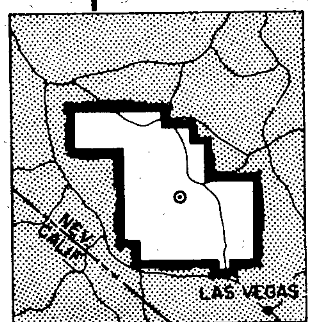
WT-1469

AEC Category: HEALTH AND SAFETY
Military Categories: 42 and 92

OPERATION PLUMBBOB



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Project 33.3

TERTIARY EFFECTS OF BLAST—DISPLACEMENT

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Report to the Test Director

TERTIARY EFFECTS OF BLAST—DISPLACEMENT

By

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Lovelace Foundation for Medical Education and Research
Albuquerque, New Mexico
February 1959

ABSTRACT

The objective of Project 33.3 was to determine the velocity-time and distance-time histories of anthropomorphic dummies and equivalent spheres (idealized models having an acceleration coefficient α equal to that of the dummy) displaced by blast winds. The dummies and spheres were located at stations within regions of about 5 and 7 psi overpressures.

The technique used for recording the movement of these objects was phototriangulation. Analysis of the films obtained gave the velocity and distance in the case of one shot. In a second shot the field of view was obscured by smoke (perhaps dust too) before any motion could be recorded by the cameras.

In one phase of the experiment, equivalent spheres were caught in flight at near predicted maximum velocity by missile traps. The depth of sphere penetration in the calibrated capture medium was then used to compute the sphere velocity.

ACKNOWLEDGMENTS

The authors are indebted to the many individuals whose cooperation and support made this project and its execution possible. We thank the members of the following organizations:

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Ballistic Research Laboratories
Edgerton, Germeshausen & Grier, Inc.
Chemical Warfare Laboratories
Reynolds Electrical and Engineering Co., Inc.
Holmes and Narver, Architectural Engineers
Kirtland Air Force Base
Indian Springs Air Force Base
Sandia Corporation

The investigations included in this project were financed primarily by the Atomic Energy Commission (Civil Effects Test Group) with some assistance by the Federal Civil Defense Administration.

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Chapter 1

INTRODUCTION

1.1 OBJECTIVES

The primary objective of Project 33.3 was to determine the velocity-time and distance-time histories of anthropomorphic dummies displaced by blast winds for correlation with laboratory research and extrapolation to man. The secondary objective was to study "models" of the dummies (in this instance, spheres) which were to be subjected to the same blast winds. These models were to be used in two ways: (a) in "free" flight, as in the case of the dummies, to obtain the complete displacement history and (b) in "captured" flight (in which the model would be captured in flight and its penetration into the capturing medium would be measured) to obtain the velocity of the model (at or near peak velocity).

The use of a model in free flight was intended to provide evidence that a model, properly designed, would be translated by winds in the same manner as would its prototype if both were subjected to the same blast field. The models chosen for these tests were spheres (the shape was picked for convenience) of several different diameters with corresponding masses so that in each instance the acceleration coefficient, α, was equal to that of the dummy, or, in other words, the spheres were equivalent (see Appendix A). The study of dummy displacement was expected to provide information interrelated with that of the study of biological-target displacement (Project 33.1, WT-1467). The use of equivalent spheres in captured flight was intended to provide information interrelated with that of the study of missiles resulting from blast (Project 33.4, WT-1470).

1.2 BACKGROUND

Results of tests conducted in 1953 (Operation Upshot-Knothole) and in 1955 (Operation Teapot)[1] indicated that, with regard to exposure of biological specimens, for conditions in which thermal and radiation hazards were significantly reduced but in which overpressure and winds were present, the winds were extremely hazardous even if the associated overpressures were not. Following Operation Teapot, experiments conducted at the Lovelace Foundation[2] gave results that corroborated this indication.

REFERENCES

1. C. S. White, T. L. Chiffelle, D. R. Richmond, W. H. Lockyear, I. G. Bowen, V. C. Goldizen, H. W. Merideth, D. E. Kilgore, B. B. Longwell, J. T. Parker, F. Sherping, and M. E. Cribb, Biological Effects of Pressure Phenomena Occurring Inside Protective Shelters Following a Nuclear Detonation, Operation Teapot Report, WT-1179, Oct. 28, 1957.
2. D. R. Richmond, M. B. Wetherbe, R. V. Taborelli, T. L. Chiffelle, and C. S. White, The Biologic Response to Overpressure: I. Effects on Dogs of Five- to Ten-Second Duration Overpressures Having Various Times of Pressure Rise, J. Aviation Med., 28: 447-460 (1957).

Chapter 2

PROCEDURE

2.1 PRESSURE INSTRUMENTATION

The static and dynamic pressures for the stations were obtained from the mechanical self-recording gauges that also served Projects 33.2 and 33.4. Installation of, and data from, these gauges were provided by the Ballistic Research Laboratories (ITR-1501).

2.2 TECHNIQUE OF PHOTOTRIANGULATION

The basic scheme was to record photographically the path of movement of the object (dummy or sphere) by two motion-picture cameras mounted so that their lines of aim intersected at about 90 deg. In addition, the background common to both cameras was a grid of identified squares (Fig. 2.1). With the cameras operating at equal speeds and starting simultaneously, the photographic records provided a means of matching frames of the same instant and thereby fixing the position of the object in space with reference to the background grid. Two gun sight aiming point (GSAP) cameras operating at 64 frames/sec were mounted on each of the two camera towers; this provided two spares (Fig. 2.2). The plates to which the cameras were fastened were 18 ft above the grid surface, inclined downward 40 deg, and oriented at 45 deg in azimuth with respect to the bearing from Ground Zero (GZ). Each of three events, the bomb flash, the arrival of the shock, and the arrival of the negative phase, was used to index the several photographic records with respect to each other. The motion-picture photography was provided by Edgerton, Germeshausen & Grier (EG&G).

In addition to the grid, a very important requirement for photography was the dust-stabilized area adjoining the grid on both sides and on the edge toward GZ. In actual construction the grid and the stabilized area were built of concrete as a unit (Figs. 2.3 through 2.6). The dimensions of the stabilized areas were determined as discussed in Appendix B.

2.3 MEASUREMENTS

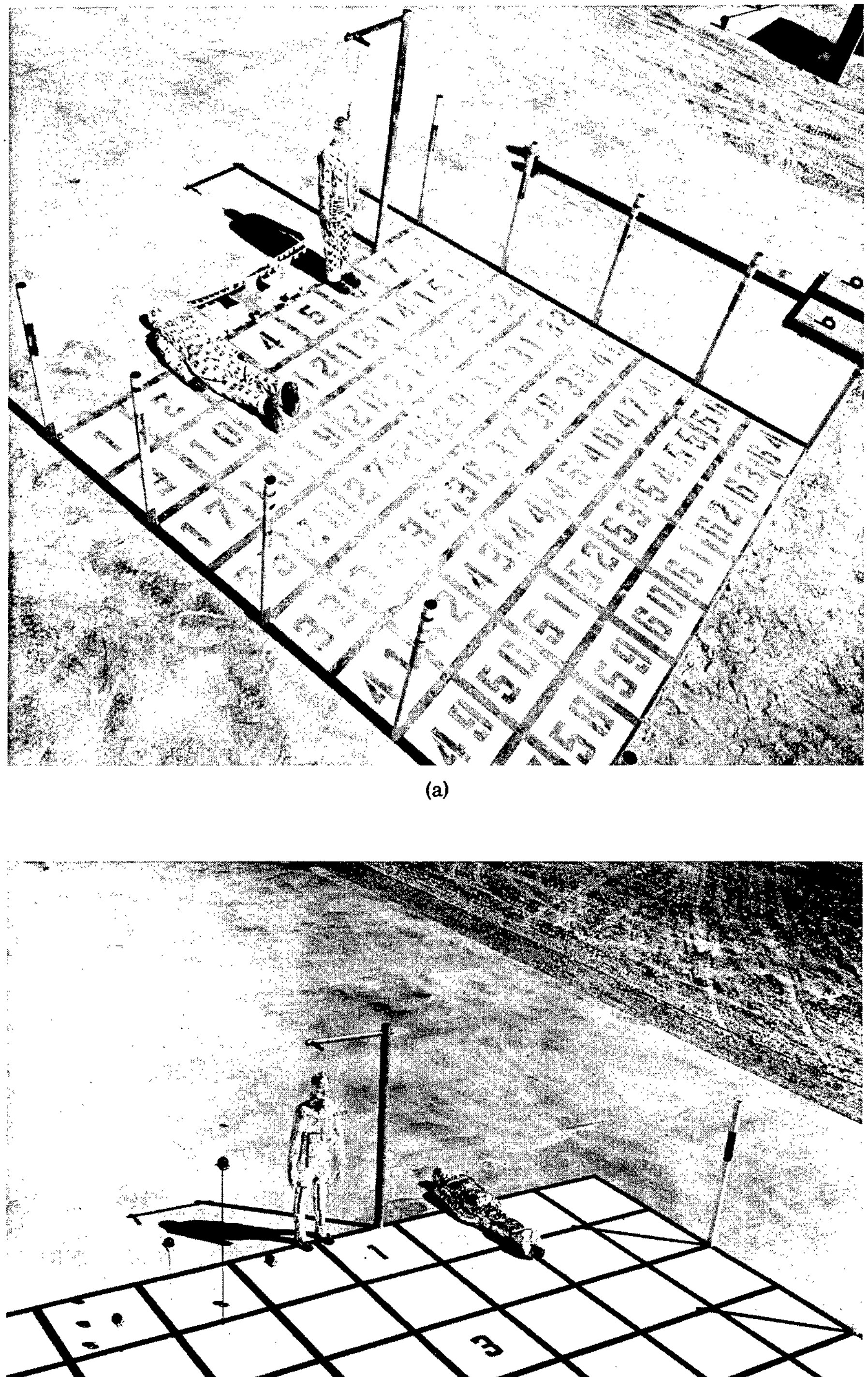
2.3.1 Free Flight

In each instance where a test object was moved through space by the blast, the coordinates of the final position with respect to the initial position were recorded.

2.3.2 Captured Flight

In those instances in which equivalent spheres were used in captured flight, the resulting penetration and the previous and subsequent calibrations of the missile trap provided data for determining the velocity of the sphere at the time of penetration.

(Text continues on page 21.)



(a)

(b)

Fig. 2.1—Views from camera tower, showing dummies and spheres. (a) Shot 1, without aluminum foil. (b) Shot 2, with foil.

