NOX
61-3-4

AERONUTRONIC
A DIVISION OF
Ford Motor Company

$12.50

16 600

SPACE SYSTEMS OPERATIONS

Prepared by

J. J. Oslake
S. Dobrin
R. J. Getz
W. L. Haight
L. J. Oberste
R. A. Romine

Systems Analysis Department
Range Systems

TECHNICAL REPORT

LAUNCH SITING CRITERIA FOR HIGH-THRUST VEHICLES

Technical Report No. U-108:118
March 31, 1961
Work Request 108-019
Contract No. N123(61756)23304A(PMR)

ASTIA
JUN 16 1961
TIPDR

Submitted to

Commander, Pacific Missile Range
Point Mugu, California

AERONUTRONIC
A DIVISION OF Ford Motor Company
FORD ROAD / NEWPORT BEACH, CALIFORNIA

Encl. (5) to PMR Serial 2919 of JUN 1 19

FORWORD

This Technical Report was prepared for the Range Development Department, Pacific Missile Range, Point Mugu, California, under Contract No. N123(61756)23304A(PMR). This publication is the fourth and final report submitted in fulfillment of the Launch Hazards Study, Task No. 108-019.

The PMR monitoring office for this program was the Systems Design Branch, Range Analysis and Planning Division of the Range Development Department.

The work was performed by a special group at Aeronutronic representing the departments of Systems Analysis and Chemistry. Those contributing on the program were Dr. Saxe Dobrin, R. J. Getz, N. L. Haight, L. J. Oberste, R. A. Romine, with J. J. Oslake serving as project leader.

Valuable assistance was rendered by military and civilian personnel at the several locations visited. The Project Engineer for PMR, L. Slavin, was most cooperative through the program.

CONTENTS

PAGE

LIST OF FIGURES

LIST OF TABLES

SECTION 1

SUMMARY AND RECOMMENDATIONS

1.1 SUMMARY

A comprehensive technique for determining the magnitude of potential launch hazards is developed as an intermediate step in the process of selecting optimum launch sites for very high-thrust booster engines, from the standpoint of safety. Three characteristic launch site hazards are considered: acoustics, explosions, and toxicity. The siting criteria developed are generally applicable to most potential launch sites.

The trend in development of high-thrust booster systems in the 1.0 to 10 million pound thrust category is briefly examined. Engine sizes, tankage and configurations, and propellant combinations are discussed in turn to establish realistic boundaries for the subsequent assessment of hazards.

Procedures and data for estimating the acoustic, explosive, and toxicity hazards are next given. Where appropriate, the launch hazards data are expressed as a function of site environment for given booster sizes and/or configurations.

In order to illustrate the site selection procedure a hypothetical three stage launch vehicle (9 million pounds thrust), and a prospective launch area with realistic environmental conditions are postulated. The resulting hazard estimates are employed to specify a particular launch complex location and configuration, and to establish launching constraints imposed by the assumed environment.

Several field surveys are found necessary to provide critical data about potential launch sites for the assessment of hazards. Two of these, an acoustical measurement program and gas release tests, are described in the appendices.

1.2 RECOMMENDATIONS

Having exhausted available sources of launch hazards information, and having transformed pertinent data into usable siting criteria, it is now appropriate to outline how these results might be applied at the Pacific Missile Range. The Naval Missile Facility at Point Arguello, NMFPA and/or the Channel Islands represent, as a first approximation, feasible areas from which the larger missile booster systems of the not-too-distant future can be launched. In the absence of specific program requirements it is expedient to assess the hazards associated with these sites by virtue of prevailing environmental conditions. Climatological, geographical, geological, and oceanographical factors strongly influence the hazard magnitude and consequences.

Needless to say, as the booster engine sizes and propellant quantities increase, and as higher energy fuels are employed, so too will the hazards increase; more than ever will the emphasis be on safety. Safe launch operations are best assured by giving due regard to potential hazards early in the site selection and site development phases of facility activation. The need for devoting effort immediately in preparation for the ultimate maximum utilization of NMFPA and vicinity is apparent.

Two significant steps, requiring no prerequisites, can be taken immediately. Further action would be contingent upon the results obtained therefrom. These immediate steps are:

a. Conduct a comprehensive acoustical field survey at NMFPA to detect the presence of any unusual modes of sound propagation, both for airborne and ground transmissions. Sound transmissions in air can, under the influence of terrain and weather conditions, deviate markedly from the theoretical free space situation, thus requiring unreasonable separation distances between source and personnel to be protected. Acoustically induced ground vibrations can cause critical displacements to sensitive range instrumentation. A complete description of the required acoustic measurement program is given in Appendix A.

b. Conduct gas release and atmospheric diffusion tests at NMFPA to determine representative values of the critical meteorological constants which influence gas dispersion. These tests are described fully in Appendix B. The objective is to correlate gas diffusion parameters with prevailing terrain and provide a basis for stipulating maximum safe quantities of toxic propellants which can be handled.

Both of the above field surveys represent worthwhile contributions to the advancement of safety at the Pacific Missile Range.

SECTION 2

INTRODUCTION

The activities conducted in launch areas are inherently hazardous because of the operation of high-energy systems designed to obtain maximum performance from missiles and space vehicles. Three types of hazards that exist during static firing or launching of chemical rockets are acoustics, explosions, and toxicity. These hazards may exist not only for the launch complex in operation, but also extend to adjacent launch complexes or other facilities.

For subsequent generations of chemical propulsion systems (those providing upwards of one million pounds thrust, and upper stage engines utilizing higher energy fuels) the potential launch hazards will assume even greater proportions. The ability to launch these vehicles will depend strongly upon site location, separation of launch pad from adjacent facilities, and other precautions taken to minimize hazards to personnel and equipment. The first step in meeting this challenge is to assess the potential hazards and establish safe criteria for location and development of pertinent range facilities.

2.1 PURPOSE AND SCOPE

The primary objective of this study is to establish site selection criteria which will minimize the hazards associated with launchings of high-thrust booster vehicles and of upper stage rockets utilizing high energy propellants.

The present report is intended to fulfill only this primary objective. Three preliminary reports were submitted earlier to (1) define techniques for predicting the magnitude of the hazards, (2) determine maximum tolerable hazards, and (3) prescribe safety practices.

Siting criteria developed herein are applicable both to the selection of land areas suitable for a launch complex as well as for the first-order siting of facilities within a launch complex. This and the previous reports are oriented more toward the needs of personnel responsible for range planning and development, rather than for range operation.

The preliminary reports completed previously are:

(1) "Acoustical Hazards of Rocket Boosters"
Volume I - Physical Acoustics
Volume II - Effects on Man

(2) "Explosive Hazards of Rocket Launchings"

(3) "Toxic Hazards of Rocket Propellants"

2.2 METHOD OF APPROACH

It had been specified that the hazards analyses particularly stress the influence of general environmental conditions upon the magnitude and effects of launch hazards. Therefore, relationships were determined wherever possible that would indicate the environmental dependence of launch hazards. The major environmental factors considered were climatological and topographical.

The results of this report may be applied to either of two situations:

a. Where a particular launch vehicle configuration is known and it is desired to make a preliminary chice of prospective launch sites.

b. Where a particular launch site is available and it is desired to determine the limitations on launch operations necessary to ensure safety to both on- and off-site personnel

In either case, the environmental characterisitics of a site, or of prospective sites, must be known or determined by field surveys before the launch hazards may be reliably estimated. Only then can the proper steps be taken to enhance the ultimate safety of launch operations.

It is emphasized that the task has been limited to a search of the available literature, a survey of probable data sources, and an analysis of the resultant information; no experimental work was authorized

2.3 PMR SITING CONSIDERATIONS

The Pacific Missile Range has no rigid boundaries and can therefore accommodate a host of missiles, satellites, and space probes. Potential launch sites for booster vehicles exist throughout the range from the mainland at Point Arguello to, and including, hundreds of downrange islands (see map in Fig. 2-1). Although the Naval Missile Facility at Point Arguello (see map in Fig. 2-2) currently is well equipped both by natural and by man-made facilities to handle most of the present-day requirements, there is some indication that higher-thrust boosters will demand a unique launch environment not readily found on the mainland. If for no other reasons, safety considerations will impose ever-increasing physical separations between launch pad and supporting facilities. Ultimately the remoteness of small, semi-deserted islands, employed in conjunction with mobile launching pads, may offer compelling advantages.

It is difficult to state the limits in booster size, or the set of operating conditions which would vitiate the obvious advantages of a mainland launch site. This is a complex problem involving much more than an evaluation of launch hazards.

The imminency of large boosters is indicated in Table 2-I, the data for which is based upon an analysis of present and extrapolated schedules for Department of Defense and National Aeronautics and Space Administration programs. The need for initiating supporting studies concerning launch hazards and siting requirements is manifest.

TABLE 2-I

SUMMARY OF PREDICTED LAUNCHINGS

BOOSTER THRUST RATING (million pounds)	FISCAL YEAR							
	63	64	65	66	67	68	69	70
0.5 to 1.5	0	1	2	4	6	8	11	11
1.5 to 9.0	0	0	0	0	1	2	4	5

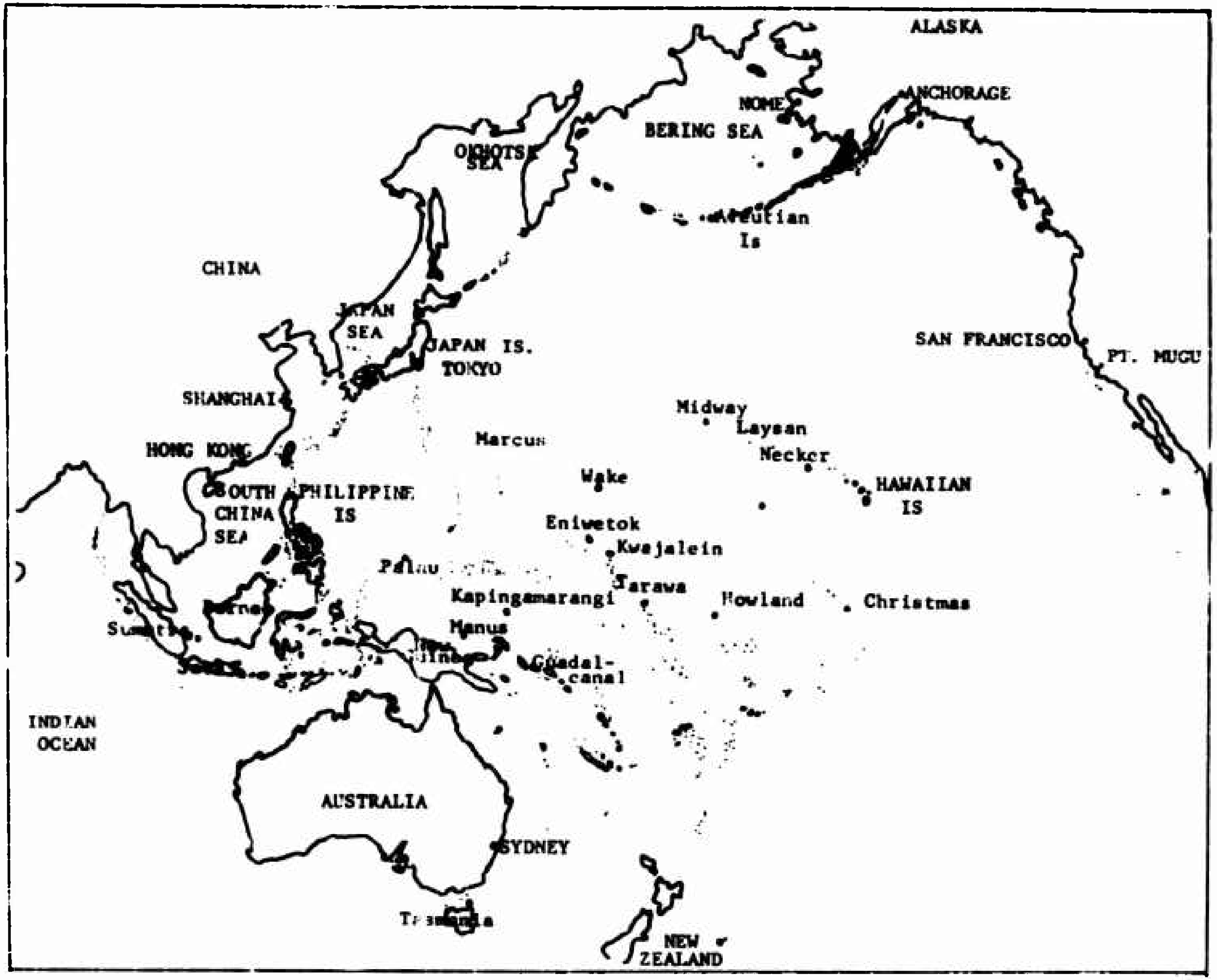


FIG. 2-1 THE CENTRAL PACIFIC OCEAN

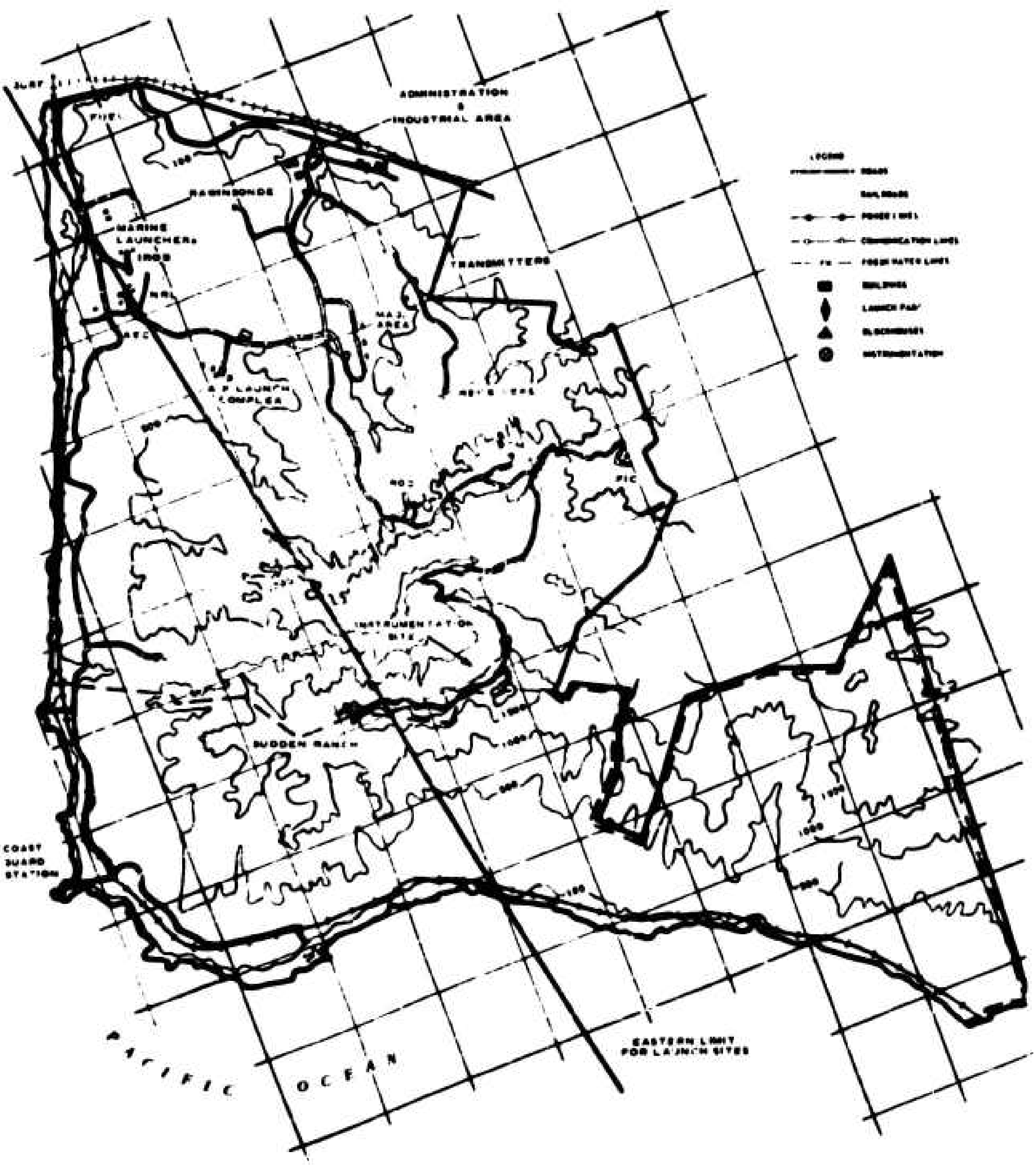


FIG. 2-2 THE NAVAL MISSILE FACILITIES AT POINT ARGUELLO

Siting requirements for a specific range program are based upon more than the hazards aspects: particular trajectories must be feasible, and proper instrumentation must be made available. Other considerations involved in the selection of launch sites include the following factors:

a. Site location

b. Size

c. Topography and hydrography

d. Climate (temperature, rainfall, winds)

e. Biota (flora and fauna of a region)

f. Ownership

g. Population

h. Land use

i. Existing facilities

j. Access (by air or by sea)

k. Water supply

l. Geologic threats (volcanic, land shifts)

A discussion of these considerations, aside from their direct effect on the launch hazards, is not within the scope of this report.

SECTION 3

HIGH-THRUST VEHICLES

Criteria for the selection of launch sites are dependent upon many of the same parameters that describe vehicle performance. A knowledge of vehicle weight and propellant combination is necessary to establish launch facility requirements. These data concerning high-thrust vehicles are determined from system sizing studies.

The thrust (F) developed by a rocket engine depends upon the propellant mass flow rate ($\dot{W}$ pounds per second) and the specific impulse (I_{sp} pounds of thrust per pound of propellant flow per second). It is expressed by

$$F = \dot{W} I_{sp} \quad \text{pounds} \qquad (3\text{-}1)$$

Booster performance is also dependent upon the specific impulse, which is a function of the chosen fuel and oxidizer, and the ratio of propellant weight to the total weight. Velocity at booster burnout (V_{bo}) is

$$V_{bo} = -g I_{sp} \log_e \left(1 - \frac{W_p}{W_g}\right) - D - G \qquad (3\text{-}2)$$

where G and D are the gravitational and drag losses, respectively, and $\frac{W_p}{W_g}$ is the ratio of booster propellant weight to the weight of the missile assembly.

From a performance standpoint the specific impulse and the propellant loading fractions are important parameters. In general, the specific impulses are higher for the less dense propellants (liquids) while the propellant loading fractions are higher for the more dense propellants (solids). Trade-offs between these two parameters provide criteria for the selection of a propellant system.

Other factors which influence the booster system configuration are reliability requirements, booster recoverability considerations, test facility needs, production problems, and the overall cost of accomplishing a given mission.

3.1 VEHICLE CONFIGURATIONS

High-thrust vehicles may employ a single engine (the F-1 engine will provide 1.5 million pounds of thrust) or a cluster of smaller engines (Saturn will utilize eight H-1 engines for a total of 1.5 million pounds of thrust). Individual engines within a cluster or multistage complex may also qualify as a high-thrust system (the Nova-type vehicles will employ a cluster of six F-1 engines for 9 million pounds of thrust).

Two versions of the Saturn vehicle are presently envisioned: the C-1 (3-stage) and the C-2 (4-stage) configurations. Pertinent characteristics are given in Table 3-I.

The Saturn booster section is 22 feet in diameter and 80 feet in length. It contains eight 70-inch diameter tanks centered around one tank 105 inches in diameter. The eight engines, shrouds, and associated plumbing essentially complete the missile structure. Total main-stage propellant capacity is 750,000 pounds.

The Rocketdyne F-1 engine is being developed under NASA contract for a Nova-type vehicle. Typical missions for the Nova-type vehicle powered with high-energy upper stages are illustrated in Fig. 3-1.

