectile. In the interim, the ψ values shown in Table 1, one for each Pasquill stability category, should be used in the height of rise equation.

6. n is the number of equal intervals into which the elapsed time (i.e., measured from dissemination at t=o) is divided. It is usually not economical to use a large n unless the true lapse rate is known in detail. In practice, one-second intervals from t=o to the final time of interest, t_f, are adequate.

7. T_i is the virtual temperature (°K) of the ambient air at the end of the ith interval. As the plume ascends the ambient temperature changes according to the true lapse rate, pressure and relative humidity.

8. τ_i is the corresponding temperature of the plume (°K) at the end of the ith interval. The value of τ_i depends upon the rate of heat loss through the surface area of the plume, which, in turn, is related to the volume occupied by the expanding plume. τ_i is calculated from the equation.

$$\tau_i = (\tau_{i-1} - T_{i-1})\, e^{k \int_{i-1}^{i} f(t)}$$

9. f(t) is the surface area of the plume (square meters) at time t. Since the volume occupied by the plume increases at a different rate for each Pasquill stability category, the surface areas are also dependent upon atmospheric stability. f(t) are shown in Table 1. Those f(t) apply only to the first 20 seconds of elapsed time. Additional efforts are being made to characterize f(t) as a simple power-law relationship with elapsed time, rather than the quadratic relationships shown in Table 1.

10. k is a constant associated with the rate of cooling of the plume. The value, $k = -2.9 \times 10^{-5}$, was inferred from the Yuma test data.

11. M is the ratio of the molecular weight of the ambient air to the molecular weight of the plume. Its value can be calculated from the relationship

$$M = \frac{4533\, T_o \rho_o}{\tau_o (1.5 + 3626 \rho_o)}$$

where ρ_o is the density of air (kg/m^3) at z_o; T_o is the virtual temperature (°K) of the air at z_o; τ_o is the initial temperature of the plume, dependent upon the ambient air temperature, pressure and relative humidity. τ_o can be calculated from the equation

$$\tau_o = 273 + \frac{7680(1+\lambda) + T_o' (1.5 + 871.79 \rho_o)}{1.5 + 871.79 \rho_c}$$

12. λ is the yield factor to be obtained from the empirical graph of Relative Humidity vs Yield Factor (see Fig 1); T_o' is the ambient air temperature (°K) at z_o; and ρ_o is the density (kg/m^3) at z_o.

AMSAR-SAM
SUBJECT: Vertical Rise of a Heated Plume

TABLE 1

PASQUILL's CATEGORY	PROBABILITY	ψ	f(t) (GOOD FOR ONLY FIRST 20 SECONDS)
A	50%	13.25	$60t^2 + 350t + 1407$
B	50%	10.75	$8.61t^2 + 228t + 1407$
C	50%	8.90	$5.1t^2 + 192t + 1407$
D	50%	7.45*	$4.8t^2 + 130t + 1407$*
E	50%	6.15*	$4.6t^2 + 93t + 1407$*
F	50%	4.95*	$4.5t^2 + 67t + 1407$*

