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AMERICAN NATIONAL STANDARD
Estimating Airblast Characteristics for Single Point
Explosions in Air, With a Guide to Evaluation of
Atmospheric Propagation and Effects

ABSTRACT

This standard provides consensus quantitative definitions of explosion characteristics for a single point explosion in air, along with methodologies for scaling these characteristics for a wide range of yield and ambient air conditions. Factors for use with common solid explosives are also included. Methods are provided for predictions of long range propagation under atmospheric refractive influences. Target damage estimation procedures are provided for use in explosion operation planning and evaluation.

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AMERICAN NATIONAL STANDARDS ON ACOUSTICS

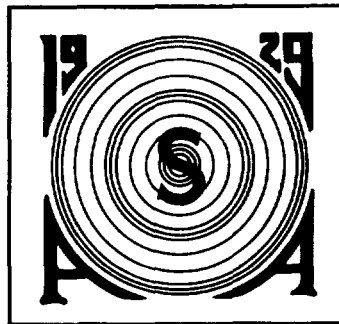
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FOREWORD

[This Foreword is not a part of American National Standard Estimating Airblast Characteristics for Single Point Explosions in Air, with a Guide to Evaluation of Atmospheric Propagation and Effects, S2.20-1983 (ASA Catalog No. 20-1983).]

This standard is the first in a planned series of definitions, standards, and specifications for use in airblast acoustics. It has been developed under the American National Standards Institute by the Standards Committee Method of Procedure under the American National Standards Committee S2, whose Secretariat is held by the Acoustical Society of America.

American National Standards Committee S2, under whose jurisdiction this standard was developed, has the following scope:

Standards, specifications, methods of measurement and test, and terminology, in the fields of mechanical shock and vibration, but excluding those aspects which pertain to biological safety, tolerance, and comfort.

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Suggestions for improvements in this standard will be welcomed. They should be sent to the Standards Secretariat, Acoustical Society of America, 335 East 45th Street, New York, NY 10017.

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American National Standard

Estimating Airblast Characteristics for Single Point Explosions in Air, With a Guide to Evaluation of Atmospheric Propagation and Effects

1 SCOPE

This standard is intended to provide methods for determining blast wave characteristics for single point or spherical explosions, estimating the variations of characteristics caused by the atmospheric medium of propagation, and predicting the expected effects on populations and structures. It applies to chemical or nuclear explosions, of yields ranging from about 1 kg to many megatons, at burst heights to at least 50 km altitude, and to distances where wave pressure amplitudes drop below 1 Pa. The phenomenology is less well defined for many practical explosions of distributed charges or shapes, wholly or partially confined explosions, either underground or underwater. In many cases, however, these effects may be normalized and an equivalent point explosion used for evaluation.

2 DEFINITIONS OF SYMBOLS AND ABBREVIATIONS

2.1 Quantity Symbols

A_i	= constant coefficients ($i = 1, 2, 3$)
c	= sound speed in air
C	= cost of damage repairs
F	= atmospheric blast focus factor, or magnification, referenced to spherical wave expansion
$\bar{F}$	= geometric average blast focus factor
h	= height above ground
I	= blast overpressure impulse
I_d	= dynamic-pressure impulse
K	= proportionality constant
K_r	= airblast overpressure reflection factor
N	= population (human)
p	= ambient air pressure
p_0	= sea level standard air pressure
p_k	= peak-to-peak pressure amplitude in the blast wave

Δp	= peak blast overpressure, or maximum positive deviation from ambient pressure in the blast wave
Δp_-	= negative peak blast pressure
$\Delta p/p$	= shock strength
$\Delta p(P)$	= overpressure causing P percent probability of window damage
P	= probability of damage
Q	= number or quantity
R	= slant range from the center of explosion
R_1	= slant range to nearest vulnerable residence
t	= time
t_a	= blast wave arrival time after detonation
t_r	= compression rise time
t_+	= positive phase duration in explosion wave
t_-	= negative phase duration in explosion wave
T_C	= temperature (Celsius)
T_K	= temperature (Kelvin)
V	= sound velocity (directed)
W	= explosion energy yield
W_a	= apparent airblast yield
x, y	= Cartesian horizontal coordinates
θ	= blast ray incidence angle, measured from the horizontal
σ_G	= geometric standard deviation

