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U.S. DEPARTMENT OF COMMERCE
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Microscale Investigation of the Temporal Changes in the BUGGY I Base-Surge Cloud

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Air Resources
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March 1971

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MICROSCALE INVESTIGATION OF THE TEMPORAL CHANGES IN THE BUGGY I BASE-SURGE CLOUD

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A microscale analysis is presented to describe the temporal changes in the base-surge cloud generated during a Plowshare nuclear cratering event on the Nevada Test Site. The analysis shows that the inertial motion of the base-surge cloud dissipated within 1 min after detonation, so that after H+1 min, the displacement of the cloud was governed by the local air flow. The report also demonstrates how aerial photography can be used to conduct investigations of early-time cloud dynamics.

Key Words: aerial photography, base-surge cloud, meteorology, microscale analysis, nuclear debris cloud, Plowshare.

1. INTRODUCTION

Project Buggy I, the first nuclear row-excavation experiment performed in the Plowshare Program, was conducted on the Nevada Test Site at 0904 PST, 12 March 1968. Five nuclear devices, each having a yield of 1.1 kilotons, were detonated simultaneously in a dry basalt formation on Chukar Mesa, 5208 ft above MSL. The explosives were buried 135 ft deep and were 150 ft apart (Toman, 1969). Immediately after detonation a circular base-surge cloud was generated as well as a main cloud column; however, several minutes after detonation there was little distinction between these two clouds because they combined to form one total cloud system.

During the Buggy event, a U. S. Air Force photo-reconnaissance flight was made back-and-forth over the test area from 0900 to about 1100 PST on 12 March. Aerial photographs obtained from this reconnaissance mission provided an excellent opportunity to investigate the temporal and spatial behavior of the base-surge cloud generated during a nuclear cratering experiment. Results of the analyses of these photographs follow.

2. ANALYTIC PROCEDURE

Horizontal cloud dimensions were estimated by scaling for distances between reference points pictured on the ground. For example, in one photograph taken 4 sec before detonation, the base-surge markers around ground zero (GZ) were clearly visible. Knowing that the base-surge markers were 500 ft apart, I constructed a distance scale directly from this photograph. Picture quality was good enough to yield a scaling accuracy of ± 50 ft.

Aircraft altitude and picture time were obtained directly from a special display panel that appeared in each photograph. During any single flight over the base-surge cloud, the aircraft altitude remained relatively constant and the flight path was straight and level. High resolution black-and-white photographs of the base-surge cloud were taken at 4-sec intervals by a camera whose optical plane was parallel to the ground when the aircraft was flying straight and level. Each photograph covered approximately 25 sq. miles.

Cloud areas were determined by planimeter for several different times. In all photographs, the visible edge of the base-surge cloud was traced onto mylar paper to determine the position of the cloud system at 8, 12, 20, 28, 36, and 44 sec after detonation. Each cloud circumference was planimetered at least six different times so that a representative estimate of the horizontal cloud area was obtained. In all cases, the fundamental assumption that was made in tracing the cloud edges was that the visible edge of the cloud represented a constant threshold density of particles that were all located in the same optical plane.

3. METEOROLOGICAL ANALYSIS

The state of the atmosphere at 0903 PST is illustrated by the atmospheric sounding plotted on a skew T log P diagram shown in figure 1. This sounding was taken from a site approximately 7 miles east-northeast of GZ. In figure 1 notice that the temperature lapse rate was very unstable through the first 100 ft of the sounding. From about 100 ft above the ground to near 8000 ft above MSL, the temperature lapse rate was nearly dry adiabatic creating a neutrally stable atmosphere. This type thermal structure is condusive to convective mixing of any suspended constituents that might

