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## DAMAGING DISTANT AIRBLAST FROM MINOR SCALE.

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### INTRODUCTION

An unexpected change in winds at 4-5 km MSL caused airblast ducting and focusing on Carrizozo, NM, 60 km east from MINOR SCALE. In result, this 4.8 kt ANFO (ammonium nitrate-fuel oil) explosion test, sponsored by the Defense Nuclear Agency (DNA), and fired at 1220 MDT, 6/27/85, rattled the town with 300 Pa (0.0435 psi) overpressure, according to the microbarograph records. Four large (8 x 10 ft) store windows were broken. Weather data which were collected during this event show that conditions changed near shot time, as needed to explain this result, but we have no clues for predicting such localized wind patterns.

Shock and acoustic waves are distorted by propagation through an atmosphere [ANSI, 1983] in which directed sound velocity varies with height, as it usually does. In a gradient condition, a vertical plane acoustic wave would travel faster near the ground than aloft, so that its wave normals (or rays) would be curved upward away from ground. The same effect bends all the emitted rays upward from a point source, or explosion.

Due to the divergence of the rays from ground level, overpressures would decrease faster with distance than would be expected from simple geometric spreading, as shown in Figure 1a. A so-called 'Standard' explosion, calculated for a calm atmosphere of uniform temperature and pressure [Needham, 1975], as shown in Figure 1b, would not have refracted or distorted rays but would have radial shock rays. Conversely, when sound velocity increases with height under an inversion as shown in Figure 1c, all emitted rays are bent downward toward the ground, in effect ducting the wave. Its spherical expansion is thus restricted, causing relatively increased overpressures to be observed along the ground.

When there is a complex dog-leg sound velocity versus height structure, as shown in Figure 2, the combination of gradient and inversion layers may focus the wave at some distance. Since this focusing occurs along a folding surface of the wave front in three dimensions and not at a point, it is properly called a caustic surface, but its intersection with the ground is often described as a focus. We do not know how intense these foci or caustics may be, but experience has demonstrated magnifications by several times above the expected Standard overpressures [Reed, 1969].

Directed sound velocity is the sum of the temperature-dependent sound speed and the directed wind component, and they both vary independently with altitude. Upper air temperature and wind reports are obtained from radiosonde balloon (raobs) ascensions.

### MINOR SCALE PREDICTIONS

Figure 3 shows the Standard overpressure distance curve, scaled to the MINOR SCALE yield of 4.8 kt ANFO or 8 kt NE (nuclear explosion). Potential weather effects on its propagation are shown by alternative curves for a strong gradient, a strong inversion, and an approximate upper bound for caustic con

ditions. The window damage threshold shown at 200 Pa is only approximate and based on three incidents from atmospheric nuclear tests. This shows that there could be window damage to almost 200 km distance, depending on shot time weather conditions.

The area surrounding WSMR is shown in Figure 4. The largest communities within about 150 km range are Socorro (population 12,969), Carrizozo (pop. 1,222), Tularosa (pop. 2,536), Alamogordo (pop. 24,024), Holloman AFB (pop. 7,245), and Truth or Consequences (pop. 5,219).

#### WINDOW DAMAGE PROBABILITIES

The probability of breaking a window by airblast is shown by an empirical curve in Figure 5, as a function of incident overpressure [Reed,1973]. Breakage appears with a lognormal probability distribution which decreases from a probability near unity at high overpressures to around  $4 \times 10^{-5}$  at 200 Pa (0.03 psi). There were about 19 window panes per capita in San Antonio, Texas, in 1964, when these data were assembled in a survey of damages from an accidental 50 ton HE explosion [Reed et al,1968]. Target population census figures can thus be used to estimate the number of exposed panes, and the expected breakage can be calculated from a predicted airblast overpressure.

#### SHOT DAY WEATHER CONDITIONS

Upper air temperatures were not unusual, although there was only a weak temperature inversion near the surface on the morning of 6/27/85. Upper winds were unusual, ENE 26 knots at 7 kft MSL at 0400 MDT, following a cold air mass outbreak over the Great Plains [Reed & Church,1986]. Upper wind speeds diminished to 13 kt by 1000 MDT. At 14 kft MSL winds were NW 10 kt at 0400 MDT, and they dropped to WNW 6 kt by 1000 MDT. Figure 6 shows these conditions, as translated to Carrizozo-directed sound velocities. The early morning dog-leg structure threatened airblast propagation enhancement, but by 1000 MDT surface warming gave a 18 ft/sec margin between the surface and 12 kft MSL sound velocities, to prevent any ducting. Conditions appeared equally good toward Alamogordo and Tularosa, and even better in all other directions. The shot-time raob showed a slight deterioration (increased upper level sound velocities) but no reason for concern. But, by the time this observation was in hand (shot time observations are made to balloon burst near 100 kft in about two hours), it had been discredited.