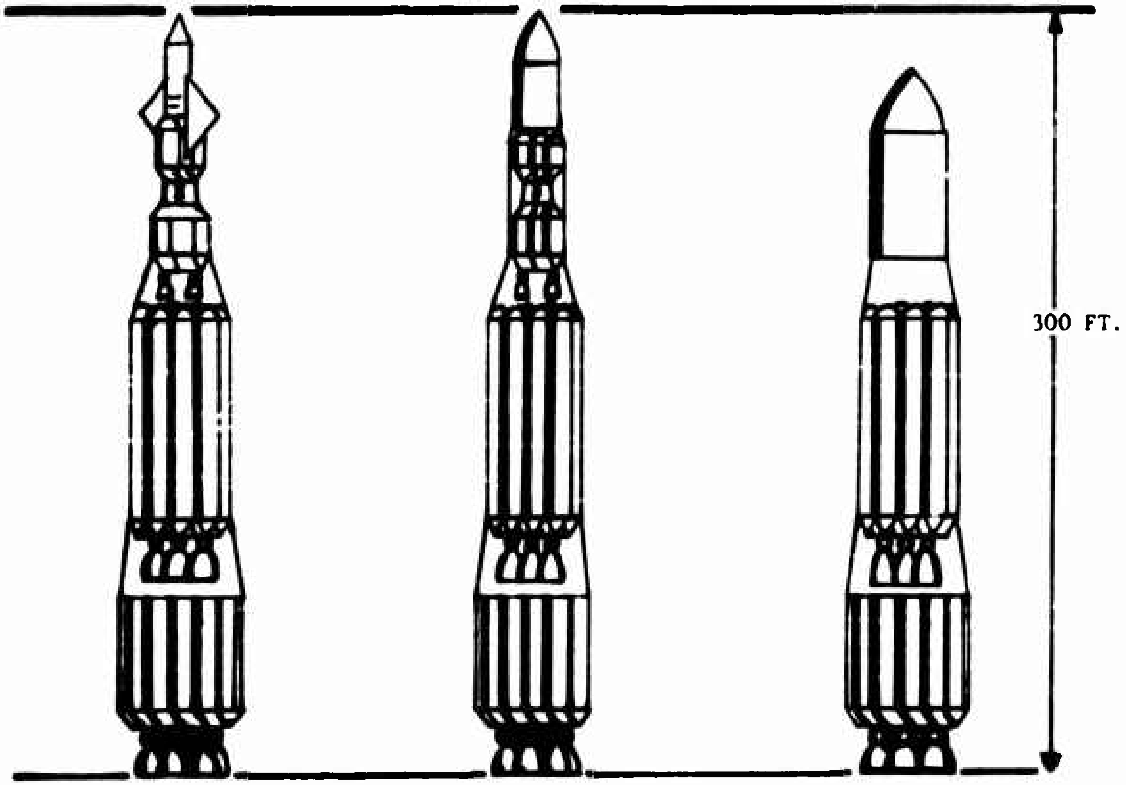
There are two ways in which a cluster of six identical engines can be arranged to obtain minimum cluster diameter. A configuration of six engines arranged uniformly along the circumference of a circle will yield a cluster diameter equal to three times the diameter of a single engine. Likewise, a configuration of five engines spaced regularly around a middle engine will result in the same cluster diameter. A triangular arrangement of the six engines is also possible, but with slight increase in cluster diameter. Each configuration offers alternate possibilities for fixed and gimbaled engines.

TABLE 3-I

SATURN CHARACTERISTICS

Parameter	Stage	C-1 Configuration		C-2 Configuration	
Engine Type[1] and Quantity	I	8	H-1	8	H-1
	II	4	LR-115	4	J-2
	III	2	LR-115	4	LR-115
	IV	-		2	LR-115
Nominal Thrust (Pounds x 10^6)	I	1.50		1.50	
	II	0.08		0.80	
	III	0.04		0.08	
	IV	-		0.04	
Propellant Configuration[2] (Oxidizer/Fuel)	I	LO_2/RP-1		LO_2/RP-1	
	II	LO_2/LH_2		LO_2/LH_2	
	III	LO_2/LH_2		LO_2/LH_2	
	IV	-		LO_2/LH_2	
Oxidizer Weight (Pounds)	I	530,000		460,000	
	II	94,000		172,000	
	III	22,700		62,500	
	IV	-		22,700	
Fuel Weight (Pounds)	I	220,000		190,000	
	II	26,000		48,000	
	III	6,300		17,500	
	IV	-		6,300	
Propellant Weight	All	899,000 lbs.		979,000 lbs.	
Approx. Height	Overall[3]	185 ft.		230 ft.	

NOTES:
1. H-1 and J-2 are Rocketdyne designations; LR-115 is a Pratt & Whitney designation.
2. LO_2 and LH_2 are liquid oxygen and hydrogen, respectively. RP-1 is hydrocarbon (kerosene) fuel.
3. Including payload.



MOON LANDING AND RETURN

MARS SATELLITE
OR
24-HR EARTH ORBIT

EARTH-ORBIT VEHICLE

FIG. 3-1 TYPICAL NOVA-TYPE VEHICLES[5]

According to industry officials, solid rocket motors can be developed to produce thrusts in the neighborhood of 20 million pounds. A possible configuration would consist of seven clustered engines each approximately 100 feet long and 10 feet in diameter. Aerojet is engaged in the preliminary design of solid boosters of up to 7 million pounds gross weight, with thrusts of 2 to 3 times gross weight. Developments are now in progress for a segmented solid rocket of over one million pounds thrust.

3.2 PROPELLANT COMBINATIONS

Insofar as the higher thrust engines are concerned, major emphasis has been and is now being given to liquid propellants. Solid rockets are generally considered more reliable and have a higher propellant loading fraction than liquid rockets, but lower specific impulse. Very large solid boosters pose some difficult manufacturing problems. The explosive hazard of large solid propellant boosters is judged to be high.

A summary of single-chamber liquid propellant engines currently available or under development is given in Table 3-II. Although present development work for very large booster engines is based on the use of liquid oxygen and petroleum fuel (RP-1) the eventual choice may become nitrogen tetroxide and hydrazine-UDMH, depending upon the experiences with storable Titan II. Similarly, success with the 200,000 pound thrust J-2 engine could inspire future development of larger engines employing the all-cryogenic combination of liquid oxygen and liquid hydrogen. Some pertinent characteristics of popular liquid propellant combinations are given in Table 3-III.

Current types of solid propellants with metal additives can deliver a specific impulse of about 250 seconds (chamber pressure of 1,000 psi at sea level). New compositions with specific impulses up to 300 seconds are under development. Typical of these materials are nitropolyurethane with lithium aluminum hydride and ammonium perchlorate, and fluoramine polymers with beryllium hydride.

TABLE 3-II

LIQUID PROPELLANT ENGINES (SINGLE - CHAMBER)

Thrust (thousands of lbs)	Propellant Combinations
10 to 25	LO_2/LH_2 , LF_2 /LH_2 . LF_2 /N_2H_4
25 to 500	LO_2/LH_2 , LO_2/RP-1, N_2O_4/N_2H_4 -UDMH
500 to 1,000	Unknown, if any
1,000 to 2,000	LO_2/RP-1

TABLE 3-III

CHARACTERISTICS OF PROPELLANT COMBINATIONS

OXIDIZER FUEL	BOILING POINT	SPECIFIC IMPULSE*	BULK DENSITY	MIXTURE RATIO BY VOL.	BY WT.	COMMENT
	DEG. F.	SEC.	LB/FT^3	(OXIDIZER/FUEL)		
Oxygen	-297					
RP-1 Petroleum Fuel	+355	286-300	63.0	1.59	2.3	Extensive experience
Hydrogen	-423	388-391	16.8	0.22	3.6	Requires large tanks. well insulated
Hydrazine	+236	301-313	66.5	0.73	0.77	
Fluorine	-307					Corrosive, highly toxic
Ammonia	- 28	330-357	72.3	1.37	3.0	Available in large quantities
Hydrogen	-423	398-410	24.0	0.28	6.1	
Hydrazine	+236	334-363	81.5	1.38	2.1	
Red Fuming Nitric Acid	+140					Storable
50/50 Hydrazine-UDMH	+190	272-279	78.0	1.13	2.0	
Nitrogen Tetroxide	+ 70					Storable
50/50 Hydrazine-UDMH	+190	278-288	74.5	1.12	1.8	

---

*Theoretical maximum based on optimum sea level expansion from 1,000 psia chamber pressure. Low value indicates condition of fixed exhaust composition; high value is for shifting composition.

Hybrid rocket engines, in which a storable liquid oxidizer is sprayed into a combustion chamber lined with a solid fuel, are receiving more attention. A Thiokol unit uses fuming nitric acid or nitrogen tetroxide and a metal-loaded plastic fuel. Becco Chemical has reported a theoretical specific impulse of 294 seconds for aluminum-enriched polyethylene in combination with 99 percent hydrogen peroxide.

The nuclear rocket engine is a serious contender for large booster systems. High specific impulses are expected to be achieved with the utilization of liquid hydrogen and a nuclear reactor heat source. Disadvantages are the low density of liquid hydrogen, the inherent weight of the reactor system, and the hazards associated with radiation from the reactor operation and from fission by-products. Nuclear propulsion hazards are currently under investigation by the U. S. Naval Radiological Defense Laboratory with the sponsorship of the Pacific Missile Range.

SECTION 4

LAUNCH HAZARDS

The hazards associated with the launch of a large-booster rocket can be broken down into three categories: acoustical, explosion, and toxicity.

Acoustical hazard results from the turbulent mixing of the high velocity exit gases with the surrounding atmosphere The acoustical power radiated does not usually exceed one or two per cent of the total mechanical stream power of the exhaust gases. Damaging ground vibrations and high sound pressure levels are possible at large distances from the vehicle depending on the ground and sub-strata at the particular site, adjoining terrain, weather conditions at the time of launch, and size and performance of the rocket propulsion system. Acoustical hazards exist independent of malfunctions· they are always present during launch.

Explosion hazards, as described here, result from the rapid uncontrolled combination of chemical propellants which creates a shock wave or an overpressure. Therefore, this hazard covers both explosions and deflagrations. Explosion hazards are dependent upon a malfunction and since absolute reliability is unrealistic, an explosion or deflagration will very likely be encountered. The magnitude of the hazard is usually expressed by denoting the TNT equivalence of the particular propellants used in the rocket engine and describing the mixing and ignition processes.

Toxicity hazards result from the vaporization of propellants and subsequent diffusion by the atmosphere. A degree of toxic hazard is present at all times because spillage and leaks occur during normal handling and storage of rocket propellants. Rocket exhaust products are another menace, but the major concern is with malfunctions causing the release of large quantities of propellant. The present guidepost for toxicity hazards is the eight hour maximum allowable concentration (MAC) for each propellant.

This section briefly summarizes the preliminary Aeronutronic reports described in Section 2 (Ref 1, 2, 3, 4) and presents working graphs and data from which to estimate the magnitude of launch hazards. Detailed data about particular rocket propellants are presented in Appendix C.

4.1 ACOUSTICAL HAZARDS

Rocket noise causes physical and physiological problems at the launch site and in adjoining areas. Representing physical problems are structural or component failure resulting from excessive vibrations induced acoustically. Physiological problems involve damage to personnel, restriction of communication, and reduced ability of an individual to accomplish required tasks. Rocket noise will also affect community reaction against the use of a launch site when sound levels are excessive. The means for estimating the overall acoustical hazards are discussed in this section.

4.1.1 Rocket Engine Noise

Rocket engine noise sources include: turbulent mixing of the exhaust gases with the surrounding medium; interaction of turbulence eddies and thermal fluctuations with any shock waves in the exhaust; pressure fluctuations in the engine chamber, particularly during combustion instability; and vibrations of the chamber walls. Such a noise field is characterized by random pressure fluctuations, continuous and extremely broad band frequency spectrum, nonuniformity of radiation with direction, and extremely high energy levels radiated.

The burned propellant emerging from the nozzle gives rise to large turbulent shearing stresses and violent mixing at the nozzle exit. Farther downstream the velocity of the exit gases decreases, mixing proceeds less violently, and larger turbulence eddies are evidenced. This mode of mixing represents a high frequency noise source at or near the nozzle exit with frequency decreasing as downstream distance increases. Noise from subsonic jets is generated principally between five to ten exit diameters downstream while for supersonic jets, which spread less rapidly, noise may be generated up to fifteen or twenty diameters downstream.

4.1.1.1 Acoustical Power Levels

The mechanical power within a rocket engine exhaust stream may be expressed in terms of the thrust and specific impulse of the system.

$$W_S = 21.8\ F I_{sp} \qquad (4\text{-}1)$$

where: W_s = stream power (watts)

F = thrust (pounds)

I_{sp} = specific impulse (sec)

Radiated acoustical power is related to the mechanical stream power by the acoustical efficiency:

$$W_A = 21.8\eta F I_{sp} \qquad (4\text{-}2)$$

where W_A = radiated acoustical power (watts)

η = acoustical efficiency

The acoustical efficiency is dependent upon the difference in velocities between the exhaust gases and the surrounding medium. For present day (LOX/RP-1) rocket engines the acoustical efficiency is approximately one per cent; however, it may approach ten per cent for high performance nuclear engines. Accurate determination of acoustical efficiency requires measurement of far field sound pressure levels from which the space average sound pressure level and acoustical power level may be determined.

An empirical relationship between mechanical power in a rocket exhaust stream to overall acoustical power levels has been determined by Von Gierke[6]. This relationship, which best fits the available data for jet stream power in excess of 10^5 watts with acoustical efficiencies of approximately one per cent, is

$$PWL = 78 + 13.5 \log_{10}(21.8\ I_{sp}\ F) \qquad (4\text{-}3)$$

where PWL = Overall sound power level (db) referenced to 10^{-13} watts.

The spectral characteristics of jet stream noise depends upon the jet stream velocity (V) and diameter (d). Spectral composition of rocket noise energy may be generalized by plotting power spectrum level as a function of dimensionless frequency as illustrated in Fig. 4-1.

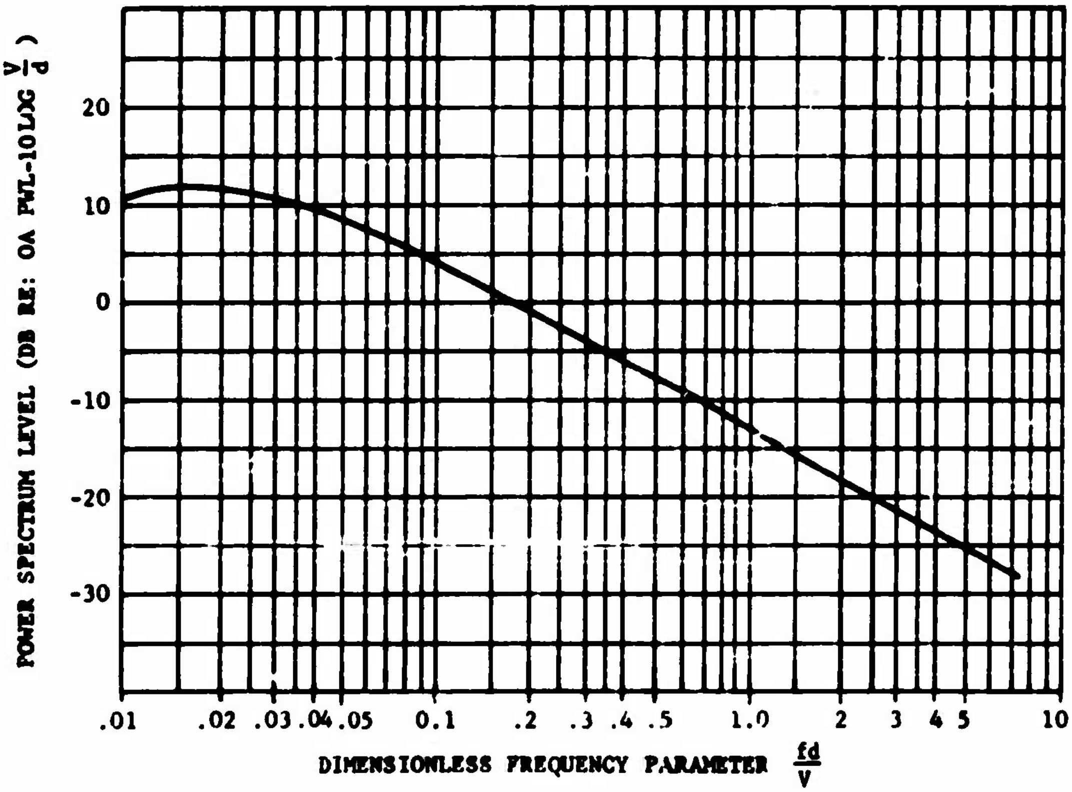


FIG. 4-1 GENERALIZED POWER SPECTRUM OF ROCKET NOISE[6]

To obtain the power levels in one-third octave bands the following steps are necessary.

A. Compute fd/V where f is the geometric mean frequency of each one-third octave band.

B. From Fig. 4-1 determine the power spectrum level in db.

C. Determine the db value of the reference level (shown as zero db), which is

$$\text{OVERALL PWL} - 10 \log V/d$$

D. Add the zero reference level to the power spectrum levels determined in step (B).

E. Correct these power spectrum levels (PSL in db re 10^{-13} watts) to one-third octave band (OB) PWL from the expression

$$\text{OB PWL} = \text{PSL} + 10 \log_{10} \Delta f$$

where Δf is bandwidth in cps.

4.1.1.2 Sound Pressure Levels and Directivity

The approximate relation, (accurate to 0.5 db) between the mean sound pressure level at a given radius and the PWL is

$$\overline{\text{SPL}}_o = \text{PWL} - 20 \log r_o - 8 \text{ db} \qquad (4\text{-}4)$$

where

$\overline{\text{SPL}}_o$ = space average of the overall sound pressure level at distance r_o from the source, in db re 0.0002 microbar

PWL = overall power level of source in db re 10^{-13} watt

r_o = distance from source, feet

The directivity pattern of a noise source is generally defined for the far radiation field, where particle velocity and sound pressure in a sound wave are in phase. A good engineering estimate is to assume that the far field begins at a radius equal to about 5 effective source diameters. A correction in decibels (directivity index) must be applied to the average sound pressure level calculated for Eq. (4-4) for various angles θ from the axis of the exhaust stream.

Figure 4-2 shows the correction in decibels that must be applied to the average sound pressure level in order to allow for the directional characteristics of the jet source. The directivity pattern of a rocket is not the same for all frequencies and the pattern changes during liftoff of a missile. Thus, the data given must be regarded as average values.

The dashed curve of Fig. 4-2 gives the sound pressure level, (referred to the average SPL at a distance r_o from the source) at various points, defined by the angle θ, on a line parallel to the jet axis and displaced a distance r_o from it. Such an analysis is called a sideline analysis and has immediate application to the problem of how the noise at a fixed receiver varies during the launching of a missile. For instance, it is clear from Fig. 4-2 that the maximum noise at a fixed receiver will occur when the height of the source above the receiver is $r_o \cot 70^o$.

By taking into account the geometrical spreading and atmospheric attenuation of the outward propagating sound, the space average SPL for each octave band at any distance may be determined. This information can be combined with the directivity indices (DI) of Fig. 4-3 to arrive at the SPL estimates of a given distance as a function of angle θ and the various octave bands of frequency.

The DI information is far-field information and cannot be extended closer than a limiting distance to the source. For purposes of prediction it is convenient to compute the space average SPL's at 200 feet. In this case,

Space Average SPL = PWL - 57 db (source in air)

Space Average SPL = PWL - 54 db (source on ground)

4.1.1.3 Engine Clusters and Blast Deflectors

One of the important rocket engine parameters that must be considered in describing its acoustical power output and frequency spectrum is the effective nozzle diameter. For a single engine, this diameter is usually taken to be equal to that of the engine nozzle itself. However, when several engines or clusters of engines are used, this diameter becomes less well defined. Furthermore, the directivity pattern, overall power, and spectra of grouped noise sources are known to be different than that of a single source because of gas mixing processes involved in clustering.

