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DASA-545

PRELIMINARY REPORT

OPERATION BLOWDOWN

Edited by Mr. Jack R. Kelso
and
Lt Col C. C. Clifford, Jr.

Blast and Shock Division
Headquarters, Defense Atomic
Support Agency
Washington 25, D. C.

June 1964

U.S. partic..ation in Operation BLOWDOWN was sponsored by the Defense Atomic Support Agency under NWER Subtask 02.065

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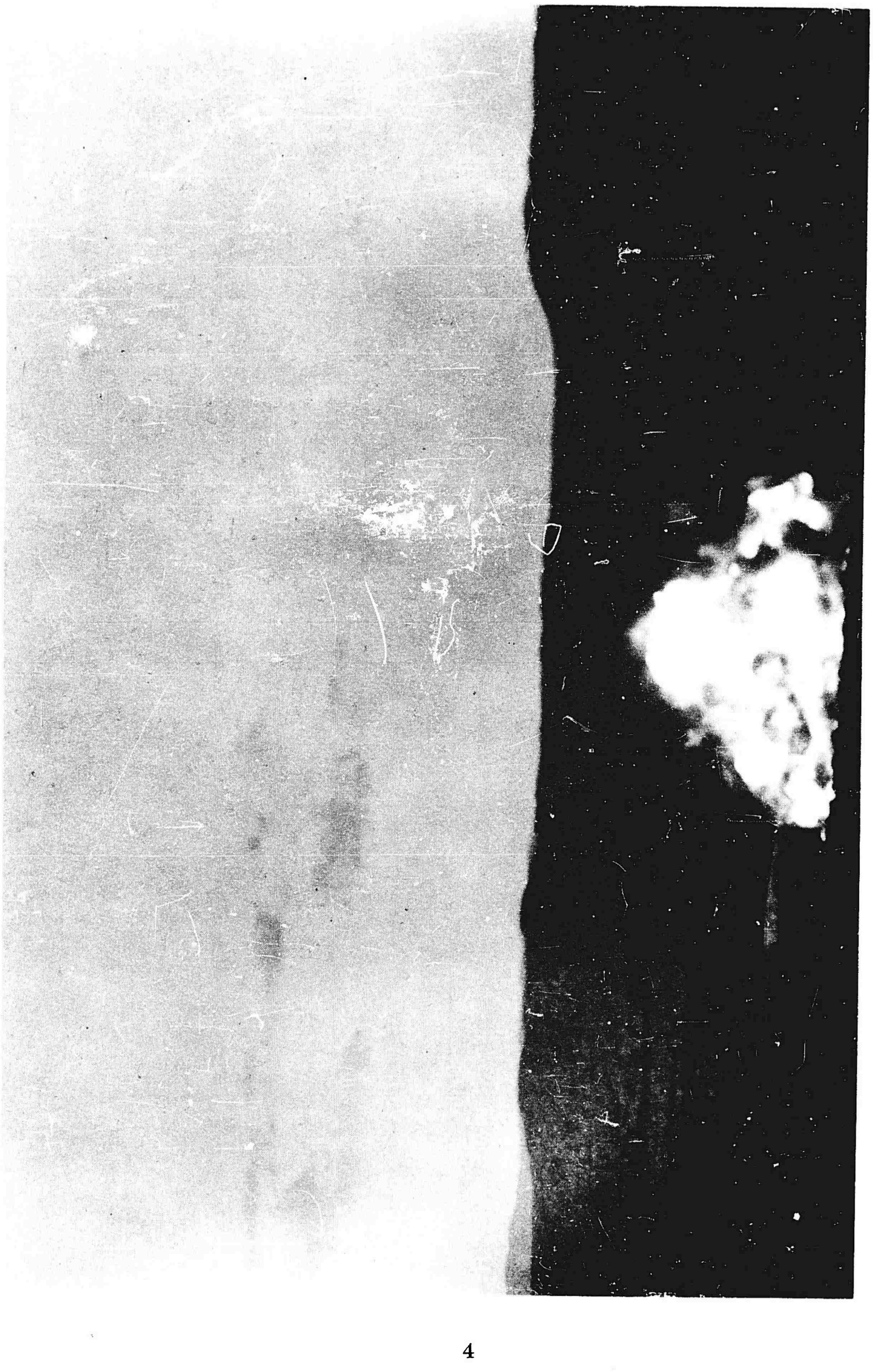
ABSTRACT

This report on Operation BLOWDOWN describes an Australian field test in which a 50-ton HE charge was detonated over a typical rain forest at the Iron Range Test Site, North Queensland, Australia. U.S. participation included the establishment of a blast line to obtain overpressure and dynamic pressure measurements, as well as the loan of instrumentation and photographic equipment.

The experiment also included military trial projects which examined the blast effects in rain forests on items of military material, field fortifications, supply points, and foot and vehicle movement.

This report presents preliminary results in each area of the experiment.

Key words: Operation BLOWDOWN
Project DOLPHIN



Frontispiece Detonation of a 50-ton TNT charge at the Iron Range Test Area, Australia.

PREFACE

The Defense Atomic Support Agency (DASA) expresses its appreciation to the Australian Government for inviting U.S. project participation in Operation BLOWDOWN, a 50-ton HE test held at Iron Range, Queensland, Australia, in July 1963. Special thanks are expressed to the military and scientific staff at the Iron Range Test Site, which was composed of personnel from the Royal Australian Army, the Department of Supply, and the Defence Standards Laboratory, for the friendliness, flexibility, competence, and spirit of good will with which all project matters were handled. In particular, Lt Col R.I. Fraser, R.A.E., Commander, BLOWDOWN Force and Military Project Leader, and Dr. P.W.A. Bowe, Department of Supply, Scientific Project Leader, were most helpful in furnishing the data and figures contained in Chapters 1, 4, and 5 of this report.

DASA also acknowledges the considerable assistance of Mr. Julius Meszaros, U.S. Army Ballistic Research Laboratories, in the planning and preparation of this event.

It was with deepest regret that news of the untimely death of Mr. W. L. Fons, Southern Forest Fire Laboratory, Macon, Georgia, on 20 October 1963, was received by members of DASA. Mr. Fons' efforts in Operation BLOWDOWN contributed materially to the success of this experiment.

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Chapter 1

INTRODUCTION

(Prepared by LtCol C. S. Grazier, Combat Development Command, U. S. Army, and Mr. Jack R. Kelso, Headquarters, Defense Atomic Support Agency.)

In July 1961, the Australian Department of Supply completed a study of the requirement for a high-explosive forest blowdown experiment and plans for conduct of such an experiment (Reference 1). This large-scale field trial, designated by the code name Operation BLOWDOWN, is part of an overall research program which has the following technical objectives:

(1) Review previous work.
(2) Develop simplified theory of damage to be expected.
(3) Conduct model experiments with small charges.
(4) Determine tree characteristics from static tests.
(5) Conduct large-scale field test.
(6) Evaluate results and derive scaling laws.
(7) Extrapolate information to other yields and forest types.

The overall objective of this program is to obtain empirical data and verify current prediction techniques as applicable to tactical employment of nuclear weapons in tropical rain forests.

Reference 1 was forwarded to the United Kingdom, Canada, and the United States early in 1962 in order to ascertain the interest of each country in the information to be obtained, determine possible participation in or observation of the experiment, and obtain any general comments on the proposed program.

The U. S. reply was prepared by the Defense Atomic Support Agency (DASA) following a comprehensive review of Reference 1 in conjunction with various Army agencies, service laboratories, and private contractors. DASA expressed interest in the proposed experiment and recommended limited U. S. participation along the following lines to obtain maximum correlation with previous research conducted by the U. S.

(1) Provide technical assistance in designing the field experiment and evaluating the results of laboratory studies.

(2) Provide technical assistance in developing pretest predictions of blowdown based on physical characteristics of the trees.

(3) Loan of certain U. S. electronic instrumentation to the Australian teams as suggested by the Working Party (Reference 1).

(4) Provide assistance in procurement of U. S. electronic gages by the Australian teams if desired.

(5) Provide a small U. S. field party to perform basic blast measurements using self-recording gages.

(6) Provide a minimum number of technical observers to assist in the posttest analysis of airblast phenomena and tree blowdown, and in assessment of the obstacle created to troop and vehicle movement.

(7) Provide a party of official observers.

The preparation of the test site and construction of the base camp was carried out in two phases as described in Reference 1. During Phase I, Mr. Julius J. Meszaros, Ballistic Research Laboratories (BRL), and Mr. Jack R. Kelso, DASA, visited the Iron Range Test Site in June 1962 to complete preliminary planning for U.S. participation and to coordinate necessary logistical support. The implementation of the large-scale field experiment was carried out in Phase III of Operation BLOWDOWN.

As a portion of U.S. participation, Mr. Fred M. Sauer, Stanford Research Institute (SRI), and Mr. Wallace L. Fons, U.S. Department of Agriculture, Forest Service, visited the Iron Range Test Site in September 1962. During this visit, Messrs. Sauer and Fons observed and evaluated the tests which were being made to determine the characteristics of the trees, discussed the application of the tests to the prediction of blast damage to tree stands, and discussed with Australian representatives the instrumentation and analysis which would be required to best utilize the results of this test in a general way. A report of this visit is contained in Reference 2. Following this visit, predictions were made by Mr. Sauer of the expected effect of the explosion on the forest stand and a comparison made of these results (Reference 3) with the predictions by Mr. J. L. Cribb, Defence Standards Laboratories, Australian Department of Supply (References 4 and 5).

The biomedical participation and assistance in the proposed field experiment was arranged for by DASA through the Surgeon General's Office, Department of the Army. A technical plan was prepared by Lovelace Medical Foundation.

The U.S. Army prepared a technical plan dealing with the engineer aspects of Operation BLOWDOWN, which was furnished to the Australian Army and integrated where possible in the plans for the experiment.

Edgerton, Germeshausen and Grier, Inc. (EG&G) prepared comments on the Australian camera plan and loaned a number of cameras to the Department of Supply for their use in obtaining technical photography.

LtCol C. C. Clifford, DASA, coordinated the participation of the U.S. team of 11 scientific and military personnel during actual field operations.

Mr. Jack R. Kelso, DASA, coordinated arrangements for the party of 10 U.S. official observers who visited the test site at the time of the detonation.

At 0830 hours, Australian time, 18 July 1963, the spherical charge of approximately 50 tons of TNT was detonated on a steel tower at a height of 136 feet, over a rain forest at Iron Range, North Queensland, Australia (see Map 1, Appendix I).

This preliminary report contains general information concerning all projects in this experiment, to acquaint the reader with general information in a specific area in which he may be particularly interested.

The following chapters, each complete in itself, present the preliminary details of individual projects. An interim report will be published by the Australian agencies in 1964. Final project reports for the U.S. participation will be distributed by the respective participating agencies.

1.1 DESCRIPTION OF TOWER

Early in the planning stages for the test, several types of towers for supporting the charge were considered. Consideration narrowed to a light guyed tower and a heavier straight-sided tower. The straight-sided tower was the final choice. The tower was constructed by a civilian contractor. Figure 1.1 shows the tower with the charge in place. Figure 1.2 is an elevation view of the tower design.

Specifications:

Height, overall: 153 feet
To center of charge: 136 feet
Sections: Nine of 13 feet
One of 12 feet 4 inches
One of 11 feet 11 inches
One of 12 feet
Plan size: 18 feet by 18 feet
Material: Hot-rolled angle iron
Uprights: 8 inches by 8 inches by $\frac{3}{4}$ inch
Cross braces: 6 inches by 6 inches by $\frac{1}{2}$ inch
Cross braces: $3\frac{1}{2}$ inches by $3\frac{1}{2}$ inches by $\frac{3}{8}$ inch
Base overall: 28 feet by 28 feet by 2 feet 9 inches TK
Reinforcing rod: 1-inch square twisted rod

The upright legs were welded to base plates containing four $\frac{3}{4}$-inch holddown bolts each 2 feet 4 inches long. These bolts were set in a stiff grout. The concrete had a design strength of a minimum of 2,000 lb/in^2 at 28 days.

For access to the tower platform a sectionalized vertical ladder was provided. The ladder was constructed of 3- by $\frac{1}{2}$-inch flat steel sides with $1\frac{11}{16}$-inch O. D. by 10-gage steel rungs welded $10\frac{1}{4}$ inches apart. Safety hoops of 2- by $\frac{1}{4}$-inch flat steel were placed 1 foot 9 inches apart along each section of ladder.

An electric platform hoist was welded to the side of the tower to assist in raising the tins of TNT and other materials to the working area at the top of the tower. The tower was constructed to a design wind loading of 120 miles per hour.

1.2 DESCRIPTION OF EXPLOSIVE CHARGE

The charge was built from specially made tins each containing about 41 pounds of TNT. The TNT was the type used in 155-mm shells, remelted and cast into tins. Support tins filled with a lightweight plastic were manufactured to be used for support of the lower surface of the sphere. The final shape of the charge as built up was a sphere having a diameter of 12 feet 10 inches (Figures 1.3 and 1.4).

The detonation system consisted of 70 CE/TNT tins as a booster. At the central can an intermediary of CE pellets was inserted with primacord attached which passed through an aluminum tube and then to electric detonators at ground level. This primacord was boosted with a detonator just outside the charge and with regularly spaced CE pellets for the remainder of its length. This method of firing was used to insure accurate timing of test equipment.

Extreme care in all phases of packaging, transportation, and stacking was used to insure a minimum of damage to the tins filled with explosive and to minimize air gaps between tins stacked in the charge. It was thought that propagation of the detonation would be affected if air gaps developed due to poor stacking or damaged tins. A large crack or gap developing from settling or stacking might have caused jetting to occur or a deformation of the blast wave.

Scientific instrumentation was inserted into the charge at various locations to obtain specific detonation measurements.

1.3 DESCRIPTION OF FOREST STAND

The forest stand selected for Operation BLOWDOWN at Iron Range is representative of rain forests occurring in North Queensland; in Southeast Asia; and on the Malayan Peninsula. This stand is unmanaged, naturally occurring, and comprised of approximately 70 different tree species. It is characterized by a random distribution of stem diameters from small to large, with a large proportion of the trees in the smaller diameter classes. This situation is shown in Figure 1.5 taken from Reference 6 which compares the size distribution of trees at Iron Range with similar curves for light and dense Malayan rain forest. Details of this stand are presented in Table 1.1.

The forest floor within the stand is generally free of fallen dead trees. Underbrush composed of about 60 different species is generally light, while young reproduction with heights less than 20 feet comprising the understory is heavy. The underbrush and understory have dense foliage and are vigorous in appearance. Because of the heavy understory and the dense foliage, the visibility in most parts of the stand is less than 100 feet.

Average spacing of trees with girth greater than 13 inches is 14 feet by 14 feet, which should permit vehicles such as weapon carriers to maneuver within this type of stand without much difficulty.

1.4 GENERAL INSTRUMENTATION PLAN

The general plan of all instrumentation for this program is shown in Figure 1.6.

1.5 METEOROLOGICAL CONDITIONS

The meteorological conditions existing at the test site at the time of detonation are discussed below:

1.5.1 Wind Velocity. Three anemometers were located at heights of 100 feet on the tower, 70 feet on a mast in the clear sector, and 6 feet on a mast in the clear sector. No wind was recorded at any of these stations during the 15 minutes prior to the detonation. The meteorologist estimated the wind to be less than 1 ft/sec at these three locations.

The wind velocity was measured with a balloon flight at 0600, 18 July, with the following results:

Height ft	Velocity ft/sec
250	0
500	3 S
1,000	11 E
1,500	12 E
2,000	34 E

The meteorologist estimated that wind speeds were essentially the same at 0830, except for the 500-foot height which may have been 7 ft/sec.

1.5.2 Temperature Measurements. The results of temperature measurements at the time of firing, combined with the study of conditions on previous similar days, are as follows:

Forest location (K13) 100 feet from GZ, 4 feet off ground, 13.3° C. (Remote-reading thermometer)

Clear sector, 1,100 feet from GZ, 4 feet off ground, 12.9° C. (Autographic recording)

Forest location (B2) 1,200 feet from GZ, 4 feet off ground, 12.2° C. (Autographic recording)

Forest location (K12) at GZ, 100 feet off ground, 17.3° C. (Remote-reading thermometer)

Based upon data obtained prior to shot date, the central areas of the forest and clear sector near the ground would be fairly even in temperature (within 5.5° C) at 13.2° C. At a height of 100 feet over the forest (20 feet above the canopy) and probably lower in the clear sector, the temperature was about 17.3° C. The temperature would be fairly uniform with height in the forest above 3 feet (and up to below the top of the canopy) at 13.2 ± 0.5° C.

In the clear sector a gradual increase in temperature from heights of 4 to 100 feet could be expected (from 13.0 to 17.3° C), and the next 100-foot interval would have a fairly uniform temperature both above the forest and above the clear sector at 17.3° C.

<u>1.5.3 Humidity.</u> Records taken on the hydrograph prior to D-day and the record to 0600 on D-day show that the humidity in the clear sector and in the forest was always over 90 percent at 0830. When the accuracy of the hydrograph was taken into consideration, the humidity was 95 ± 5 percent (the hydrograph showed 100 percent) at shot time.

<u>1.5.4 Pressure.</u> The station level pressure measured on a Kew barometer was 1,013.0 mb (an interpolation between the 0400 and 1000 readings, 18 July 1963). These readings were obtained at a height 60 feet above sea level.

Based on 1,013 mb, the pressure at 60 feet above MSL = 14.70 psi.

TABLE 1.1 STAND TABLE FOR IRON RANGE RAIN FOREST

Girth		Average	No. trees	Basal area at breast height	
Class	Midpoint	height	per acre	By girth class	Cumulated
in	in	ft		ft^2	ft^2
13-15	14	41	48.78	5.27	134.0
16-18	17	47	45.73	7.30	128.7
19-21	20	53	27.13	5.99	121.4
22-24	23	58	21.00	6.14	115.4
25-27	26	62	19.25	7.19	109.3
28-30	29	66	12.69	5.90	102.1
31-33	32	69	10.50	5.94	96.2
34-36	35	71	8.76	5.93	90.3
37-39	38	73	7.87	6.28	84.3
40-42	41	75	4.59	4.26	78.0
43-45	44	77	5.47	5.85	73.8
46-48	47	78	2.85	3.48	67.9
49-51	50	80	1.54	2.13	64.5
52-54	53	81	2.63	4.08	62.4
55-57	56	82	2.63	4.56	58.4
58-60	59	83	2.63	5.06	53.8
61-63	62	84	2.41	5.12	48.7
64-66	65	85	0.88	2.05	43.6
67-69	68	86	1.54	3.93	41.6
70-72	71	87	2.63	7.32	37.6
73-75	74	88	0.66	2.00	30.3
76-78	77	89	0.66	2.16	28.3
79-81	80	89	0.44	1.56	26.2
82-84	83	90	1.10	3.39	24.6
85-87	86	91	0.44	1.80	21.2
	89	91	0.22	0.96	19.4
	94	92	0.22	1.07	18.4
	97	93	0.22	1.14	17.4
	103	94	0.22	1.29	16.2
	107	94	0.22	1.39	14.9
	108	94	0.22	1.42	13.6
	125	95	0.22	1.90	12.1
	154	96	0.22	2.88	10.2
	161	97	0.22	3.15	7.4
	186	98	0.22	4.20	4.2

Total trees: 237

Average spacing: 14 ft. x 14 ft.

(Photo to be reproduced from slide.)

Figure 1.1 Tower with charge in place.

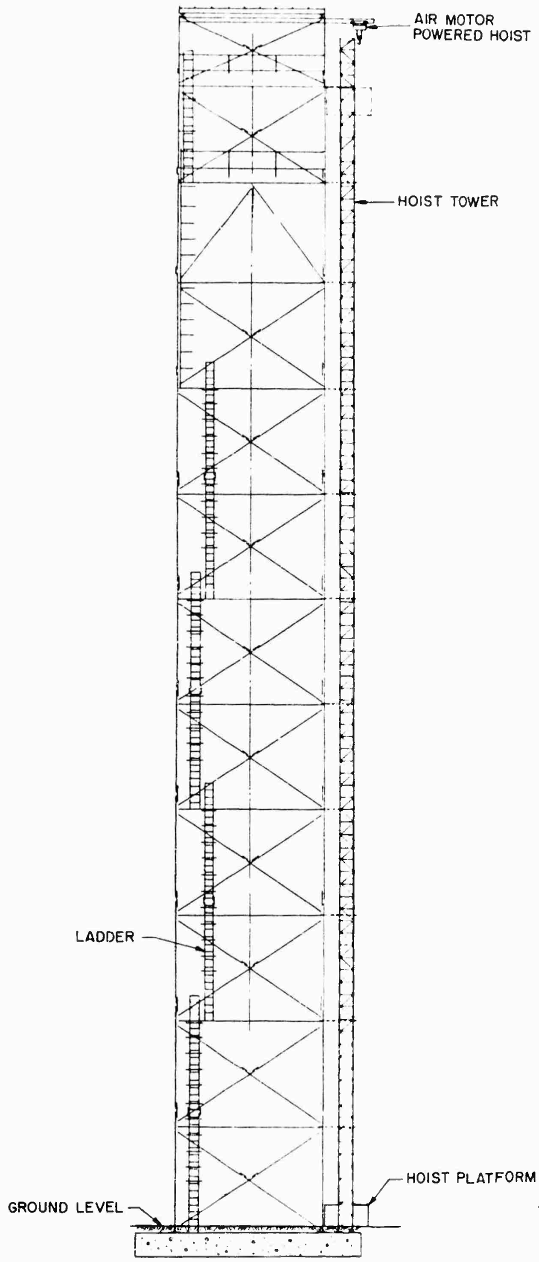
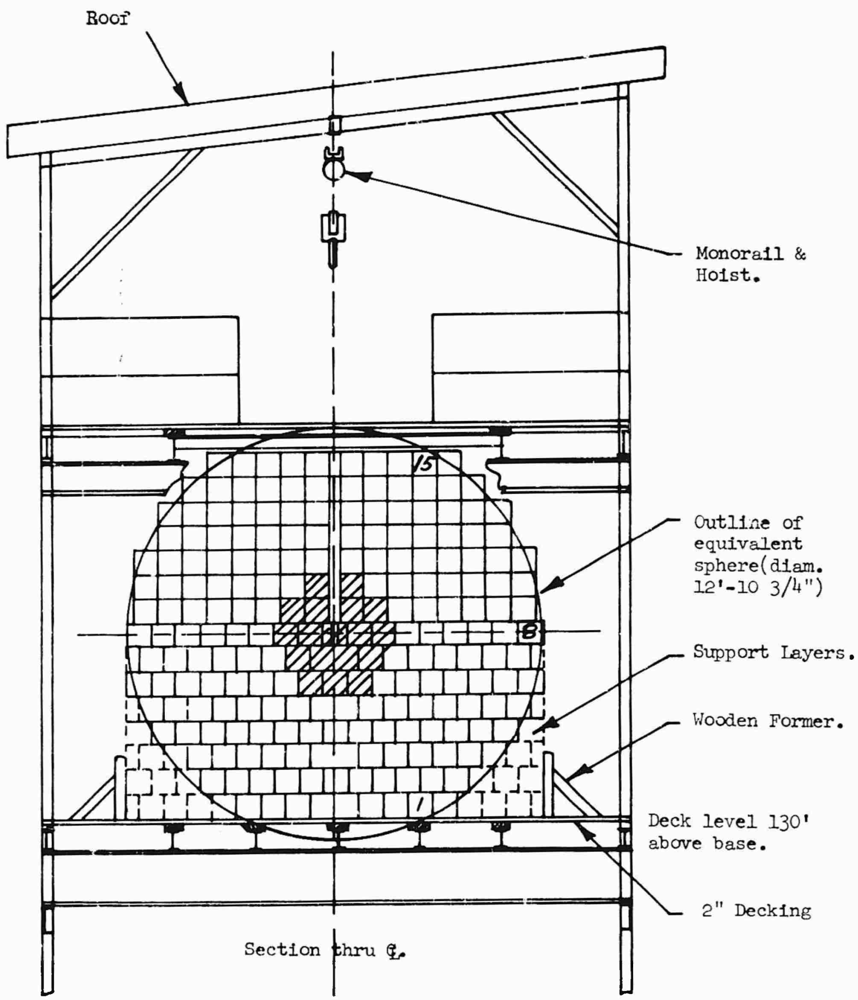


Figure 1.2 Elevation view of tower design.

Note: Cube dimensions 9" nominal (9.1" external).
Shaded area represents 70 N°. CE/TNT canisters.
Unshaded area represents TNT canisters.



Layer No.	No. of Canisters		
	TNT	CE/TNT	Supports
15	88	--	--
14	120	--	--
13	152	--	--
12	176	--	--
11	204	--	--
10	204	8	--
9	200	16	--
8	200	21	--
7	200	16	--
6	204	9	8
5	188	--	28
4	177	--	44
3	148	--	68
2	109	--	112
1	68	--	148
Total No. of Canisters	2438	70	408
Total Wt. of Explosive (lbs)	97257	2860	--

Figure 1.3 Elevation of explosive charge on tower.

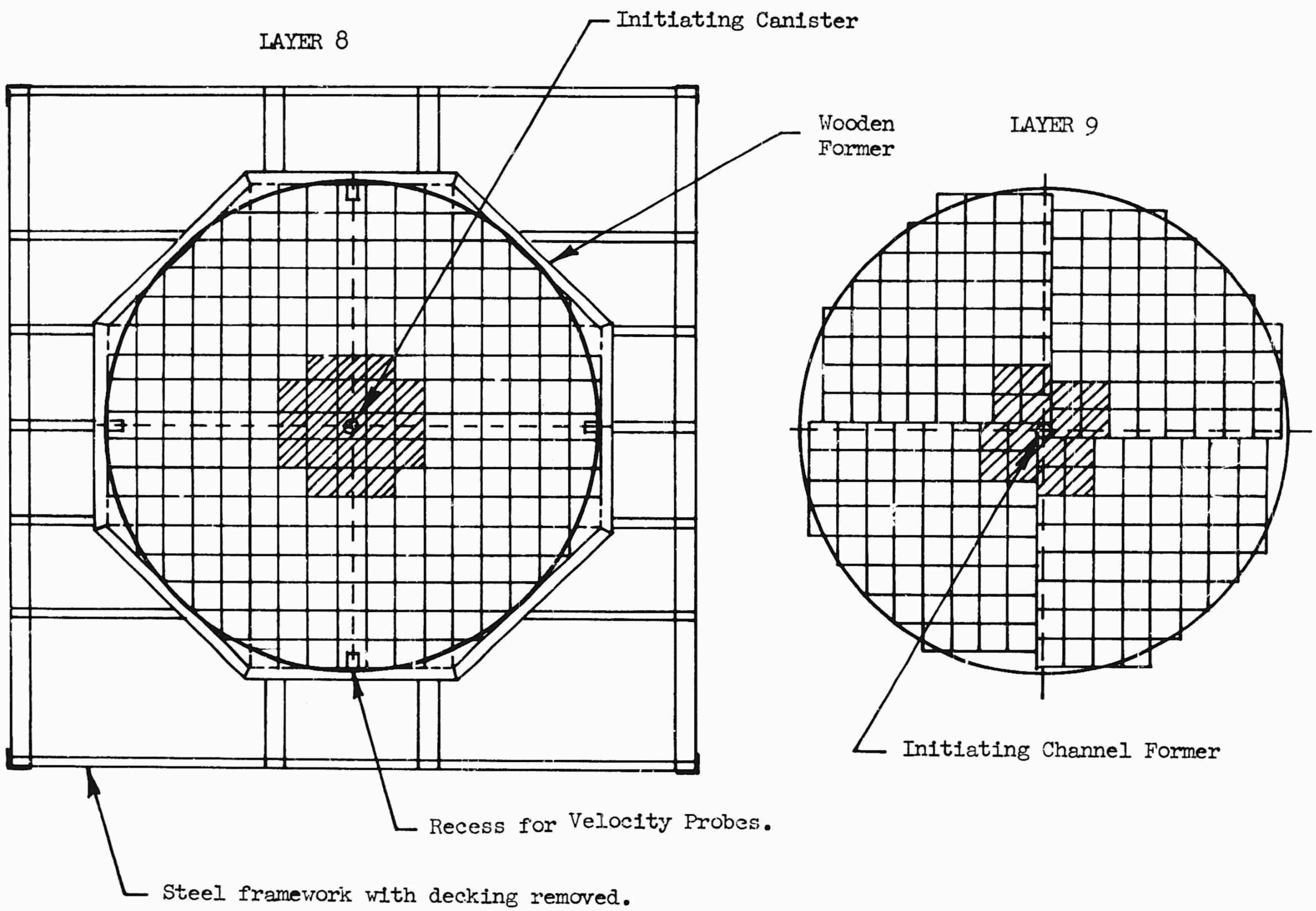


Figure 1.4 Plan of central layers.

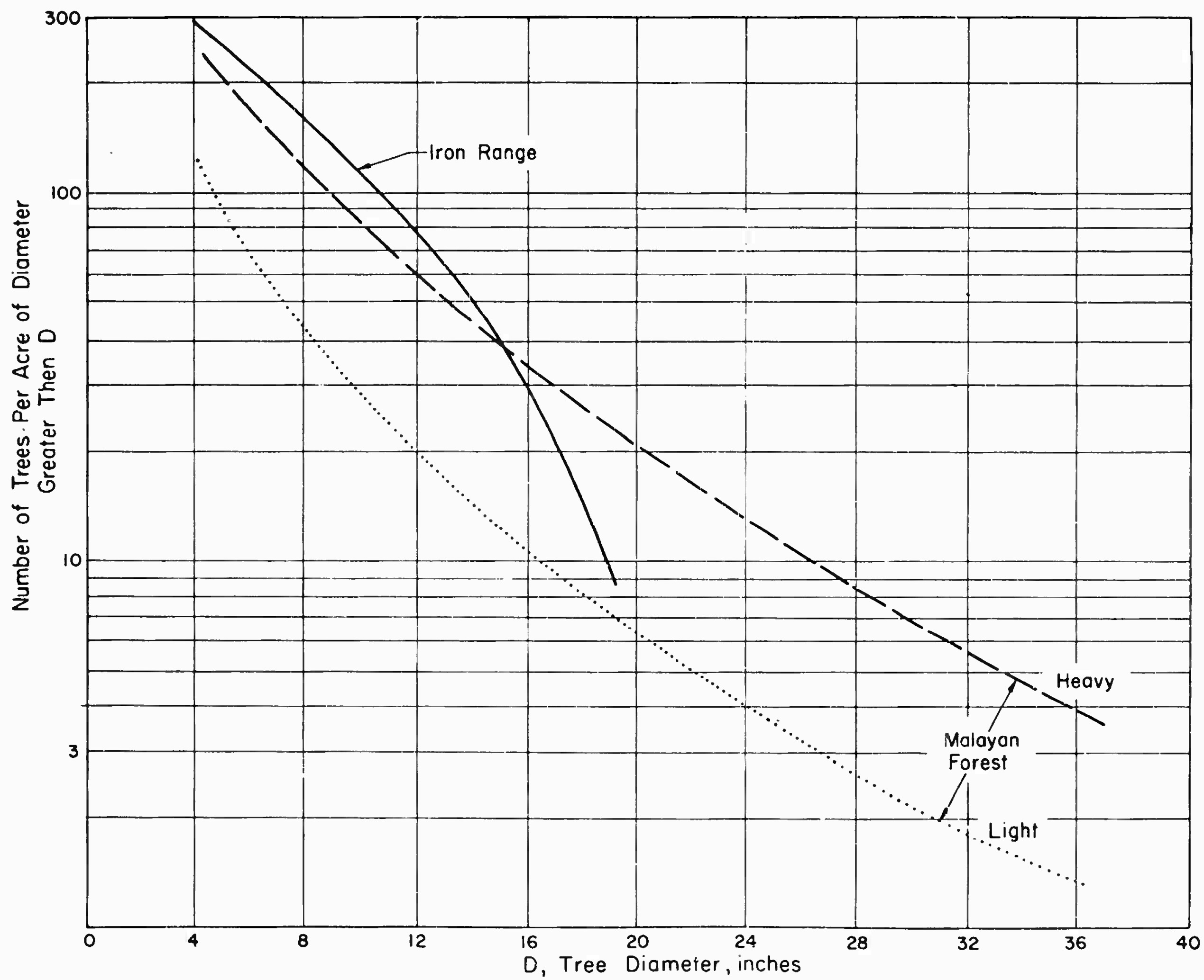
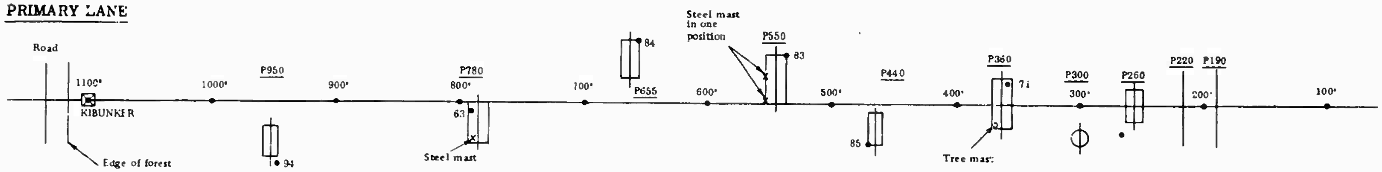


Figure 1.5 Comparison of Australian and Malayan forest.

PRIMARY LANE



M 1100'

INSTALLATION	P950 3-5 PSI	P780 5-1 PSI	P655 7-2 PSI	P550 9-8 PSI	P440 14-2 PSI	P360 20-4 PSI	P300 30 PSI	P260 39-5 PSI	P220 60 PSI	P190 80 PSI	
Tree Instrumentation	S.G. S.M.P.	S.G. S.M.	S.G. S.M.	S.G. S.M.	S.G. S.M.	S.G. S.M.		S.G.			
Dynamic Pressure Waveform						$4H_1P_1$ 3 on mast	H_1P_1	H_1P_1			$6 H_1P_1$
Missile Stations	M.	M.	M.	M.	M.						6 M.
GSAP Cameras	M TH P17 P16	M Dy TV P15 P14 P13	M TV P12 P11	Dy DPI TH TV P10 P9 P8 P7	Dy TV P6 P5	DPI TH TV P4 P3 P2		TV P1			17 GSAP
DPI Gages	3D.U.	3D.U. 11D.I., 9 on mast. A.	6D.U. 4D.I.	6D.U. 13D.I., 9 on mast. A.	6D.U. 4D.I.	B. 9D.U. 15D.I., 9 on mast.		B.			33D.U., 2A, 2B, 47D.I.
Overpressure Gages	L.C.60 $3xH_3$ on mast.	L.C.60	L.C.60	L.C.60 3xL.C.33. on mast. S.R.	L.C.60	L.C.60 S.R. D.		S.R.			3S.R., 5L.C.60, 3L.C.33, 3H, 1D.
Shock Velocity Gages	B.D.15 2S.V.	B.D.15 2S.V.	B.D.15 2S.V.	B.D.15 2S.V.	B.D.15 2S.V.	B.D.15 2S.V.	B.D.15 2S.V.	B.D.15 2S.V.	B.D.15 2S.V.	B.D.15 2S.V.	10 B.D.15, 20 S.V.
Dummies		2 Dy.		2 Dy.	2 Dy.						6 Dy.
DPI Shields (No)	1G.S.	1G.S.	2G.S.	2G.S.	2G.S.	3G.S.	1G.S.	1G.S.			13 G.S.

L.C. Scratch Gage
S.M. Strain Meter
S.M.P. Strain Meter (Phillips Pick-up)
H_1P_1 Total Head & O.P. Gages (Norwood)
H_2P_2 Total Head & O.P. Gages (Microsystem)

M. Missile Stations
Dy. Dummies
S.R. Self Recording O.P. Gages
S.V. Diaphragm Shock Vel. Gages

D.P.I. Gauges

D.U. Plastic Deformation (Upright)
D.I. Plastic Deformation (Inverted)
A & B Pendulum Type
B.D.15 Shock Vel. Gages in Canopy on suitable trees near primary lane.

Tree Photography

T.V. View from beneath
T.H. View from side
G.S. Gage Shields
M.F. Foam Missile Boxes

O. American Self-Recording O.P. Gages
D. American Self-Recording Total Head Gages
M.E. Military Equipment
F.R. Fastair Cameras

SECONDARY LANE

		L.C.60		L.C.60 S.R. 3D.U. 2D.I. G.S.							2L.C.60, 1S.R., 3D.U., 2D.I., G.S.

FOREST

No particular radial direction from GZ.) See separate plan.

2M. at 1100'	S.G. 2M.	S.G. M.	S.G. ME. GSAP. M.	S.G. 2G.S. 3S.R. M. 6D.U. 4D.I. GSAP	S.G. ME.	S.G. G.S. 3D.U. 2D.I. H_2P_2	S.R. ME.				6S.G., 3GSAP, 3G.S., 4S.R., 9D.U., 6D.I., $1H_1P_1$

U.S. LANE

	O.	O.	O.	O.	O.	O. D.		O. D.		O. D.	
INSTALLATION	P950 3-5 PSI	P780 5-1 PSI	P655 7-2 PSI	P550 9-8 PSI	P440 14-2 PSI	P360 20-4 PSI	P300 30 PSI	P260 39-5 PSI	P220 60 PSI	P190 80 PSI	10 (O), 3D. (Two (O) Gages at 160' and 320')

Figure 1.6 General instrumentation plan.

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Chapter 2

RAIN FOREST EFFECTS ON BLAST WAVE PARAMETERS

(Prepared by Mr. John C. Keefer, Ballistic Research Laboratories.)

The primary objectives of the BRL participation in Operation BLOWDOWN were to: (1) establish a U.S. blast line within the forest area, utilizing the BRL self-recording overpressure and dynamic pressure gages to study, on a limited scale, the blast phenomena variations within the forested area; (2) assist the Australian scientists with the electronic instrumentation phase by making available on loan a number of electronic transducers and a recording system; and (3) have available at the test site qualified personnel for consultation to insure that the instrumentation on loan was operating correctly.

2.1 PREDICTIONS OF BLAST PHENOMENA

The BRL participation in Operation BLOWDOWN was primarily concerned with the measurement of airblast overpressure and dynamic pressure within a rain forest. It was planned to correlate these measurements with similar ones made in a cleared area, to determine the blast attenuation within the forested area. No attempt was made at BRL to predict the attenuation that might be expected within the forest, but the cleared sector blast parameters were predicted. The assumed input values were a yield of 50 tons or 100,000 pounds of TNT detonated at a height 140 feet above ground surface. Standard sea-level conditions were also assumed to prevail.

2.1.1 Airblast Overpressure. The values used in the prediction of the free-field overpressure along the surface versus horizontal distance for the stated height of burst and yield were taken from various sources. The primary source was a Sandia Corporation report for overpressures below 75 psi (Reference 7). The overpressures in the regular reflection region were calculated using a computer program developed from J. Von Neuman's work on reflection of oblique shock waves. The predicted values are listed in Table 2.1 and plotted in Figure 2.1. Those values below 30 psi check exceptionally well with some height-of-burst curves for TNT developed by the Atomic Weapons Research Establishment (AWRE), located in Great Britain. The final report is in the process of publication; therefore, the title, report number, and authors are not available for reference at this time.

The airblast arrival times predicted for BLOWDOWN were also obtained from various sources. In the regular reflection region, the TNT free-air shock arrival time values from DASA-1200 were used. From a ground range of 88 to 481 feet, the arrival values were obtained from nuclear height-of-burst curves assuming 1-kt nuclear yield equivalent to 500 tons of TNT. From a ground range of 502 to 1,812 feet, the values of shock arrival times were obtained from the AWRE report. The values overlap quite well and form a smooth curve as shown in Figure 2.2. The values are listed in Table 2.1.

The predicted duration of the positive phase of the blast wave was obtained from DASA-1200 for distances from ground zero out to 80 feet which is in the regular reflection region. Here it was assumed that the duration of the reflected wave is approximately the same as the side-on or incident shock wave at a similar radial distance. The durations at distances from 100 to 1,266 feet were obtained from Reference 7. These values check quite well with the AWRE values which range from 336 to 932 feet. The predicted durations versus distance are listed in Table 2.1 and plotted in Figure 2.3.

The predicted positive impulse of the blast wave along the surface of the ground was obtained from three sources. The reflected impulse at ground zero was obtained from BRL Report 1093. The next impulse value was obtained from the Sandia report at a distance of 130 feet from ground zero. Values from Reference 7 are plotted as "O" on Figure 2.4, while values from the AWRE work are noted with a "△." There is some deviation in the data, but the mean curve has been drawn between the points. The predicted values of the positive overpressure impulse versus distance from ground zero are listed in Table 2.1 and plotted in Figure 2.4.

2.1.2 Dynamic Pressure. The dynamic pressures predicted to meet the objectives of this project are those associated with the horizontal component of the particle velocity along the surface. Therefore, the dynamic pressure would be zero at ground zero and increase with distance until the Mach stem is formed. After the Mach stem is formed, then the dynamic pressure follows a normal decay with distance. This decay bears a relationship with the peak overpressure of the blast wave and may be calculated from the following equation,

$$P_d = \frac{2.5\ (P_S)^2}{7\ (P_O) + P_S}$$

Where: P_d = peak dynamic pressure
P_S = peak overpressure
P_O = atmospheric pressure (14.7 psi)

The dynamic pressure along the surface within the regular reflection region was obtained from a computer program based on Von Neuman's oblique reflection theory. The values obtained from these two methods are listed in Table 2.1 and plotted in Figure 2.5.

The dynamic pressure impulse was obtained from two sources, DASA-1200 and calculations using the classical decay equation from TM 23-200. A comparison between the Australian and U. S. predictions is shown in Figure 2.6. The dynamic pressure impulse was rather a difficult parameter to predict because of the small amount of experimental data available.

2.1.3 Height of Mach Stem. When a charge is exploded near an unyielding surface, the blast wave moves out initially in all directions. When this incident blast wave reaches the surface, a complicated interaction takes place, and a new blast wave is formed by the reflection process. This reflected wave then moves back up into air which has already been heated by the passage of the incident wave. The reflection process can be considered as occurring in three distinct zones: (1) normal reflection, which occurs directly under the charge; (2) regular or oblique reflection, which occurs when the shock front impinges with a small angle between the plane of the shock and the plane of the reflecting surface; and (3) irregular or Mach reflection, which occurs at near-grazing incidence. In the latter case, a new phenomenon takes place at a critical angle and shock front overpressure, as determined by the burst conditions. At this point, termed the "limit of regular reflection," the reflected wave catches up with the incident wave, and their intersection rises off the ground. This intersection is known as the triple point, since it represents the convergence of three shock fronts, namely, the incident, reflected, and Mach. The latter, called the Mach stem, is essentially vertical, and propagates radially from ground zero. The path of the triple point and the Mach stem height for the conditions of the Australian experiment, i.e., 50 tons of HE at 140 feet, are shown in Figure 2.7.

2.2 INSTRUMENTATION

The self-recording gages used in the U. S. sector were BRL designed. These standard gages have been successfully used on many nuclear and HE tests in the past 10 years. The gage is basically a self-contained pressure versus time recording instrument, employing a nestled diaphragm-type pressure sensing capsule (Figure 2.8). A stylus attached to the capsule scribes the diaphragm movement on an aluminum-coated glass disk that is rotated by a chronometrically governed dc drive motor. The dynamic pressure gage employed microphoned metal recording disks. Pictorial views of the self-recording pressure-time gage are shown in Figures 2.9 and 2.10.

The dynamic pressure self-recording pressure-time gage employs two separate pressure sensors, scribing simultaneously on a one-motor-driven recording disk. These sensors record total pressure and overpressure. Basically, the recording mechanism is the same as the standard pressure-time gage, mounted in a probe of pitot tube design as shown in Figure 2.11.

The pressure capsule ranges used were from a low of 0 to 15 psi to 0 to 1,000 psi. Motor speeds were 10 and 20 rpm operating on 6 and 9 volts. A preset number of turntable revolutions was determined by a limit switch mechanism.

Initiation of the gage was accomplished by a remote timing signal originating in the main control bunker. The signal activated a relay distribution box that, in turn, furnished a starting closure to the individual gages.

Appendix A provides additional discussion of instrumentation recording equipment.

2.3 FIELD LAYOUT

The U. S. lane comprised 10 stations extending from GZ to 950 feet in the forest and normal to the cleared sector (Figure 2.12). One standard pressure-time (P-T) gage was located at each station. In addition, three gages to obtain dynamic pressures were included in the lane as shown in Figure 2.12.

The dynamic pressure gages were mounted on concrete bases, and the first five P-T gages were flush-mounted in concrete boxes.

The remaining P-T gages were embedded in the soil. All P-T gages were mounted flush with the surface of the ground. The axis of the dynamic pressure gage (pitot tube) was parallel to the ground at an elevation of 36 inches. The surrounding forest foliage was disturbed only a minimum.

2.4 CALIBRATION

Calibration of the self-recording gage pressure sensors was performed in the laboratory before shipment to Australia. A commercially available calibrator with interchangeable dial gages was used to apply pressure to the sensors. The dial gages were checked for accuracy with a deadweight tester prior to being used. The disk-drive motors, used for a time base on the records, were checked for constancy of rpm with an accurate timer. The BRL shock tube facility was used to dynamically test the gages.

2.5 RESULTS

2.5.1 Overpressure. Records were obtained from all gages. All records with the exception of the two close-in P-T gages were of good quality. The 94-foot station was apparently subjected to extremely high accelerations resulting in a questionable record. At the 144-foot station, acceleration affected both the pressure capsule and the turntable drive motor. Photographs of the pressure-time records are displayed in Figure 2.13 and the values listed in Table 2.2.

A plot of the maximum overpressure versus distance from GZ is shown in Figure 2.14. Duration of the positive phase versus distance is shown in Figure 2.15. The 260-foot gage motor governor apparently malfunctioned. This motor will be examined at BRL.

2.5.2 Dynamic Pressure. Records were obtained from all gages, and all are of good quality. Photographs of the records are not available, since field facilities are inadequate for photographing metal disks.

The dynamic pressure versus distance from GZ plot (Figure 2.16) was obtained by subtracting the overpressure from the total pressure. No gage or compressibility corrections were applied in this report.

The effect of variation in the horizontal component of dynamic pressure from a zero value at ground zero to a predicted maximum of 235 psi along the surface at 130 feet can be seen in the postshot aerial photograph (Figure 2.17).

2.6 DISCUSSION

2.6.1 Overpressure. The pressures measured along the clear sector were somewhat higher than predicted (Figure 2.18). This small increase can be attributed to the increase in the effective charge weight by the addition of booster blocks. These blocks were added to the charge in order to insure complete detonation. The total weight of the boosters was 2,880 pounds with a ratio of 1.31 TNT equivalent. This gives a total charge weight of 51.2 tons. Calculating the charge weight from the measured overpressures at 30 psi and comparing this with prediction, one obtains a yield of 51.3 tons, which agrees with the apparent weight of the charge if the booster blocks are considered.

Based on the measured data from the cleared sector and comparison of overpressures measured along the U. S. lane, the conclusion is that a reduction of approximately 8 percent of overpressure existed in the forest within 500 feet. Beyond 500 feet, the difference decreases with distance, and the curves merge. A comparison of the curves is shown in Figure 2.19.

2.6.2 Dynamic Pressure. The dynamic pressures measured along the clear sector are also higher than predicted (Figure 2.20). This increase corresponds with the higher measured overpressures along the clear sector. Using the measured data from the clear sector and comparing it with the dynamic pressure measured along the U. S. lane, one can conclude that in close a reduction of as much as 40 percent was present within the forest (Figure 2.21). At 360 feet, the difference decreases to approximately 10 percent, and beyond this point the curves are believed to merge as in the overpressure case.

The complex interaction of the shock wave with the dense foliage of a tropical rain forest poses many problems. Leaves and twigs on small trees and vines provide a continuum of foliage from the ground to the crowns of the tallest trees. A leaf density of one per cubic foot with accompanying small twigs was estimated within the forest. Postshot photography shows the large amount of small missiles that were picked up and carried by the blast wave (Figures 2.22 and 2.23).

TABLE 2.1 PREDICTED AIRBLAST PARAMETERS ALONG THE SURFACE (CLEAR SECTOR)

Station No.	Ground Range feet	Maximum Over-Pressure psi	Arrival Time msec	Positive Duration msec	Over-Pressure Positive Impulse psi-msec	Maximum Dynamic Pressure psi	Dynamic Pressure Impulse psi-msec
1	90	320	32	34	1750	150	1060
2	145	160	46	45	1200	210	1600
3	190	80	65	54	850	74	880
4	260	40	95	67	570	28	410
5	360	20	152	87	460	17.5	175
6	440	14	200	102	395	9.2	100
7	550	9.2	280	120	345	2.0	55
8	655	7.0	350	135	310	1.1	35
9	780	5.0	450	150	280	0.6	20
10	950	3.5	580	164	200	0.3	14

TABLE 2.2 U.S. LANE RESULTS

Ground Range feet	Type Measurement	Location	Maximum Pressure psi	Positive Duration msec	Remarks
94	Overpressure	Surface	-	-	Questionable record.
144	Overpressure	Surface	188.0	-	Poor record.
191	Overpressure	Surface	83.0	66.5	Good record.
	Overpressure	3 feet	72.0	-	Good record.
	Total pressure	3 feet	135.0	-	Good record.
260	Overpressure	Surface	41.0	125	Slow rise—Poor duration.
	Overpressure	3 feet	32.0	-	Good record.
	Total pressure	3 feet	55.0	-	Good record.
360	Overpressure	Surface	22.5	91.7	Good record.
	Overpressure	3 feet	22.0	-	
	Total pressure	3 feet	36.0	-	
440	Overpressure	Surface	13.5	115.0	Good record.
550	Overpressure	Surface	9.1	136.7	Good record.
655	Overpressure	Surface	6.8	150.0	Good record.
780	Overpressure	Surface	5.3	155.0	Good record.
950	Overpressure	Surface	3.4	165.0	Good record.