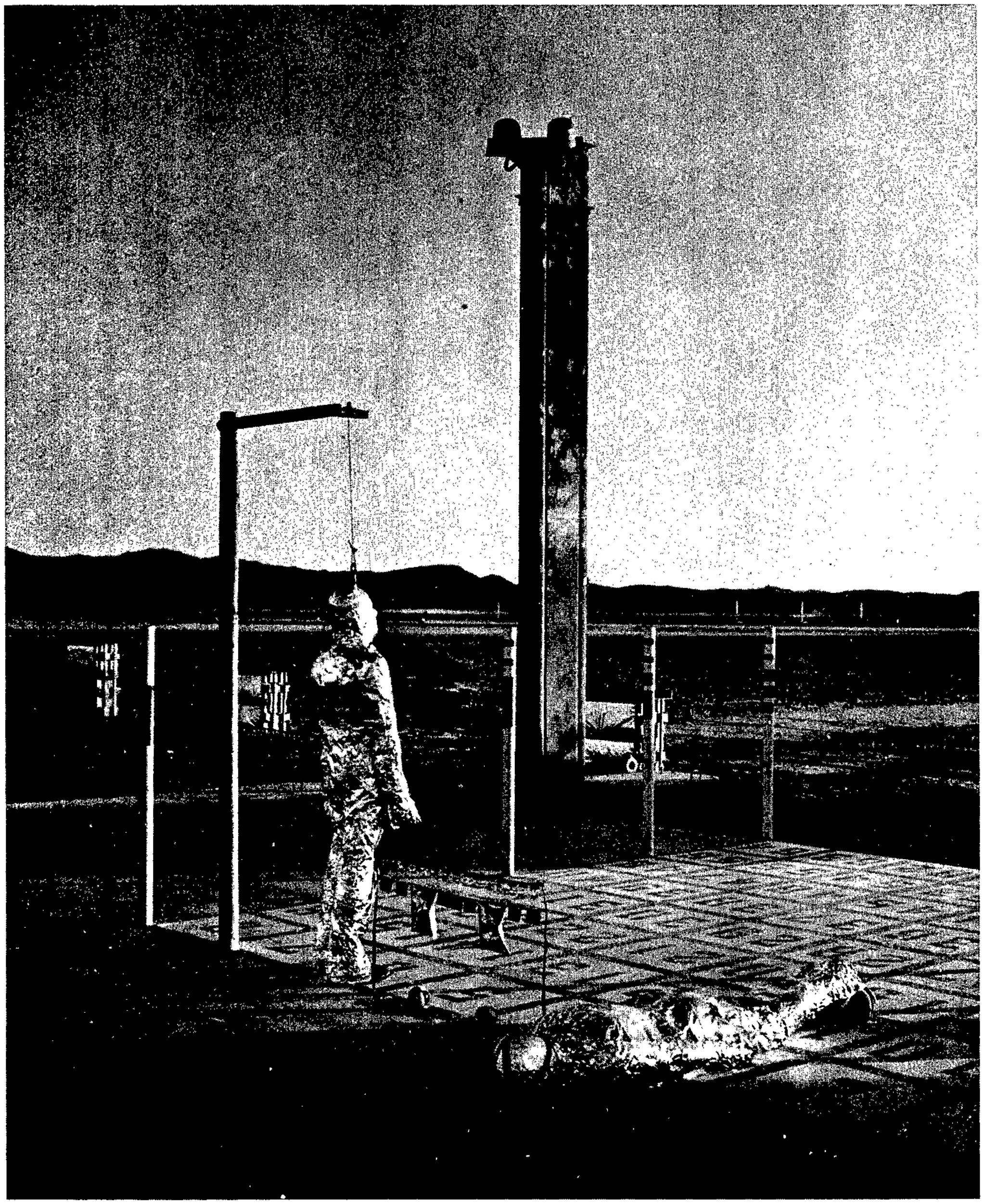
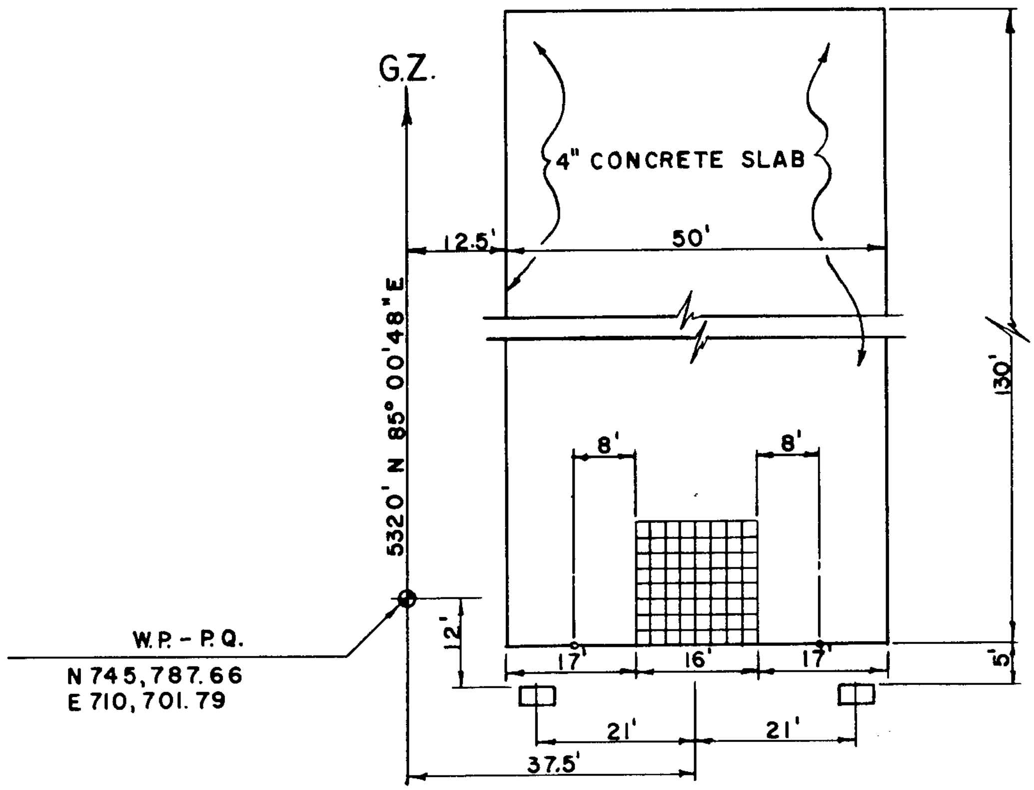


Fig. 2.2—One of two camera towers, showing two cameras mounted under protective hoods.



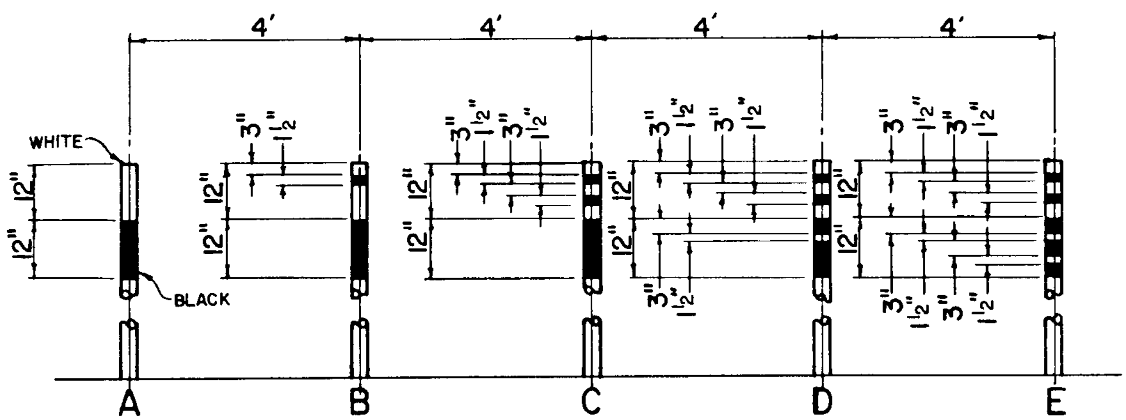


Fig. 2.3—Concrete pad and photography grid (shot 1).

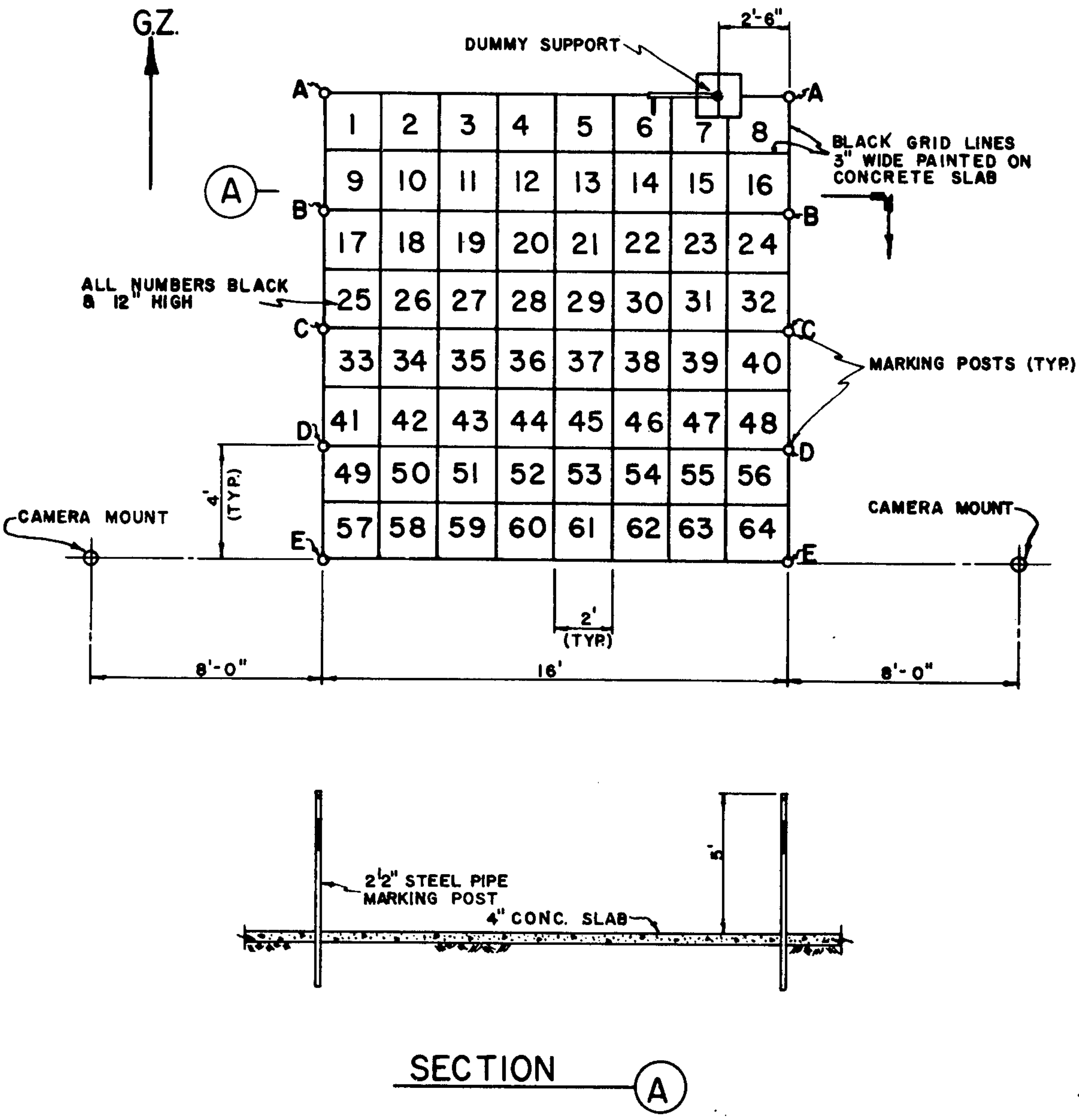


Fig. 2.4—Details of the photography grid, showing the positions of the camera towers and the marking posts (shot 1).