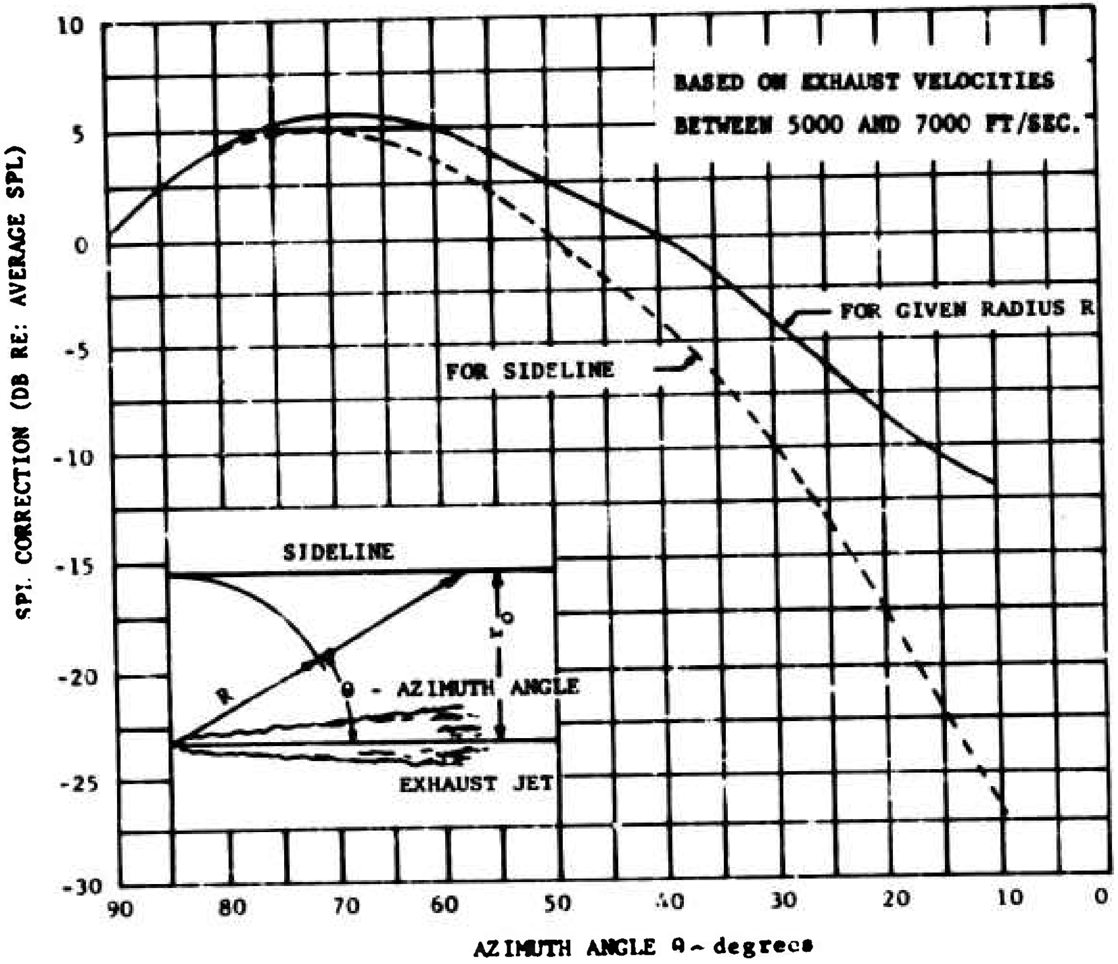


FIG. 4-2 ROCKET ENGINE NOISE DIRECTIVITY CORRECTION[7]

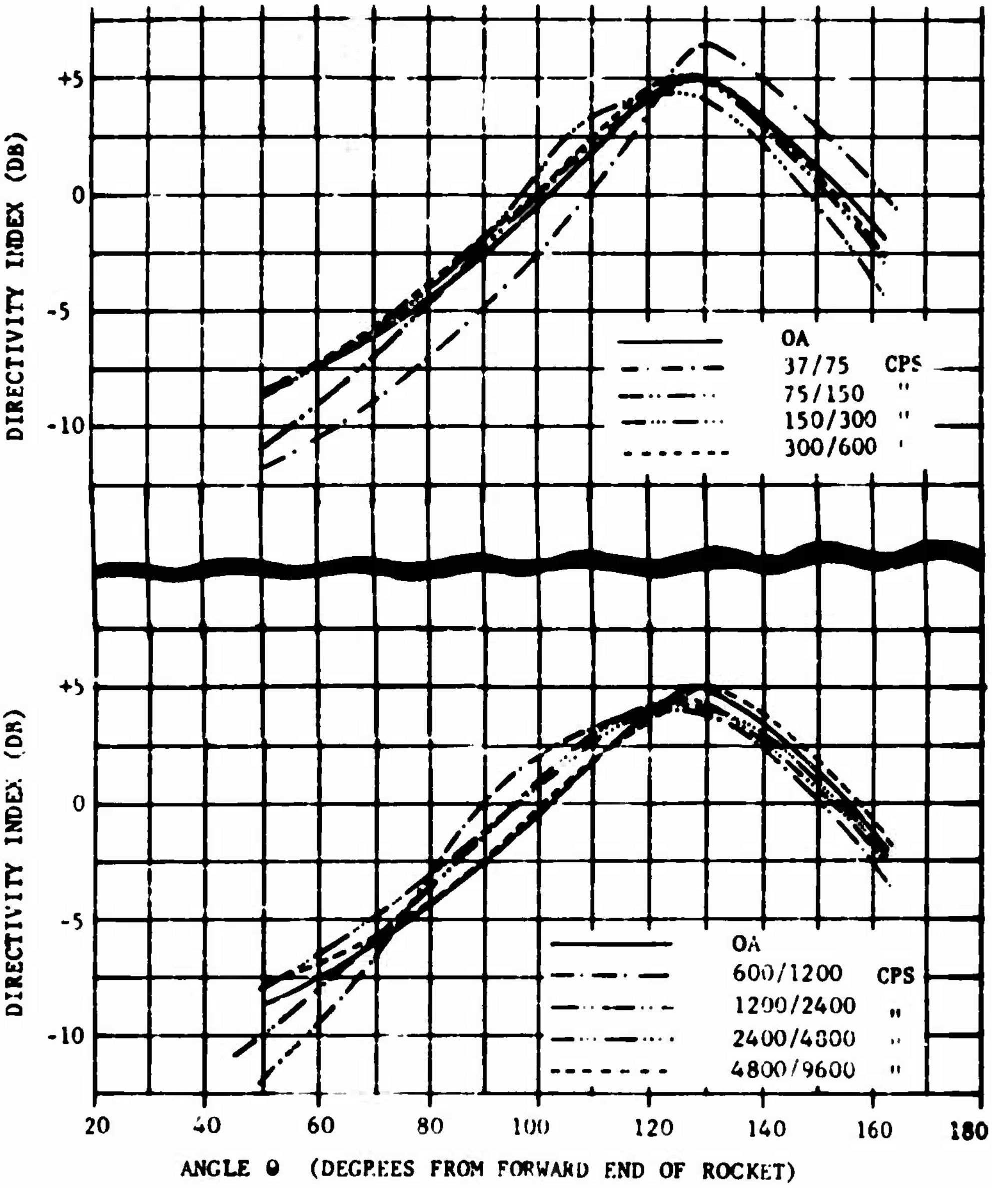


FIG. 4-3 GENERALIZED DIRECTIVITY INDICES[6]

The power spectra of noise produced by different cluster configurations tends to shift to lower frequencies as the number of engines increases. Figure 4-4 shows that in model scale tests the power in the higher frequency octave bands increases by only 3 db, while power in the lower frequency bands increases by 20 db as the number of engines in the cluster increases from one to eight.

Experiments indicate that the acoustic power is directly proportional to the mechanical power developed by the cluster, and doubling the engines in the cluster increases the acoustical power levels by 2 or 3 decibels. Clustering of rocket engines also affects directivity in the far field (see Fig. 4-5).

It is generally assumed that a valid acoustic scale model of a jet noise source duplicates the known or measurable parameters of the jet exhaust. The basic scaling principles and equations, stated below, are illustrated in Fig. 4-6.

a. The mean square pressure at a given frequency in the field of a sound source is proportional to the source strength times a near field and directivity weighting function, and inversely proportional to the square of the path length.

b. The frequency of the source is characterized by the ratio of a typical source velocity to a typical source dimension.

c. The source intensity can be defined uniquely by the kinetic energy terms, velocity and density.

d. For similar gases typical dimensions and velocities within the jet, normalized by exit diameter and exit velocity, respectively, will be funtions of dimensionless position.

When these concepts are combined, an expression for the mean square pressure is found in terms of a set of dimensionless ratios times a measure of unit source intensity. The product of frequency times jet diameter is also a function of similar dimensionless ratios. Thus, a set of ratios of source dimensions to observation distance is sufficient to equate the sound fields around two jets which differ only in their size.

The major rocket engine noise source (the region of turbulent mixing of the exhaust gases with the atmosphere) is a function of deflector configuration. Many deflector designs can cause increases of more than 10 db in the average near-field sound pressure levels in regions where the missile structure would be located. Deflectors can also significantly influence the total output and spatial distribution of acoustic power produced by rocket engine operations. Small scale tests for six typical blast deflectors were performed at Wright Air Development Division and the results are summarized in Fig. 4-7.

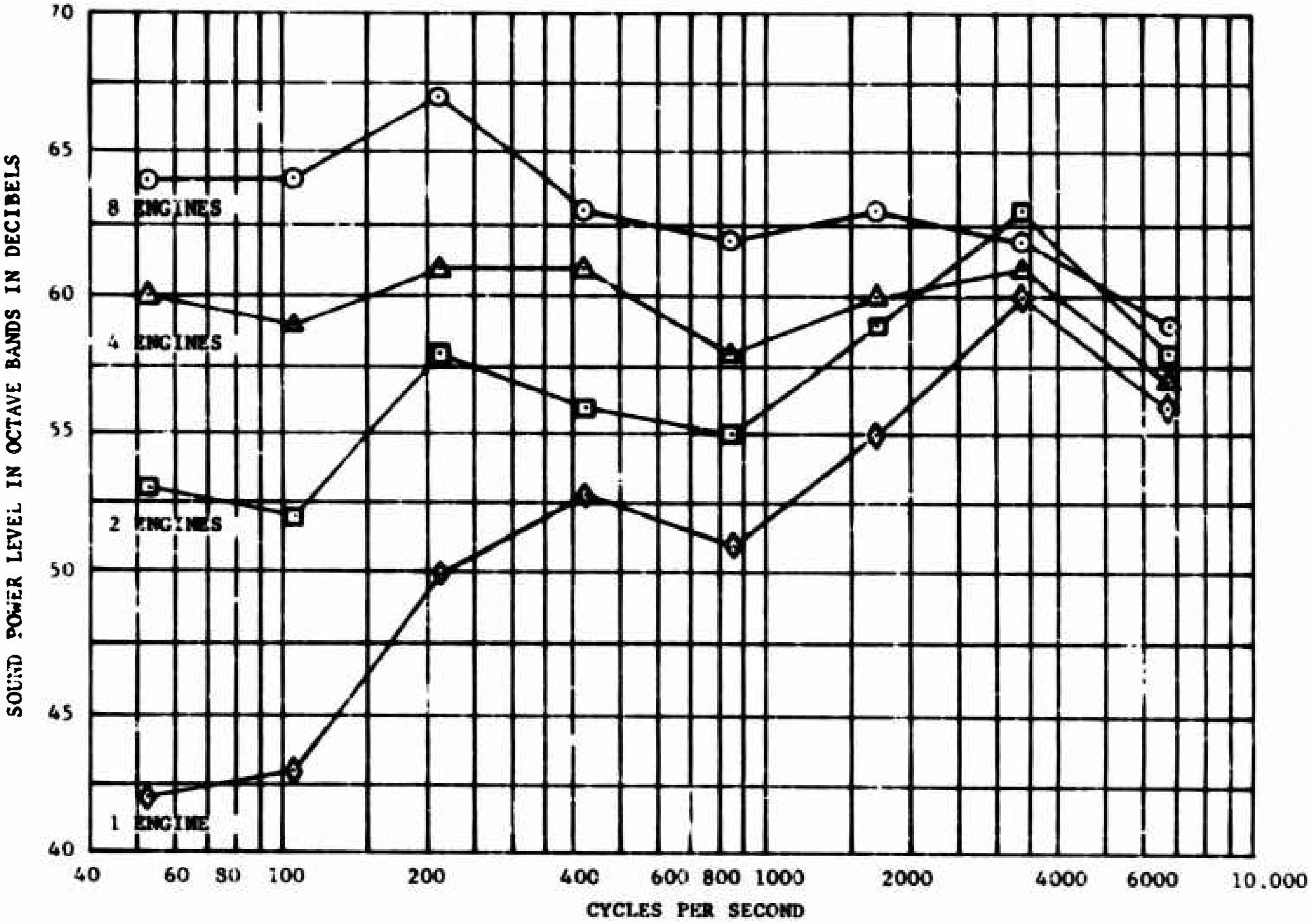
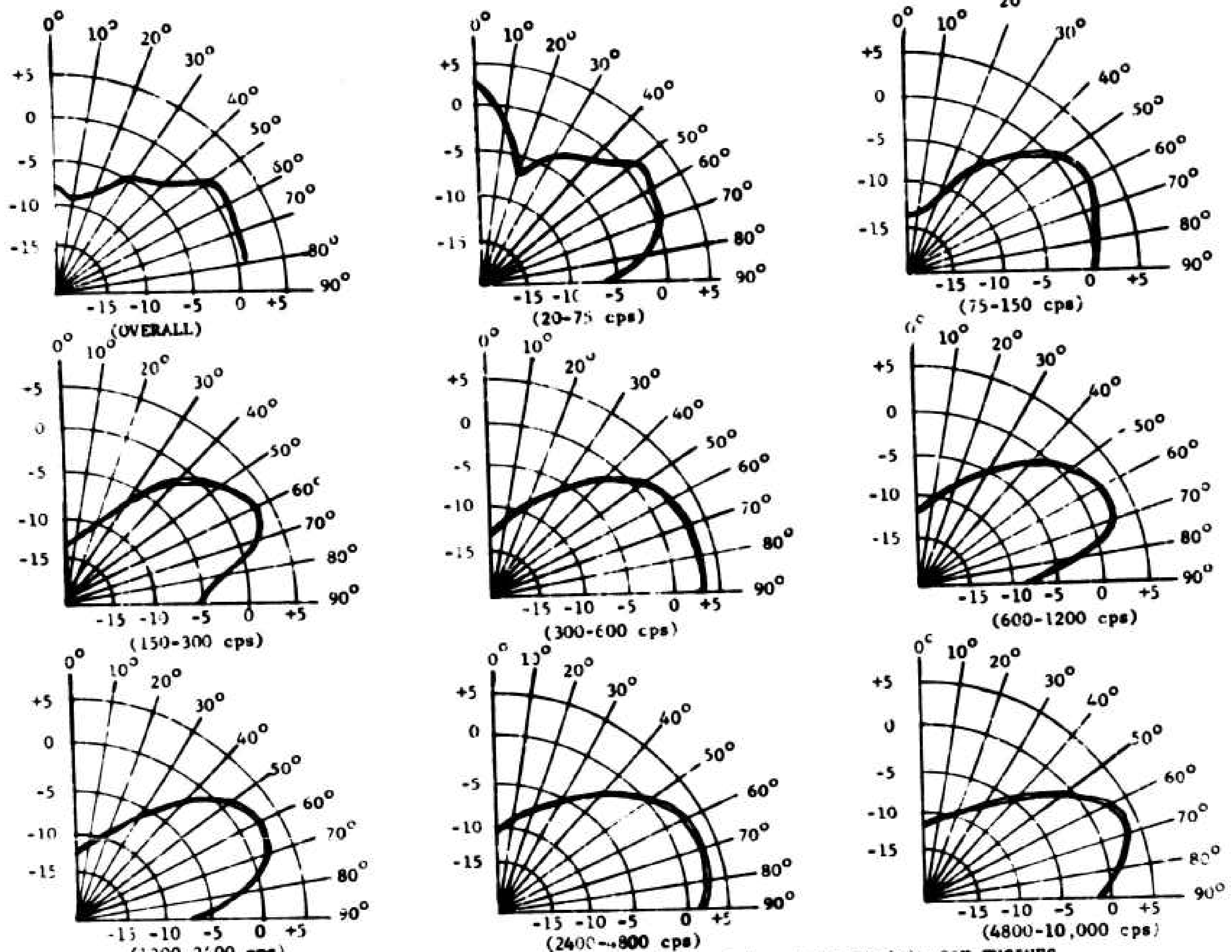
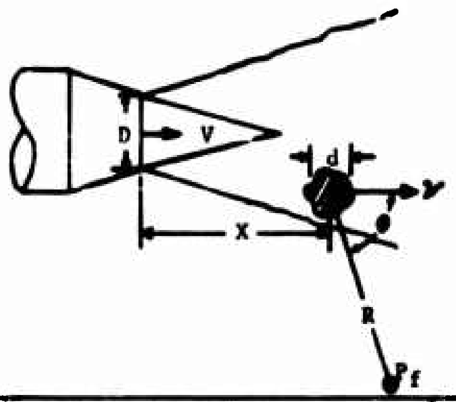


FIG. 4-4 ACOUSTIC POWER SPECTRUMS FOR ENGINE CONFIGURATIONS[8]



(OVERALL)
(20-75 cps)
(75-150 cps)
(150-300 cps)
(300-600 cps)
(600-1200 cps)
(1200-2400 cps)
(2400-4800 cps)
(4800-10,000 cps)

FIG. 4-5 ESTIMATED DIRECTIVITY PLOTS (Directivity index in Decibels) - **SIX ENGINES**



NOISE SOURCE CHARACTERISTICS

DIMENSION	d	CM
VELOCITY	ν	CM/SEC
DENSITY	ρ	GM/CM^3
SOURCE INTENSITY	Q_f	WATTS/CM^2
SOUND FREQUENCY	$f = \frac{c}{\lambda}$	CPS

ACOUSTIC SIMILARITY

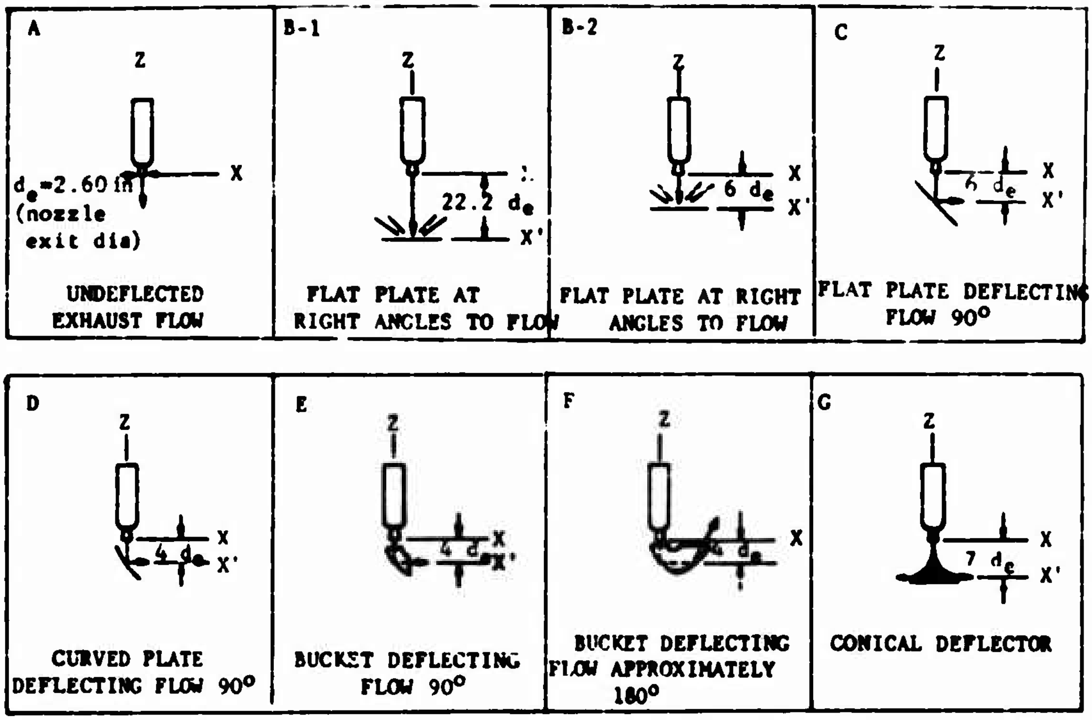
GIVEN
$$\begin{cases} P_f^2 \sim \left[Q_f \cdot d^2\right] \dfrac{A\left[\frac{R}{\lambda} \cdot \theta\right]}{R^2} & (1) \\ f \sim \dfrac{\nu}{d} & (2) \\ Q_f \sim B\left[\frac{1}{2}\rho\nu^3\right] & (3) \end{cases}$$

JET FLOW SIMILARITY

AND
$$\begin{Bmatrix} \dfrac{d}{D} \sim F\left[\dfrac{X}{D}\right] \\ \dfrac{\nu}{V} \sim G\left[\dfrac{X}{D}\right] \end{Bmatrix} \qquad (4)$$

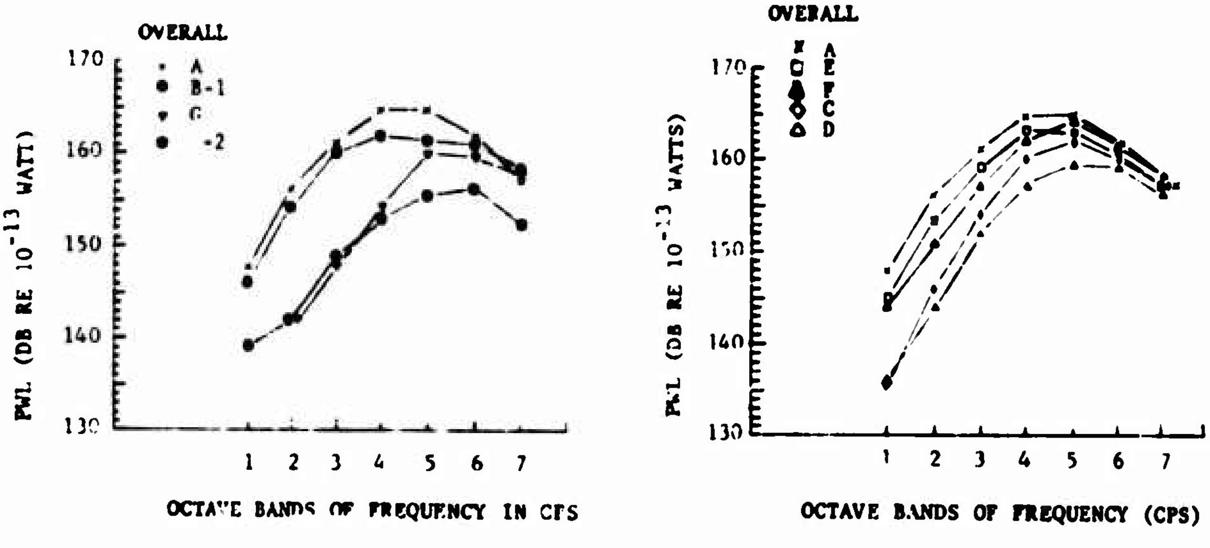
$$\therefore \begin{cases} P_f^2 \sim \left[\dfrac{1}{R/D}\right]^2 A\left[\dfrac{R}{D} \cdot \dfrac{V}{c} \cdot \theta\right] B\left[\frac{1}{2}\rho V^3\right] \\ fD \sim H\left[\dfrac{X}{D}, V\right] \end{cases}$$

FIG. 4-6 CHARACTERISTICS OF A JET EXHAUST NOISE SOURCE [9]



OCTAVE BANDS

1 - 75 to 150 cps
2 - 150 to 300 cps
3 - 300 to 600 cps
4 - 600 to 1200 cps
5 - 1200 to 2400 cps
6 - 2400 to 4800 cps
7 - 4800 to 9600 cps



ROTATIONALLY SYMMETRICAL DEFLECTORS

TRANSVERSELY SYMMETRICAL DEFLECTORS

FIG. 4-7 ACOUSTIC POWER LEVEL SPECTRA FOR BLAST DEFLECTORS[10]

4.1.2 Propagation of Rocket Noise

The launch of a large missile involves the following operational sequences which are influential in the propagation of rocket engine noise to a receiver in the vicinity of the launch site.

