USAELRDL Technical Report 2367

STUDIES OF METEOROLOGICAL TECHNIQUES FOR SOUND-RANGING

PART I

Raymond Bellucci

June 1963

UNITED STATES ARMY
ELECTRONICS RESEARCH AND DEVELOPMENT LABORATORY
FORT MONMOUTH, N.J.

U. S. ARMY ELECTRONICS RESEARCH AND DEVELOPMENT LABORATORY

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STUDIES OF METEOROLOGICAL TECHNIQUES FOR SOUND-RANGING

PART I

Raymond Bellucci

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Abstract

In October 1961, a series of meteorological and sound-ranging measurements were made at Fort Sill, Oklahoma, to provide sound-ranging data under meteorological conditions prevailing during the fall season.

The standard method of applying meteorological corrections to the sound-ranging data, as employed by the Artillery, was studied. Errors in target location obtained by the application of the Artillery technique, using meteorological data at the time of detonation, were compared to:

(1) Errors in target location using sound-ranging data that were not corrected for meteorology

(2) Errors in target location in the Artillery technique using meteorological data between one-half and one hour old.

The results indicated that a significant improvement in target location was obtained by applying the Artillery technique for sound-ranging corrections to the firing data and that the Artillery method for applying meteorological corrections to sound-ranging data gave positive improvements for the upwind targets, but variable results for downwind targets.

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STUDIES OF METEOROLOGICAL TECHNIQUES FOR SOUND-RANGING: PART I

INTRODUCTION

Sound-ranging is the process of locating sound sources produced by the firing of guns, bursting of shells, or other explosions, by measuring the time interval of the sound wave at several accurately located microphones. In the Field Artillery method for sound ranging, the sound-ranging set GR-8 is used to obtain the arrival times of the sound wave to a maximum of six microphones placed in a straight line and spaced in a predetermined manner. Apparent bearings to the sound source are obtained; and by the geometry of the sound-ranging system, the position of the sound source is deduced.

Since sound travels through the atmosphere, the arrival times of the sound waves are affected by the state of the atmosphere which prevails at the time of the recording. Therefore, meteorological corrections must be made to the apparent bearings in order to obtain the true target location. Thus, before the observer can use the record of the arrival times to establish the true position of the sound source, he must be provided with certain meteorological data.

The data of interest to the sound ranger are the wind speed, wind direction, sonic temperature, and the times of sound arrival.

DISCUSSION

A plan to conduct a series of tests at Fort Sill, Oklahoma, was formulated by USAELRDL during the fall of 1960 for the purpose of obtaining sound-ranging data under all meteorological conditions. The objectives of the tests were stated in detail in a letter to the U. S. Army Artillery and Missile School, dated 26 Jan 60, subject: "Validity of Present Sound Ranging Meteorological Message," namely,

(1) To determine the variability of the sound-ranging meteorological data both in time and space.

(2) To determine a method for obtaining the optimum meteorological message.

(3) To apply the results of an effective meteorological message to obtain a more accurate location of the target.

(4) To improve the present plotting procedure.

(5) To improve sound-ranging accuracy for targets off to the flanks.

(6) To improve sound-ranging accuracy by utilizing the tilt of the incoming wave front.

(7) To study techniques to account for terrain effects on sound-ranging accuracy.

DESIGN OF EXPERIMENT

In October 1961, a series of tests was conducted at Fort Sill, Oklahoma, to obtain sound-ranging data under meteorological conditions prevailing during the fall season. The experimental design adopted for these tests to fulfill the above objectives consisted of scheduling 17 two-hour test periods through eight testing days, beginning on 19 Oct 61 and ending on 29 Oct 61. Each testing day consisted of at least one two-hour period. Demolition teams made one firing of TNT every 15 minutes at each of four firing points. The firing points, referred to as "targets" in this report, were located as follows: Targets 1 and 2 were, respectively, 8200 and 4800 meters north of the east-west sound-ranging array; target 3 was 6100 meters south of the array; and target 4 was approximately 12,000 meters southwest of the center of the array.