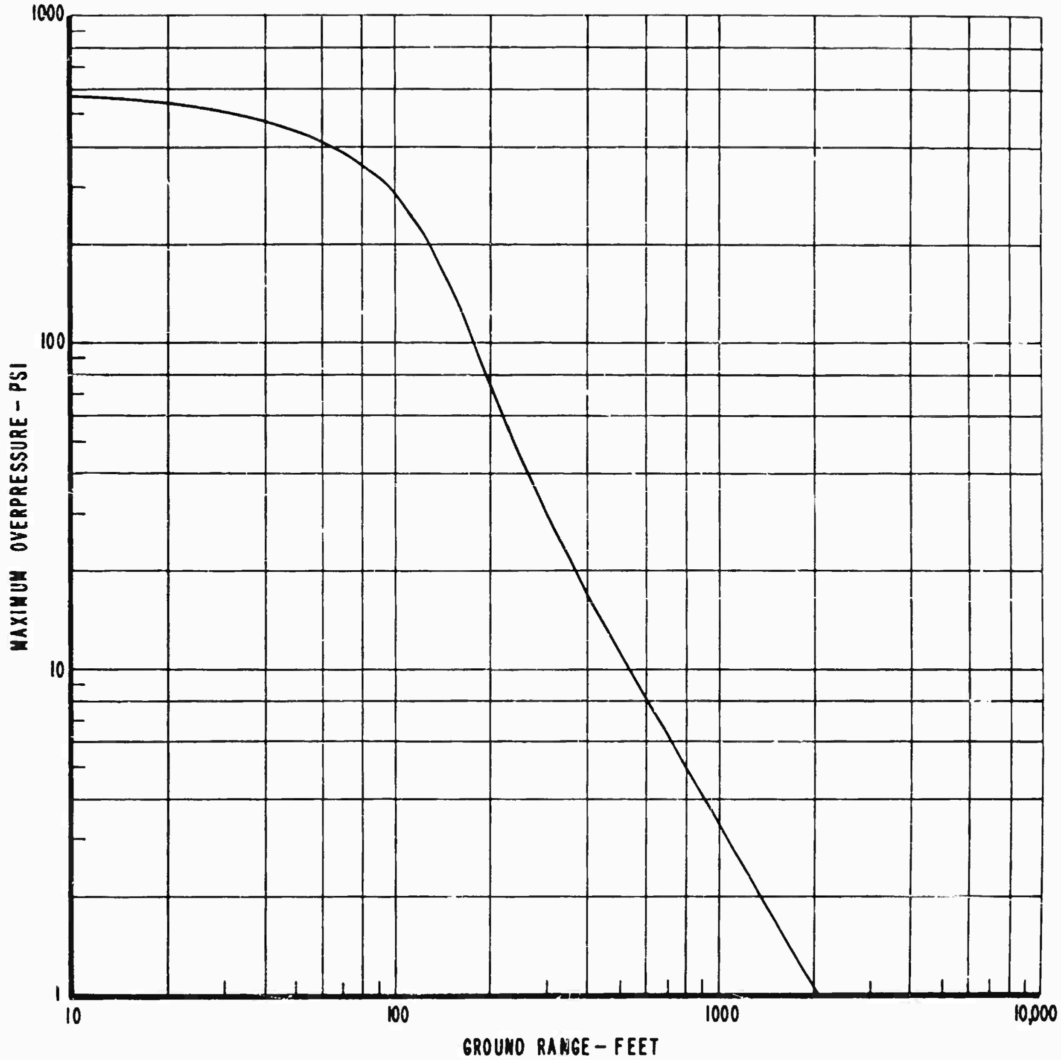


Figure 2.1 Predicted peak overpressure versus ground range.

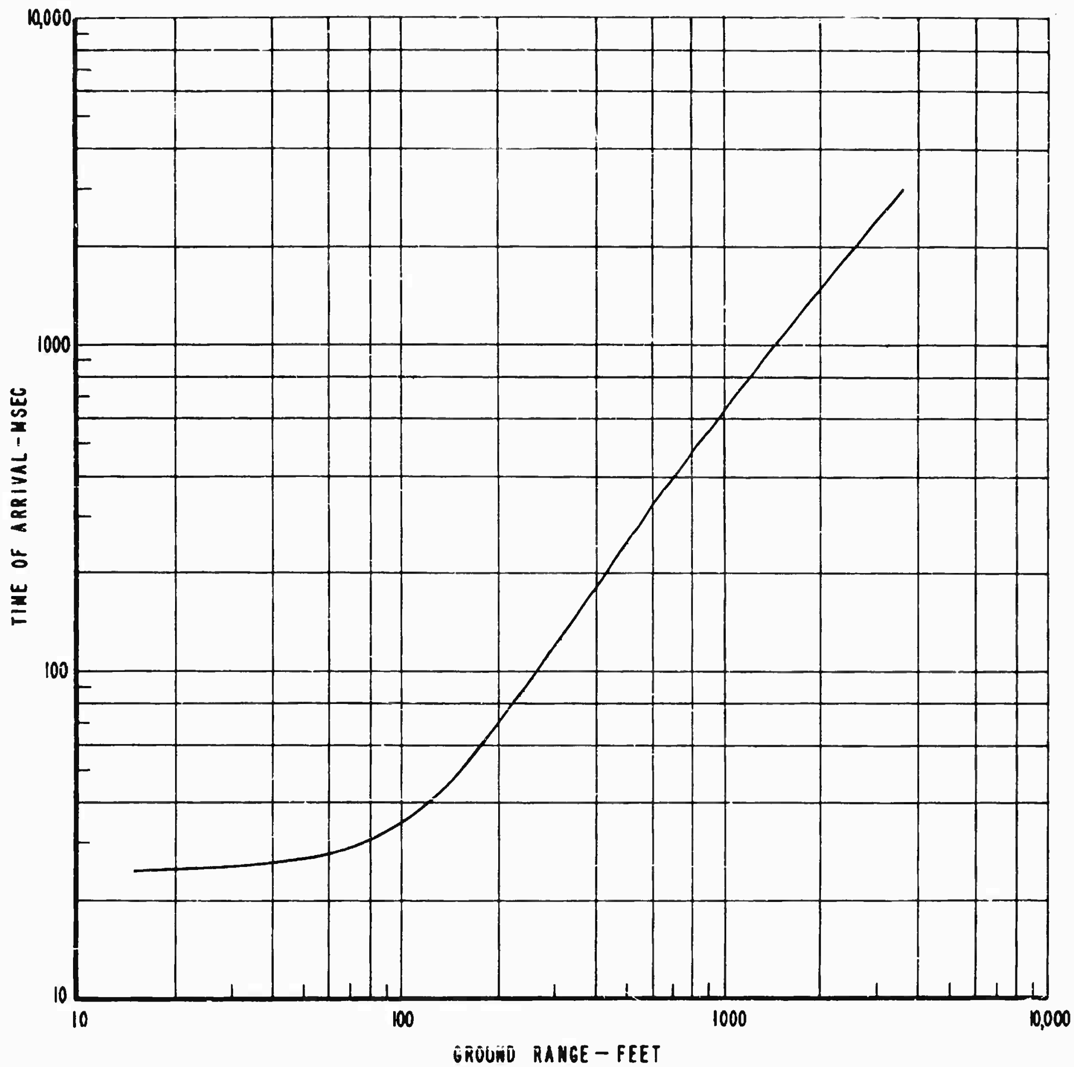


Figure 2.2 Predicted time of arrival versus ground range.

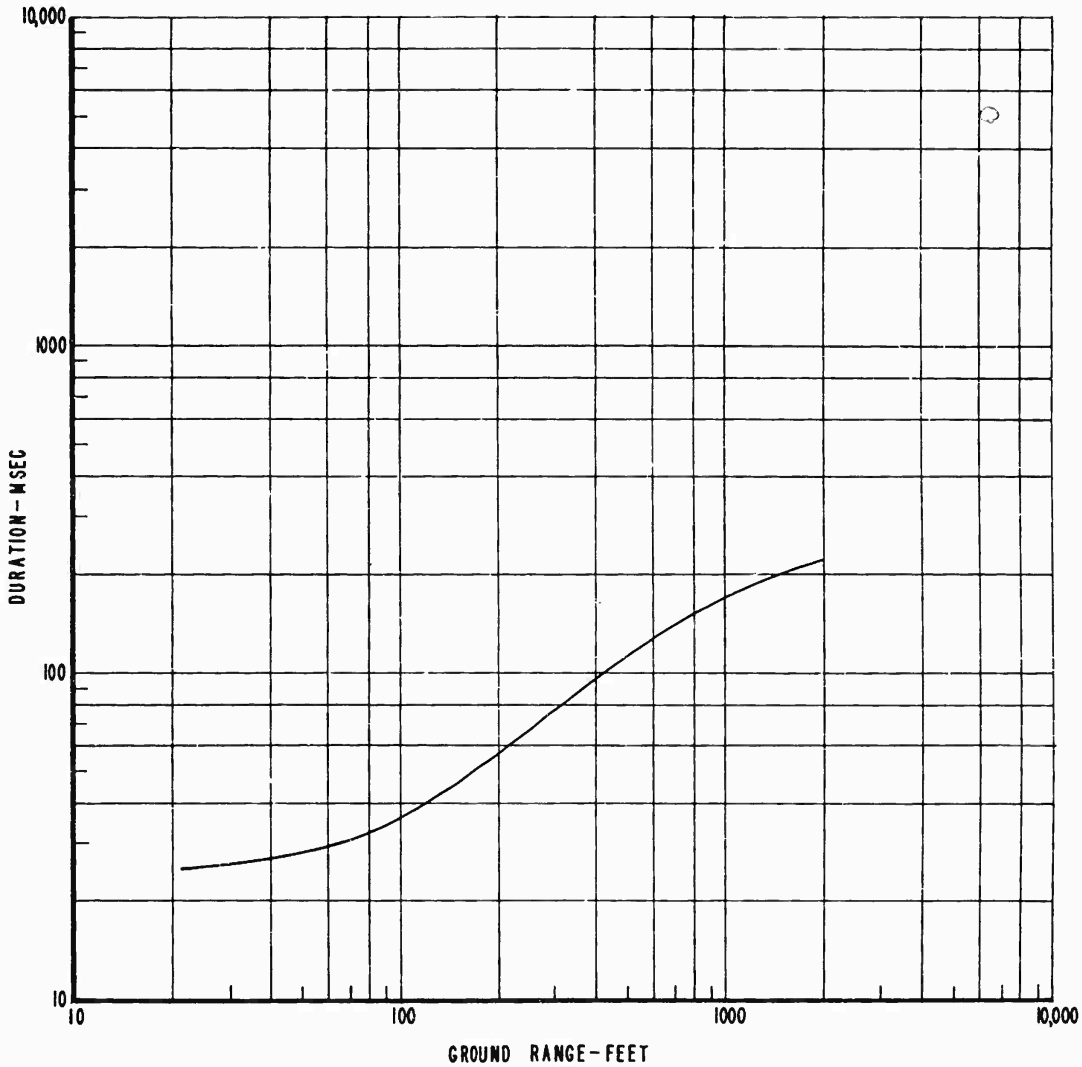


Figure 2.3 Predicted positive phase duration versus ground range.

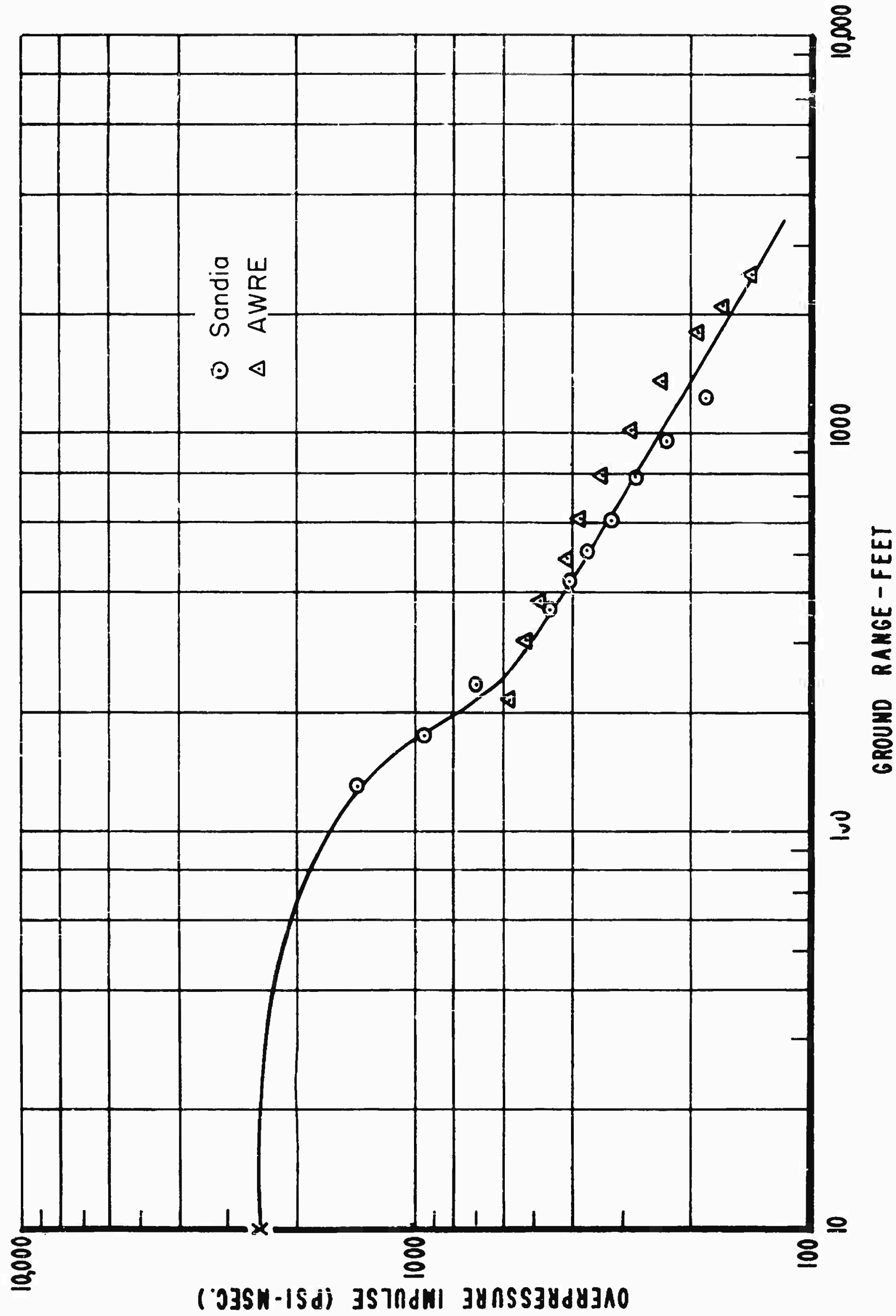


Figure 2.4 Predicted positive phase overpressure impulse versus ground range.

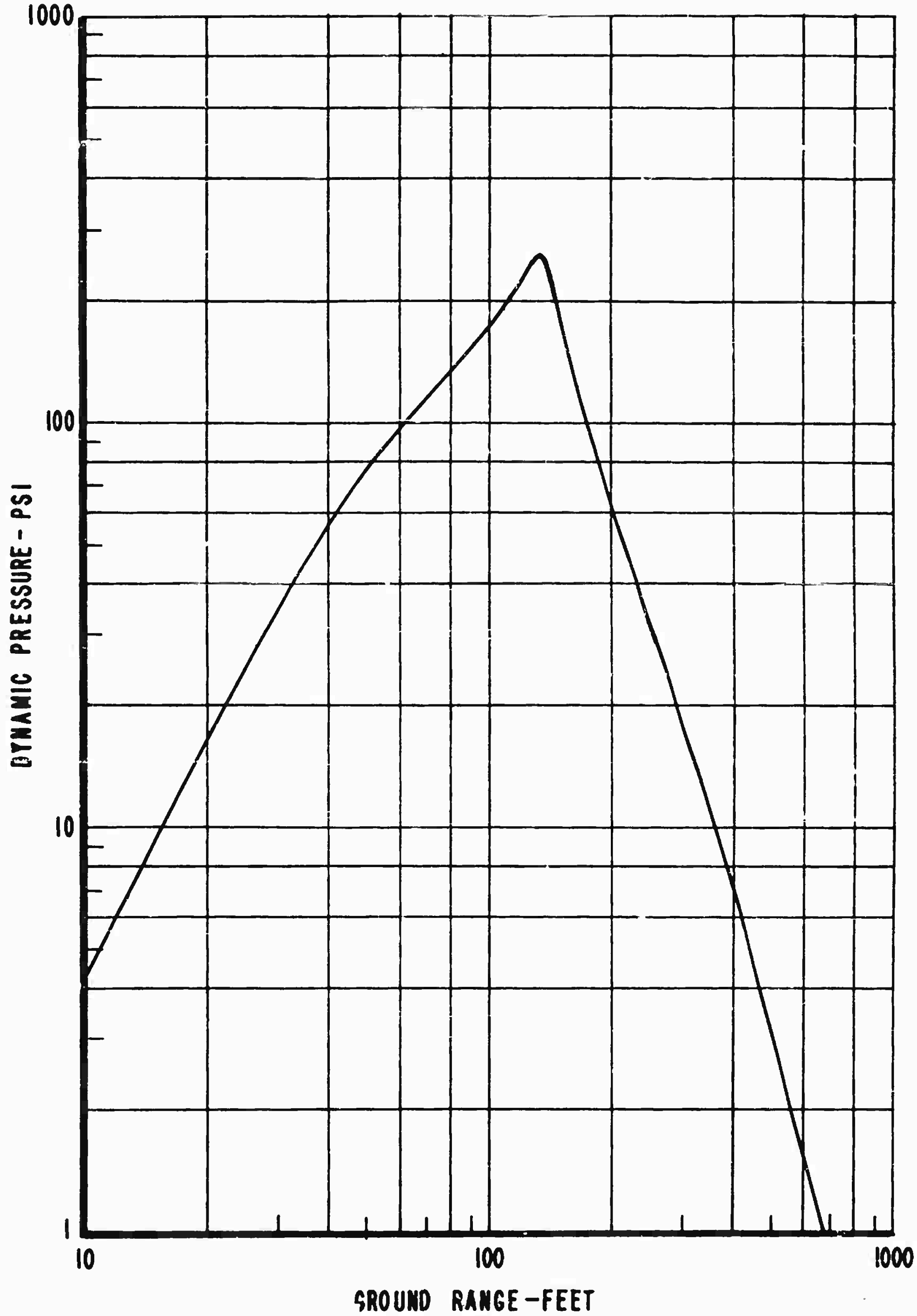


Figure 2.5 Predicted dynamic pressure versus ground range.

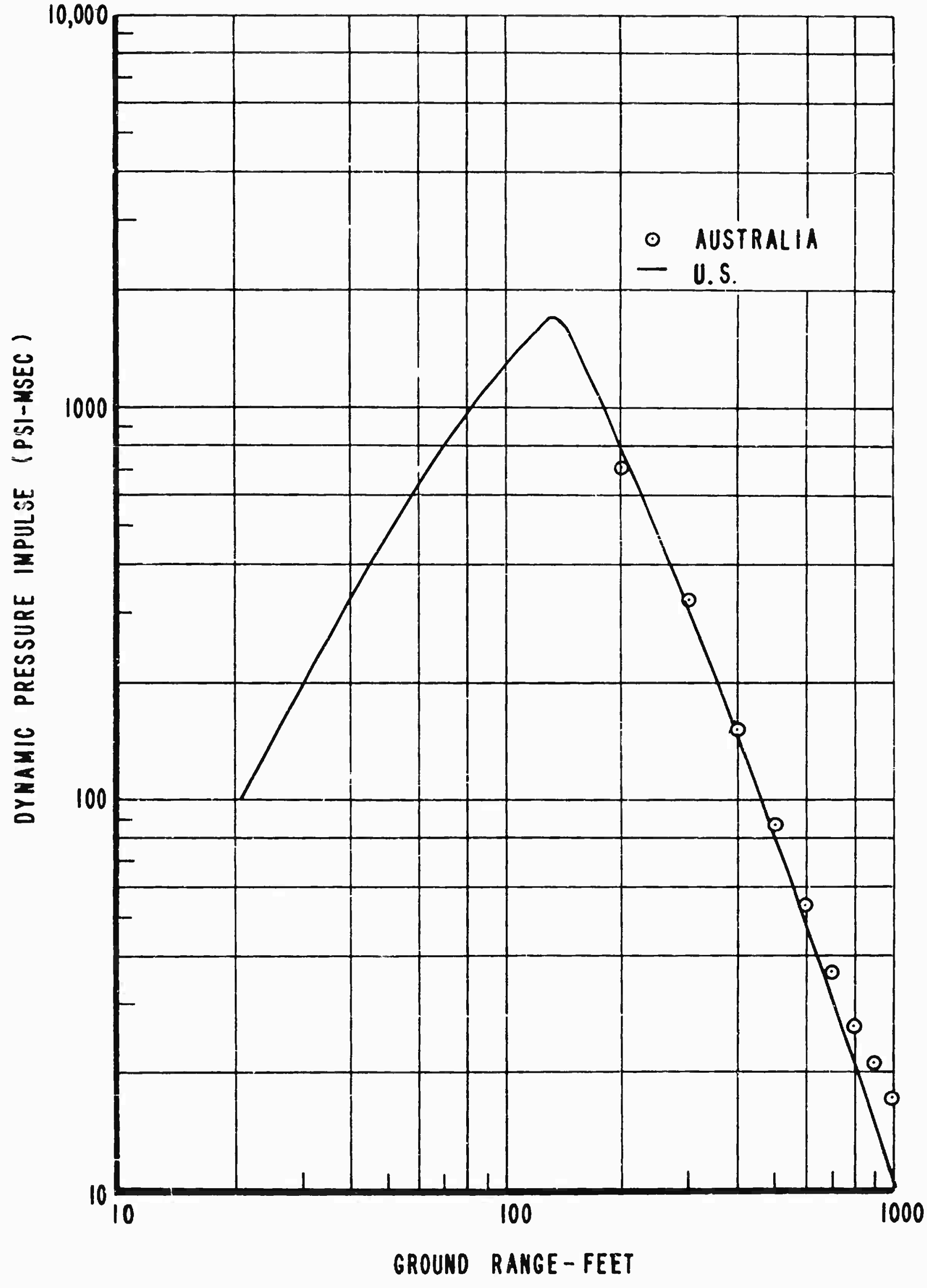


Figure 2.6 Predicted dynamic pressure impulse versus ground range.

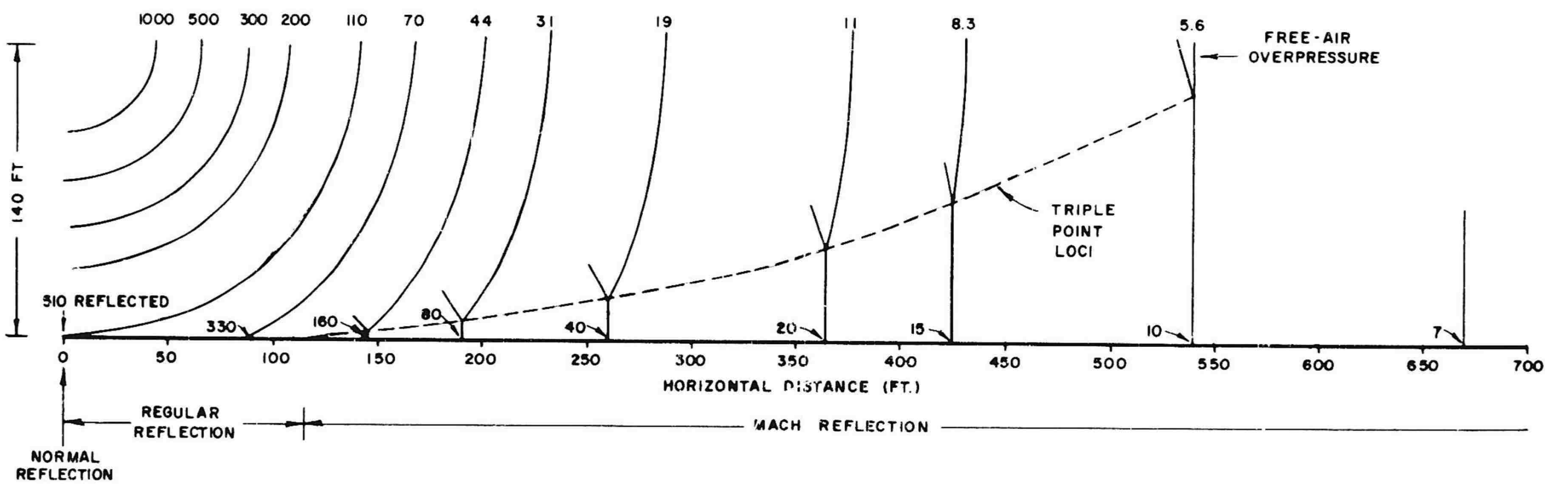


Figure 2.7 Predicted reflected shock wave and Mach stem height.

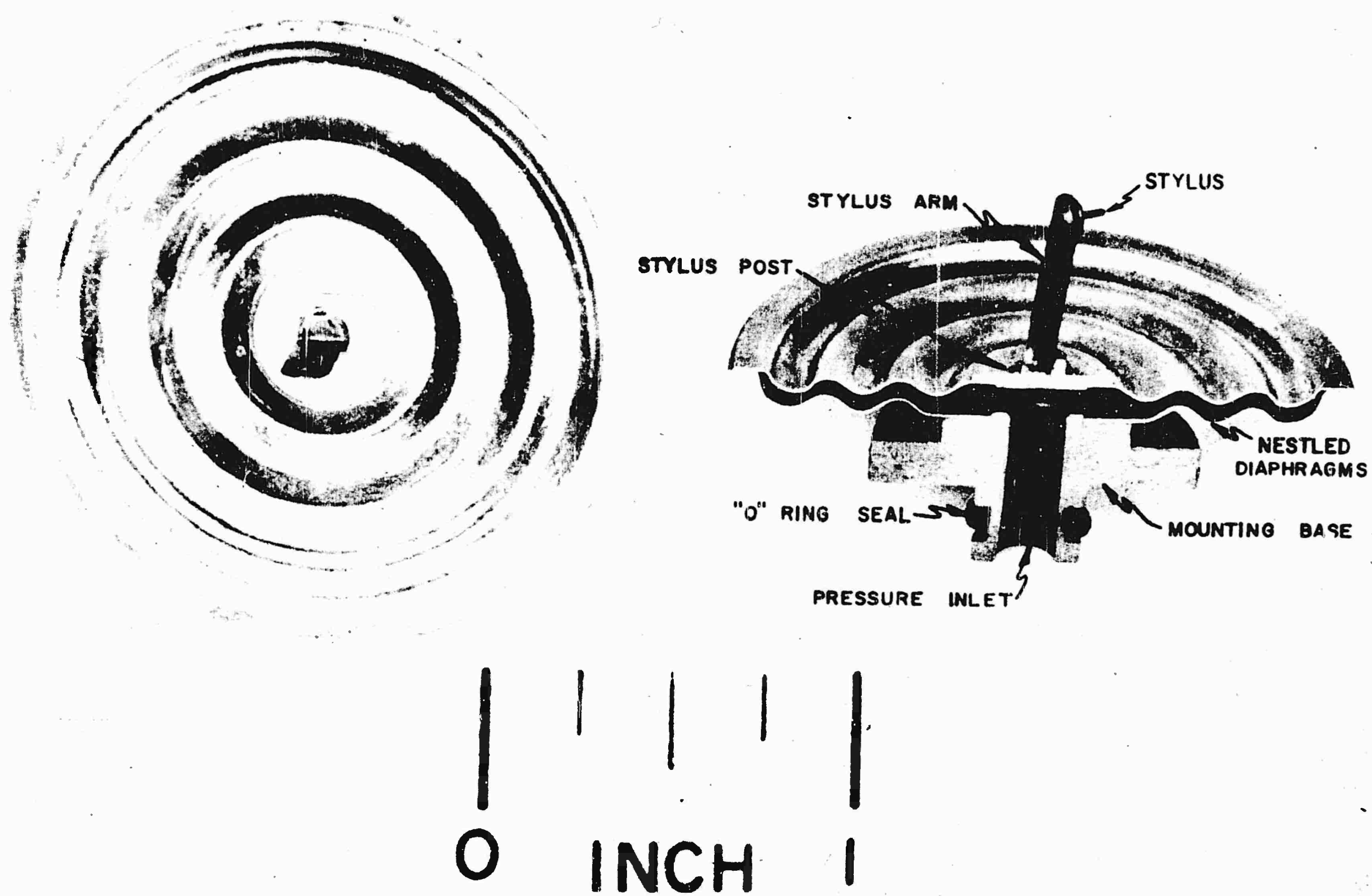


Figure 2.8 Nested diaphragm-type pressure-sensing capsule.

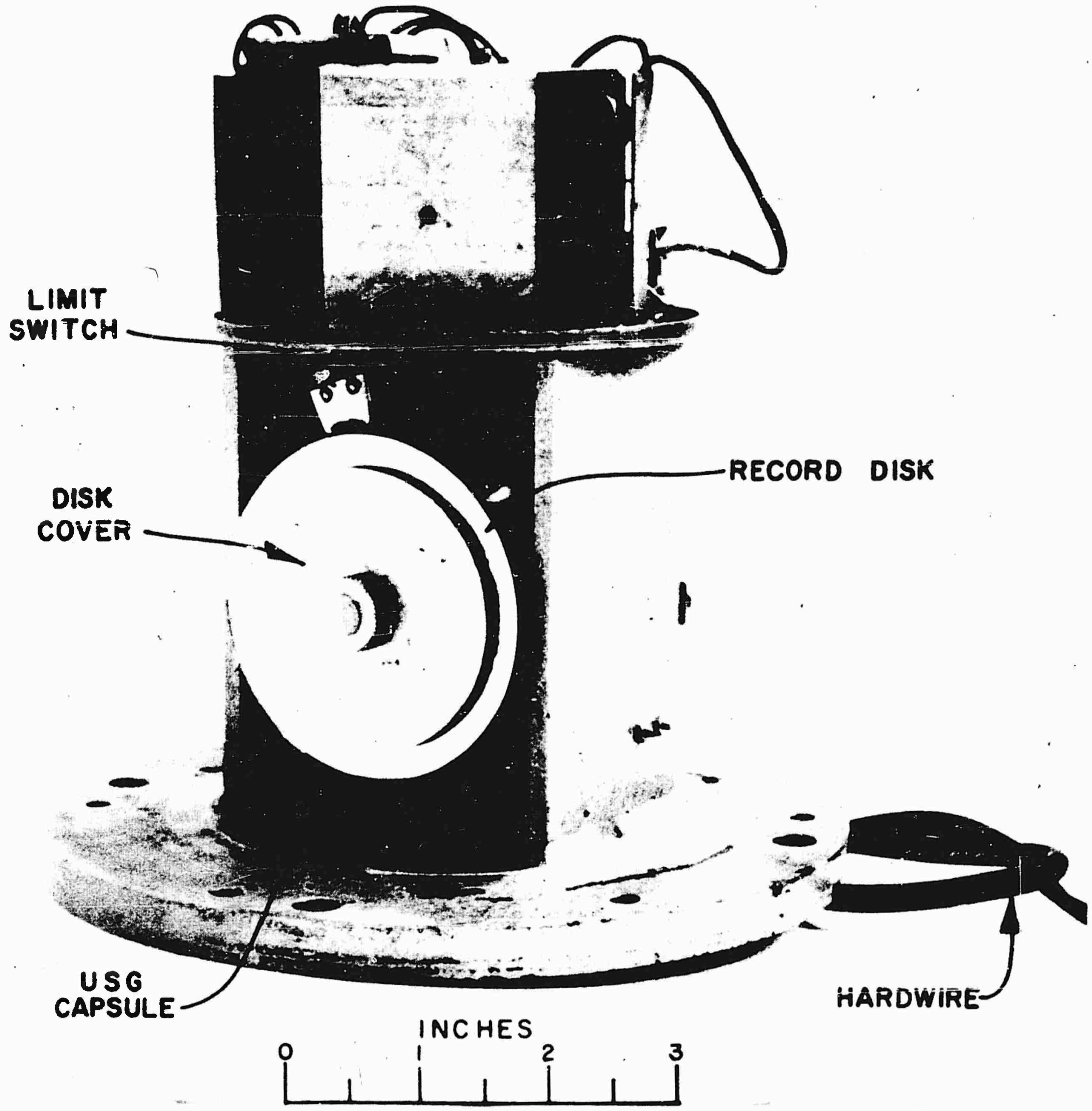


Figure 2.9 Front view of self-recording overpressure-time gage.

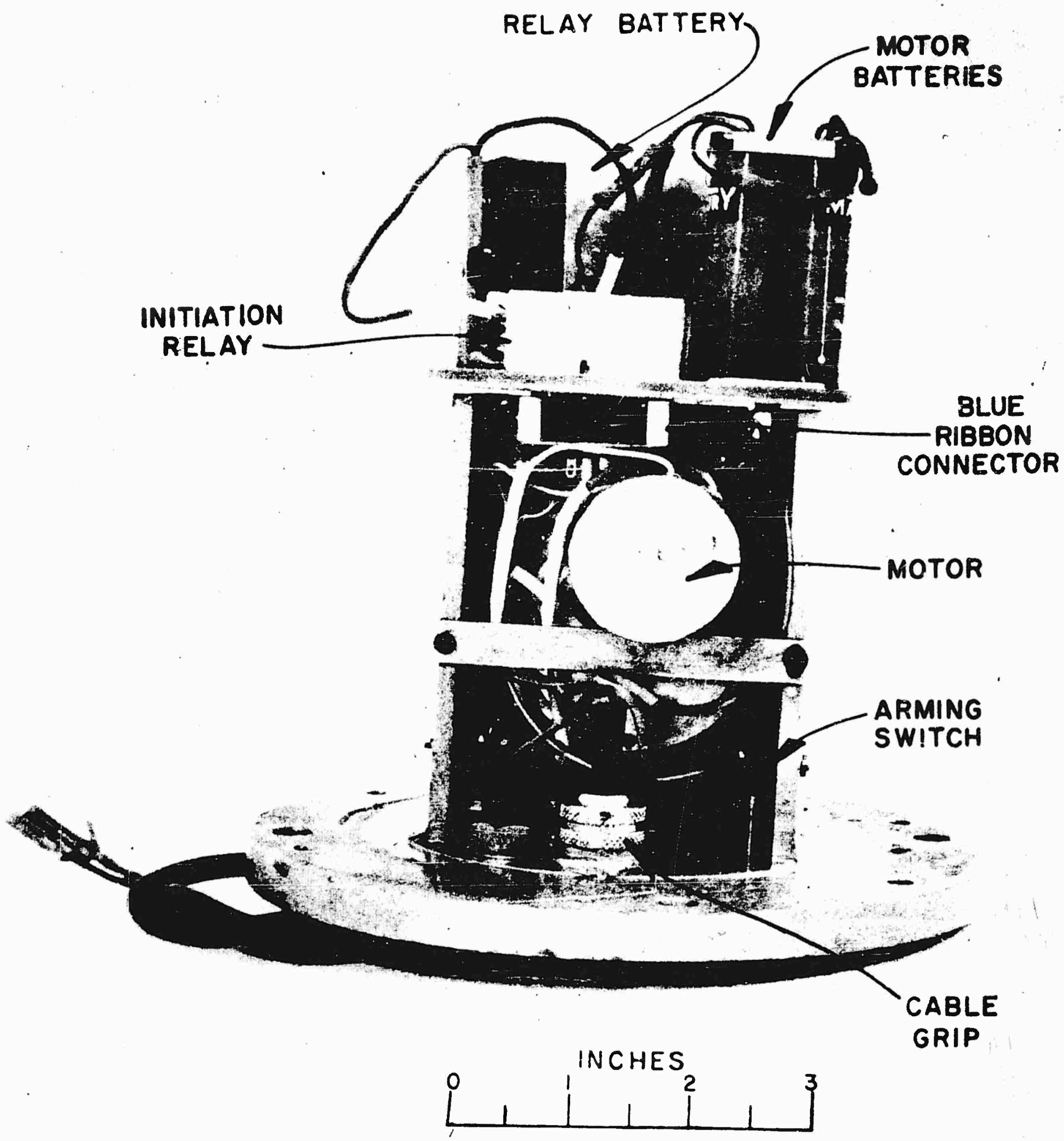


Figure 2.10 Rear view of self-recording overpressure-time gage.

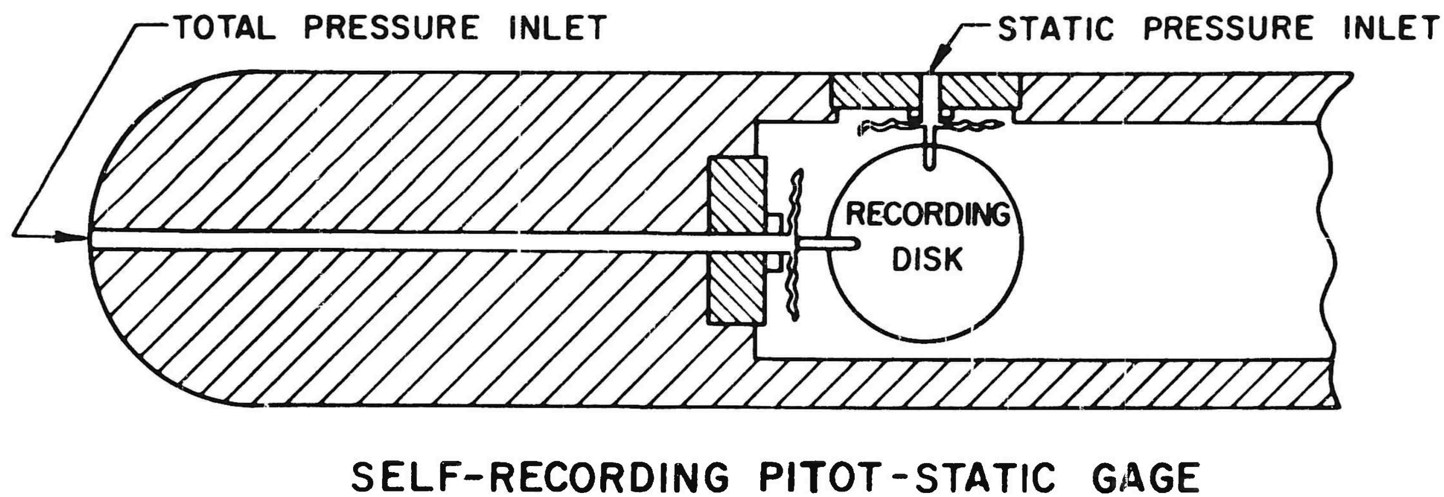


Figure 2.11 Schematic of dynamic pressure gage.

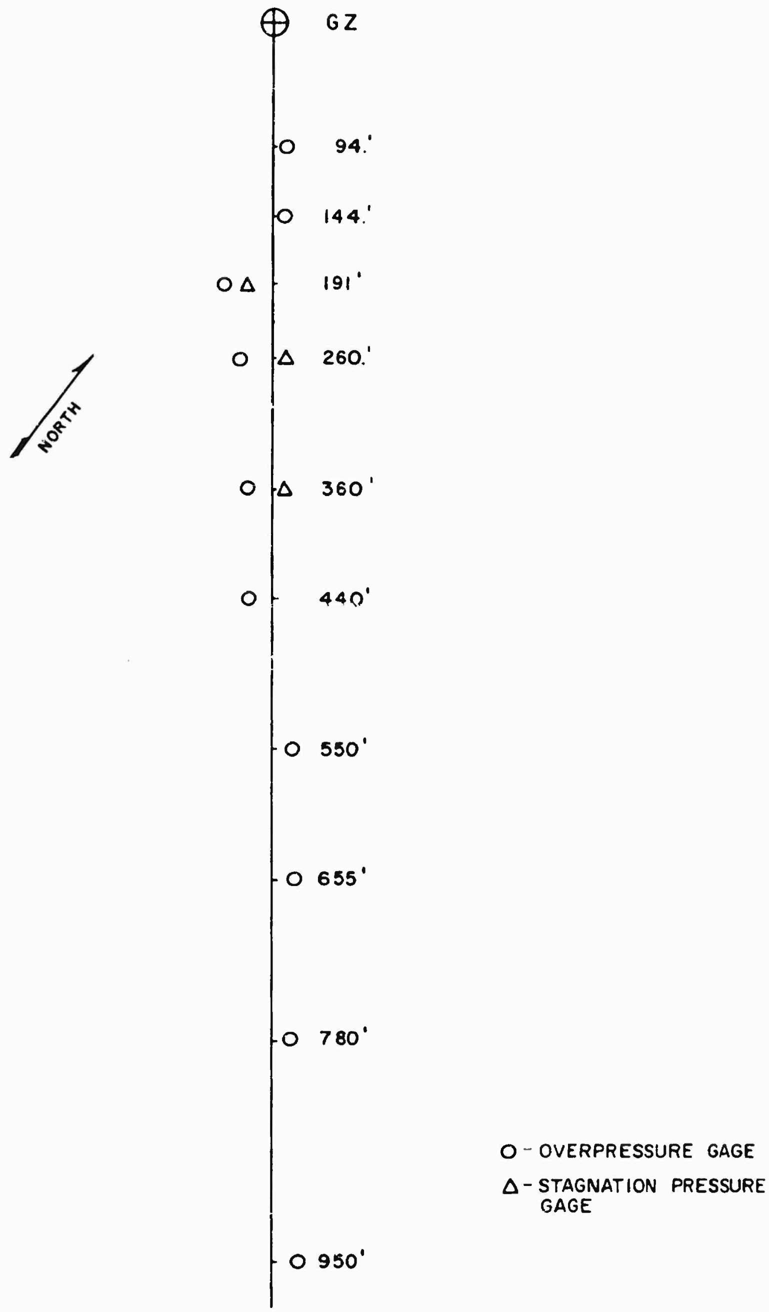


Figure 2.12 Layout of U.S. lane.

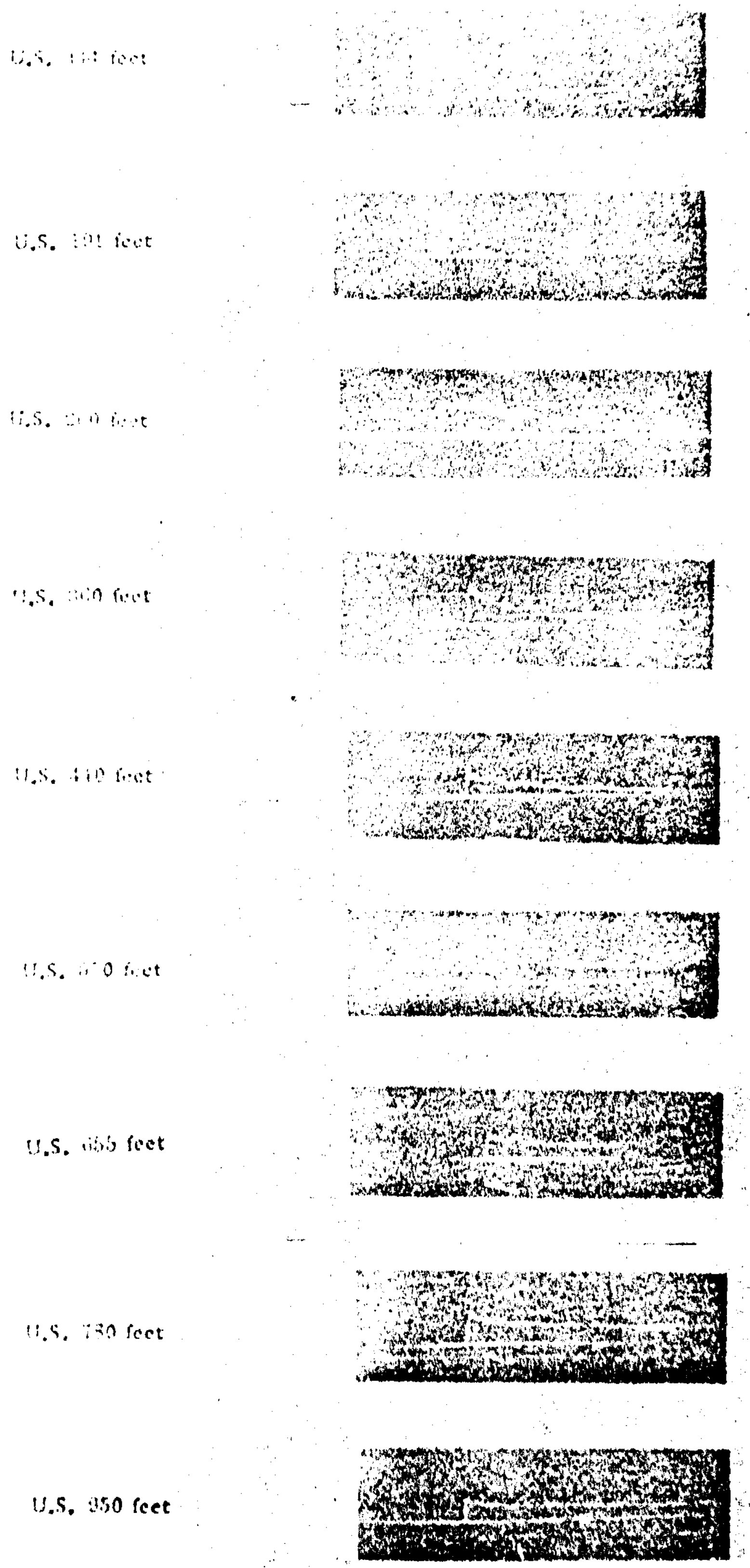


Figure 2.13 Pressure-time records from U.S. lane.

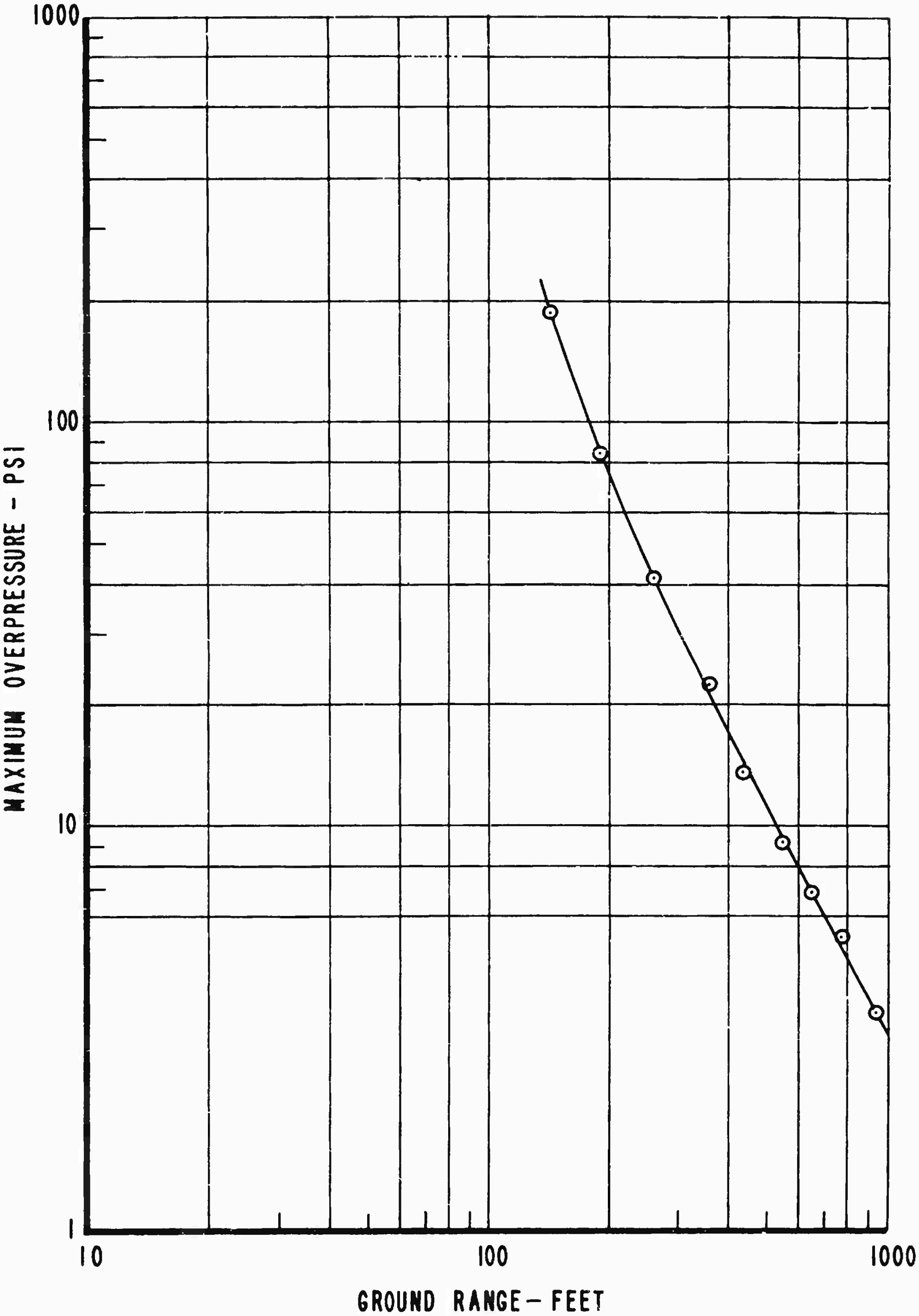


Figure 2.14 Measured maximum overpressure versus ground range.

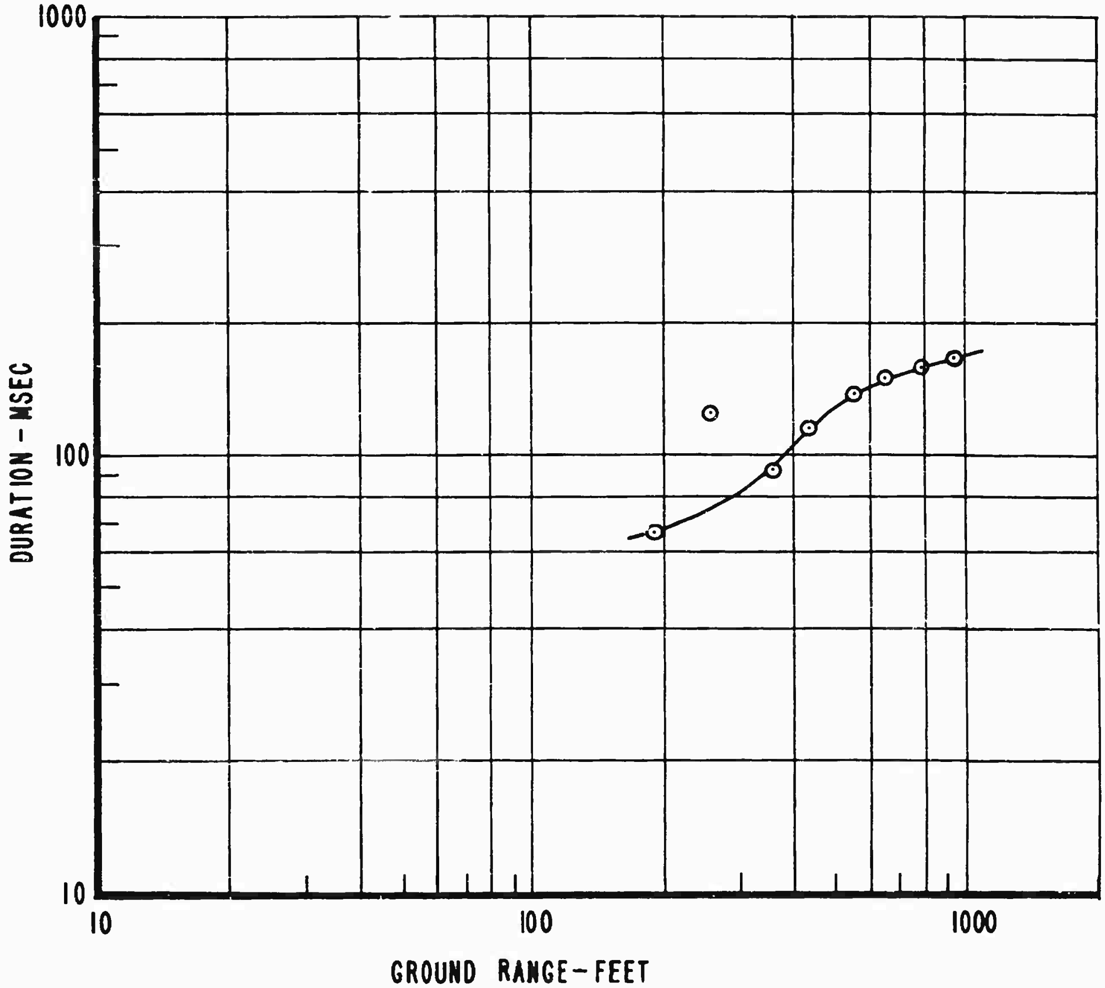


Figure 2.15 Measured positive phase duration versus ground range.