(1) Ignition and lift-off

(2) Low acceleration of the missile at small elevation angles

(3) Medium and/or high missile acceleration at large elevation angles

For each of these operational conditions, the amount of rocket noise transmitted to a receiver on the ground will be affected by attenuation due to spherical divergence in the air and/or damping of the macrosonic waves. In addition, the attenuation due to meteorological factors, e.g., temperature gradient, wind velocity, wind velocity gradient, wind direction and humidity must be considered along with the physical effects of ground transmission, barriers, missile elevation angles, and blast deflectors.

4.1.2.1 Ground/Ground Propagation

Ground to ground propagation occurs during ignition of a rocket booster engine and during the initial lift-off conditions. The equation for the sound pressure at a point in the far field due to spherical divergence is

$$P = \frac{K}{R} e^{-\alpha R} \tag{4-5}$$

where K is dependent upon the source amplitude, α is dependent upon air conditions, and R is the distance to the source.

Attenuation due to spherical divergence alone causes a reduction of 6 db for each successive doubling of distance from the source. A plot of db loss versus distance is shown in Fig. 4-8.

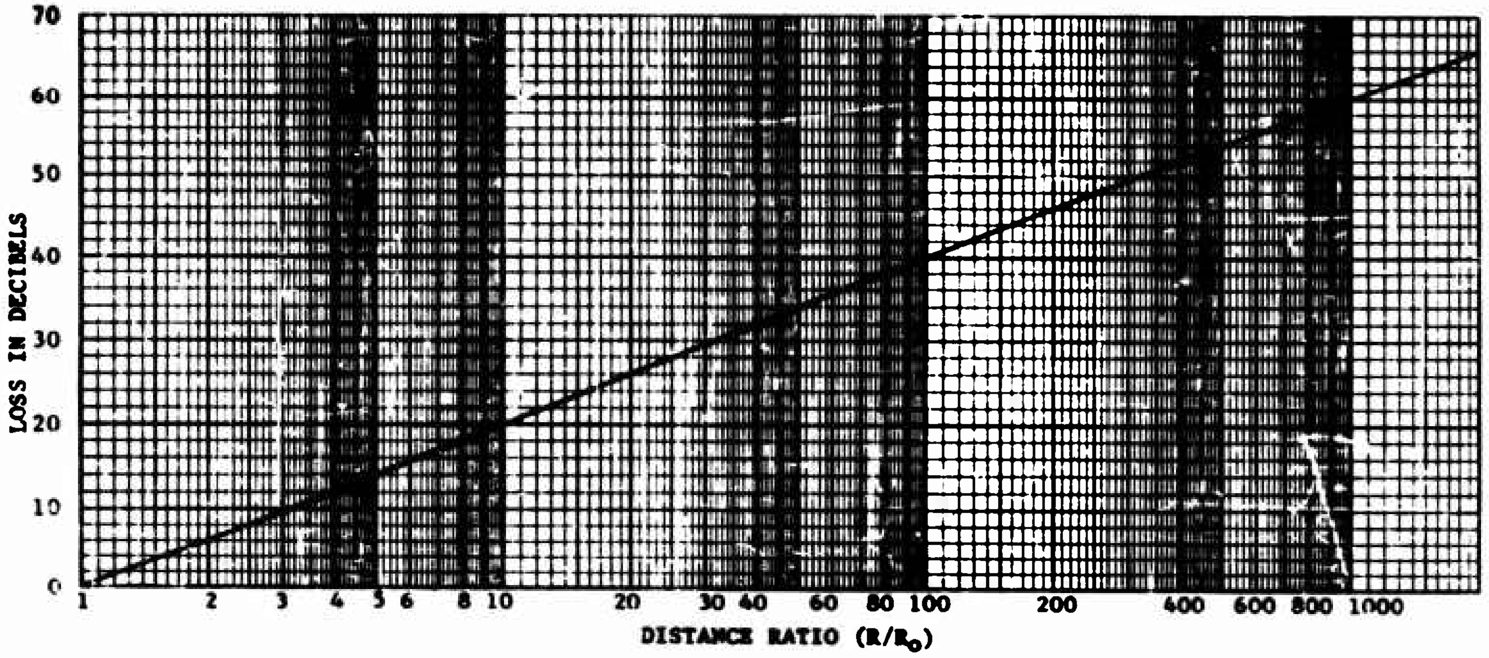


FIG. 4-8 SQUARE LAW ATTENUATION

Atmospheric attenuation represents all reductions in sound pressure level over a given path of propagation in excess of the reduction due to square law attenuation. For large rocket booster noise propagation only the molecular absorption (classical absorption will be negligible) need be considered. It is dependent upon absolute humidity and air temperature as given by the following approximate equation

$$A_H \simeq 0.1(T + 45) \ (f/h)^2 \qquad (4\text{-}6)$$

where

A_H = molecular absorption in db/1000 ft.

T = air temperature in $^{\circ}F$

f = geometric mean frequency of an octave band in kilocycles

h = absolute humidity in grams cm^{-3}

Sound attenuation as a result of molecular absorption, turbulence, terrain effects, and propagation through fog, rain and/or snow may be lumped together into a single value of excess attenuation (greater than inverse square) A_{e_1}. Figure 4-9 shows a family of curves giving A_{e_1} for propagation over level terrain with uniform ground cover at the air temperatures and humidities indicated.

Over open level ground where appreciable vertical temperature and wind gradients usually exist it is possible to have a "shadow zone" into which no direct sound can penetrate. These shadow zones are never sharp because sound energy is diffracted into the shawdow zone and scattered into it by turbulence. A shadow zone is most commonly encountered upwind from a source. Sound refraction caused by temperature gradients tends to be symmetrical about the source of sound.

The distance X to the onset of the shadow zone can be estimated from the mean temperature and wind gradients evaluated at one-half the average source and receiver heights, using the following equation:

$$X = \left[\frac{2c_o}{\beta\cos\phi - \alpha}\right]^{1/2} \left[S^{1/2} + R^{1/2}\right] \text{ feet} \qquad (4\text{-}7)$$

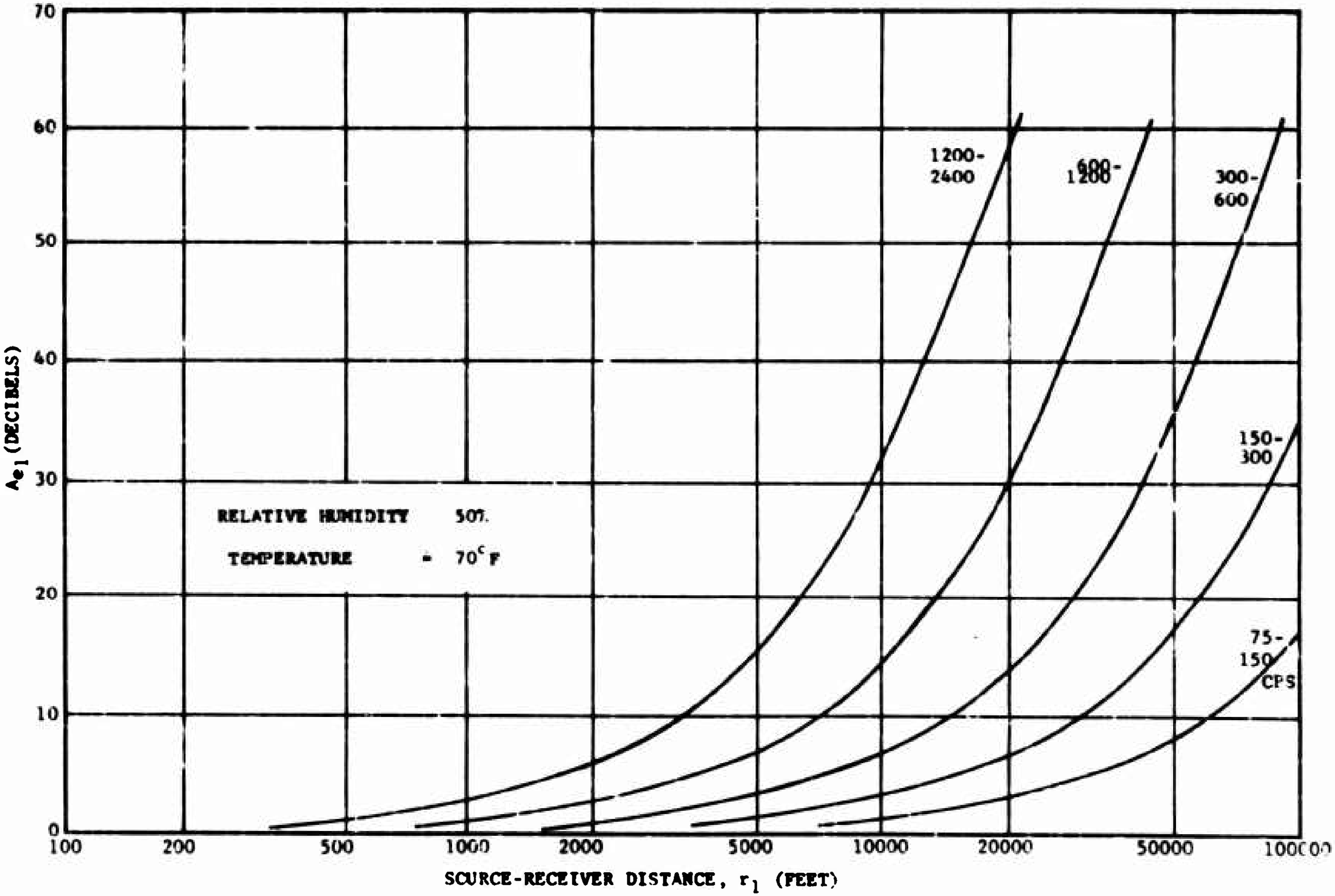


FIG. 4-9 ESTIMATED EXCESS ATTENUATION (A_{e_1})

where

c_o is the ambient velocity of sound, in feet per second

S is the height of the sound source above the ground in feet

R is the height of the receiver above the ground in feet

ϕ is the wind-to-sound angle

β is the mean wind gradient in $\sec^{-1}$

$$\alpha = \frac{c_o}{2T_o} \frac{\partial T}{\partial z}, \text{ in } \sec^{-1}$$

T_o is the absolute ambient temperature, in degrees Rankine

z is the height above sea level, in feet

The estimated excess attenuation into a shadow zone (A_{e_2}) directly upwind is represented by Fig. 4-10 for medium, high and low frequencies. These results are not expected to differ much over land or water or in moist humid air, e.g. fog. The A_{e_2} attenuation is expected to be approximately 7 db less when ϕ is 45^o and 15 db less when ϕ is 90^o.

The variation of wind and temperature gradients in the first few thousand feet of the atmosphere may cause substantial changes in the velocity of sound with height. For example, Fig. 4-11 represents a plot of travel time (t) versus angle of departure (θ) and range (R) versus (θ) for the case of sound transmission through the atmosphere in which two velocity gradients K_1 and K_2 exist (K_1 being less than K_2). At $\theta = \theta_1$, the travel time curve and the range pass through a minimum. Furthermore, both the travel time and range change very slowly with θ in the vicinity of θ_1. This indicates that a cone of rays (essentially in phase) will be converged at a range of R_1 and will produce an increase in intensity. Various combinations of gradients will produce this focussing. Once the magnitude of the gradients in the vicinity of a launch site are known, an analog computer can be used to calculate and trace the ray paths to determine if focussing of sound rays will occur. Figure 4-12 indicates the reinforcements of sound energy possible for various velocity profiles.

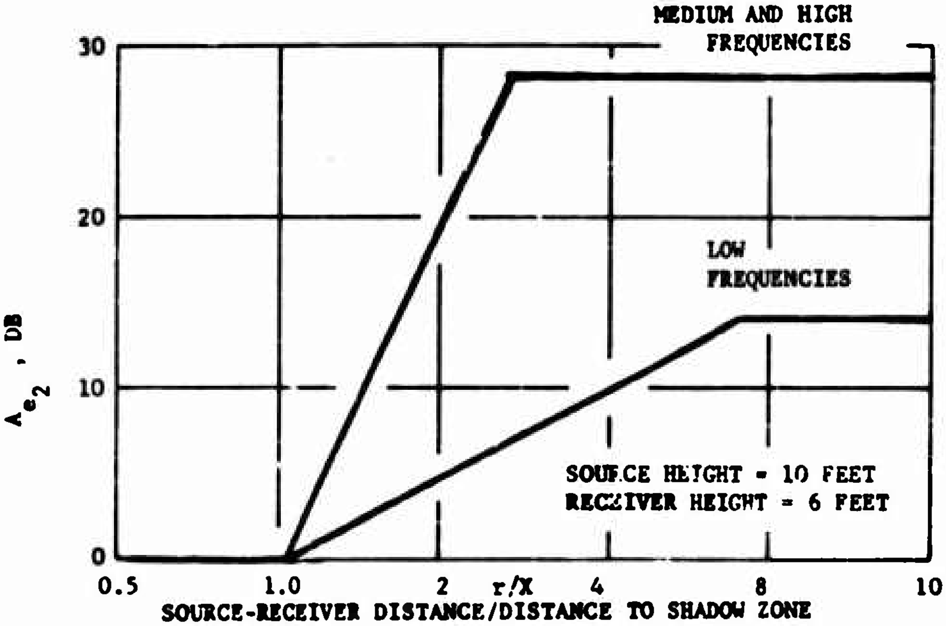


FIG. 4-10 ESTIMATED EXCESS ATTENUATION (A_{e_2})[12]

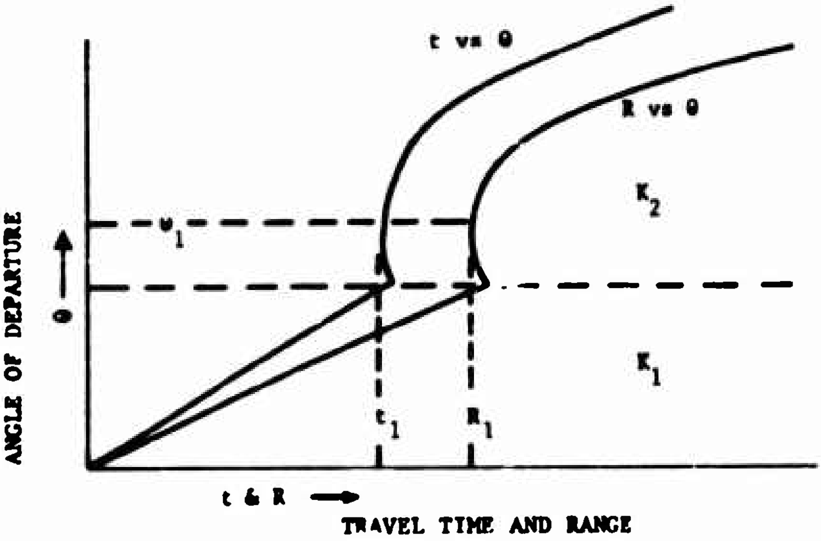
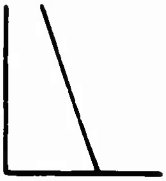
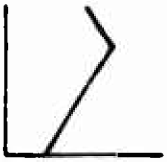
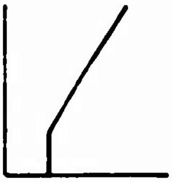
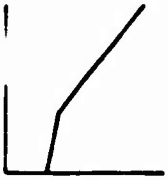
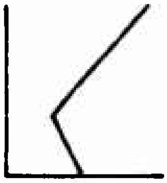


FIG. 4-11 FOCUSSING OF SOUND RAYS

CATEGORY	DESCRIPTION		ADDITIVE FACTOR
1	SINGLE NEGATIVE GRADIENT		0
2	SINGLE POSITIVE GRADIENT		+14 DB
3	ZERO GRADIENT NEAR SURFACE WITH POSITIVE GRADIENT ABOVE		+20 DB
4	WEAK POSITIVE GRADIENT NEAR SURFACE WITH STRONG POSITIVE GRADIENT ABOVE		+28 DB
5	NEGATIVE GRADIENT NEAR SURFACE WITH STRONG POSITIVE GRADIENT ABOVE		+40 DB

[illegible] 4-1. VELOCITY GRADIENTS AND INTENSITY AT A FOCUS[13]

4.1.2.2 Air/Ground Propagation

As the sound source increases in elevation angle, ground cover and terrain effects become less significant usually resulting in less attenuation of the sound energy. Residual attenuation (A_o) is defined as the atmospheric attenuation in excess of the humidity attenuation and is due principally to the scattering effects of air turbulence and to the formation of sound shadows by the upward refraction of rays near the surface of the earth. Estimates of the effects of turbulence in the 75-150 cps octave band are given in Fig. 4-13. In order to estimate the residual attenuation A_o due to shadow formation it is necessary first to know whether the observation point is within the shadow zone. This can be determined from Fig. 4-14.