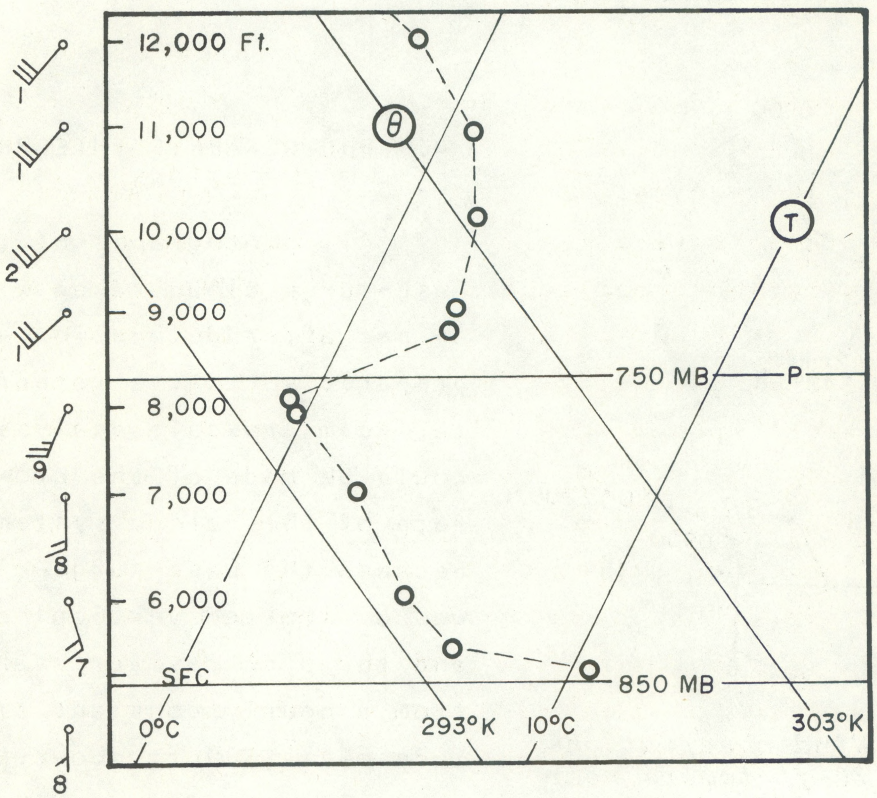

Figure 1. Skew T log P diagram of the vertical temperature structure and vertical wind profile near GZ at 0903 PST, 12 March 1968.

be released into the atmosphere. However, the sharp temperature inversion that existed between the 8000- and 9000-ft levels would tend to act as a lid, or upper limit, for any deep mixing process. Above the 11,000-ft level the temperature lapse rate was again nearly dry adiabatic.

Figures 1 and 2 reveal the vertical and horizontal distribution of the wind just before detonation. Of particular interest is the fact that within the lowest levels of the sounding there was little directional vertical wind shear, so that the base-surge cloud was not stretched in several different directions. Figure 2 illustrates the winds detected 30 ft above the ground near GZ, 4 min before and 1 min after detonation. Notice, in particular, that these winds were southerly at 10 to 16 kt, so that the southward movement of the base-surge cloud should have been retarded.

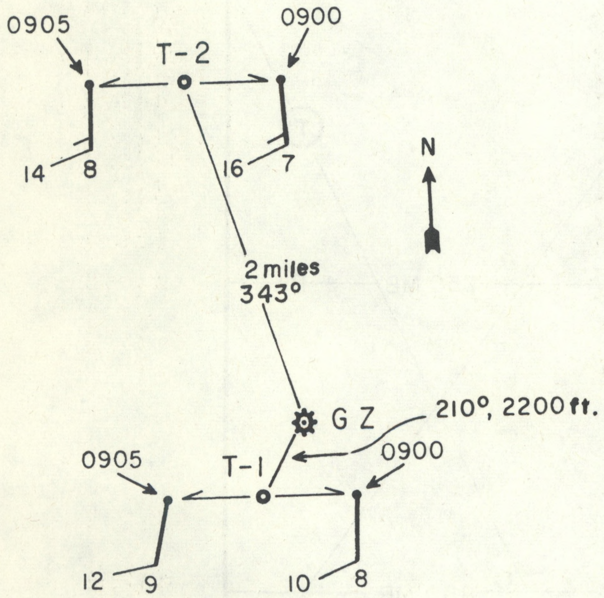

Figure 2. Wind observations from two 30-ft towers near Gz. Number left of wind barbs is wind speed in knots; number at base of barbs represents wind direction.

4. PHOTOGRAPHIC INTERPRETATIONS

All photographs of the base-surge cloud taken within 44 sec after detonation were prepared so that a rather detailed microscale analysis could be made of the growth rate of this cloud system. Because the base-surge cloud was of limited vertical extent and the pictures were taken from a nearly constant altitude of 14,700 ft above MSL, the calculated cloud dimensions should be reliable, especially in a relative reference frame. Aerial photographs were also available for about 1 min after detonation; however, in the last few frames the cloud system was near the edge of each picture, and optical distortions caused by the camera lens were apparent. Consequently, these latter pictures were not considered to be of good enough quality for analysis.

Figure 3 portrays the displacement of the leading edge of the base-surge cloud for 8-sec intervals. Each contour in this figure represents a direct tracing of the base-surge cloud as it appeared in several aerial photographs taken within 44 sec after detonation. In figure 3, notice that the southward movement of the base-surge cloud was being retarded while the northern portion of the cloud continued moving. This differential movement was related to the wind field and to the inertial motion of the base-surge cloud.