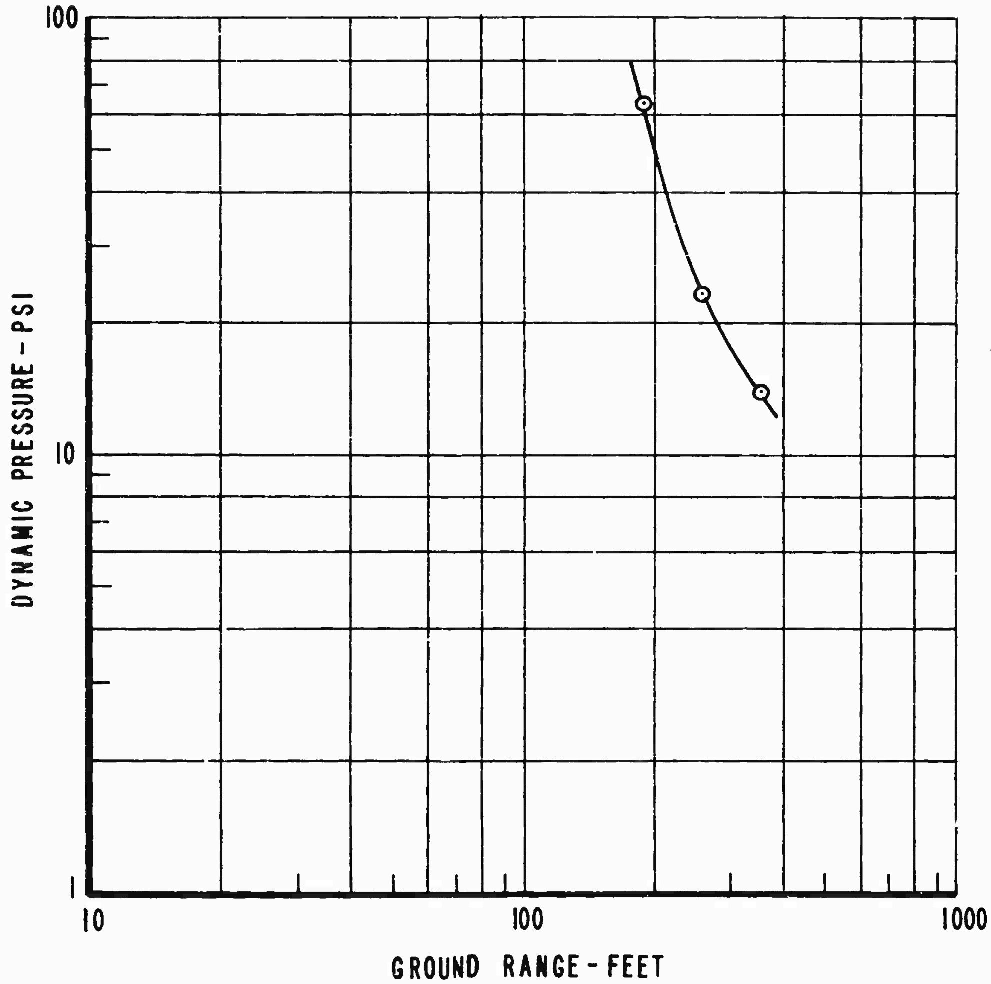
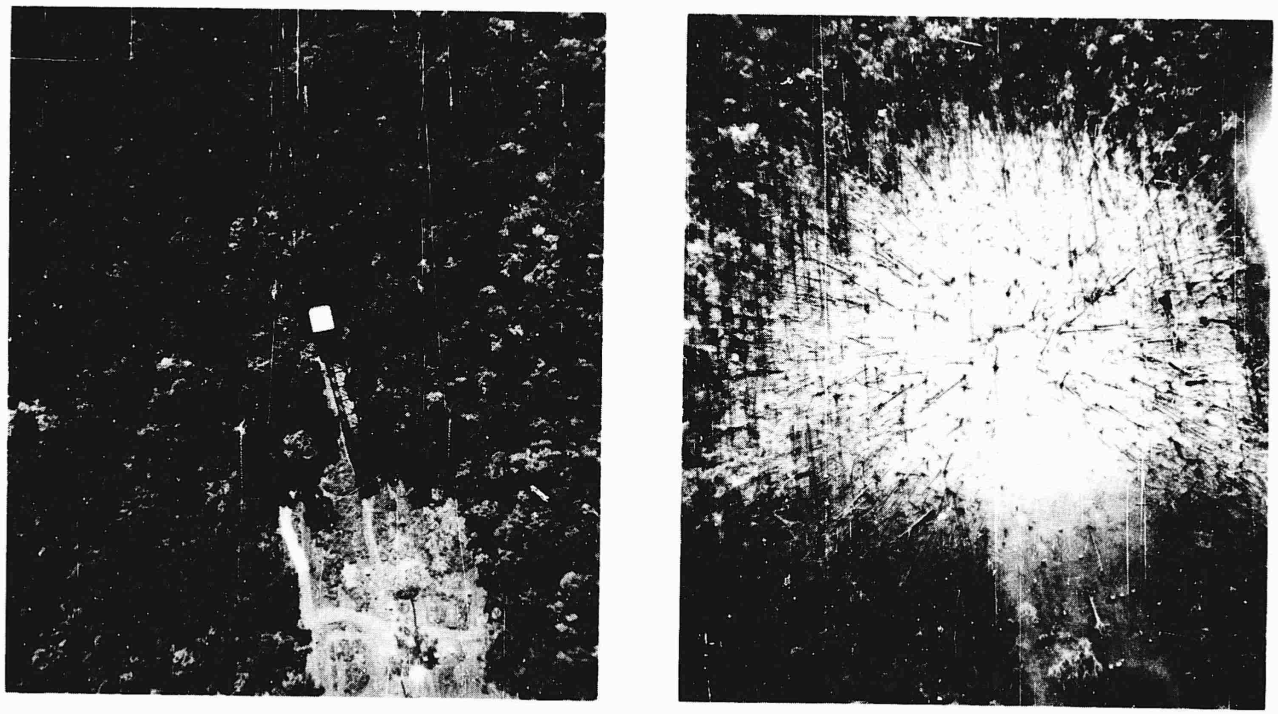


Figure 2.16 Measured maximum dynamic pressure versus ground range.



Preshot Postshot

Figure 2.17 Aerial photographs of test site.

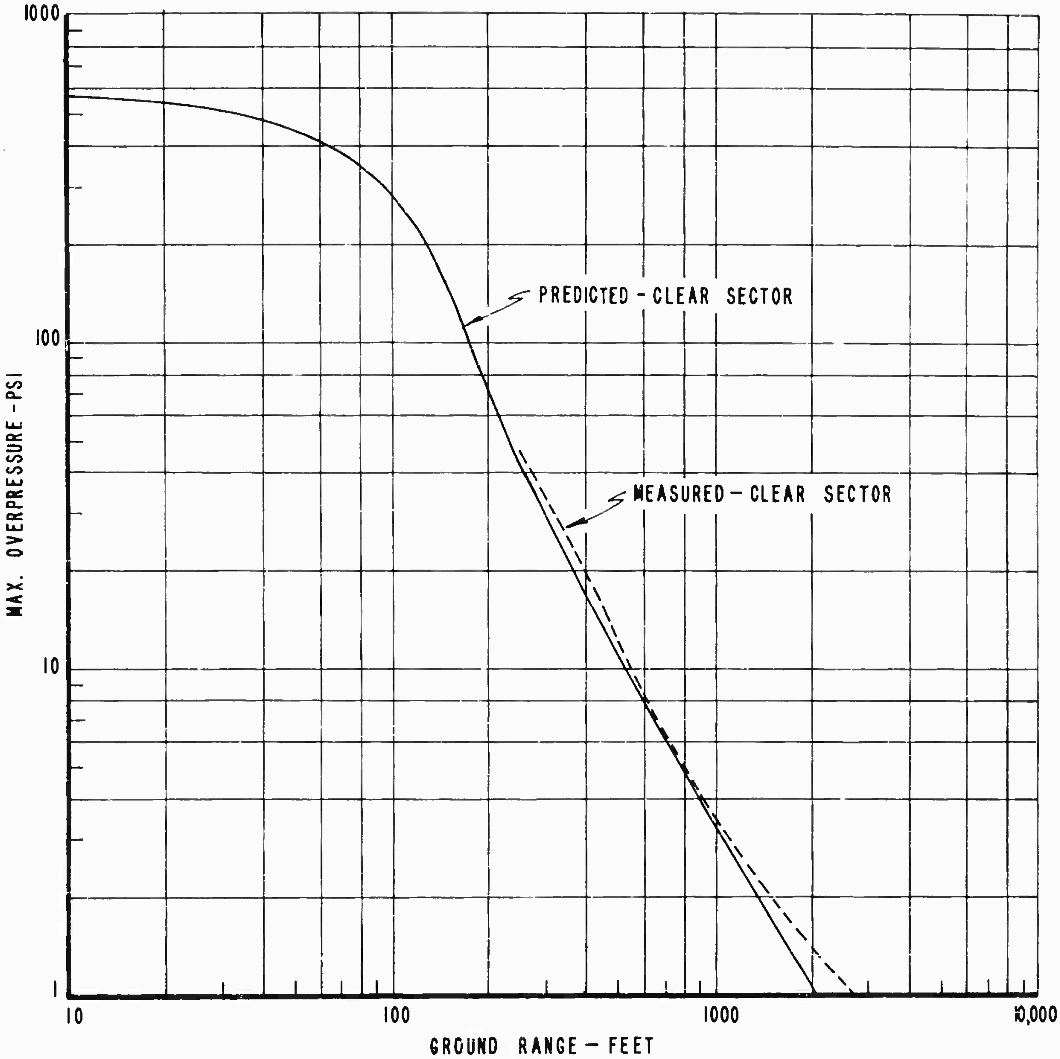


Figure 2.18 Comparison of measured overpressure in clear sector with predictions.

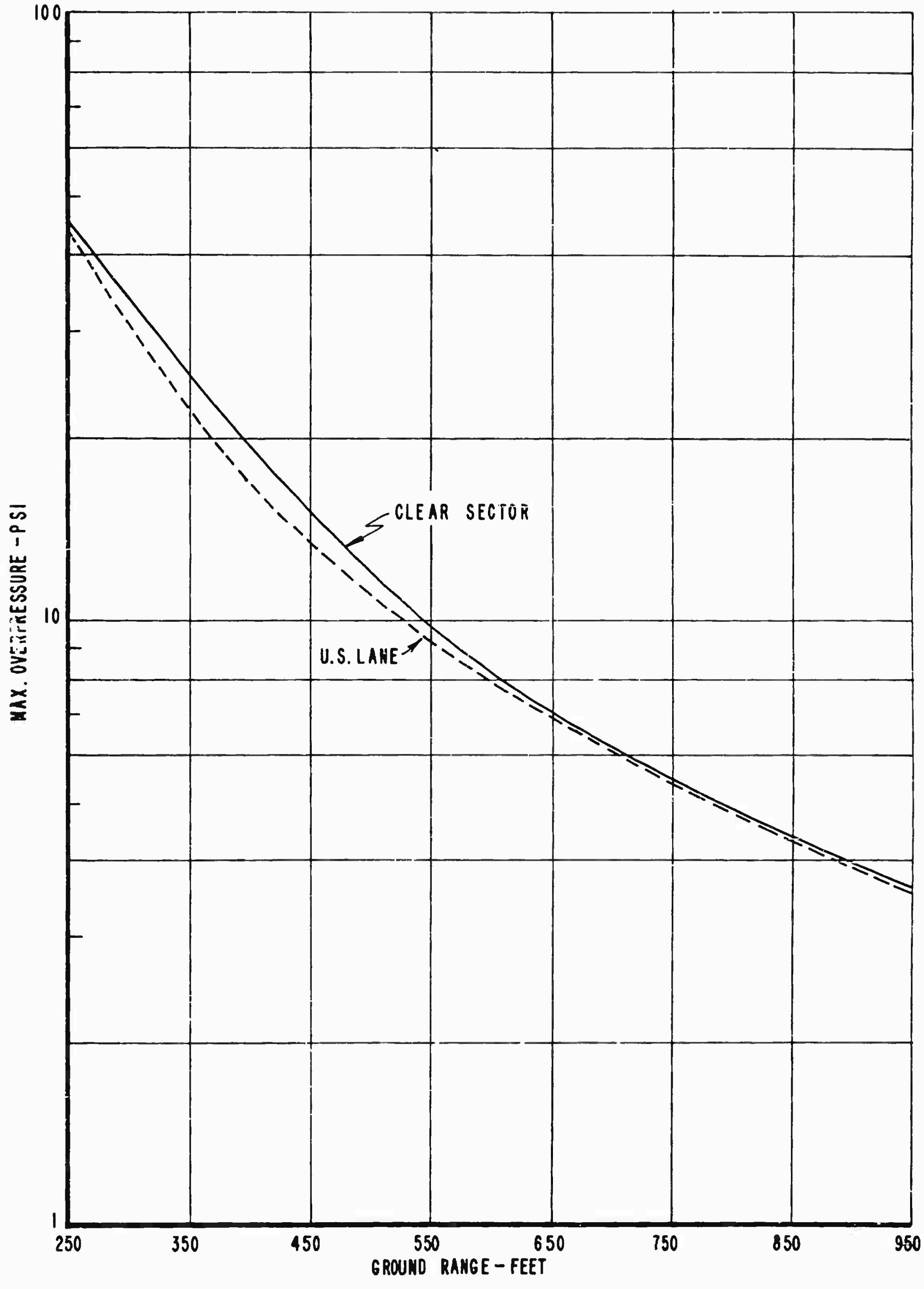


Figure 2.19 Comparison of measured overpressure along clear sector and U.S. lane.

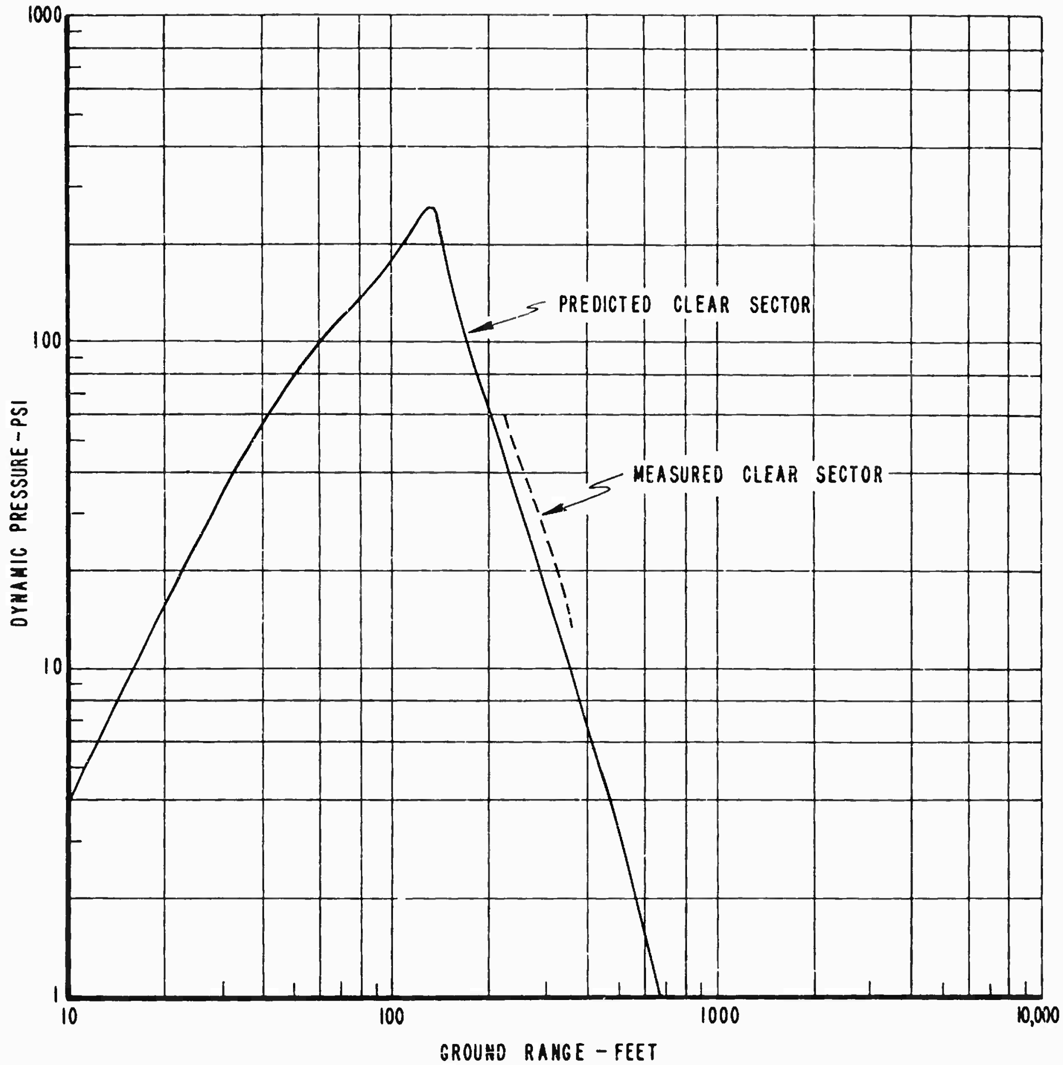


Figure 2.20 Comparison of measured dynamic pressure in clear sector with predictions.

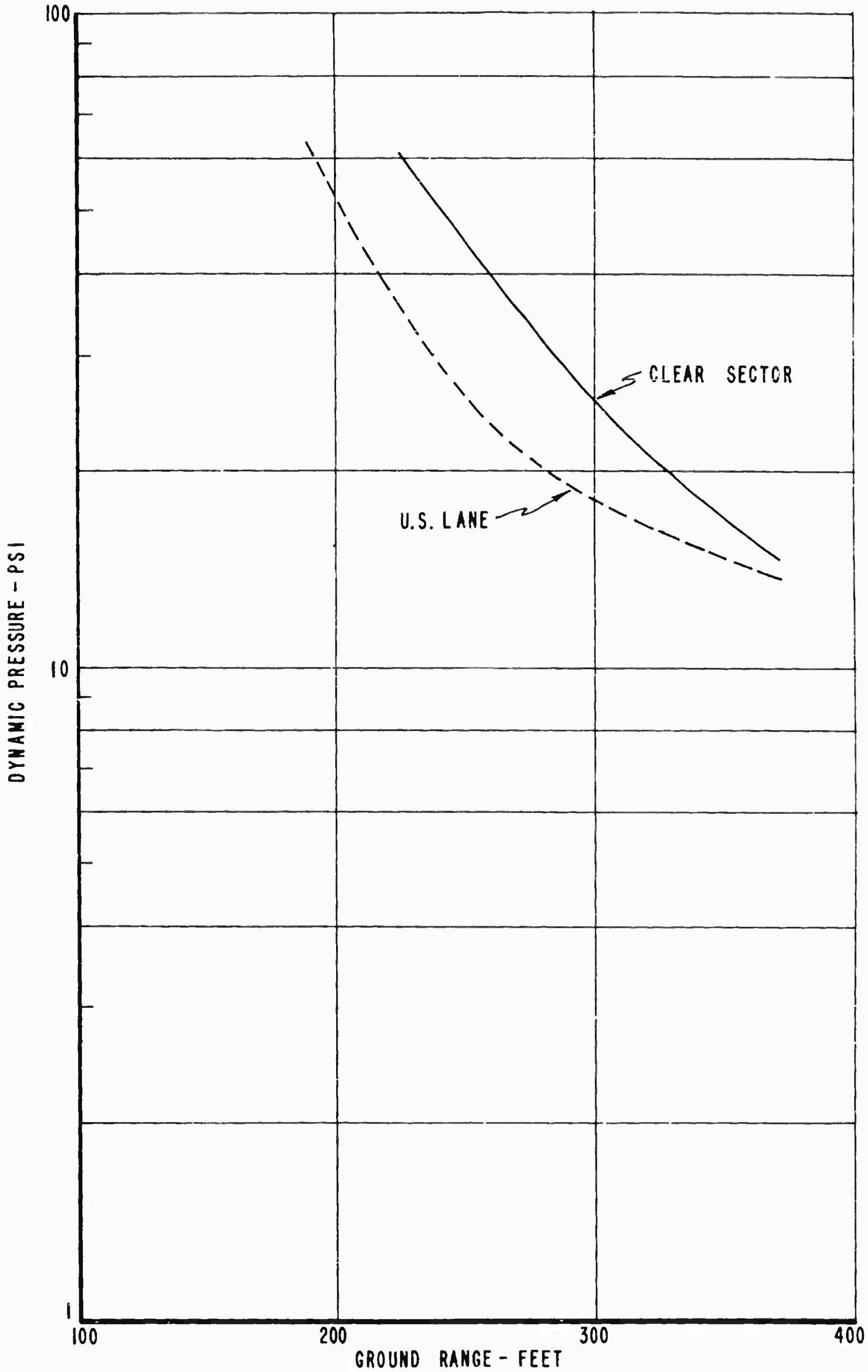
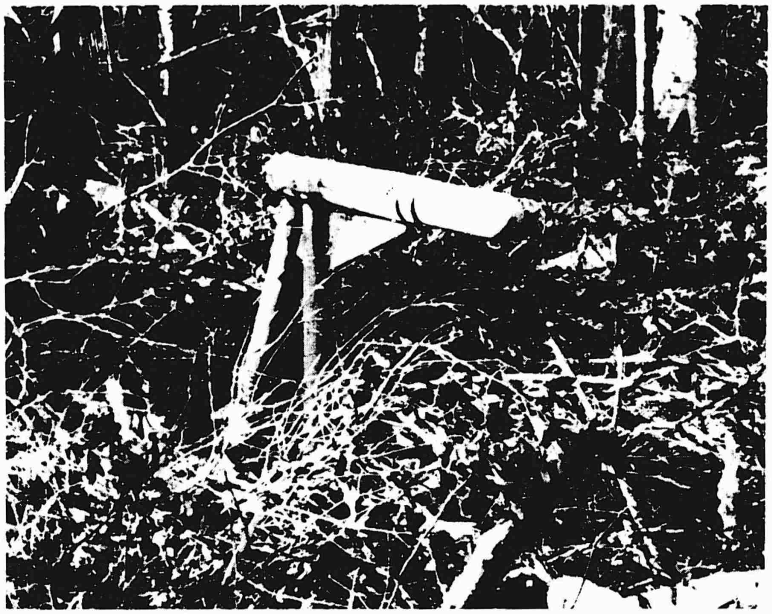
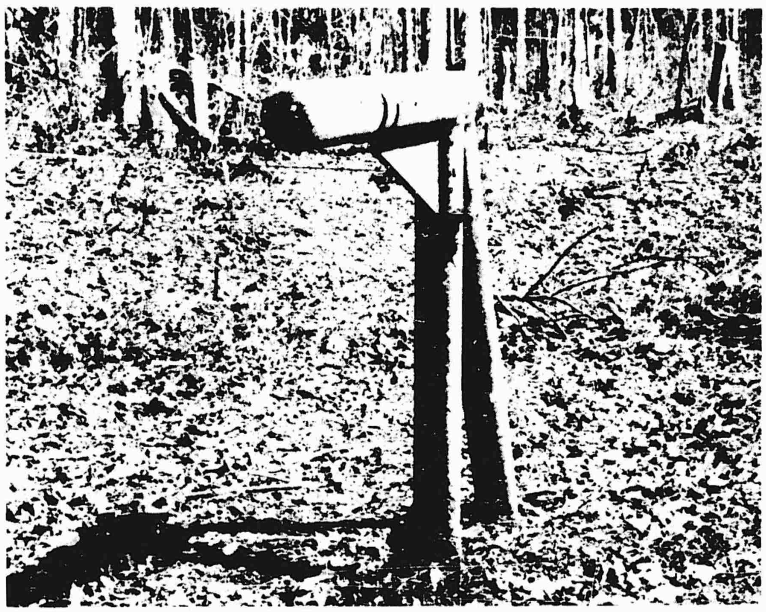


Figure 2.21 Comparison of measured dynamic pressures along clear sector and U.S. lane.

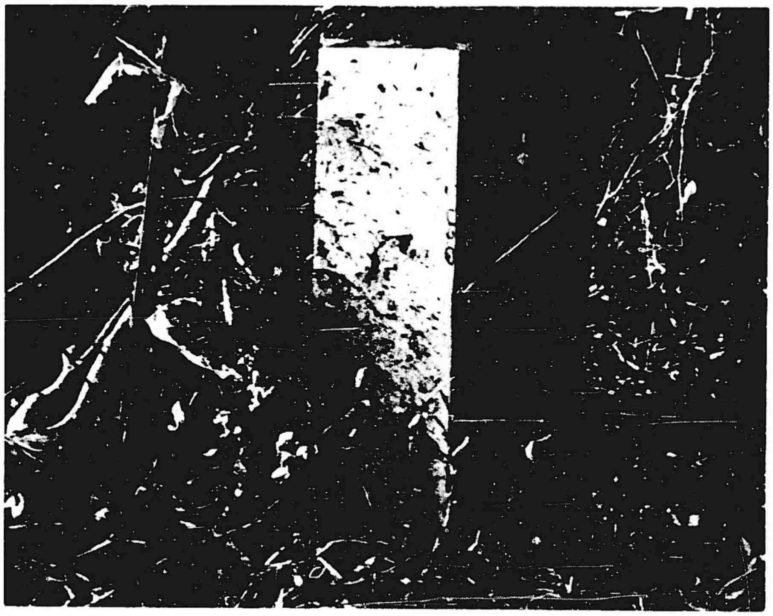


U.S. Lane - 360 feet



Clear Sector - 300 feet

Figure 2.22 Leaves and twigs around dynamic pressure gages.



U.S. Lane - 360 feet

Clear Sector - 300 feet

Figure 2.23 Leaves and twigs stopped by missile traps.

Chapter 3

TREE BLOWDOWN

(Prepared by Mr. Wallace L. Fons, Forest Service, Department of Agriculture.)

Prior to the actual detonation, every effort was made to obtain every conceivable form of data, as time allowed, which would be needed to assess the blowdown and to compare this forest stand with other types in extending the results of the experiment to forests of other types.

The following types of data were obtained prior to the detonation:

(1) Tree height versus diameter at breast height or girth.

(2) Detailed tree counts of several sample plots along a radius from ground zero at several azimuths.

(3) Data for estimating center of pressure of trees by girth classes.

(4) Number of trees less than 13 inches in girth per acre, to establish the density of the understory.

(5) Data for establishment of number of trees per acre by girth classes.

3.1 HEIGHT VERSUS GIRTH RELATIONSHIP OF TREES IN THE FOREST STAND

To establish height versus girth relationship for the forest stand, the heights of 54 trees growing adjacent to the clear sector were measured with a theodolite. The data is plotted in Figure 3.1.

3.2 DAMAGE ASSESSMENT SAMPLE PLOTS

The pretest survey of the sample plots consisted of a tree count and the recording of detailed data for all trees in the following categories with a girth greater than 13 inches:

(1) Measurement of girth at breast height.

(2) Estimation of total height of each tree.

(3) Estimation of height to first limb.

(4) Identification of each by species.

(5) Information obtained in (1) through (4) above was written on tags and attached to the trees at breast height to assist in the posttest surveys.

Under the supervision of Mr. W. L. Crofts of the Defence Standards Laboratories of Australia, two 4-man crews were organized for the detailed survey of the damage assessment sample plots. A Biltmore stick to measure tree heights was used to check the two crews on their height estimates by eye at the beginning of the survey. It was found that in estimating tree heights by eye there was a tendency to underestimate the height of the trees. Estimated height versus measured girth relationship on the 24 sample plots is shown in Figure 3.2 and compared with measured heights and girths as shown in Figure 3.1.

Table 3.1 indicates the location of the sample plots. These locations in the test site area are shown on Map 2, Appendix I.

3.3 HEIGHT TO CENTER OF PRESSURE

From the estimated height to first limb and estimated total height of each tree on the damage assessment plots, the height of crown, H_c, was calculated. The data was then grouped into girth classes. For each girth class total height, H_t, was determined from the curve in Figure 3.1. The center of pressure was assumed to be $\frac{1}{3} H_c$ measured from the top of the tree; thus, the height to the center of pressure, measured from the ground surface,

$$H_{cp} = H_t - \frac{1}{3} H_c$$

The height of center of pressure versus girth of trees in the test area is shown in Figure 3.3.

3.4 DENSITY OF UNDERSTORY

To establish the density of the understory for the stand, the trees or saplings were counted on 47 subplots, each 10 feet by 10 feet square, located in damage assessment plots D6A, F8B, F-16(Z-7), and Q11A. The count included all saplings 1 to 20 feet in height. Figure 4.4 shows the relationship between height of tree stems and the number of trees per acre with total height less than 20 feet in the stand composing the understory at the test site.

3.5 VISUAL ASSESSMENT OF RESULTING TREE BLOWDOWN

For several days following D-day, a careful visual appraisal was made along several radii from ground zero of the damage to the trees. The results of this visual assessment are discussed below:

(1) Damage appeared to be symmetrical with respect to ground zero.

(2) There was no appearance of so-called domino effect in the tree blowdown area.

(3) There was surprisingly little evidence of hang-ups, that is, broken stems or large limbs leaning on or being supported by crowns or stems of undamaged trees.

(4) Within the first week following D-day, several trees which had the stems or the root systems presumably damaged by the blast wave were blown down by natural wind during the day. For example: the "blue tree" (Figure 6.1) in the clear sector with stem damage near the ground level fell within 24 hours after the shot.

(5) A layer, approximately 6 inches deep, of shattered green leaves, was found on the ground out to 200 feet from ground zero. Tree stems and limb wood on the ground were covered with a layer of green leaves. This indicated that, after the leaves were blown off the trees by the blast wave, they were moved upward by the convection column created by the ascending fireball and then dropped to the ground when the vertical wind weakened.

(6) At H+2 hours, several small fires were found burning in decayed wood out to 150 feet from ground zero.

(7) The accumulated fine litter, mainly composed of shattered green leaves, in the tree blowdown area within a radius of 500 feet from ground zero, could easily become a potential fire hazard after a few days of dry weather.

Preliminary visual assessment of damage was made along radii from ground zero at several azimuths by Mr. Volek and Mr. Fons. It was concluded that the extent of damage at equal distances from ground zero for the several azimuths was practically identical. As a result, detailed notes were compiled of the damage observed along the primary lane. The extent of damage found at specified distances from ground zero along the primary lane follow:

(1) From ground zero to 50 feet. Severe damage.

Some trees were sheared off at 10 to 40 feet above the ground, and others were uprooted. There was no evidence of limbs on the ground. The ground was covered with a deep layer of shattered green leaves.

(2) From 50 to 100 feet. Severe damage.

The smaller trees, less than 18 inches in girth, were literally pulled or lifted out of the ground and moved 10 to 20 feet away from their original positions. The larger trees were either broken along the stem or uprooted. Broken pieees of limb wood and small tree stems were covered with a layer of shattered leaves.

(3) From 100 to 150 feet. Severe damage.

Both large and small trees were either broken along the stem or uprooted. Most stems were broken up into various lengths. There was no evidence of limbs in the area.

(4) From 150 to 200 feet. Severe damage.

All trees were down. Approximately 90 pereent were downed by stem breakage, and 10 percent were uprooted. All stems on the ground were intact. There was practically no evidence of limbs on the top of the layer of the aceumulated litter.

(5) From 200 to 250 feet. Severe damage.

There was some uprooting of small trees but no uprooting of the large trees. Approximately 5 percent of the large tree stems remained standing but were denuded of limbs. Some broken limbs were in evidence on top of the layer of accumulated litter.

(6) From 250 to 300 feet. Severe damage.

Approximately 80 percent of the tree stems were broken. Tree stems broken near the ground level were still attaehed to the stump. The remaining 20 percent of the tree stems still standing were denuded of limbs. There was some accumulation of large and small limbs on the ground.

(7) From 300 to 350 feet. Severe damage.

Approximately 50 percent of the tree stems were broken. The trees that remained standing were mostly denuded of limbs. The ground was covered with a heavy accumulation, 4 to 6 feet deep, of small and large limbs.

(8) From 350 to 400 feet. Moderate damage.

There was some stem breakage of small trees but no stem breakage of the larger trees. On some of the large trees, there was extensive breakage of large limbs. A few of the large trees were not completely defoliated. Part of the heavy limb aeeumulation at this distanee appeared to have come from the 300- to 350-foot seetor.

(9) From 400 to 450 feet. Moderate damage.

There was no stem breakage or uprooting of the trees, but there was a considerable amount of limb breakage, espeeially of the small limbs. The understory was defoliated, but its stems and limbs remained intaet.

(10) From 450 to 550 feet. Light damage.

Limb breakage on all trees was light. Limb accumulation on the ground was moderate. Defoliation of trees and understory was approximately 90 percent.

(11) From 550 to 750 feet. Light damage.

Breakage of small limbs was light. Defoliation of trees and understory was about 50 percent at 600 feet, dropping to about 20 percent at 750 feet.

(12) From 750 to 950 feet. No damage.

Defoliation of the trees was noticeable beyond the distance of 800 feet only because there were new leaves scattered on the ground.

3.6 POSTTEST SURVEY OF DAMAGE ASSESSMENT SAMPLE PLOTS

Following the detonation, two survey teams assessed the damage resulting to the individual, tagged trees in the sample plots. Preliminary results of this survey are given in Tables 3.2 through 3.10.

Table 3.2 is a recapitulation of all trees in these sample plot areas. Tables 3.3 through 3.10 contain data for trees counted within girth classes as indicated.

TABLE 3.1 LOCATION OF DAMAGE ASSESSMENT SAMPLE PLOTS

Secondary Lane 1/	Primary Lane 1/	45° Lane 2/	Azimuth 2/
M-11B	K-2B	H-10B	Z-1(G7-H7)
N-11B	K-4A	F-8B	Z-2(M6-M7)
O-11B	J-5B	E-7B	Z-4(N17-O17)
P-11B	K-6B	D-6A	Z-7(F16)
Q-11A	K-7B	B-4B	
R-11A	K-8B		
S-11A	K-10B		
	K-11 3/		

1/ Plot sizes: 50 ft x 100 ft

2/ Plot sizes: 70 ft x 70 ft

3/ Plot sizes: 100 ft x 100 ft

TABLE 3.2 RECAPITULATION OF DAMAGE TO ALL TREES AT GROUND RANGES FROM 25 TO 1,130 FEET

Distance Range from GZ, ft	Total No. of trees	Percent Undamaged	Percent Standing
25 - 115	74	0	0
95 - 155	117	0	1.7
140 - 200	159	0	3.8
190 - 250	141	0	1.4
210 - 290	65	0	0
240 - 300	127	0	1.2
290 - 365	204	3.5	17.0
350 - 410	115	31.3	42.5
350 - 430	53	7.5	41.5
400 - 460	114	53.6	58.8
420 - 510	186	62.4	70.5
500 - 565	135	71.2	78
550 - 610	485	82.0	90.8
570 - 660	159	92.5	93.0
650 - 700	155	91.6	92.3
700 - 770	174	95.5	95.5
750 - 800	108	97.2	99.0
780 - 850	161	96.4	97.0
850 - 900	165	98.8	98.8
900 -1000	210	98.6	98.6
1000 -1130	211	98.2	99.0

EXPLANATORY REMARKS FOR TABLES 3.3 THROUGH 3.9

Column (1)	Center distance from GZ.
Column (2)	Total number of trees in area counted for the girth class, N_t.
Column (3)	Number of trees uprooted and percent compared to N_t.
Column (4)	Number of trees with broken stems and percent compared to N_t.
Column (5)	The number of trees which could not be found after the explosion. This number is actually the difference between (U + B + S + Undamaged) and N_t. Note that this number decreases rapidly with distance from GZ, is nearly 100 percent for small girth trees near GZ, and near zero beyond approximately 350 feet. The number is also less for large girth trees that could be identified in the debris.
Column (6)	Refers to trees with all or nearly all limbs removed, but the stem itself still intact.
Column (7)	Includes trees with moderate limb breakage, defoliation, and nil damage.
Column (8)	Number of trees not counted as undamaged.
Column (9)	Number of trees with stems intact.
Column (10)	Number of trees with stems broken, trunks on the ground, or not present.

TABLE 3.3 BLOWDOWN DATA FOR TREES WITH 13- TO 16-INCH GIRTH

Distance from GZ (feet)	Total No. of Trees N_t	Uprooted "U"		Broken Stem - "B"		(U/B) Uprooted And/or Broken		Severely Damaged "S"		Undamaged		U+3+S+U/B		Standing		U+B+U/B	
		No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
(1)	(2)	(3)		(4)		(5)		(6)		(7)		(8)		(9)		(10)	
50	17	2	11.7	2	11.7	13	76.5					17	100	0	0	17	100
125	35	5	14.3	4	11.4	26	74.3					35	100	0	0	35	100
175	29	3	10.3	2	6.9	24	82.8					29	100	0	0	29	100
225	40	17	42.5	6	13	17	42.5					40	100	0	0	40	100
250	20	5	25	2	10	13	65					20	100	0	0	20	100
275	30	5	16.7	5	16.7	20	66.7					30	100	0	0	30	100
325	55	7	12.7	13	23.6	32	58.2	3	5.5			55	100	3	5.5	52	94.5
375	26	4	15.4	15	57.7			1	3.8	6	23.1	20	77	7	26.9	19	73
390	11	1	9.1	2	18.2	6	54.5	1	9.1	1	9.1	10	91	2	18.2	9	81.8
425	26	1	3.9	10	38.5	3	7.8	4	15.4	8	30.9	18	69.2	14	46.1	12	53.8
470	42	3	7.1	11	26.2	4	9.5	1	2.4	23	54.8	19	45.2	24	57.2	18	42.8
530	25	4	16	8	32			4	16	9	36	16	64	13	52	12	48
575	117	3	2.6	8	6.8	1	0.91	9	7.7	96	82.1	21	17.9	105	90	12	10.3
620	33	1	3	3	9					29	87.8	4	12	29	87.8	4	12
675	34									34	100			34	100		
730	42	1	2.4	2	4.8					39	92.8	3	7.2	39	92.8	3	7.2
775	22							2	9.1	20	90.9	2	9.1	22	100	-	-
820	35							1	2.9	34	97.1	1	2.9	35	100		
875	38			2	5.3					36	94.7	2	5.3	36	94.7	2	5.3
950	37									37	100			37	100		
1050	53									53	100			53	100		

TABLE 3.4 BLOWDOWN DATA FOR TREES WITH 16- TO 19-INCH GIRTH

Distance from GZ (feet)	Total No. of Trees N_t	Uprooted "U"		Broken Stem - "B"		(U/B) Uprooted And/or Broken		Severely Damaged "S"		Undamaged		U+B+S+U/B		Standing		U+B+U/B	
		No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
(1)	(2)	(3)		(4)		(5)		(6)		(7)		(8)		(9)		(10)	
50	19			3	15.8	16	84.2					19	100	0	0	19	100
125	15	2	16.7	2	16.7	10	66.7					15	100	0	0	15	100
175	34	9	26.5	5	14.7	20	58.8					34	100	0	0	34	100
225	31	8	25.8	4	12.9	19	61.3					31	100	0	0	31	100
250	12	4	33.3	3	25	5	41.7					12	100	0	0	12	100
275	17			6	35.3	10	58.8	1	5.9			17	100	1	5.9	16	94.1
325	38	4	10.5	18	47.4	13	34.2	3	8.1			38	100	3	8.1	35	91.9
375	12	3	25	4	33.3	1	8.3	-	-	4	33.3	8	67.7	4	33.3	8	66.7
390	6	-	-	3	50	-	-	2	33.3	1	16.7	5	83.3	3	50	3	50
425	19	3	15.9	7	36.8	1	5.3	-	-	8	42.4	11	57.6	8	42.4	11	57.6
470	36	1	2.8	9	25	-	-	3	8.3	23	63.9	13	36.1	26	72.2	10	27.8
530	16	1	6.2	4	25					11	68.7	5	31.2	11	68.7	5	31.2
575	79	2	2.5	4	5.1	2	2.5	11	13.9	60	75.9	19	24.1	71	89.9	8	10.1
620	23			3	13					20	86.9	3	13	20	87	3	13
675	25			6	24					19	76	6	24	19	76	6	24
730	26			3	11.5					23	88.5	3	11.5	23	88.5	3	11.5
775	12									12	100			12	100		
820	19			2	10.5					17	89.5	2	10.5	17	89.5	2	10.5
875	23									23	100			23	100		
950	31									31	100			31	100		
1050	37			1	2.7					36	97.3	1	2.7	36	97.3	1	2.7

TABLE 3.5 BLOWDOWN DATA FOR TREES WITH 19- TO 25-INCH GIRTH

Distance from GZ (feet)	Total No. of Trees N_t	Uprooted "U"		Broken Stem - "B"		(U/B) Uprooted And/or Broken		Severely Damaged "S"		Undamaged		U+B+S+U/B		Standing		U+B+U/B	
		No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
(1)	(2)	(3)		(4)		(5)		(6)		(7)		(8)		(9)		(10)	
50	11	1	9.1	-	-	10	91.9	-	-	-	-	11	100	0	0	11	100
125	22	5	22.7	5	22.7	12	54.8					22	100	0	0	22	100
175	39	12	30.7	3	7.7	24	61.4					39	100	0	0	39	100
225	21	6	28.6	7	33.3	8	38.1					21	100	0	0	21	100
250	15	8	53.3	5	33.3	2	13.3					15	100	0	0	15	100
275	24	1	4.2	13	54.2	8	33.3	2	8.3			24	100	2	8.3	22	91.7
325	35	8	22.9	19	54.3	7	20	1	2.9			35	100	1	2.9	34	97.1
375	33	3	9.1	11	33.3	9	27.3	3	9.1	7	21.2	26	78.8	10	30.3	23	69.7
390	9			6	66.7	1	11.1	2	22.2			9	100	2	22.2	7	77.8
425	20	1	5	6	30	1	5			12	60	8	40	12	60	8	40
470	42	2	4.7	10	23.5	3	7.1	3	7.1	24	57.1	18	42.9	27	64.3	15	35.7
530	25	2	8	6	24			1	4	16	64	9	36	17	68	8	32
575	85	1	1.2	5	5.9	1	1.2	7	8.4	71	83.5	14	16.8	78	91.8	7	8.4
620	34			2	5.9					32	94.1	2	5.9	32	94.1	2	5.9
675	35			4	11.4					31	88.6	4	11.4	31	88.6	4	11.4
730	36			2	5.6					34	94.4	2	5.6	34	94.4	2	5.6
775	23			1	4.3					22	95.7	1	4.3	22	95.7	1	4.3
820	41			1	2.4					40	97.6	1	2.4	40	97.6	1	2.4
875	35									35	100			35	100		
950	42			2	4.8					40	95.2	2	4.8	40	95.2	2	4.8
1050	47									47	100			47	100		

TABLE 3.6 BLOWDOWN DATA FOR TREES WITH 25- TO 35-INCH GIRTH

Distance from GZ (feet)	Total No. of Trees N_t	Uprooted "U"		Broken Stem - "B"		(U/B) Uprooted And/or Broken		Severely Damaged "S"		Undamaged		U+B+S+U/B		Standing		U+B+U/B	
		No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
(1)	(2)	(3)		(4)		(5)		(6)		(7)		(8)		(9)		(10)	
50	15	-	-	6	40	9	60	-	-	-	-	15	100	0	0	15	100
125	17	6	35.3	5	29.4	6	35.3					17	100	0	0	17	100
175	27	6	22.2	9	33.3	12	44.4					27	100	0	0	27	100
225	30	3	10	18	60	8	26.7	1	3.3			30	100	1	3.3	29	96.7
250	6	3	50	2	33.3	1	16.7					6	100	0	0	6	100
275	27	4	14.8	15	55.6	4	14.8	4	14.8			27	100	4	14.8	23	85.2
325	25	4	16	13	52	1	4	6	24	1	4	24	96	7	28	18	72
375	18	1	5.6	7	38.9	1	5.6	2	11.2	7	38.9	11	61.1	9	50	9	50
390	9			6	66.7			2	22.2	1	11.1	8	88.9	3	33.3	6	66.7
425	23	1	4.3	5	21.5	1	4.3			16	69.6	7	30.4	16	69.6	7	30.4
470	30	2	6.7	3	10	1	3.4	3	10.0	21	70	9	30	24	80	6	20
530	27			5	18.5			1	3.7	21	77.8	6	22.2	22	81.5	5	18.5
575	84			2	2.4	4	4.8	8	9.6	70	83.3	14	16.1	78	92.9	6	7.2
620	29	1	3.4	1	3.4					27	93.1	2	6.8	27	93.1	2	6.8
675	26			2	7.7					24	92.3	2	7.7	24	92.3	2	7.7
730	40									40	100			40	100		
775	27									27	100			27	100		
820	24			1	4.2					23	95.8	1	4.2	23	95.8	1	4.2
875	32									32	100			32	100		
950	50			1	2					49	98	1	2	49	98	1	2
1050	40							1	2.5	39	97.5	1	2.5	40	100		

TABLE 3.7 BLOWDOWN DATA FOR TREES WITH 35- TO 45-INCH GIRTH

Distance from GZ (feet)	Total No. of Trees N_t	Uprooted "U"		Broken Stem - "B"		(U/B) Uprooted And/or Broken		Severely Damaged "S"		Undamaged		U+B+S+U/B		Standing		U+B+U/B	
		No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
(1)	(2)	(3)		(4)		(5)		(6)		(7)		(8)		(9)		(10)	
50	6	2	33.3	4	66.7							6	100			6	100
125	10	1	10	3	30	5	50	1	10			10	100	1	10	9	90
175	13	6	46.1	7	53.9							13	100			13	100
225	9			8	88.9	1	11.1					9	100			9	100
250	5	1	20	3	60	1	20					5	100			5	100
275	16			13	81.3	1	6.25	2	12.5			16	100	2	12.5	14	87.5
325	23	3	13	13	56.5	1	4.3	6	26.1			23	100	6	26.1	17	73.9
375	11			3	27.3			4	36.4	4	36.4	7	63.7	8	72.8	3	27.3
390	5			2	40			3	60			5	100	3	60	2	40
425	8			3	37.5	1	12.5			4	50	4	50	4	50	4	50
470	10			2	30			2	20	6	60	4	40	8	80	2	20
530	18									18	100			18	100		
575	59	1	1.7	6	10.2			4	6.8	48	81.4	11	18.7	52	88.2	7	11.9
620	19									19	100			19	100		
675	11									11	100			11	100		
730	13									13	100			13	100		
775	11									11	100			11	100		
820	18			1	5.6					17	94.4	1	5.6	17	94.4	1	5.6
875	10									10	100			10	100		
950	29									29	100			29	100		
1050	13									13	100			13	100		

TABLE 3.8 BLOWDOWN DATA FOR TREES WITH 45- TO 60-INCH GIRTH

Distance from GZ (feet)	Total No. of Trees N_t	Uprooted "U"		Broken Stem -,"B"		(U/B) Uprooted And/or Broken		Severely Damaged "S"		Undamaged		U+B+S+U/B		Standing		U+B+U/B	
		No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
(1)	(2)	(3)		(4)		(5)		(6)		(7)		(8)		(9)		(10)	
50	5	2	40	2	40	1	20					5	100			5	100
125	9	3	33.3	3	33.3	3	33.3					9	100			9	100
175	9	1	11.1	7	78.8	1	11.1					9	100			9	100
225	8	2	25	4	50	2	25					8	100			8	100
250	3	1	33.3	2	66.7							3	100			3	100
275	8			4	50			4	50			8	100	4	50	4	50
325	13	5	38.5	4	30.8	1	7.7	3	23.1			13	100	3	23.1	10	76.9
375	9			2	22.2	1	11.1	2	22.2	4	44.4	5	55.3	6	66.7	3	33.3
390	7			2	28.6	1	14.3	3	42.9	1	14.3	6	85.8	4	57.2	3	42.9
425	11	1	9.1	2	18.2					8	72.8	3	27.3	8	72.8	3	27.3
470	15			2	13.3			2	13.3	11	73.3	4	26.6	13	86.7	2	13.3
530	10									10	100			10	100		
575	31			1	3.2	1	3.2	1	3.2	28	90.3	3	9.6	29	93.5	2	6.4
620	11							1	9.1	10	90.9	1	9.1	11	100		
675	13									13	100			13	100		
730	11									11	100			11	100		
775	9									9	100			9	100		
820	14									14	100			14	100		
875	16									16	100			16	100		
950	11									11	100			11	100		
1050	12			1	8.3			1	8.3	10	83.3	2	16.6	11	91.6	1	8.3

TABLE 3.9 BLOWDOWN DATA FOR TREES GREATER THAN 60 INCHES IN GIRTH

Distance from GZ (feet)	Total No. of Trees N_t	Uprooted "U"		Broken Stem - "B"		(U/B) Uprooted And/or Broken		Severely Damaged "S"		Undamaged		U+B+S+U/B		Standing		U+B+U/B	
		No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
(1)	(2)	(3)		(4)		(5)		(6)		(7)		(8)		(9)		(10)	
50	4	2	50	2	50							4	100			4	100
125	9	3	33.3	3	33.3	2	22.2	1	11.1			9	100	1	11.1	8	88.9
175	8			2	25			6	75			8	100	6	75	2	25
225	2	1	50					1	50			2	100	1	50	1	50
250	4			4	100							4	100			4	100
275	5			3	60			2	40			5	100	2	40	3	60
325	15			4	26.7			5	33.3	6	40	9	60	11	73.3	4	26.7
375	6					1	16.7	1	16.7	4	66.7	2	33.3	5	83.4	1	16.7
390	6			1	16.7			5	83.3			6	100	5	83.3	1	16.7
425	7							2	28.6	5	71.4	2	28.6	7	100		
470	11	1	9.1	1	9.1			1	9.1	8	72.8	2	18.2	9	81.9	2	18.2
530	15			1.	6.7			3	20.1	11	73.3	4	26.8	14	93.4	1	6.7
575	30			3	10			2	6.7	25	83.3	5	16.7	27	90	3	10
620	10									10	100			10	100		
675	11							1	9.1	10	90.9	1	9.1	11	100		
730	6									6	100			6	100		
775	4									4	100			4	100		
820	11			1	9.1					10	90.9	1	9.1	10	90.9	1	9.1
875	11									11	100			11	100		
950	11									11	100			11	100		
1050	9									9	100			9	100		

TABLE 3.10 DAMAGE TO TREES OF GIRTH ≥ 60 INCHES

All large trees in distance ranges were observed except for those within 100 feet of the clear sector or in the VI quadrant.

GZ Distance, ft	N_t	%B	%U	%S	%M	%L	%N	Mean Distance	% Un-damaged	% Standing
100 to 150	5	40	40	20	—	—	—	125	0	0
150 to 200	13	54	0	38	8	—	—	175	8	46
200 to 250	8	62.5	12.5	12.5	12.5	—	—	225	12.5	25
250 to 300	19	37	16	37	5	5	—	275	10	47
300 to 350	31	42	0	16	22.5	19.5	—	325	42	58
350 to 400	35	23	3	8.5	20	45.5	—	375	65.5	74
400 to 450	35	14.5	0	5.5	17	63	—	425	80	85.5
450 to 500	35	14.5	3	11.5	0	68	3	475	71	82.5
500 to 550	42	9.5	0	5	14	62	9.5	525	71.5	85.5
550 to 600	48	2	0	12.5	4	65	16.5	575	81.5	85.5
600 to 650	34	0	0	0	3	94	3	625	100	100

Beyond 650 feet, negligible number B, U, or S.

N_t, total number of trees. %B, percentage with broken stems. %U, percentage uprooted. %S, percentage with severe limb breakage (i.e., all limbs removed). %M, percentage with moderate limb breakage. %L, percentage with twigs broken and/or defoliated. %N, percentage with nil disturbance. % Undamaged = (%M + %L + %N). % Standing = (%S + %M + %L + %N).