The gradient B_T due to temperature is given approximately by

$$B_T = 4(T - To) \times 10^{-4} \ {}^oF \qquad (4\text{-}8)$$

Similarly, the gradient B_w due to wind at 30 feet above the ground is approximately

$$B_w = 1.5\ W_{30} \cos\phi_c \times 10^{-4} \qquad (4\text{-}9)$$

where

W_{30} = wind speed in miles per hour

$\phi_c = \cos^{-1}\left[\frac{-B_T}{1.5\ W \times 10^{-4}}\right]$ is the critical angle where $B_T = B_W$

The wind speed at 30 feet may be estimated from the known speed W_z at any other height (up to about 300 feet) by the relation

$$W_{30} = \frac{W_z}{1 + 0.27\ \log_{10}(Z/30)} \quad \text{miles per hour} \qquad (4\text{-}10)$$

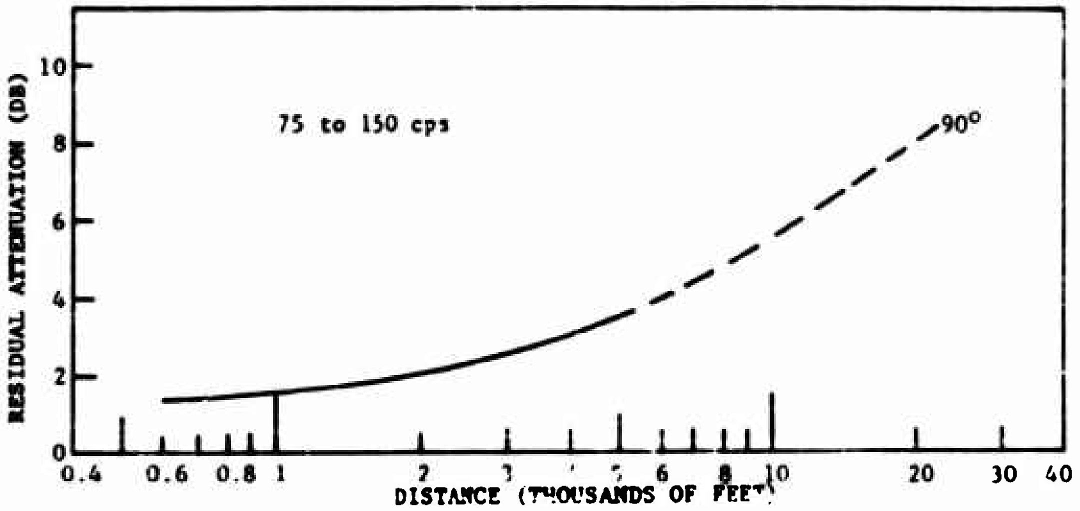


FIG. 4-13 ESTIMATED AVERAGE RESIDUAL ATTENUATION DUE TO TURBULENCE[1]
(FOR VERTICAL LAUNCH)

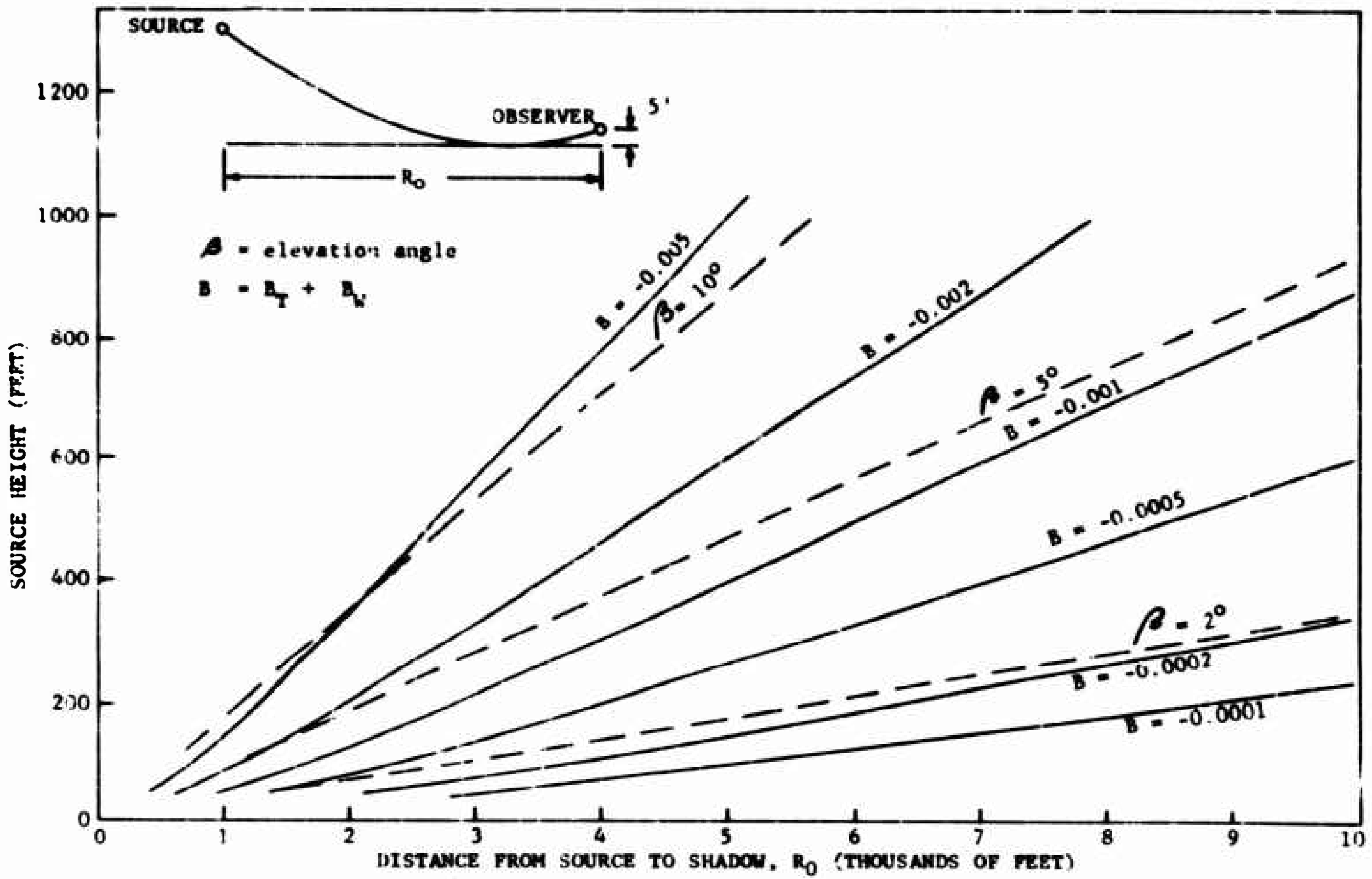


FIG. 4-14 HORIZONTAL DISTANCE FROM SOURCE TO SHADOW BOUNDARY[14]

Representative maximum values of B resulting from combined temperature and wind gradients are -.005, and thus shadow zones are not apt to occur at an observation point when the source elevation angle exceeds 10 degrees.

As the observation point moves into the shadow zone away from the boundary, the residual attenuation A_0 first increases rapidly and then attains a limiting value at which it remains essentially constant. Available data are not adequate to permit an exact prediction of this limiting value, but it is generally within the range of 25 to 35 db.

The distance from the shadow boundary at which the shadow attenuation reaches the limiting value is difficult to predict exactly. For wind-sound angles between 110° and 250°, this distance may be taken as three times the distance from the source to the shadow boundary. For wind-sound angles outside this range the distance becomes much larger.

Long range propagation is considered within this report to begin when the vehicle altitude is approximately 5000 feet. At this altitude, the major influencing factors on the propagation of rocket noise are spherical divergence, turbulence molecular absorption and wind and temperature gradients.

Absolute humidity decreases considerably with altitude, and for low values of humidity, the molecular absorption in any given atmospheric layer is

$$a_H = \frac{.1\, f\, (T + 45)}{f/h^2 + h^2/f} \qquad (4\text{-}11)$$

where

f = geometric mean frequency of an octave band in kilocycles

T = temperature in $^\circ$F

h = absolute humidity in gm/rm^3

The total humidity attenuation from source to ground is the sum of the attenuations in successive layers of the atmosphere.

At altitudes above 5,000 feet, wind and temperature gradients tend to be more uniform with height and subject to less fluctuation with time than at lower altitudes. A mean value of approximately -4°F per 1,000 ft. has been determined for the temperature gradient in this portion of the atmosphere. Maximum values of wind component gradient depending on the scalar wind velocity at the tropopause, are of the order of ±7 ft/sec per 1,000 ft. or ±0.007 sec^{-1}. As in the case of temperature gradients, actual wind component gradients may show irregularities associated with frontal boundary layers.

The sound velocity gradient due to wind component depends both on the scalar wind velocity gradient and on the direction of the wind with respect to the direction of sound propagation. The total sound velocity gradient g is given by

$$g = (g_W + g_T)\,sec^{-1} \qquad (4\text{-}12)$$

where g_W is the gradient of the component of wind velocity in the direction of sound propagation, and g_T is the sound velocity gradient due to temperature.

For any negative sound velocity gradient up to the 40,000 ft. height, the sound field of an ascending source such as a rocket will have a shadow whose boundary touches the ground at a horizontal distance which increases with source height and decreases with increasing negative gradient.

It can be shown by further geometric constructions that focussing on the ground can occur with a concave velocity profile, but only if the shape of the profile is such that there is some height at which the velocity is greater than at the ground.

4.1.2.3 Propagation Around Barriers and Through Soil

When rocket noise is incident upon a hill and/or other obstacle, some of the sound energy is diffracted. The amount of sound energy that is transmitted to a point on the other side of the barrier is dependent upon the distances represented by the sketch in Fig. 4-15. From Fresnel diffraction it is assumed that $a \gg \lambda$, $b \gg \lambda$, $d_o \ll (a + b)$ and $d_o \ll (b/a)\,(a + b)$ and that a quantity v can be defined as indicated by expression (A) of the figure. The expected loss in decibels can then be determined from Fig. 4-15. Expression (B) of the figure includes the correction which must be applied to expression (A) due to the existence of a sound velocity gradient.

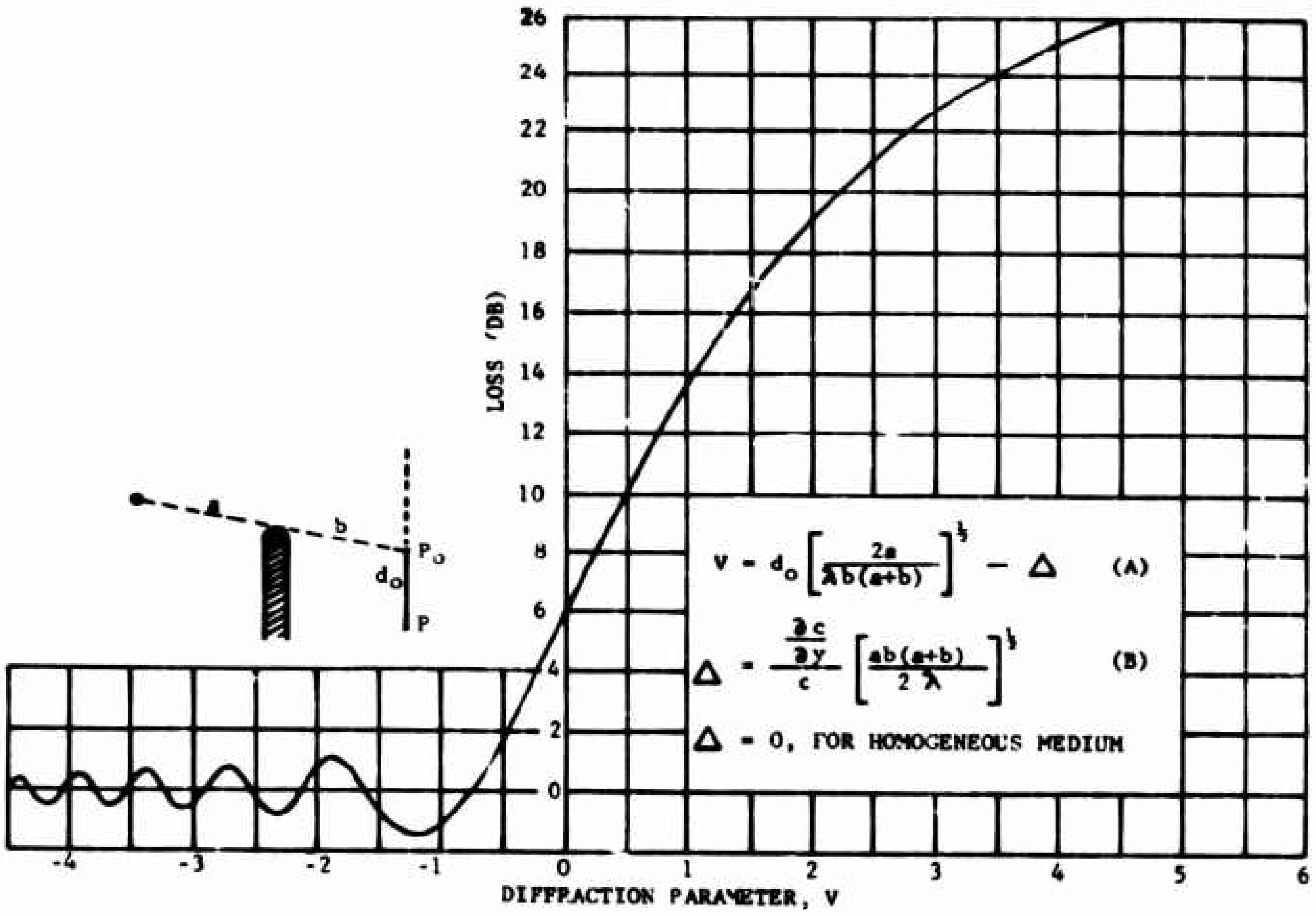


FIG. 4-15 SOUND LEVEL LOSS VERSUS DIFFRACTION PARAMETER[15]

Forests represent another type of barrier which may be encountered in the vicinity of launch sites. Estimates of the loss coefficients for various forests are represented by Fig. 4-16.

The earth beneath the test stand is excited during firings in essentially two ways: first, the engines and vehicle vibrations are imparted directly to the test stand itself and thence to the strata of soil into which the stand is structurally anchored. Second, the exhaust jet, impinging on the blast deflector, excites the ground into vibrations. Cylindrical waves will be generated by the first condition in a manner similar to the ground excitation obtained from quarry blasts. The maximum component of vertical displacement for fairly large distances can be represented by the graph in Fig. 4-17.

Somewhat different attenuations are expected when the launch site is located on bedrock (see Fig. 4-18). It is assumed here that spherical spreading takes place up to a distance from the source roughly equal to the depth of the bedrock layer, with cylindrical spreading beyond. A rough estimate of an upper limit of the magnitude of the ground vibrations excited by acoustic waves can be made as follows. The fluctuating pressures p generated by the exhaust stream impinging on the ground can be interpreted as fluctuations in the dynamic pressure in the exhaust stream, namely

$$p = \rho v (\Delta v) \qquad (4\text{-}13)$$

where ρ is the density of the gas and v is the expanded exhaust velocity. At most, $\Delta v = 0.1 v$ and therefore

$$p \leq \frac{1}{10} \rho v^2 \qquad (4\text{-}14)$$

The velocity u of the ground vibrations can be estimated from a knowledge of the ground impedance. Assuming that the ground is "hard" compared with the specific acoustic impedance of air, ρc; i.e., a ground impedance of $100 \rho c$, then, from Eq.(4-14) and observing that $u = p/100\rho c$, the velocity is

$$u \lesssim 10^{-3} Mv \qquad (4\text{-}15)$$

where M is the appropriate Mach number of the exhaust stream. Assuming $M \lesssim 3$ in the region where the pressure fluctuations are generated, then

$$u < 3 \text{ ft/sec} \qquad (4\text{-}16)$$

NUMBERS IN ZONES REPRESENT DIFFERENT JUNGLES AS FOLLOWS:

(1) VERY LEAFY - VISIBILITY DISTANCE, "d", APPROXIMATELY 20'

(2) VERY LEAFY - d = 50'

(3) LEAFY - d = 100'

(4) LEAFY - d = 200'

(5) LITTLE LEAFY UNDERGROWTH, LARGE BRACKETED TRUNKS - d = 300'

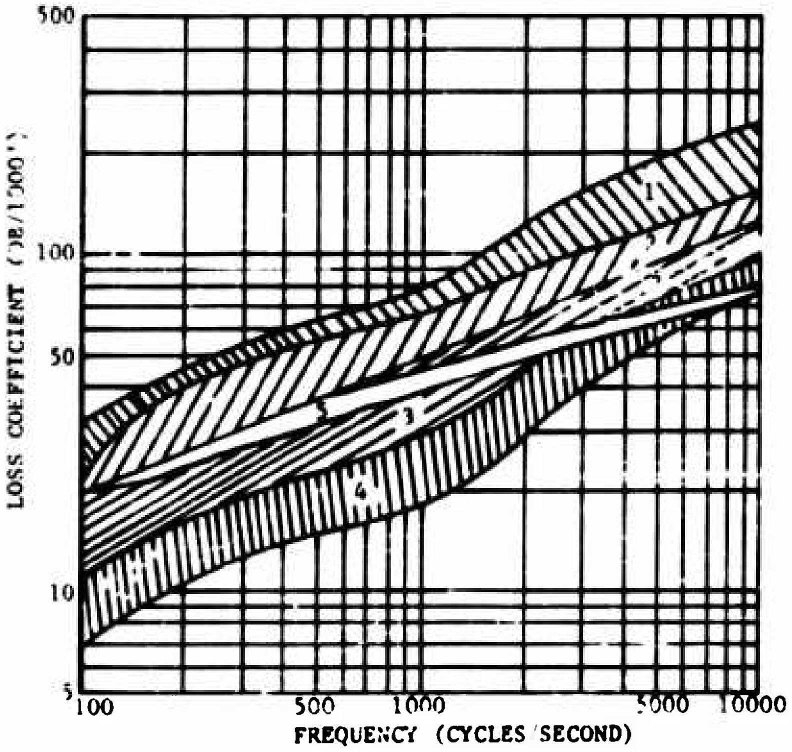


FIG. 4-16 ESTIMATED LOSS COEFFICIENTS IN FORESTS

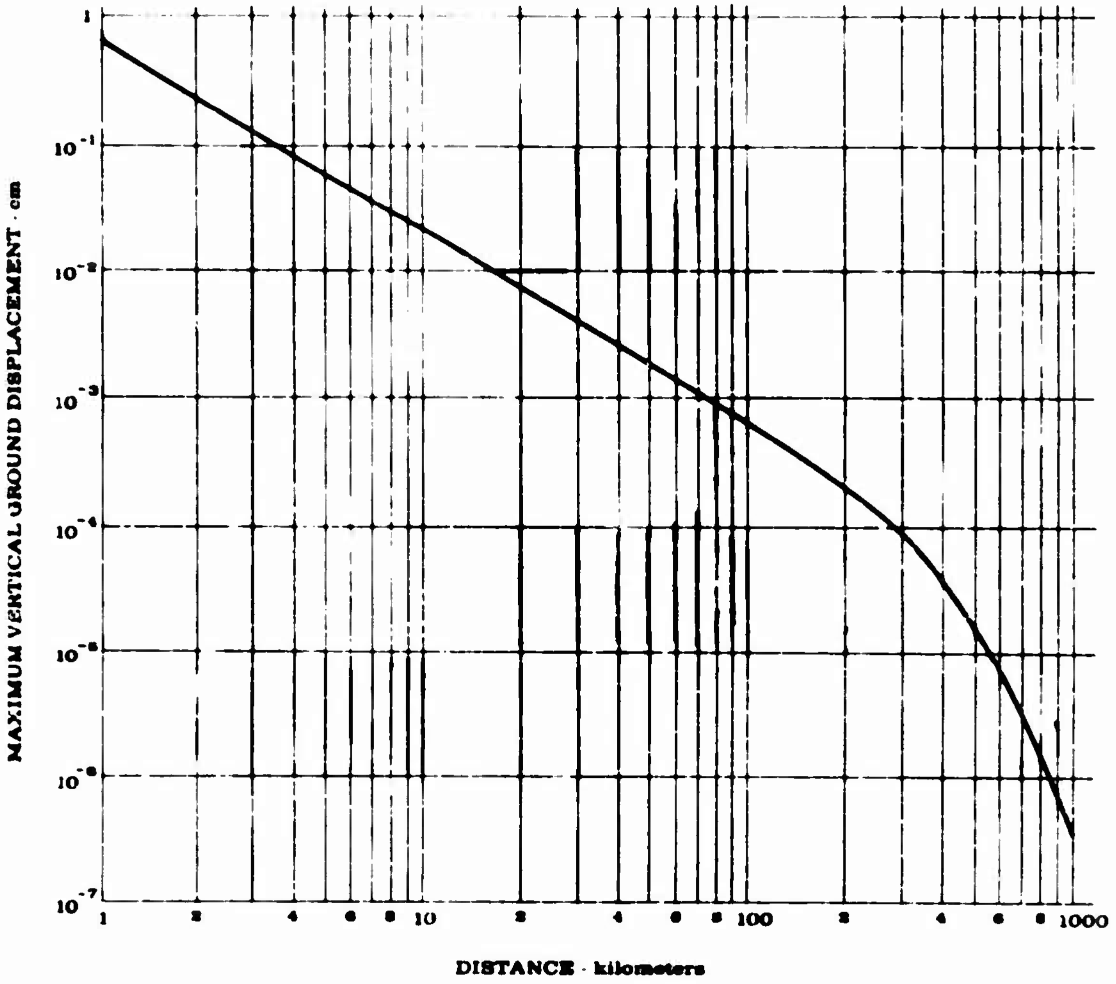


FIG. 4-17 MAXIMUM VERTICAL GROUND DISPLACEMENTS FOR EXPLOSIVE BLASTS [16]
(1.7 KT)
(NORMALIZED TO RAINIER USING $A_R = A_1 \left[\frac{1700}{W_1}\right]^{1.0}$)

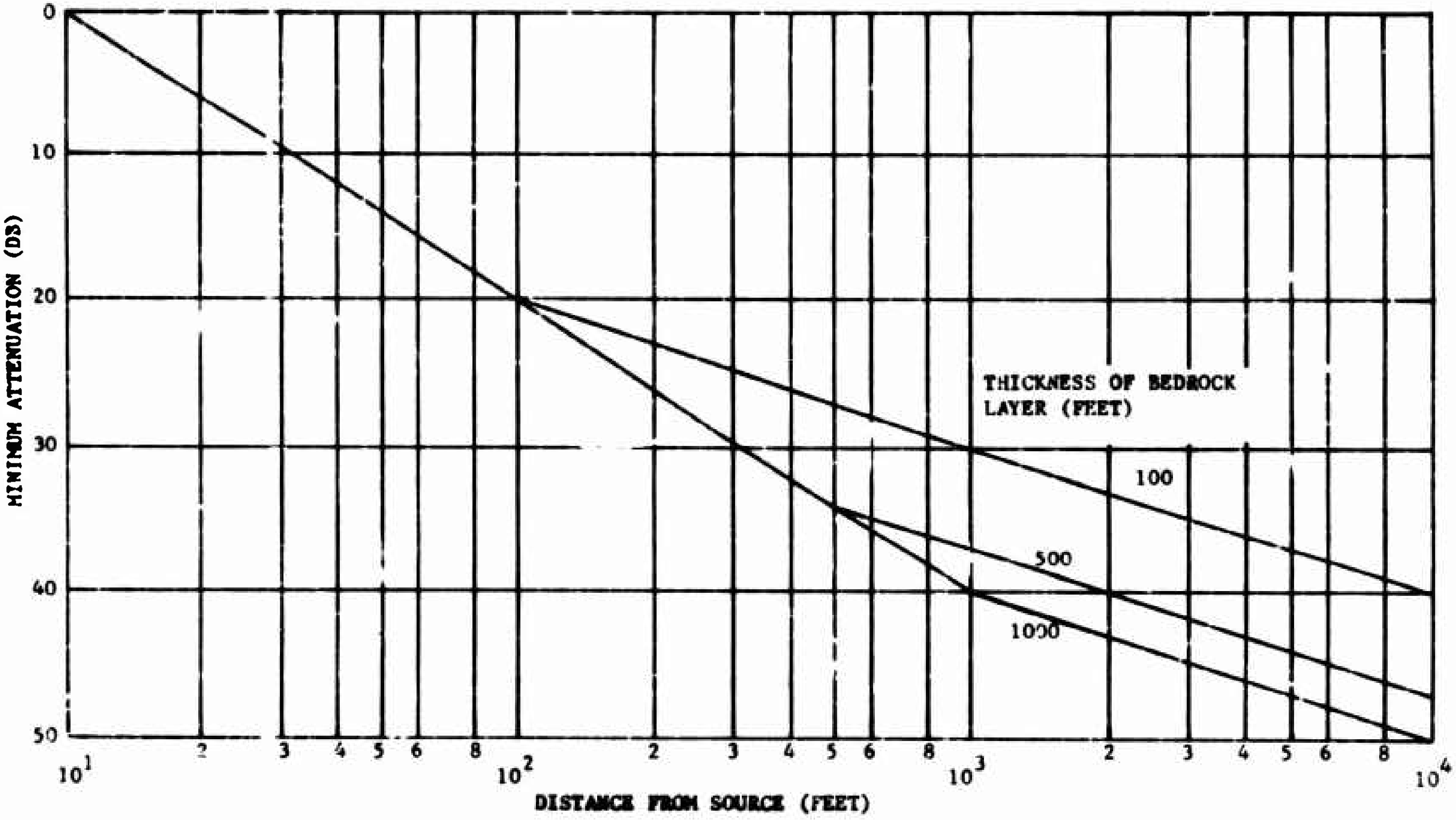


FIG. 4-18 MINIMUM ATTENUATION OF GROUND-BORNE VIBRATIONS[11]

4.1.3 Effects of Noise

The effects of the noise generated by the missile during launch are divided into two categories, effects on personnel, and the effects on structures and equipment. The noise resulting from missile launch operations should also be considered with respect to its effect on base facilities and the surrounding communities.