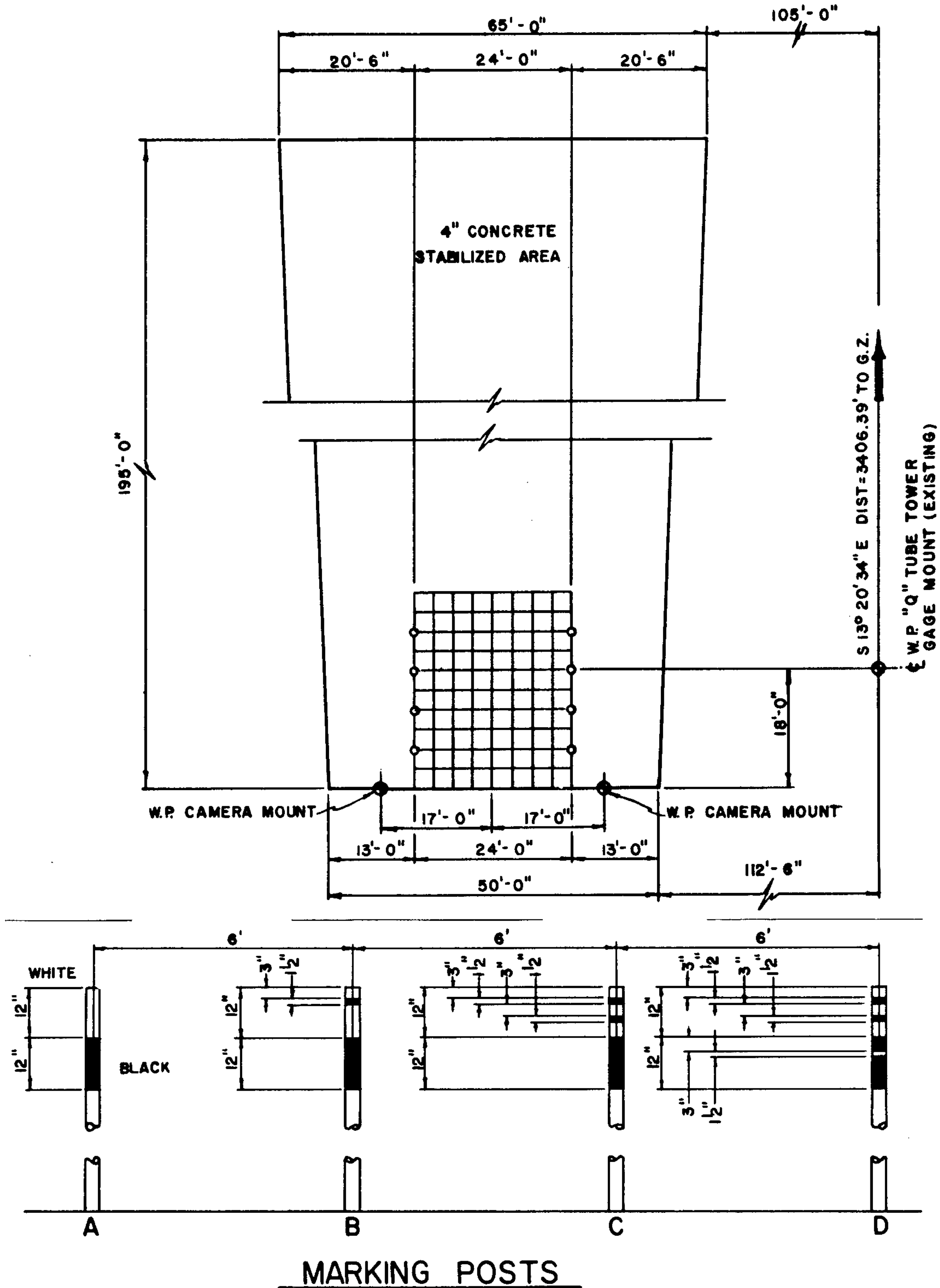
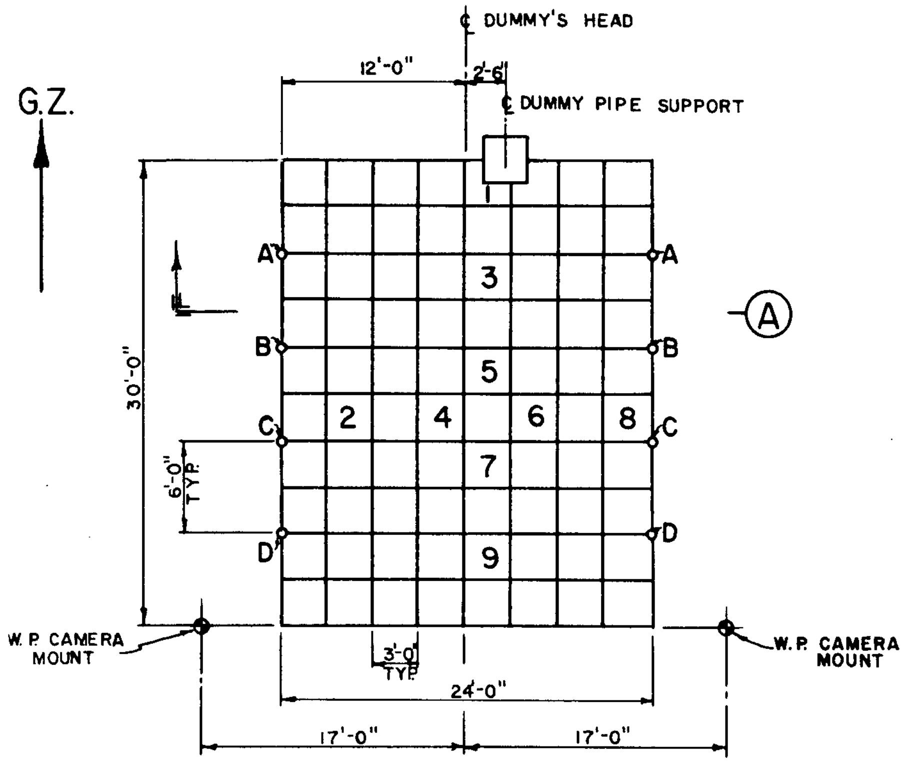


Fig. 2.5—Concrete pad and photography grid (shot 2).



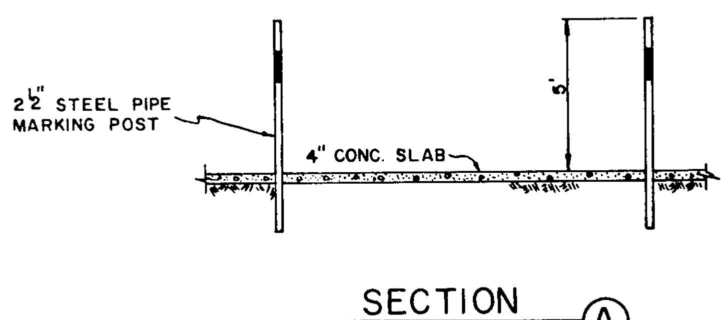
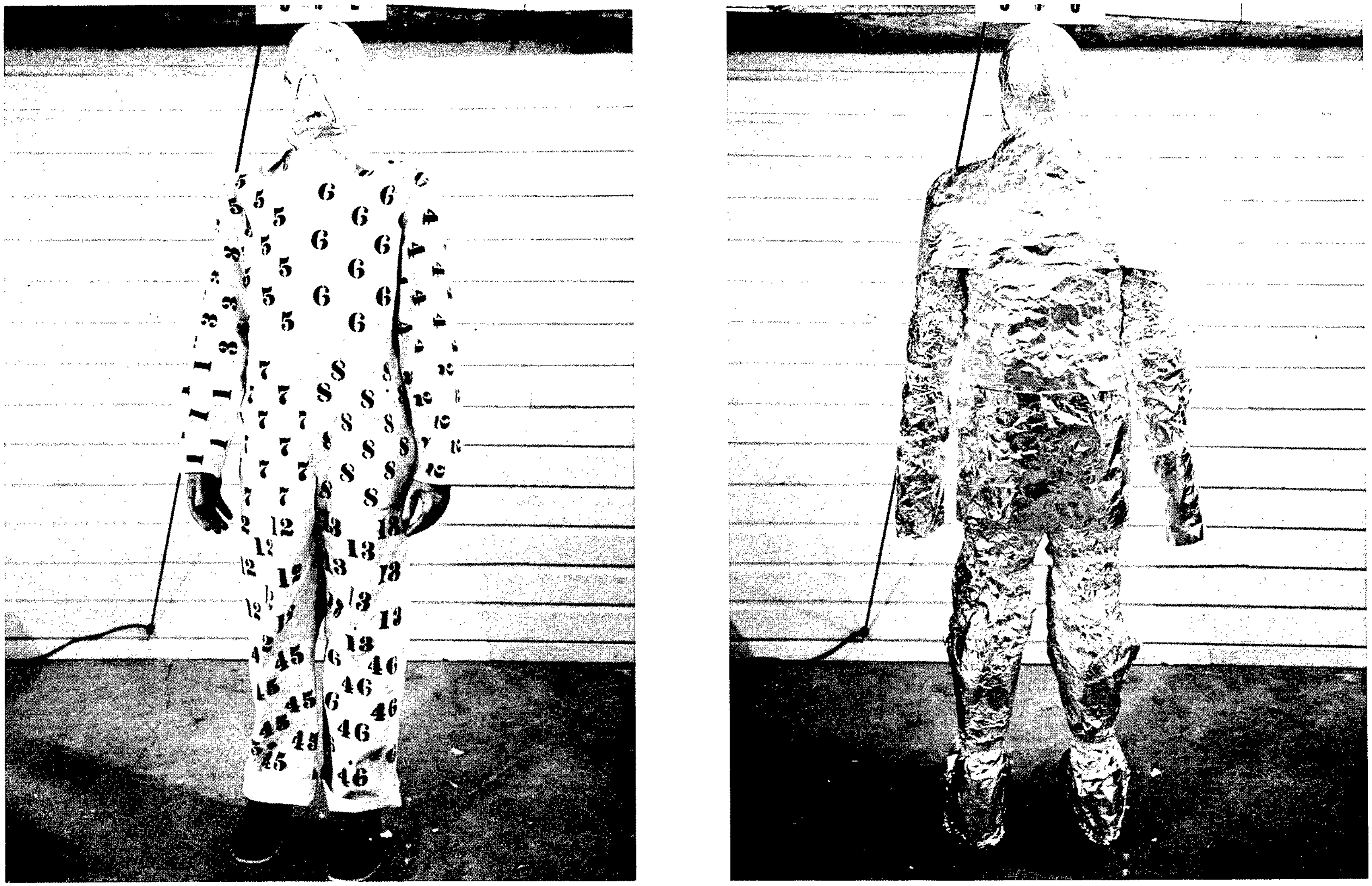
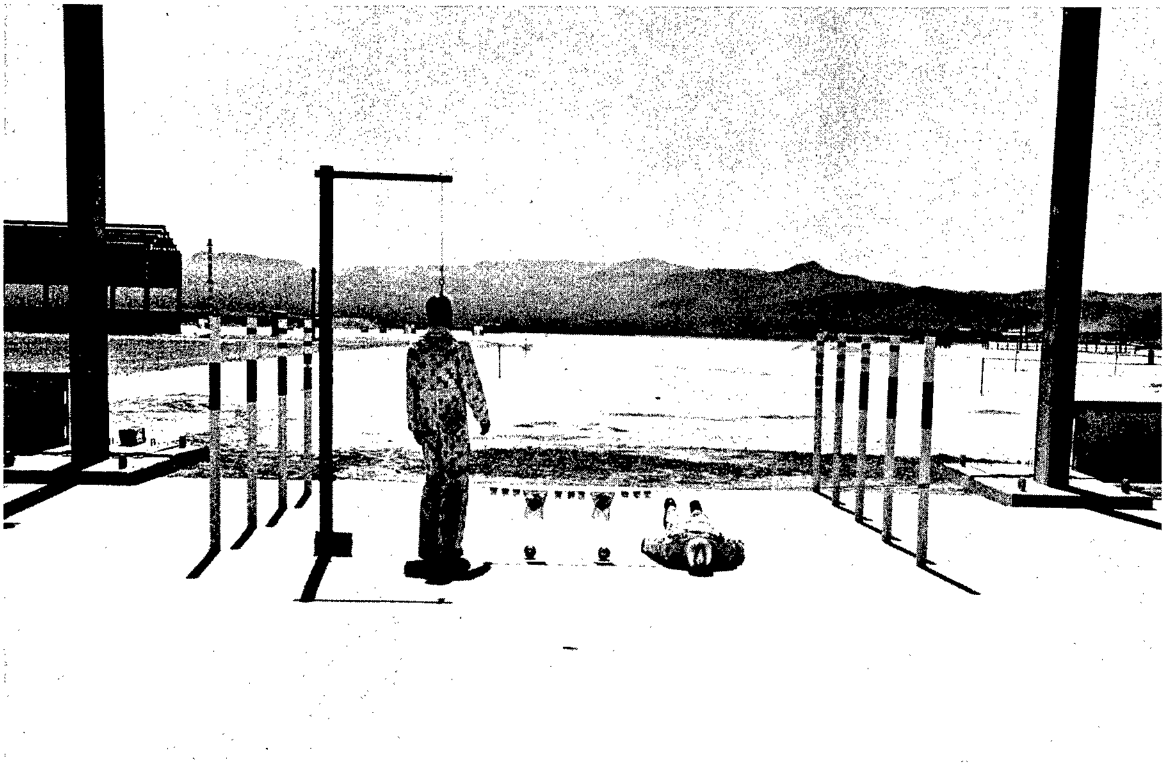