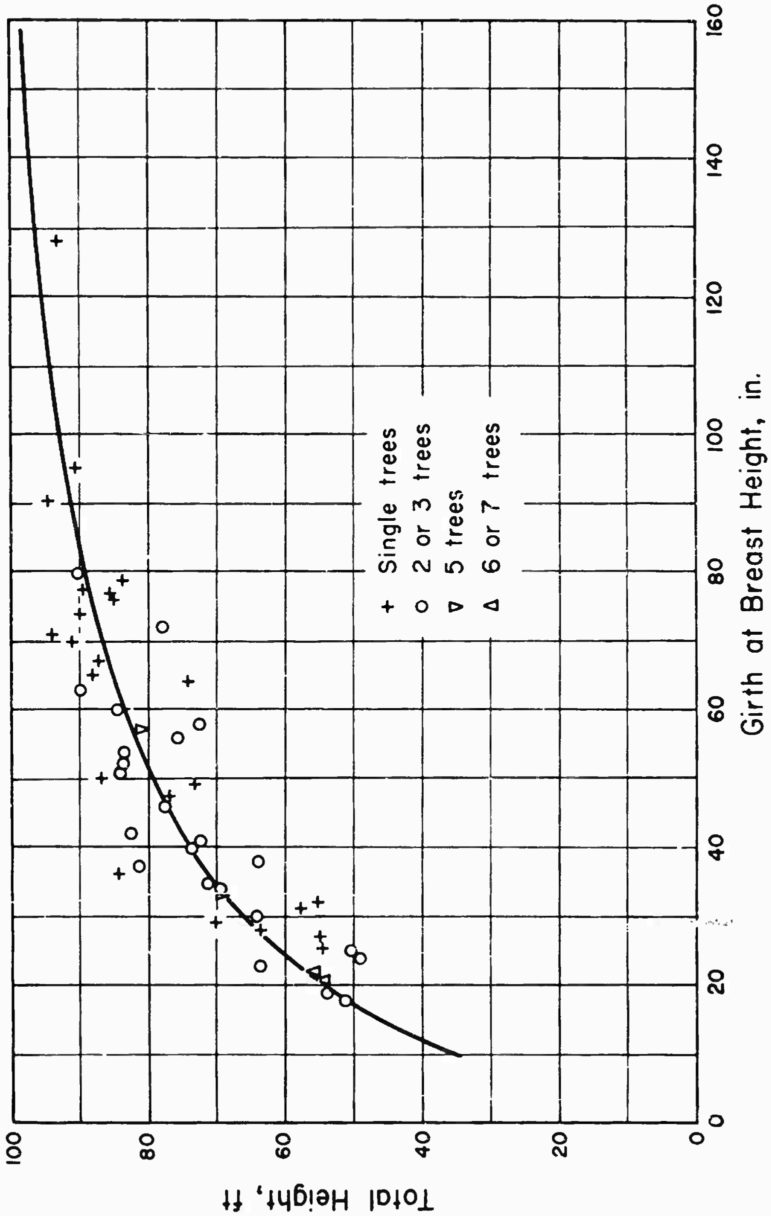


Figure 3.1 Tree height versus girth.

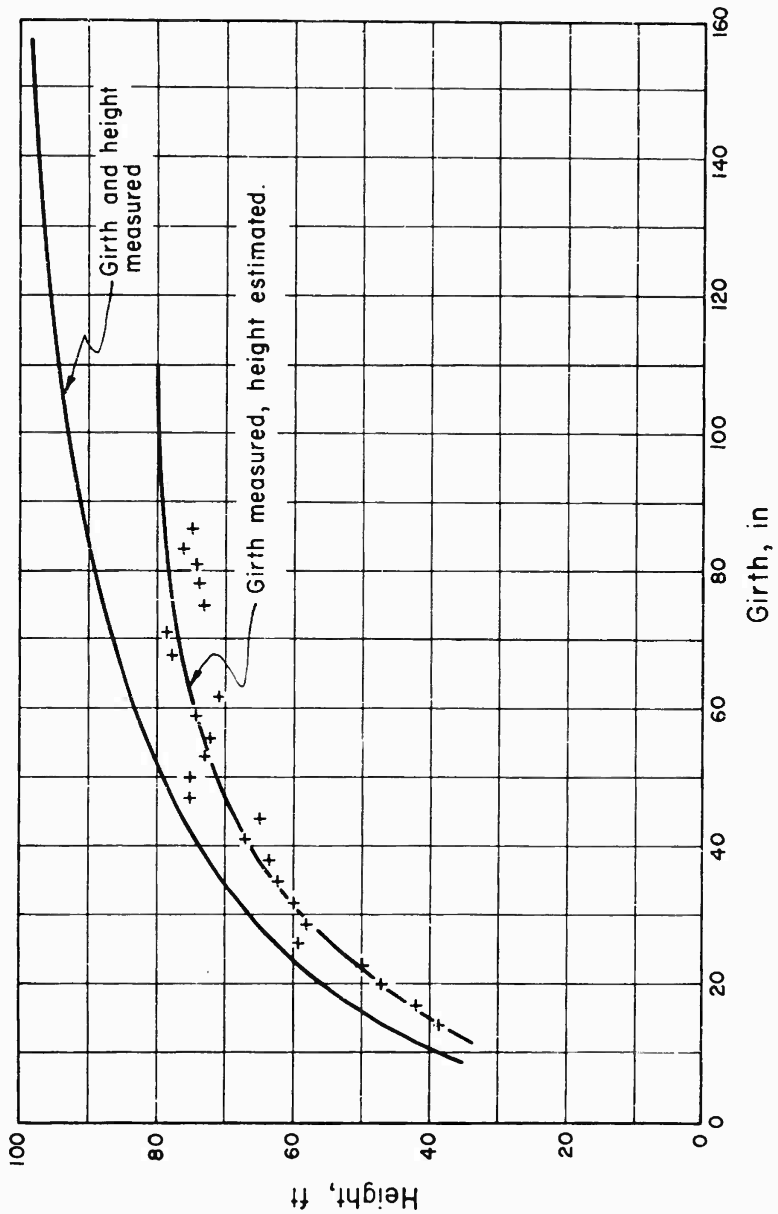


Figure 3.2 Tree height versus girth compared with measured tree height versus girth.

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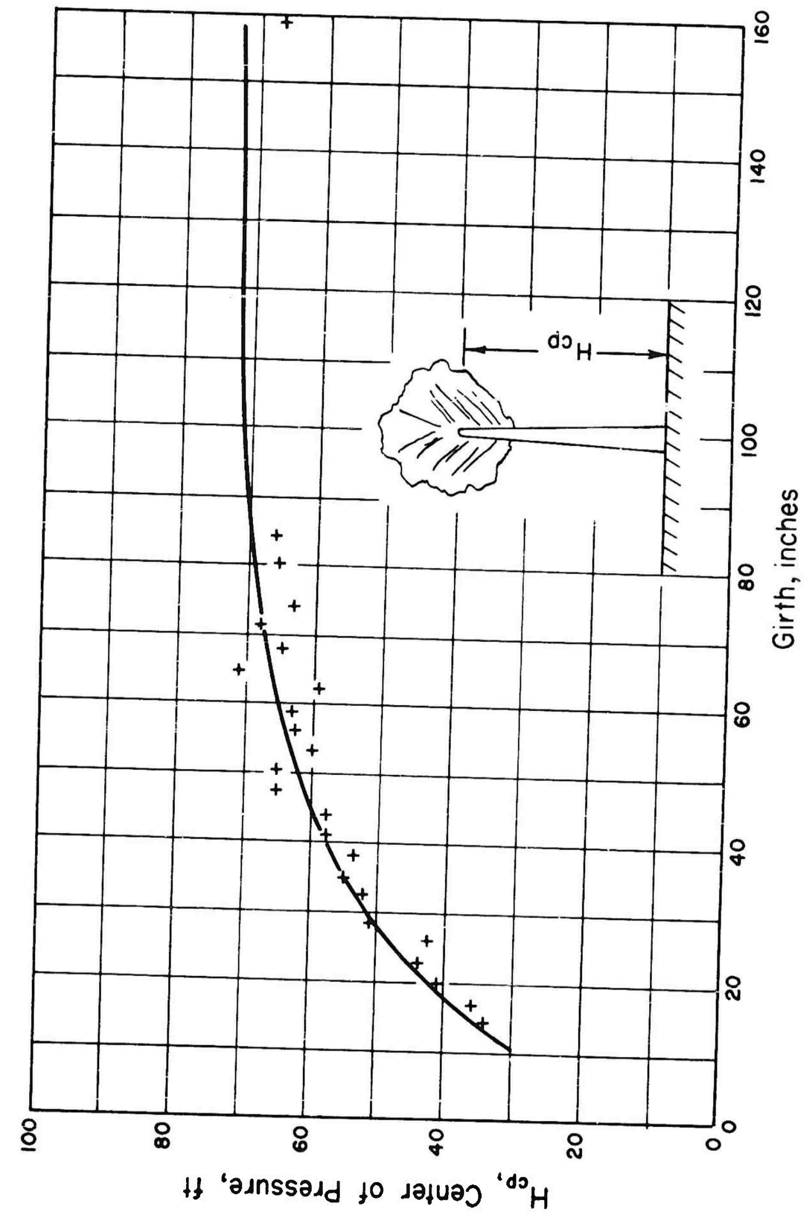

Figure 3.3 Height of center of pressure versus tree girth.

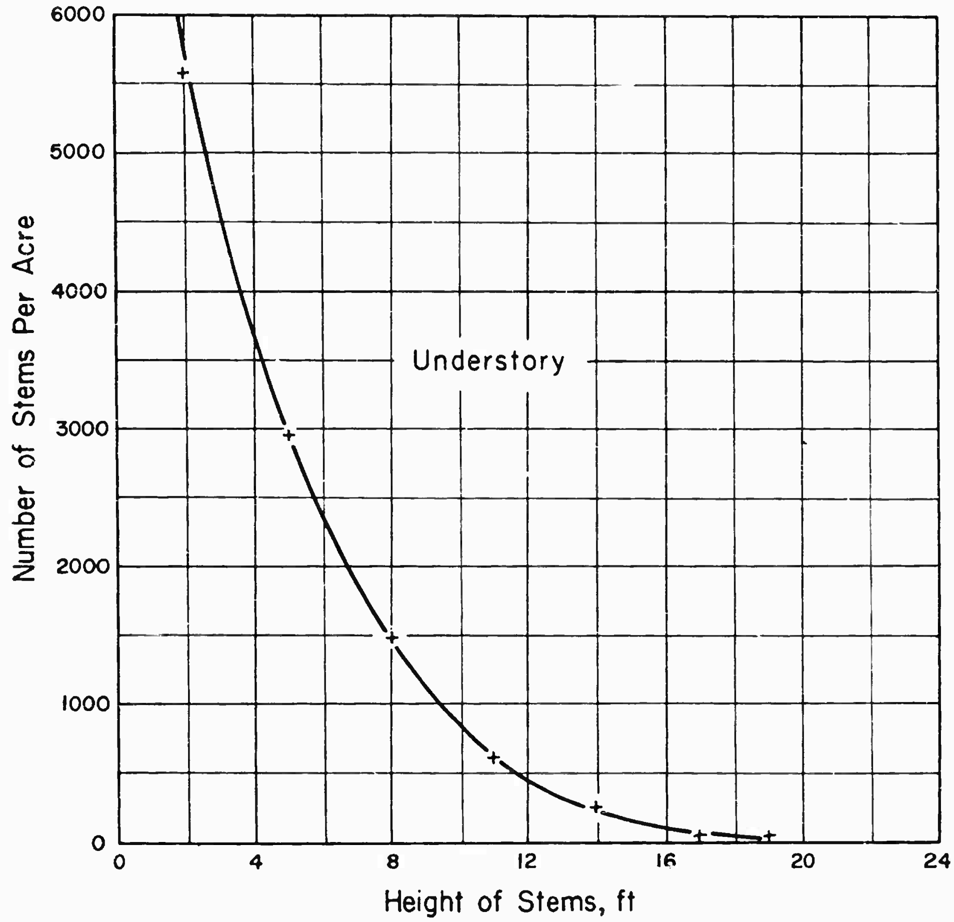

Figure 3.4 Number of trees/acre with total height < 20 feet versus height of tree stems.

Chapter 4

BLOWDOWN PREDICTIONS AND PRELIMINARY ANALYSIS OF RESULTS

(Prepared by Mr. Fred Sauer, Stanford Research Institute.)

Before going into details of the tree blowdown prediction methods developed specifically for the Australian field trials, it is worthwhile to reflect on the methodology used throughout the temperate zone tree blowdown predictions developed in the United States during the 1950's (Reference 8), hereafter referred to as the U. S. method, and compare the U. S. method with that developed by the Defence Standards Laboratory (Reference 4), hereafter referred to as the DSL method. Both methods characterize a tree stem and its associated crown by a lumped mass fixed to the end of a massless cantilever spring and calculate the response of this single-degree-of-freedom system under the action of the drag forces taken as proportional to the dynamic pressure of the airblast. Results of these calculations, given in terms of the potential energy absorbed by the theoretical stem, are then equated to the experimentally determined energy required for stem breakage, resulting in a relationship between stem breakage and airblast parameters.

In the U. S. method the tree stem was assumed to behave elastoplastically, and the crown drag coefficient-area product decreased according to an experimentally determined relationship as the strain at the base of crown increased, resulting in a highly nonlinear system. The DSL method on the other hand assumes a linear tree stem (spring) and a constant crown drag coefficient-area product. The results of the two methods are not, however, vastly different, especially when they are expressed in terms of energy absorbed by the stem.

The major difference in methodology lies in the treatment of the energy required for stem breakage. The U. S. method normalizes the breakage energy of a particular stem by dividing by the energy resulting in the modulus of rupture for green wood of that particular species at the position of maximum stress along a linear fixed-end cantilever stem of the same stem form as that tested (References 9 and 10). The deviations in this normalized breakage energy are postulated to be statistical in nature, and a population is formed from all stems broken. Hence, a particular value of normalized breakage energy corresponds to a probability of breakage; the larger the energy the higher the probability of breakage and vice versa. The U. S. method postulates that crown and stem characteristics and crown drag are uniquely related to stem height and girth and percent crown, so that intrinsically all variations in stem breakage carry back to statistical variations in strength of green timber. The DSL method, however, groups together all crown and stem characteristics by means of the theoretical dynamic pressure impulse, DPI, corresponding to stem breakage (Equation 4.9). The DPI is correlated against stem diameter (girth), and statistical deviations from the regression curve are interpreted as breakage probabilities.

Experimental methods of determining tree characteristics also differed, and although the final results may be equivalent, the form in which they are given limits to a large extent the course of the analysis of stem breakage as a function of tree dimensions. The U. S. method involved a detailed analysis of tree parameters, e.g., crown weight versus crown dimensions (References 11 and 12), and tree period versus percent crown and stem dimensions (Reference 13), as a function of tree species. Most of these correlations were extremely significant, some having correlation coefficients of greater than 0.99 and errors of estimate less than 10 percent. Aerodynamic drag of tree crowns at velocities between 10 and 55 mph was also studied as a function of crown geometry and species (References 14 and 15). Standard stocking tables (Reference 16), from which the distribution of stem diameters, heights, and stem form could be determined, were used to construct typical pure (single species) forest stands and, in the case of the experimental stand, used to evaluate the blowdown prediction method measurements made on every tree in the stand (Reference 17).

In sharp contrast to the pure stands analyzed under the U. S. method, the tropical rain forest plot being investigated during the Australian trail contains over 70 species, the majority of trees being contained within 10 species. It is logical to assume that this varied species content is typical of tropical rain forests in general. In the final analysis the only data known pertinent to the overall stand (or to tropical rain forests in general) is the distribution of tree sizes by girth classes. Hence, all tree characteristics eventually must be correlated against girth as the only parameter, and it is to be expected that these correlations will have errors of estimate significantly larger than correlations obtained during the U. S. investigations, due first to the inadmissibility of other stem or tree dimensions, and second, to the admixture of species. The only solace to be found from the U. S. analysis is that, for the fairly large number of broad-leaved species investigated, the relationships found to hold between tree characteristics and stem dimensions were consistently of the same functional form, although the constants varied between species. Thus, it could be anticipated that, in spite of the large species content of the tropical rain forests, a fair degree of correlation could be obtained between tree characteristics and girth alone.

Of much greater concern is the subject of crown aerodynamic drag. It has been fairly well established that the drag coefficient (drag force divided by dynamic pressure) for tree crowns in a steady aerodynamic flow decreases as the dynamic pressure (or aerodynamic drag) increases (References 14, 15, 18, and 19), first due to the streamlining movement of the leaves or needles, then due to the bending of the branches, and finally due to the bending of the stem. This is Nature's way of providing trees with protection against high winds. Since the U. S. crown drag measurements were made at speeds exceeding approximately 10 mph, it is a reasonable assumption that even at the lowest speeds the drag coefficients found corresponded to the condition where the leaves or needles were folded into a semistreamlined position. This postulate is supported by the fact that stem breakage predictions based on these data were consistent with observed stem breakage during the U. S. nuclear trials (Reference 17), as will be explained in more detail later.

Crown drag on the tropical rain forest trees can be obtained from analysis of the DSL twanging experiments. (The twanging experiments consist of deflecting the tree stem and allowing it to snap back through use of a quick-release mechanism on the pulling cable. The oscillations of the estimated center of pressure of the crown are recorded as a function of time.) The maximum velocity during these experiments was fairly low, and therefore, the leaf movement would be small. This was confirmed by observation. Consequently, the crown drag coefficients determined by this method were significantly larger than would be anticipated from the U. S. data. Furthermore, a preliminary blowdown experiment conducted by DSL using eucalypt saplings and a 100-pound charge indicated effective crown drag coefficients substantially lower than determined from twanging experiments on the saplings.

This apparent contradiction may be rationalized as follows. As the airblast engulfs the tree crown, the leaves (or needles) quickly bend toward their streamlined configuration, due to the high initial dynamic pressure of the airblast; this takes a time of approximately one-quarter of the natural period of the leaves, τ_l . The result is a very rapid decrease in crown drag coefficient (Curve ab of Figure 4.1) followed by a much slower decrease as the crown bends under the action of the continuing drag forces (Curve b). The minimum drag coefficient occurs as the stem reaches its maximum deflection at a time of approximately one-quarter the period of the stem and its associated crown. However, if the airblast duration is very short, i.e., impulsive loading with respect to τ_S , then the leaves return quickly to their configuration associated with velocities typical of the twanging experiments, and the drag coefficient would be expected to increase rapidly toward the drag coefficient also typical of the twanging experiments, C_{DT} (Curve a of Figure 4.1). Thus, during the impulsive loading phase, the effective drag coefficient, C_{DO} , would be expected to be less than C_{DT} ; while during the response, i.e., the slowing down, phase, the drag coefficient would equal C_{DT} . This postulate significantly affects the analysis of stem breakage, since the large twanging drag adsorbs considerable energy as compared with the drag anticipated on the basis of the U.S. data.

The method of analysis does not account for the large initial drag coefficient since the U.S. initial drag coefficient [$(D/\rho U^2)_0$ of Reference 8] was obtained by extrapolation of moderate velocity drag data to zero velocity, i.e., zero bending moment about the base of the crown (Curve c of Figure 4.1). The agreement between predicted and observed stem blowdown is probably due to the fact that the airblast positive phase durations during the U.S. nuclear experiments (References 17 and 20) were of the same order as τ_S . Hence, the error in calculating the impulse adsorbed during the high-drag phase was only a small fraction of the total impulse adsorbed up to the time of maximum deflection. Such an error would become less and less significant as the weapon yield increased, but for subkiloton yields would eventually produce a discrepancy in the U.S. prediction method.

The concept of an effective drag coefficient for the impulsive loading phase, defined by the relation

$$C_{DO} = \frac{\int_0^\infty C_D(t)\, q(t)\, dt}{I_+} \tag{4.1}$$

where q is the airblast dynamic pressure and I_+ the net positive dynamic pressure impulse, introduces an open independent parameter into any prediction method, since there is at present insufficient data to evaluate this quantity. As will be seen, the dynamic pressure impulse corresponding to a given level of stem breakage is inversely proportional to the effective drag coefficient, C_{DO} .

4.1 THEORETICAL BASIS FOR PREDICTION METHOD

4.1.1 Response of Stem to Airblast Loading. The ratio of the airblast positive duration to tree period is of the order of 0.01, indicating that the airblast may be considered as an impulsive loading. The tree stem is assumed to be a linear massless spring, the crown to be a lumped mass located at its center of pressure, and the aerodynamic drag to be proportional to the square of the velocity, resulting in the equation of motion

$$m\frac{d^2x}{dt^2} + kx + \rho\frac{C_D A}{2}\frac{dx}{dt}\left|\frac{dx}{dt}\right| = 0 \tag{4.2}$$

Since the velocity does not change sign prior to the first maximum, Equation 4.2 may be written in dimensionless form as

$$\frac{d^2X}{d\tau^2} + \frac{1}{2}\left(\frac{dX}{d\tau}\right)^2 + X = 0 \tag{4.3}$$

where

$$\left.\begin{aligned} X &= \rho\frac{C_D A}{m}x \\ \tau &= \omega t \end{aligned}\right\} \tag{4.4}$$

The impulsive boundary condition results in the initial condition

$$x = 0,\ \frac{dx}{dt} = \frac{C_{DO}A}{m} I_+ \quad \text{at} \quad t = 0$$

or

$$X = 0,\ \frac{dX}{d\tau} = \frac{\rho}{\omega}\left(\frac{C_D A}{m}\right)^2 \tilde{I} = J \quad \text{at} \quad \tau = 0$$

with

$$\tilde{I} = \left(\frac{C_{DO}}{C_D}\right) I_+$$

where the effective drag coefficient C_{DO} during the impulse phase has been taken as different from the drag coefficient during the response phase, C_D. Solving Equation 4.3 for the maximum displacement, x_m, one obtains (Reference 4)

$$J = \sqrt{2 + 2(X_m - 1)e^{X_m}} \tag{4.5}$$

where

$$X_m = \rho\frac{C_D A}{m}x_m \tag{4.6}$$

It is instructive to introduce the ratio $R(X_m) = J/X_m^2$ (Figure 4.2) so that the solution may be written as

$$\tilde{I} = \rho R \omega x_m^2 = 2\rho R\omega \frac{E_m}{k} \tag{4.7}$$

where E_m is the maximum energy absorbed by the stem.

The general behavior of the solution can be illustrated by writing $R \propto X_m^{n(X_m)}$; then

$$C_{DO} I_+ \propto C_D^{n+1} x_m^{n+2} \tag{4.8}$$

For $X_m \ll 1$ ($X_m \leq 0.25$ for less than 10-percent error), $n \simeq -1$, and Equation 4.8 becomes independent of the drag coefficient during the response phase, i.e.,

$$C_{DO} I_+ \propto C_D^0 x_m$$

and one obtains the DSL equation for the stem breakage dynamic pressure impulse (DPI)

$$DPI = \frac{\sqrt{2mE_m}}{C_{DO}A} \tag{4.9}$$

As X_m increases, n increases, e.g., at $X_m = 2.6$, $n = 0$, and

$$C_{DO} I_r \propto C_D x_m^2$$

For X_m greater than 2.6, n increases rapidly, and the impulse becomes a directly varying function of the drag coefficient in the response phase and an even stronger function of the maximum deflection. This behavior illustrates the point that, for the postulated behavior of the crown drag coefficient during impulsive loading, an increasing crown drag coefficient (per unit-mass) does not necessarily result in a decreasing impulse required for a fixed maximum deflection. This fact may indeed be the logical explanation for the apparent discrepancy between the eucalypt blowdown data and the DPI calculated according to Equation 4.9, using twanging data to evaluate the drag coefficient.

4.1.2 Response of Stem in Twanging Experiments. The initial condition for solution of Equation 4.3 relevant to the twanging experiment is

$$X = -X_0, \quad \frac{dX}{d\tau} = 0 \quad \text{at} \quad \tau = 0$$

Solving Equation 4.3 for the relationship between the initial displacement, x_0, and the next maxima, x_1, one obtains (Reference 21)

$$(1 + X_0)e^{-X_0} = (1 - X_1)e^{X_1} \tag{4.10}$$

Reference 21 also contains tables of $X(\tau)$ from which the time of zero deflection, p_{01}, and the time of the maxima, p_1, can be determined (Figure 4.3). Since X_1, p_{01}, and p_1 are functions of X_0 only, we also can obtain X_0, p_{01}, and p_1 as functions of $X_0/X_1 = x_0/x_1$ (Figures 4.4 and 4.5). Hence, knowing x_0, x_1, t_{01}, and/or t_1, one can obtain the drag per unit mass from the relation

$$\rho \frac{C_{DT}A}{m} = \frac{X_0}{x_0} \tag{4.11}$$

and the natural undamped period by

$$T = \frac{t_{01}}{p_{01}} = \frac{t_1}{p_1} \tag{4.12}$$

4.2 PREDICTION METHOD

As previously mentioned, the U. S. method of stem breakage prediction normalizes the breakage energy, E_b, by dividing the energy, E_r, resulting in the modulus of rupture at the theoretical position of maximum stress along the stem. Lacking information as to the stem form of the rain forest trees, we must make two assumptions in order to make a similar formulation:

(1) The maximum stress occurs near the base of the stem at the position of measurement of girth, G.

(2) The theoretical stem spring constant, k_r, corresponds to the mean experimentally determined spring constant (Reference 22),

$$k_r\,(\mathrm{lb/ft}) = 16\,G^{2.68}\,(\mathrm{ins})\,H_p^{-1.82}\,(\mathrm{ft}) \tag{4.13}$$

(The departure from the relationship for a uniform fixed-end cantilever beam is due to stem form. By a simple argument the spring constant for tapered stem would be expected to follow the relationship $k = \text{const}\ G^{4-m}\ H^{-(3-m)}$, $0 \leq m$, which approximates Equation 4.13). We have then for the reference energy

$$E_r = \frac{R_r^2}{2k_r} \tag{4.14}$$

and

$$\text{Modulus of rupture} = 16\pi^2 \frac{R_r H_p}{G^3}$$

where R_r is the reference force and H_p is the height of pull. It follows that

$$E_r \propto G^{3.32}\ H_p^{-0.18} \tag{4.15}$$

The static stem breakage energy modulus is then defined as

$$\bar{E}_b = \frac{H_p^{0.18}}{G^{3.32}} E_b \tag{4.16}$$

Stem breakage data of Reference 22, normalized according to Equation 4.13, are shown plotted on logarithmic-probability coordinates in Figure 4.6. The variations in stem spring constant about the mean values given by Equation 4.13 are significant, probably due to the influence of base firmness in determining the spring constant for individual trees. Anticipating the deleterious effect this result has on the correlation of tree characteristics, a reference stem deflection is defined as

$$x_r^2 = \frac{2E_r}{k_r} \propto G^{0.64}\ H_p^{1.64} \tag{4.17}$$

and a static stem breakage deflection modulus is then defined as

$$\bar{x}_b^2 = G^{-0.64}\ H_p^{-1.64}\ \frac{E_b}{k} \tag{4.18}$$

Stem breakage data normalized according to Equation 4.18 are also shown in Figure 4.6. Applying the chi-square tests indicates that this grouping conforms closer to a normally distributed population than does the $\bar{E}_b$ data. (It should be noted for the record that attempts to normalize breakage data on the basis of the theoretical spring constant for a uniform fixed-end cantilever beam, i.e., $k_r \propto G^4\ H^{-3}$, lead to significant departures from normally distributed populations, and hence, initial efforts in this direction were abandoned.)

4.3 STEM BREAKAGE PREDICTION METHODS

4.3.1 General Method. The prediction methods closely follow the U. S. method in that the experimentally determined static breakage energy, E_b, is equated to the maximum energy absorbed by the stem, E_m, in Equations 4.6 and 4.7, or equivalent equations, resulting in equations of the form

$$X_b = \psi_1(G)\,\phi(P) \tag{4.19}$$

$$\tilde{I}_b = \theta(X_b)\,\psi_2(G)\,\phi^n(P) \tag{4.20}$$

where P is the probability for stem breakage. In selecting the form of Equations 4.19 and 4.20, it is necessary that the same probability of breakage function, ϕ, appears in both equations. It is not readily apparent that ϕ should not contain crown drag data (since, as will be seen, significant departures from the mean also occur for these data), but manipulation of the equations demonstrates that these data cannot appear in ϕ without also appearing in ψ_2 which would be invalid. One also has some latitude in choosing $\theta(X_b)$; the choice being made to result in maximum correlation of data used to produce $\psi_2(G)$. Experimentation with various forms of Equation 4.20 leads to the R formulation, i.e., $\theta = R$. In the R formulation, drag data does not appear in Equation 4.7; hence, maximum correlation of tree characteristics with girth is obtained.

For a given girth and probability of breakage, the corresponding dynamic pressure, $\tilde{I}_b$, can be calculated by means of Equations 4.19 and 4.20, and by cross-plotting, the function $P = P(G,\tilde{I}_b)$ can be obtained for constant values of $\tilde{I}_b$. Girth data are given in terms of the number of stems per acre, N, of girth equal to or greater than girth G (Figure 4.7 and Table 4.1).

The number of stems per acre of girth equal to or greater than G which are broken is given by *

$$B(G,\tilde{I}_b) = \int_0^{N(G)} P(G,\tilde{I}_b)\,dN(G) \tag{4.21}$$

which can be evaluated numerically.

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* Let

n_j = number of stems per acre having girth G_j

then

$$N(G) = \sum_0^{\infty} n_j(G_j) = \int_G^{\infty} n(G)\,dG$$

so that

$$dN(G) = -n(G)\,dG$$

The total number of stems per acre broken of girth greater than G is then

$$B(G,\tilde{I}_b) = \sum_0^{\infty} n_j P(G_j,\tilde{I}_b) = \int_G^{\infty} n(G)P(G,\tilde{I}_b)\,dG$$
$$= \int_0^{N(G)} P(G,\tilde{I}_b)\,dN(G)$$

In evaluating Equations 4.19 and 4.20, three assumptions can be made:

(1) The response drag coefficient of the crown equals that obtained by the twanging experiments, and the impulsive loading drag coefficient of the crown is proportional to the twanging drag coefficient.

(2) The response and impulsive loading drag coefficients of the crown are proportional to the twanging drag coefficient.

(3) The response and impulsive loading drag coefficients of the crown are equal and independent of girth.

The following sections will investigate each of these assumptions separately.

4.3.2 Response Crown Drag Coefficient Equal to Twanging Crown Drag Coefficient. The formulation of Equations 4.19 and 4.20 may be based on either Equation 4.6 or Equation 4.7, using a normally distributed population in $\bar{E}_b$ or in $\bar{x}_b^2$. Except for the larger deviation of the $\bar{x}_b^2$ population, the results are equivalent. Letting the height of pull equal the height of the center of pressure of the crown, H_{cp}, Equations 4.6 and 4.7 become

$$X_b = \sqrt{2}\; G^{0.32} f_1(G) \cdot \bar{\chi}_b(P) \tag{4.22}$$

$$= \sqrt{2}\; G^{1.66} f_2(G) \cdot \sqrt{\bar{E}_b(P)} \tag{4.23}$$

$$\tilde{I}_b = 2\rho R(X_b)\, G^{0.64} f_3(G) \cdot \bar{\chi}_b^2(P) \tag{4.24}$$

$$= 2\rho\, R(X_b)\, G^{3.32} f_4(G) \cdot \bar{E}_b(P) \tag{4.25}$$

where, using Equation 4.11, the various functions of girth become

$$f_1(G) = \frac{X_o}{\chi_o} H_{cp}^{0.82} \tag{4.26}$$

$$f_2(G) = \frac{X_o}{\chi_o} \frac{H_{cp}^{-0.09}}{k_{cp}^{0.50}} \tag{4.27}$$

$$f_3(G) = \frac{H_{cp}^{1.64}}{T} \tag{4.28}$$

$$f_4(G) = \left[T K_{cp} H_{cp}^{0.18}\right]^{-1} \tag{4.29}$$

Now

$$k_{cp} = k_r \left(\frac{H_p}{H_{cp}}\right)^{1.32} \tag{4.30}$$

so that, using Equation 4.16, Equations 4.23 and 4.25 can be written as

$$X_b = 2\, G^{0.32} f_1(G) \left[\frac{\sqrt{\bar{E}_b(P)}}{4}\right] \tag{4.23a}$$

$$\tilde{I}_b = 2\rho R(X_b) G^{0.64} f_3(G) \left[\frac{\bar{E}_b(P)}{16}\right] \tag{4.25a}$$

The results of computations by Equations 4.23 and 4.25 are thus seen to be identical to those by Equations 4.22 and 4.24 if $P/(\bar{E}_b/16)$ is substituted for $P(\bar{x}_b^2)$. (The slight difference (~ 0.5 percent) in the mean value of Figure 4.6 is due to round-off error, and in subsequent calculations the curves were adjusted to agree exactly.)

The functions f_1 and f_3, computed from the DSL data, are plotted against girth in Figures 4.8 and 4.9. Regressions through the 37 better data (see Note, Reference 22) result in the relationships (G given in inches)

$$f_1(G) = 0.476\, G_{ins}^{0.840} \quad (\times \text{ or } \div\ 2.21) \tag{4.31}$$

$$f_3(G) = 52.5\, G_{ins}^{0.828} \quad (\times \text{ or } \div\ 1.27) \tag{4.32}$$

the correlation coefficients being 0.45 and 0.85 for Equations 4.31 and 4.32, respectively.

Using an air density corresponding to 70° F and 1 atmosphere ($\rho = 2.33 \times 10^{-3}$ slugs/ft^3), the computation equations become

$$X_b = 0.68\, G_{ins}^{1.16}\, \bar{x}_b \tag{4.33}$$

$$\left(\frac{C_{DO}}{C_{DT}}\right) I_b = 1.7 \times 10^{-3} R G_{ins}^{1.47} \bar{x}_b^{2} \quad \text{(psi-sec)} \tag{4.34}$$

Effective dynamic pressure impulse is shown as a function of percent of stems broken and girth in Figures 4.10 and 4.11. Figure 4.12 shows the percent of stems broken for the Iron Range tree stand as a function of the effective dynamic pressure.

4.3.3 Crown Drag Coefficient Proportional to Twanging Crown Drag Coefficient. If the crown drag coefficients pertinent to the Iron Range blowdown experiment are less than one-tenth the drag coefficients determined from the twanging experiments (as may be deduced from the eucalypt sapling blowdown experiment, Reference 22), then the results of the calculations of Section 4.3.2 indicate that no serious error (say less than 2:1 in impulse) would occur in prediction of stem breakage for the Iron Range stand if R were taken inversely proportional to X_b (the limiting case of small deflection, Section 4.1.1). For this case we have, using Equation 4.11,

$$\tilde{I}_b = \frac{\rho\sqrt{2}}{T}\left(\frac{x_o}{X_o}\right)\left(\frac{C_{DT}}{C_D}\right)\sqrt{\frac{E_b}{k}} = \rho\sqrt{2}\left(\frac{C_{DT}}{C_D}\right)G_{ins}^{0.32}\frac{f_3(G)}{f_1(G)}\bar{x}_b \tag{4.35}$$

Hence

$$\left(\frac{C_{DO}}{C_{DT}}\right)I_b = 2.5\times10^{-3}\,G_{ins}^{0.31}\,\bar{x}_b \quad (\text{psi-sec}) \tag{4.36}$$

(An alternative procedure would be to use the first equation of Equation 4.35 directly by obtaining first the regression equation

$$\frac{1}{T}\left(\frac{x_o}{X_o}\right)\sqrt{\frac{E_b}{k}} = f(G)$$

and then testing the deviations about the mean against a normally distributed population. While this method has considerable potential merit, it was not pursued because of lack of time.)

The Iron Range stand breakage predictions according to Equation 4.36 are shown in Figure 4.13.

4.3.4 Crown Drag Coefficient An Arbitrary Constant. The same assumptions apply as in Section 4.3.3, but Equation 4.35 is written as

$$C_{DO}I_b = \frac{\sqrt{2}\,G_{ins}^{0.32}}{f_5(G)}\bar{x}_b \tag{4.37}$$

where

$$f_5(G) = \frac{A_c}{T\,k_{cp}\,H_{cp}^{0.82}} \tag{4.38}$$

A regression curve through the data grouped according to Equation 4.38 results in the equation

$$f_5(G) = 5.30\,G_{ins}^{-1.10} \quad (\times \text{ or } \div 3.30)$$

with a correlation coefficient of 0.4. Due to the large error of estimate and the low correlation coefficient, the method was not pursued further.

4.4 PRELIMINARY COMPARISON OF BLOWDOWN RESULTS WITH STEM BREAKAGE PREDICTIONS

The horizontal component of dynamic pressure impulse, DPI, at the center of pressure of each tree crown is the salient airblast parameter that, for small yields and long tree periods, determines the breakage probability for that particular tree stem. For yields of several kilotons, such as those experiments used to test the U. S. method, the average height to the center of pressure of the tree canopy per 1/3 power of yield, i.e., the scaled height to center of pressure, is not significantly large so as to warrant consideration of the burst geometry as it affects the horizontal component of DPI.

However, the BLOWDOWN yield was sufficiently small, and the average height to center of pressure of the canopy was an important fraction of the height of burst. As a consequence, the significant component of DPI was less than that at ground level. From the results of Table 4.2, the horizontal component of DPI at a height of 45 feet (approximately average crown center of pressure) appears to be one-third to one-fourth of the DPI at ground level. This result is in agreement with the reduction in DPI calculated using a sonic approximation to the shock wave flow field. The shock triple point does not appear to have reached the height of the crown center of pressure until after (or about) the 600-foot radius.

Another factor affecting comparison of results with predictions is the photographic observation of the stripping of leaves from the crown quite early during the loading phase. This action may limit the amount of impulse transmitted to the tree crowns and certainly reduces the energy dissipated by crown drag during the response phase. This unforeseen behavior makes any theoretical calculation tenuous for the prediction of severe damage. However, in the light-damage region, leaves and crown remain intact, and hence, the theoretical model should be checked at the low end of the damage scale.

The fraction of trees damaged, of girth 13 inches or greater, is plotted in Figure 4.13 versus the horizontal component of DPI at crown center of pressure, estimated by means of the sonic approximation. (A more accurate calculation of horizontal component of DPI is being made by BRL, but results are not yet available.) For less than 20-percent damage, the DSL prediction agrees with the data using a crown drag coefficient of unity based on the estimated DPI or a drag coefficient of between one-third and one-fourth if the ground level DPI is used. As damage increases, the slope of the damage-impulse curve appears to decrease (although the data are much too scattered to prove this), and the predictions developed in the preceding sections can be made to best fit the BLOWDOWN results using the $\overline{E}_b$ basis of breakage correlation, a $C_{DO}/C_{DT} = 1/10$, and the estimated DPI. This procedure results in good agreement for less than 50-percent breakage.

Below 50-percent breakage, damage defined either as 100 percent minus "undamaged" or 100 percent minus "standing" is essentially the same within the scatter of data typified by the azimuthal results at 575-foot radius (all trees). However, above 50-percent damage (corresponding to approximately 400-foot radius from ground zero), the percent of trees undamaged decreases much more rapidly than the percent of trees standing, and both decrease at a much greater rate than predicted.

The behavior can be associated with the loss of crown (especially leaves) within the framework of the prediction system developed in the previous sections. Since the decrease in slope of the $\overline{E}_b$ basis prediction curve is associated with aerodynamic breaking due to crown drag during the response phase, loss of leaves and/or crown after a significant fraction of the total impulse was delivered would be expected to increase stem breakage. This is the effect we seem to observe, but to put it on a qualitative basis may be a too difficult and impractical task, e.g., what is the difference between "undamaged" and "standing" in mathematical terms?

4.5 INSTRUMENTED TREES

Twelve trees were instrumented with strain meters and photographed with cameras during the test to obtain information concerning tree deflection as effected by the airblast. The general locations of the trees within the test site are shown in Figures 6.1 and 6.3.

Information currently available concerning the results of this portion of the experiment are very preliminary. Table 4.3 contains a summary of data available.

The predicted deflections shown in Table 4.3 are provisional only. They were calculated from values of period that were not corrected for damping, and with no allowance for the difference between heights of pull and heights of center of pressure. These values are based on predicted dynamic pressure impulse at ground level and a crown drag coefficient of 1.0.

The maximum tree deflections at the point of pull as shown in Table 4.3 were calculated from the maximum measured strain and the values of strain constants (strain/unit deflection) as determined experimentally for each tree prior to the test.

The values of deflection by photography indicated in Table 4.3 are the maximum deflection at the camera marks (painted on most trees) as obtained from measurements on the photographic films.

The measurements for the various heights shown in Table 4.3 were obtained as follows:

(1) The height of pull was measured by tape.

(2) The height of the center of pressure and the height of camera mark were arrived at by estimating the distance of these points from the point of pull.

(3) The heights of strain meter locations were measured by tape.

Figures 4.14 and 4.15 indicate the results of photographic and strain meter measurements for two of the instrumented trees. The dotted portions of the camera curves in these figures indicate doubtful results due to dust obscuration or other reasons. The tree in Figure 4.15 was photographed by a gun-sight-aiming-point (GSAP) camera operating at 32 frames per second. The discrepancies along the time axis in Figure 4.14 were probably due to errors in the camera speed.

The spikes evident on the strain meter curves in Figures 4.14 and 4.15 are probably due to the blast wave vibrating the strain meter amplifiers. Experiments conducted by personnel of the Defence Standards Laboratory showed no output when a tree under test was jarred strongly, but dropping the strain meter amplifier in its protective box from a height of about 1 inch produced similar spikes in the amplifier output.

TABLE 4.1 NUMBER OF TREE STEMS EQUAL TO OR GREATER THAN GIRTH G FOR IRON RANGE TEST AREA

Reference 22.

G Inches	N Stems per acre	G Inches	N Stems per acre
13	228	55	16.6
16	181	60	11.9
19	144	70	7.10
22	115	80	4.30
25	94.5	90	2.73
30	70.5	100	1.65
35	52.7	120	0.64
40	40.1	140	0.21
45	30.6	180	0.04
50	22.9		

TABLE 4.2 DYNAMIC PRESSURE IMPULSE

Ground Range	Height	Dynamic Pressure Impulse (psi-msec.)			
		Hinge	Pendulum	Total Pressure Gages	Static Pressure Gages
Feet	Feet	(1)	(2)	(3)	(4)
Clear Sector					
260	Ground			476	457
300	"			391	300
360	"	222	325	-	186
440	"	141			
550	"	58	81		
655	"	36			
780	"	25.2			
950	"	15.9			
Primary Lane					
260	Ground		450	190	370
300	"		229	234	230
350	"	169		125	168
350	"			-	144
343	30.3			-	137
343	44.5			-	66
343	57.2			-	126
440	Ground	140			113
550	"	66	70		57
	22.7				20
	46.7				13
	70.7				7
650	Ground	36			38
780	"	27	30		23
780	5.5				19
	40.7				22
	88.7				34
950		16.7			13.9

TABLE 4.3 DATA FROM INSTRUMENTED TREES

Tree (Girth at Breast Ht)	Colour	Distance from GZ	Species	Predicted Deflection	Strain Meter Deflection	Deflection by Photog.	Comments	Height of Centre of Pressure	Height of Calibration Pull	Height of Camera Mark	Position of Strain Meter on tree (Mounting Height)
SM 1 (58")	Red	360'P.L.	Castanospermum australe	41.7'	12.2'		Initially leaning. Lost entire crown in blast. Major debris around base.	74'	66'	66'	Back (6'9") 69"-Girth
SM 2 (8[illegible]")	Yellow	440'P.L.	Eugenia Sp. No. 25	8.1'	7.9'	8.2'	Many large Branches. Large scar on trunk near strain gauge.	74'	54'	52'	Front (6'6") 91"-Girth
SM 3 (76")	Blue	550'P.L.	Dysoxylum Oppositifolium	52.2'	10.6'	6.8'	Tree hit by another falling tree.	72'	60'	60'	Front (8') 79"-Girth
SM 1A (26")	Pink	650'P.L.	?	17.3'	12.0'	No Camera	"Ideal" tree. Compact crown.	47.5'	42.5'	No Camera	Back ([illegible]'6") 27"-Girth
SM 5 (60")	Unpainted	780'P.L.	Biopharocarya involucrigera	6.3'	5.8'	7.5'	Axe notch facing GZ. Split slightly at notch in blast.	62'	54.6'	54.6'	Front (8'6") 54"-Girth
SM P1 ([illegible]6")	Grey	950'P.L.	" "	1.[illegible]'	6.1'	5.6'	Many large branches.	70'	57.5'	58.5'	Back (10') 87"-Girth
SM 7 (7[illegible]")	White	[illegible]40'C.S.	Dysoxylum Oppositifolium	42.7'	Broke		Broke near base. Limbs shattered on hitting ground. Strain gauge bent.	58.5'	18'	17.5'	Back (8'9") 62"-Girth
SM 8 (Nugget) (130")	Blue	12[illegible]'C.S.	Eugenia Sp. No. 2	1[illegible].[illegible]'	Broke	.	Split up center in blast. Fell 24 hrs. later. Hit by several missiles.	65.5'	61.5'	69.5'	Front (7'9") 132"-Girth
SM 9 (106")	Yellow	55[illegible]'C.S.	Antiaris toxicaria	[illegible]9.6'	5.4'	5.5'	Leaves yellow and falling. Stripped in blast. Gage wire and trunk hit by missiles.	68.5'	64.5'	6[illegible].5'	Front (1[illegible]'6") 80"-Girth
SM 10 ([illegible]")	Red	[illegible]20'C.S.	" "	[illegible].6'	7.2'	6.7'	Leaves starting to yellow. Large gashes made by lower members on trunk.	68.5'	6[illegible]'	55'	Back (10') 82"-Girth
SM 11	Grey-Purple	6[illegible]0'C.S.	Aleurites Moluccana	18.7'	8.9'	8.8'	Sharp kink in cable near missile cover	70'	63.5'	7[illegible].5' (Estimated)	Front (5') 66"-Girth
SM P2	Unpainted	690'C.S.	" "	20.0'	10.7'		—	55'	5[illegible]'	58' (Estimated)	Front (6') 47"-Girth

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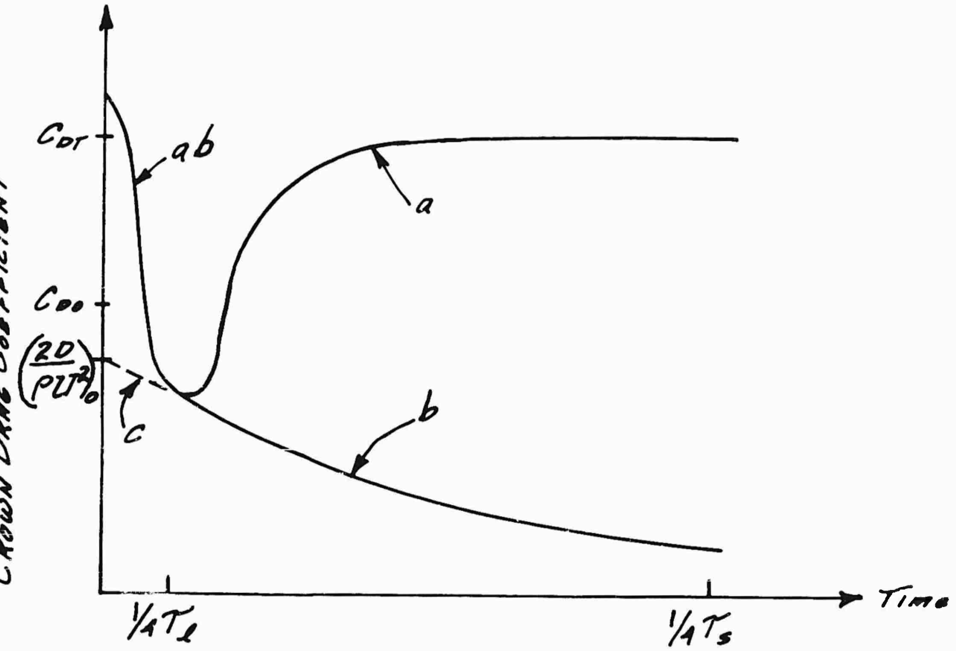


Figure 4.1 Schematic of postulated variation of crown drag coefficient during airblast loading (Curve a, impulsive loading; Curve b, long-duration loading; Curve c, zero bending moment about the base of crown.)

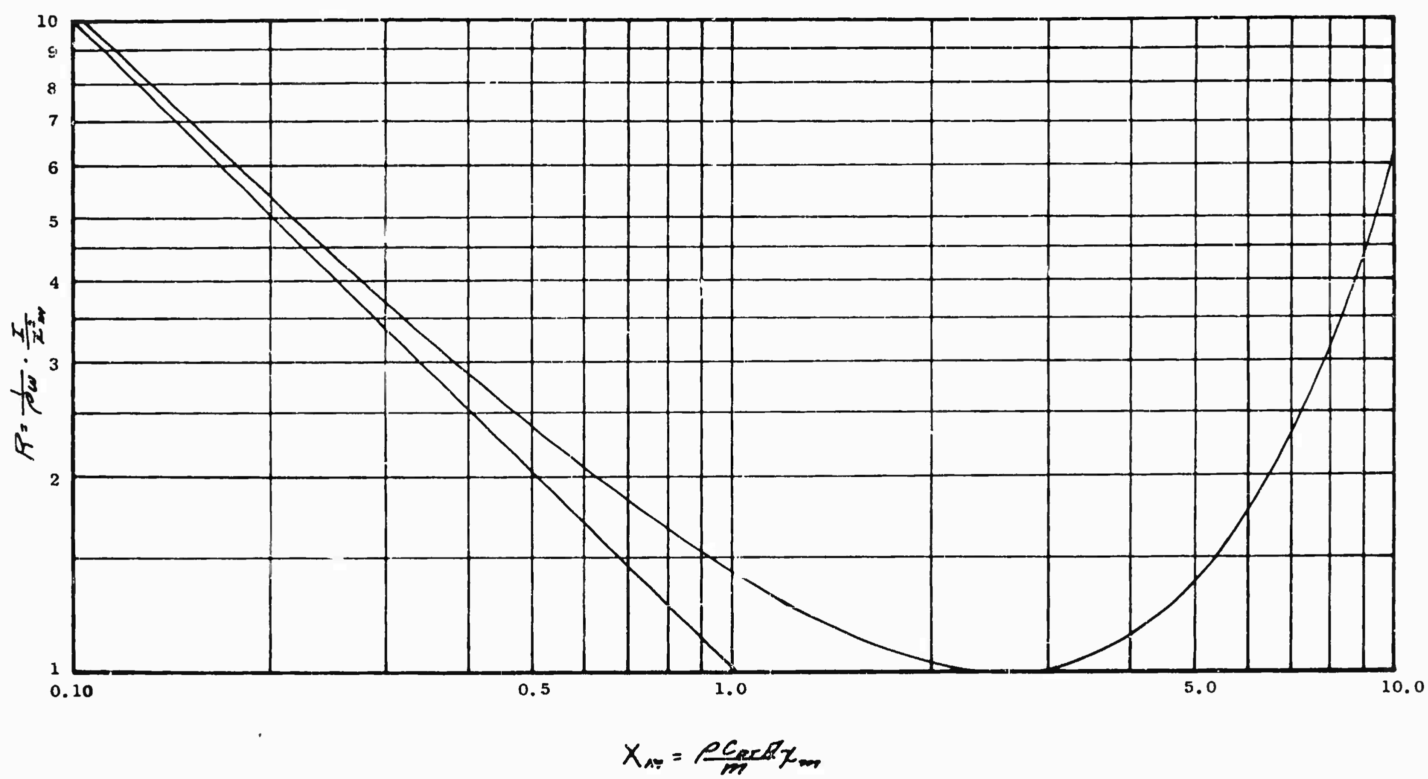


Figure 4.2 Dynamic pressure amplification factor, R, versus nondimensional maximum deflection, X_m.