The first firing was made two minutes after the release of meteorological balloons from each of three rawinsonde stations located, respectively, at Frisco Ridge, Adams Hill, and Potato Hill. Frisco Ridge is five miles northwest of Potato Hill and seven miles due north of Adams Hill, Potato Hill being the location of the eastern end of the sound-ranging array. In addition, four double theodolite stations were included to provide a finer structure of the wind field.

A second GR-8 sound-ranging system was oriented in a north-south direction and positioned so that the southern end of this array was located at the eastern end of the first array. Only data from the east-west system have been utilized in the present study. In addition to the GR-8 sound-ranging systems, five AN/TNS-5 sets were placed on the arrays. The location of the rawinsonde stations, demolition shot points, etc., is shown in Fig. 1 (Field-Station Layout), where north is at the top of the diagram.

Meteorological teams released five radiosondes and nine pibals each two-hour period per station. The radiosondes were tracked to 15,000 feet, and the pibals to 7000 feet. Psychron (Bendix-Friez) and sling psychrometer readings were made every 30 minutes during each two-hour period at the radiosonde and double-theodolite stations. Recordings of the wind velocity were made at six locations with low-level wind set AN/GMQ-11. Weather radar surveillance of the area was provided by an AN/APQ-13 radar set. Weather observations were also taken, although the information was not used in the analysis given in this report.

These tests were supported by the following agencies:

USAARTYBD, USAAMS, USAAMC, of Fort Sill, Oklahoma
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USASMSA, White Sands, New Mexico
USAELRDL, Fort Monmouth, New Jersey