2.2 Unit symbols

Pa	= pascal (N/m ²)
K	= kelvin
kg	= kilogram
m/s	= meters per second

2.3 Abbreviations

HE	= chemical high explosives
NE	= nuclear explosives
MSL	= mean sea level
HOB	= height of burst
STP	= standard sea level pressure (101.325 kPa) and temperature (288.15 K)
SD	= standard deviation
AFWL	= Air Force Weapons Laboratory
NSWC	= Naval Surface Weapons Center

2.4 Common Conversion Factors

100 kPa	= 1000 mbar = 14.504 lb _f /in. ² (psi)
T_K	= $T_C + 273.15$
1 m/s	= 3.2808 ft/s = 2.2369 mph = 1.9438 knots
1 kton (NE)	= 4.2×10^{12} J (equivalent explosion yield)
1 Mton (NE)	= 4.2×10^{15} J (equivalent explosion yield)

3 INTRODUCTION

3.1 Purpose

The purpose of this standard is to provide, where possible, consensus quantitative methods for estimating explosion characteristics, effects of atmospheric propagation, and typical responses to explosion waves. Published literature gives a wide variety of results from a multitude of experiments dealing with some or all of these three major categories in explosion phenomenology. It now appears that some of the most important complexities, which have confused explosion evaluation in the past, are fairly well understood. Various interactions have been identified, their effects removed from the data, and a satisfactory evaluation and prediction system has finally been assembled in one published standard.

3.2 Applicability

3.2.1 Potential Users

This standard will help explosives operators to design adequate and safe systems, predict troublesome

conditions that may occur, prepare environmental impact statements, and evaluate damages that are caused by intentional or accidental explosions, as well as assess the credibility of damage claims which may arise. It will also allow more realistic public evaluation of proposed projects, with consideration of credible costs as well as benefits, so that decision makers are able to delineate between the physical and political factors.

3.2.2 Methodologies

For strong shock regions, airblast characteristics are defined by the source model, in terms of yield and distance, in 4.1.3. Responses of idealized target structures are briefly described in 6.1. Details are adequately treated in several textbooks, following common physical principles. Distant propagations, more influenced by meteorology and thus less generally understood and less reproducible, are stressed in 5.3 to aid prediction of nuisance level effects (6.3) on target populations that are likely unassociated with the explosion operators.

3.3 Background

3.3.1 Explosions

An explosion is defined by Webster as "a violent expansion or bursting that is accompanied by noise and is caused by a sudden release of energy from a very rapid chemical reaction, from a nuclear reaction, or from an escape of gases or vapors under pressure." Because of its destructive nature it has been difficult to adequately measure precisely what happens in an explosion as well as how it affects its nearby environment, including structural or biological systems that might be exposed. Many important data collections have relied on after-the-fact evaluations from both wars and accidents. Laboratory and experimental determinations have often been limited by safety or expense. In consequence, conflicting and confusing results have been reported, from a variety of sources. This has led to many divergences of predictions. It now appears, however, that enough is known to explain most of these phenomena, at least those associated with the simplest case, of an explosion in air.

3.3.2 Source, Propagation, and Effects

3.3.2.1 Chronological Order

Predictions of explosion phenomena are conveniently divided into three phases. The historical, or chronological approach used in Secs. 4, 5, and 6 con-

siders source, propagation, and effects phases in that order, as they occur. Some users may first wish to understand something about immediate causes for concern, nuisance noise, or blast damage as examples. They would then want to learn about how these conditions developed and how to ameliorate them. In this case they could begin by skipping from 3.3.3 to 6.1.

3.3.2.2 Airblast Source

Source definition (Sec. 4) depends on the kind and amount or yield of energy release, its timing, and the dimensions over which it is rapidly spread. This standard only addresses the airblast wave which is emitted by an explosion. Included are the air compression, subsequent decompression, and eventual return to ambient pressure that radiates from an explosion. It will not treat special emissions from particular kinds of explosions such as electromagnetic or particulate radiations from nuclear explosions or contaminants from chemical explosions.

3.3.2.3 Atmospheric Propagation

Propagation of the airblast wave at close ranges in air depends primarily on ambient temperature and pressure. Waves traveling to long distances, however, may be refracted by an atmospheric acoustic lens effect, which is dependent on temperatures and winds as described in Sec. 5. Refracted waves may be considerably focused in some cases, or diverged to negligible magnitude in others.