4.1.3.1 Effects on Personnel

The damage risk for personnel in the vicinity of the launch site depend on the intensity, duration, and frequency of the noise plus the age of the individual exposed (see Fig. 4-15). Personnel required to remain in areas determined as hazardous will be required to wear ear defenders to attenuate high frequency sound above 100 cps. However, even though ear defenders are worn, damage to tissue, effects on the central nervous system (fatigue and impairing of judgement), and blurring of vision are possible in environments where the intensity of the noise exceeds 150 db (re. 0.0002 dynes/cm^2).

To determine speech interference levels (SIL) caused by high intensity noise, calculate the arithmetic average of the sound pressure level in the 600-1200, 1200-2400, and 2400-4800 cps octave bands. Consult Table 4-I to determine the maximum distance between talker and listener, and the voice level required to permit reliable speech communication. This distance may be from person to person, person to loudspeaker, or person to microphone. If the SIL exceeds this level speech communication interference can be expected. If pure tone auditory warning signals are required in the presence of high noise levels generated by auxiliary equipment at the missile launch site, then Fig. 4-20 represents the sound level, that must be generated by the auditory warning devices to be audible in the presence of the masking noise.

TABLE 4-I

SPEECH INTERFERENCE LEVELS (IN db re 0.0002 MICROBAR)

Distance, ft, between source and listener	Normal voice level, db	Raised voice level, db
0.5	71	77
1	65	71
2	59	65
3	55	61
4	53	59
5	51	57
6	49	55
12	43	49

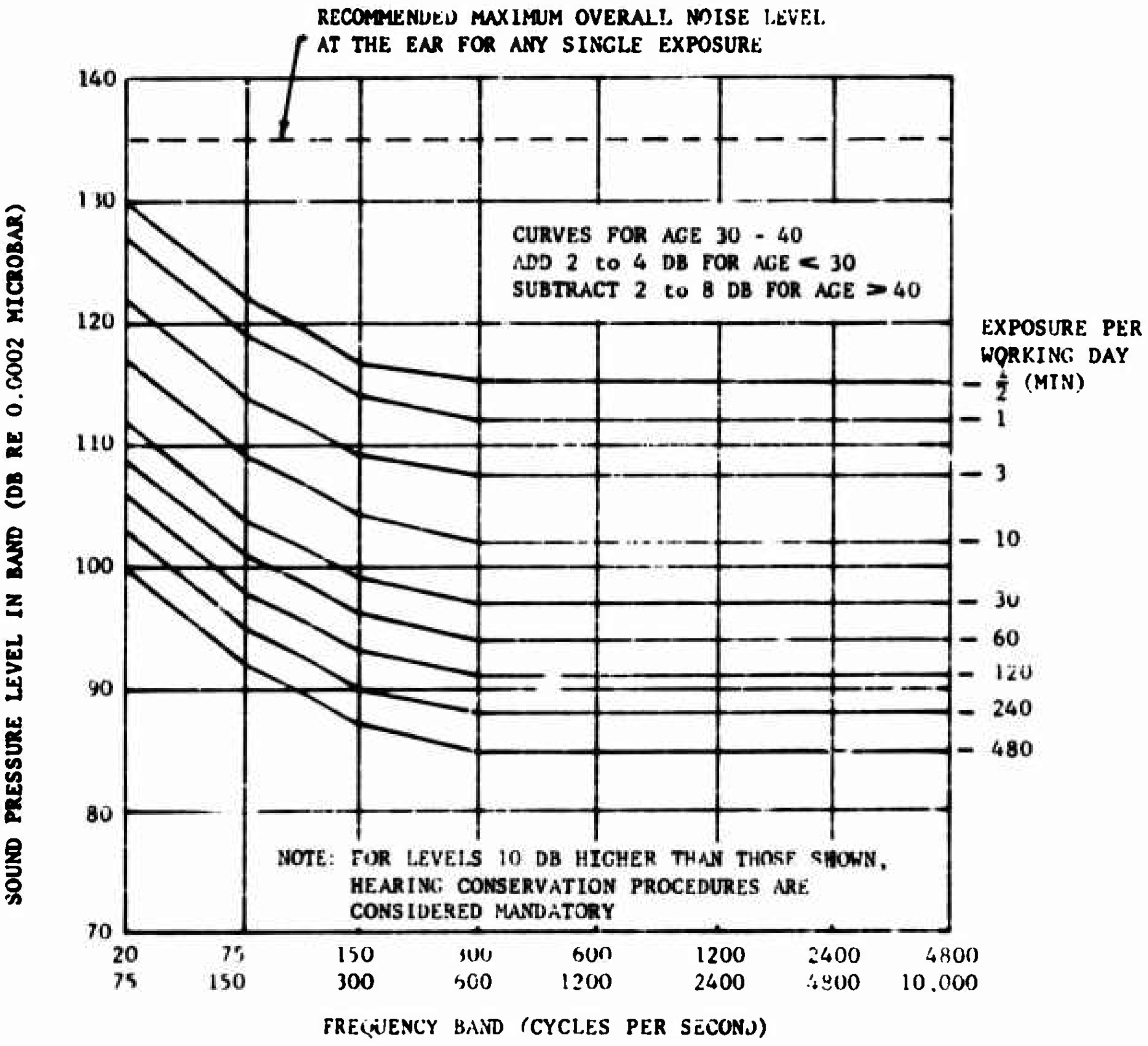


FIG. 4-19 REQUIREMENTS FOR HEARING PROTECTION

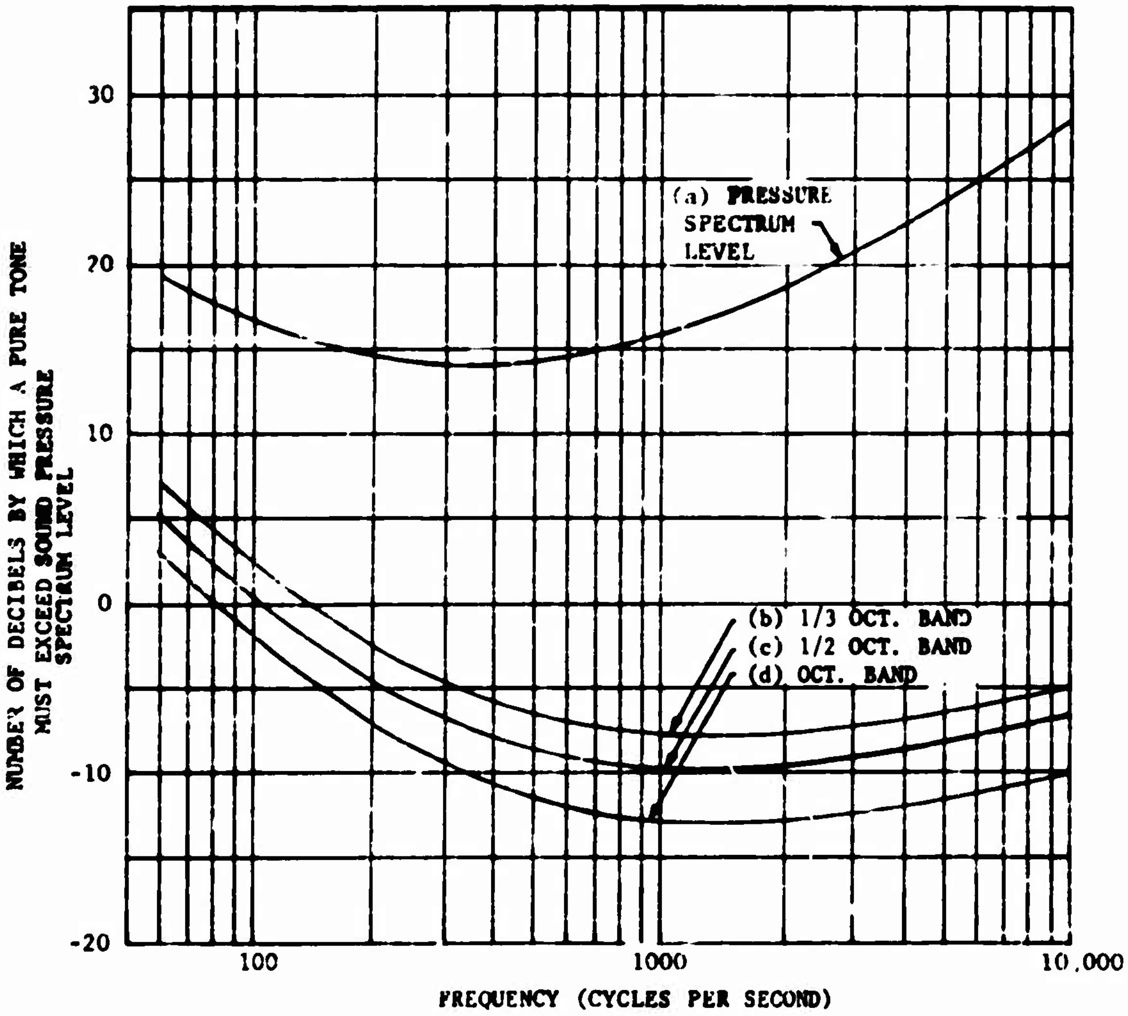


FIG. 4-20 DIFFERENTIAL SOUND PRESSURE FOR A TONE AUDIBILITY ABOVE NOISE[17]

4.1.3.2 Effects on Structures

Intense noise may damage structures or cause equipment to malfunction. If a structure is composed of panels mechanically coupled in some manner the mean squared panel velocity ($\bar{v}^2$) for a given sound pressure spectrum S(f), f = frequency, is given by

$$\bar{v}^2 = \frac{S(f)}{4\pi^2\eta + m^2} T^2 \qquad (4\text{-}17)$$

where η = ratio of damping to critical damping (varies from .01 to .1 for most materials)

m = mass of panel

T = transmissibility (T=1 for maximum)

The rms strain ϵ_{rms} resulting is

$$\epsilon_{rms} = \frac{v_{rms}}{C_L}$$

where C_L = speed of flexural waves in the material. The resultant damage is in the form of fatigue cracks. Damage of this type may be expected to result when the sound pressure level is above 150 db. Damage criteria for conventional buildings as a function of peak displacement are given in Fig. 4-21. Malfunctioning of electronic equipment may also be expected above 130 db.

The transmission loss (TL) resulting from the passage of sound at random incidence through a structure, e.g. a single wall, as a function of frequency is shown in Fig. 4-22. This treatment assumes that the mass of the wall, is the only contributing factor in producing the observed transmission loss. Corrections due to absorption effects from openings around doors and windows are shown in Fig. 4-23. Average values of TL for various materials are shown in Fig. 4-24.

Even though the sound may be attenuated by its transmission through a structure, the intensity may increase inside the structure due to reverberation. Thus the full benefit of the transmission loss

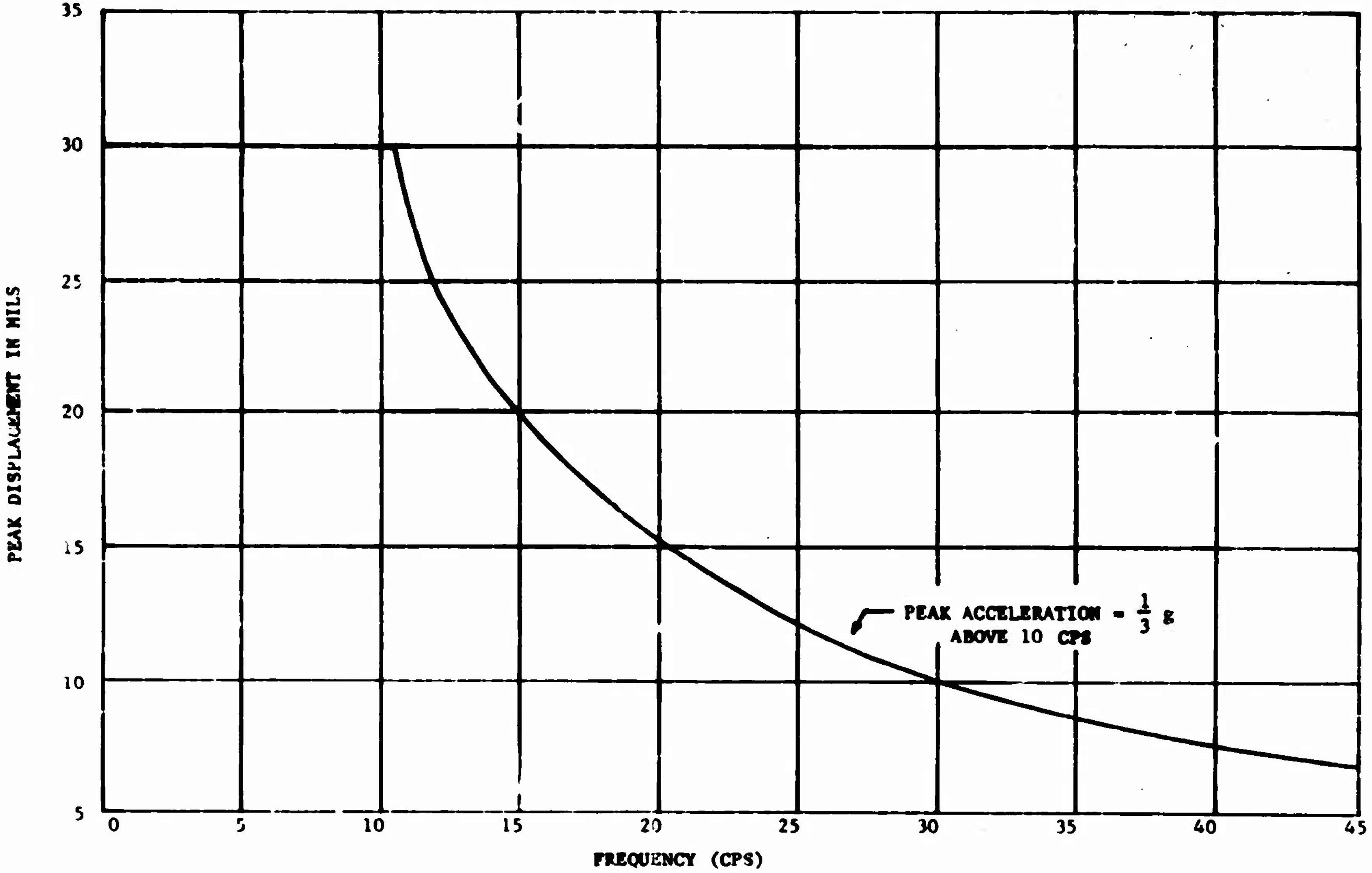


FIG. 4-21 DAMAGE CRITERION FOR CONVENTIONAL BUILDING STRUCTURES[11]

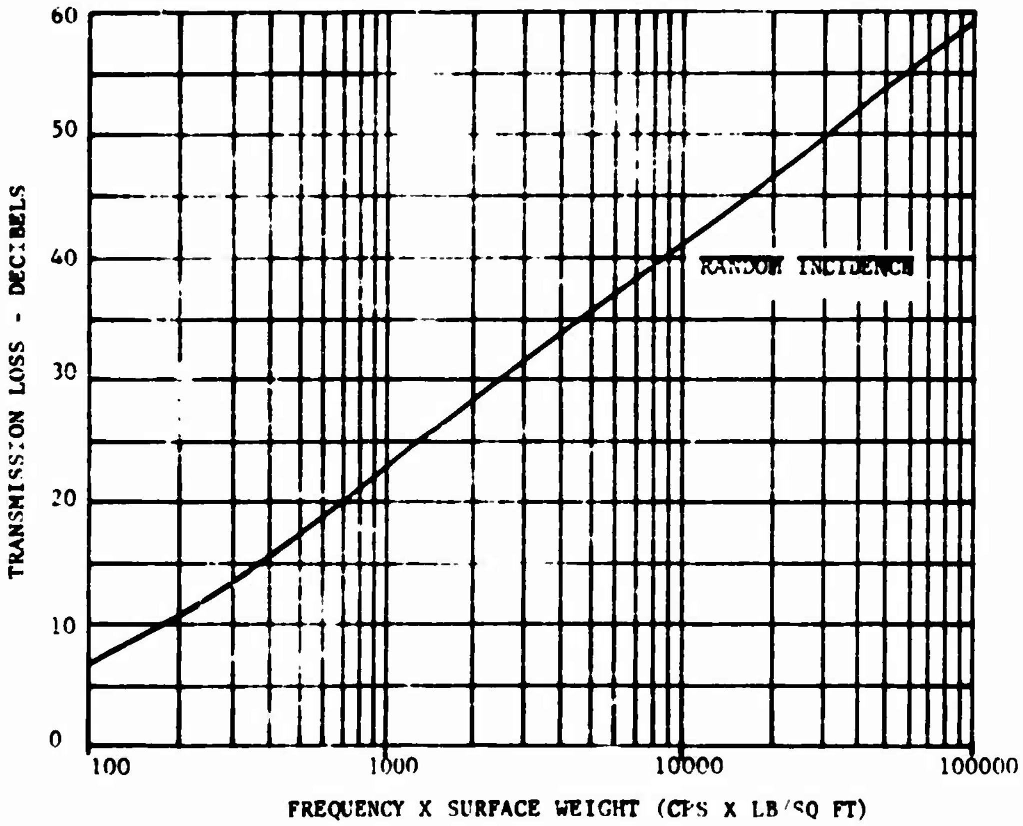


FIG. 4-22 MASS LAW CURVE[18]

FIG. 4-23 AVERAGE TRANSMISSION LOSS FOR COMPOSITE BARRIERS [18]