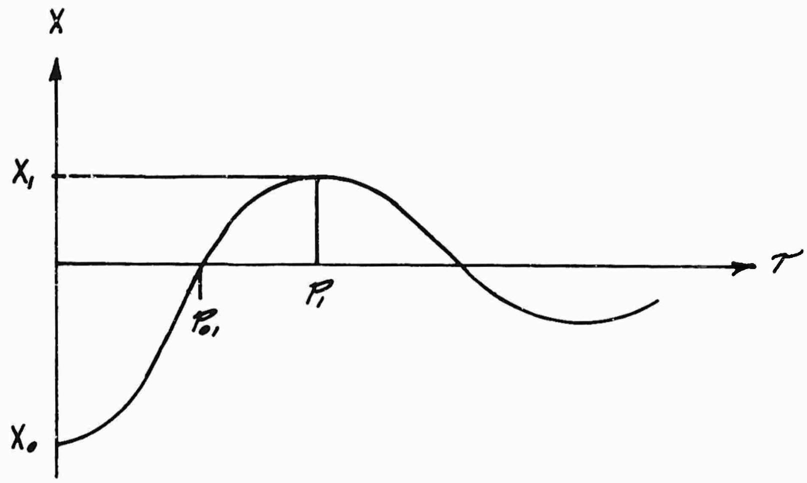


Figure 4.3 Definition of terms for twanging experiments.

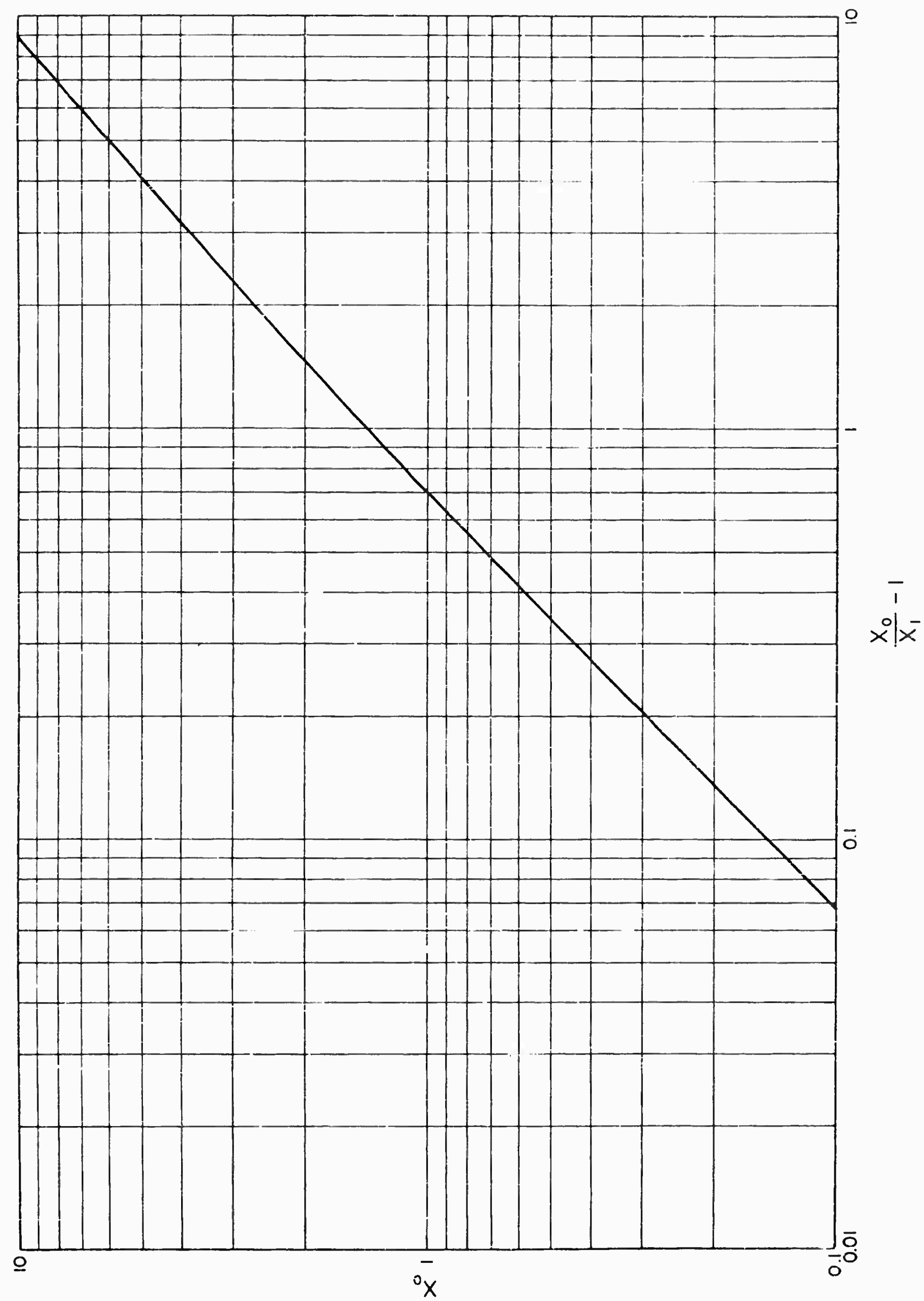


Figure 4.4 Nondimensional initial deflections as a function of the ratio of initial to first maximum deflection.

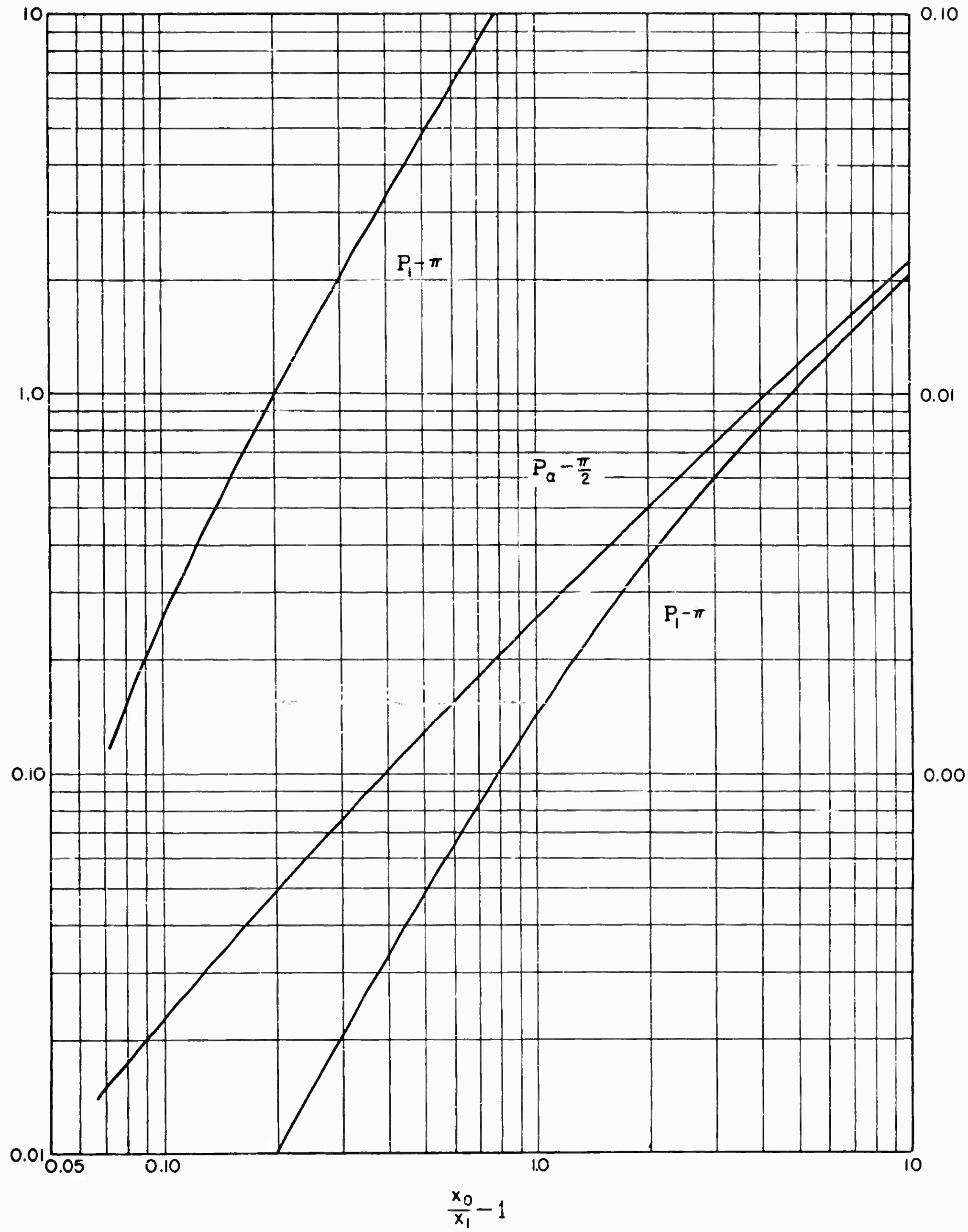


Figure 4.5 Stem period as a function of the ratio of initial to first maximum deflection.

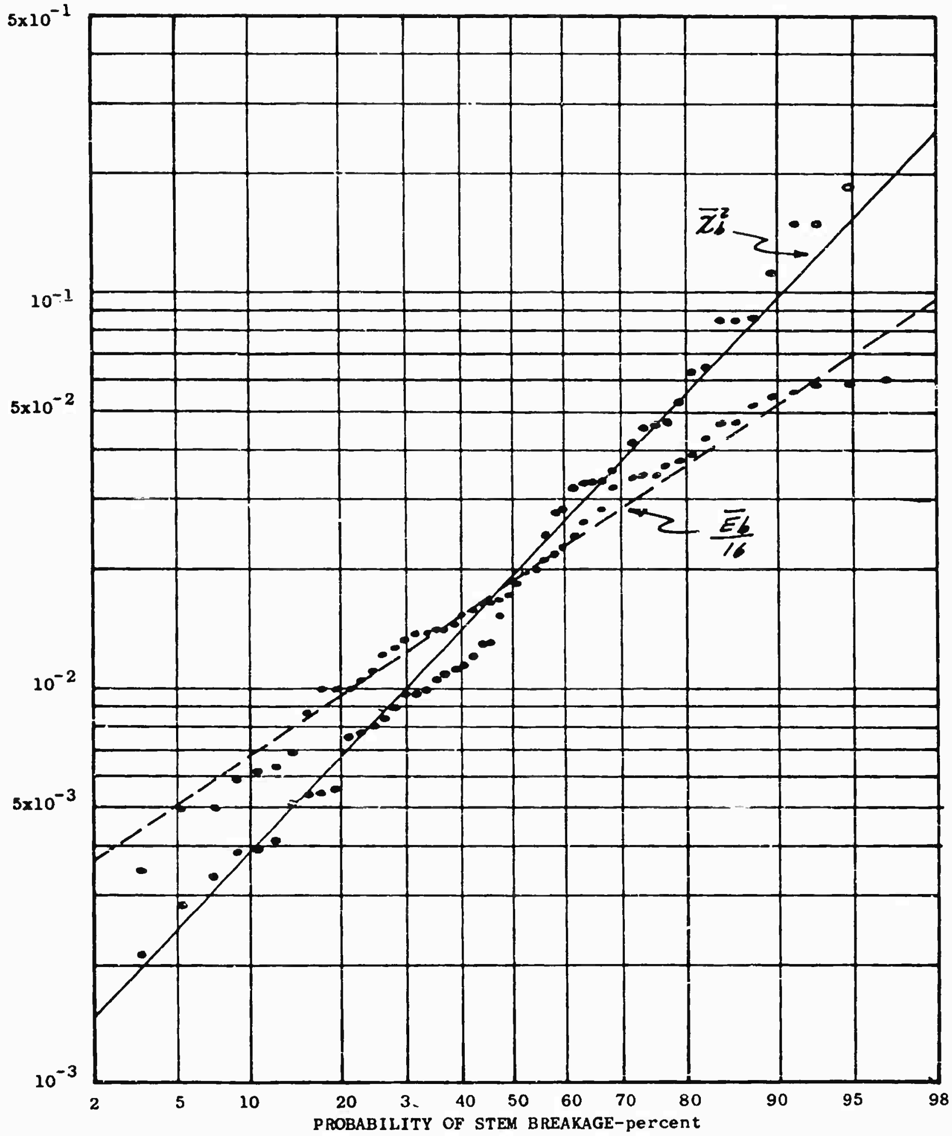


Figure 4.6 Normalized stem breakage parameters versus probability of breakage.

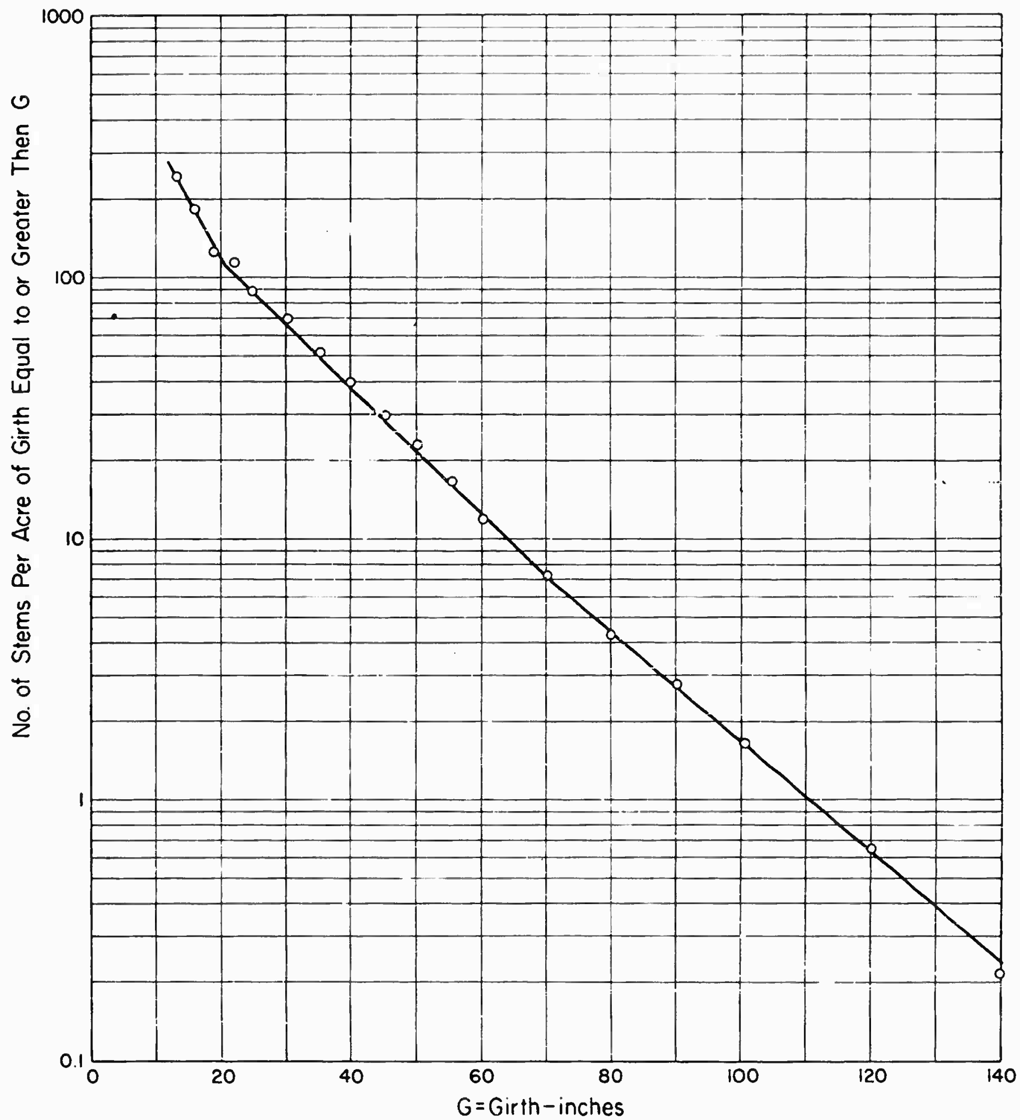


Figure 4.7 Number of trees by girth class, Iron Range.

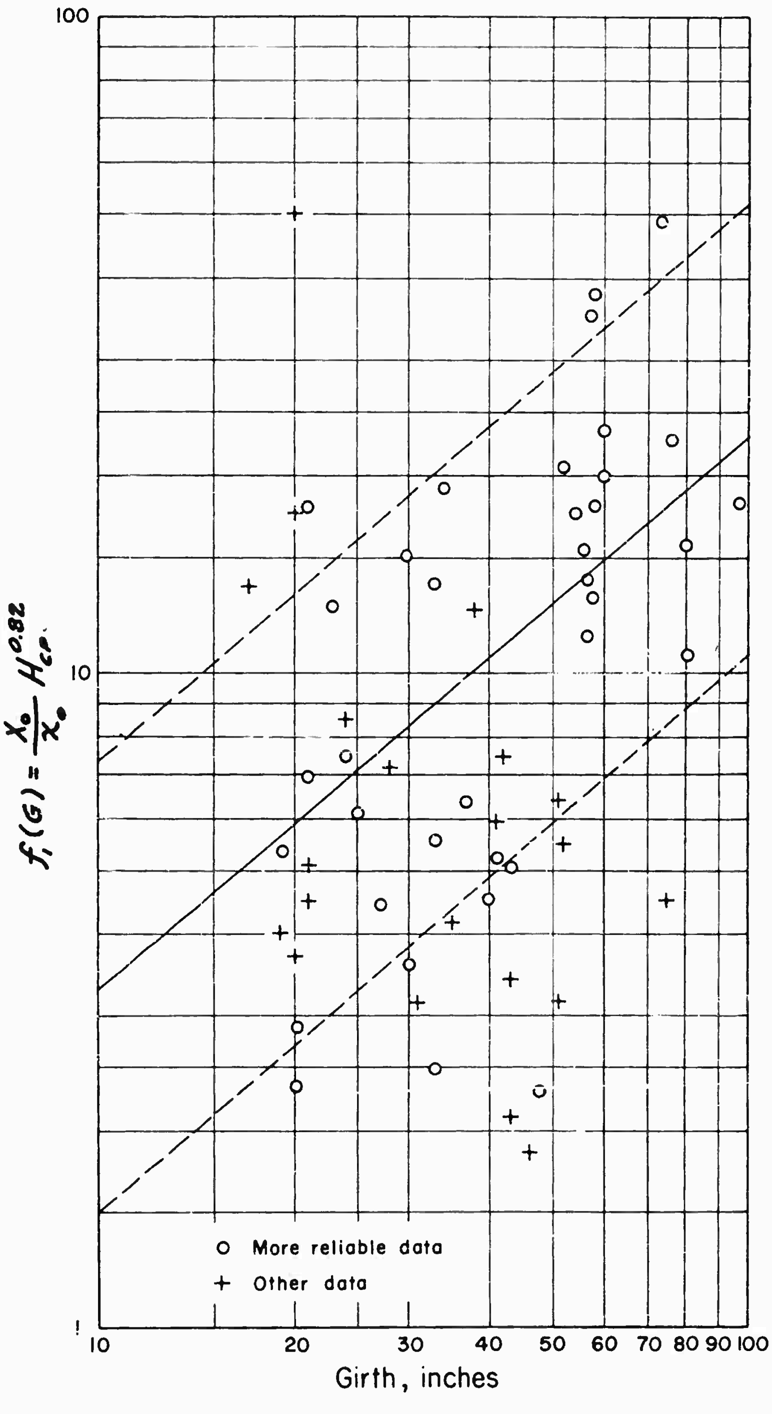


Figure 4.8 Function f_1 versus girth for Iron Range trees.

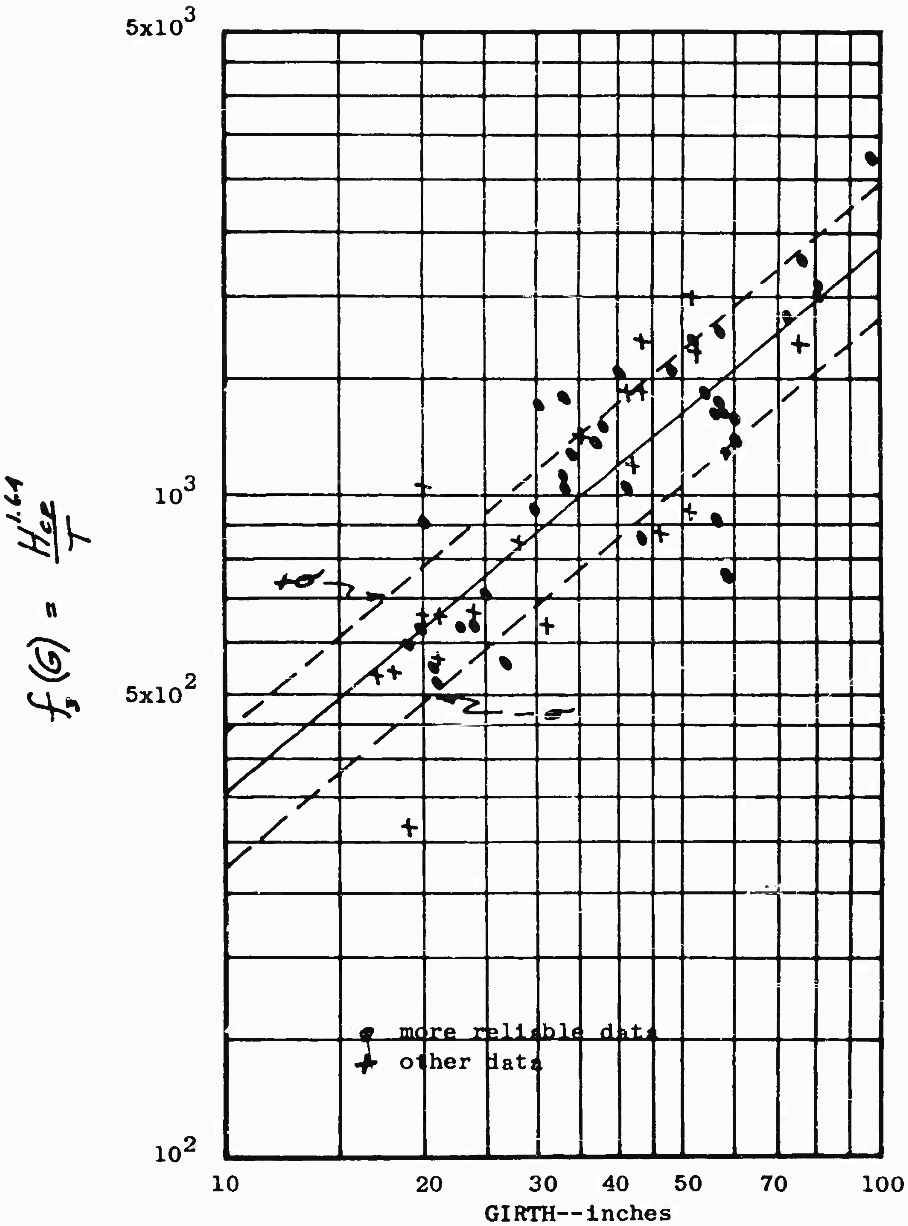


Figure 4.9 Function f_3 versus girth for Iron Range trees.

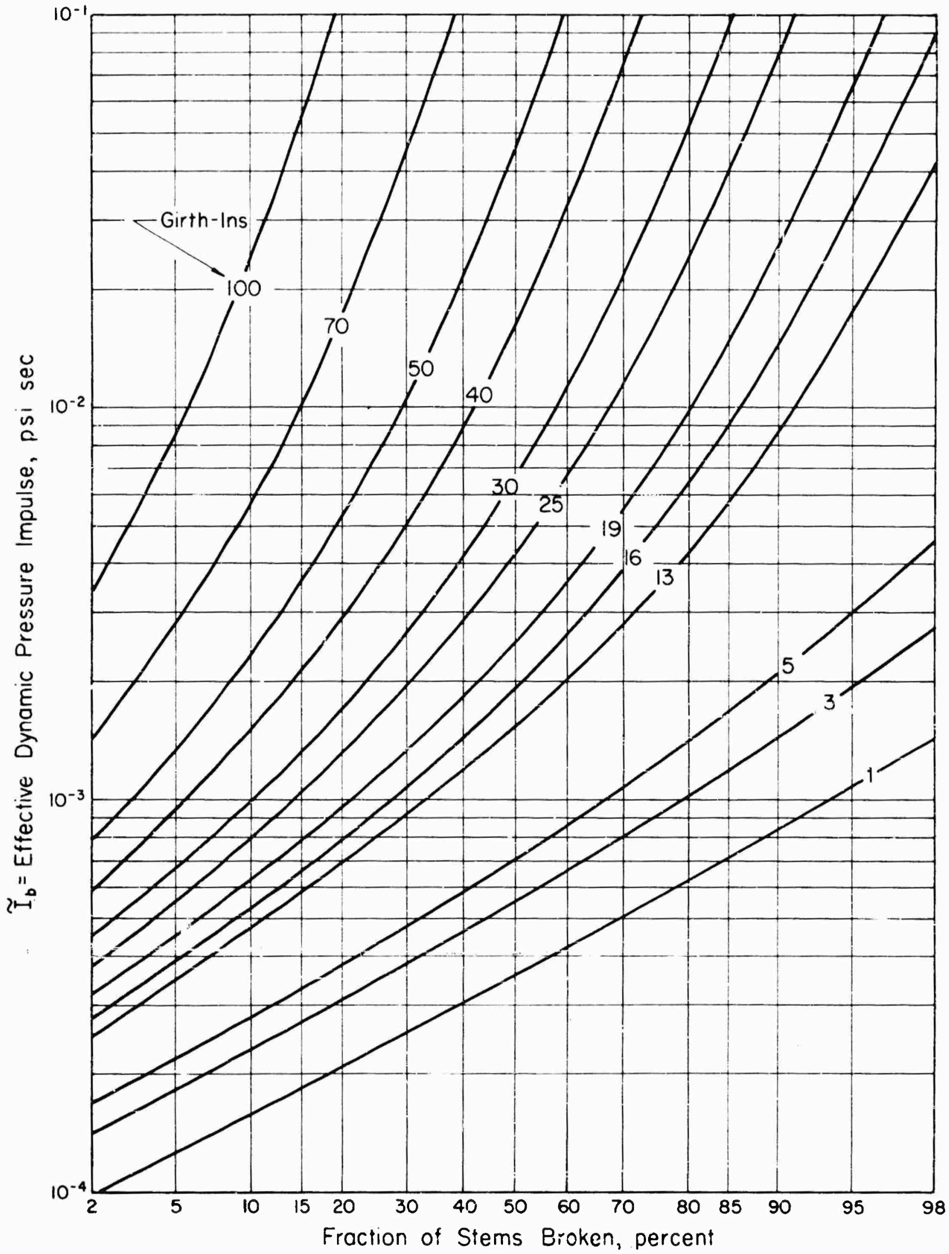


Figure 4.10 Effective dynamic pressure impulse versus percent stems broken for Iron Range trees.

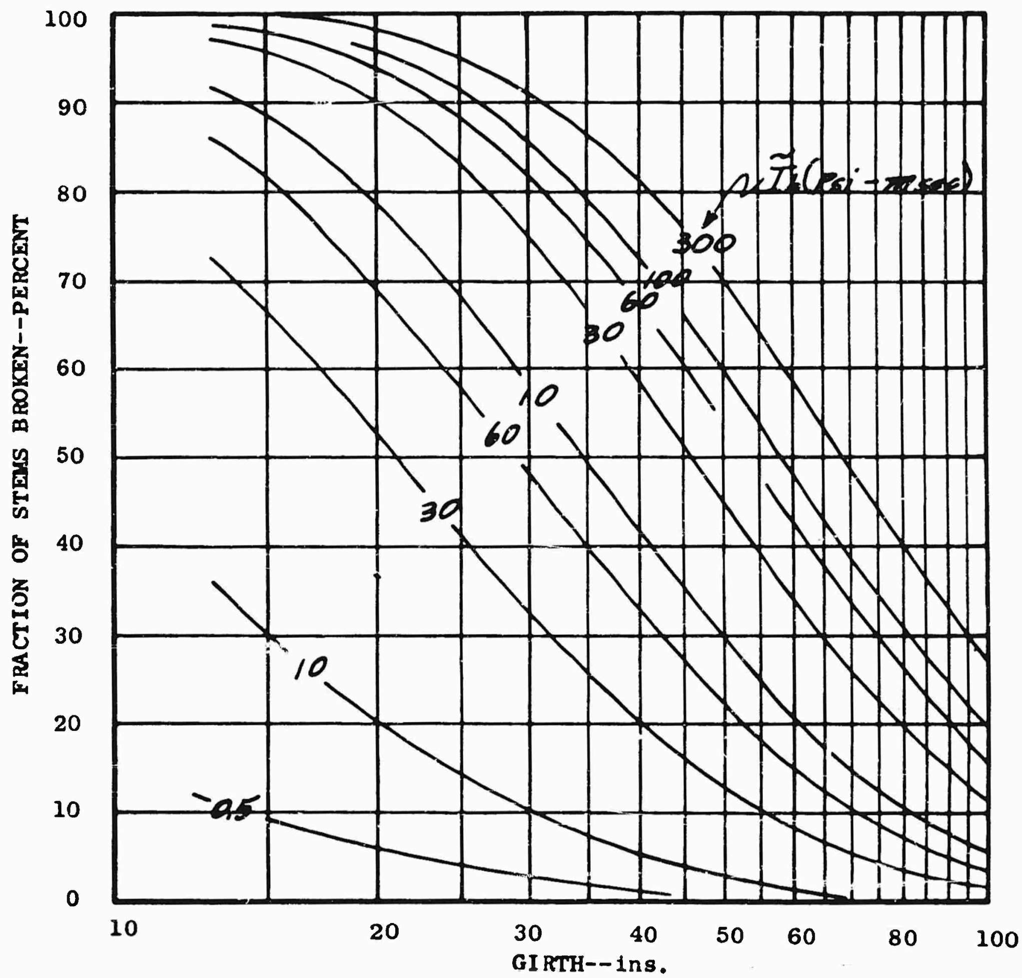


Figure 4.11 Effective dynamic pressure versus girth for Iron Range trees.

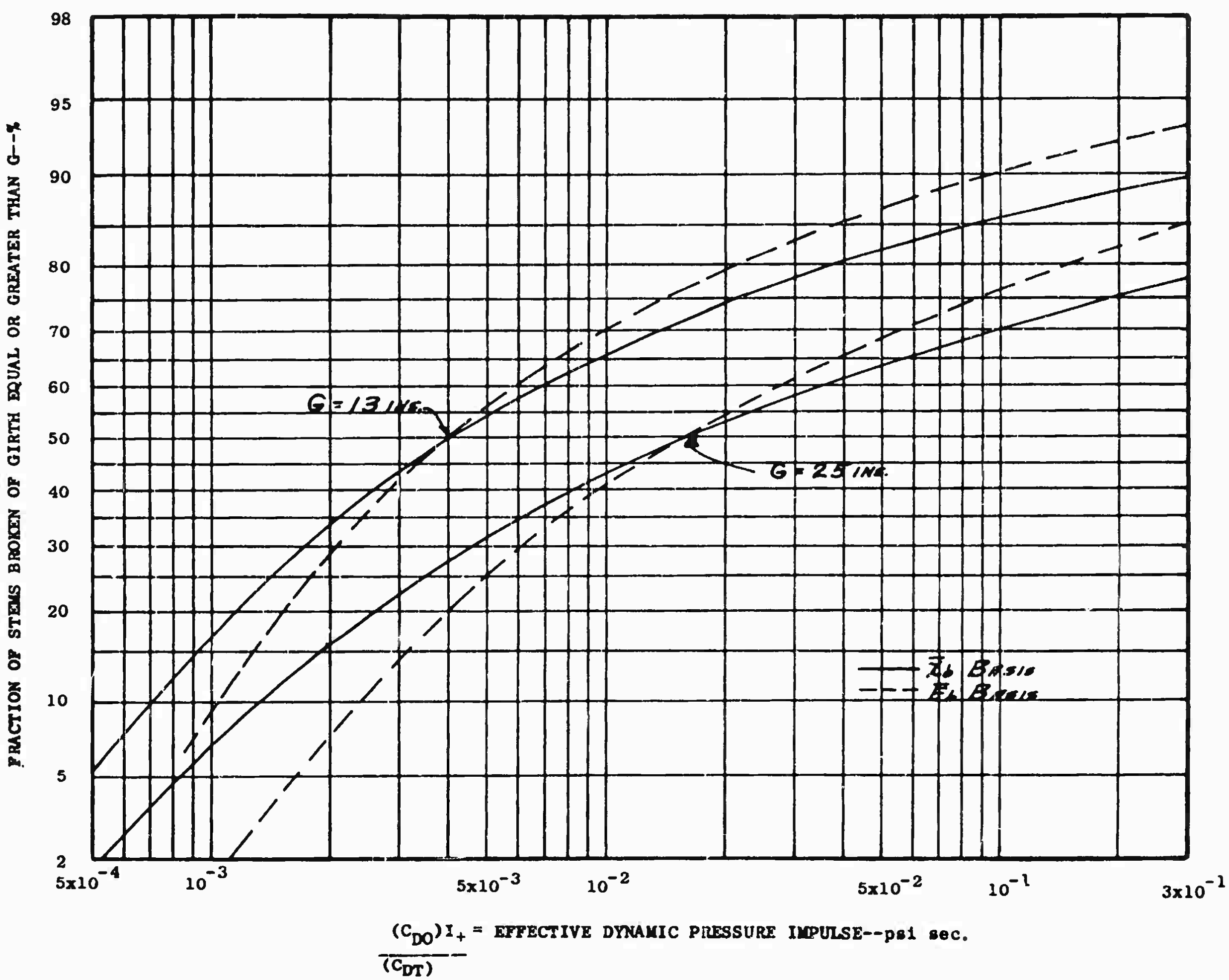


Figure 4.12 Stems broken versus effective dynamic pressure impulse for Iron Range stand—large deflection theory.

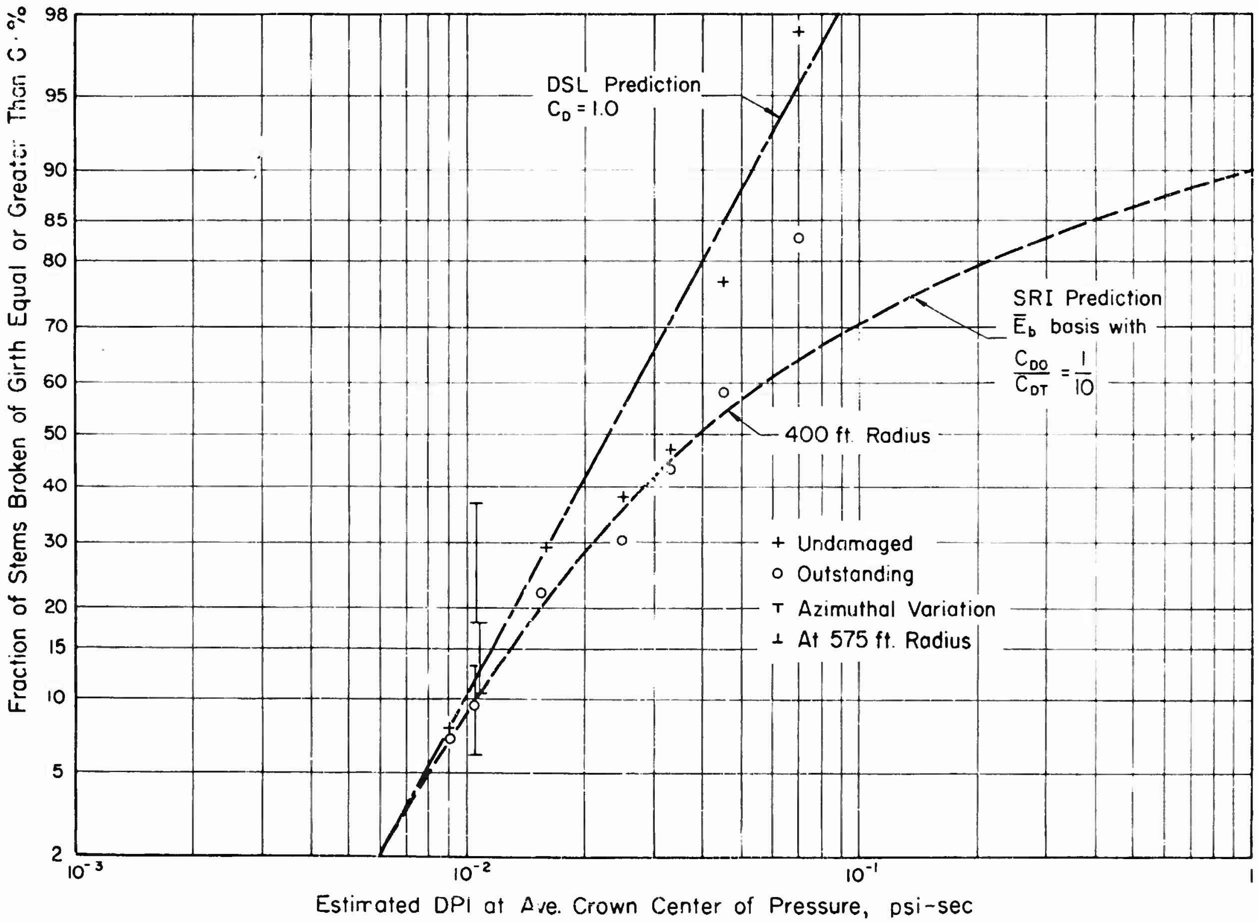


Figure 4.13 Comparison of predicted stem breakage with observed stem breakage.

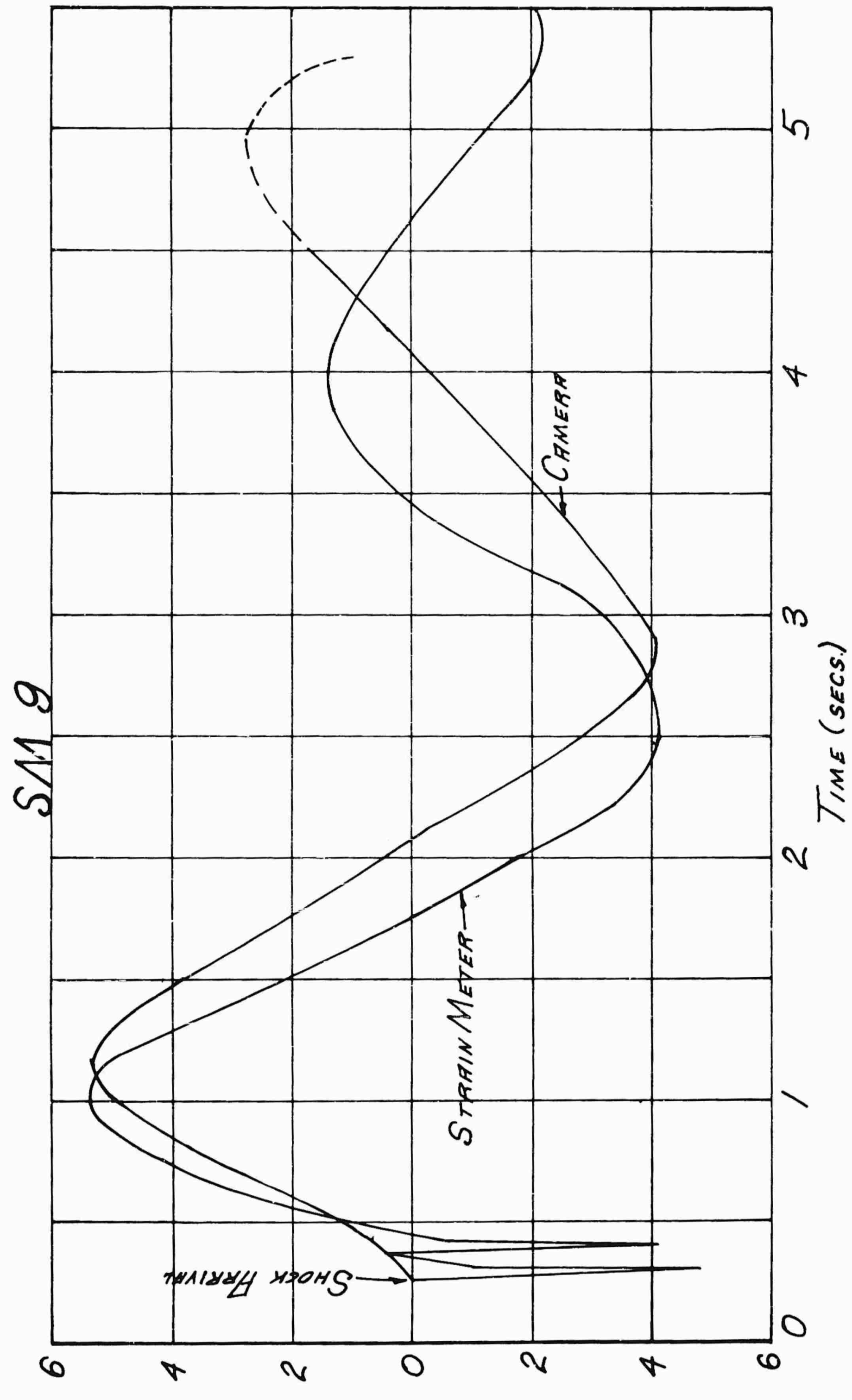


Figure 4.14 Photographic and strain meter measurements, SM 9.

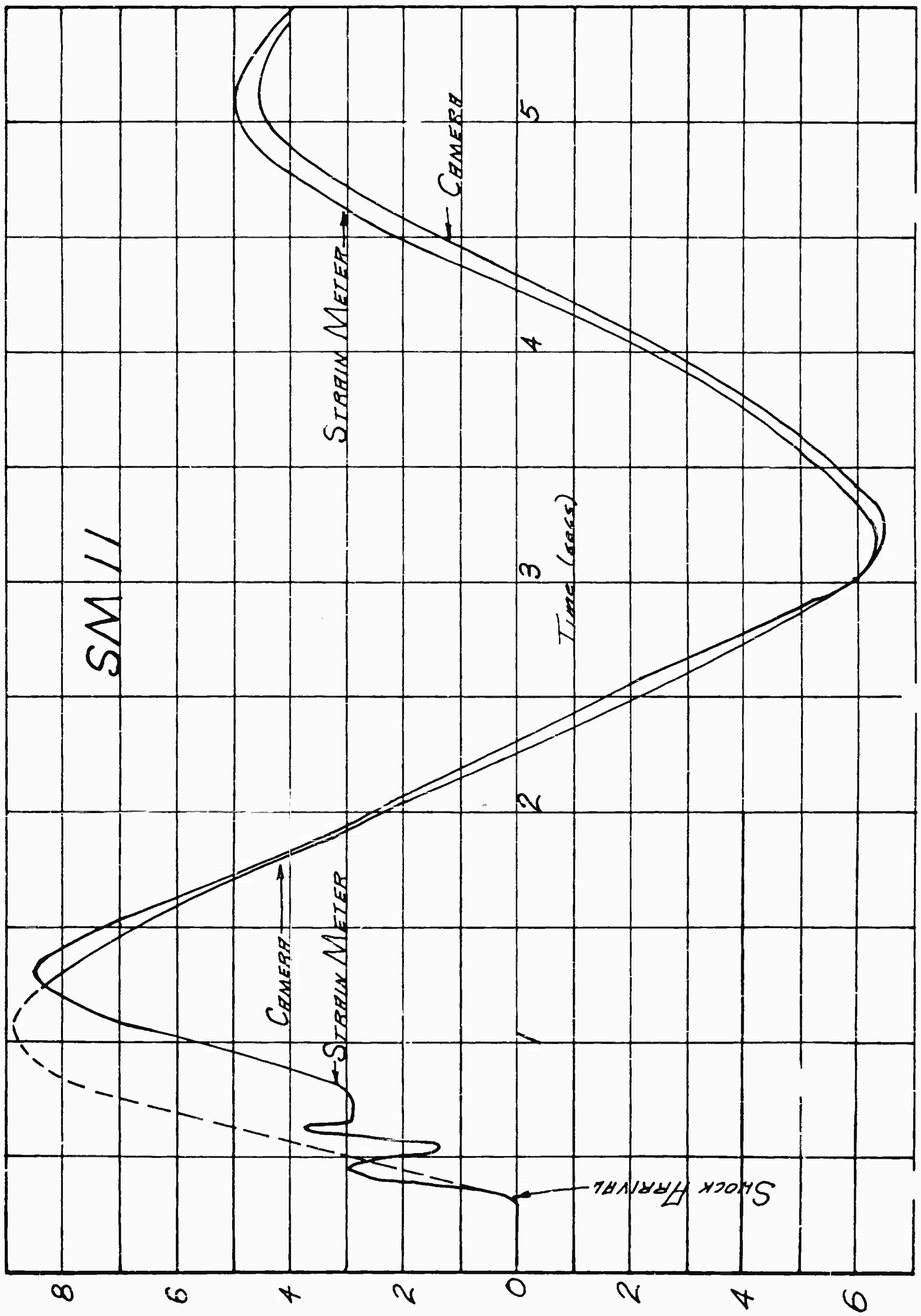


Figure 4.15 Photographic and strain meter measurements, SM 11.

Chapter 5

MILITARY TRIALS

(Prepared by Lt Col C.C. Clifford, Jr., Hqs, DASA, and Lt Col C.S. Grazier, Combat Development Command, U.S. Army.)

Limited military trials were conducted in connection with Operation BLOWDOWN to assess the effects of the airblast in certain areas of consideration. Information obtained will be utilized by the Australian Army in improvement of planning techniques for, and the conduct of, operations in tropical terrain.

The detailed plans for the conduct of this portion of the experiment are found in Appendixes B through G.

In this portion of the experiment, U.S. participation was limited to observation of those exercises which were conducted during the period of time in which U.S. personnel were present. Therefore, this chapter merely outlines the conduct of the particular exercise and the preliminary results available at this time. In the future, DASA will receive the Australian reports containing detailed discussions and conclusions resulting from information obtained in each area of interest and will forward them to appropriate Department of Defense agencies for their consideration in future review and possible revision of planning procedures, damage prediction techniques, and conduct of operations in an area of this type.

5.1 INFANTRY PATROL MOVEMENT

Four Australian infantry patrols were conducted as outlined in Appendix B. These four consisted of a day and night patrol prior to the detonation, and a day and night patrol after the detonation. Personnel had not been given any special training for movement in this type of terrain prior to the exercises.

The general trace of the route followed on the patrols and the actual times involved in these movements are shown on Map 2, Appendix I.

Note that the posttest patrols took less time to complete than the same movement before the test. Absence of "enemy" personnel stationed along the route of the pretest patrol as "observers" partially accounted for the length of the maneuver. Also, the detonation had resulted in blowdown of vines, underbrush, and smaller trees, which had slowed the movement of the earlier patrols. It was evident to the author who participated in the posttest night patrol that the clearing by the blowdown did not account for the entire time differential. Movement would have been slower (to reduce noise and attain surprise) had enemy elements again been positioned along the route.

The night patrols were made in single file, using a rope tied around the leadman's waist and passed back through the length of the patrol. The leadman used a compass to maintain direction.

In the opinion of the writer the posttest patrol through the areas of tangled logs and branches and of fallen logs produced few valid conclusions concerning patrol movement. A first aid man and radio operator located in the vicinity of ground zero were using a bright lantern. The resulting light throughout the blowdown area was sufficient to permit members of the patrol to select the easiest route of movement.

The radio set used to check communications signal strength during these patrols was the C/PRC-26, because the communications exercises on 11-12 June had pointed out the weaknesses of using the AN/PRC-10 in this type of terrain. The results of the communications checks in the night patrol of 20 June are given in Table 5.1.

5.2 PLATOON IN THE ATTACK

The purpose, scope, and plan for conduct of this portion of the military trials are stated in Appendix B.

5.2.1 Platoon Attack Prior to Detonation. The route used and time required for movement in this exercise are shown on Map 2, Appendix I. Visibility throughout this phase of the trial was at most 25 yards.

The enemy force was in position in the vicinity of L13 on the objective. A simulated patrol base had been established at the TURKEY NEST at N14 through which the attack was to be launched.

In movement from the START POINT (V23) to the HARBOUR Area (Final Assembly Area) the platoon formation was:

Section   Platoon Headquarters   Section

Section   Mortar Section   Section

(All elements were in single file)

This approach movement was reasonably fast (100 yards in 2 minutes) and quiet. The platoon front was 40 yards. Control by the platoon leader was effected by the use of movement axes and by hand signals. Because of the rate of movement and relatively poor visibility, it was difficult for the platoon leader to maintain control. However, he chose this formation for ease of movement on a relatively wide front, while maintaining the platoon in a compact group.

In making his reconnaissance, the platoon leader found it very difficult to locate the enemy positions. A line through the forward edge of the TURKEY NEST was selected as the START LINE (line of departure) because visibility and, hence, control would be less restricted than along the road, which would have been a better defined line.

The formation in the assault was as follows:

(Assault Section) (Assault Section) (In Line)

(Platoon Headquarters)

(Reserve Section)

(Cutoff Section)

The mortar section remained in the HARBOUR Area until called forward to the objective. The platoon leader was unable to establish a position for a covering-fire section. The rate of advance in the assault was 13 yards in 1 minute.

5.2.2 Platoon Attack After the Detonation. The route used and time required for movement in this exercise are shown on Map 2, Appendix I.

The objective of this portion of the military trials was the same as for the attack before the detonation.

The formation for the movement from the START POINT to the HARBOUR Area was basically the same as before the detonation, except that the platoon front was approximately 50 yards in this instance. Control and maintenance of direction during this movement were more easily accomplished, because the detonation had thinned out some of the underbrush, and hand signals were more effective. However, because visibility from the enemy's viewpoint was much improved after the detonation, the START LINE and HARBOUR Area were farther from the objective, and the route from START POINT to HARBOUR Area was longer, for the enemy could observe the TURKEY NEST after the detonation. The platoon leader's reconnaissance required more time after the detonation, because the blowdown decreased available concealment; however, for the same reason his reconnaissance was more effective, since the enemy position could be observed from positions along the road.

The rate of advance in this exercise was 100 yards in 3 minutes. This rate was slower than the pretest rate because of the difficulty of moving through the obstacles created by blowdown.

The assault formation used two sections attacking on line, with the platoon headquarters behind and in the center. In this instance a covering section was able to establish a base of fire in the vicinity of the TURKEY NEST. The fourth section was the reserve and followed in line 150 yards behind the two assault sections. The mortar section was in firing positions in the vicinity of the START LINE until the objective had been seized. Then, the section moved forward to the objective in single file on order of the platoon leader. Control and maintenance of direction during the assault was much easier to accomplish after the detonation, since the increased visibility made hand signals much more effective.

However, casualties in the attacking platoon would have been greater, since the enemy picked up the movement of the covering section and were able to pinpoint the position of each man in this base of fire.

5.2.3 Discussion. The following general observations were made by the writer, based upon an assumption that the defender was able to maintain an effective fighting force following the detonation.

(1) The fallen logs provided cover and concealment for troops advancing by fire and maneuver. However, they did restrict visibility and fields of fire to troops occupying prone firing positions. In the case of troops attacking through the area, the logs forced the men to expose themselves much more than in the undisturbed portions of the forest.

(2) In the area in which blowdown debris consisted of fallen logs, the tangled logs and branches presented serious impediment to movement by attacking troops, since movement was physically exhausting. Troops must concentrate on finding footholds and routes for rapid movement. Therefore, troops were forced to expose themselves more than in the undisturbed forest. It was obvious that the requirement for adequate covering fire would be of prime concern in the posttest operation.