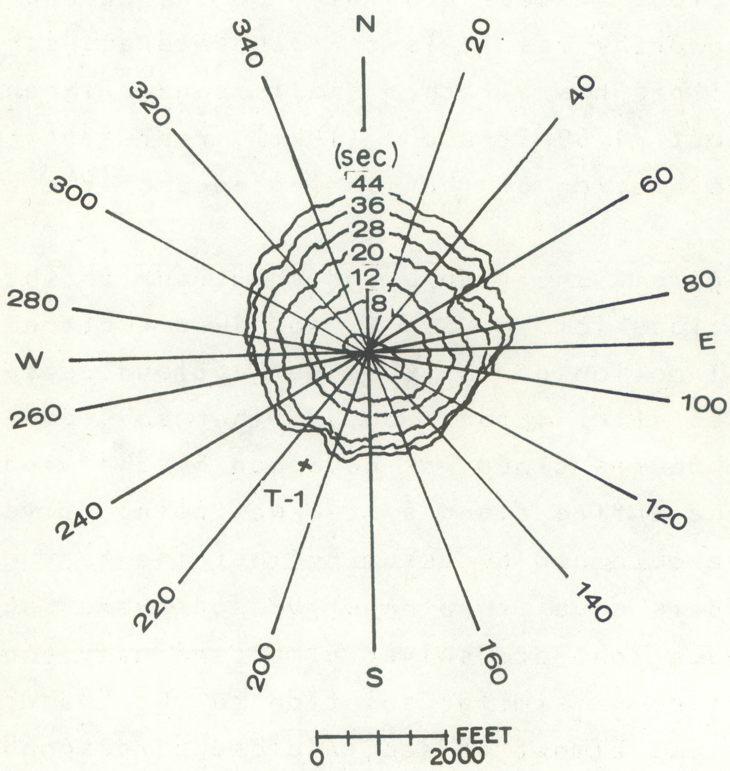

Figure 3. Positions of the leading visible edge of the base-surge cloud as determined directly from aerial photographs.

Wind observations (figs. 1 and 2) indicate that near GZ, the surface wind was from the south (180°-190°) at about 10 kt while at the 6000-ft level the wind was southerly (170°) at approximately 14 kt. Consequently, the mean wind velocity through this shallow atmospheric layer was, in general, southerly at about 12 kt. This type air flow regime would tend to retard the southward movement of the debris cloud.

Figure 4 shows the results of the calculations of the different displacement speeds of the base-surge cloud in eight different directions from GZ and the results of the calculation of each of the lines of best fit by linear regression. Displacement speeds were determined directly from the distances between cloud positions portrayed for selected times in figure 3. Although only five points were used in each case, the correlation coefficients indicate a strong linear relationship between the time and the speed of the base-surge cloud, except possibly for the NE and NW cases. Another noteworthy result is that the average slope of the regression lines has a rather small range with an average value of about -1.69 ft sec^{-1} (1 kt), representing a constant average deceleration of the leading edge of the base-surge cloud.

In figure 4 the graphs and solutions to the resulting linear equations for the SE, S, and SW directions show that the inertial motion of the base-surge cloud ceased approximately 38 sec after detonation, so that subsequent displacement of the debris cloud was governed by the wind field. The time when the entire cloud system was being driven by local winds can be obtained by assuming that the northward speed of the cloud is equal to a negative southward speed. If these two equations are solved simultaneously, one obtains a time of 46 sec. A similar solution to the E and W linear equations gives almost 48 sec, a close correspondence to 46 sec; the difference is explained by the fact that the