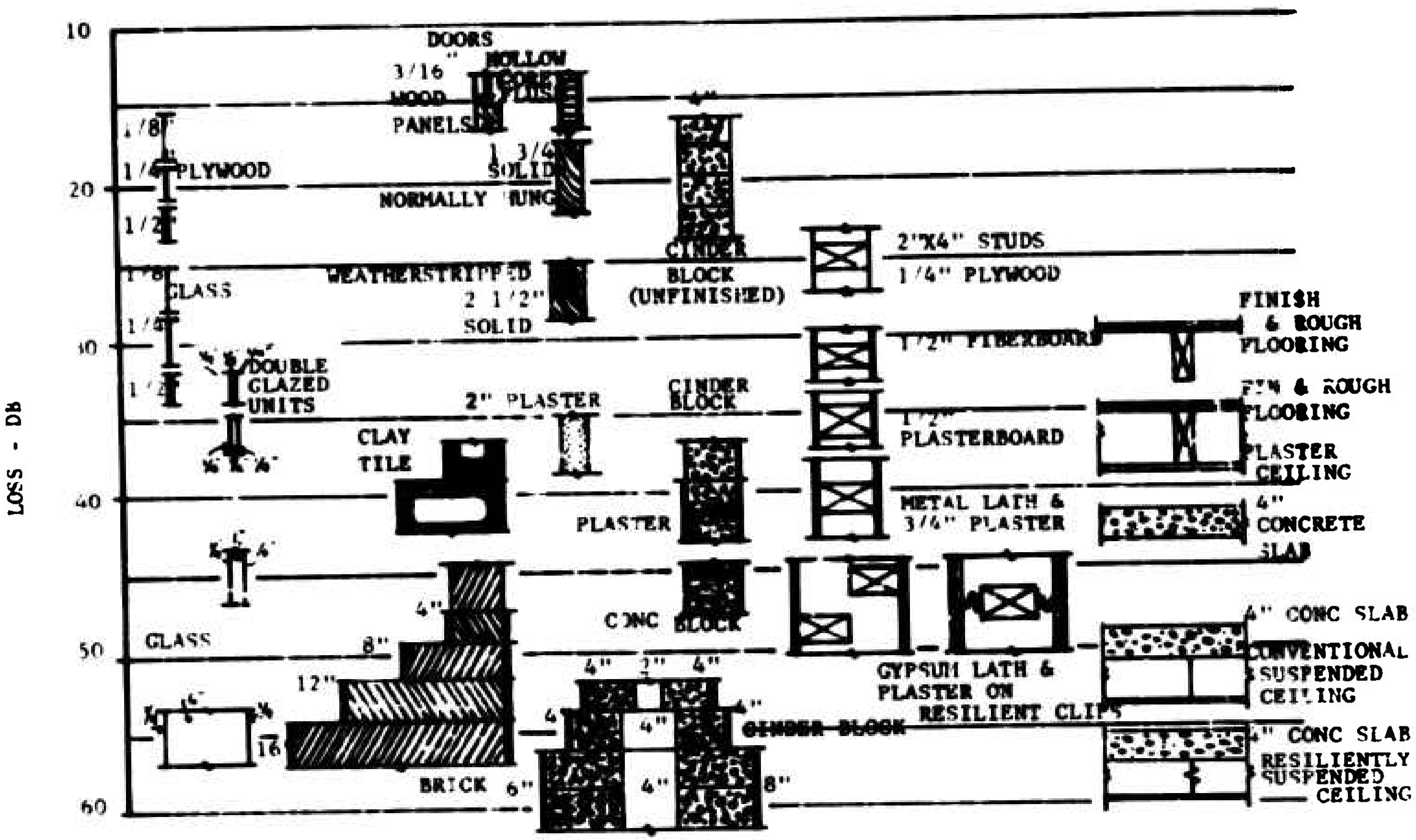


FIG. 4-24 AVERAGE TRANSMISSION LOSS FOR VARIOUS STRUCTURES[18]

is not obtained. The total difference between the noise intensity inside and outside the structure in the above case is called noise reduction (NR) and is defined, in decibels, as

$$NR = TL - 10 \log_{10} (1/4 + \frac{S_w}{R}) \qquad (4\text{-}18)$$

where

S_w = area of transmitting wall

$R = \frac{S\bar{\alpha}}{1-\bar{\alpha}}$, the room constant

$\bar{\alpha}$ = average sound absorption coefficient of the room surface

A nomogram of the above expression is given in Fig. 4-25. The use of this nomogram is limited in that the distances from the transmitting wall of the receiving enclosure to the point of observation must be greater than one wall width.

4.1.3.3 Community Reaction

Rocket noise generated during the launch of a missile may interfere with the performance of personnel at locations other than near the launch site. Criterion curves for determining maximum permissible sound pressure levels in each of the eight octave bands in accordance with the NCA (noise criterion) numbers are plotted in Fig. 4-26. These curves define the envelope (of the sound pressure levels in octaves) to which the rocket noise source should be attenuated for a desired communication environment.

Using the information from sections 4.1.1 and 4.1.2, the noise spectrum from a particular missile launch can be estimated in a particular area. For simplification, the noise spectrum is reduced to a single number called the equivalent SPL in the 300/600 cps band by use of Fig. 4-27. The duration of the exposure combined with the equivalent SPL in the 300/600 cps band gives the estimated noise exposure (ENE) at a given location. The correction in db to be added to one launch ENE (from Fig. 4-27) as a function of N (the number of launches per month, or the number of seconds of static firings per month) is simply $10 \log_{10} N$. If several different missiles are launched, compute the ENE for each and add logarithmically. Acceptable ENE for off-base and on-base housing as a function of the time of day of the launches is given in Fig. 4-28.

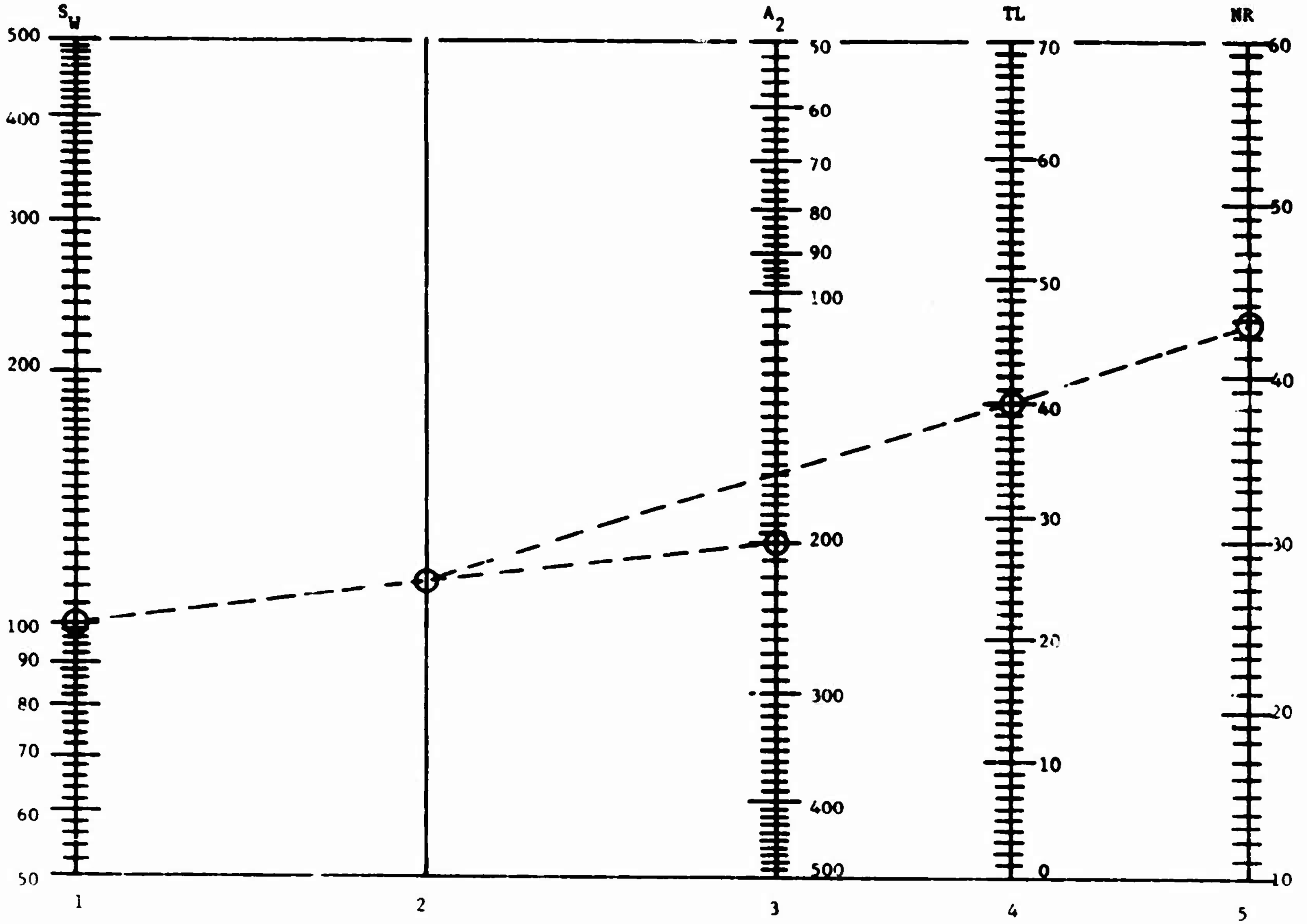


FIG. 4-25 NOMOGRAM FOR DETERMINING NOISE REDUCTION[18]

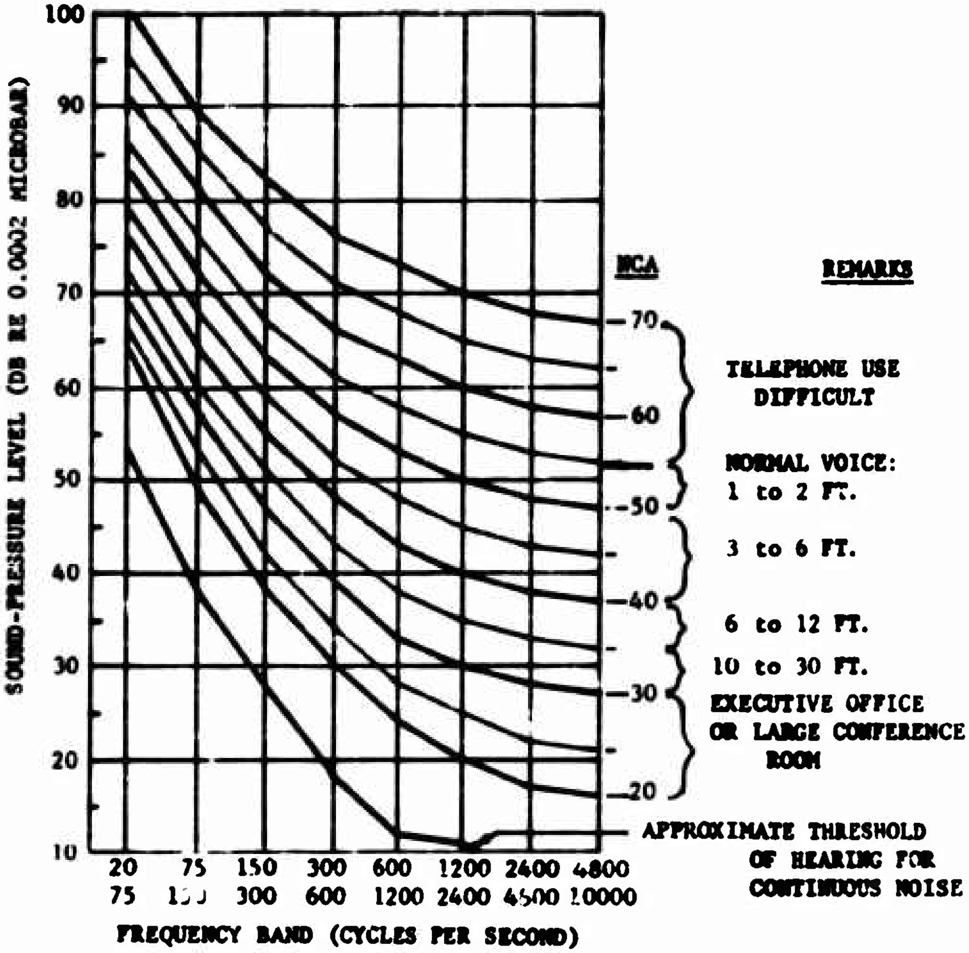


FIG. 4-26 NOISE CRITERION CURVES

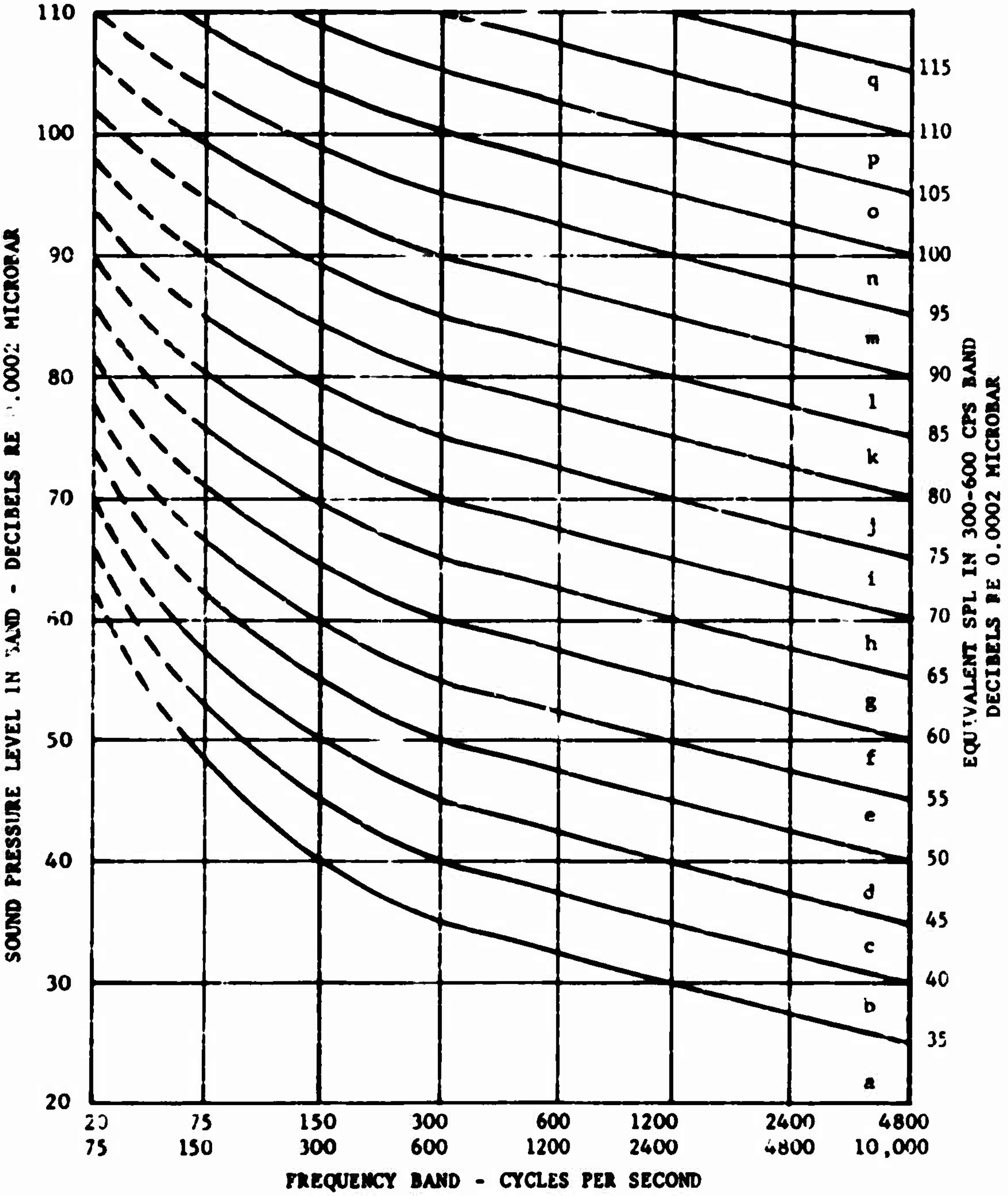


FIG. 4-27 BAND CONVERSION CHART [19]

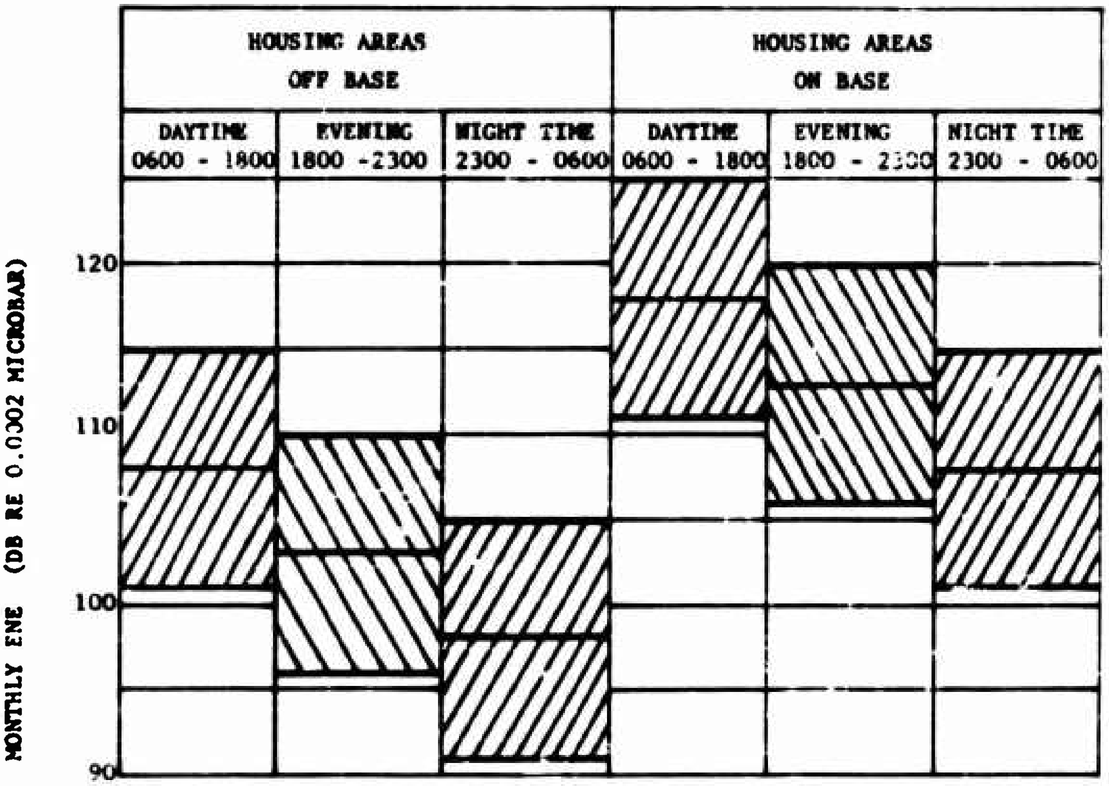


FIG. 4-28 MONTHLY ENE CRITERIA FOR HOUSING AREAS[20]

An alternate criteria for predicting the subjective response of a neighboring community is as follows:

1. Plot the incident acoustic spectrum on the curves of Fig. 4-29. The level rank for the total noise is the highest rank in any frequency band.