Fig. 2.6—Details of the photography grid, showing the positions of the camera towers and the marking posts (shot 2).

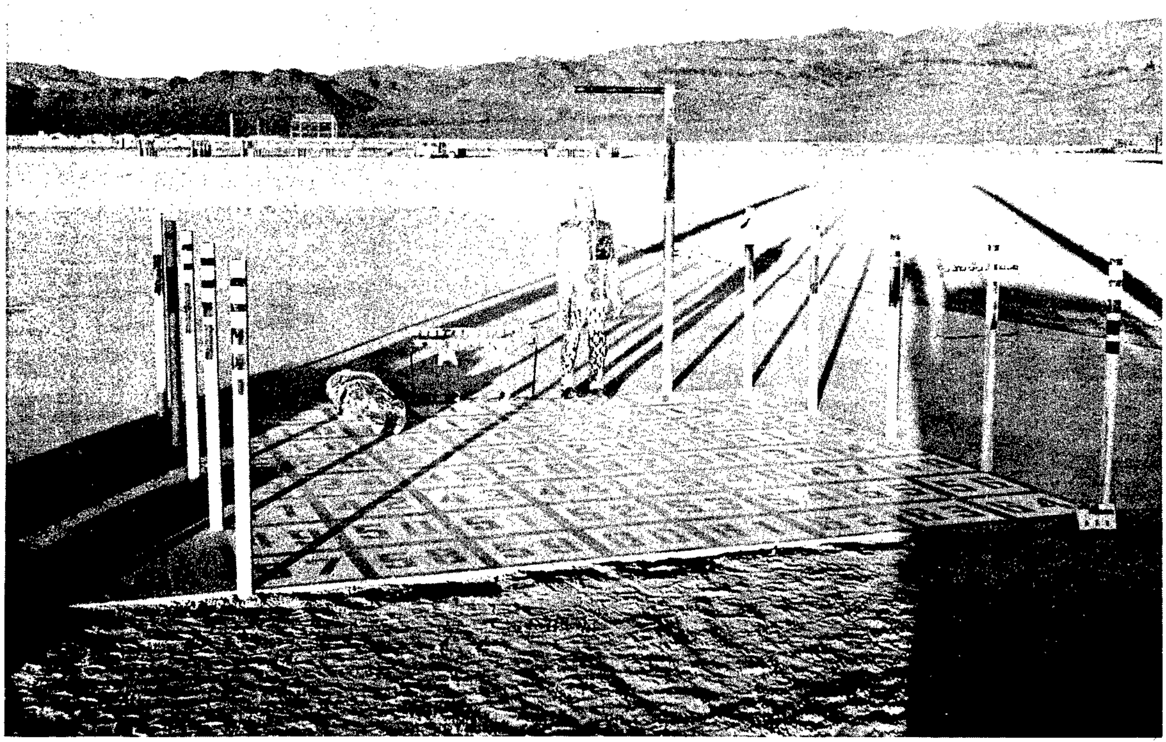


(a) (b)

Fig. 2.7—Front and rear views of dummy. (a) Front view, showing method of identification of the various parts of the body. (b) Rear view (toward GZ), showing protective aluminum foil.

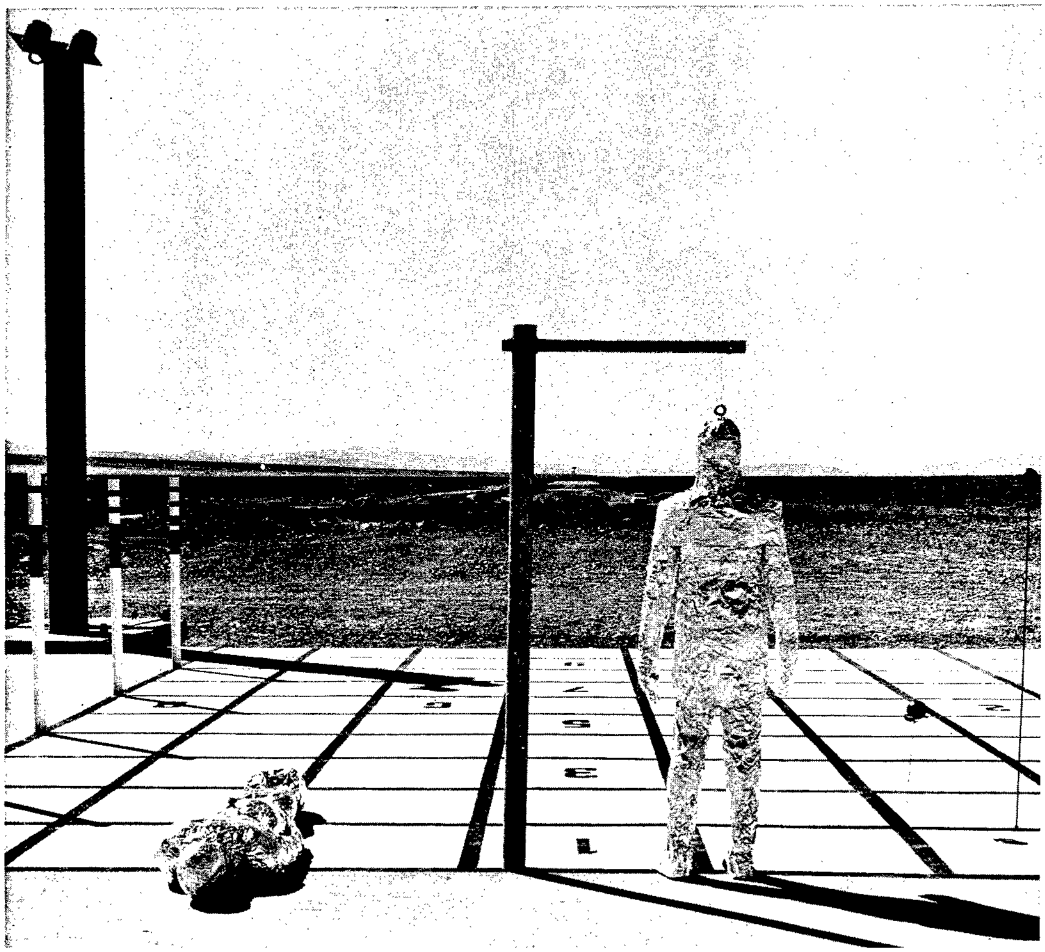


(a)

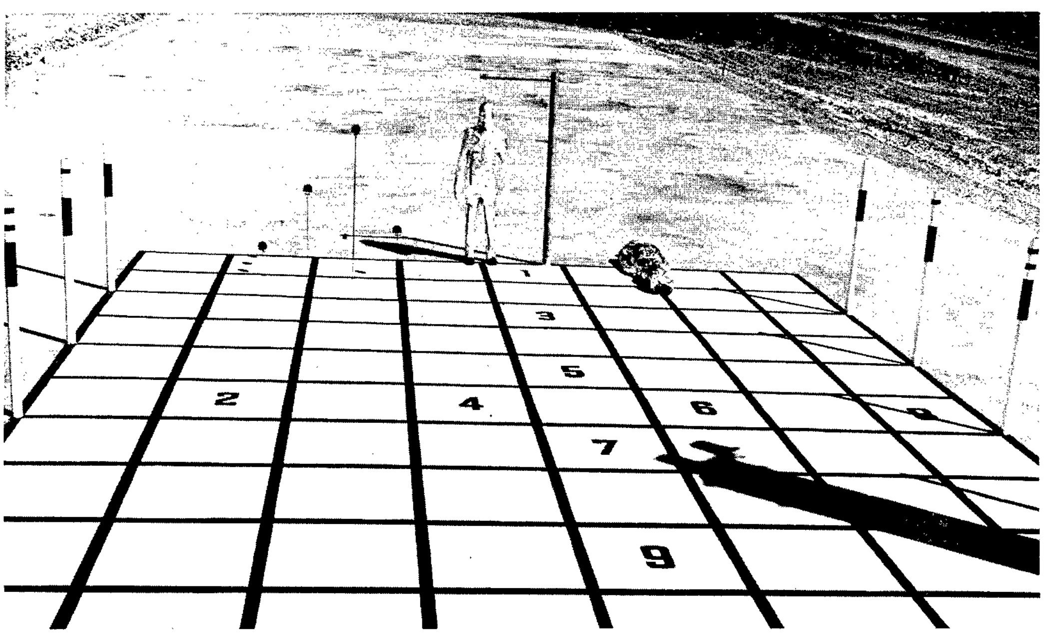


(b)

Fig. 2.8—General arrangement of the dummies and spheres for shot 1. (a) Looking away from GZ. (b) Looking toward GZ.