(3) Command and control was much easier to effect in all areas of blowdown than in virgin forests, except perhaps in the tangled branch and log areas.

(4) From the viewpoint of the defending force, even the closest positions could have been refurbished and occupied in a relatively short period of time. However, in the areas of fallen logs and tangled logs and branches, visibility and fields of fire would have been severely limited at ground level by the masses of logs and other debris. Use of defensive positions that were slightly elevated would have increased the effectiveness of the defensive force considerably. Similarly, the use of such elevated defensive positions would also have offered many advantages to the attacking force.

(5) It is apparent that additional experiments should be conducted in both the attack and defense of areas of this type where severe blowdown is effected.

5.3 CLEARING OPERATIONS

5.3.1 Background. A serious lack of knowledge exists covering the effects of the detonation of nuclear weapons on trees and forested areas. Such factors as the extent of the area of damage and the degree of the resulting obstacle to movement are of prime importance to military planners considering operations in forested areas. It was decided that a large-sized conventional explosives detonation over a forested area would give data that might be extrapolated to the effects produced by a nuclear weapon.

5.3.2 Objective. The objective of this portion of the military trials was to obtain information concerning the effects of a simulated nuclear weapon airburst over a tropical rain forest.

5.3.3 Discussion and Results. For the obstacle portion of the test the engineers opened a series of 12-foot-wide roads through portions of the forest where severe, moderate, and light tree blowdown were expected. Two methods were used for cutting the tracks. See Map 1, Appendix I, for traces of tracks cleared.

Machine Clearing. An International Harvester TD-18 with an angle dozer blade cut a 12-foot-wide track about 2,046 feet long in an elapsed machine time of about 3 hours. During the cutting of the track, the dozer encountered and removed 376 trees having a 2- to 4-inch diameter, 66 trees having a 4- to 8-inch diameter, 28 trees having an 8- to 10-inch diameter, and an uncounted amount of vine ranging in size up to 6-inch diameter. This calculates to a clearing rate of about 11.7 feet per minute for the TD-18 for clearing the track through undisturbed forest.

After the detonation, the dozer was sent over the previously cleared track to restore it to the pretest condition. This clearing effort took 40 minutes elapsed machine time for a clearing rate of 51.1 feet per minute. Part of the reduction in clearing time is due to the fact that for about 411 feet no clearing effort was required. By subtraction of this distance and the travel time required for the dozer, a clearing rate of 40.8 feet per minute is established. Also, a reduction in speed of restoration compared to original clearing time probably can be assumed due to increased operator visibility and to absence of vines in the previously cleared area.

To determine clearance time through previously uncleared areas of the forest after the test, a total of 1,185 feet of 12-foot track was cleared. The elapsed machine time for this clearance was 55 minutes. This second clearing was laid off 30 feet to the side of the original cleared lanes. This was done to approximate closely the original areas and to gain clearing times for mixed standing and fallen trees. This rate calculates to a clearing rate of 21.5 feet per minute. The original clearing time over the comparable area was 30 minutes, calculating to a clearing rate of 39 feet per minute.

An unscheduled clearing effort (N-O-P-Q) was made starting from near ground zero running radially through the area of total destruction and light damage and return. This clearing totaled 504 feet and entailed moving 2,260 feet of tree trunks having an average length of 22.4 feet and diameter of 6.4 inches. Diameters up to 22 inches were encountered in this area. The clearing time was 42 minutes for a clearing rate of 12 feet per minute.

Manual Clearing. The manual clearing was accomplished by one sapper section composed of 9 men and 1 NCO using machetes, axes, and one or two 15-inch chain saws. The chain saws were difficult to keep in operation, and frequently both were out of service. The sapper section originally cleared approximately 2,950 feet of 12-foot-wide track through areas where severe, moderate, and light damage were expected. This clearing required a total of 200 man-hours for a clearing rate in original forest of 14.5 feet per hour. Clearing progress was impeded by heavy vine growth and a fairly thick undergrowth.

After the test, 1,659 feet of manual clearing over the previously cleared track was finished by the time this observer had to leave the test site. This clearing effort was to restore the track to its original condition. This clearing required a total of 21 man-hours by a comparable-sized sapper section using the same hand tools. The clearing rate calculates to 79.0 feet per hour. Again, clearing was speeded by the lack of vines and underbrush. Increased visibility and excellent task assignment with NCO supervision tended to quicken operations.

The work organization that was developed during practice clearing runs was as follows:

(1) Two men with machetes went into the area to cut branches and small debris sufficiently so that men with axes would have a relatively clear area in which to work. This party progressed 20 to 30 feet before the axmen started.

(2) Two men with axes then started cutting all branches and trunks that could not be lifted or pushed off the track. They cut to a 12-foot width and left the debris lie.

(3) Following the axmen was the remainder of the party. Their task was to lift or push out of the track all cut wood and to trim with machetes anything left by the preceding parties. The section worked for 45 minutes each hour and rested for 15 minutes. When a man in either the leading machete party or the ax party became fatigued, a man from the cleanup party replaced him. As this manual clearing can be dangerous, close supervision must be exercised to maintain safe working distances between parties and individuals. When the chain saws were available, they were used to supplement and follow the ax party. In this case, the axmen cut only those branches and trunks that could be cut quickly by axes. The limiting diameters were generally from 2 to 3 inches.

The saws were then used to cut all larger sizes of debris.

It was agreed that a probable way to speed the overall clearing operation in an actual obstacle situation would be to start several sapper sections spaced along the road to be cleared and have all sections work simultaneously. Due to the small size of the area to be cleared and the number of hand tools available, only one section was employed in this operation.

The rates of clearing the roads (pre- and posttest) by machine and manually are compared in Table 5.2.

5.3.4 Conclusions. The clearance rates tend to indicate that clearing an existing track in a damaged area can be accomplished much faster manually or by machine than clearing the original track in an undamaged state.

• Good work party task assignment and close supervision are required for efficient clearing operations.

5.4 DEFENDED LOCALITIES, EARTHWORKS, AND OBSTACLES; WEAPONS, EQUIPMENT, AND AMMUNITION

Three infantry section defensive positions were constructed at 60, 120, and 200 yards from ground zero as indicated in Appendix C. These positions included open fire trenches (revetted and unrevetted), overhead protection of soil with timber revetment in one instance, and cleared fields of fire, and wire entanglements of the following types: low wire entanglement, double apron fence (barbed wire and barbed type), and double concertina fence.

A Bren LMG, an Owen machine carbine, three 0.303-inch rifles, drill grenades, and inert 0.303-inch or 7.62-mm ammunition were located in each infantry section position.

In addition, weapons pits were constructed containing weapons as indicated in Appendixes C and D. These positions included one 3-inch mortar pit, including ammunition bay, containing a mortar; one 106 recoilless rifle position with ammunition bay; and one standard 25-pounder gun pit containing one OQF 25-pounder and three boxes of inert ammunition.

The locations of these positions are shown on Map 1, Appendix I.

A posttest damage assessment was accomplished by the Australian damage assessment team. This preliminary information has not yet been released by that group. The posttest survey included sketching of the positions and materiel in their final condition and location, and determination of the work effort required to reconstruct the positions into a usable condition. However, the writer observed that the weapons in the forwardmost positions were blown about by the blast wave. The LMG and carbine barrels of weapons in these positions were actually bent. These weapons were located under heavy logs and under the layer of leaf debris which covered the area. There was some damage to the 25-pounder. The 3-inch mortar was blown to the opposite side of the position, but appeared to be in usable condition.

5.5 SUPPLIES AND POL

Small, camouflaged supply points were located as shown on Map 1, Appendix I. The purpose of this portion of the military trials is discussed in Appendix F. The supply points contained jerricans filled with water, ration packs, and representative stocks of each type of supply container.

Again, the information concerning the preliminary analysis by the Australian damage assessment team has not been released by that group. It was observed in posttest visits to the test site that the blast wave had scattered the containers about the immediate area. Some jerricans had been punctured by missiles, and other containers had broken open in many cases.

5.6 AERIAL MASTS

Two triangular latticed steel (DEECO) masts were erected for instrumentation in the primary lane. One was 72 feet high, located 550 feet from ground zero; the other was 90 feet high at 780 feet from ground zero. The only damage sustained was to one guy on the 90-foot mast, which was severed by shrapnel. Both masts were still erect after the blast. Map 2, Appendix I, shows the location of these masts.

5.7 WIRELESS COMMUNICATION EQUIPMENT

This portion of the military trials was conducted basically as outlined in Appendix E. The results are tabulated in Tables 5.3 through 5.6.

The preliminary analysis by the Signal Officer, Operation BLOWDOWN Force, resulted in the following comments:

The results obtained during the day tests were disappointing with the exception of the C/PRC-26, which gave excellent performance, considering its output power.

The A510 tests were not considered indicative, as the inductance tuner of one set was damaged early in the test in moving through the jungle. This, it was discovered during the tests, is a very real problem with this set. There is no flexibility in the aerial mounting, and the inductance tuner is too rigid and will not withstand too much tension, such as when the aerial becomes entangled in overhead growth. This was rectified during night trials by removing both aerial and tuner when moving through jungle.

The AN/PRC-10 sets were most disappointing in both day and night phases. These sets were operated by infantry signallers, the same two who conducted the tests with the infantry patrols, using the same sets. The performance of the sets cannot be explained in view of the success of the C/PRC-26 set. Both sets were tested and appeared to operate satisfactorily prior to the trial.

5.8 COMMUNICATION CABLES

Prior to the test, communication cables had been installed above ground, on the surface, and buried at various depths as indicated in Appendix E. All cabling had been tested by means of telephones and proved to be in good working order.

The locations of these cables are shown on Map 2, Appendix I.

Following the detonation, six men (including three experienced linemen) attempted to relocate and test with telephones all of the original cable. The results of this post-test effort are listed in Table 5.7.

TABLE 5.1 COMMUNICATION REPORT, NIGHT PATROL, 20 JUNE 1963. (C/PRC-26 RADIO SET)

Patrol Location	Signal Strength	Base Station	Signal Strength
V23	L	A23	L
T21	L	A23	L
S19	L	A23	V
R19	L	A23	V
Q17	N	A23	V
P16	L	A23	L
O15	N	A23	N
N15	V	A23	L
M14	N	A23	N
L13	N	A23	N

Legend: L = Loud and Clear
R = Readable
V = Very Weak
N = Nothing Heard

TABLE 5.2 RATES OF CLEARING ROADS THROUGH THE TEST SITE

	Cleared by Machine ft/min	Cleared Manually ft/min
Pretest		
Original Road	~ 12	~ 0.25
Posttest		
Original Road	~ 51 (uncorrected)	—
	~ 41 (corrected)	~ 1.3
New Road	22 (mixed)	—
	12 (radially)	—

TABLE 5.3 DAY TEST, 11 JUNE 1963

(North Set being moved initially.)

A510 Set				AN/PRC-10 Set				C/PRC-26 Set			
North Set Location	Result	South Set Location	Result	North Set Location	Result	South Set Location	Result	North Set Location	Result	South Set Location	Result
V1	R	A21	V	V1	N	A21	N	V1	N	A21	V
L12	R	A21	V	L12	N	A21	N	L12	R	A21	N
T3	L	A21	N	T3	N	A21	N	T3	R	A21	N
S4	N	A21	N	S4	N	A21	N	S4	N	A21	N
R5	N	A21	N	R5	N	A21	N	R5	N	A21	N
Q6	L	A21	R	Q6	N	A21	N	Q6	V	A21	N
P7	L	A21	R	P7	N	A21	N	P7	R	A21	R
O8	R	A21	N	O8	N	A21	N	O8	R	A21	N
N9	V	A21	N	N9	N	A21	N	N9	L	A21	N
M10	V	A21	N	M10	N	A21	N	M10	L	A21	R
L11	N	A21	N	L11	V	A21	N	L11	L	A21	L
L11	N	B20	N	L11	V	B20	N	L11	L	B20	L
L11	N	C19	N	L11	V	C19	N	L11	L	C19	L
L11	N	D18	N	L11	R	D18	N	L11	L	D18	L
L11	N	E17	L	L11	L	E17	L	L11	L	E17	L
L11	L	F16	L	L11	L	F16	L	L11	L	F16	L

Legend: L = Loud and Clear
R = Readable
V = Very Weak
N = Nothing Heard

TABLE 5.4 DAY TEST, 11 JUNE 1963

(South Set being moved initially.)

A510 Set				AN/PRC-10 Set				C/PRC-26 Set			
North Set Location	Result	South Set Location	Result	North Set Location	Result	South Set Location	Result	North Set Location	Result	South Set Location	Result
V1	N	A21	N	V1	N	A21	N	V1	N	A21	R
V1	N	B20	N	V1	N	B20	N	V1	N	B20	N
V1	N	C19	N	V1	N	C19	N	V1	N	C19	N
V1	N	D18	N	V1	N	D18	N	V1	V	D18	N
V1	N	E17	N	V1	N	E17	N	V1	R	E17	L
V1	N	F16	N	V1	N	F16	N	V1	R	F16	R
V1	N	G15	N	V1	N	G15	N	V1	L	G15	L
V1	N	H14	N	V1	V	H14	N	V1	L	H14	L
V1	N	J13	N	V1	V	J13	N	V1	L	J13	L
V1	R	J13	N	V1	LC	J13	N	V1	N	J13	L
U2	N	J13	N	U2	R	J13	N	U2	N	J13	L
T3	N	J13	N	T3	R	J13	N	T3	V	J13	L
S4	N	J13	N	S4	N	J13	N	S4	R	J13	L
R5	N	J13	N	R5	V	J13	N	R5	N	J13	L
Q6	N	J13	N	Q6	N	J13	N	Q6	N	J13	L
P7	N	J13	N	P7	V	J13	N	P7	L	J13	L
08	N	J13	N	08	N	J13	N	08	L	J13	L
N9	N	J13	N	N9	N	J13	R	N9	L	J13	L
M10	N	J13	N	M10	R	J13	R	M10	L	J13	L
L11	N	J13	N	L11	R	J13	L	L11	L	J13	L

Legend: L = Loud and Clear
R = Readable
V = Very Weak
N = Nothing Heard

TABLE 5.5 NIGHT TEST, 12 JUNE 1963

(North Set being moved.)

A510 Set				AN/PRC-10 Set				C/PRC-26 Set			
North Set Location	Result	South Set Location	Result	North Set Location	Result	South Set Location	Result	North Set Location	Result	South Set Location	Result
V1	V	A21	L	V1	N	A21	N	V1	R	A21	L
U2	N	A21	L	U2	N	A21	N	U2	V	A21	N
T3	R	A21	L	T3	N	A21	N	T3	N	A21	V
S4	V	A21	L	S4	N	A21	N	S4	R	A21	R
R5	R	A21	L	R5	N	A21	N	R5	N	A21	N
Q6	R	A21	L	Q6	N	A21	N	Q6	V	A21	V
P7	R	A21	L	P7	N	A21	N	P7	N	A21	N
O8	L	A21	L	O8	V	A21	N	O8	L	A21	L
N9	L	A21	L	N9	N	A21	N	N9	L	A21	L
M10	L	A21	L	M10	N	A21	L	M10	L	A21	L
L11	L	A21		L11	L	A21	L	L11	L	A21	L

Legend: L = Loud and Clear
R = Readable
V = Very Weak
N = Nothing Heard

TABLE 5.6 NIGHT TEST, 12 JUNE 1963

(South Set being moved.)

A510 Set				AN/PRC-10 Set				C/PRC-26 Set			
North Set Location	Result	South Set Location	Result	North Set Location	Result	South Set Location	Result	North Set Location	Result	South Set Location	Result
V1	L	A21	L	V1	N	A21	V	V1	R	A21	L
V1	N	B20	L	V1	N	B20	N	V1	N	B20	N
V1	N	C19	L	V1	N	C19	N	V1	R	C19	L
V1	N	D18	N	V1	N	D18	N	V1	N	D18	N
V1	R	E17	L	V1	N	E17	N	V1	L	E17	L
V1	R	F16	L	V1	L	F16	-	V1	US	F16	-
V1	L	G15	L	V1	L	G15	L	V1	US	G15	-
V1	L	H14	L	V1	N	H14	N	V1	US	H14	-
V1	L	J13	L	V1	N	J13	N	V1	US	J13	-

Legend: L = Loud and Clear
R = Readable
V = Very Weak
N = Nothing Heard
US = Set unserviceable

RADIAL LAYING

TABLE 5.7 POSTTEST CONDITION OF CABLES

All Cables Terminated 28 feet from GZ

1. BURIED CABLE - 12"

Distance of Break from GZ	Twin Assault Cable		DIO Twisted Cable		Cause of Damage	Time to Restore
	Condition of Cable	Condition of Insulation	Condition of Cable	Condition of Insulation		
(a)	(b)	(c)	(d)	(e)	(f)	(g)
37'8"	Broken	Good	Broken	Good	Shrapnel	)Time to locate all)breaks was approximately 30 mins. Time)to restore another 1)hr. Total time to)make operational; ap-)prox. 1½ to 2 hrs.
103'	1 Strand OK Other Broken	Good	Broken	Good	Shrapnel	
180'	Broken	Good	Broken	Good	Shrapnel 4"x2" piece recovered	

2. BURIED CABLE - 2" - Twin Assault & DIO Twisted

(a)	(b)	(c)	(d)	(e)	(f)	(g)
37'8"	Broken	Good	Broken	Good	Shrapnel	) 2 - 2½ hours total) to make operation-) al as in) 1 above.
75'	Broken	Good	Broken	Good	Shrapnel	
103'	Broken	Approx. 2" Burnt. Probably from hot metal	Broken	Good	Shrapnel	
180'	Broken	Good	Broken	Good	Shrapnel	

3. BURIED CABLE - 6" - Twin Assault, DIO Twisted, Also Spiral 4 Terminated 425' from GZ

Distance of Break from GZ	Twin Assault Cable		DIO Twisted Cable		Spiral 4 (Carrier Quad)		Cause of Damage	Time to Restore
	Condition of Cable	Condition of Insulation	Condition of Cable	Condition of Insulation	Condition of Cable	Condition of Insulation		
37'8"	Broken	Burnt near break, probably due to metal	Broken	Slightly Burnt	Good	Slightly dented but conductors OK	Shrapnel	) Approx. 2½ hrs.) This again in-) cluded time to) locate and) repair.
75'	Broken	Good	Broken	Good	Broken	Good	Shrapnel	
103'	Broken	Good	Broken	Good	Broken	Good	Shrapnel	
180'	Broken	Good	Broken	Good	Good	Good	Shrapnel	

TABLE 5.7 CONTINUED

LATERAL LAYING

All Cable runs approx. 50 yards in length

1. OVERHEAD CABLES - 12' High - Single Aslt. DIO and Spiral 4

Predicted Zone at which located and Dist. from GZ	Single Assault Cable		DIO Twisted		Spiral 4				
	Condition of Cable	Condition of Insulation	Condition of Cable	Condition of Insulation	Condition of Cable	Condition of Insulation	Cause of Damage	Time to Restore	Remarks
(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(j)	(k)
TOTAL (175 ft)	All cables and their insulation completely destroyed beyond repair. Severe burning, numerous breaks and pieces thrown in every direction						Heat, blast flying debris (probably shrapnel)	All cables would have to be re- placed	None
SEVERE (375 ft)	Broken at ter- minating tree & 61 ft from this	Good	Broken 35' from termi- nating tree	Good	Good. No breaks	Good	Aslt & DIO broken by trees and/or debris	Aslt - 15 mins. DIO - 10 mins.	All cables were on the ground
MODERATE (525 ft)	Broken at 12'& 40' from ter- mination	Good	Broken 10' from one end	Good	Good. No breaks	Good	Aslt & DIO broken by trees and/or debris	Approx. 15 mins. for all re- pairs	Still part- ly raised
SLIGHT (725 ft)	Good	Good	Good	Good	Good	Good	Not appli- cable	Not appli- cable	All cables still in the air

2. GROUND LAID CABLES - Aslt (Single), DIO & Spiral 4

(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(j)	(K)
TOTAL	As for overhead cables - All beyond reclamation and repair.								
SEVERE	Broken 12' from termi- nals	Good	Good	Good	Good	Good	Trees and/or debris	10 mins. approx.	Cables scat- tered slight- ly. Had sep- arated at terminal points
MODERATE	Good	Good	Good	Good	Good	Good	Not appli- cable	Not appli- cable	)Cables still)intact and
SLIGHT	D Ho	Good	Good	Good	Good	Good	Not appli- cable	Not appli- cable	)none were)moved.

TABLE 5.7 CONTINUED

RADIAL LAYING

All cables terminated 28 feet from GZ

1. OVERHEAD CABLES - 12' High - Twin Aslt cable. DIO Twisted & Spiral 4

Distance from GZ	Twin Assault Cable		DIO Twisted		Spiral 4 Cable		Cause of Damage	Time to Restore	Remarks
	Condition of Cable	Condition of Insulation	Condition of Cable	Condition of Insulation	Condition of Cable	Condition of Insulation			
(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(j)	(k)
Up to 130'	Completely Lost.	Burnt, broken, Bared.	Completely Lost	Burnt, broken, bared.	Badly severed. Cut in short lengths	Severely burnt in patches	Heat, blast, flying debris including shrapnel	Beyond repair. Would have to be replaced	All but first 103' of Spiral 4 Cable was serviceable.
230'	Completely Lost	Broken and bared	Completely Lost	Broken and bared	Broken	Good	Shrapnel	Approx. 15 mins. including locating	
320'	Completely Lost	Broken and bared	Completely Lost	Broken and bared	Broken	Good	Shrapnel	Approx. 15 mins. including locating	
Up to 570'	Beyond repair. Many breaks. No breaks in last 205'	Insulation bared in numerous places under strain	Completely Lost	Broken and bared	Good	Good	Trees, falling debris	Approx. 1 hr. to lay & rebuild	Only last 205' of Aslt & DIO were serviceable.

2. GROUND LAID CABLE - Twin Aslt. DIO Twisted. 250' of Spiral 4 laid from 190' from GZ to peg 014 (44 0' from GZ).

(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(j)	(k)
230'	Broken and ripped in short lengths		Broken and ripped in short lengths First 130' burnt, ripped & broken		Broken	Good except where severed	Shrapnel	15 mins.	Spiral 4 perfect except for 2 breaks
Up to 240'	Broken & ripped in short lengths		Broken & ripped in short lengths		Good	Good		Impossible to repair first 240' of DIO	At 230 & 270' Aslt good except for first 250'
Up to 250'	Broken & ripped in short lengths	First 130' as for DIO	Good	Good	Good	Good		First 250' of Aslt cable beyond repair	DIO good except for first 240' Overhead crossing at 520' still intact.
270'	Good	Good	Good	Good	Broken	Good except where severed		15 mins.	

TABLE 5.7 CONTINUED

WIRE AERIALS - LATERALLY ERECTED

Predicted Zone of which located & Dist. from GZ	Cause of Damage to all aerials	Aerials Lightweight 68' (2 per DIPOLE)			Aerials, end fed, adjustable 135 ft.			Remarks
		Time taken to Locate	Damage Sustained	Effort to Restore	Time taken to Locate	Damage Sustained	Effort to Restore	
SEVERE (375 Feet)	Falling Trees and Branches. Also considerable debris evacuated from GZ area by blast effect.	3 men - 30 mins (This aerial was erected along existing bush track and therefore should have been comparatively easy to locate.	3 pieces of aerial recovered. Lengths 30', 45' and 21'. 38 feet of feeder recovered. No reels or feeder cage were found.	Not determined. Since not all the aerial was found, considerable time could be spent in trying to locate missing parts.	$1\frac{1}{2}$ man-hours spent endeavoring to find aerial without success. This was erected in extremely thick forest.	Completely destroyed. None of aerial found. Debris & lumber were piled very high and thickly entangled.	Would have to be replaced.	Debris piled 3' to 4' high at this zone. Severely tangled shrubs, vines & tree parts evacuated by blast. A piece of the tower $2\frac{1}{2}$ feet long was found nearby.
MODERATE (525 Feet)	Falling Trees and/or branches. Slight amount of debris evacuated from GZ area by blast.	2 men - 15 mins. This aerial also erected along existing bush track.	2 pieces of aerial recovered. (Lengths 67' & 63'3".) No reels found. Complete feeder found intact.	Considerable time could be wasted in trying to locate reels & remaining 4' of one leg; but minimum effort required to make remainder operational.	2 men - 1 hr. Laid on GZ side of existing bush track.	83' of aerial found in 5 pieces. Only 1 reel was found. In general, breaks were located either side of coupling link.	Would have to be replaced.	Debris at this Loc. thinner than above, but some substantially large trees had been felled by the blast.
SLIGHT (725 Feet)	Mainly falling branches. A few odd small trees were felled by missiles or by other trees.	2 men - about 2 mins. Erected in moderately thick jungle.	Very little. One side had slipped from feeder, but was not broken. This side was complete & still attached to its reel. Other side was broken 2' from reel, which was also located.	Little effort required. Need only to repair break near reel & re-erect. Estimate 10 mins. to repair & make operational.	2 men - 5 mins Erected in fairly thick jungle.	One break only, approximately central, location just at coupling link.	10 minutes to repair & make operational.	Debris slight. Small branches & vines hanging from trees.)

Chapter 6

TECHNICAL PHOTOGRAPHY

(Prepared by Mr. L. Mahoney, Edgerton, Germeshausen and Grier, Inc.)

Under DASA sponsorship, EG&G provided 19 documentary and high-speed cameras for the use of the Australians. An EG&G representative was present at the test site to give advice and assistance on the installation, operation, and repair of photographic equipment.

6.1 INSTRUMENTATION

Because the camera plan was completed only shortly before the test and because of the shipment time involved, it was not possible to resolve by correspondence all details of compatibility of U.S.-Australian timing marker equipment and electrical requirements for this experiment. An effort was made to correct the situation after arrival of the EG&G representative at the site, but the equipment requested from Boston did not arrive in time for the event. As a result, the cameras supplied by the U.S. did not have timing marks for measuring the speed of the camera records. However, useful data can be derived from the camera records by using nominal film speeds during analysis. Records from those cameras that were aimed at forest areas to document the motion of trees and projectiles are unaffected by the lack of time marks, because precise timing is not essential to the analysis of the data.

The cameras and photographic experiments were arranged along two sectors, each 1,000 feet long. The first, called the clear sector, ran southwest from ground zero (Figure 6.1). The other, or primary lane, extended northwest from ground zero. Figure 6.2 is a map of the general area showing a few of the camera locations.

In general, the camera stations were located along the primary lane at regular intervals as shown in Figure 6.3. The subjects for photography were trees, dummies, blast gages, and military equipment such as gun emplacements, foxholes, and supplies. General information pertaining to the types and numbers of cameras employed may be found in Table 6.1. Of the total complement of cameras used in the experiment, 19 were EG&G cameras furnished by DASA. Detailed information regarding distances of cameras from ground zero and camera characteristics can be found in Tables 6.2 through 6.5.

Tables 6.2 and 6.3 describe the characteristics of the cameras used in the clear sector and primary lane, respectively. The characteristics of the high-speed cameras used for photographing the detonation from South Bunker (2,400 feet from ground zero) are given in Table 6.4. Table 6.5 lists the characteristics of the medium- and low-speed cameras used to photograph the detonation from Lamond Mountain, 8,500 feet from ground zero. A legend of abbreviations used in Tables 6.2 through 6.5 is presented in Table 6.6.

Two major problem areas developed during the operation of the cameras. First, water condensation on the lenses, caused by cold nights and hot days, made good photography impossible. This problem was satisfactorily overcome only on the GSAP cameras, by installing 25-watt light bulbs in the stanchion beneath the camera, providing sufficient heat to dry the lenses. The second problem was the low light levels in the forest areas at the hour originally scheduled for the detonation (0730). Test runs showed that at 0730 the light level was too low even for proper exposure of Tri-X film. Changing the zero hour to 0830 and installing faster lenses on the cameras in the most heavily shaded areas alleviated the poor light conditions.

All cameras were battery operated except those at the South Bunker camera station where two Fastax WF-4 high-speed cameras requiring 220 vac were generator powered. Four standard 6-volt wet-cell storage batteries connected in series were used at each station to operate all other types of cameras. Batteries and control boxes were placed in wooden boxes in holes 3 to 4 feet deep (Figure 6.4). Logs and sandbags were used to cover the holes, and dirt was shoveled over the entire installation. Since Operation BLOWDOWN was a one-shot test, a more elaborate power distribution and control system was not needed. The high percentage of successful camera operations indicates that the protective measures employed were basically sound.

Two Fairchild HS-100 cameras; at Stations F1 and F2, and one Fastair camera, at Station F3, were mounted on tree stumps about 6 feet above ground (Figure 6.5). Natural materials were used extensively in building the various structures and mounts. The Fastair, Bolex, and Arriflex cameras on Lamond Mountain, and the Cine Special at the South Bunker, were manually started. All other cameras were started by a relay closure on a signal from the sequence timer at the Control Bunker. The Fastair and HS-100 Fairchild cameras were started at −2 seconds, and GSAP cameras were started at −5 seconds. The WF-4 Fastax cameras were operated by the Fastax Goose Control Unit. Cameras were programed to start approximately 0.7 second prior to zero time.

The GSAP camera mounts (stanchions) were steel pipes set in concrete as shown in Figures 6.6 and 6.7. The pipes were set into the ground at varying depths depending on their distance from ground zero. Stanchion overpressure rating was based on the depth to which the stanchions were buried. Table 6.7 lists the characteristics of the stanchions as they relate to their overpressure rating. All stanchions were identical in design except for the type of protective dome used. Two types of domes were used—one for vertical photography of the forest canopy, the other for horizontal views of forest and equipment. A 3-inch hole was machined in the top of the vertical-type dome, and a rectangular slot was machined in the side of the horizontal-type dome.

6.2 RESULTS AND CONCLUSIONS

Three cameras had mechanical problems and failed to function. All of the remaining 39 cameras operated successfully.

The four cameras installed at the South Bunker control point, (two Fastax Type WF-4, one Fairchild HS-100, and a Cine Special) as shown in Figure 6.8, operated successfully.

The camera mounts proved adequate in every respect. One GSAP camera mount was subjected to the direct impact of a large falling tree. As a result, the dome was driven downward, shearing three of the four $\frac{1}{2}$-inch bolts used to fasten the dome to the pipe stand (Figure 6.9). The Angenieux lens on the GSAP was shattered. The dome was wedged on so tightly that a sledge hammer was needed to remove it. The tree stump mounts proved satisfactory. No damage to the cameras and no loosening of the mounts occurred to instruments mounted on these stumps.

One of the main photographic problems during Operation BLOWDOWN was the low light levels, in the dense areas of the forest, even at the 0830 zero time. Royal X Pan film with an ASA index of 1250 might have been a better choice of film than Tri-X reversal film. Because of low light levels, the GSAP cameras were restricted to a framing rate of 32 frames/second. If the faster film had been used, the GSAP cameras could have been run at 64 frames/second, thus doubling the information content of the records.

Some difficulty was experienced in fitting the domes to the GSAP pipe mounts. Better tolerances of fitted parts would have prevented the cocking and jamming that was experienced in the normal course of installing and removing the covers. The inability to sight through the GSAP cameras with a boresight tool, even with the domes removed, proved a major handicap when aiming. However, useful records were obtained from all 39 cameras that operated. Excellent results were also obtained at the TV positions. These cameras ran at 32 frames/second.

A condensation cloud seems to have caused at least as much interference as dirt and leaves. Figures 6.10 through 6.12 are candid photographs of the detonation and aftereffects at ground zero area.

TABLE 6.1 NUMBERS AND TYPES OF CAMERAS

Camera	Film Size (mm x ft)	Frames Per Second	Lens Focal Lengths (mm)	Number of Cameras
GSAP	16 x 50	32	9.5	12
			12.5	17
			17	3
WF-4 Fastax	16 x 100	6,000	75	1
			50	1
HS-100 Fairchild	16 x 100	650	13.5	3
Fastair	16 x 100	650	25	1
			70	1
Kodak Cine Special	16 x 100	64	25	1
Bolex H-16	16 x 100	24	25	1
Arriflex	16 x 100	24	Variable Zoom	1
	Total Number of Cameras			= 42

TABLE 6.2 CHARACTERISTICS OF CAMERAS USED IN CLEAR SECTOR

Type	Camera Location	Target	Dist. from G. Z. (ft)	Stanchion PSI rating	f/number	Frames Per Second	Lens Focal Length (mm)
GSAP	R1	TH	645	10	11	32	12.5
GSAP	R2	TV	670	7	16	32	12.5
GSAP	R3	TH	717	7	11	32	12.5
GSAP	R4	TV	716	7	16	32	12.5
GSAP	S1	TV	514	20	16	32	12.5
GSAP	S2	DPI	546	10	11	32	12.5
GSAP	S3	TV	637	10	11	32	12.5
GSAP	T1	TH	450	20	11	32	12.5
GSAP	T2	TH	519	10	11	32	12.5
GSAP	V1	TH	296	30	11	32	9.5
GSAP	V2	TH	369	20	11	32	9.5
GSAP	V3	SPI	354	20	11	32	12.5
GSAP	V4	GUN	351	30	22	32	9.5
Fair-child HS-100	FR-1	Trees & Forest	391	tree stump	Unknown	650	70
Fastair	FR-2	Trees & Forest	560	tree stump	Unknown	650	13.5
Fair-child HS-100	FR-3	General view clear sector & G. Z.	878	tree stump	Unknown	650	13.5

TABLE 6.3 CHARACTERISTICS OF CAMERAS USED IN PRIMARY LANE

Type	Location	Target	Dist. from G. Z. (ft)	Stanchion PSI Rating	f/number	Frames Per Second	Lens Focal Length (mm)
GSAP	F-1	Dugouts	625	7	2.5	32	17.0
GSAP	F-2	Stores	466	10	2.2	32	9.5
GSAP	A-1	TV	252	40	8	32	12.5
GSAP	A-2	TV	350	20	11	32	12.5
GSAP	A-3	TH	347	20	4	32	9.5
GSAP	A-4	DPI	347	20	2.5	32	17.0
GSAP	B-1	DY	450	10	2.2	32	9.5
GSAP	B-2	TV	461	20	6.3	32	12.5
GSAP	C-1	TH	547	10	4.0	32	9.5
GSAP	C-2	DY M area	560	10	3.5	32	12.5
GSAP	C-3	TV	553	10	8	32	12.5
GSAP	C-4	Canopy	548	10	6.3	32	17.0
GSAP	D-1	M area	669	7	2.2	32	9.5
GSAP	D-2	TV	662	7	11	32	12.5
GSAP	D-3	DY M area	815	5	2.2	32	9.5
GSAP	D-4	TH	797	5	5.6	32	9.5
GSAP	E-1	TV	799	5	11	32	12.5
GSAP	E-2	M area	963	5	2.2	32	9.5
GSAP	E-3	TH	956	5	5.6	32	9.5

TABLE 6.4 CHARACTERISTICS OF HIGH-SPEED CAMERAS LOCATED AT SOUTH CONTROL BUNKER USED FOR PHOTOGRAPHING THE DETONATION

Type	Target	Distance to GZ (ft)	f/number	Frames Per Second	Lens Focal Length (mm)
16mm Fastax WF4-1	GZ	2400	22	6,000	75
16mm Fastax WF4-2	GZ	2400	11	6,000	50
16mm Fairchild HS-100	GZ	2400	UNK	650	13.5
16mm Kodak Cine Special	GZ	2400	16	64	25

TABLE 6.5 CHARACTERISTICS OF CAMERAS LOCATED ON LAMOND MOUNTAIN, 650 FEET ABOVE SEA LEVEL

Type	Target	Distance to GZ (ft)	Frames Per Second	Lens Focal Length (mm)
16mm Fastair	GZ	8500	650	25
16mm Bolex	GZ	8500	24	25
16mm Arriflex	GZ	8500	24	Variable Zoom

TABLE 6.6 ABBREVIATIONS USED IN TABLES 6.2 THROUGH 6.5

Abbreviation	Description
TH	GSAP view of forest and trees from side
TV	GSAP view of forest top from below the 6 foot level
DY	Dummies
DPI	Dynamic pressure gage
GUN	Artillery piece below ground level
DUGOUT	Log construction below ground level
STORES	Canned water and food stores, supplies
DY M area	Dummies and missile traps
CANOPY	View of overhanging tree cover and jungle growth

TABLE 6.7 DESIGN CHARACTERISTICS OF GSAP CAMERA STANCHIONS

PSI Rating	Length (ft)	Diameter (in)	Wall thickness (in)	Depth Below Ground (ft)	Approximate Dist. (Ground to Lens) (ft)
40	9.5	12	1/4	5.5	4.0
30	9.5	12	1/4	5.5	4.0
20	9.0	12	1/4	4.0	4.0
20 SHORT	3.5	12	1/4	2.0	1.5
10	6.75	12	1/4	2.75	4.0
10 SHORT	3.0	12	1/4	1.5	1.5
7	6.25	12	1/4	2.25	4.0
5	6.0	12	1/4	2.0	4.0

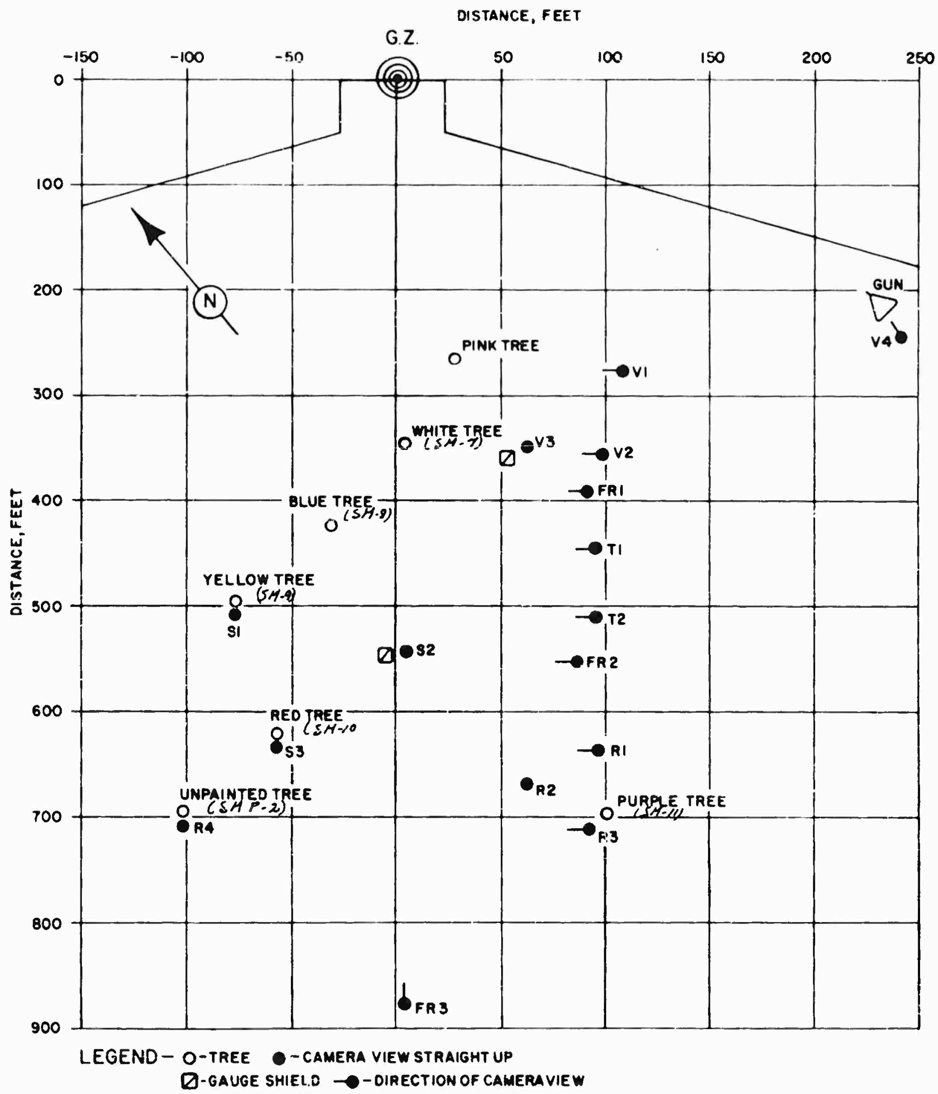


Figure 6.1 Map of clear sector.

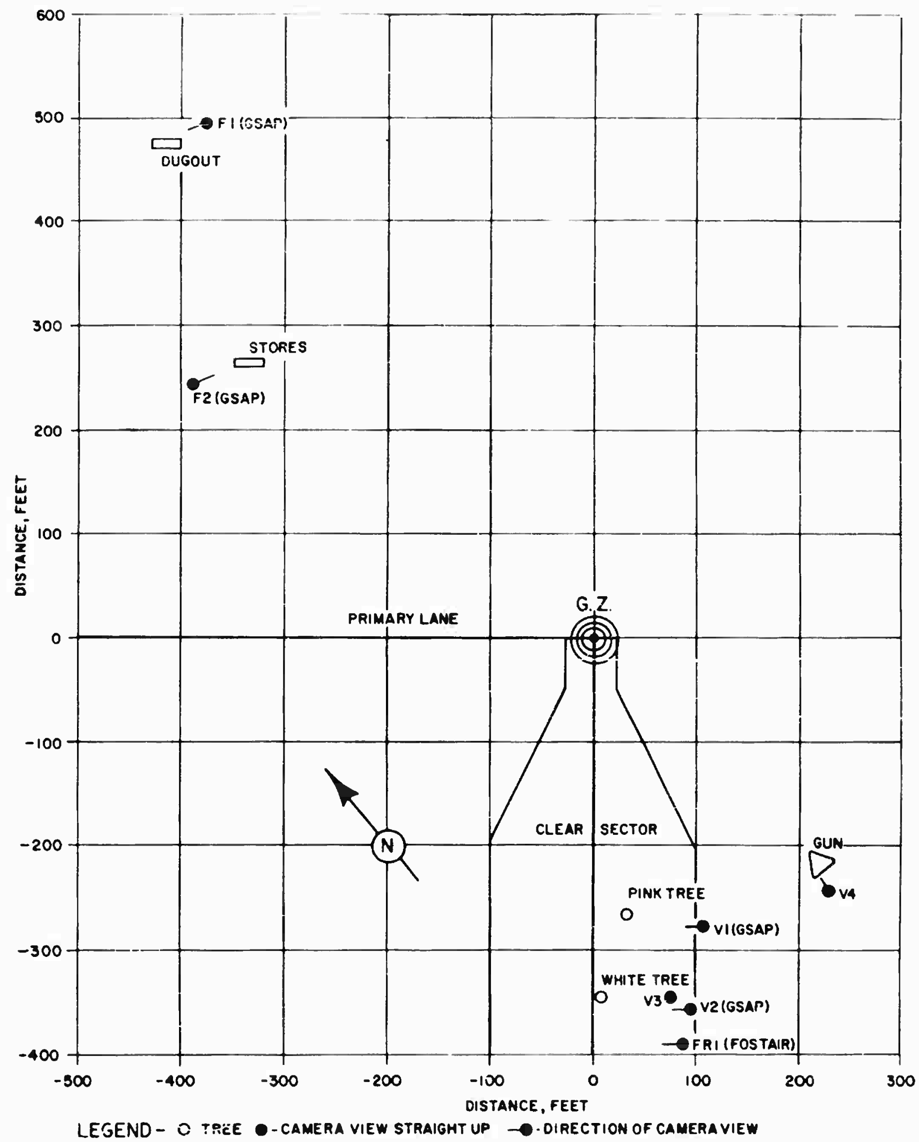


Figure 6.2 Map of area.

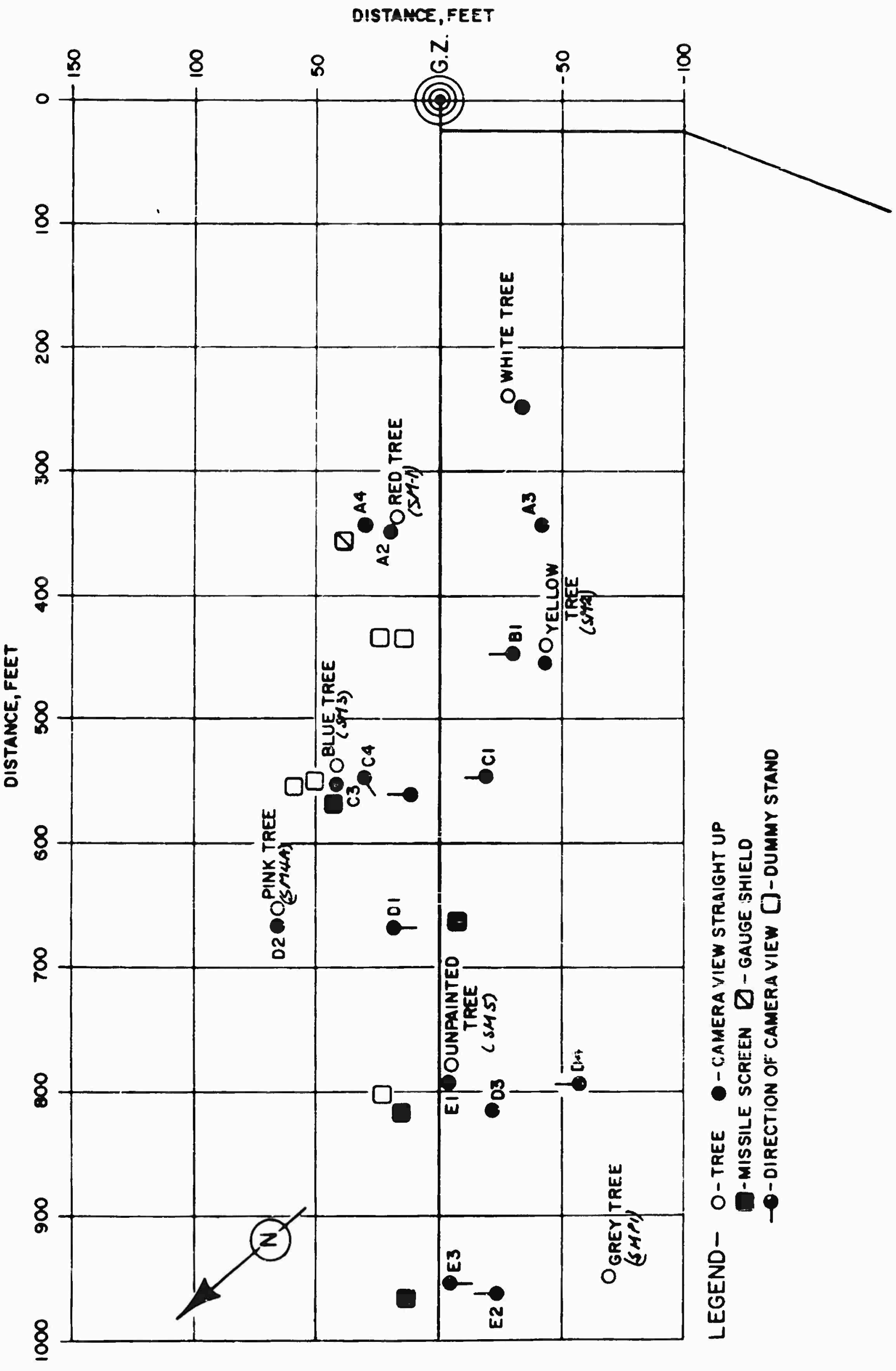


Figure 6.3 Map of primary lane.

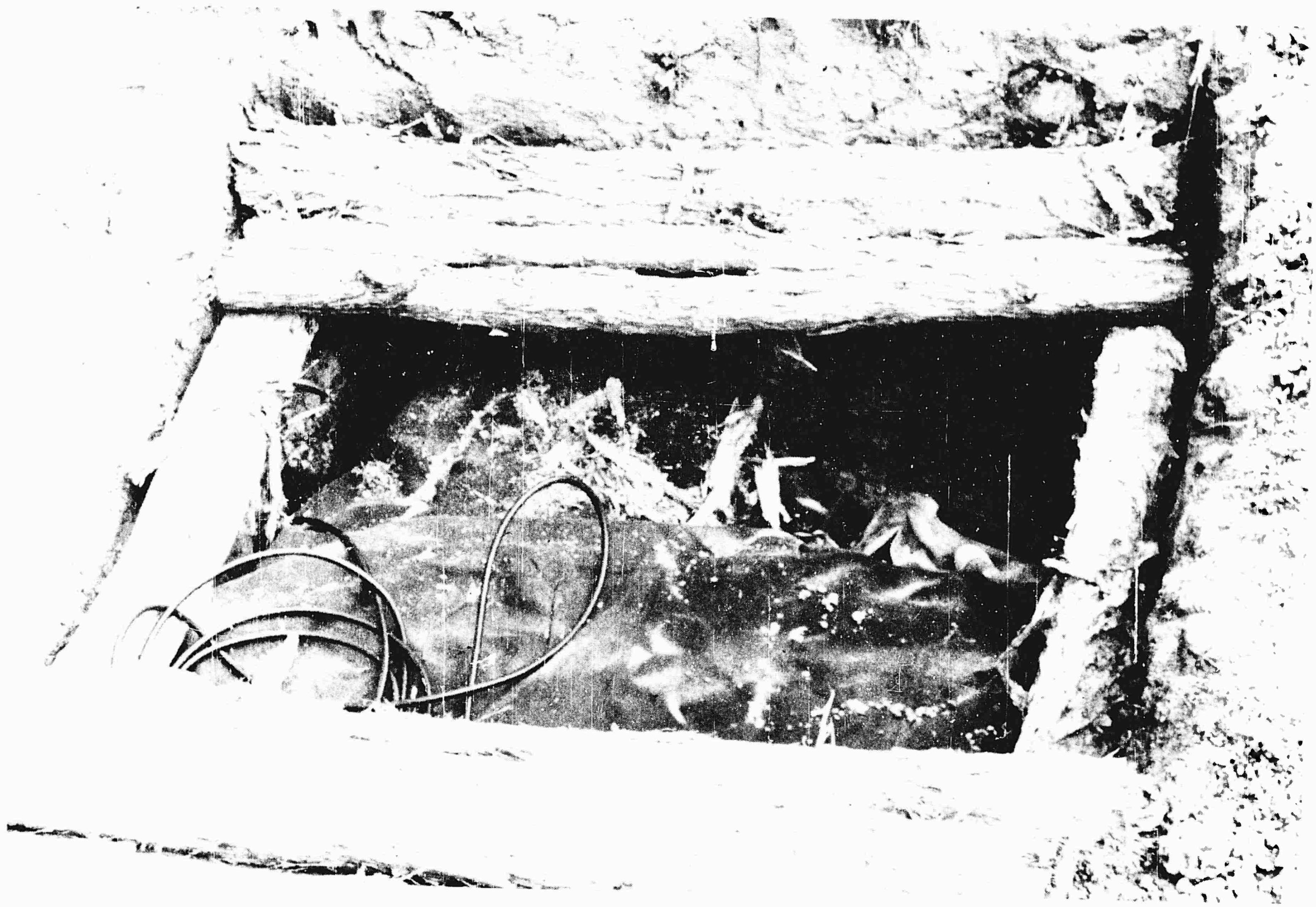


Figure 6.4 Typical dugout installation for protection of batteries and camera control boxes.