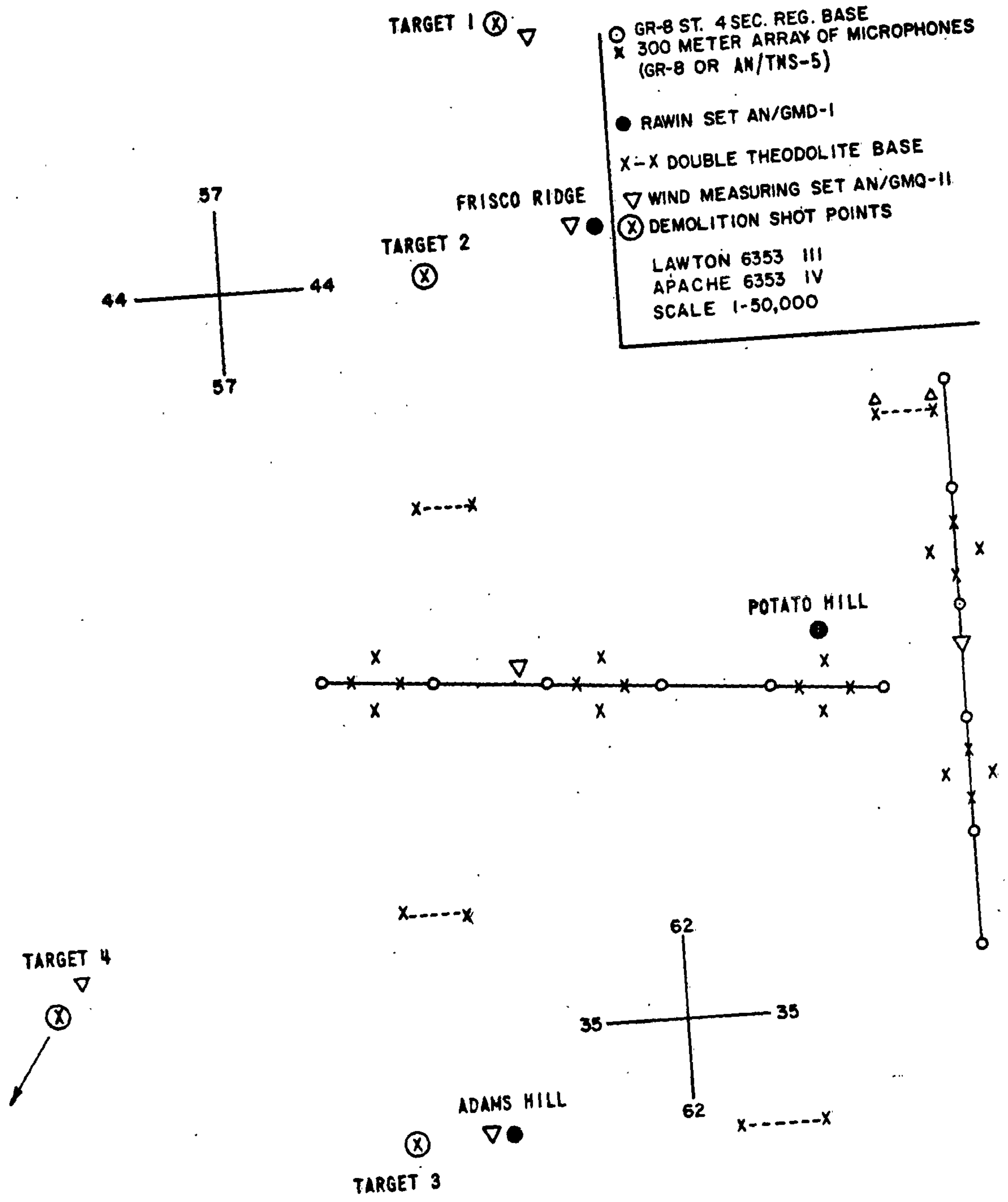

FIG. 1. FIELD STATION LAYOUT

METEOROLOGICAL CONDITIONS DURING TESTS

Fort Sill was under the influence of high pressure and northerly winds on the 19th and 26th of October, and high pressure and southerly winds on the 20th of October. On 21, 22, 27, 28, and 29 October, Fort Sill was under the influence of low pressure and southerly winds. No firings were made in precipitation, although the project was carried out under varying conditions of cloudiness, ranging from clear skies to overcast. Table I shows the surface conditions existing during the tests.

Table I. Surface Weather Conditions

Date Oct 1961	Time	Direction	Speed (knots)	Temp. °F
19	0500	↓	12	48
	0700	↓	9	48
	0900	↓	8	52
20	0500	↑	3	45
	0700	↑	5	44
	0900	↑	5	54
21	1500	↑	14	81
	1700	↑	11	78
	1900	↑	5	69
22	1000	↑	12	69
	1500	↑	21	83
	1800	↑	14	78
	2000	↑ ↖	11	72
26	0400	↓	6	41
	0600	↓	6	40
	0800	↓	4	45
27	0400	↑	8	53
	0600	↑	12	55
	0800	↑	14	56
28	0900	↑	12	67
	1000	↑	14	70
	1100	↑	18	73
29	1000	↑ ↖	14	73
	1300	↑ ↖	17	79
	1900	↖	12	75
	2000	↖	8	73

GENERAL

The accuracy* of target location can be defined as the difference between the true target location and the computed target location. This difference is dependent on the accuracy of the base line survey, length of sound base, distance from the sound source, weather conditions, readability of the oscillograms, appearance of the oscillogram traces, appearance of the polygon of error, and the meteorological technique for sound-ranging correction.

The data analysis for this series of tests is based on the assumption that, if all needed corrections were applied to the observed time intervals, the centroid of the polygon of error would coincide with the true target location. The amount by which the applied corrections fail to bring the centroid to the target location is the error or measure of accuracy of the sound-ranging system and correction technique in locating the target. This error can be expressed mathematically by the following formula:

$$\sigma_E^2 = \sigma_m^2 + \sigma_s^2 + 2\, r_{ms}\, \sigma_m\, \sigma_s \,,$$

where σ_E^2 is the error variance,

σ_m^2 is the variance due to weather and technique of weather correction,

σ_s^2 is the variance due to sound ranging system (survey error etc.),

r_{ms} is the correlation coefficient between the two factors.

Since no estimates of σ_s^2 and r_{ms} are available for the GR-8 sound-ranging system, the estimate of error computed for the Artillery technique of applying meteorological corrections includes the sound-ranging errors listed above. In this report the estimate of σ_E is given as the mean radial error corrected for meteorology.