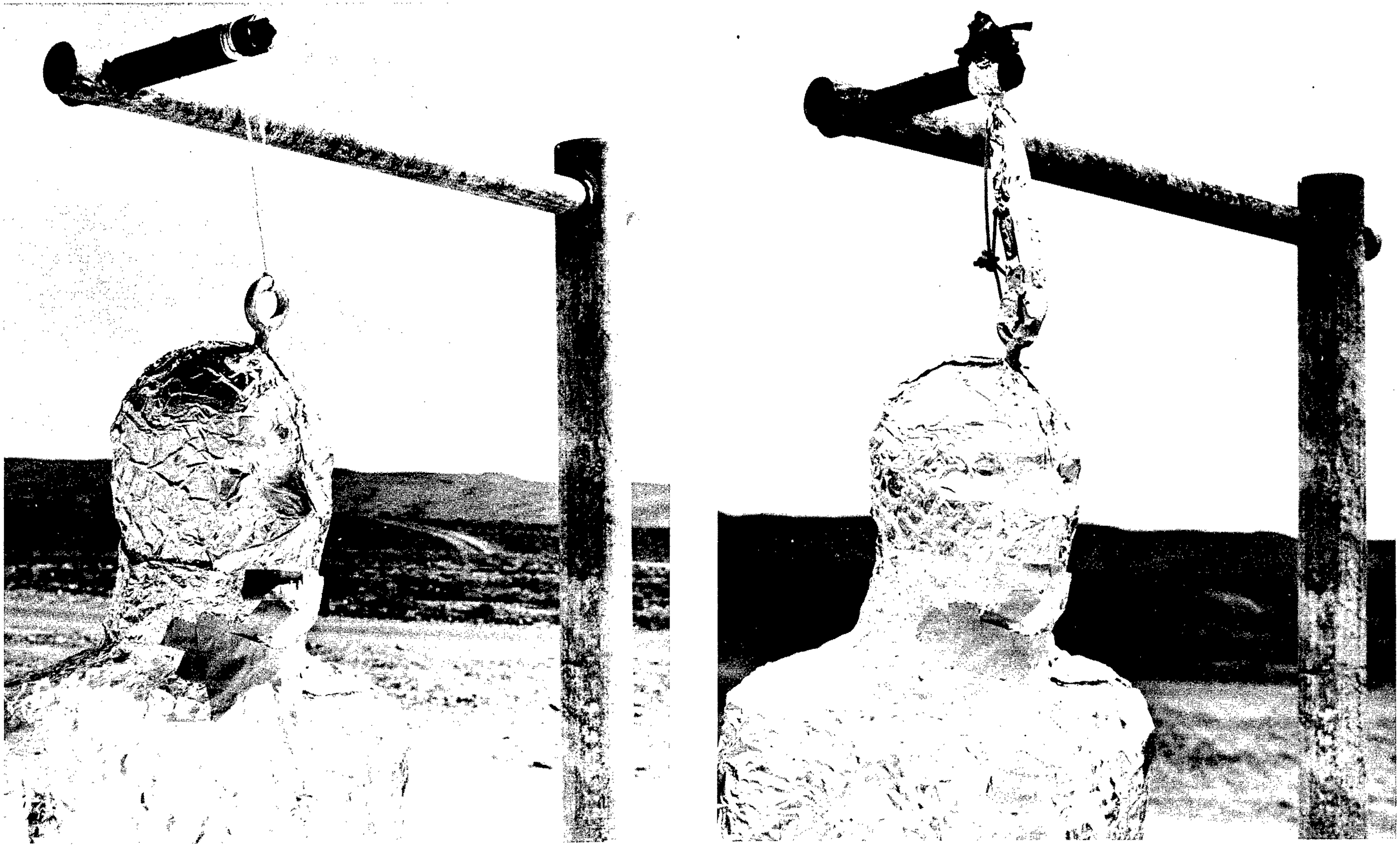


(a)



(b)

Fig. 2.9—General arrangement of the dummies and spheres for shot 2. (a) Looking away from GZ. (b) Looking toward GZ.



(a)

(b)

Fig. 2.10—Close-up of dummy as rigged for shot 2.

2.4 TEST OBJECTS

2.4.1 Dummies

Two anthropomorphic dummies (Fig. 2.7) were used in each of two detonations, shot 1 and shot 2. The dummies were manufactured by Alderson Research Laboratories, Inc., and represent the 50 percentile man, weighing 165 pounds (169 dressed) and measuring 5 ft 9 in. in height. The silhouette of the upright face-on position measures 6.2 sq ft. The distribution of weight among the components of the body and the construction of the joints simulated the human body to a high degree. One dummy was used in a prone position in both shots. The prone position was face down, head toward GZ, arms against body, and legs close together. The other dummy was used in the upright position with its back to GZ in both instances, but with major differences in each instance (Figs. 2.8 and 2.9). In shot 1 the dummy was suspended by its head with negligible weight on its feet (less than 3 lb per foot) and with all its joints loose and free to move. The idea here was to allow the body and components to move freely during displacement. In shot 2 the upright dummy had all its joints tightened enough to permit it to stand with no support. A very light string (10 lb breaking strength) was tied from an overhead support to the dummy's head to hold it in the zone of stability against natural gusts of wind which might have toppled it before H-hour. With this arrangement the full weight of the dummy was supported on its feet. As an additional safeguard against the dummy's falling if the light string did break, steel-wire rope $^1/_8$ in. in diameter was rigged. The wire rope was mounted in a slot overhead in such manner that it would offer little resistance during any translation caused by the blast winds (Fig. 2.10). In each shot the dummies were covered with aluminum foil as protection against thermal radiation (Fig. 2.7).

2.4.2 Equivalent Spheres

Two quite different applications of equivalent spheres were made: (a) free flight with phototriangulation and (b) captured flight with calibrated penetration.[1] In the free-flight application the spheres were intended to be subjected to conditions the same as those to which the dummies were subjected. Some differences are discussed in Chap. 3. In the captured-flight application the spheres were placed a predetermined distance from the missile trap. The distance was calculated as the distance necessary to allow the spheres to reach maximum or near maximum velocity. It can be seen that the captured-flight method gives one point of displacement data as compared to a complete history (if photography is successful) from the free-flight method.

Two different sizes of spheres were used. For the free-flight application, spheres 3.7 in. in diameter and weighing 351 g were used; for the captured-flight application, spheres $^7/_{16}$ in. in diameter and weighing 5.6 g were used.

REFERENCE

1. I. Gerald Bowen, Allen F. Strehler, and Mead B. Wetherbe, Distribution and Density of Missiles from Nuclear Explosions, Operation Teapot Report, WT-1168, March 1956.

Chapter 3

RESULTS

3.1 TABLE OF DATA

The data obtained from the two shots are presented in Table 3.1. These data include those obtained from Ballistic Research Laboratories, from direct measurements in the field, from analysis of the photography, and from analysis of the traps. Each of these sources is indicated in the table and, where applicable, reference is made to an illustration. It is to be noted that motion-picture films EG&G 41-361, 41-362, and 41-363 of reel P-57, and EG&G 42-939, 42-940, and 42-941 of reel P-164 constitute a part of the results.

3.2 SHOT 1—5-PSI STATION

3.2.1 Film Analysis—Dummy

Of the three usable films recovered, two were used to determine the exact position of the dummy in space (Fig. 3.1 shows several frames from a film). These two cameras were located on opposite sides of the pad, and the third camera, which was adjacent to one of the other two, was used only to check the camera speeds. The positions of the top of the head and the bottom of the feet of the dummy were determined at intervals of 2 frames (approximately $\frac{1}{32}$ sec). This was done by extending an imaginary line from the camera to the top of the dummy's head and then on to the grid on the pad. When the location of the camera and the point where the line intersects the grid are known, the equation of the line can be determined by the two-point method. This line was then intersected with the vertical plane in which the dummy moved to find the actual position of the head. The camera speeds were checked, with the arrival of the flash, the arrival of the blast wave, and the duration of the blast wave used as reference points. Two of the three cameras agreed in speed, but the third was found to have run slower. Its average speed throughout the run was computed using the other two cameras and the several specific events recorded as references. The record from the slower camera was then adjusted for proper matching with those from the other two cameras. The plot of the trajectory of the dummy included the paths of movement of the head, of the feet, and of the center of gravity.

Figure 3.2 shows the final plot of the displacement of the center of gravity of the dummy as determined from two cameras and as smoothed for best fit to the data analyzed. Attention is directed to the fact that this plot of the center of gravity is for the path to the point of contact with the ground and does not show the tumbling of the dummy along the ground, which is discussed later. The curve "Measured Displacement" of Fig. 3.2 was differentiated to give the velocity curve, and that, in turn, was differentiated to give the acceleration curve.

The actual movement of the dummy, with variations of the area presented to the wind, was just as important as the factors displacement, velocity, and acceleration, particularly if an analysis of the acceleration coefficient, α, and the evaluation of the use of equivalent spheres

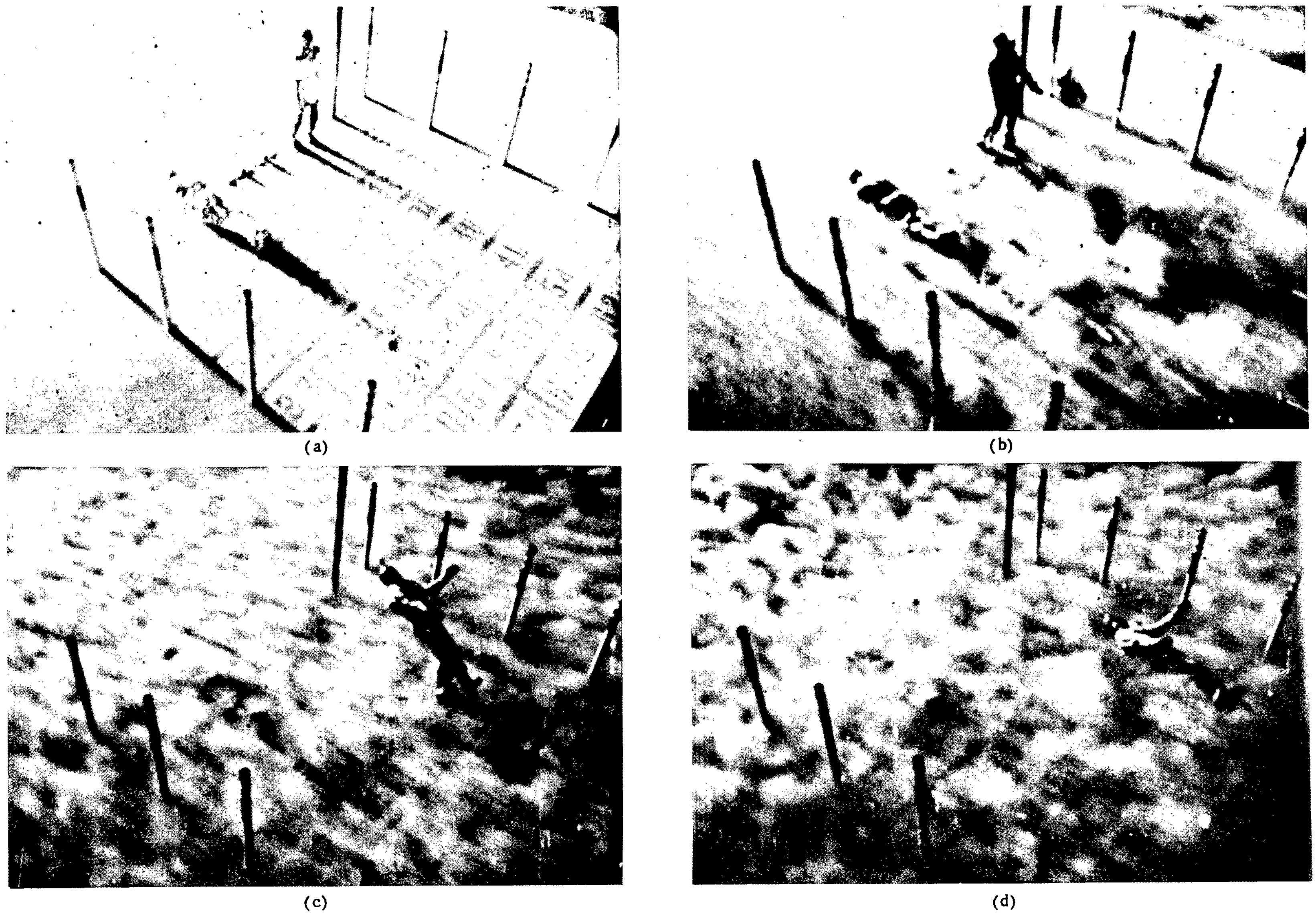


Fig. 3.1—Four frames from the film of the dummy of shot 1. (a) At the flash before arrival of shock. (b) 0.063 sec after the arrival of shock. (c) 0.359 sec after the arrival of shock. (d) 0.500 sec after the arrival of shock.