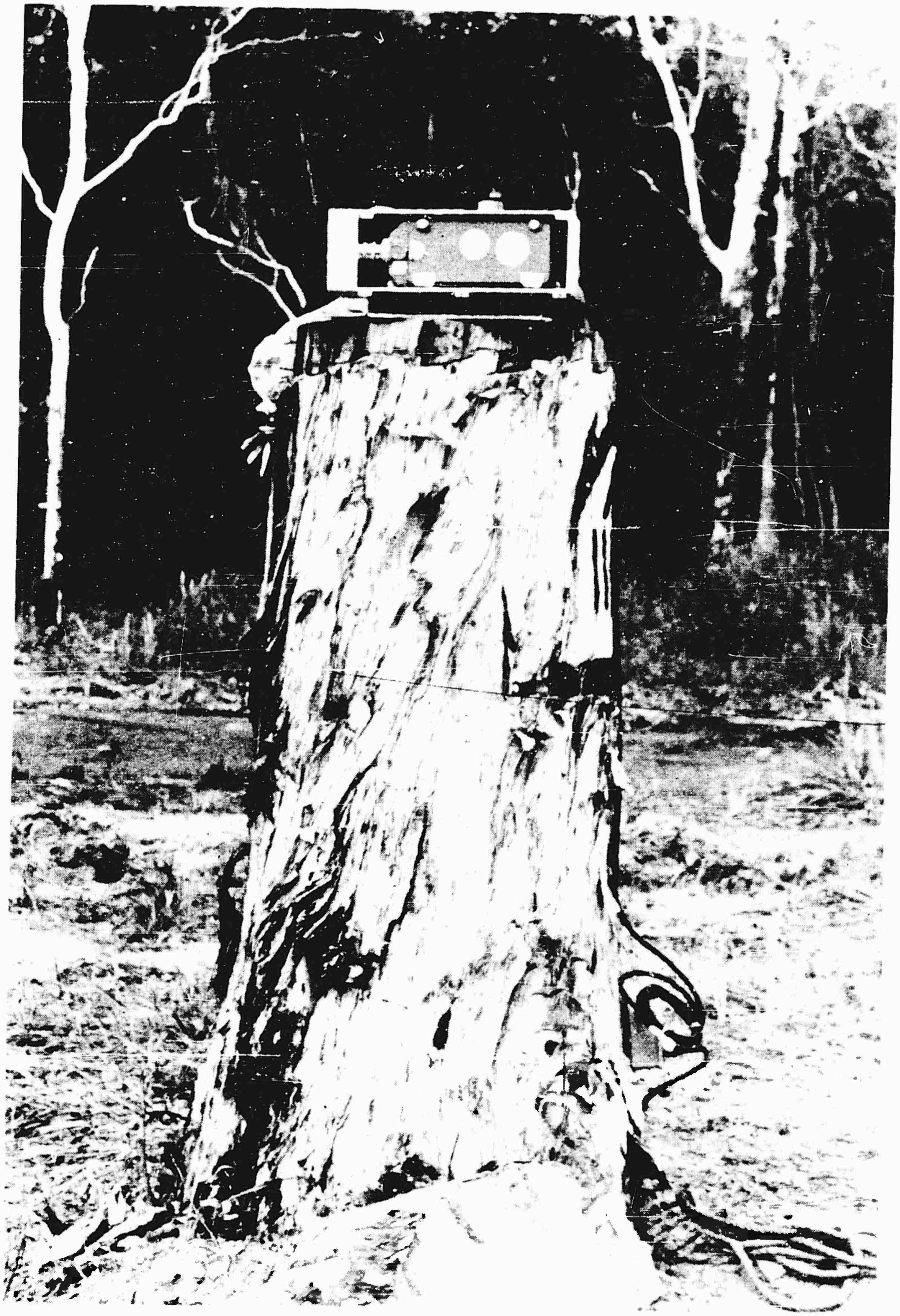


Figure 6.5 Fairchild HS-100 camera mounted on a tree stump.

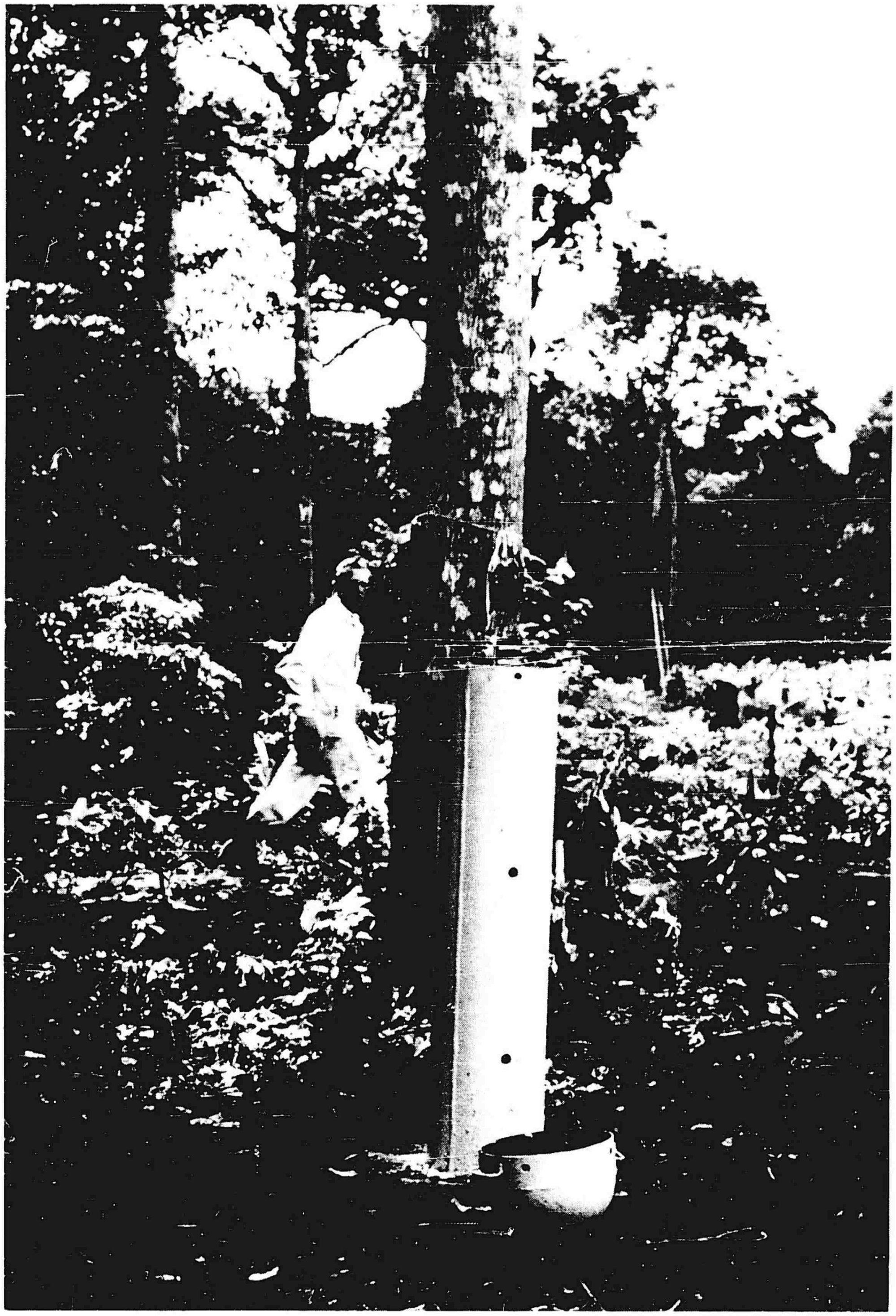


Figure 6.6 Typical GSAP camera installation with protective cover removed.

Figure 6.7 Typical GSAP camera installation, protective cover in place.

Figure 6.8 Camera installation at the South Bunker control point.

Figure 6.9 GSAP camera station damaged by falling tree.

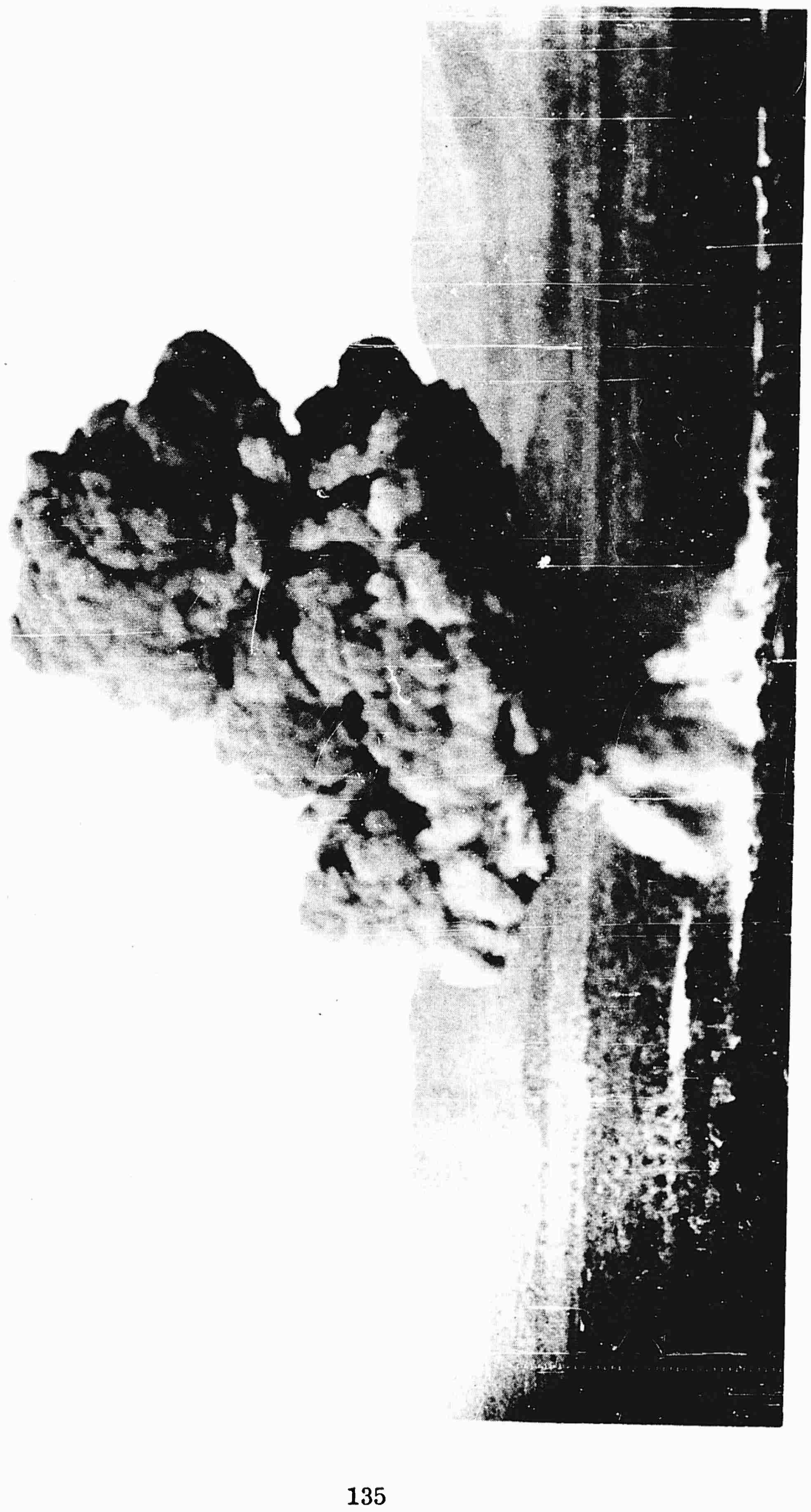


Figure 6.10 Mushroom cloud viewed from Mt. Lamond.

Figure 6.11 Forest damage near ground zero.

Figure 6.12 Ground Zero after detonation of charge.

Chapter 7

SPHERE TRANSLATION EXPERIMENTS

(Prepared by Mr. I.G. Bowen, Lovelace Medical Foundation)

It has been shown both theoretically (Reference 23) and experimentally (Reference 24) that the translational behavior of an object exposed to a particular blast wave is largely dependent on its acceleration coefficient, defined as the area presented to the wind times the drag coefficient divided by the mass of the object. Thus, spheres of appropriate mass and density can be substituted for man as experimental objects, provided the acceleration coefficients are equivalent.

Man, of course, is not a symmetrical object and thus has different acceleration coefficients for different orientations with respect to the wind (Reference 25). If the blast wave has a relatively long duration, as those from nuclear explosions, the accelerative time and distance are also relatively long. Under these conditions the effects of changing orientation must be taken into account (Reference 26). For an explosion of the size used in Operation BLOWDOWN (50 tons of TNT), however, it can be shown from data in Reference 27 that about 99 percent of maximum velocity is reached in the first 22 inches of travel or less. Since minimal rotation could occur in this short distance of travel, it would probably be sufficient to consider only the acceleration coefficient corresponding to the position of the man when the blast wave arrives.

Also, by similar reasoning, ground friction is less effective in modifying translational velocities during acceleration for blast waves from low yields compared to those from high yields since the accelerative distances are shorter. Of course, to attain the same velocity with a low-yield explosion as with a high-yield one, the object must be located in a higher pressure field where the dynamic pressures of the winds are greater.

The purpose of the translation experiments with steel spheres was to measure impact velocities of various sizes of spheres by a trapping technique described in the next section. These velocities, determined as a function of acceleration coefficient and range from ground zero, could then be used to help evaluate the translation hazard to man of various sizes and in various initial orientations. Also, it was hoped to determine the effect of a rain forest upon the translation of objects.

Another purpose of the sphere experiments was to help validate the computational procedures used in References 23 and 27 to predict translational velocities as functions of time and distance. To do this, the measured blast parameters were used as input to the translation model and the computed velocities were compared to those measured with the trapping technique.

7.1 TRAPPING TECHNIQUE

The trapping technique consists of mounting a suitable absorbing material in such a way that translated objects will strike it. The depth that a particular object penetrates the absorber is then related to the object's impact velocity, using the results of calibration tests made in the laboratory.

The absorbing material used in the BLOWDOWN experiments consisted of sheets of expanded polystyrene 1 foot by 3 feet by 2 inches. Some of the physical characteristics of three types of this material which were used are listed in Table 7.1. Not indicated in the table is the fact that the material is very nonresilient, i.e., deformations which occur are permanent. Another desirable quality is that the deformations due to impact are localized to the area of impact. This makes it possible to evaluate velocities for objects which strike near each other.

In most instances, use was made of trees and stumps to anchor the missile traps. A piece of $^3/_4$-inch bondwood whose dimensions were 1 inch larger than the sheets of absorbing material was secured in a vertical position to a tree or stump on the side facing ground zero. A single 2-inch layer of absorber was then cemented to the bondwood with linoleum cement, clamped in place, and left to dry for about 24 hours. If a tree or stump was not available for anchoring a trap, a 6-foot post about 12 inches in diameter was mounted in a hole 3 feet deep. The bondwood was then secured to the post as described above.

In three instances, the 2-inch layer of absorber was cemented to a flat surface of a wooden box which was secured to a concrete slab whose top surface was approximately even with the floor of the forest. These traps were only 1 foot high but 3 feet wide.

Spheres were held in place at appropriate positions in front of the traps in shallow troughs made of aluminum foil suspended from a horizontal wire stretched between two steel posts. The troughs were attached to the supporting wire on one edge; the other edge faced ground zero so that the blast winds would catch in the trough and rip it open, releasing the spheres. A typical station is shown in Figure 7.1.

7.2 GROSS RESULTS

Thirteen traps were used, 5 in the cleared sector and 8 in the U.S. sector (forested). Data for the traps in the cleared sector are presented in Table 7.2 and those for the U.S. sector in Table 7.3.

The 5 traps in the cleared sector were placed at 5 different ranges where the expected maximum overpressures ranged from 7 to 30 psi (see Table 7.2). All traps survived the blast experience without unusual damage except the one at 30 psi. This trap was mounted on a 12-inch-diameter post set in the ground 3 feet. Although the post did not fracture, the blast winds caused it to lean away from ground zero. Also, the face of the absorber was covered with a layer of leaf and grass mulch about 2 inches thick.

The 8 traps in the U.S. sector were placed at 6 different ranges where the maximum overpressures expected ranged from 5 to 40 psi (see Table 7.3). Only the trap at 40 psi was partially dislodged from its tree anchor.

The sphere samples used with each of the 13 traps are described in Table 7.4. The heights above the bottom of the traps at which the spheres were placed are also listed. The distances the spheres were placed in front of the traps are listed in Tables 7.2 and 7.3. These distances were computed by methods described in References 23 and 27 to be those necessary for the spheres to attain about 99 percent of their maximum velocities.

Typical results are shown in Figures 7.2 and 7.3, postshot photographs.

Although the spheres which were caught by the traps have not been extracted, a count was made of the captured spheres and also of the impressions made where the spheres were not captured. The sphere making an impression can be identified if the impression is sufficiently deep (about one sphere radius). Tables 7.2 and 7.3 list for each trap the numbers of spheres caught and their estimated sizes. Also listed are the number of impressions of sufficient depth that identification of the impacting sphere may be possible.

Most of the spheres which were caught were of the smaller sizes while most of the impressions (without capture) were made by the larger ones. A total of 152 spheres were caught and an additional 364 made impressions without capture. Thus, it may be possible to determine impact velocities for as many as 516 spheres.

7.3 AUSTRALIAN DUMMY EXPERIMENT

The Australians conducted a limited dummy translational experiment. This portion of the test is discussed in Appendix H.

TABLE 7.1 EXPANDED POLYSTYRENE USED AS MISSILE ABSORBERS
(Manufactured by Dow Chemical Company, Midland, Michigan)

Absorber type	II	III	IV
Manufacturer's designation	Styrofoam 22	Q103.15	HD2
Density, lbs/ft^3	1.4-2.0	2.8-3.2	4.4
Compressive yield strength, psi	28	50-80	130
Shear strength, psi	32	53-62	88
Maximum temperature for continuous use	175°F	175°F	175°F

TABLE 7.2 DATA FOR TRAPS IN CLEARED SECTOR
(All traps were 1 foot wide and 3 feet high)

Trap Number	C7	C10	C15	C20	C30	Total
Range, ft	670	550	425	360	300	
Approx. maximum overpressure	7.0	9.8	15	20	30	
Type of Absorber*	II	II	III	III	IV	
h, in.	2	-1	-1	9	4	
d, in.	14	22	22	22	22	
1/8 in. spheres caught	0	1	54	37	19	
1/4 in. spheres caught	0	0	3	0	4	
1/2 and 9/16 in. spheres caught	0	0	0	0	1	
Total spheres caught	0	1	57	37	24	119
Sphere impressions	21	45	19	45	3	133
Total possible velocity determinations	21	46	76	82	27	252

*See Table 7.1

h: height of bottom of trap above forest floor.

d: distance of spheres in front of trap.

TABLE 7.3 DATA FOR TRAPS IN U.S. SECTOR
(Traps were 1 ft wide and 3 ft high except where noted)

Trap No.	U5*	U7a	U7b*	U10a*	U10b	U15	U20	U40	Total
Range, ft.	770	659	659	550	550	439	372	260	
P_m (approx), psi	5.2	7.2	7.2	9.8	9.8	14	19	40	
Absorber**	II	II	II	II	II	III	III	IV	
h, in.	2	15	2	2	8	22	14	12	
d, in.	9	12.5	13	22	22.2	22	21.5	22	
1/8in. spheres caught	0	3	1	8	5	2	5	4	
1/4 in. spheres caught	0	1	0	0	2	0	2	0	
1/2 & 9/16 in. spheres caught	0	0	0	0	0	0	0	0	
Total caught	0	4	1	8	7	2	7	4	33
Sphere impressions	6	10	24	18	37	39	30	67	231
Total possible velocity determinations	6	14	25	26	44	41	37	71	264

*These traps were 3 ft. wide and 1 ft. high.

**See Table 7.1

P_m: maximum overpressure.
h: height of bottom of trap above forest floor.
d: distance of spheres in front of trap.

TABLE 7.4 PLACEMENT OF STEEL SPHERES IN FRONT OF TRAPS

Trap	h_1	h_2	h_3	h_4	h_5	h_6
C7	C	B	A			
C10	C	B	A			
C15	C	B	A			
C20	C	B	A			
C30	C	B	A			
U5				A	B	C
U7a	C	B	A			
U7b				A	B	C
U10a				A	B	C
U10b	B	C	A			
U15	B	C	A			
U20	B	C	A			
U40	C	B	A			

Sphere Samples

A: 10 spheres 9/16 in. in dia., 14 spheres 7/16 in. in dia.
B: 48 spheres 1/4 in. in dia., 192 spheres 1/8 in. in dia.
C: 12 spheres 1/2 in. in dia., 16 spheres 3/8 in. in dia.

Heights of Placement above Bottom of Traps

h_1: 8.5 in.
h_2: 18.5 in.
h_3: 28.5 in.
h_4: 6.5 in. on left side of trap.
h_5: 6.5 in. in the center of trap.
h_6: 6.5 in. on right side of trap.

Figure 7.1 Typical station for trapping experiment (preshot).

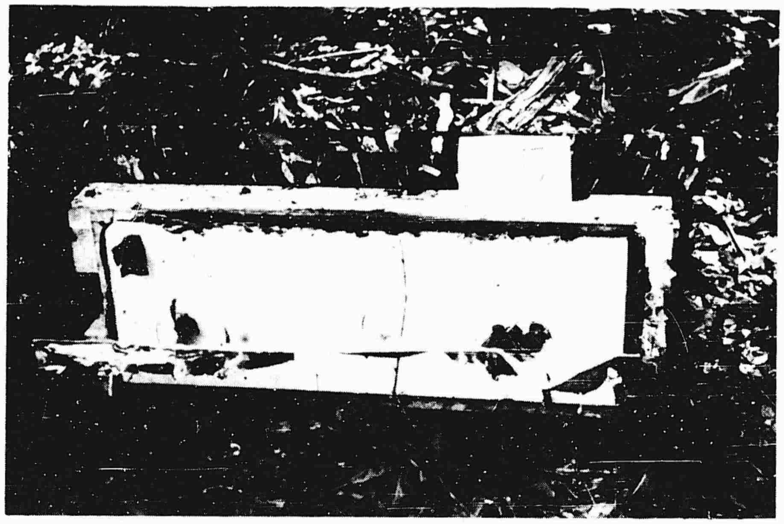


Figure 7.2 Typical station for trapping experiment (postshot).

Figure 7.3 Typical station for trapping experiment (postshot).

Chapter 8

SUMMARY

(Prepared by Mr. J.R. Kelso and Lt Col C.C. Clifford, Jr., Headquarters, DASA)

Operation BLOWDOWN provided an excellent opportunity to verify U.S. tree-blowdown prediction techniques. It was extremely well planned and executed as part of a comprehensive research effort carried out by the Australian Department of Supply. The logistical effort provided by the Australian Army, to include construction of the base camp and test area, as well as the continuing scientific support provided during Phases I, II, and III, contributed greatly to the success of the experiment. In particular, U.S. participants were impressed by the overall control and safety procedures established by Northern Command for test operations in the field. As a result of this joint scientific-military teamwork, large-scale blast effects in a natural rain-forest environment were thoroughly documented. A considerable number of instrumentation and photographic records covering blast phenomena, tree-blowdown, and military trials were obtained. Further analysis of this information is required in order to evaluate the overall military significance of this experiment with regard to ultimate effects on tactical operations.

REFERENCES

1. "Report by Working Party on Assessment of Blowdown Experiment;" RD/37 Australian Department of Supply, July 1961, (CONFIDENTIAL).

2. DASA-619, "Project DOLPHIN—U.S. Participation with Australia in a High Explosive Experimental Program;" July 1963; Defense Atomic Support Agency, Washington, D.C. (CONFIDENTIAL).

3. Stanford Research Institute letter by F. M. Sauer to Chief, DASA, dated 17 October 1962 (UNCLASSIFIED).

4. Cribb, J. L.; "Theoretical Investigations into the Blowdown Problem;" Defense Standards Laboratories (DSL) Tech. Note 58 (CONFIDENTIAL).

5. Cribb, J. L, and Bowe, P.W.A.; "Prediction of Blowdown;" Defense Standards Laboratories (DSL) Report 263, June 1963 (CONFIDENTIAL).

6. "Implications of Fire and Blowdown Resulting from Tactical Nuclear Weapons;" CECD 59-3, December 1959 (UNCLASSIFIED).

7. Vortman, L.J., and Shreve, J.D.; "The Effects of Height of Experiments on Blast Parameters;" Sandia Report 38-58, June 1956; Sandia Corporation, Albuquerque, New Mexico.

8. Fons, W.L., F.M. Sauer, and W.Y. Pong; "Blast Effects on Forest Stands by Nuclear Weapons;" AFSWP-971, December 1957.

9. Pong, W.Y.; "Tree Breakage Characteristics under Static Loading of Several Hardwood Species;" AFSWP-970, U.S. Forest Service, Division of Fire Research, 1956.

10. Fons, W.L., and Pong, W.Y.; "Tree Breakage Characteristics Under Static Loading—Ponderosa Pine;" AFSWP-867, U.S. Forest Service, Division of Fire Research, 1957.

11. Storey, T.G., et al; "Crown Characteristics of Several Coniferous Tree Species—Relations Between Weight of Crown, Branchwood and Foliage, and Stem Diameter;" AFSWP-416, U.S. Forest Service, Division of Fire Research, 1955.

12. Storey, T.G., and Pong, W.Y.; "Crown Characteristics of several Hardwood Tree Species—Relations Between Weight of Crown, Branchwood and Foliage, and Stem Diameter;" AFSWP-968, U.S. Forest Service, Division of Fire Research, 1957.

13. Storey, T.G., and Fons, W.L.; "Natural Period Characteristics of Selected Tree Species;" AFSWP-864, U.S. Forest Service, Division of Fire Research, 1956.

14. Lai, W.; "Aerodynamic Crown Drag of Several Broadleaf Tree Species;" AFSWP-863, U.S. Forest Service, Division of Fire Research, 1955.

15. Sauer, F.M., et al; "Experimental Investigation of Aerodynamic Drag in Tree Crowns Exposed to Steady Wind—Conifers;" ORO Phase Report, U.S. Forest Service, Division of Fire Research, 1951.

16. Clements, V. A., et al; "Form-Class Volume Tables for Ponderosa Pine, Douglas Fir and White Fir in California;" Res. Note No. 60, California Forest and Range Experiment Station, 1949.

17. Sauer, F. M., et al.; "Blast Damage to Coniferous Tree Stands by Atomic Explosions;" Project 3.19, Operation UPSHOT-KNOTHOLE: WT-731, Confidential. U.S. Forest Service, Division of Fire Research, 1954.

18. Tiren, L.; "Nagra Undersokningar Over Stamformen;" (Some Research on Tree Stem Form), Sjogsvardsforeningens Tidskrift, XXIV, pp. 23-88, 1926.

19. Hedgren, Av. B., and K. Hendriksson; "Tallens och Granens Stormfasthet;" (Resistance Against Storms of Pines and Firs), Foisvarets Forskningsanstalt, FOA4, Report No. A 4142-452, June 1960.

20. Brown, A. A., et al; "Blast Damage to Trees—Isolated Conifers;" Project 3.3, Operation SNAPPER, WT-509, Confidential. U.S. Forest Service, Division of Fire Research, 1953.

21. Milne, W. E.; "Damped Vibrations;" Univ. of Oregon Publications, Vol. 2, No. 2, 1923.

22. Defence Standards Laboratory letter by J. Cribb and P. W. A. Bowe to F. M. Sauer, dated December 7, 1962.

23. Bowen, I. G., R. W. Albright, E. R. Fletcher, and C. S. White; "A Model Designed to Predict the Motion of Objects Translated by Classical Blast Waves;" Civil Effects Test Operations, U.S. Atomic Energy Commission, CEX-58.9, June 29, 1961.

24. Bowen, I. G., M. E. Franklin, E. R. Fletcher, and R. W. Albright; "Secondary Missiles Generated by Nuclear-Produced Blast Waves;" Civil Effects Test Operation, (in press), WT-1468.

25. Fletcher, E. R., R. W. Albright, V. C. Goldizen, and I. G. Bowen; "Determinations of Aerodynamic-Drag Parameters of Small Irregular Objects by Means of Drop Tests;" Civil Effects Test Operations, U.S. Atomic Energy Commission, CEX-59.14, October 1961.

26. Taborelli, R. V., I. G. Bowen, and E. R. Fletcher; "Tertiary Effects of Blast—Displacement;" Civil Effects Test Operations, U.S. Atomic Energy Commission, WT-1469, May 22, 1959.

27. Bowen, I. G., P. B. Woodworth, M. E. Franklin, and C. S. White; "Translational Effects of Air Blast from High Explosives;" Technical Progress Report, DASA 1336, Defense Atomic Support Agency, Washington 25, D.C., November 7, 1962.

APPENDIX A

U.S. INSTRUMENTATION EQUIPMENT

A.1 INSTRUMENT BUNKER K-1

The K-1 bunker was a surface excavation approximately 8' wide by 12' long by 6' deep. Stabilization of the earthen pit was provided by lining the walls with saplings and veneering this with masonite panels. This wall was utilized as a support for the lid that covered the instrument bunker. Beneath the plywood floor, a sump pit was provided to insure against the rise of water due to flooding or seepage. A ladder constructed of saplings provided the means of entry to the shelter. During the preparation stage, a tarpaulin provided adequate protection against sudden tropical rains. This temporary canvas was removed and replaced with a pre-formed metal cover during button-up operations on D-day. A layer of saplings was placed atop the metal lid to prevent missiles from crashing through the roof. Sand bags were used to seal the openings between the roof edge and the pit walls.

The entire recording instrumentation was placed on a bench running the length of the bunker. Constant voltage transformers and other related components were located in the area beneath the bench.

A.2 INSTRUMENTATION (K-1 BUNKER)

The instrumentation in K-1 bunker recorded the outputs from the Norwood Transducers located in positions H-1, P-1 through H-6, P-6. This instrumentation, the U.S. loaned equipment, consisted of twelve (12) channels of Consolidated Electrodynamics (CEC) carrier amplifiers type 1-127 and two (2) oscillograph paper recorders. Associated with the recording instruments were the necessary coupling and logic units, power and timing equipment.

A.2.1 Amplifiers.

Consolidated Electrodynamics (CEC) Amplifiers.

The type 1-127 carrier amplifier is a complete carrier amplification system, contained in a single cabinet a 20-kilocycle carrier oscillator, four carrier amplifier channels, a regulated power supply and controls for balancing, setting sensitivity, metering output and calibrating.

This amplifier is designed for operation with two - or four - element resistive bridge transducers, with resistances of 60 to 1,000 ohms, as well as reluctance and differential transformers which operate in the region of 20 kilocycles and have phase shifts not exceeding 45°.

The nominal sensitivity of the amplifiers is such that an unattenuated input signal of 1.0 millivolt rms, with a source impedance of 350 ohms, will cause full scale output. For nominal carrier voltage and nominal amplifier sensitivity, the system sensitivity is such that a strain of 100 micro-inches per inch will cause full scale output, using a four-active-arm; 350-ohm, strain bridge, with a gage factor of 2.0. The nominal carrier voltage developed by the oscillator is 5 volts rms.

Each amplifier has a precision attenuator which provides 20 individual steps of input attenuation. The voltage attenuation steps provided are: 1, 1.5, 2, 3, 5, 7, 10, 15, 20, 30, 50, 70, 100, 150, 200, 300, 500, 700, 1000 and off. A sensitivity control, R-116, located in the rear of each individual amplifier, allows adjustment to full scale output for a 0.1-mv, rms, open-circuit signal from any bridge with a resistance from 60 to 1,000 ohms. The amplifier frequency response extends from 0 to 5000 CPS. The output is sufficient to produce 1.5 inches deflection with one of the several type CEC galvanometers having flat response of 3000 CPS or greater.

A.2.2 Coupling and Logic Units (BRL design).

The coupling units were designed to broaden the phasing and balancing capabilities of the CEC amplifier systems. In addition, they provide local and remote control of electrical calibration steps and reversal switches for transducer and calibration signals. The logic units accept remote field commands from which they cycle the recording systems through a data gathering sequence.

A.2.3 Oscillographic Recorders.

The oscillographic recorders used in the K-1 bunker were the CEC type 5-114, capable of recording dynamic phenomena. This instrument is designed to record signals obtained from sensing transducers. The electrical impulses received from the gage are amplified and introduced into the galvanometer chamber of the 5-114. Once here, the intelligence signal is translated by use of a reflected light beam on a rotating galvanometer mirror against a rapidly moving photographic media. The record of the signal impulses produced by the transducers is reproduced on the surface of this sensitized paper. By presetting the controlling features in the proper combinations offered by this recorder (i.e., light intensity and paper speed), clear, legible, transducer signals are permanently reproduced.

Six of the twelve transducer amplifier channels were fed to type 7-326 galvanometers having a flat frequency response of 3,000 cps on each of the two recorders. Other galvanometers were utilized to record timing, time zero, reference lines or spacings.

The recorder paper speed was geared to run at 70.5 inches per second, driving Lino-Writ 4 Ultra Thin Paper in 225-foot rolls. The trace interrupters, available for trace identification, were disconnected to prevent the possibility of the interruption occurring during a critical peak mode of a channel signal.

A.2.4 Pressure Transducers.

The twelve transducers instrumented from K-1 bunker were all Model 111, Norwood-bonded, 4-arm, strain gages. This gage was developed to measure the static and dynamic pressures in internal combustion engines. It incorporates a pressure sensitive diaphragm and a pre-loaded strain tube with bonded strain gages. The small mass and minute deflection of this assembly results in high frequency response characteristics. The gage assembly is very resistant to vibration and acceleration effects. The unique design of the pressure transducer provides a highly accurate electrical output with exceptional temperature compensation. The pressure to be measured is imposed on the diaphragm. As the pressure increases, the slender cylindrical tube decreases in length while increasing in diameter. These dimensional changes are detected by the strain gages which are bonded directly onto the strain tube in such a manner that the resistance of the circumferential winding increases and the longitudinal winding decreases. The unbalance in resistance is proportional to the applied pressure.

General gage specifications - Norwood Pressure Transducers

Bridge -	Four active arms.
Non-Linearity -	Better than 0.25% by best straight line through zero.
Hysteresis -	Better than 0.5% full-scale.
Repeatability -	Better than 0.1% full-scale.
Acceleration -	Less than 0.01% full-scale per "G" in all planes.
Vibration -	Insensitive from 50 to 2000 cps to 100 G in 3 planes.
Temperature Range -	65°F to 300°F uncooled.
Zero unbalance -	Less than ± 2% full-scale.
Temperature Effects -	0-200° F. Zero shift less than 0.02% FS/F° change Sensitivity shift less than 0.01% FS/F° change.
Resonant Frequency -	45000 cps.
Negative Pressure -	Usable to full vacuum.
Pressure Limit -	125% full-scale static 100% full-scale Dynamic.
Excitation-	10 Volts AC or DC"17V max."
Electrical Output -	30-35 mv/V.

A.2.5 Procedure.

Transducer Calibration.

All transducers with the exception of those on the tower were calibrated in their final position. Adapters to fit the calibration equipment were fastened over each transducer and left permanently in place during the calibration phase. A recalibration required only re-connecting the calibrator to the connector.

Static pressures were applied to the transducers in 20-percent steps up thru 120 percent of the predicted pressure. Some non-linearity of the calibration plots suggested that the dial gages were inaccurate. A recalibration of these gages gave a more accurate indication of the true pressure. This correction was applied to the final calibration plots.

A.2.6 Time Zero (TZ) and Timing.

Time zero was recorded on dual galvanometers in each of the oscillographs. This signal was established with silicon solar cells having an output of 0.6 to 0.85 volt. These were mounted on a 90-foot tower approximately 780 feet from GZ. The shot light intensity was sufficient to drive the galvanometers several inches to give excellent time zero traces. Timing was derived by driving a galvanometer in each recorder with a Hewlett Packard Oscillator locked on the 1.0-kc position. This instrument has the capacity of generating an excellent wave form in the 1.0-kc range. Since its signal originates from a source of low distortion and high stability, its trace with 1.0 ms peaks is an ideal reference by which the intelligence signal timing can be measured.

A.2.7 System Power

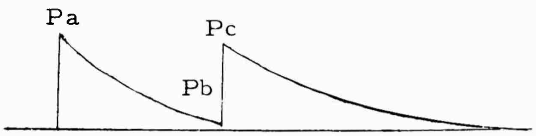
Power for K-1 bunker was received from underground cables terminating at a generator near the south bunker. The power source was 230 volts at 50 cycles. A voltage stabilizer and step-down transformer were required to power the 115 volt U.S. equipment. During the earlier stages of preparation for the shot, K-1 power caused noise on the south bunker signal lines. Line balancing and filtering minimized this effect. The 50-cycle power appeared to drive the 60-cycle equipment satisfactorily; however, the speed of the induction sequencing motor was affected. The slower speed required use of a slightly lower paper speed in order to record the post shot calibrations.

A.2.8 Instrumentation Results.

The performance of the instrumentation of K-1 bunker was completely satisfactory. The signal records obtained were of good quality. The signal from H-1 transducer was shifted when a missile struck the gage mount; however, the record is usable. One channel of information (P-4) showed approximately 22 percent change in electrical calibration between D-2 and shot. A post-shot calibration of this channel revealed a maximum of 5-percent error would be inserted in the data by using the original calibration. A detailed summary of instrumentation results is tabulated in Table A.1.

TABLE A.1 U.S. INSTRUMENTATION - K-1 BUNKER

Gauge Range	Gauge No.	System No.	Cable No.	100% Pressure	Measured Pressure			Positive Duration	Time of Arrival	Height of Gage
ft.					Pa	Pb	Pc	m sec.		
260	H 1	1	3-4	70	67.2	--	--	071.	104.5	1' 9"
260	P 1	1	1-2	40	40.3	--	--	076.	104.5	----
300	H 2	2	7-8	50	50.9	--	--	103.	125.5	1' 9"
300	P 2	2	5-6	30	30.9	--	--	104.	125.5	----
360	H 3	1	11-12	30	34.0	--	--	097.	154.0	1' 9"
360	P 3	1	9-10	20	23.5	--	--	103.	154.0	----
360	H 4	2	15-16	30	11.6	7.6	20.3	097.	139.5	30' 3"
360	P 4	2	13-14	20	11.5	7.2	17.7	095.	141.5	30' 3"
360	H 5	1	19-20	30	13.6	6.7	15.8	089.	134.0	44' 6"
360	P 5	1	17-18	20	13.5	3.4	12.5	089.	136.0	44' 6"
360	H 6	2	23-24	30	13.4	2.0	10.3	131.	131.0	57' 2"
360	P 6	2	21-22	20	13.2	5.7	12.3	081.	133.0	57' 2"



APPENDIX B

TACTICAL MOVEMENT AND ROUTE CLEARANCE

B.1 PURPOSE

1. To assess the effects of an air burst nuclear weapon in a heavily timbered tropical area on:

   (a) tactical movement of dismounted personnel and vehicles
   (b) route construction and clearance.

B.2 DISMOUNTED MOVEMENT

1. Infantry patrol movement: To assess the relative difficulties of dismounted movement in patrol formations, control and direction finding, an infantry assault section with section weapons and equipment will operate as a 5-hour fighting patrol through the test site area. The patrol will conduct both day and night movements, before and after the detonation. Accurate records of each patrol will be maintained including:

   (a) Patrol route, including details of movement visibility, obstacles, and weather conditions.
   (b) Timings for each phase of movement.
   (c) Formations used and methods of control.
   (d) Direction finding methods for each phase of movement.
   (e) Cover against ground and aerial observations for each movement phase.

2. Infantry movement in attack will be carried out by a rifle platoon acting as a forward assault platoon of a company accompanied by one 3-inch mortar detachment and moving by day on a clearly defined axis within clearly defined platoon/company boundaries before and after detonation. The following records will be maintained for each attack:

   (a) Details of loads and equipment carried
   (b) Timings for movement from which relative rates of advance may be assessed
   (c) Timings for movement of the 3-in mortar detachment including details of route followed. (A route will be selected to permit arrival of the detachment as soon as possible after assaulting sections).
   (d) Details of movement, obstacles to movement, methods of control, weather conditions, and cover for movement.

3\. (a) The ability of normal infantry manpack VHF radio equipment to provide satisfactory voice communications during dismounted movement in a blowdown area will be assessed during the tactical movements described in paras 2 and 3 above.

(b) The section patrol will carry a radio set AN/PRC - 10 and, during the day and night, patrol movements will attempt to establish voice radio contact with a radio set AN/PRC - 10 located at A23 from the following points:

(1) Start Line near O23
(2) Turkey nest near N21
(3) Water course near N18
(4) Road near N17
(5) Point near M15
(6) Point near M13
(7) US instrumentation lane near K14
(8) Road near G14
(9) Water course near E15
(10) Point near C16
(11) Finish near A16.

(c) The assault platoon attacking by day will carry a radio set C/PRC-26 and will attempt to establish voice radio contact with a radio set C/PRC-26 located at A23 from the following points:

(1) Start Line near C21
(2) Point near E20
(3) Edge of bamboo near F19
(4) Water course near J18
(5) US instrumentation lane near K17
(6) Road near L16
(7) Point near M15
(8) Objective near N14

4\. (a) In order to obtain comparable results, the same operators will be nominated by the Signals Representative of the Trials Assessment Team for the manpack set and the base station for both the patrol and the attack movements.

(b) All records of signal strengths at the above points will be in the terms, "loud and clear", "readable", "very weak", "nothing heard".

(c) The records will be maintained for day and night (where applicable) both before and after BLOWDOWN by the operators of both the manpack set and the base station set.

(d) In addition, the signaller carrying the manpack set on the patrol and in the attack will report on any limitations or restrictions physically imposed on him during the carriage and operation of the set. This report must specifically include the effect of debris and additional obstacles after blowdown.

(e) The format for the above records and reports is shown in Table B.1.

B.3 VEHICLE MOVEMENT

1. Vehicle movement trials will be carried out with real or representative loadings.

2. Records of all movement by vehicles will be maintained covering details of routes, movement, obstacles, weather conditions, timings for movement, and methods employed to overcome obstacles.

B.4 ROUTE CONSTRUCTION AND CLEARANCE

1. To assess the relative difficulty of route construction and clearance, one field troop augmented by one size 4, tracked tractor with angledozer and winch from a field park squadron will carry out specified tasks using equipment normally available to the troop.

2. Accurate records will be maintained before and after detonation covering:

(a) Methods used in route construction and clearance
(b) Man hours of work for each task
(c) Plant hours of work for each task
(d) Surface conditions
(e) Weather (rainfall, temperature, humidity, wind)
(f) Breakdowns

TABLE B.1 COMMUNICATIONS REPORT

Report by operator of AN/PRC-10 manpack set carried by the section patrol

1. Time of test

   a. Day/Night*
   b. Before/After BLOWDOWN*
   c. Date
   d. Time

* - Delete whichever is inapplicable

2. Signal strengths

LOCATION OF PATROL NEAR	SIGNAL STRENGTH
O23	
N21	
N18	
N17	
M15	
M13	
K14	
G14	
E15	
C16	
A16	

Legend:
L - Loud and Clear
R - Readable
V - Very Weak
N - Nothing Heard

3. Report on physical limitations

4. Any other comments on communications

APPENDIX C

DEFENDED LOCALITIES, EARTHWORKS, AND OBSTACLES

C.1 PURPOSE

1. To assess the effects of blowdown and secondary missiles resulting from the detonation of an airburst nuclear weapon in a heavily timbered tropical environment against forward defended localities, earthworks, and artificial obstacles.

C.2 SCOPE

1. Trials will be carried out using infantry section defended localities representing platoon localities in the second day stage of occupation with:

   (a) Cleared fields of fire
   (b) Local protection artificial obstacles.

2. Earthworks prepared for these trials will also be used for trials assessing the effects of detonation on:

   (a) Personnel
   (b) Equipment
   (c) POL and supplies
   (d) Ammunition

3. To reduce the effort involved, where the desired range at which the detonation effect is to be assessed permits:

   (a) Earthworks and excavation other than normally associated with platoon defended localities may be incorporated in these localities, and

   (b) Artificial obstacles and fields of fire normally associated with platoon defended localities will be constructed in their normal tactical position in relation to the defended locality.

C.3 SECTION-DEFENDED LOCALITIES

1. Three infantry section localities will be constructed at 60 yds, 120 yds, and 200 yds from GZ. Each position will contain the following at stages of development as shown:

   (a) Two open fire trenches connected by crawl trenches. These trenches will be unrevetted and will contain equipment as listed in Appendix D.

(b) One fire trench with:

(1) local timber revetment
(2) overhead protection alternating soil and timber to 18 inches
(3) sand-bagged entrances and fire bays.

(c) One fire trench unrevetted and with 18 in. overhead protection of soil with timber or flexible revetting material support

(d) Normal fire lanes as for protracted defenses as at Day 2 of occupation. At least one long fire lane will be cut or thinned out in each position to give optimum defensive fire. The fire lane will be reopened after detonation. The effective range will be tested in each lane by live firing at representative figure targets.

(e) Artificial Obstacles:

(1) 20 yds of low wire entanglement.
(2) 20 yds of double apron fence (barbed wire)
(3) 20 yds of double concertina fence
(4) 10 yds of double apron fence (barbed tape)
(5) 20 yds of mixed minefield using inert mines capable of recording activation.

C.4 WEAPON PITS

1. Weapon pits will be constructed as follows:

(a) One 3-in. Mortar pit including ammunition bayaat 100 yds from GZ. This pit will contain one complete 3-in. Mortar.

(b) One 106-recoilless rifle emplacement with ammunition bay at 100 yds from GZ. No weapons or ammunition will be used in the trial.

(c) One standard 25-pounder gun pit as part of a troop position in tropical rain forest. The pit should be at a distance from GZ to be determined by the Joint Project Officers but not to exceed 800 ft. This pit will contain one OQF 25-pounder and three boxes of inert ammunition.

C.5 PROTECTIVE WORKS

1. Revetments and dozer scrapes will be constructed to provide protective bunds for POL and supplies.

2. Accurate records will be maintained for incorporation in the final report covering:

Platoon Localities and Excavations

(a) Soil conditions, dimensions, and orientation to GZ for all excavations and bunds.

(b) Revetting materials and overhead protective cover materials.

(c) Construction, density, dimensions and orientation of artificial obstacles including effectiveness as an obstacle before and after detonation.

(d) Visibility before and after detonation from weapon pits.

(e) Fire lanes (for direct fire weapons at ground level):

(1) Time to construct before and after detonation and the methods used.

(2) Effective range and orientation. The effective range will be proved by live firing at representative figure targets.

(f) Cover from ground, air and photo reconnaissance for each locality before and after detonation.

(g) Condition of artificial cover before and after detonation.

Protective Works

(h) Nature and purpose of work (type of item protected if applicable).

(j) Dimensions and orientation to GZ.
(k) Time to construct and methods used.
(l) Condition after detonation and degree of protection afforded.

3. Table C.1 is a questionnaire to be used as a guide in preparing the report covering this portion of the Military Trials.

TABLE C.1 QUESTIONNAIRE

1. What is the extent of damage to each earthwork and the estimated time for reconstruction?

2. What caused the damage?

3. Comment on any other effect which defeated the purpose of the earthwork and the degree to which this occured.

   a. for offensive defence, and
   b. for passive defence.

4. Comment on the degree of cover offered to personnel or equipment or stores in earthworks.

5. What is the effect of blowdown on established fields of fire and a section fire plan?

6. What is the time factor imposed by blowdown in re-establishing a fire lane for LMG? Comment on the effort and any other problems encountered.

7. What is the extent of damage to each wire or barbed tape obstacle? Comment on blast and secondary missile effects.

8. To what extent was the purpose of each type of obstacle defeated? Comment on such aspects as trees briging wire obstacles and minefields and mines detonated by blast and any other effects.

9. Could each obstacle be restored to its former effectiveness? Comment on the degree of effect in terms of man hours and stores required to do this.

10. What is the effect if any on crest and other clearances for projectile paths for 3-in. Mortar and 25-pounder after blowdown? Comment on relative aspects before and after detonation.

11. What is the degree of cover from aerial or ground reconnaissance for each position after blowdown relative to the cover before blowdown?

APPENDIX D

WEAPONS, EQUIPMENT, AND AMMUNITION

D.1 PURPOSE

1. To assess:

   (a) The effects of blowdown and secondary missiles resulting from the detonation of an airburst nuclear weapon in heavily timbered country against weapons and equipment.

   (b) The effectiveness of defensive fire in an area subjected to the effects of blowdown.

D.2 WEAPONS

1. The following weapons will be subjected to trial:

   (a) One OQF 25-pounder in a standard gun pit
   (b) One OML 3-in. mortar complete in a mortar position
   (c) The following weapons will be positioned in open weapon pits in each section position:

      (1) One Bren LMG
      (2) One Owen machine carbine
      (3) Three Rifles .303-in.

D.3 AMMUNITION

1. Drill or completely inert ammunition packed in service containers will be placed in each infantry section position as follows:

   (a) Two boxes of drill grenades
   (b) Two boxes of drill SAA (either .303-in. or 7.62-mm).

2. Twelve inert rounds (either 25-pounder or 105-mm HE) will be placed with the OQF 25-pounder in the standard gun pit as "ready use" rounds.

D.4 AERIALS

1. (a) The aerials to be tested are:

      (1) Aerials, end fed, adjustable 135 ft.
      (2) Aerials lightweight 63 ft (2 per dipole)

   (b) One of each of these aerials will be erected at the outer edge of the predicted zones of severe, moderate, and slight damage.

D.5 RECORDS

1. The following records will be maintained accurately and incorporated in the final report. Table D.1 is a questionnaire to be used as a guide in preparing this portion of the report.

(a) The condition of all items before and after detonation including:

(1) Distance and aspect in relation to GZ

(2) Condition and type of cover provided

(3) Accessibility and serviceability

(b) Details of any damage to items including:

(1) Degree and causative agent

(2) Extent to which the item damaged is repairable or salvageable including the man hours required and the recovery effort involved. Where damage to actual items has occurred, this will be recorded during progress of the item through normal recovery and repair or salvage channels.

(c) Details of field of fire, crest, and timber clearance before and after detonation for each weapon.

(d) Details of mortar/grenade and shell effective lethality before and after detonation as shown on representative targets.

TABLE D.1 QUESTIONNAIRE

Weapons

1. What type of damage due to blowdown or secondary missiles may be expected for:

   a. LMGs?
   b. Machine carbines?
   c. Rifles?
   d. Mortars?
   e. Guns?

2. Would the weapons sited in each locality be ready for immediate use? If not:

   a. In what category would EME class the casualty,
   b. What level of repair would be required; and
   c. What time would elapse before the weapon would be ready for re-issue?

3. What overall damage factor may be expected for weapons in open weapon pits at infantry sections and platoon level?

Ammunition

4. What damage factor may be expected for boxed and unboxed ammunition in:

   a. Open weapon pits?
   b. Standard gun pits?

5. a. What will be the effect if any on the ability to develop defensive fire power from:

      (1) Infantry weapon pits?
      (2) Artillery gun pits?

   b. Comment on the degree to which ammunition is scattered, buried, or is otherwise inaccessible or unusable.

Aerials

6. a. What degree of damage was sustained by aerials left in each position during detonation?

   b. What was the cause of damage in each case?

   c. What degree of effort would be required to make each damaged aerial serviceable?

APPENDIX E

COMMUNICATIONS

E.1 PURPOSE

1. To assess the relative effectiveness of VHF and HF radio communications and line communications in an area of blowdown.

E.2 WIRELESS EQUIPMENT

1. The wireless equipment listed below will be required for the tests:

   (a) WS A510 - Qty 2
   (b) C/PRC - 26 - Qty 2
   (c) AN/PRC - 10 - Qty 2

2. Each type of equipment will undergo the following tests:

   (a) The sets shall be designated NORTH SET and SOUTH SET for the purpose of these tests.

   (b) SOUTH SET will be established at A21 and the NORTH SET will be established at V1.