#### AIRBLAST AT CARRIZOZO

A microbarograph (MB) station was operated in Carrizozo and it obtained the pressure-time signatures shown in Figure 7. Three 2500 lb ANFO shots were fired before MINOR SCALE, at 0759 MDT (H-2 hours on the schedule) and 1114 MDT (H-1) to verify raob-based propagation calculations, and at 1218 MDT (T-2 minutes) to check yield scaling laws for long range propagation (5 MB stations were operated at 200 km range). The early shot gave an unexpectedly small wave at Carrizozo. Amplitude at 1114 MDT may have been 27 Pa as shown, but the high wind noise level makes it quite uncertain. The H-2 minute wave amplitude might have alerted our MB operator of what was coming (the cube root of yield multiplies 12.9 Pa to 202 Pa), but he was too busy changing the equipment to a less sensitive set range. At MS-150 seconds there was a small, explosion wave shaped noise clearly recorded on the sensitive A pen - MINOR SCALE was a dud! The ensuing bang quickly dispelled that thought. An overpressure of 297.5 Pa rattled windows and doors in spite of its slow compression, taking 400 ms from start to peak.

After this recording was completed with post-cals and time hacks, our MB operator called the city police to check on any damage reports. They had not received any calls, but they had thought their ceiling was going to fall from the blast which sprinkled their office and desks with dust and plaster powder. The sheriff had received a report of windows broken at a mid-town store. When the MB operator called these reports in, I had a credibility problem biased by the available weather information. At the scene of the damages, four large (about 8'x10') store windows were found broken of the seven which were exposed.

It was established that they had been about 1/4" or 3/8" thick plate glass, but the sheriff advised our man to leave town before he could make the detailed assessment and measurements which we had requested.

Two months later this store front had been completely remodelled with smaller panes, but the general dimensions of the original installation were verified. According to a WSMR attorney, they have settled this case with about \$2400.

#### IN EXPLANATION

The MB overpressure record indicates  $2.13 \times 10^{-4}$  window damage probability. Carrizozo's population of 1,222 (1980 census) leads to a guess that it also has around 23,218 window panes. Thus five should have been broken; only four were broken but they were big ones. A similarly good correlation with our prediction model was obtained at DIRECT COURSE in 1983, when 4.8% of the panes in the DNA Project Admin Park were smashed by an estimated overpressure around 2 kPa, which could be calculated to give from 4.5% to 7.8% breakage [Reed & Church, 1984].

But how did the overpressure get amplified to such an extent? It certainly is not explained by the shot-time raob made at Stallion, 28 km north of Ground Zero (GZ). There was, however, another raob made for another project at 1.25 hours after MINOR SCALE at Jallen Site, 50 km south of GZ. This observation showed, in Figure 8, a complex blast duct toward Carrizozo caused by a WNW 22 knot wind reported at 12 kft MSL. Only a narrow belt of the initial blast wave would have been ducted, according to ray path calculations, and it could have been focused near 30 km range after skipping above the 9000 ft Oscura Peak. But it apparently was reflected and repeated its atmospheric path to strike Carrizozo at 60 km range. Even the measurement errors and horizontal inhomogeneity of the atmosphere make these focal distance calculations uncertain by about 35%, but something quite similar likely occurred.

On the other hand, directed sound velocities calculated from the Jallen raob toward Tularosa and Alamogordo also showed very similar structures, while only very weak waves were recorded there by our MBs. Figure 9 shows these reports on the overpressure prediction graph, along with some yield-scaled points from DICE THROW [Reed, 1977]. That event almost broke some windows in Alamogordo, again - apparently - from wind effects that were not encountered by the shot time raob balloon. Had the MINOR SCALE yield been shot for DICE THROW, nearly 1000 windows would likely have been broken.

#### CONCLUSIONS

In spite of reliance on series of upper air weather balloon observations to predict distant airblast propagations from WSMR explosion tests, there have already been two incidents of wide misses.

Cont'd  
It appears that the variability of winds over the mountainous region around WSMR is appreciably larger than over flatter terrain, so that airblast propagation predictions are subject to significant error.

Microbarographs are essential in surrounding communities, to document the explosion airblast strength when unexpectedly enhanced blasts occur.

The provided empirical model for estimating window damage from expected overpressure appeared to work well.

As expected, large windows were the first to fail from the blast. Large plates are indeed hazardous when they break, so that such window damage should be avoided, in spite of their relatively low replacement cost in comparison with test delays.