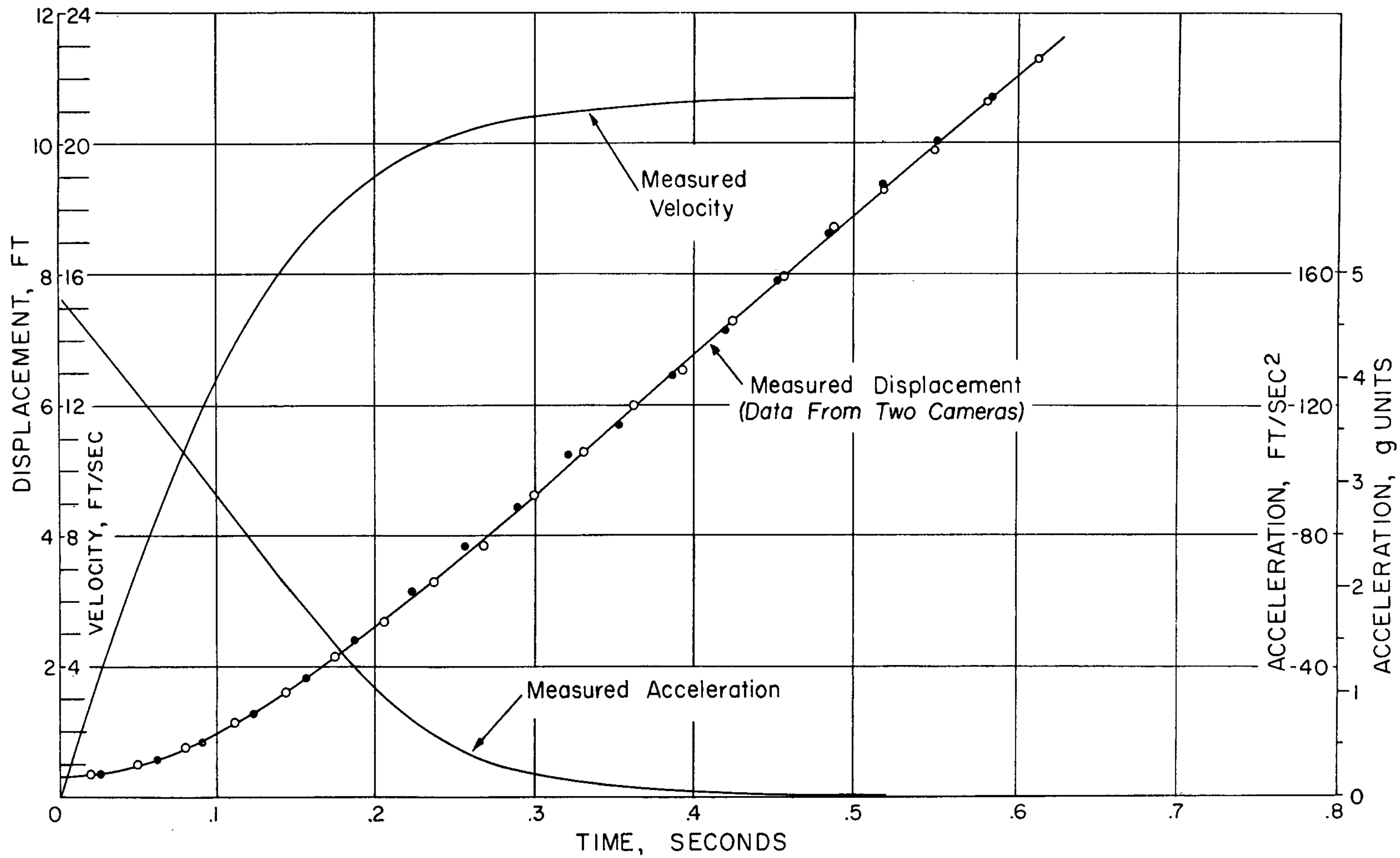


Fig. 3.2—Displacement, velocity, and acceleration of the dummy (shot 1).

are to be significant. The films indicated quite clearly that the dummy did not veer from a path straight and parallel to a bearing from GZ and through both the starting point and the final position. It was necessary, therefore, to plot only a side view of the vertical plane in which the dummy moved (see Fig. 3.3). It is well to recall, when reading this plot, that the dummy had negligible weight on its feet in the initial position. Also, a comparison of the position at 0.6 sec with the final position (Fig. 3.8) indicates that a bounce and perhaps some tumbling on the ground took place after this last recordable position at 0.6 sec. The position at 0.5 sec is that in which the presented area is at a minimum.

Figure 3.4 was developed from (a) the angle of the dummy with the horizontal and (b) the resolution[1] of α into components α_H and α_V. The wind is indicated as horizontal in this figure, although it is recognized that boundary effects must have been present. The films, however, do not indicate that this simplification is unreasonable, i.e., the traces of smoke and dust during the positive phase of the wind appear straight and mutually parallel. The assumption of an "ideal" wind is certainly not more unreasonable than is the idealization of the dummy as a cylinder. This latter step was used to resolve α into its components, α_H and α_V (Fig. 3.4). α_H is the component of α which is effective in the translation of the dummy along the direction of the wind; α_V is the lift component.

3.2.2 Film Analysis—Sphere

Figure 3.5 is a plot of the results obtained from the analysis of the movement of one equivalent sphere. This sphere was photographed on the same film as the dummy but was observable for a shorter period because the dust obscured it. Although only one of the four 3.7-in. 351-g spheres that were placed on the base line along with the dummies was recorded for a good part of its displacement, all four are shown to have moved upon arrival of the wind. The films do not provide an explanation for the position of the sphere shown in Fig. 3.6. A discussion of the "equivalence" between dummy and sphere is given in Sec. 4.2.

3.2.3 Field Measurements

Table 3.1 gives the distance traveled by the dummies as measured on the site (Figs. 3.6 and 3.7). As mentioned earlier, the final position of the upright dummy indicated that this was not the point of initial contact with the ground. Although the film confirms this, neither film nor final position discloses where the first point of contact was. Of four spheres placed for this test, only one was recovered, and this was in a position that cannot be explained positively (Fig. 3.6).

3.3 SHOT 2—7-PSI STATION

3.3.1 Film

In this shot the paint of the photography grid burned. The resulting smoke very quickly obscured all but a small portion of the field of view. In this small portion, the upright dummy was visible; however, it also was obscured as the blast arrived and before any motion could be seen. All four films from shot 2 were useless for analyzing the translation of any of the several test objects.

3.3.2 Field Measurements

In addition to the several measurements of the final positions of the two dummies (Figs. 3.8 and 3.9) and three spheres shown in Table 3.1, the captured-flight technique gave a velocity of 75.2 ft/sec, the average of the five spheres captured. It is to be noted that these spheres were placed on a line 17.1 ft upwind from the trap. The distance of 17.1 ft was predicted as that which would permit the spheres to reach maximum velocity at the moment of capture.

REFERENCE

1. Sighard F. Hoerner, editor and publisher, "Fluid Dynamic Drag," Chap. III, pp. 11-14, Midland Park, N. J., 1958.

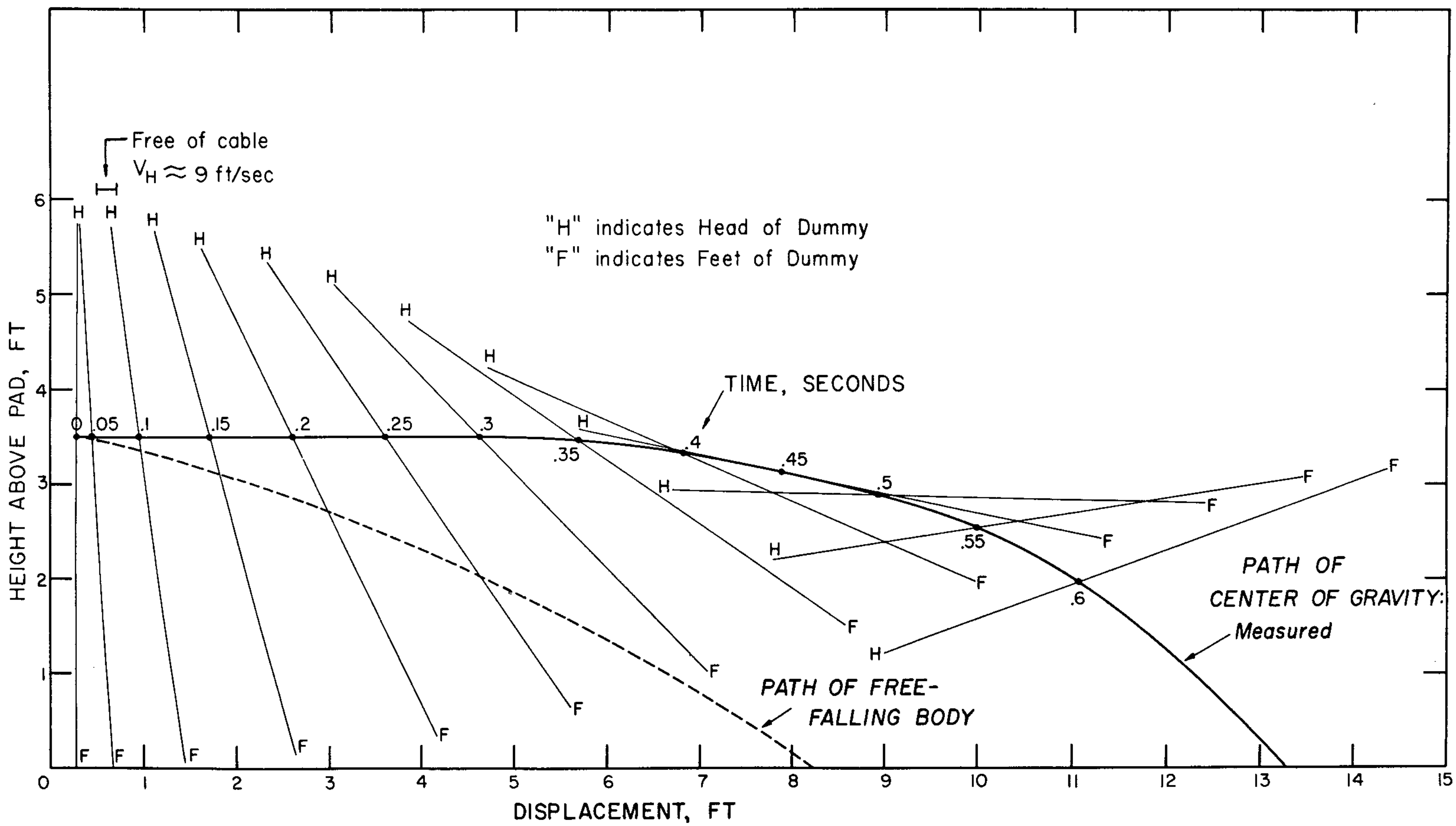


Fig. 3.3—Plot of the position of the dummy during translation as viewed at the side of the vertical plane in which it moved (shot 1).