RESULTS

The analysis given in this report is with respect to the east-west sound-ranging array, and was designed to answer the following questions concerning the sound-ranging problem:

(1) What are the magnitudes of the errors obtained by the present GR-8 sound-ranging system when the apparent bearings are not corrected for the state of the atmosphere prevailing at the time of detonations?

(2) What improvements, if any, are made by applying the artillery method for meteorological corrections to the apparent bearings when meteorological information from a single sounding station is used?

*In this report the accuracy is referred to as the magnitude of the vector error in target location, and is given as the mean radial error.

(3) Does a distance of seven miles between stations contribute significantly to the error in target location?

(4) What is the effect of time variability of the sound-ranging meteorological data on the error in target location?

The results with respect to each individual rawinsonde station are given in Tables II, III, IV, and V. Mean radial errors in target location, corrected for the meteorological conditions observed at each AN/GMD-1 station near the time of detonation, are shown in column 2 for each station. The percent improvement in target location obtained by correcting the data for weather is given in column 3. For example, on 20 October, only two shots from target 1 were available for comparison, using the meteorological data from the Adams Hill station. A mean radial error for the uncorrected data was computed and compared to the mean radial error computed for the weather corrected data, resulting in an improvement of 12 percent for the two cases available for comparison.

The tables are divided into three parts and show the following:

(1) The mean radial errors in target location when the target is upwind and downwind of the sound-ranging array, and

(2) Total error for both conditions given in the row labelled "composite," weighted average.

In general, the least error was obtained for the targets located upwind of the sound-ranging array. For example, when the meteorological corrections obtained from the Adams Hill rawinsonde station were applied to the sound-ranging data, the weighted average upwind error for target 1 was 169 meters, while the downwind error was 216 meters. Similar results were obtained for all targets and for the three rawinsonde stations.

Before the results could be combined for the three radiosonde stations, it had to be ascertained that the mean radial errors for each station were not significantly different from each other. The results of an analysis of a variance test for a one-factor experiment indicated that the mean radial errors obtained for each rawinsonde station were not significantly different from each other. Thus the errors between stations do not significantly contribute to the error in target location, indicating that a distance of 5 to 7 miles between stations was not a significant factor for this series of test firings made at Fort Sill, Oklahoma.

Since there was no significant difference in the error of target location between rawinsonde stations, the mean radial errors were combined, resulting in the values shown in Table VI. The magnitude of the mean radial errors (not corrected for meteorology), being a function of both the distance and angle of the target to the center of the sound-ranging array, increased from a minimum of 113 meters for target 2 to a maximum of 294 meters for target 1. Targets 1, 2, and 3 were approximately orthogonal to the center of the sound-ranging array. The error increased to a value of 3825 meters for the flanking target, which was approximately 12,000 meters southwest of the array.

Table II. Mean Radial Errors for Target 1

	Meteorological Stations											
	Adams Hill				Frisco Ridge				Potato Hill			
	Error in Meters Without Met	Error in Meters With Met	% Improvement	N	Error in Meters Without Met	Error in Meters With Met	% Improvement	N	Error in Meters Without Met	Error in Meters With Met	% Improvement	N
Downwind 20 Oct 61	102	90	12	2	151	153	-1	10	---	---	---	---
21 Oct 61	398	217	45	9	398	181	55	9	398	191	52	9
22 Oct 61	392	238	39	12	294	256	13	5	392	247	37	12
Subtotal downwind weighted average	369	216	41	23	273	185	32	24	395	223	44	21
Upwind 26 Oct 61	224	169	25	12	210	142	32	15	210	142	32	15
Composite weighted average	319	200	37	35	249	168	33	39	318	189	41	36