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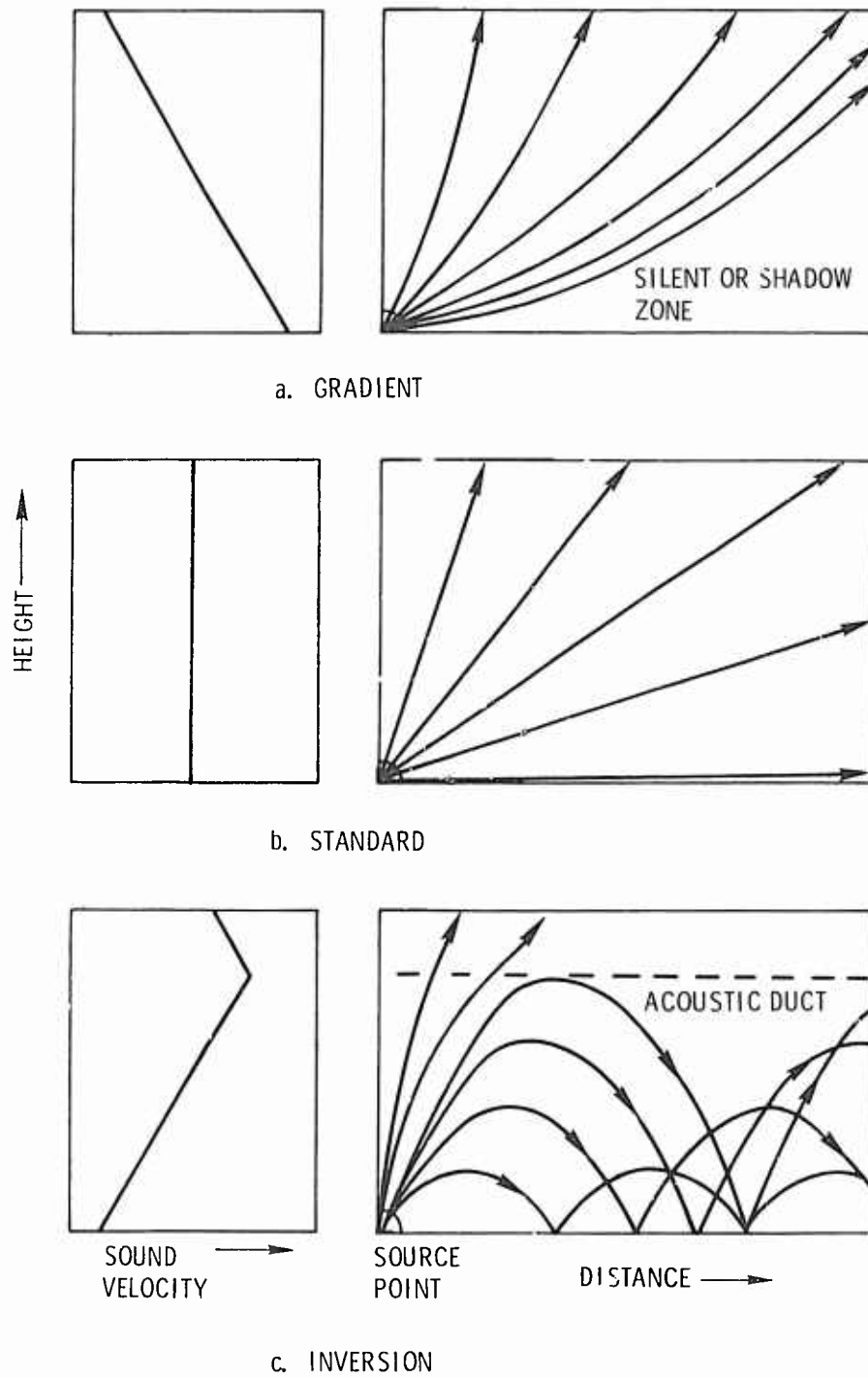
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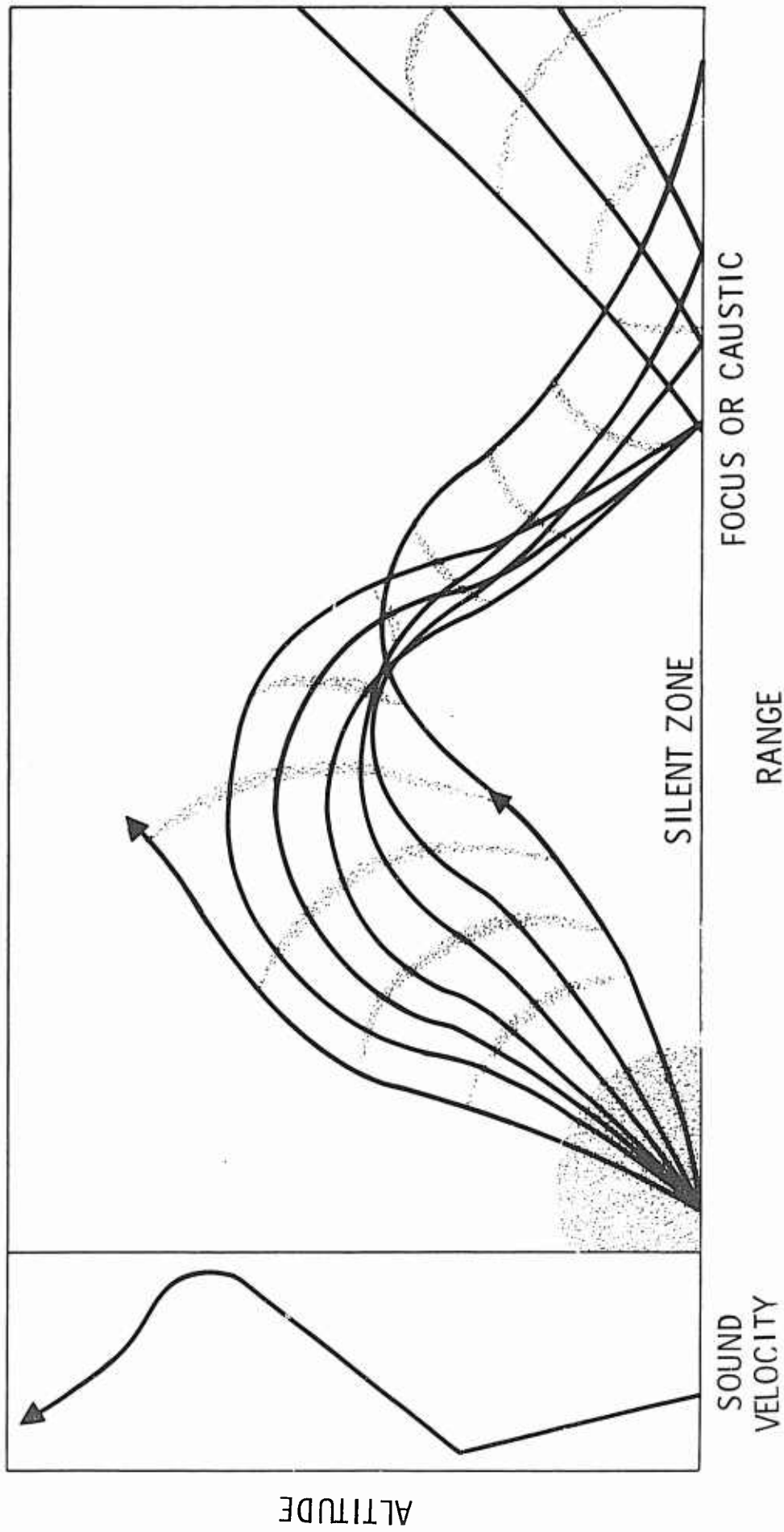