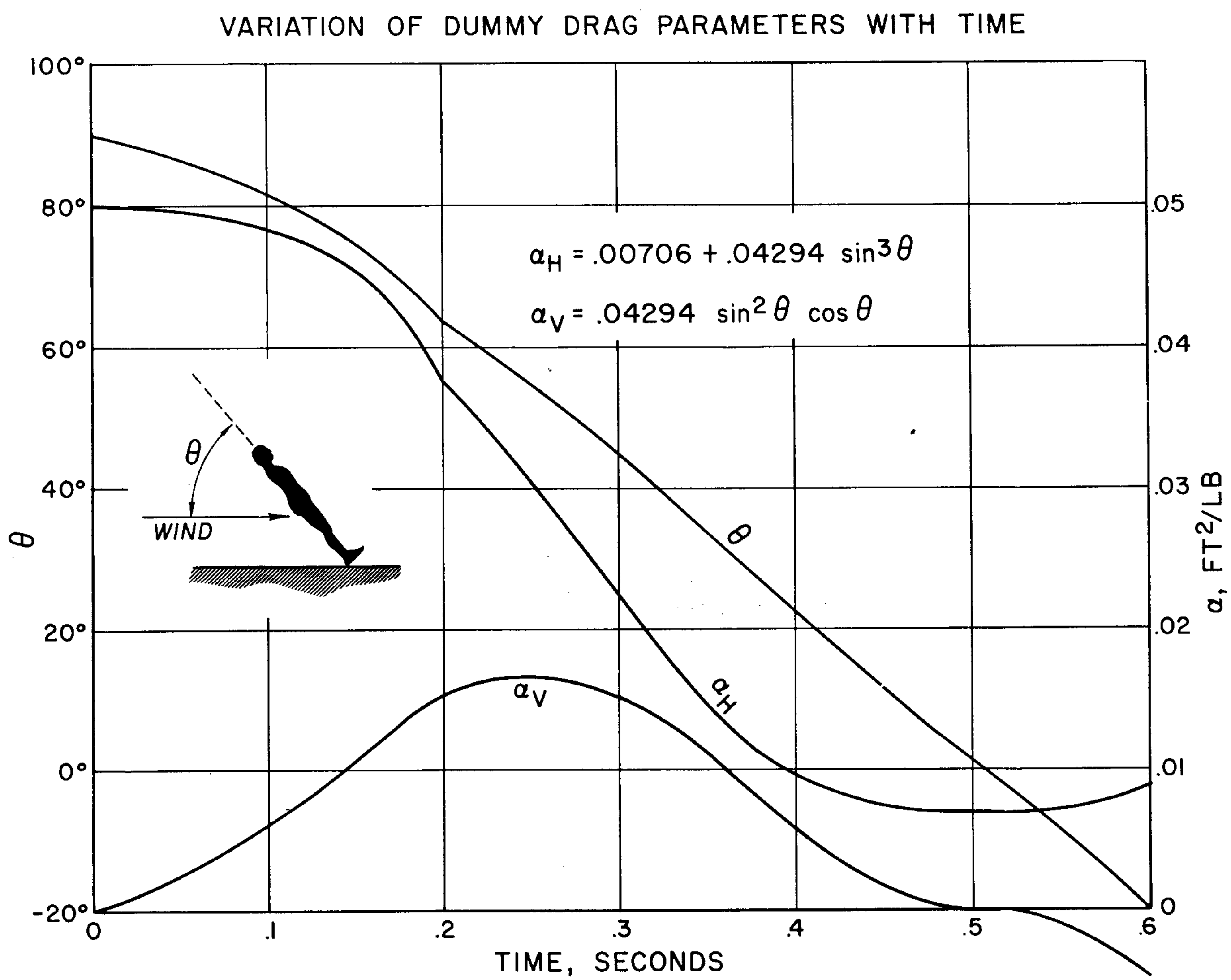


Fig. 3.4—Plots of the angle (θ) of the dummy with a horizontal wind, of the horizontal (translation) component (α_H) of the acceleration coefficient, and of the vertical (lift) component (α_V) of the acceleration coefficient.

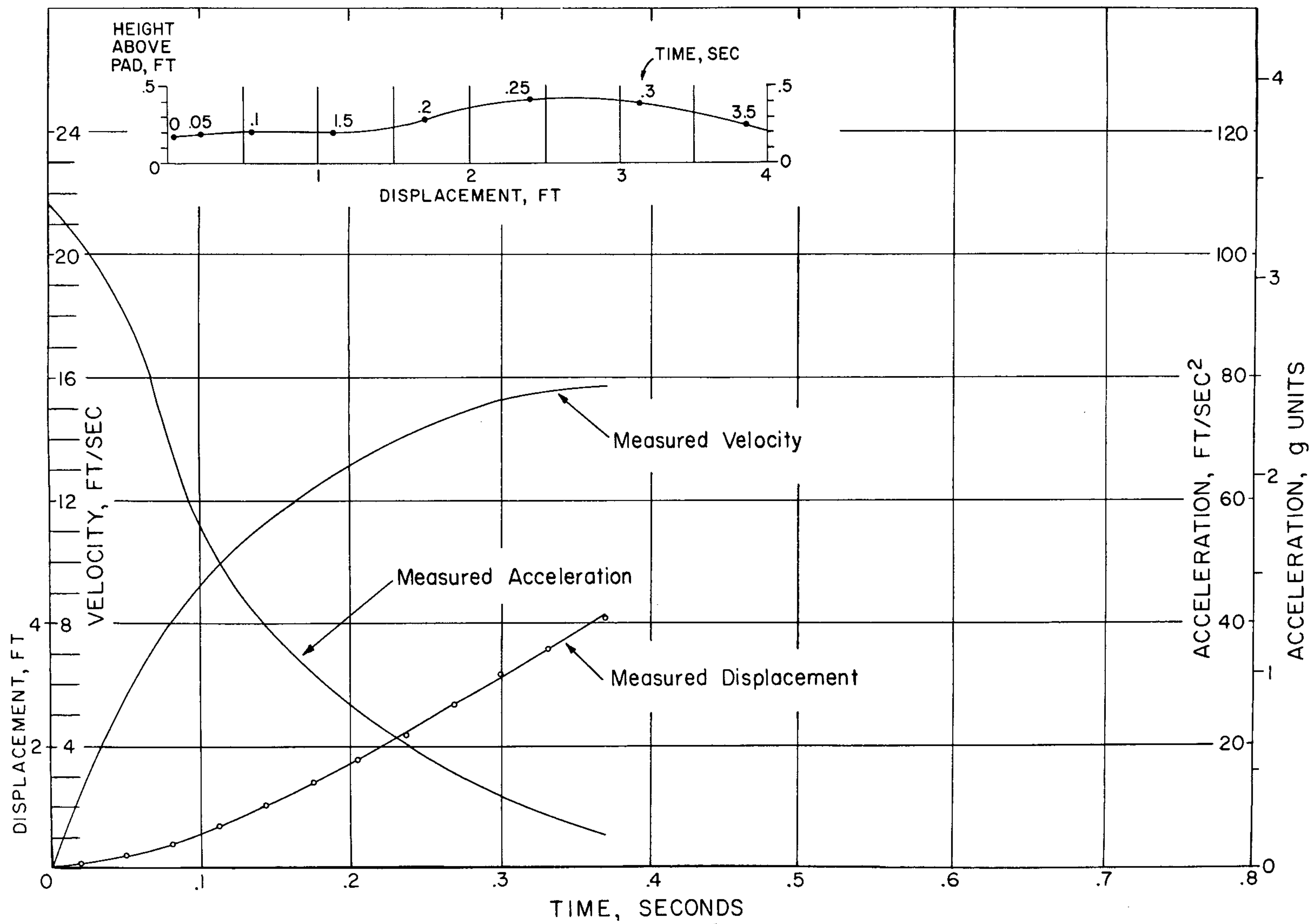


Fig. 3.5—Displacement, velocity, and acceleration of the equivalent sphere, shot 1. The insert is a plot of the lift of this sphere.

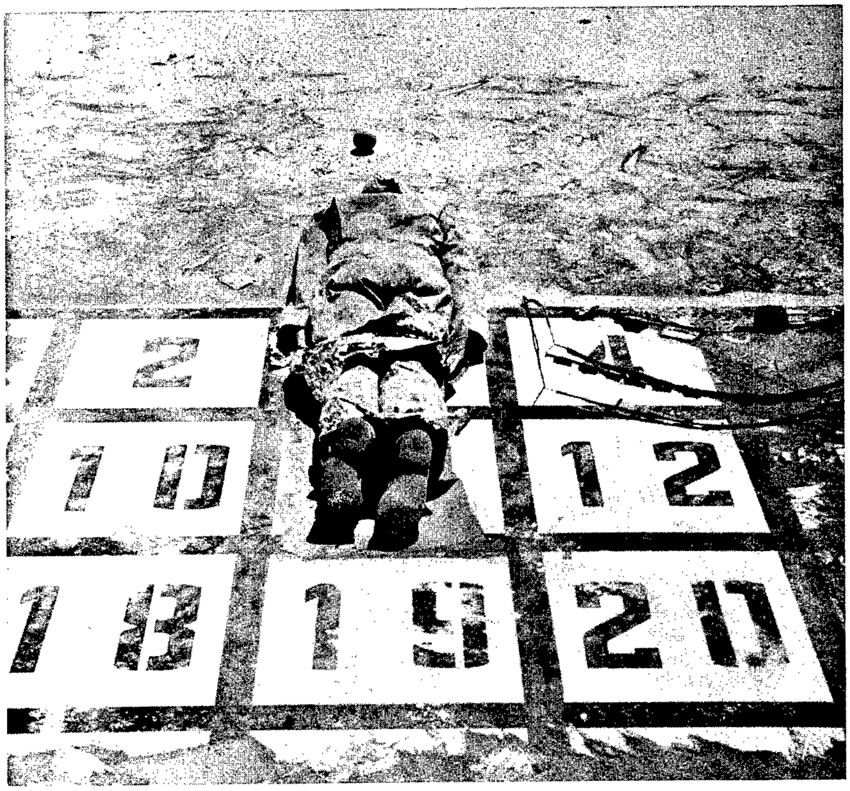


Fig. 3.6—Prone dummy after shot 1. The area around the dummy was swept to uncover the grid numbers. The position of the equivalent sphere shown here is not consistent with the film record.

Fig. 3.7—Upright dummy after shot 1. The area beyond the dummy was swept to uncover the grid numbers.

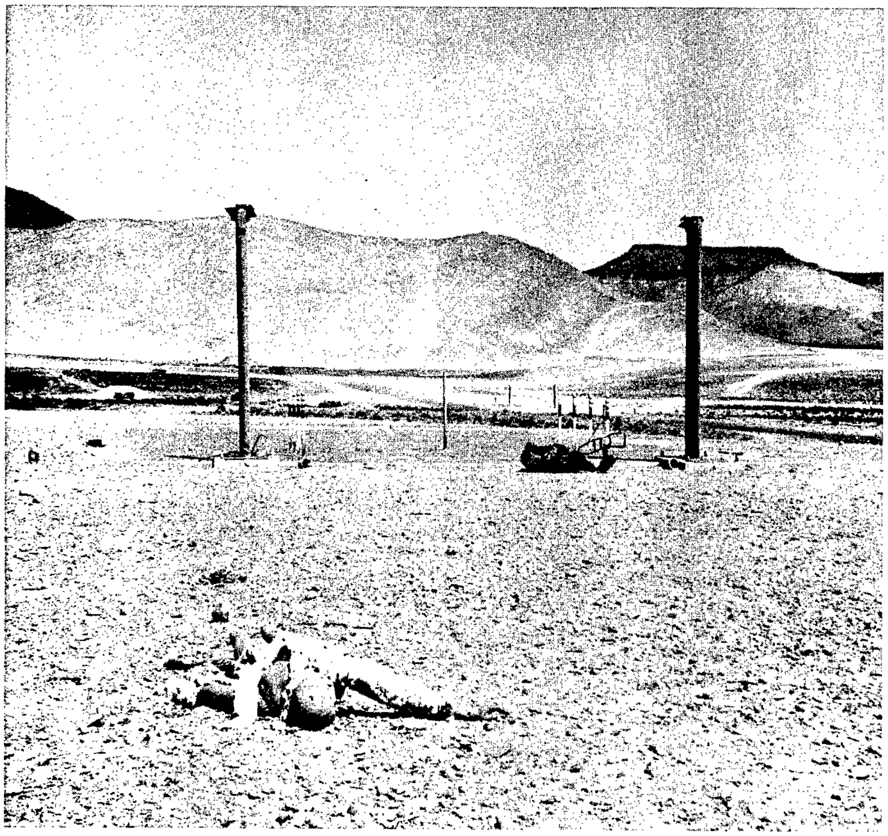


Fig. 3.8—Prone dummy after shot 2.