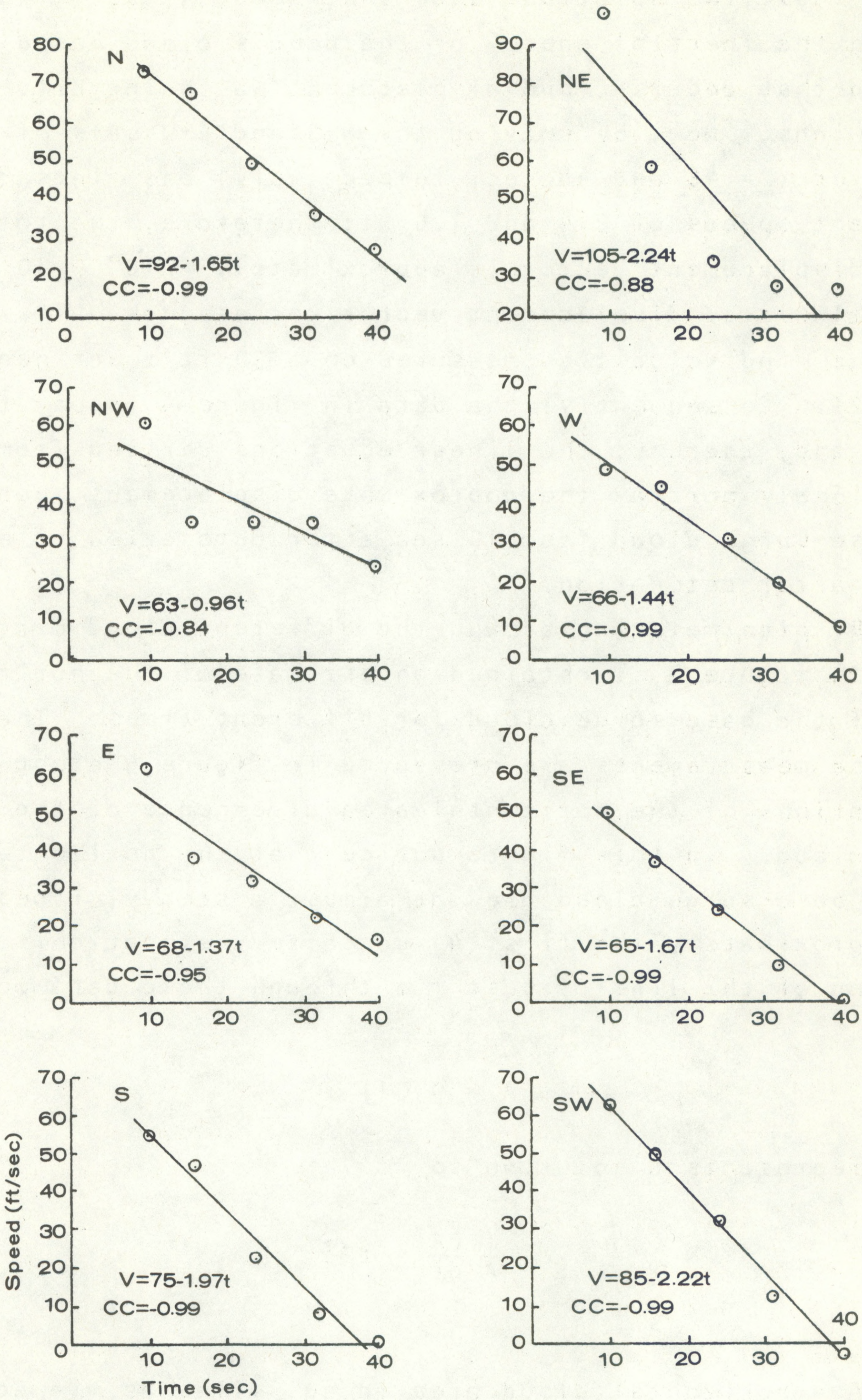

Figure 4. Temporal changes in the base-surge speed for various directions.

four equations are only linear approximations to the observed data. These two solutions show that about 47 sec after detonation the inertial energy of the debris cloud has dissipated and that debris cloud displacement was being driven by local winds. Now, by solving the N-S and E-W sets of equations for t = 46 and 48 sec, respectively, one finds cloud displacement speeds of 9.4 and 1.6 kt; therefore, the total cloud displacement vector is approximately 010° @ 10 kt. This calculated displacement vector corresponds quite nicely with the wind velocities measured on a 30-ft tower near GZ (fig. 2). Consequently, the data in figure 4 appear to be valid, and, thereby, the linear equations derived from these data closely portray the approximate displacement speeds of the base-surge cloud from 10 sec after detonation to about 40 sec after detonation.

By planimetering around the different cloud circumferences in figure 3, I obtained an estimate of the horizontal area of the base-surge cloud for different times. The results of these measurements are presented in figure 5 along with calculations of the horizontal area divergence of the base-surge cloud. In this figure notice that the horizontal area of the base-surge cloud grew at almost a steady, linear rate for approximately the first 44 sec after detonation. The equation of the line of best fit through these data points is

$$A = 0.011\ t, \qquad (1)$$

which represents a solution to

$$\frac{1}{A}\frac{dA}{dt} = t^{-1} \qquad (2)$$

where

A = horizontal cloud area in sq. miles as viewed in an aerial photograph.

t = time after detonation in seconds.