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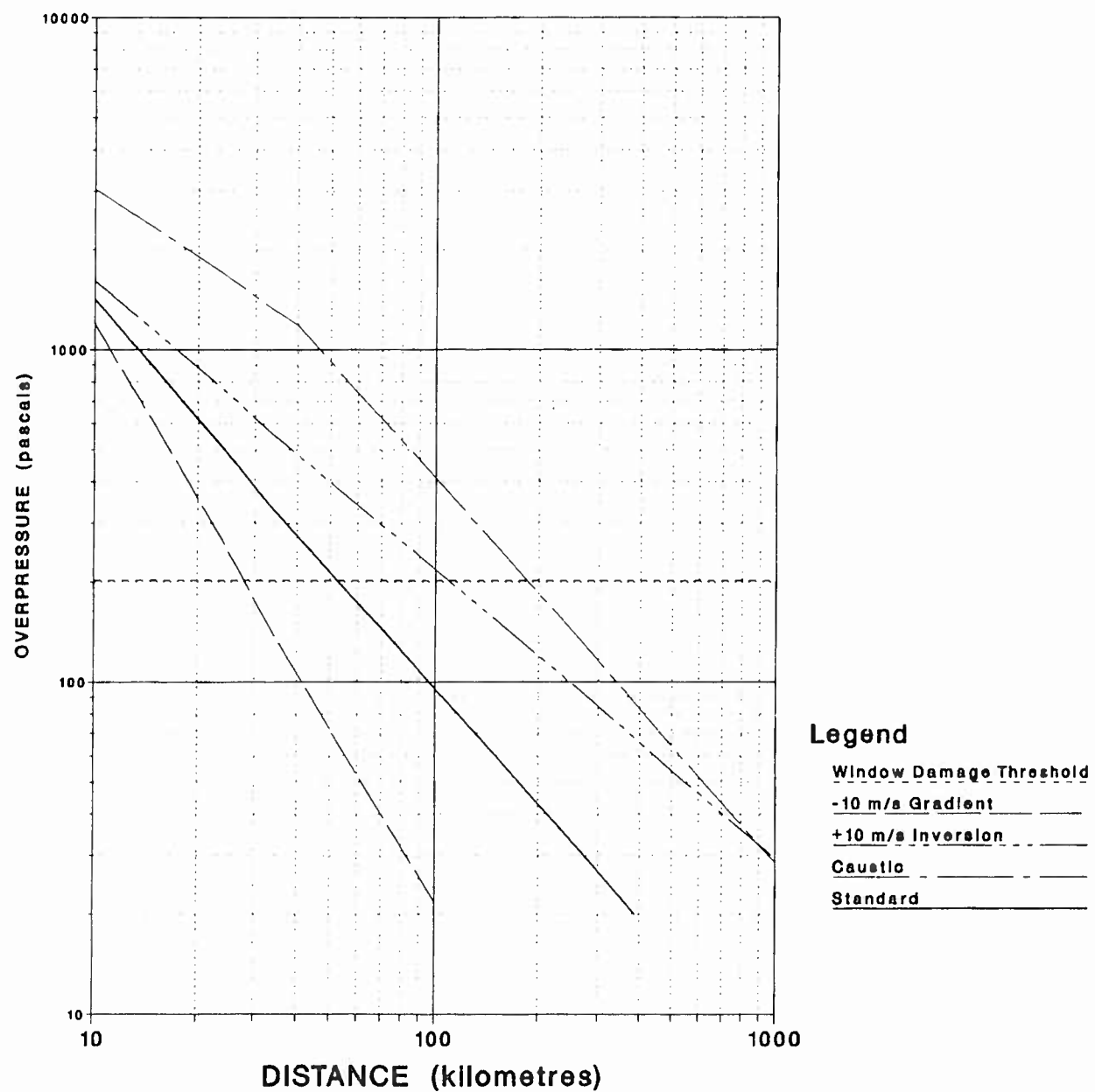
**Figure 1. Atmospheric Refraction Effects on  
on Sound Waves.**