   (c) The NORTH SET will then be moved to points U2, T3, S4..... .....L11 towards GZ. At each point, signal strengths will be recorded by both stations. Signals strengths, "loud and clear", "readable", "very weak", "nothing heard", will be used.

   (d) If the signal strength between L11 and A21 is other than "loud and clear", the SOUTH SET at A21 will be moved to B20, C19..........until this signal strength is achieved.

   (e) The above procedure will then be repeated with the NORTH SET at V1 remaining static in the first instance and the SOUTH SET at A21 being moved to B20, C19...........J13.

   (f) Paras 3(a) to 3(e) will be conducted by day and by night with each set, before and after BLOWDOWN. Should it be necessary to move the sets further apart or laterally to achieve loud and clear communications, the details will be recorded in the result sheets.

3. Results will be tabulated in the form shown in Table E.1.

4. Should the above test be inconclusive, the Signals Representatives of the Trials Assessment Team may, with the concurrence of the Joint Project Leader and SAMB representative, conduct such tests

as he considers necessary to achieve the aim. Accurate records will be kept of any such tests and these records should follow those outlined in Table E.2.

5. It is considered that sets should not be located near GZ during these tests since the presence of the steel tower before BLOWDOWN, and its probable absence after, would not allow comparison of results.

E.3 FIELD CABLE

1. The following cables will be tested:

(a) Assault cable
(b) Cable Electric D10
(c) Spiral 4.

2. (a) One radial route will be laid, starting at GZ and terminating 100 feet past the predicted outer edge of slight damage.

(b) The radial route will consist of all three nominated cables, each laid in the following manner:

(1) Tree slung
(2) Loose laid on ground
(3) Buried 2" deep
(4) Buried 6" deep
(5) Buried 12" deep.

(c) The buried cables will all be laid in one trench. The samples of each cable buried 12" deep will be color-coded RED. The trench will then be filled in to a depth of 6" and samples of each cable color-coded BLUE will be laid. Finally, samples of each cable will be laid 2" below ground and covered and these cables will NOT be coded.

(d) The loose laid and tree-slung cables will follow the route of the trench as closely as possible. The tree-slung cables will be slung at the same tensions and height and from the same trees.

3. (a) One set of cables 50 yards long will be laid along the edge of each predicted zone of damage, generally following the circles shown on the BLOWDOWN 100-feet-to-1-inch Task Map.

(b) The approximate distances of these paths from GZ are 170 feet, 380 feet, 550 feet, and 730 feet.

(c) Each set of cables will consist of all three nominated cables, each laid in the following manner:

(1) Tree slung
(2) Loose laid on the ground.

(d) The provisions of para 8 (d) apply to these cables.

4. Before BLOWDOWN, voice communication will be established between two telephone sets K over each cable. The telephones will be removed prior to BLOWDOWN.

5. After BLOWDOWN, voice communication between the telephones will be attempted over each cable. The remains of each cable will then be recovered.

6. The report to be submitted on each cable will include:

(a) The communication state of the cable before BLOWDOWN
(b) The communication state of the cable after BLOWDOWN
(c) The condition of insulation on the cable
(d) The number of breaks in the cable, their location, and the probable cause of damage
(e) An estimate of the work and time required to restore line communications.

TABLE E.1 COMMUNICATIONS REPORT

Report of communications through GZ

1. Type of set: WS A510 *
AN/PRC-10 *
C/PRC-26 *

2. Designation: NORTH/SOUTH set *

3. Time of test

a. Day/Night Test *
b. Before/After BLOWDOWN *
c. Date
d. Time

* Delete whichever is inapplicable

4. Signal strengths

LOCATION OF NORTH SET	LOCATION OF SOUTH SET	RECEIVED SIGNAL STRENGTH

TABLE E.2 QUESTIONNAIRE, COMMUNICATIONS

Wireless communications

1. Comment on the quality of communications achieved before detonation.

2. Could wireless communications be re-established without further effort from the original locations after detonation? If not, give details of the methods used to re-establish communications either by moving the set or by other means.

3. Comment on any problems encountered in maintaining wireless communications with the sets tested when used by:

    a. Infantry:

        (1) During movement in a blowdown area
        (2) In a static role in an area subjected to blowdown.

    b. Other users under similar conditions.

Line communications

4. a. Could line communications be re-opened after detonation without further effort? To what extent could this be achieved.

    b. What degree of damage was sustained by cable in each case?

    c. What was the cause of damage in each case?

    d. What degree of effort would be required to re-establish line communications to each position?

5. Comment on any preferred methods of locating wireless sets, aerials or cable to reduce damage due to blowdown and maintain communications.

APPENDIX F

SUPPLIES AND POL

F.1 PURPOSE

1. To assess the effects of detonation of an airburst nuclear weapon against POL and supplies stored in a heavily timbered tropical area.

F.2 POL

1. Small camouflaged POL dumps each containing 200 jerricans representing token stacks and filled with water will be established at three sites selected by the Assessment Team and confirmed by Joint Project Officers in:

   (a) Protected dumps
   (b) Unprotected dumps.

2. Representative stocks of each type of supply containers (boxes, sacks, cartons, drums, and paper sacks) filled with condemned or cheapest available commodities will be established in

   (a) Protected dumps
   (b) Unprotected uumps

F.3 WATER AND RATION PACKS

1. Canned water and ration packs will be sited in infantry weapon pits if the effects on these supply items cannot be assessed from trials shown above.

F.4 RECORDS

1. The following records will be maintained and incorporated with answers to specific questions in the final report.

   (a) The position, degree of protection, type of camouflage and orientation to GZ of each dump.

   (b) The degree of damage sustained (including details of causative agent) by:

      (1) Containers
      (2) Camouflage.

   (c) Percentage of recoverable containers/commodities after detonation.

   (d) Details regarding ease of access and working of each dump before and after detonation.

2. Table F.1 is a questionnaire to be used as a guide in preparing this portion of the report.

TABLE F.1 QUESTIONNAIRE

1. How effective was the banding/strapping containing the load on its pallet (if pallets were used)?

2. How effective was the strapping used in containing drums?

3. Comment on the extent and cause of seam damage sustained in in drums and sacks?

4. Comment on the extent and cause of damage from puncturing and the percentage of recovery in the case of cased, cartonned and drummed commodities.

5. What were the relative percentages of recoverable items from palletised loads and normal stacks?

APPENDIX G

PERSONNEL: CASUALTY OCCURRENCE

G.1 AIM

1. To assess the effects of detonation of an airburst nuclear weapon against personnel in a heavily timbered tropical area.

G.2 ASSESSMENT

1. The following direct military results will be assessed during the trials:

   (a) The effect of blast shielding afforded by trees and undergrowth.

   (b) The number and type of casualties sustained from blast and secondary missiles during blowdown.

   (c) The degree of protection afforded to personnel against blast and secondary missiles.

initial positions of the dummies, the impacts occurred after maximum velocity had been attained and during the decelerative phase of displacement.

A postshot photograph of a dummy is shown in Figure H.1.

Figure H.1 Postshot photograph of dummy.

APPENDIX I

MAPS

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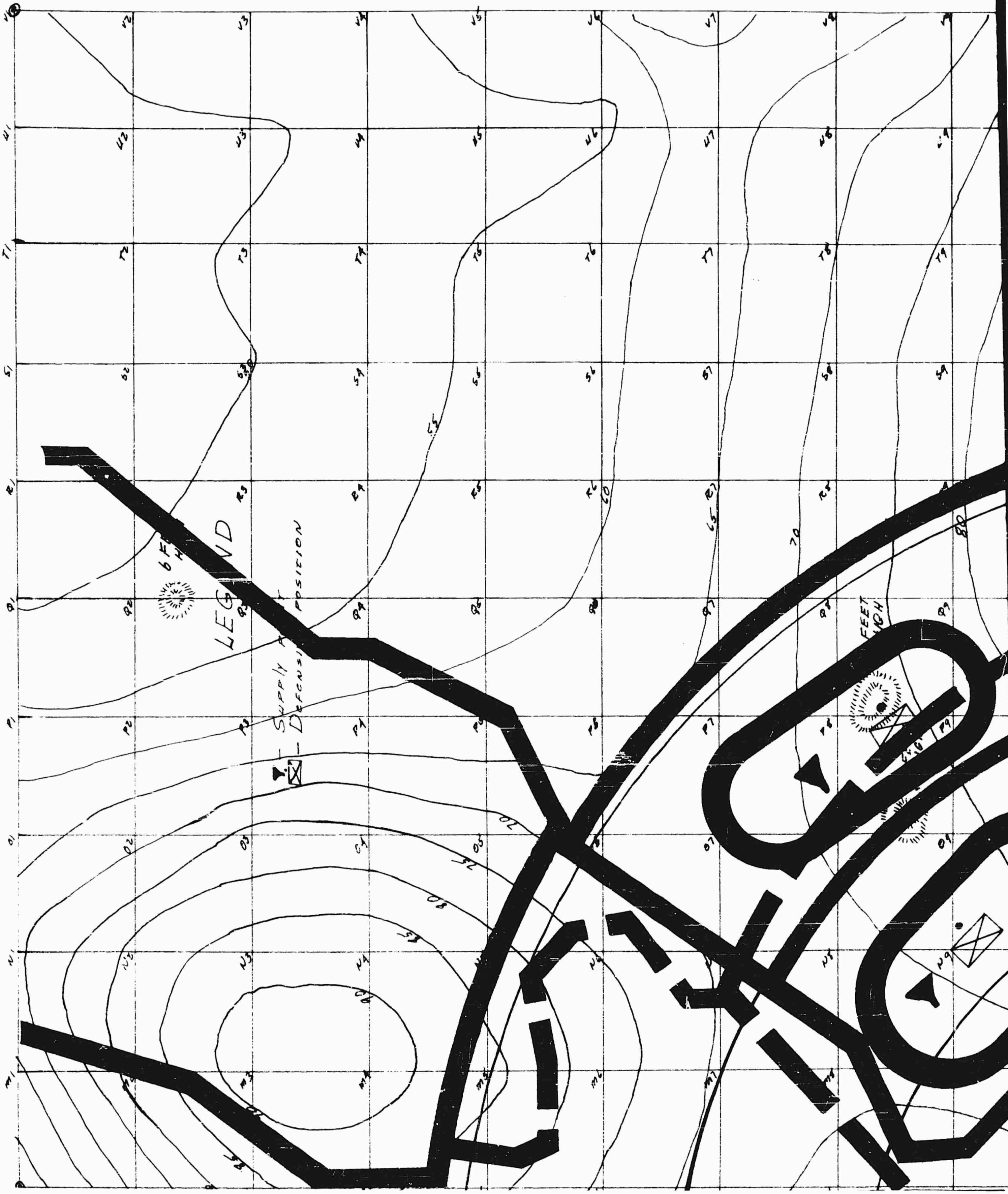

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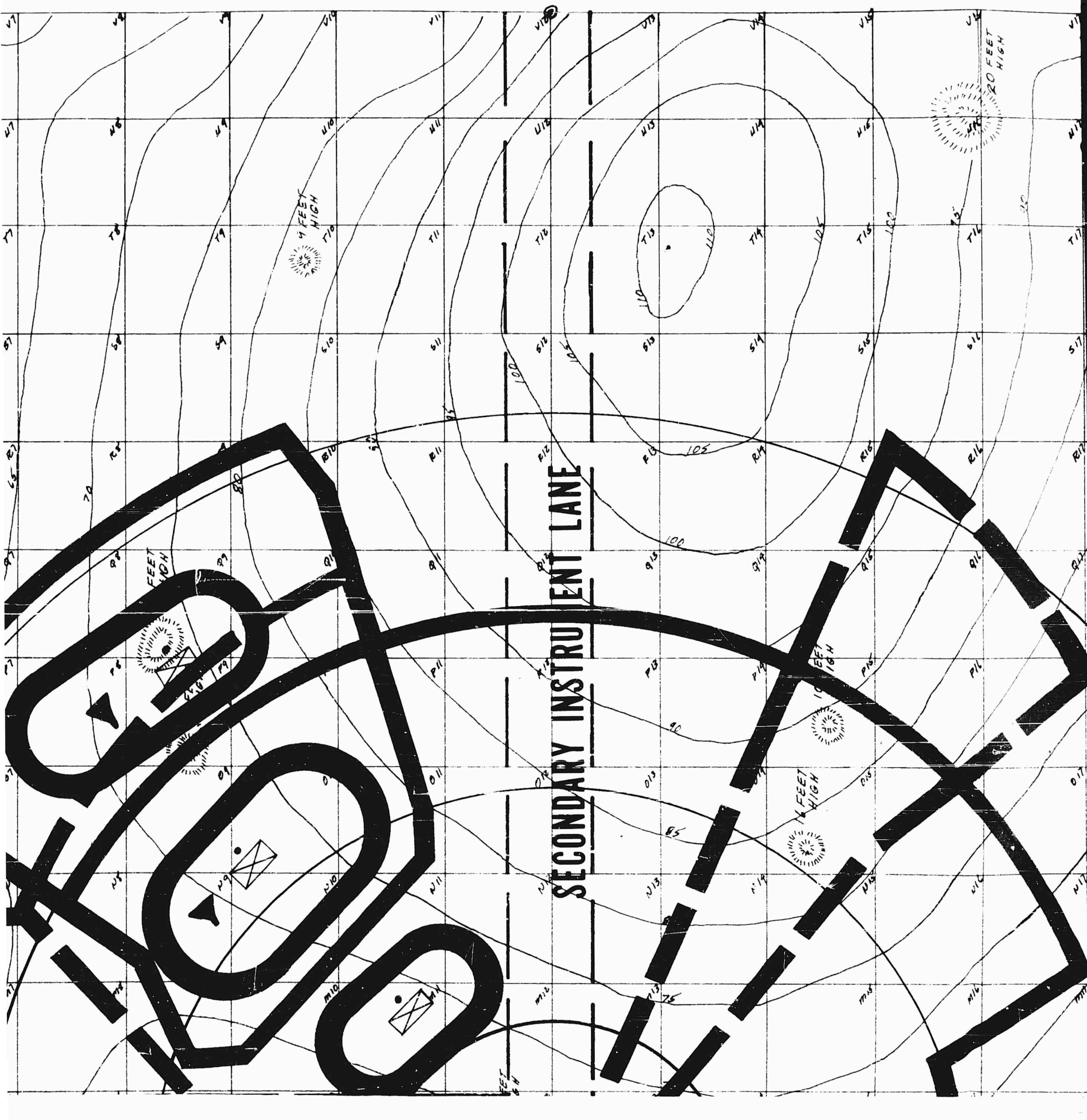
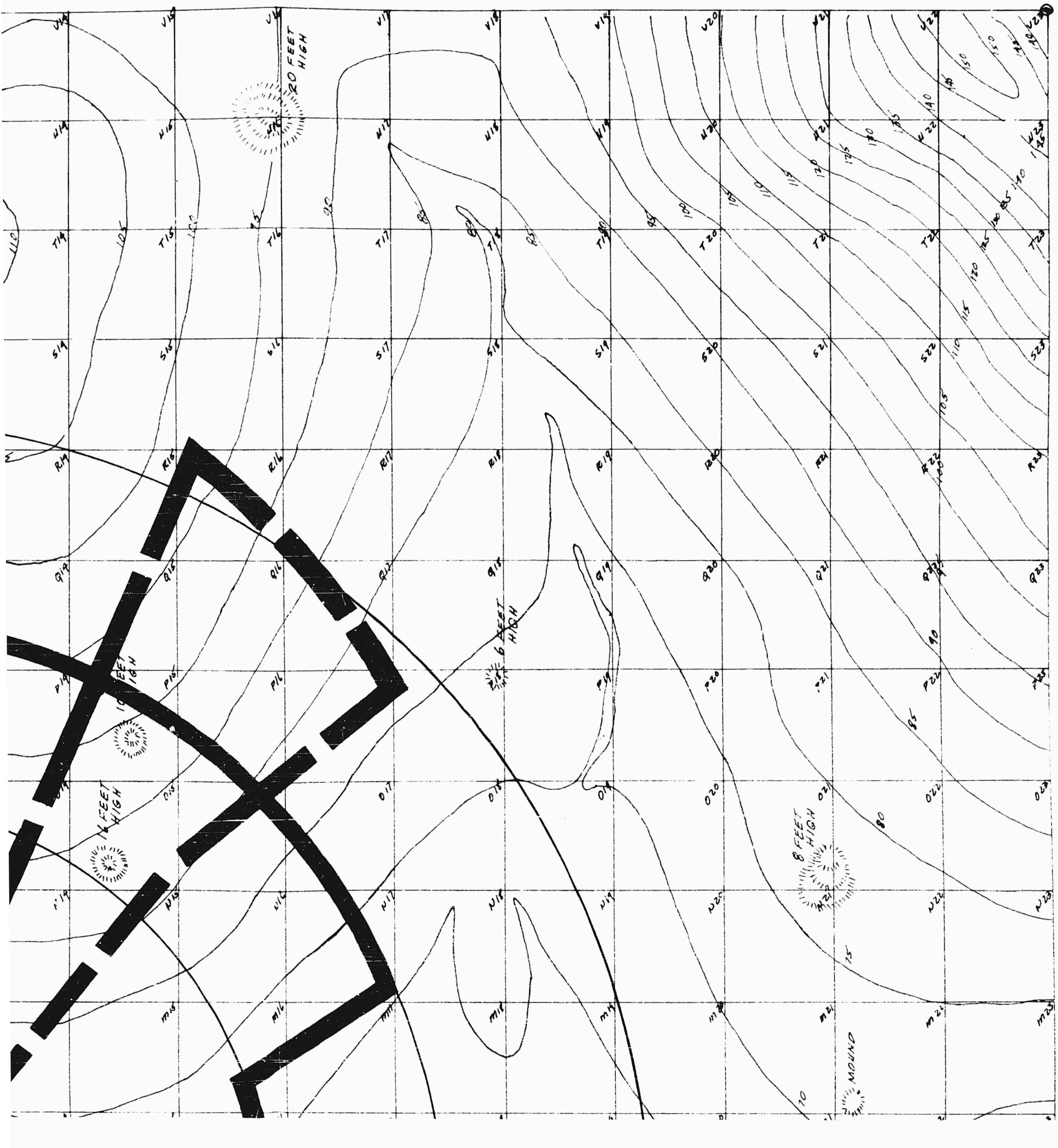

SECONDARY INSTRUMENT LANE
20 FEET HIGH
9 FEET HIGH
14 FEET HIGH



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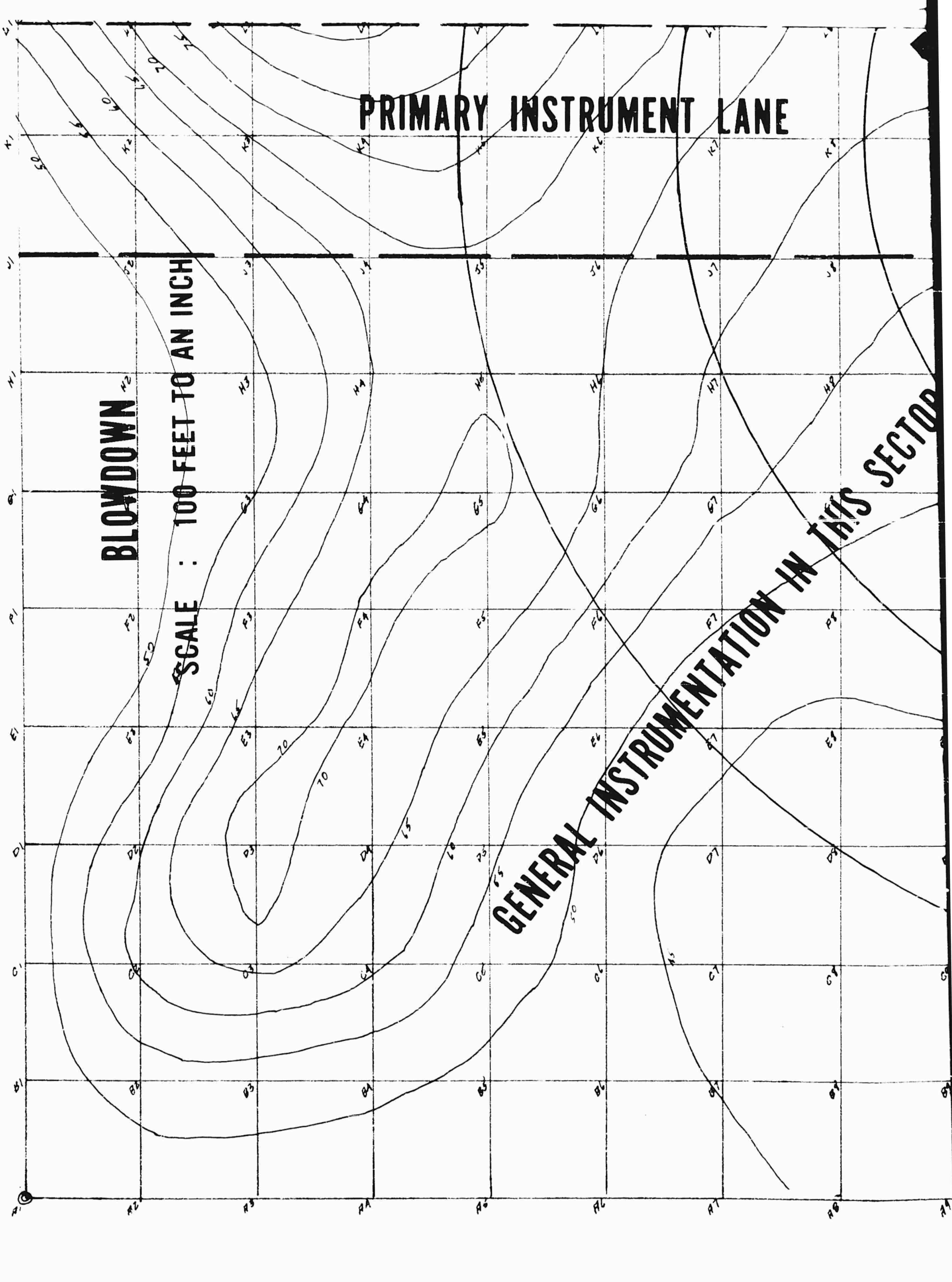
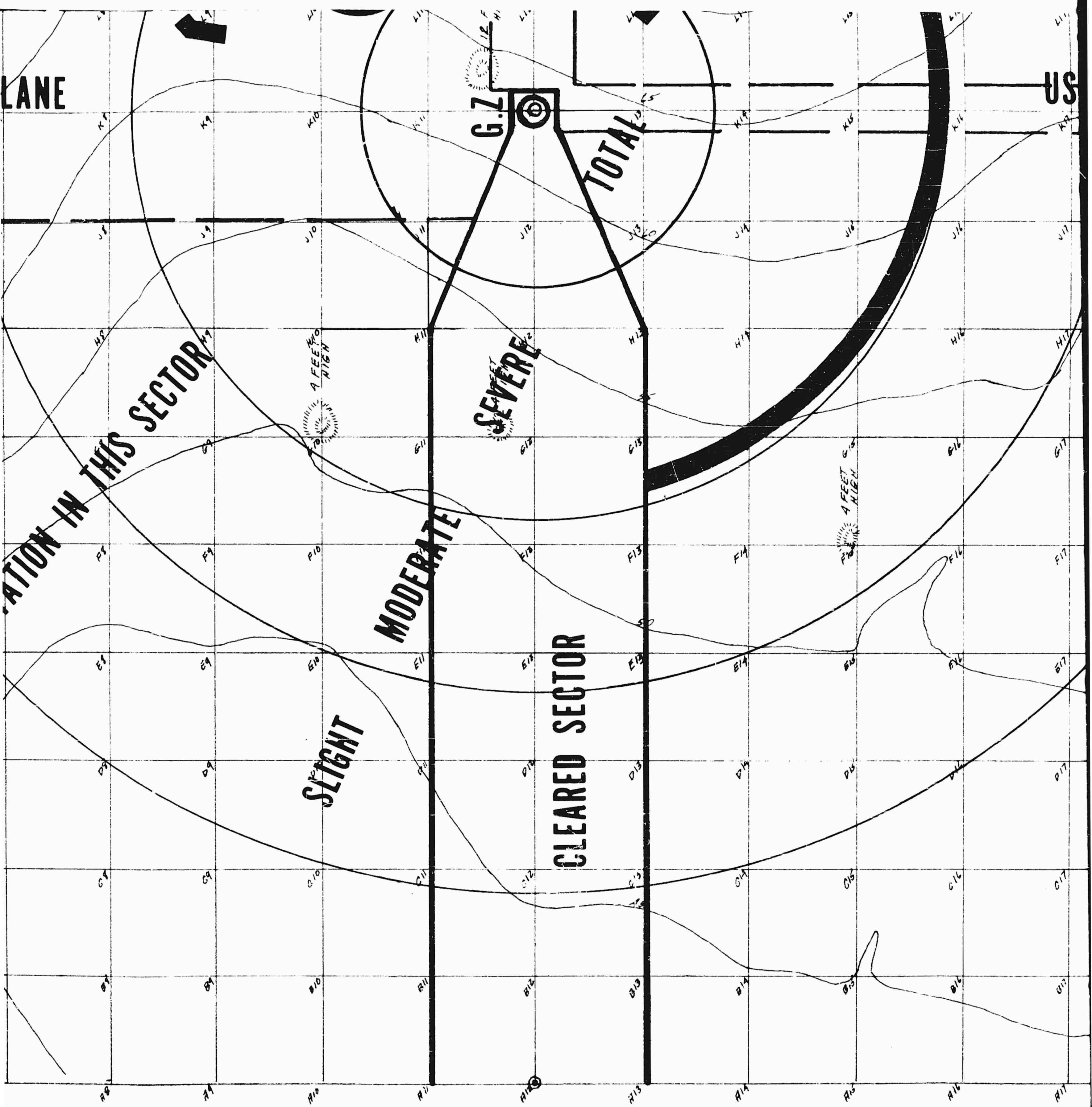
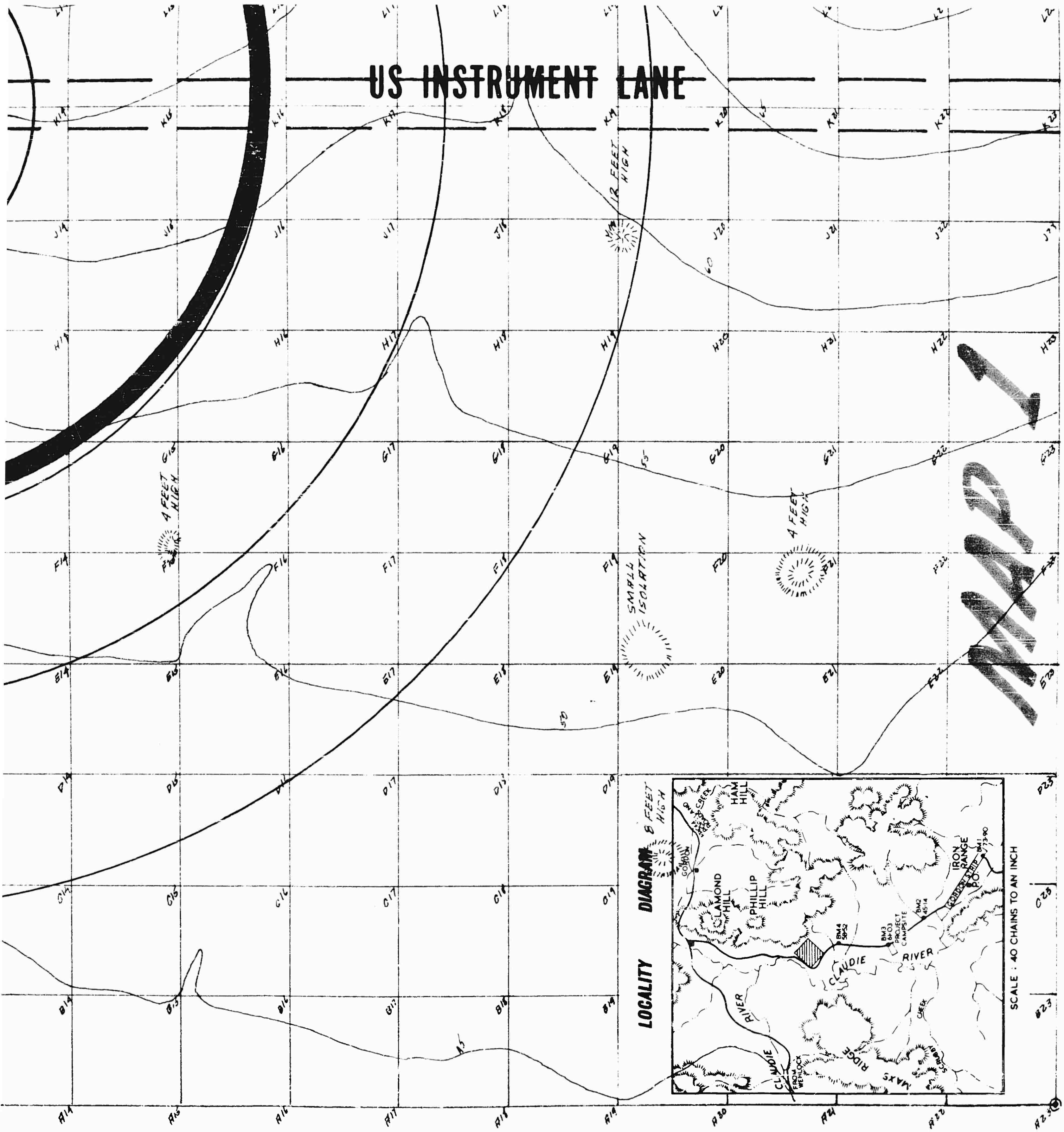


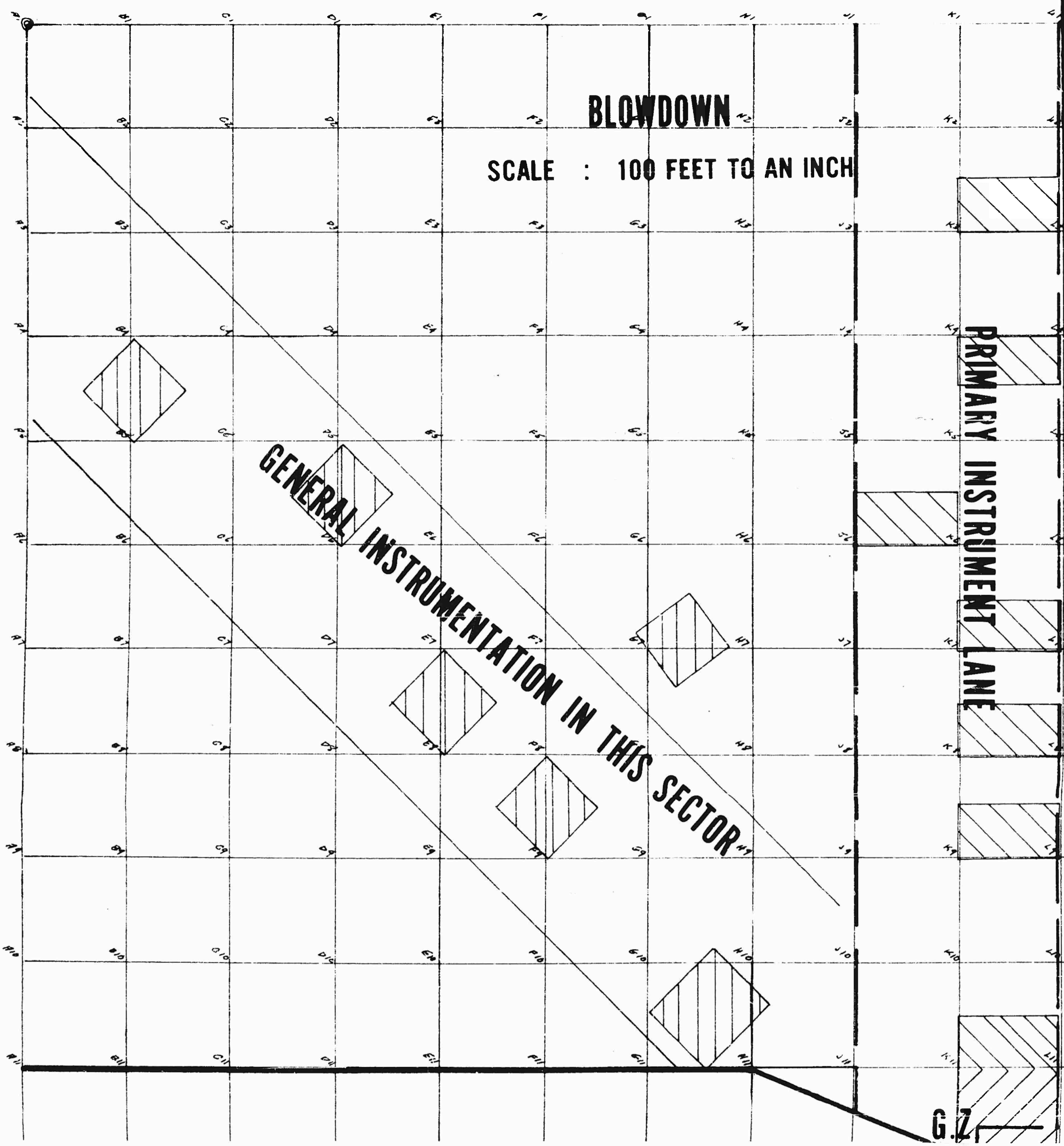
PRIMARY INSTRUMENT LANE
BLOWDOWN
SCALE : 100 FEET TO AN INCH
GENERAL INSTRUMENTATION IN THIS SECTOR

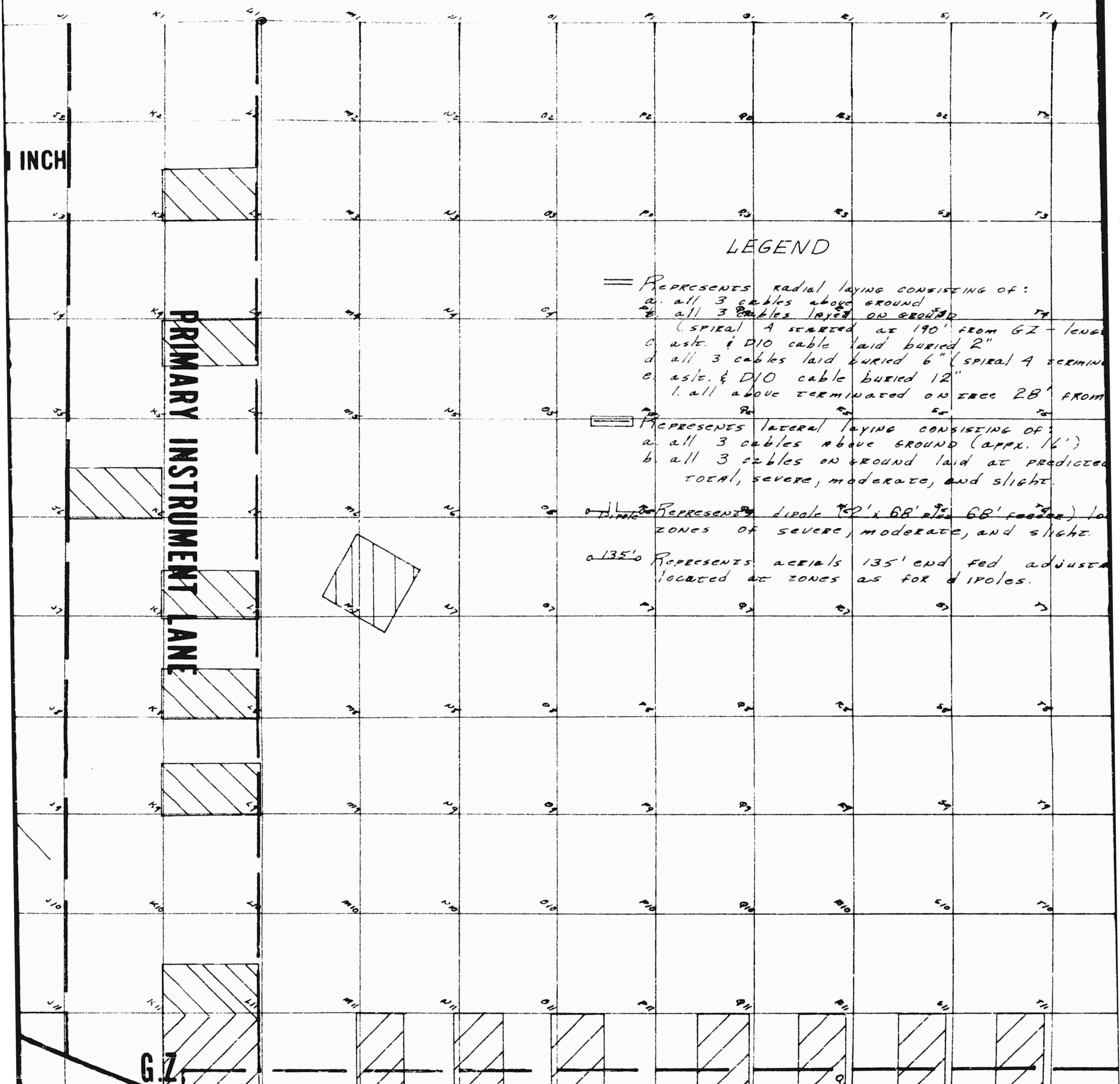


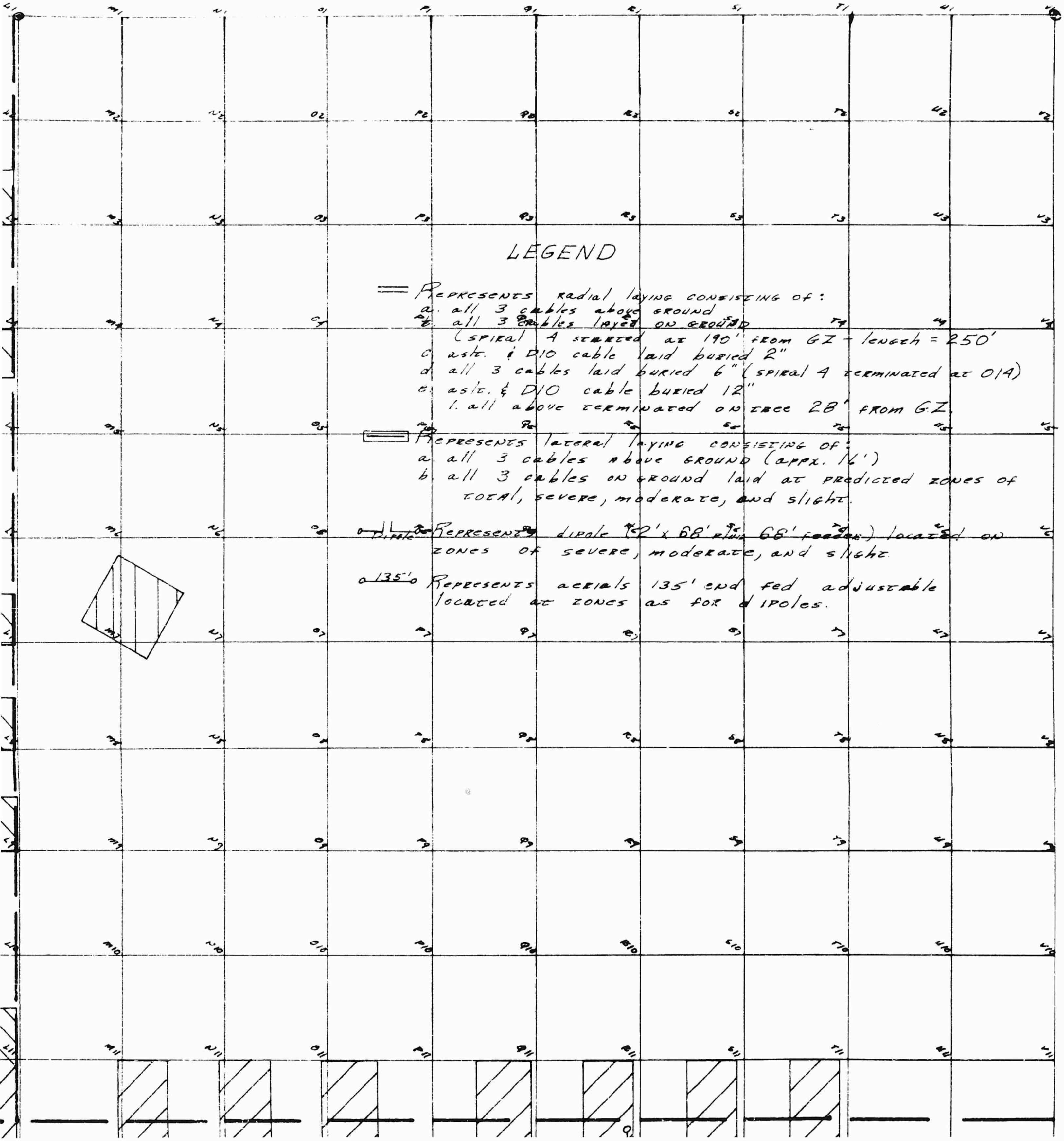
LANE
US
G.Z
TOTAL
SEVERE
MODERATE
SLIGHT
CLEARED SECTOR
ATION IN THIS SECTOR
A FEET HIGH
A FEET HIGH

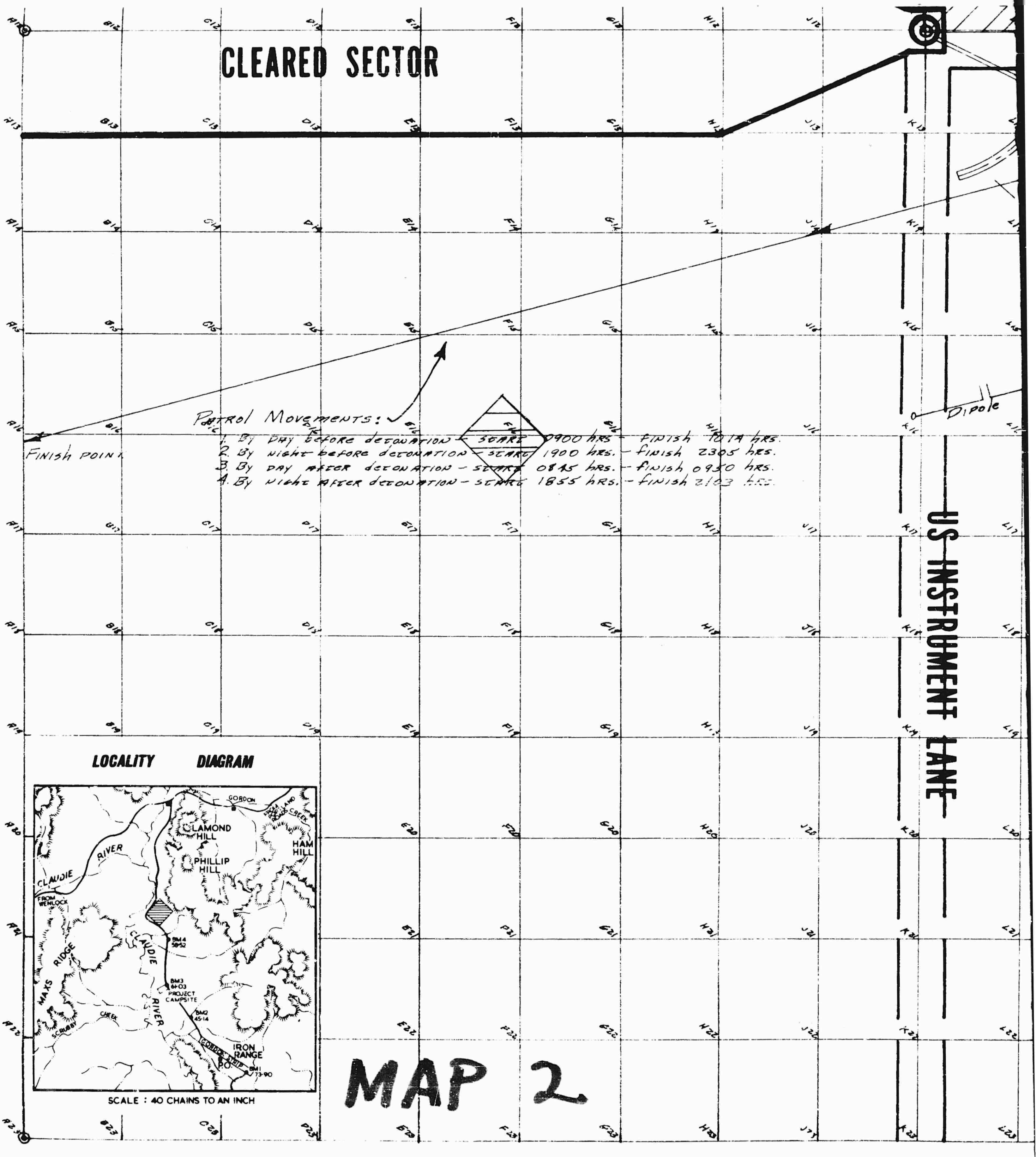


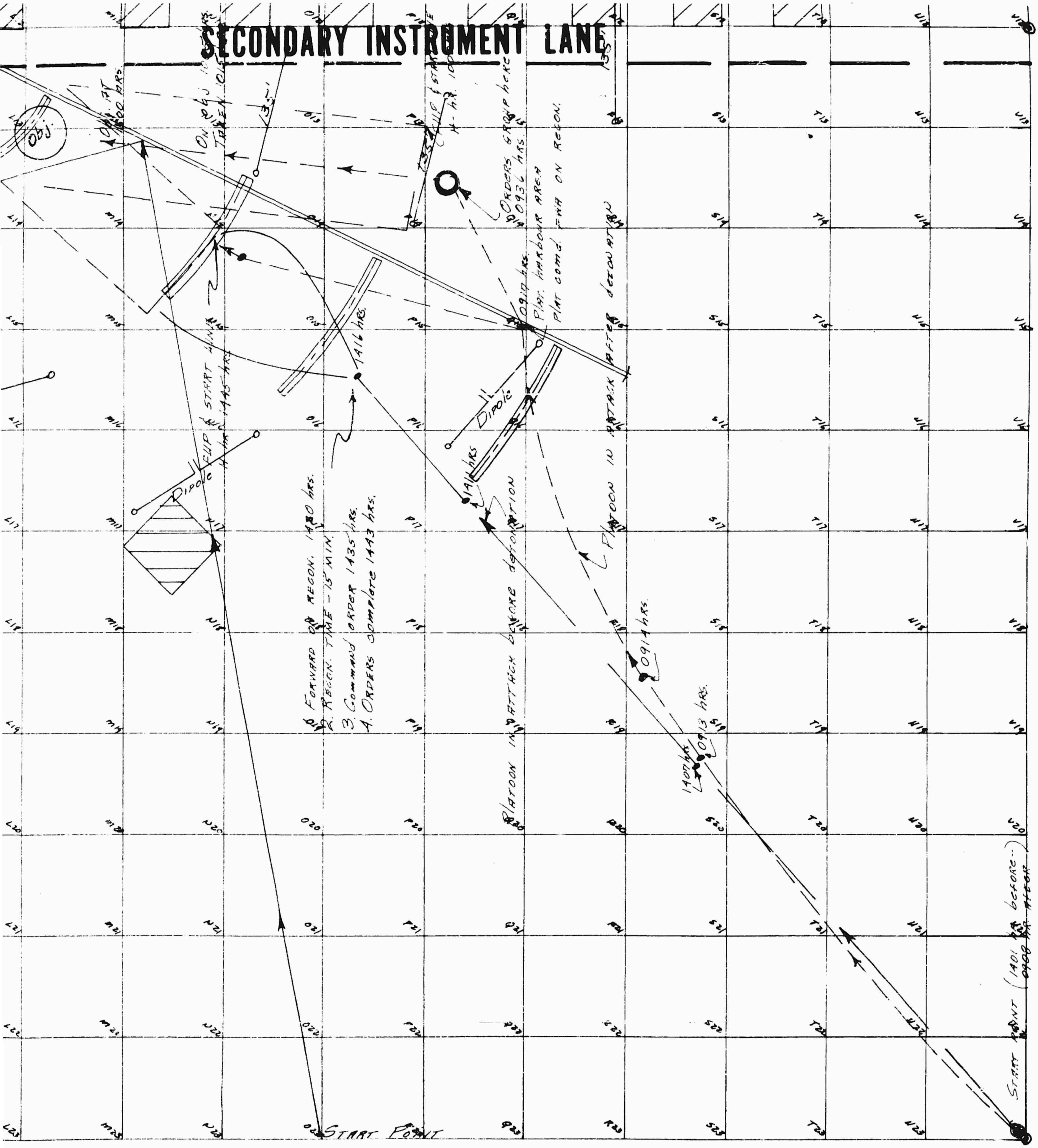
US INSTRUMENT LANE
MAP 1
12 FEET HIGH
4 FEET HIGH
4 FEET HIGH
SMALL ISOLATION
8 FEET HIGH
LOCALITY DIAGRAM
HAM HILL
CLAMOND HILL
PHILLIP HILL
IRON RANGE P.O.
PROJECT CAMPSITE
CLAUDIE RIVER
CLAUDIE
RIVER
MAXS RIDGE
FROM WENLOCK
SCALE : 40 CHAINS TO AN INCH


BLOWDOWN
SCALE : 100 FEET TO AN INCH
GENERAL INSTRUMENTATION IN THIS SECTOR
PRIMARY INSTRUMENT LANE
G.Z.


INCH
PRIMARY INSTRUMENT LANE
G.Z.
LEGEND
Represents radial laying consisting of:
a. all 3 cables above ground
b. all 3 cables layed on ground
(spiral 4 started at 190' from GZ - leng
c. ast. & D10 cable laid buried 2"
d. all 3 cables laid buried 6" (spiral 4 termin
e. ast. & D10 cable buried 12"
1. all above terminated on tree 28' from
Represents lateral laying consisting of:
a. all 3 cables above ground (appx. 16')
b. all 3 cables on ground laid at predicted
total, severe, moderate, and slight.
Dipole Represents dipole (2' x 68' plus 68' feeder) lo
zones of severe, moderate, and slight.
135' Represents aerials 135' end fed adjust
located at zones as for dipoles.


LEGEND
Represents radial laying consisting of:
a. all 3 cables above ground
b. all 3 cables layed on ground
(spiral 4 started at 190' from GZ - length = 250'
c. aslt. & D10 cable laid buried 2"
d. all 3 cables laid buried 6" (spiral 4 terminated at 014)
e. aslt. & D10 cable buried 12"
1. all above terminated on tree 28' from G.Z.
Represents lateral laying consisting of:
a. all 3 cables above ground (appx. 16')
b. all 3 cables on ground laid at predicted zones of total, severe, moderate, and slight.
Dipole
Represents dipole (62' x 68' plus 68' feeder) located on zones of severe, moderate, and slight.
135'
Represents aerials 135' end fed adjustable located at zones as for dipoles.


CLEARED SECTOR
Patrol Movements:
1. By day before detonation - start 0900 hrs. - finish 1014 hrs.
2. By night before detonation - start 1900 hrs. - finish 2305 hrs.
3. By day after detonation - start 0845 hrs. - finish 0950 hrs.
4. By night after detonation - start 1855 hrs. - finish 2103 hrs.
Finish point
Dipole
US INSTRUMENT LANE
LOCALITY DIAGRAM
GORDON
CREEK
LAMOND HILL
PHILLIP HILL
HAM HILL
CLAUDIE RIVER
FROM WENLOCK
MAXS RIDGE
CLAUDIE RIVER
BM4 58·52
BM3 61·03
PROJECT CAMPSITE
BM2 45·14
SCRUBBY CREEK
IRON RANGE P.O.
BM1 73·90
SCALE : 40 CHAINS TO AN INCH
MAP 2



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