Fig. 3.9—Upright dummy after shot 2.

TABLE 3.1 — TABLE OF DATA

Item	Shot 1	Shot 2	Source	Reference
Static pressure	5.3 psi	6.6 psi	BRL	
Dynamic pressure	0.7 psi	15.8 psi	BRL	
		Movement of Object		
Prone dummy	0	124 ft ahead; 19.5 ft right	Field measurement	Figs. 3.6 and 3.7
Upright dummy	21.9 ft ahead	255.7 ft ahead; 43.7 ft right	Field measurement	Figs. 3.8 and 3.9
3.7-in. sphere on ground	4.1 ft in 0.37 sec (not recovered)	160 ft ahead; 31.5 ft right	Film analysis Field measurement	Sec. 3.2.2; Fig. 3.5
3.7-in. sphere, 12 in. above ground	Not obtained	Not recovered		
3.7-in. sphere, 20 in. above ground	Not applicable	Not recovered		
3.7-in. sphere, 35 in. above ground	Not applicable	303 ft ahead; 116 ft right	Field measurement	
3.7-in. sphere, 60 in. above ground	Not applicable	399 ft ahead; 89 ft right	Field measurement	
$^{7}/_{16}$-in. spheres	Not applicable	17.1 ft straight	Penetration trap	
		Velocity of Object		
Prone dummy	0	(These data were not obtained because the film for this shot was totally obscured)*	Film analysis†	Sec. 3.2.1; Figs. 3.1, 3.2, 3.3, 3.4
Upright dummy	21.4 ft/sec max. at 0.45 sec			
3.7-in. sphere on ground	16.0 ft/sec at 0.37th sec		Film analysis	Sec. 3.2.2; Fig. 3.5
3.7-in. sphere, 12 in. above ground	Not obtained			
3.7-in. sphere, 20 in. above ground	Not applicable			
3.7-in. sphere, 35 in. above ground	Not applicable			
3.7-in. sphere, 60 in. above ground	Not applicable			
$^{7}/_{16}$-in. spheres (5)	Not applicable	70 to 83 ft/sec; 75.2 ft/sec av.	Penetration trap	Sec. 3.3.2

*Films: EG&G P-164, 42-939, 42-940, and 42-941.
†Films: EG&G P-57, 41-361, 41-362, and 41-363.

Chapter 4

DISCUSSION

4.1 PHOTOTRIANGULATION

Although triangulation is a well-known technique, it appears propitious to describe several steps used for this analysis. Starting with a tracing of the grid and dummy as photographed in a frame of film before the arrival of the blast (similar to Fig. 2.1a), an extension of the grid was constructed graphically as necessary to provide a background for the upper part of the dummy. The extension was constructed by extending each family of original grid lines to its point of convergence. For intermediate grid lines, one original grid space of each coordinate family was divided into equal parts, and these points were connected to the respective point of convergence. It is admitted that a more accurate division of a grid space would be that in which the parts are in ratio as are the original grid spaces to each other in the projection. The error introduced by the use of equal parts instead of proportionate parts was deemed acceptable.

As mentioned earlier, a preliminary inspection of the films indicated that the dummy moved in a straight line parallel to the meridians of the grid (GZ being the pole). In the first steps of triangulation then, the reference points of the head and of the feet were located by the projection of the line from each camera independently through this vertical and parallel plane of the trajectory. The two independent runs coincided, thereby proving that the dummy did move in a vertical plane parallel to the meridians.

The coordinates within the plane for each successive position of the head and of the feet were determined by measurements along the meridian of the plane and along each Z axis. The Z axes were established by means of a third point of convergence, that to which all vertical lines converged.

The advantages of the photographic method are many, but perhaps the most important is the availability of a permanent visual record. A record of this type permits unlimited review of the action. The results obtained in shot 2 indicate the limitations of this method.

4.2 EQUIVALENT SPHERES

The comparisons of the translation of the dummy with that of the sphere which can be made from these results are few and limited. They do raise some questions about the use of a spherical model.

The use of an average value of α for the dummy appears reasonable if, in fact, the dummy and the environment to which it is exposed do experience this average value. The dummy does present a complete cycle of area from a maximum to a minimum, but this cycle is a particular one with respect to the wind. The maximum area is presented at the start of the translation, and the minimum, when the velocity is at a maximum. A test in which this same cycle of presented area was reversed undoubtedly would result in a different trajectory. The sphere, of course, retains its value of α under all conditions. A cylinder might well be a better model for the dummy.

The use of spheres in free flight for displacement measurements without photography (see results in shot 2, Table 3.1) is somewhat questionable because of the rolling which occurs after the landing. Also, if the test required that the model start on the ground, the sphere is not suitable because of some rolling before flight (this can be seen in the films).

In general, the use of a model for this type test would entail more study and investigation about optimum size and shape, the relative location of the centers of gravity of model and prototype with the ground or any other surface which might influence the winds, and the relative initial positions.

Chapter 5

SUMMARY

1. The two dummies in each of the two shots moved as follows:

(a) Shot 1, 5.3 psi, prone	0 ft
(b) Shot 2, 6.6 psi, prone	124 ft ahead; 19.5 ft to the right
(c) Shot 1, 5.3 psi, upright	21.9 ft
(d) Shot 2, 6.6 psi, upright	255.7 ft ahead; 43.7 ft to the right

2. Only in shot 2 were equivalent spheres of 3.7 in. diameter recovered. The final positions were:

(a) Start on ground	160 ft ahead; 31.5 ft to the right
(b) Start at 35 in. elevation	303 ft ahead; 116 ft to the right
(c) Start at 60 in. elevation	399 ft ahead; 89 ft to the right

3. The divergence from a straight-ahead displacement in shot 2 was approximately 9 deg for the dummies and 15 deg for the spheres.

4. Of the two films obtained, only that for shot 1 was usable for analysis. The film for shot 2 was useless because the field of view was totally obscured by smoke and dust.

5. The displacement of the upright dummy in shot 1, as analyzed in the film showed:
   (a) A maximum velocity of 21.4 ft/sec attained in about 0.45 sec with about 90 per cent in 0.2 sec.
   (b) An initial acceleration of 150 ft/sec/sec, representing an accelerative transverse load of almost 5 g.
   (c) A variation in the angle between the wind and the long vertical axis of the dummy from 90 deg, the initial position, through 0 deg, at about 0.5 sec, to minus 20 deg, at 0.6 sec. The negative angle represents that position in which the head and shoulders are lower than the legs and feet.

6. The 3.7-in.-diameter equivalent sphere had traveled 4.1 ft in 0.37 sec (the limit of the film analysis for this sphere). During this same time, the dummy had moved 6.4 ft.

7. The velocity of the 3.7-in.-diameter sphere had reached 16 ft/sec at the 0.37th sec. At this same time, the velocity of the dummy was 21 ft/sec.

8. In shot 2 an average velocity for five $^7/_{16}$-in.-diameter spheres was determined (by the trap method) to be 75.2 ft/sec.

Appendix A

THEORY OF EQUIVALENT SPHERES BASED ON THE ACCELERATION COEFFICIENTS

Mathematical procedures have been used to estimate the velocity acquired by an object free to move when subjected to blast winds.[1,2] The acceleration of a particular object has been shown to be proportional to its presented area and to its drag coefficient and inversely proportional to its mass. These parameters can be combined into a single quantity designated as the "acceleration coefficient," α, equal to AC_D/m; where A is the effective area, m is the mass, and C_D is the drag coefficient. The importance of α lies in the fact that two entirely different objects possessing the same value of α would experience the same acceleration, and thus the same change in velocity, if exposed to the same wind conditions. Because of this it was possible to construct a model of a man, having as its only similarity to man the value of its acceleration coefficient. A conveniently shaped model, one for which the drag coefficient is well known, might be a sphere.

The use of equivalent acceleration coefficients requires the recognition of several factors:

1. The limitation set by the range of wind speeds wherein the drag coefficients of the prototype and of the model remain constant[3] (Reynolds number from about 10^3 to about 4×10^5).
2. The requirement that the model be resistant to any distortion by the wind load.
3. The acceleration coefficient used when matching model and prototype, at best, is a representative one for the translation expected. In this factor the initial position is very important because it influences, by means of the presented or effective area, the resulting acceleration-time history.
4. The determination of the acceleration coefficient for the prototype from which the model is to be designed may involve an extensive series of experiments itself.

In this work, the data reported by Hoerner[4] indicated that a representative value of α for man, initially standing and later tumbling, might be between 0.03 and 0.04 sq ft/lb.

With these various factors in mind, the decision was made to use 3.7-in. spheres (croquet balls) weighted to give an α of 0.035 sq ft/lb. The small spheres were of steel with a $^7/_{16}$-in. diameter and a value of 0.040 sq ft/lb for α.

A more comprehensive study of the behavior of these types of spheres in various blast situations will be included in later reports.[5]

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Appendix B

DETERMINATION OF DIMENSIONS OF STABILIZED AREAS

The determination of the dimensions of an area of stabilization necessary to reduce the dust accompanying a blast wave is possible because of the limited excursion of a particular air molecule, and thus a dust particle. To illustrate, in the 5-psi maximum overpressure region, it can be computed that, during the entire positive phase of about 1 sec, an air particle would move about 114 ft. The stabilized area for shot 1 was made 130 ft long to include the 16-ft-long photography grid.

The distance of travel, or excursion, of an air particle was estimated from the relation of wind speed to time for the 5-psi region in shot 1. This relation was computed for a fixed distance from GZ; however, an air particle does not, of course, remain at this fixed distance. Thus, the air particle under consideration begins its journey in a pressure region slightly higher than 5 psi and ends about 114 ft away 1 sec later. During this time the shock front travels about 1200 ft. It is conceivable that a dust particle would overshoot and thus travel farther than the air particle. Since the overshoot would occur near the end of the positive-pressure phase, the effect would be insignificant from the standpoint of photography.

The principal considerations for deciding the width of the stabilized area were (1) entrainment of dust from the adjacent regions and (2) possibility of the shock winds traveling in a nonradial direction from GZ. These phenomena, unfortunately, do not lend themselves to easy numerical evaluation. The stabilized area for shot 1 was arbitrarily made 50 ft wide.

A procedure similar to the one described above was used to compute the length of the stabilized area (195 ft) for shot 2. The width of this area was arbitrarily made 65 ft at the end toward GZ, tapering to 50 ft at the end away from GZ.

The material of which the stabilized area is composed must not itself yield undue amounts of dust particles or smoke as a result of wind or of thermal radiation.