**Figure 2. Typical Explosion Ray Paths under Complex Conditions.**



**Figure 3. Weather Effects on Overpressure-Distance Curve for MINOR SCALE, 4.8-kt ANFO Surface Burst.**



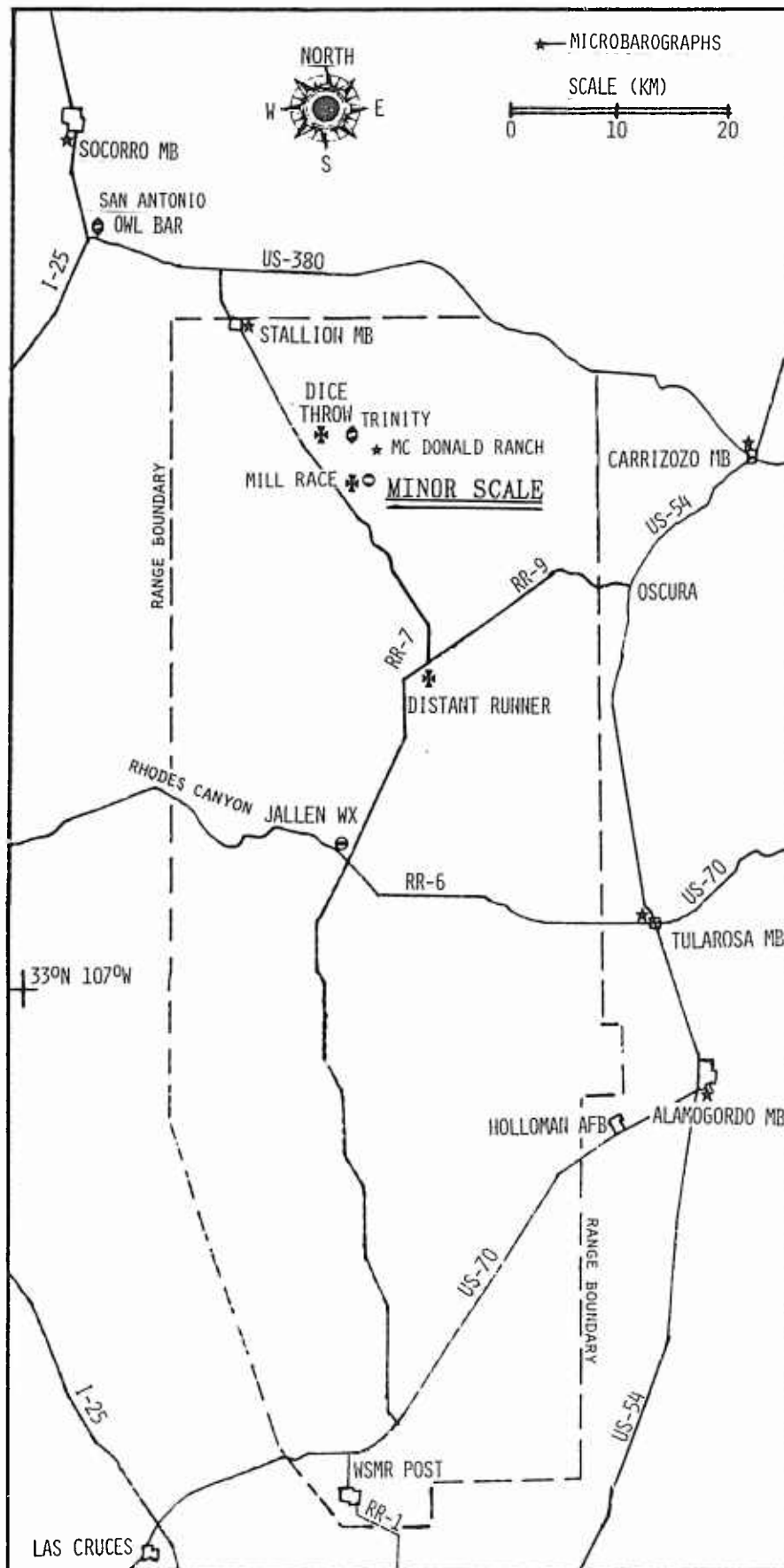


Figure 4. Map of White Sands Missile Range, New Mexico.

Figure 5. Window Breakage from Airblast.  
Based on 1964 Pane Size Distributions, San Antonio, TX.