Table III. Mean Radial Errors for Target 2

	Meteorological stations											
	Adams Hill				Frisco Ridge				Potato Hill			
	Error in Meters				Error in Meters				Error in Meters			
	Without Met	With Met	% Improvement	N	Without Met	With Met	% Improvement	N	Without Met	With Met	% Improvement	N
Downwind 20 Oct 61	74	69	7	4	78	90	-15	13	---	---	---	---
21 Oct 61	90	188	-109	11	90	175	-94	11	90	163	-81	11
22 Oct 61	140	53	62	5	150	54	64	6	150	39	74	6
Subtotal downwind weighted average	99	130	- 31	20	97	114	-18	30	111	119	- 2	17
Upwind 19 Oct 61	82	52	37	3	92	49	47	7	90	45	50	2
26 Oct 61	143	88	38	12	139	85	39	15	139	74	47	15
Subtotal upwind weighted average	131	81	38	15	124	74	40	22	133	71	47	17
Composite weighted average	113	109	3	35	108	96	11	52	122	95	22	34

Table IV. Mean Radial Errors for Target 3

	Meteorological Stations											
	Adams Hill				Frisco Ridge				Potato Hill			
	Error in Meters Without Met	Error in Meters With Met	% Improvement	N	Error in Meters Without Met	Error in Meters With Met	% Improvement	N	Error in Meters Without Met	Error in Meters With Met	% Improvement	N
Upwind 20 Oct 61	65	65	0	5	77	57	26	15	---	---	---	---
21 Oct 61	244	92	62	15	244	94	61	14	244	97	60	15
22 Oct 61	252	82	67	19	201	69	66	7	247	96	61	21
27 Oct 61	159	125	21	13	163	130	20	13	162	129	20	15
28 Oct 61	214	82	62	7	222	120	46	8	222	104	53	8
29 Oct 61	234	111	53	16	234	107	54	16	226	106	53	18
Subtotal upwind weighted average	214	97	55	75	187	96	49	73	222	106	52	77
Downwind 19 Oct 61	167	74	56	3	167	171	-2	5	170	120	29	2
26 Oct 61	177	133	25	12	177	139	21	14	177	139	21	14
Subtotal downwind weighted average	175	121	31	15	174	147	16	19	176	137	22	16
Composite weighted average	208	101	51	90	184	107	42	92	214	111	48	93

Table V. Mean Radial Errors for Target 4

		Meteorological Stations											
		Adams Hill				Frisco Ridge				Potato Hill			
		Error in Meters Without Met	Error in Meters With Met	% Improvement	N	Error in Meters Without Met	Error in Meters With Met	% Improvement	N	Error in Meters Without Met	Error in Meters With Met	% Improvement	N
Upwind	20 Oct 61	1644	1475	10	4	1343	1095	18	13	----	----	----	---
	21 Oct 61	2193	1055	52	11	2193	1035	53	11	2193	1147	48	11
	22 Oct 61	2765	1115	60	12	3212	1206	62	4	2804	1221	56	13
	27 Oct 61	6200	5526	11	11	6686	5865	12	13	6454	5548	14	14
	28 Oct 61	8895	5500	38	5	8430	6416	24	6	8430	5579	34	6
	29 Oct 61	4027	2311	43	13	4027	1744	57	13	4231	2420	43	14
Subtotal upwind weighted average		4088	2665	35	56	4071	2778	32	60	4496	2992	33	58
Downwind	26 Oct 61	1967	2513	-28	10	1797	2309	-28	12	1862	2495	-34	13
Composite weighted average		3766	2642	30	66	3692	2700	27	72	4013	2901	28	71

Table VI. Combined Mean Radial Errors

	Targets											
	1			2			3			4		
Range to center of base line	8200 m			4800 m			6100 m			12,000 m		
Angle from normal to base line	10°			21°			11°			60°		
	Error in Meters		%	Error in Meters		%	Error in Meters		%	Error in Meters		%
	Without Met	With Met	Improve-ment	Without Met	With Met	Improve-ment	Without Met	With Met	Improve-ment	Without Met	With Met	Improve-ment
Upwind	214	150	30	129	75	42	208	100	52	4218	2813	33
Downwind	343	207	40	101	120	-19	175	136	22	1870	2436	-30
Composite weighted average	294	185	37	113	100	12	202	107	47	3825	2750	28

A significant improvement in target location was obtained by the application of the Artillery method for meteorological correction to the Fort Sill firings, reducing the error from 3.2 percent to 1.7 percent of the range for targets 1, 2 and 3 when they were upwind of the sound-ranging array. Variable results were obtained when they were downwind of the array. The error for the flanking target, however, remained considerable (approximately 21 percent of the range for the weighted composite average).

