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JUN 5 1961

MR. JACK W. REED - 5112

Re: Review of enclosures

Conf-610603--1

Enclosures:

- (a) SHOCK PROPAGATION AT LARGE DISTANCES
by J. W. Reed, 5112. SCDC-2342
- (b) Transmittal memorandum dated 25 May 1961,
J. W. Reed to K. A. Smith - 3400

Your manuscript has been reviewed. We believe that the manuscript is unclassified and that it may be presented without undue risk to the common defense and security.

Original Signed By
D. E. WYLDER
D. E. WYLDER
Classification Division

MASTER

Your manuscript has been reviewed. There is no objection from a patent standpoint to its release to the public.

Original Signed By
Gene C. Newlin

G. C. NEWLIN
Invention Reports Division

JUN - 7 1961
CENTRAL RECORD FILE

In your transmittal you stated that the manuscript has been prepared for oral presentation and public release at the Symposium on Atmospheric Acoustic Propagation, Texas Western College, El Paso, Texas, June 14-16, 1961.

Because both your manuscript and the intended audience are primarily technical, approval of the Public Relations Organization is not required. This letter authorizes release to the audience specified.

Original Signed by
Max K. Linn

for W. F. CARSTENS
Technical Information Division

LDP:3423-5:nb

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May 25, 1961

Mr. Coates
5/29

MR. K. A. SMITH - 3400

Re: Material submitted for review prior to release, identified as:
"Shock Propagation at Large Distances"

1. The attached manuscript has been prepared for oral presentation and public release at the Symposium on Atmospheric Acoustic Propagation, Texas Western College, El Paso, Texas, June 14-16, 1961.
2. The material is not classified and does not contain Restricted Data or other security information.

JACK W. REED

5112

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Shock Propagation at Large Distances*

Jack W. Reed

Sandia Corporation

Albuquerque, New Mexico

ABSTRACT

An assumption is usually made that weak shock waves (overpressure < 1 psi) are propagated adiabatically and acoustically. In a homogeneous atmosphere this gives overpressure inversely proportional to distance from an explosion and inversely proportional to the square root of distance from a supersonic projectile. An opposing theory was proposed by DuMond et al in 1946 to show that entropy changes in a shock front would cause explosive overpressures to decay faster with distance and projectile bow waves to decay like (distance)^{-3/4}. A few bits of experimental evidence show that neither scheme is exactly correct. Measurements at low overpressures over large distances free of refractive effects are necessary to more accurately resolve the propagation decay laws. This requires vertical shock paths through a real atmosphere. Project Banshee tests will allow measurements where blast pressure differences between different predictions are more than a factor of ten. High altitude atomic tests have only given a factor of two difference, so instrument errors may have obscured correct interpretation. Some preliminary small charge experiments have just been completed where the difference was a factor of four.

Symposium on Atmospheric Acoustic Propagation

Texas Western College, El Paso, Texas

June 14-16, 1961

Sponsored by the U.S. Army Signal Missile Support Agency

*Work performed under the auspices of U. S. Atomic Energy Commission

Shock Propagation at Large Distances

A common approach to problems of long distance shock propagation is to assume ideal acoustic transmission. This means small amplitude waves are propagated without loss of energy and without change of pressure-time form. Each part of the wave travels at sound speed. Pressure amplitudes may be calculated from the geometric divergence of energy. As a wave passes a point, total sound energy flux density, ξ , is proportional to the integral over time of the squared overpressure, $(\Delta p)^2$, or

$$\xi = \int_0^T \frac{(\Delta p)^2}{\rho c} dt, \quad (1)$$

from $t = 0$ at wave arrival to $t = T$, the wave period or duration, where c is sound speed and ρ is air density. Net or source energy, W , is the total flux integrated over the wave front area, A ,

$$W = \int_A \xi dA. \quad (2)$$

Combining these two integrals shows that

$$\Delta p = (W \rho c)^{1/2} (KAT)^{-1/2} \quad (3)$$

where the integration constant K depends on the shape of the pressure-time wave trace.¹ Thus for three common wave geometries

Plane Wave:	$A = \text{constant},$	$\longrightarrow \Delta p = \text{constant},$
Conical Wave:	$A \sim \text{radius}, r,$	$\longrightarrow \Delta p \sim r^{-1/2},$
Spherical Wave:	$A \sim \text{radius squared},$	$\longrightarrow \Delta p \sim r^{-1}.$

In passing, we note the following on yield scaling for explosive (spherical) blasts: times, including pulse duration, T , are proportional to the cube root of yield, $W^{1/3}$, in close-in high-pressure regions.² If this carries into acoustic range,

$$\Delta p \sim W^{1/3}$$

A more sophisticated treatment of weak shocks, which recognizes that amplitudes so small as to travel in true acoustic manner are really of no concern, was described by DuMond et al in 1946.³ Based on an equilibrium N-wave shape, which should eventually be reached by any perturbation, two derivations are made for the pressure-distance functions which are in agreement. One is based on thermal considerations for energy absorption in lead and tail pressure rises while the other is based on a hydrodynamical model for the linear intermediate part of the N-wave form. In summary DuMond predicted, and verified experimentally to 2-millibar conical wave overpressures from 40-mm projectiles, that for the

Conical Wave:	$\Delta p \sim r^{-3/4}$
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The same theory applied to explosion geometry results in

Spherical Wave: $\Delta p \sim r^{-1}(\ln r/a_1)^{-1/2},$

where a_1 is an integration constant.