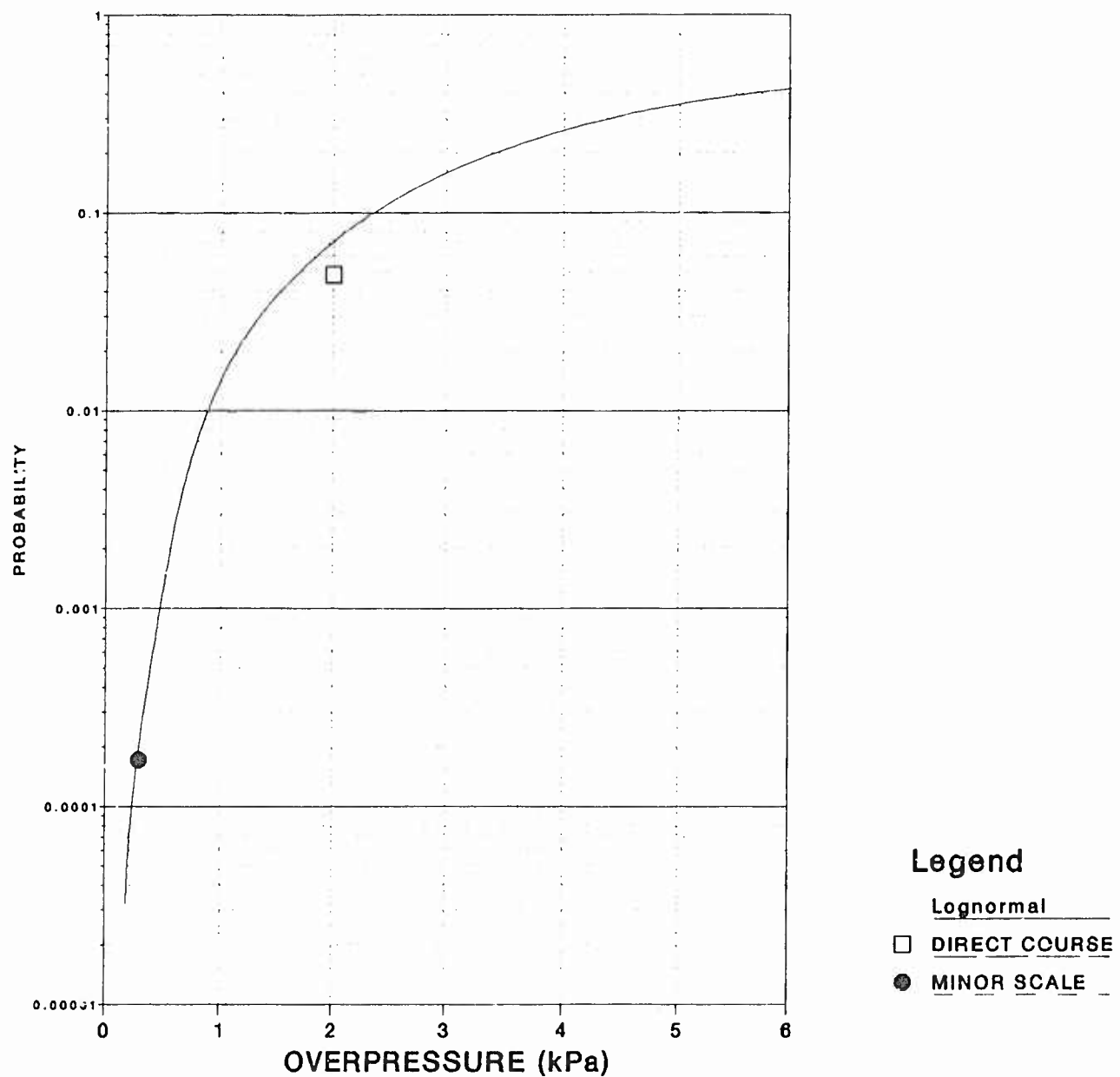
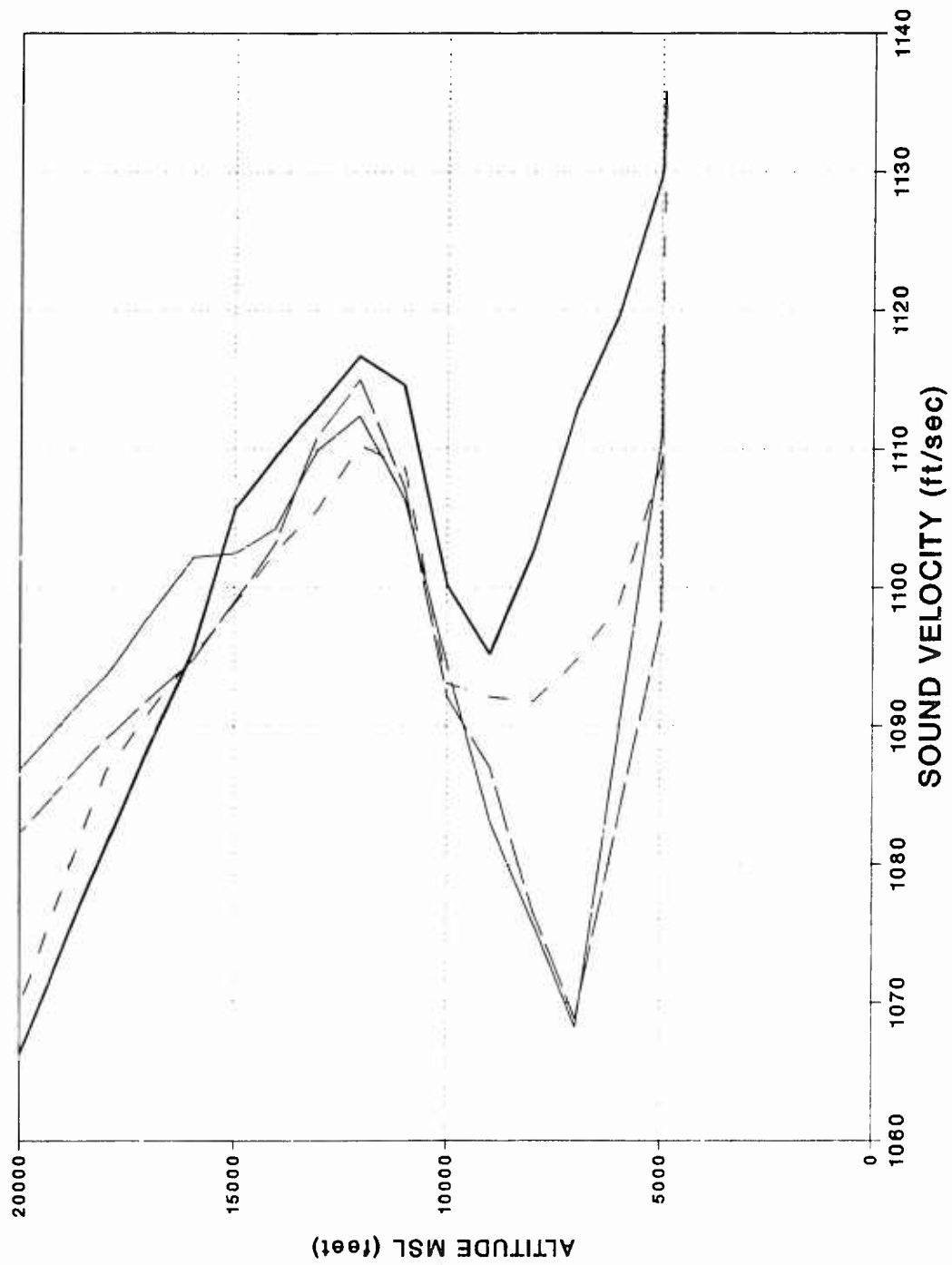