Figure 2 shows the dependence of the improvement in target location on wind direction. The percent of improvement in locating the targets was plotted for the upwind and downwind cases as a function of range. No significance can be attached to the curve drawn through the points, since there is too much scatter between them and too few points. However, the error data indicate that the Artillery method for applying meteorological corrections to sound-ranging data gives positive improvement for upwind targets, but variable results for downwind targets.

VARIABILITY OF SOUND-RANGING METEOROLOGICAL DATA

One objective of the tests was to determine the variability of the sound-ranging meteorological data, both in time and space. The Artillery method was used for computing the meteorological parameters of interest from the balloon soundings made at each rawinsonde station. For each sounding, an effective wind speed, wind direction, and sonic temperature were computed. Time-lags of one-half hour and one hour were analyzed because of the limited number of data available for analysis.

Pairs of flights for the above time-lags were compared for each rawinsonde station. The statistic used for the measure of time variability was the mean absolute value of the vector velocity difference, $\overline{|\Delta V|}$, between pairs of flights. The results are shown in table VII.

Table VII. Time Variability of Effective Wind

	Meteorological Stations		
ΔT in Hours	Adams Hill	Frisco Ridge	Potato Hill
1/2	2.1 mph	1.5 mph	1.5 mph
1	2.5 mph	1.7 mph	1.6 mph

The differences in the time-variability estimates of the effective wind between the rawinsonde stations were not statistically significant. This agreed with the findings for the mean radial errors between stations mentioned on page 6 of this report. The data for the three stations were combined, providing a more reliable estimate of the time variability of the effective wind. The results are shown in table VIII.

Table VIII. Time Variability of Effective Wind

ΔT in Hours	$\overline{\|\Delta V\|}$	σ	N
1/2	1.7 mph	1.9 mph	143
1	1.9 mph	1.8 mph	109