3.3.2.4 Target Response

Effects which result from blast wave interaction with an exposed body, either structural (Sec. 6) or biological may depend on the strength, the compression rate, and sometimes the duration of the wave, as well as response characteristics of the target body.

3.3.3 Limitations and Uncertainties

3.3.3.1 Explosion Yield

Conditions within or near a specified explosion yield may generally be stated, but, for a variety of reasons, there is usually a significant uncertainty about yield. Two apparently identical samples, such as TNT, may indeed differ in internal local density and crystal structure. Such differences may affect detonation to

give partial low order yield, or there may be locally intensified detonation emitting strong shock jets. Error ranges are not generally known and specified, but at least 10%–20% variations in airblast characteristics may be expected, even for nuclear explosions.

3.3.3.2 Atmospheric Conditions

Airblast propagation through the atmosphere encounters air turbulence, wind gusts, and convective plumes and bubbles of air, all of various scales and strengths that are practically never known in detail, particularly over large distances. The result is an acoustic analogy to optical heat shimmer and star twinkle. Such variability limits predictability so that errors of a factor of two in airblast overpressure are commonplace, even for repeated explosions shot only minutes apart.

3.3.3.3 Target Response

Finally, the response of targets is often governed by nonideal conditions of particular installations. There is variance in material strength, and, of course, natural differences between biological targets.

3.3.3.4 Statistical Approaches

In consequence, statistical probability estimation is essential in designing for or evaluating explosion effects. There will be surprises, both good and bad. This standard sets forth prediction principles as well as the uncertainties, so that explosions can be used without harmful surprises, but also without excessive costly controls.

4 SOURCE DEFINITIONS

4.1 Point Explosions

4.1.1 Nuclear Explosions

Since a nuclear explosion is the closest thing presently available to the ideal hypothetical point source of an instantaneous energy pulse, it is used as the standard reference explosion. At moderate to large distances an airborne shock wave has little memory of its origin. Thus, for many applications, other explosions may be related to nuclear equivalents.

4.1.2 Point-Explosion Scaling Laws

Atmospheric explosion waves, in the absence of reflections, are known to obey the following three simultaneous relationships¹ (numbered references are found in Sec. 7) known as Sach's scaling,² for comparing two similar explosions of different yields (volumes) at different ambient pressures (altitudes):

$$\frac{\Delta p_1}{p_1} = \frac{\Delta p_0}{p_0}, \quad (1)$$

$$\frac{R_1}{R_0} = \left(\frac{W_1 p_0}{W_0 p_1} \right)^{1/3}, \quad (2)$$

$$\frac{t_1}{t_0} = \left(\frac{W_1 p_0}{W_0 p_1} \right)^{1/3} \left(\frac{c_0}{c_1} \right). \quad (3)$$

Subscripts 0 and 1 distinguish the variables that are associated with the two different explosions. Note that time scaling is quite general, applying equally to t_a , t_+ , and t_- . It does not apply to compression rise time, however, which is one result of nonscalable attenuation (see 4.1.5). Also, for bursts below about 20 km altitude, the scaling pressure, p_1 , is ambient at the gauge or target rather than at burst altitude. As most often used, these scaling laws state that shock strength is conserved at distances which are scaled for yield and ambient pressure.

4.1.3 Standard Explosion Characteristics

4.1.3.1 Hydrodynamic Models

One dimension hydrodynamic calculations³ have provided good estimates of blast wave characteristics for free air explosions of nuclear devices in a homogeneous, calm atmosphere (with constant temperature and pressure throughout), out to ranges and down to peak overpressures where numerical integration became either unreliable or prohibitively expensive. The most recent and sophisticated AFWL calculation for 4.2 TJ (1 kton NE) at STP conditions,⁴ has been adopted for this standard. Comparison with other important models is described in Appendix A.

NOTE: In practice, the type of "ton" is not important, since short tons, long tons, and metric tons vary at most by 12%. Scaled blast effects would only vary by the cube root of the difference, or 4%.