Figure 6. DIRECTED SOUND VELOCITIES TOWARD CARRIZOZO.  
 AZIMUTH 087 DEG. - STALLION RAOBS



**Legend**  
0400 MDT  
0630 MDT  
1000 MDT  
1220 MDT

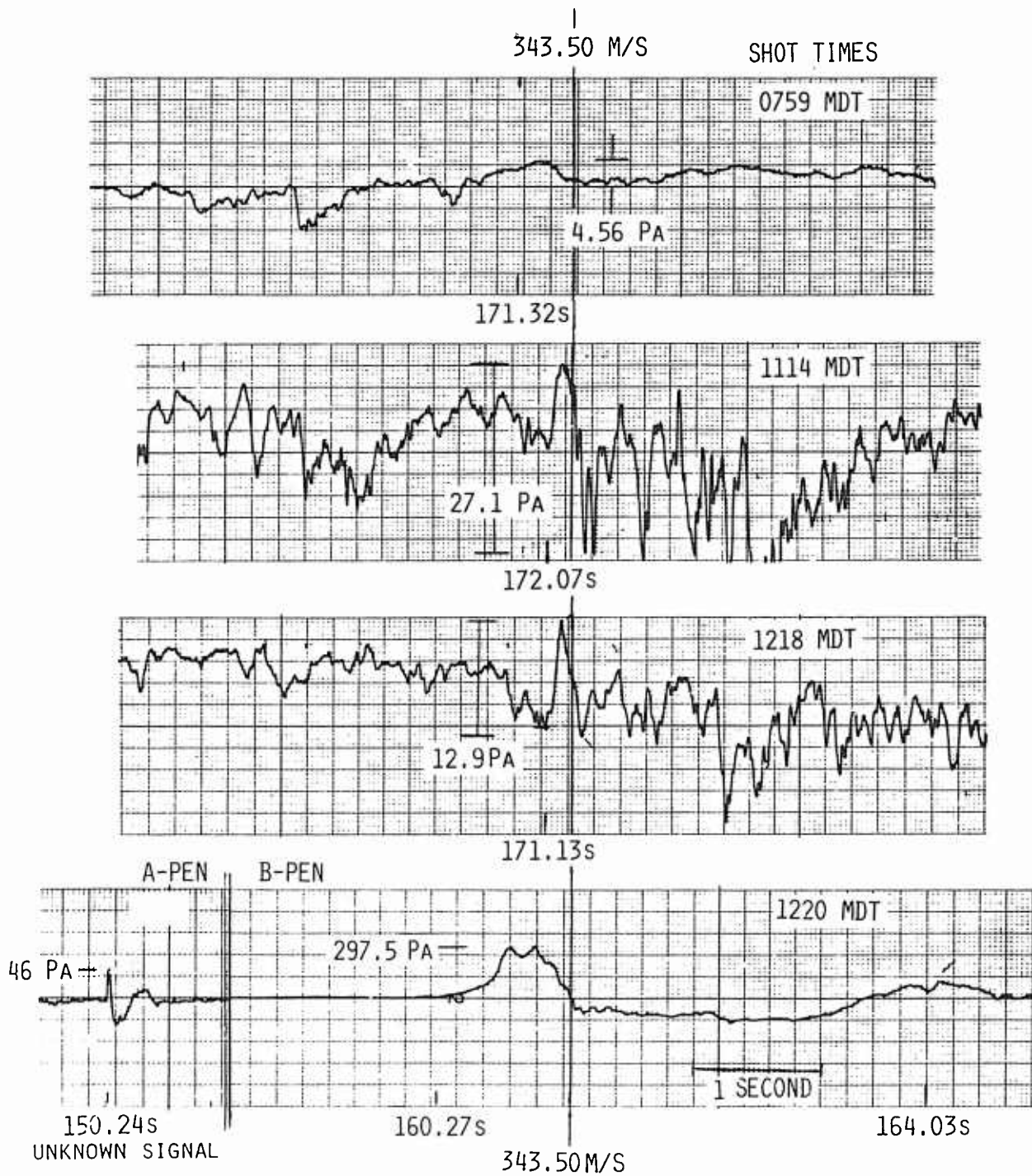


Figure 7. Carrizozo Microbarograms of MINOR SCALE and Pre-test Check Shots.