*extrapolated values

Reginald G. Joules

REGINALD G. JOULES
SP/5

Methodology Division
Systems Analysis Office

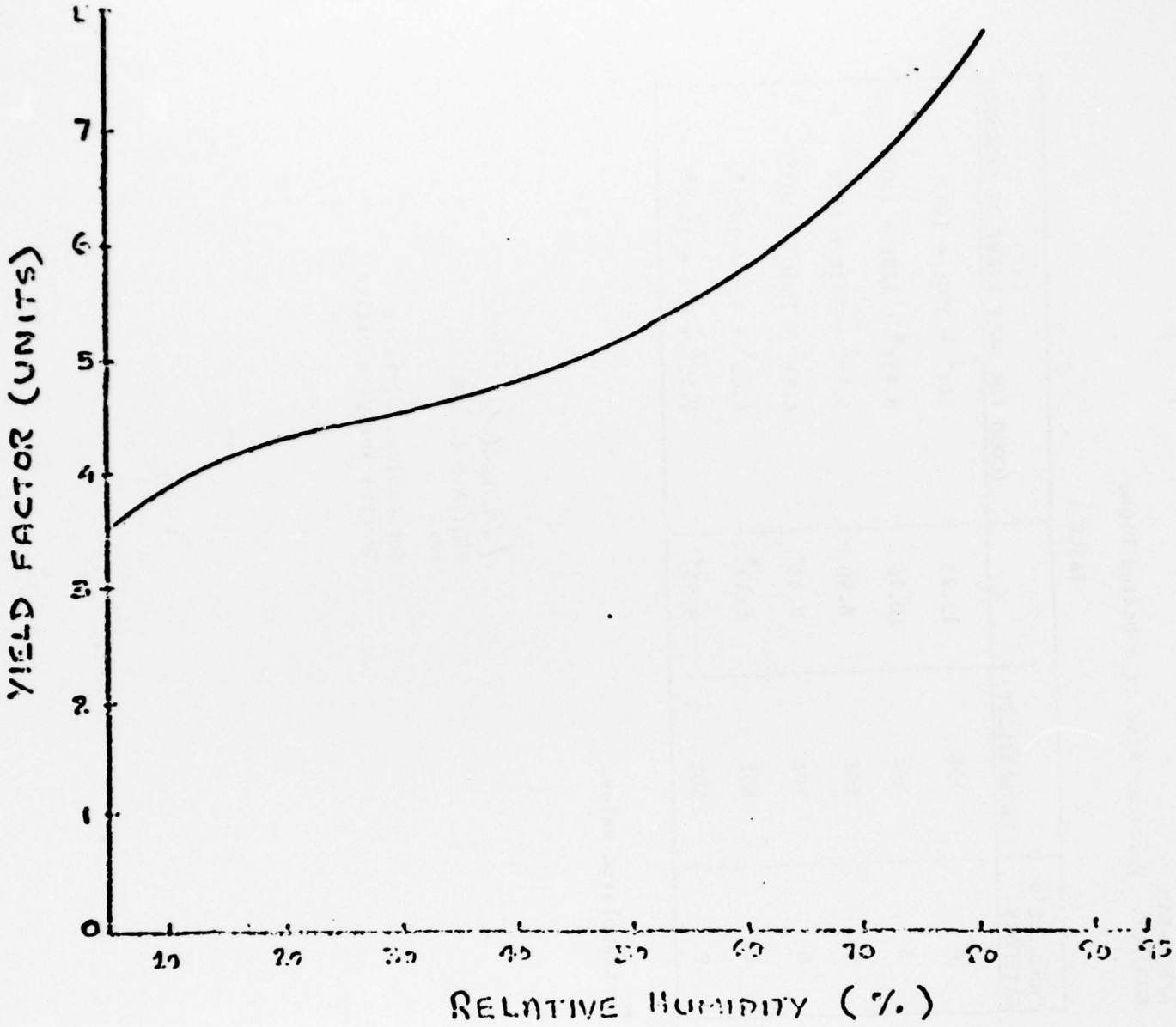

YIELD FACTOR (UNITS)
0
1
2
3
4
5
6
7
10
20
30
40
50
60
70
80
90
95
RELATIVE HUMIDITY (%)

FIG 1.

DISTRIBUTION LIST

No. of Copies	Organization
12	Commander Defense Documentation Center ATTN: TCA Cameron Station Alexandria, VA 22314
1	Commander US Army Materiel Development and Readiness Command ATTN: DRCPA 5001 Eisenhower Avenue Alexandria, VA 22333
1	Commander Harry Diamond Laboratories ATTN: DRXDO-RAF (Mr. Dominick Giglio) 2800 Powder Mill Road Adelphi, MD 20783
1	Commander Naval Weapons Support Center ATTN: Mr. Duane Johnson Crane, IN 47522
1	The Pentagon ODDR&E (E&PS) Rm 3D1079 ATTN: Thomas Walsh Washington, DC 20301
1	Director Naval Research Laboratory Code 5709 ATTN: Mr. Wm E. Howell Washington, DC 20375
1	Lockheed Missiles and Space Co., Inc. Huntsville Res & Eng Center ATTN: Mr. L. Ray Baker 4800 Bradford Drive Huntsville, AL 35804
1	Science Applications, Inc. ATTN: Frederick G. Smith Box 328 Ann Arbor, MI 48107
1	Commander USA Mobility Equipment Research & Development Command ATTN: DRXFB-RCT (Fred Kezer) Fort Belvoir, VA 22060
1	Commander Naval Weapons Center Code 385 ATTN: Russell Reed, Jr China Lake, CA 93555
1	Martin-Marietta Corporation P.O. Box 5837 ATTN: William A. Buss Orlando, FL 32805
1	Teledyne Brown Engineering ATTN: James C. Majure Huntsville, AL 35807
1	Director Night Vision Laboratory ATTN: DRSEL-NV-VI (Richard J. Bergemann) Fort Belvoir, VA 22043
1	Oklahoma State University School of Technology ATTN: Dr. Marvin D. Smith Stillwater, OK 74074
1	RAND ATTN: John K. Walker, Jr. 2100 M. St., NW Washington, DC 20037

DISTRIBUTION LIST (CONT)

No. of Copies	Organization
1	Commander US Army Combined Arms Combat Developments Activity ATTN: ATCA-COA (Robert A. Davidson) Fort Leavenworth, KS 66027
1	Commander US Army Missile Research and Development Command (MIRADCOM) ATTN: DRDMI-CGA (Dr. Bruce Fowler) Redstone Arsenal, AL 35809
1	Commander Frankford Arsenal ATTN: Dr. Ed Stubing Philadelphia, PA 19124
1	Battelle Institute ATTN: Mr. Milton Cutler Columbus, OH 43216
2	Chief Defense Logistics Information Exchange USA Logistics Management Center ATTN: DRXMC-D Fort Lee, VA 23801
2	Director USA TRADOC Systems Analysis Activity ATTN: ATAA-SA ATAA-T White Sands Missile Range, NM 88002
1	Commander US Army Concepts Analysis Agency 8120 Woodmont Avenue Bethesda, MD 20014

Aberdeen Proving Ground, MD

Dir, Chemical Systems Laboratory,
ATTN: DRDAB-CLY-A (Mr. Ron Pennsyle)

Cdr, USATECOM, ATTN: DRSTE-ME (Mr. Warren Baity), Bldg 314

PM for Smoke/Obscurants, ATTN: DRCPM-SMK, Bldg 324

Dir, BRL, ATTN: Warhead Mechanics Div, Bldg 328

Ch, Tech Lib, Bldg 305

Dir, HEL, Bldg 520

Dir. USAMSAA, ATTN: DRXSY-GP (10 Copies)