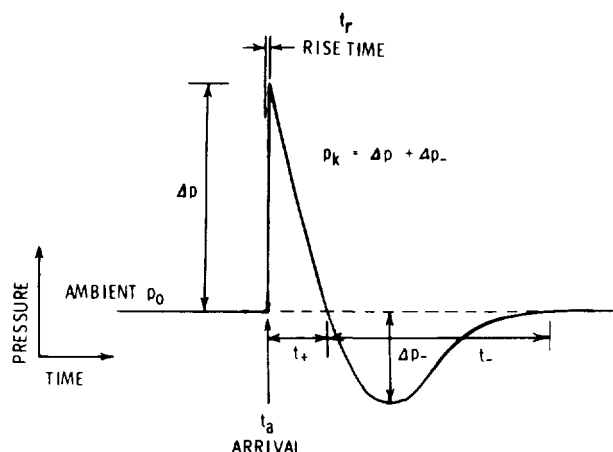


FIG. 1. Typical explosion wave pressure-time signature.

4.1.3.2 AFWL Model Characteristics

Basic airblast wave characteristics are shown in Fig. 1 for a typical pressure versus time signature, as recorded by a gauge. The standard incident overpressure versus distance curve for strong shock waves is shown in Fig. 2, and the curve at long range and low overpressure is shown in Fig. 3. Positive phase pressure impulse versus distance, or radius, is shown in Fig. 4. Time of arrival, positive phase duration, and negative phase duration (at recovery to 80% of ambient) are shown versus radius in Fig. 5. Numerical values at regular logarithmic distance intervals are shown in Table I to aid scaling calculations for other explosions. Analytical equations for producing the standard overpressure, overpressure impulse, and phase duration curves are included with some history of their development in Appendix A. Ambient conditions for the standard explosion are STP, that is $p_0 = 101.325$ kPa and $T_0 = 288.15$ K, where $c_0 = 340.294$ m/s.

TABLE I. Standard 4.2 TJ (1 kton) NE airblast parameters versus distance.

R (m)	t_a (s)	Δp (Pa)	t_+ (s)	I (Pa·s)
10	2×10^{-4}	3.289×10^8	0.12	1.2×10^5
10^2	6×10^{-2}	5.069×10^5	0.097	9.5×10^3
10^3	2.4	8.917×10^3	0.34	1.2×10^3
10^4	30	518.3	0.52	1.1×10^2
10^5	...	38.78	0.93	...
10^6	...	3.241	1.33	...
10^7	...	0.2843	1.73	...

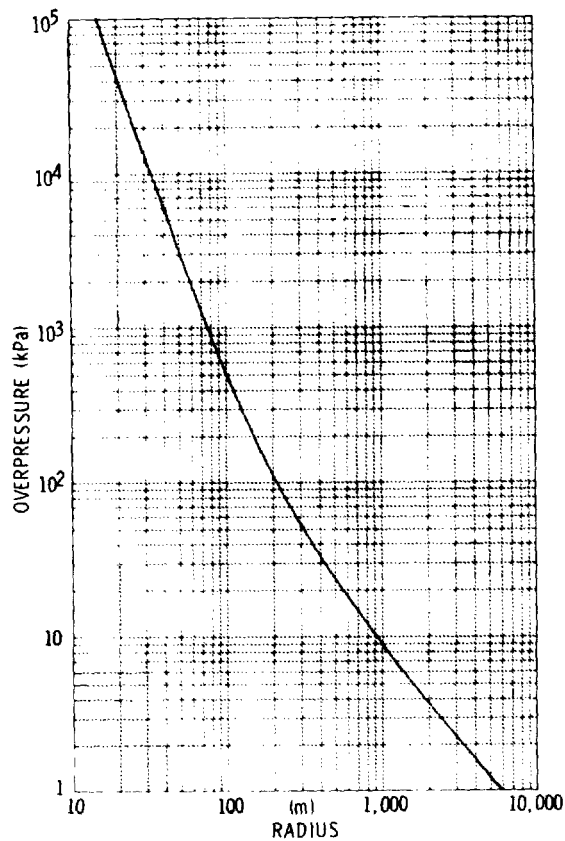


FIG. 2. AFWL 4.2 TJ (1 kiloton) standard overpressure versus radius, high pressures.⁴