Figure 8. DIRECTED SOUND VELOCITIES TOWARD CARRIZOZO.  
AZIMUTH 087 DEG.

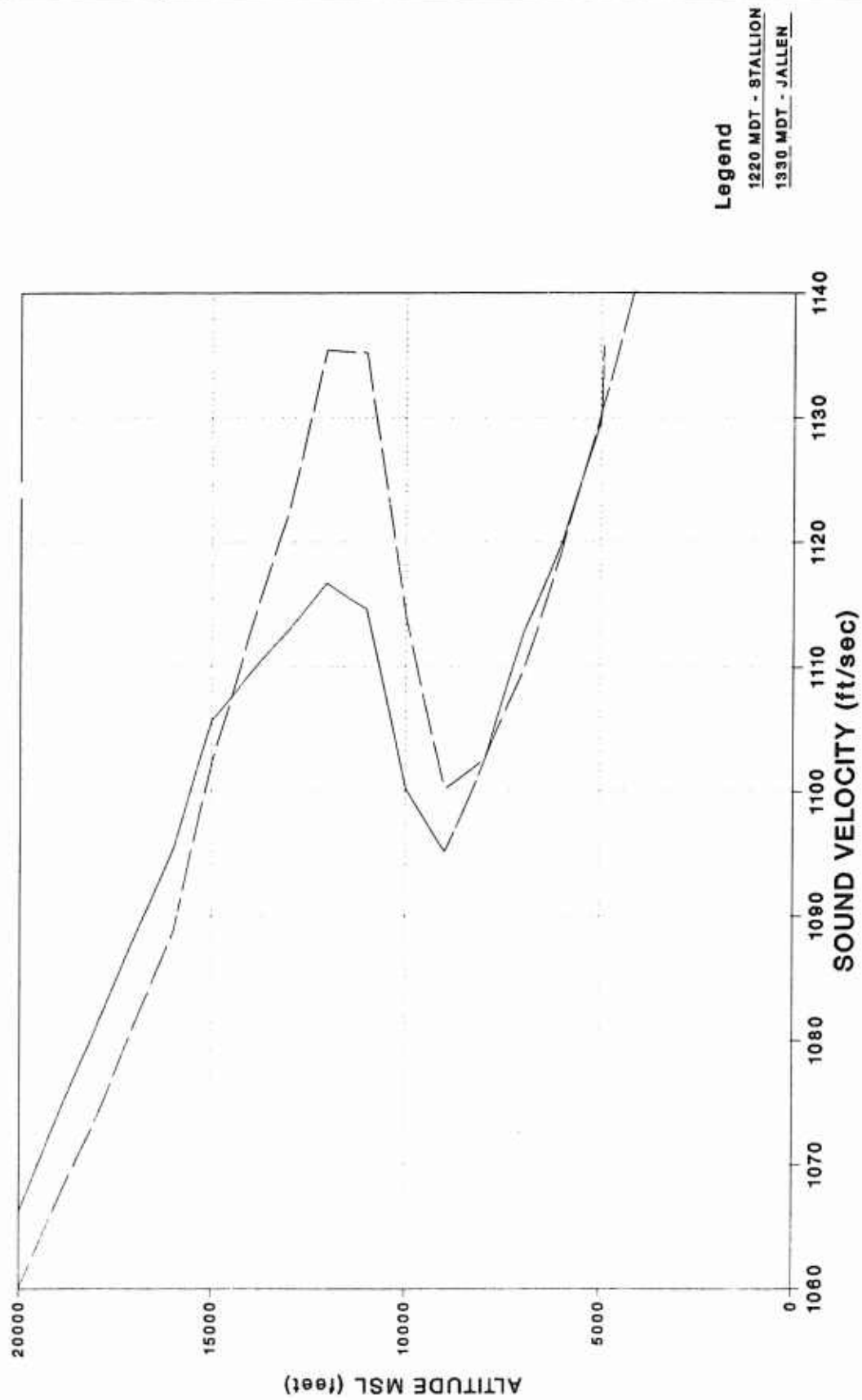


Figure 9. Predicted and Observed Overpressures for MINOR SCALE, 4.8-kt ANFO Surface Burst.