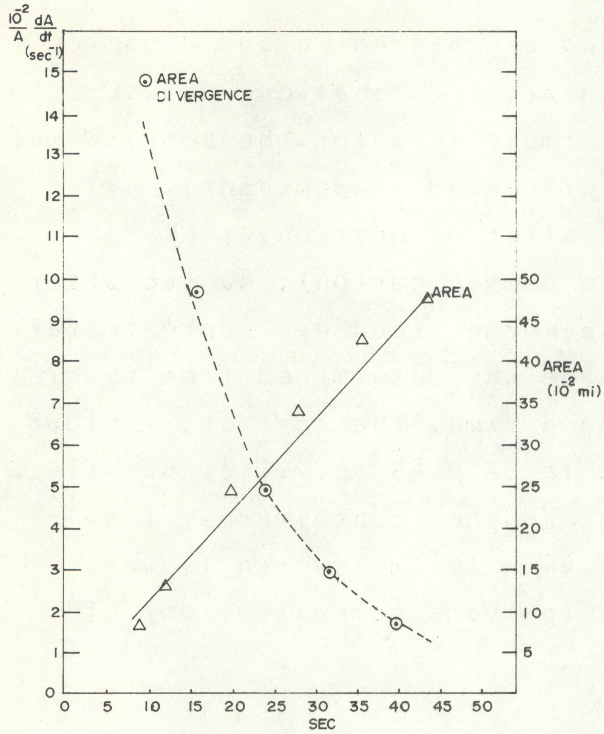

Figure 5. Temporal changes in the base-surge area (Δ) and in the area divergence (⊙). Solutions to (1) and (3) are included.

Although (1) is based on only six data points, it has a correlation coefficient of 0.99. These data indicate that between 8 to 44 sec after detonation, the base-surge cloud was apparently growing at a steady rate; however, by calculating the horizontal area divergence of this cloud system, I found that the expansion rate of the base-surge cloud was being retarded. Figure 5 reveals that this retardation was quite pronounced between 10 and 24 sec after detonation, and that nearly all the kinetic energy of motion, generated directly and indirectly by the device, was being dissipated quite rapidly by the atmosphere. By fitting an exponential equation through the data points representing horizontal area divergence, I found that

$$\nabla \cdot A \simeq 0.05 \exp[0.07(24-t)], \qquad (3)$$

which is another solution to (2), where $\nabla \cdot A$ = the horizontal area divergence of the base-surge cloud as determined from aerial photographs.

Equation (3) fits the five data points in figure 5 quite well, especially between 24 and 40 sec, and indicates that (1) does not adequately show A as a function of t. Equation (3) and the equations in figure 4 predict that nearly all the base-surge cloud expansion created by internal cloud dynamics was dissipated within about 1 min after detonation. Consequently, figures 4 and 5 and (3) imply that for the Buggy event, the base-surge cloud was being influenced predominantly by atmospheric motions within 1 min after detonation.

According to Rohrer (private communication), 40 sec after detonation the height of the base-surge cloud was approximately 125 m above the ground. This value was determined from special ground-based cameras. For the same time, the horizontal cloud area was estimated from figure 5 to be 0.45 sq. miles or 1.17×10^6 m^2. Knowing the cloud height and horizontal area, I calculated the cloud volume to be 1.46×10^8 m^3, which is very close to an estimation by Rohrer (private communication) of 1.5×10^8 m^3.

5. SUMMARY

Aerial photographs of the base-surge cloud generated by a Plowshare cratering event have been analyzed to evaluate the temporal changes that occurred in this microscale cloud system. Analyses of the base-surge pictures revealed the effects of the air flow in retarding and accelerating this cloud system and revealed a deceleration constant of about -1.69 ft sec^{-1} for the base-surge cloud at very early times (<1 min after detonation). A volumetric calculation of this small cloud, based on aerial photographic data, was consistent with another value obtained from an independent analysis of photographs from ground-based cameras. Calculations of the horizontal area divergence of the debris cloud and an analysis of figure 4 indicated that within about 38 to 60 sec after detonation the motion of this cloud system was dominated by the atmospheric wind field.

This report has demonstrated the usefulness of aerial photography in studying the small-scale behavior of a nuclear debris cloud. In future cratering events, I recommend that stereographic aerial photography be used so that a more detailed three-dimensional analysis of the debris cloud structure and dynamics can be made.

6. ACKNOWLEDGEMENTS

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7. REFERENCE

Toman, J. (1969), Project Buggy: A nuclear row-excavation experiment, Nuclear Applications and Technology, 7, No. 3, pp. 243-252.