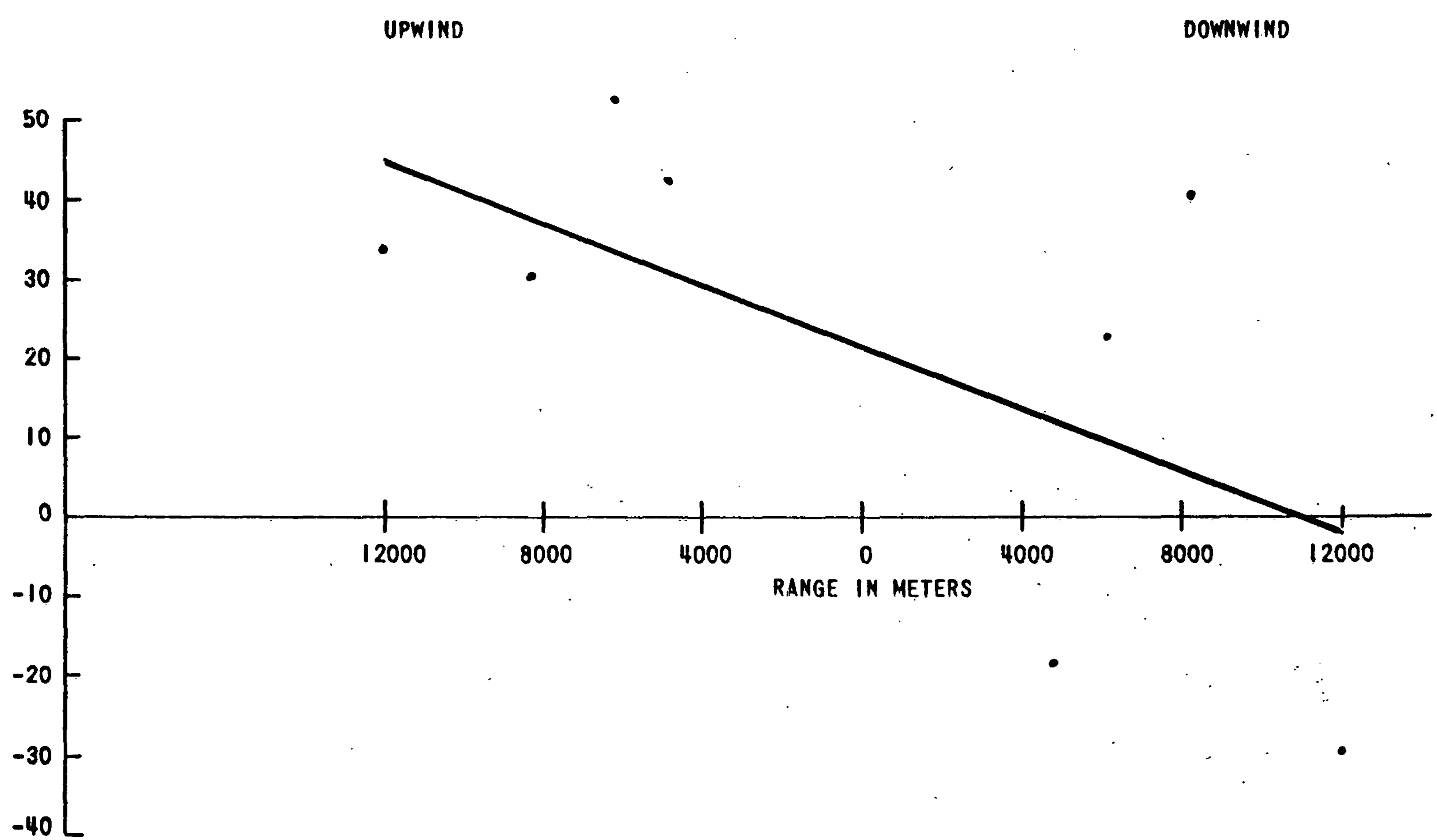

FIG. 2 DEPENDENCE OF IMPROVEMENT IN TARGET LOCATION ON WIND DIRECTION

The effect of the time variability of the sound-ranging data on the radial error in target location was computed for targets 1, 2, and 3, and is shown in table IX.

Table IX. Effect of Time Variability on Target Locations

ΔT in Hours	Target 1	Target 2	Target 3
$0 < \Delta T \leq \frac{1}{2}$	185 m	100 m	107 m
$\frac{1}{2} < \Delta T \leq 1$	203 m	126 m	124 m

The first column indicates the age of the meteorological data used to correct the Fort Sill firings. Thus, meteorological information up to one-half hour old resulted in mean radial errors given in row 1, and meteorological data between one-half and one hour old resulted in mean radial errors shown in row 2. A significant increase in the error in target location was obtained for targets 1, 2, and 3. Not enough data were available to make a valid comparison for the flanking target.

This significant increase in error was not deducible from the results of the wind variability estimates given in table VIII. The reason for this discrepancy is not apparent at this stage of the analysis. However, the results seem to indicate that the time variability of the sound-ranging data is an important factor.

CONCLUSIONS

Errors in target location with respect to the east-west sound-ranging array were calculated for all targets, first by not correcting the sound-ranging data for weather effects, and secondly by applying the Artillery method for meteorological corrections to the data.

It was shown that the error in target location uncorrected for meteorology for the straight-line sound-ranging array, while being dependent on distance and angle of the target to the base line, averaged greater than 100 meters for all targets.

The results to date indicate that:

(1) Meteorological corrections applied to the GR-8 sound-ranging system's apparent bearings did significantly reduce the error in target location.

(2) A significant improvement in target location was obtained by applying the Artillery technique for sound-ranging correction to the firing data.

(3) A distance of 5 to 7 miles between rawinsonde stations was not a significant factor in these firings.

(4) The time variability of the sound-ranging data did contribute significantly to the error in target location.

(5) The Artillery method for applying meteorological correction to sound-ranging data gave positive improvements for upwind targets, but variable results for downwind targets.

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