This later form is somewhat dependent on yield at even large but fixed range. Propagation becomes more nearly acoustic with increasing yield and thus with scaled initial range. This may be intuitively noted from the fact that with smaller yields, a larger fraction of total wave energy is concentrated near the frontal discontinuity where diabatic or dissipative processes operate.

DuMond's derivation suffers from some now apparent errors in assumption. Most important, shock pressure rise times are not nearly so short as his theory indicates, i.e., at 10-millibars overpressure rise time is 10^{-7} second; at 1-microbar rise time is 10^{-3} second. In millibar overpressure regions rise times are more like several milliseconds to give more nearly adiabatic compressions. Furthermore, waves do not necessarily become N-shaped at great distances; many recordings from atomic blast waves which were refracted back to ground from ozonosphere (100,000-150,000 feet MSL) or ionosphere (300,000-500,000 feet MSL) levels to 135 mile horizontal ranges have maintained the typical explosion shock front form of an N-shaped positive phase but a round, smaller-amplitude negative phase. Of course DuMond is not responsible for the N-shape generation assumption which was much earlier suggested by Lord Rayleigh,⁴ and still has considerable logical attraction.

Finally, verification at short ranges of a few yards has limitations imposed by the poor definition of absorptivity. This is an extremely small quantity that only becomes important when compounded exponentially over large distance. Yet verification at very long range presents many other very practical difficulties.

Empirical data on explosives blasts led Perkins et al⁵ to accept $\Delta p \sim r^{-1.4}$. Their data source is not clear however, and may be measurements from Pacific Proving Ground nuclear tests, in which case the fast decay at ground level may have been caused by atmospheric refraction of waves away from ground in the unstable tropical air mass.

On the other hand, a purely acoustic propagation assumption also has many questionable facets. It is first doubtful whether any man-made model perfectly duplicates nature; then it is further unlikely that completely loss-free energy propagation is possible. In this case it only appears that losses are so small as to be nearly indistinguishable with laboratory scales. Further reference to atomic blast records shows that at 135 miles (Nevada Test Site circular recording array range) pressure wave periods are much longer than at on-site ranges (less than 20 miles). Positive phase duration extensions are in general, but not very exact, agreement with expectations from finite-amplitude, sharp-front wave propagation speeds and an assumption that the zero-overpressure point following the positive phase travels at sound speed.

As previously mentioned, high frequency components in a sharp front wave are slightly attenuated in atmospheric transmission. Applying the appropriate Schrodinger's (classical-theory) intensity absorption coefficient⁶ to Fourier components of the positive phase blast N-wave, (i.e., with attenuation proportional to frequency squared and inversely proportional to air density), shows that even for one-ton high explosives waves very little peak amplitude reduction results from sea level propagation even to 135 miles. However, along more common ray paths to this range, through low air density ozonosphere regions, classical attenuation causes amplitude reduction to about one-half. For kilotons or larger yields only a few percent reduction is calculated for ozonosphere signals. However, these calculations were based on close-in wave periods which are known to increase with great range and thus should reduce the overall attenuating effect as lower frequency Fourier components are added. Furthermore, as high frequency components are absorbed to round off the wave front, re-shocking likely reforms them to some degree. Sound attenuation by atmospheric turbulence, as described by Jorand,⁷ depends on frequency, f , as $f^{2/3}$ and not on air density. A treatment by Lighthill⁸ may also be interpreted to remove density dependence and give dependence on $f^{1/3}$. Obviously the situation has become too confusing for treatment with naive models.

Empirical analysis at very long range is fraught with inaccuracy. Amplitudes measured are mainly determined by atmospheric refraction effects which may combine convergent focusing with interference among ray paths, etc. These may be roughly calculated if rare bits of high altitude wind and temperature data happen to be available. Still, atmospheric variability is such as to allow only approximate accuracy instead of order-of-magnitude estimate otherwise possible. To avoid refraction effects, the obvious solution, other than maintaining uniform conditions over a hundred mile tube, is to record waves along vertical ray paths, parallel to the sound velocity gradients of our stratified atmosphere which bend low elevation angle rays and turn fronts. This experiment has not been carried out to small millibar or microbar blast pressure levels necessary to accurately set the exponent for distance in the pressure-distance decay law. If we assume that r^{-1} and $r^{-3/2}$ bound the true decay, high altitude nuclear tests have only been made where the ground-zero pressure difference between r^{-1} and $r^{-3/2}$ predictions is less than a factor of two. Instrument inaccuracies (+20%) obscure resolution from these tests.

Project Banshee tests at WSMR, beginning about July 1, 1961, will allow measurements where predictions differ by as much as a factor of twenty. Instruments twenty percent accurate will here give resolution of the distance exponent to a few percent.

At Sandia Corporation we have just finished some measurements from one-pound charges at heights to 500-feet aboveground. In these tests factor-of-five differences separate forecasts by the two laws. Our records show that the exponent average is _____, and Banshee recorder set ranges will be made on the basis of this figure.

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