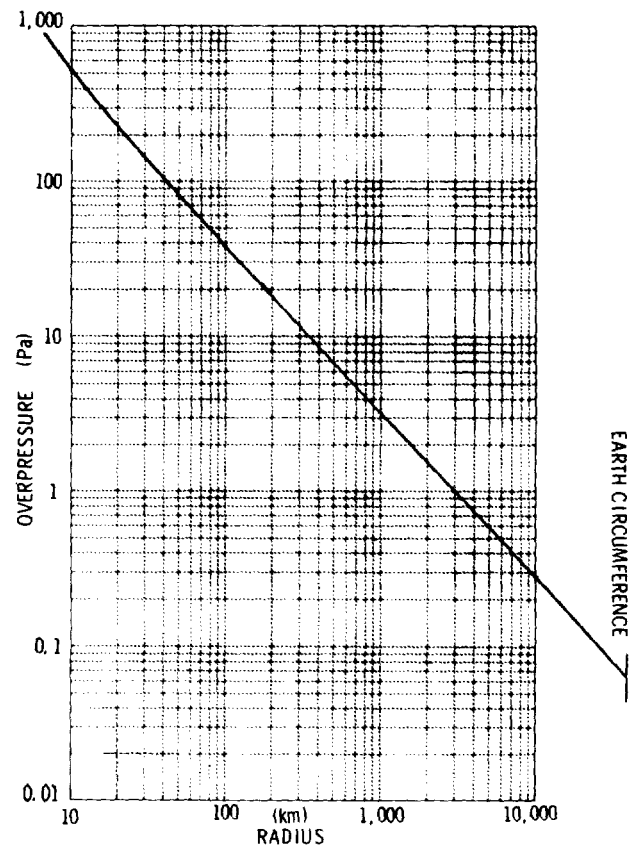


FIG. 3. AFWL 4.2 TJ (1 kiloton) standard overpressure versus radius, low pressures.⁴

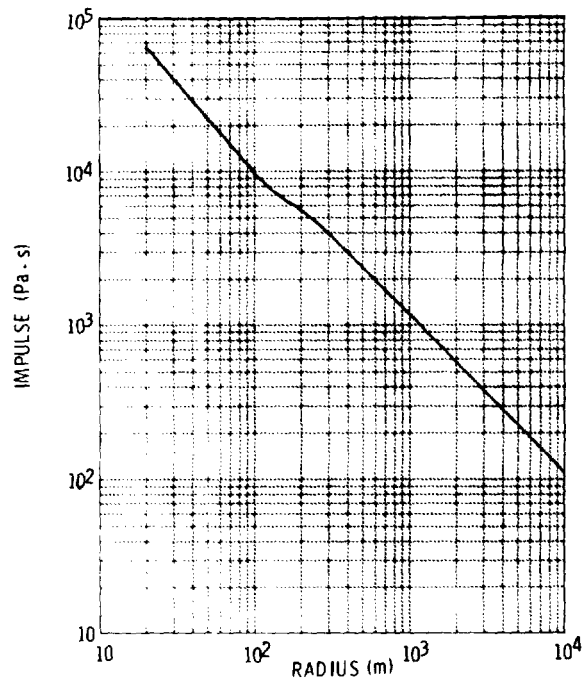


FIG. 4. AFWL 4.2 TJ (1 kiloton) standard overpressure impulse versus radius.⁴

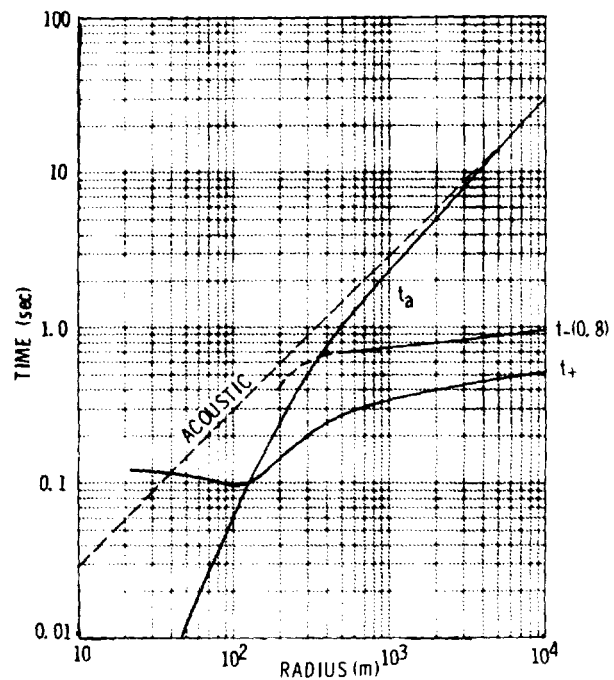


FIG. 5. AFW 4.2 TJ (1 kiloton) standard radius versus time.⁴