2. Adjust the rating by the influencing factors of Table 4-II.

3. Find the expected response of the community from the adjusted level rank and Fig. 4-29.

TABLE 4-II

LEVEL RANK CORRECTIONS[21]

INFLUENCING FACTOR	POSSIBLE CONDITIONS	CORRECTION NO.
Spectrum Character	Continuous	0
	Pure-tone components	+1
Peak Factor	Continuous	0
	Impulsive	+1
Repetitive character (20- to 30-sec exposures assumed)	One exposure per min (or continuous)	0
	10-60 exposures per hr	-1
	1-10 exposures per hr	-2
	4-20 exposures per day	-3
	1-4 exposures per day	-4
	1 exposure per day	-5
Background Noise	Very quiet suburban	+1
	Suburban	0
	Residential urban	-1
	Urban near some industry	-2
	Area of heavy industry	-3
Time of day	Daytime only	-1
	Night time	0
Adjustment to Exposure	No previous exposure	0
	Considerable previous exposure	-1
	Extreme conditions of exposure	-2

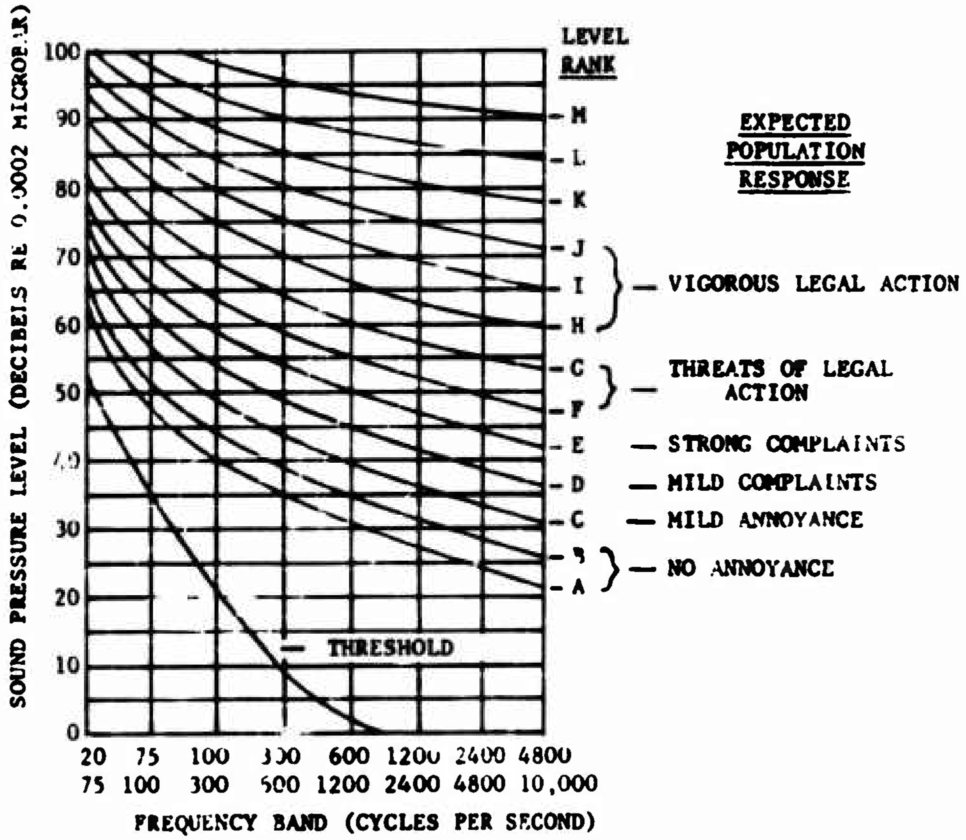


FIG. 4-29 RELATION BETWEEN FREQUENCY SPECTRUM AND LEVEL RANK[21]

4.2 EXPLOSION HAZARDS

Rocket propellants, liquid or solid, are capable of releasing large quantities of energy; the manner of release depends upon the physical circumstances under which the reaction takes place. The desired mode of release is to perform useful work in propelling a payload on some predetermined mission; however, there also exists a probability of malfunction or accident which would cause a sudden release of energy. The energy release may occur as a detonation or deflagration.

4.2.1 Propellant Explosions

The violence of a liquid bipropellant explosion depends upon the manner and the amount of oxidizer and fuel which is mixed. Liquid propellant systems which are hypergolic present little chance of explosion. Although they will burn violently when mixed, only a small amount of oxidizer and fuel would mix during the short ignition delay. This mixture would deflagrate and the rest would be dispersed by the turbulence created. Table 4-III lists hypergolic combinations.

Non-hypergolic propellant systems may react with explosive violence. Actual test data are not available to reliably estimate the hazards. A common viewpoint is to consider the propellant equivalent in explosive violence to a lesser amount of trinitrotoluene (TNT). Liquid monopropellants and solid propellants, being intimately mixed, might detonate and cause an explosive shock wave much like TNT.

The destructive combustion (thermal explosion or detonation) characteristics of a liquid oxidizer and a liquid fuel will depend primarily on two factors: (1) the total (potential) energy available per unit weight (or volume) from the reaction of the mixture, and (2) the rate this energy can be liberated.

The calculation of the energy available from the reaction is relatively simple if the composition is known. Potentially these energies can be very large. For an oxygen balanced or oxygen positive composition, the heat of complete combustion represents the heat of explosion and varies from 2000 - 3000 cal/gm of mixture. By comparison, a typical detonating high explosive liberates about 1000 cal/gm. The energy of reaction decreases rapidly as the quantities of oxidizer and fuel deviate from the stoichiometric point. This mixture for liquid oxygen and hydrocarbon corresponds to about 23% hydrocarbon by weight. Decreasing the hydrocarbon content to 1% decreases the energy release from about 2300 cal/gm to 100 cal/gm. The energy release rate would have to be very rapid to allow propagative detonation with so low a heat release. Sufficiently slow energy release would result in little or no damage from shock waves.

TABLE 4-III

HYPERGOLIC COMBINATIONS[22]

OXIDIZER	FUEL
Liquid Fluorine	Ammonia Hydrazine Hydrogen Methyl Alcohol
90% Hydrogen Peroxide	UDMH Hydrazine
Nitrogen Tetroxide	Aniline Hydrazine Furfuryl Alcohol
Red Fuming Nitric Acid	Diethylenetriamine Hydrazine
White Fuming Nitric Acid	Aniline Furfuryl Alcohol Hydrazine
Chlorine Trifluoride	Ammonia Hydrazine Methyl Alcohol

4.2.1.1 Detonation and Deflagration

During a detonation the chemical reactions proceed in a very rapid manner and maintain a close proximity to the initiating disturbance, while during deflagration, the reaction is maintained by a thermal degradation at the surface. Temperature and pressure gradients within the reaction front are steeper for a detonation than for a deflagration. However, both can cause serious overpressures; and at sufficient distance the damage effects are similar when equal amounts of energy are released.

In a detonation, the shock front leaves the explosive source at the detonation velocity of several thousand feet per second. The high pressure gases behind this shock front are the major causes of breaking and shattering damage. Both the detonation velocity and the overpressure decrease as the distance from the explosion increases. Figure 4-30 shows this effect.

The solid curve of Fig. 4-31 shows the pressure-time effect at a given point for a detonation. The dotted curve illustrates the pressure-time effect for a violent deflagration. Here the reaction lags the shock wave.

4.2.1.2 TNT Equivalence

Since overpressure-distance data for propellant explosions are not available it is convenient to evaluate the hazard of a system by comparison to a familiar explosive. TNT equivalence is the ratio of the heats of explosion of the propellant to that of TNT. Nuclear blasts are also rated on a scale of kilotons or megatons of TNT. Although the merits of using TNT equivalence for propellant mishaps are dubious, this technique is used for want of something better.

Launch sites and static testing areas are commonly designed on an equivalent TNT basis. However, there is much disagreement as to what constitutes the proper equivalence percentage for various propellant combinations. The problem is complicated further by the uncertainties associated with the mixing of liquids. Examples of the explosive equivalents which have been used are given in Table 4-IV. The most recently known determination was that of the Saturn launch-site planning committee which arrived at a value of ten percent equivalent weight for the LO_2/RP-1 system[602]. Most of the values used as equivalents appear to be more than adequate. Figures which would

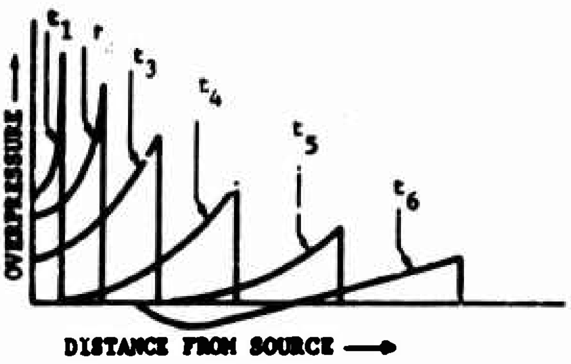


FIG. 4-30 VARIATION OF OVERPRESSURE WITH DISTANCE AT SUCCESSIVE TIMES[23]

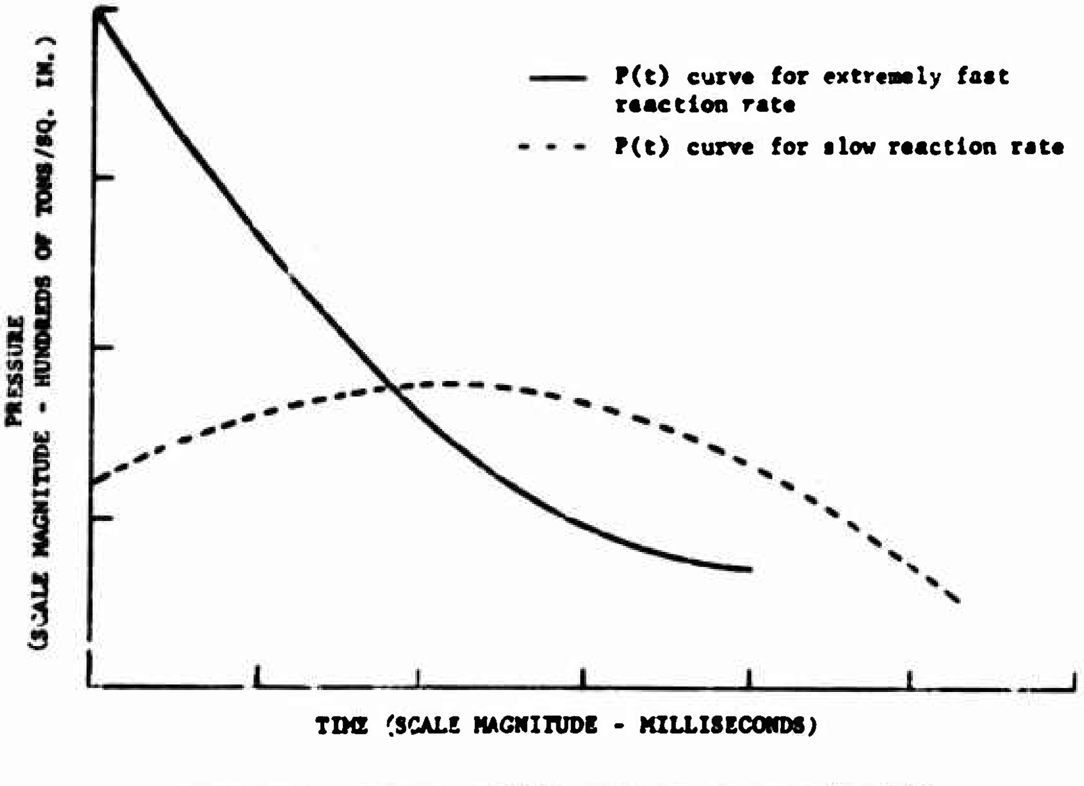


FIG. 4-31 TYPICAL PRESSURE-TIME CURVES FOR EXPLOSIVES HAVING DIFFERENT REACTION RATES[24]

TABLE 4-IV

EXPLOSIVE EQUIVALENTS[25]

Propellant Combination	TNT Equivalence*	User	Remarks
LOX/RP-1	25%	Aerojet General Corp.	For engine testing facilities
LOX/RP-1	10%	Ramo-Wooldridge Corp.	For operational facilities for the Titan missile
LOX/RP-1	60%	Convair	For the Atlas flight missile
LOX/RP-1 and others	100%	White Sands Missile Range	For positioning of observation personnel
LOX/RP-1 and others	30%	Edwards Air Force Base	For static testing of flight missiles
LOX/RP-1	55%	Cape Canaveral	For spacing launch pads. The resulting safety distance is then increased by 50%

* Expressed as a percentage of the total propellant weight

permit the use of the least possible distances are economically desirable. Additional information for each propellant system is now required. First, the type of reaction occurring between a particular oxidizer and fuel must be defined. Under conditions of complete mixing and stoichiometric quantities it is suspected that all systems would explode. The variable effect of mixing and non-stoichiometric amounts of propellant requires investigation.

Space Technology Laboratories, after examination of experimental data from controlled LO_2/RP-1 spill tests, discontinued attempts to determine the equivalent weight of TNT of liquid propellants because of too many unknowns. Safety distances are now specified based on tolerable overpressures which in turn are related to propellant weight by a fourth root function (see Fig. 5-23).

The results thus obtained agree closely (98% confidence) with experimental data from Atlas explosions experienced at the Atlantic Missile Range.

Spill tests are currently being conducted at Edwards Air Force Base using Titan II propellants. Rough estimates for the TNT equivalence of the N_2O_4 and N_2H_4-UDMH combination are tentatively thought to be 0.3 percent by weight[26]. These values were obtained by one-tenth and one-sixteenth linear scale Titan spills conducted in both lined and unlined "test silos".

4.2.2 Structural Damage

The amount of damage which can be inflicted upon an object depends upon the magnitude and duration of the positive and negative pressures, and the structural integrity of the object. There are two classes of forces on structures; diffraction and drag. Closed structures are generally subject to diffraction loading; however, structural members usually require analysis for both diffraction and drag loading.

Additional hazards are created by flying fragments. The degree of the resulting hazard depends upon the size, shape, density, energy, and angle of attack of the fragment on a target structure.

4.2.2.1 Overpressure

In order to assess the probable damage as a function of distance for a surface explosion, it is necessary to establish a relationship between an air burst and a surface burst. Glasstone[23] has indicated that for a fixed overpressure the distance as a function of TNT weight varies as the cube root of the charge (in contrast with the fourth root relationship established by STL for liquid propellants). Assuming the earth to be a rigid reflector, the surface explosion has twice the effect of an air burst. This assumption leads to the conclusion that for a fixed energy release the distance variation between equal overpressure values for the surface and air bursts will vary by a factor of the cube root of two (1.26).

Overpressure damage can be estimated from material available on air blast damage. Figure 4-32 indicates extrapolated values for constant overpressures as a function of distance and yield prepared from air blast information. Figure 4-33 represents a nomogram for determining the damage expected for air bursts varying from one kiloton to twenty megatons of TNT. It was determined in a preliminary report[3] that distances and yields corresponding to a fixed overpressure obtained from Fig. 4-32 yield equal damage estimates from Fig. 4-33.

Figure 4-34 shows the separation distances required for buildings with glass windows, filled storage tanks, and blast resistant reinforced concrete windowless buildings, which are affected mainly by diffraction forces. The dashed portion represents an extrapolation of the available information.

Large hills affect air blast overpressures by increasing them in some areas and decreasing them in others. The increase or decrease in peak overpressure at the surface is dependent upon the change in slope of the land. For very steep slopes, there may be increases up to twice the normal value due to reflection. Some reduction in overpressure might be expected on the reverse slope if it is also quite steep. These deviations from normal overpressure are very short in duration compared to the length of the positive phase. For this reason the effects of terrain are not expected to be significant.

Prominent features of the landscape may shield structures from thermal radiation, missiles and drag forces, but little reduction in overpressure can be expected.

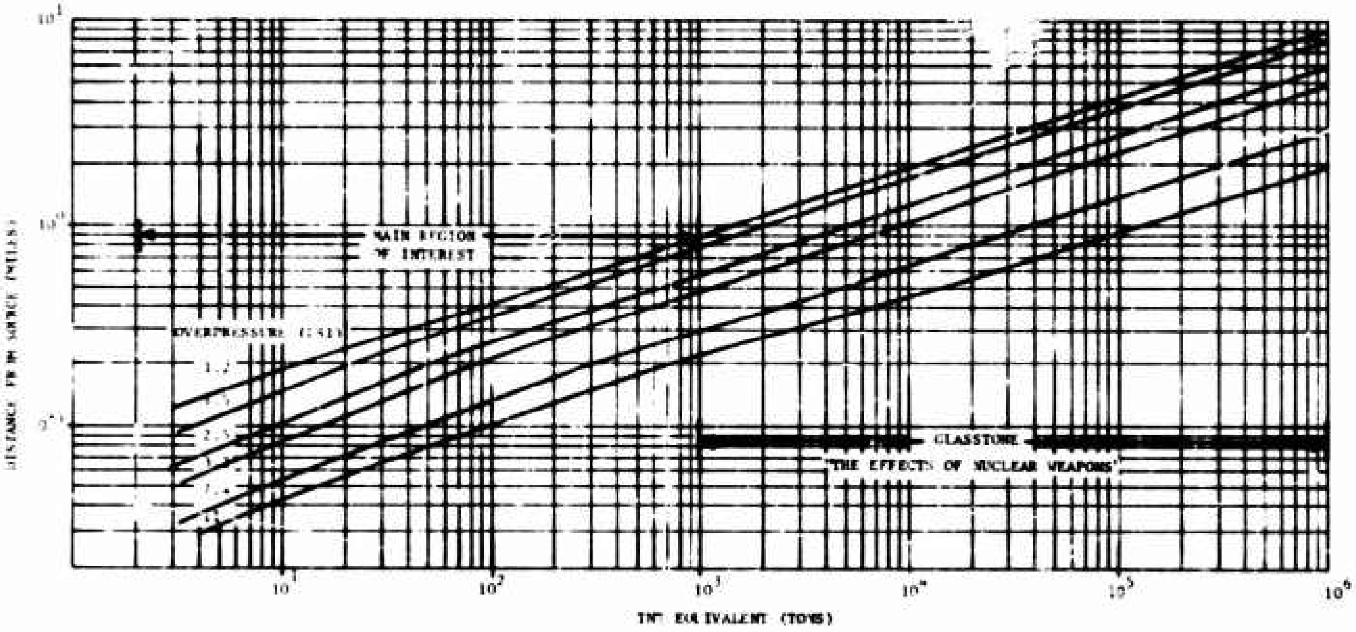


FIG. 4-12 DISTANCE-OVERPRESSURE RELATIONSHIPS FOR TNT EXPLOSIONS

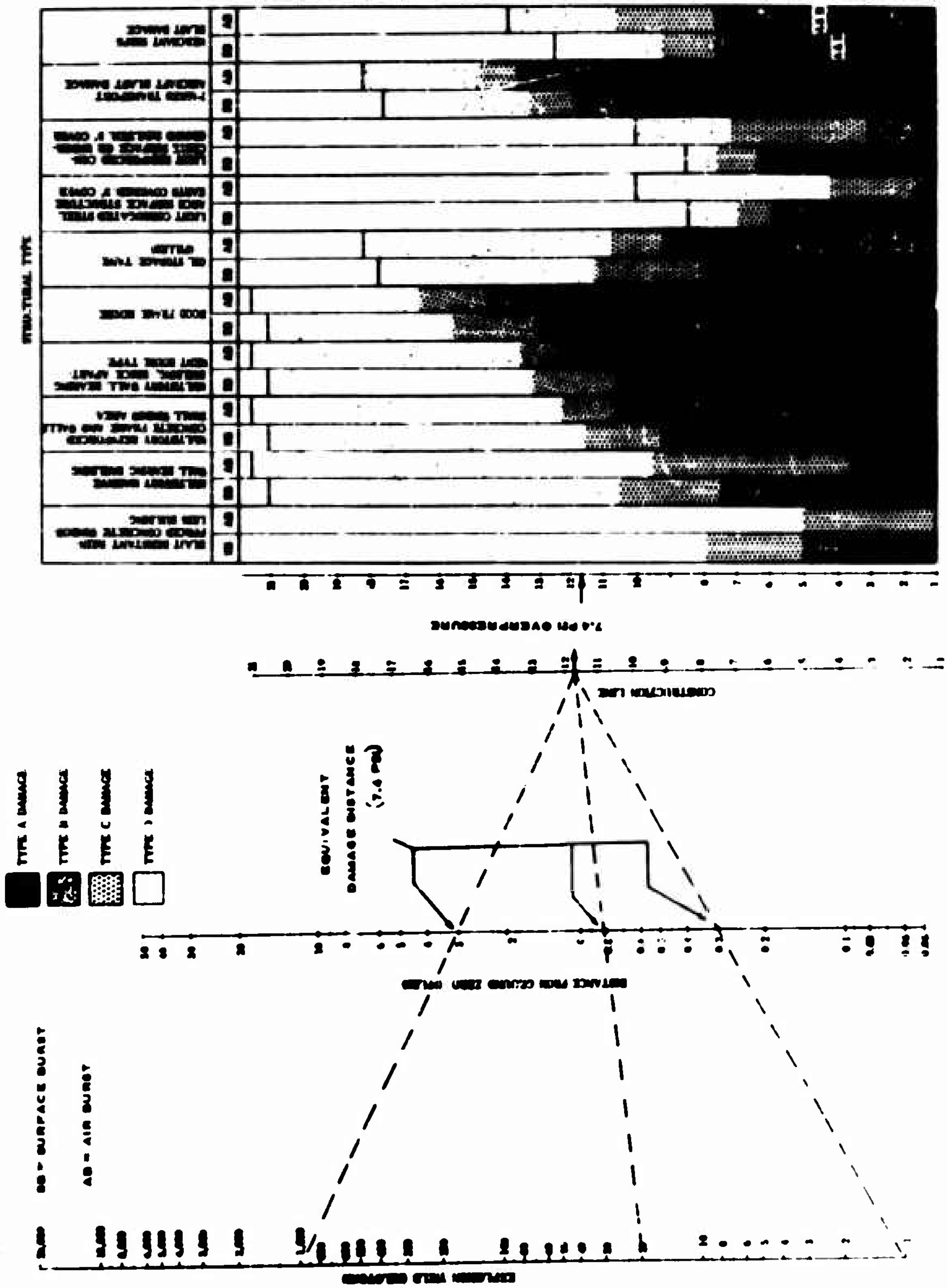


FIG. 4-33 DAMAGE-DISTANCE RELATIONSHIPS FOR DIFFRACTION-TYPE STRUCTURE[23]

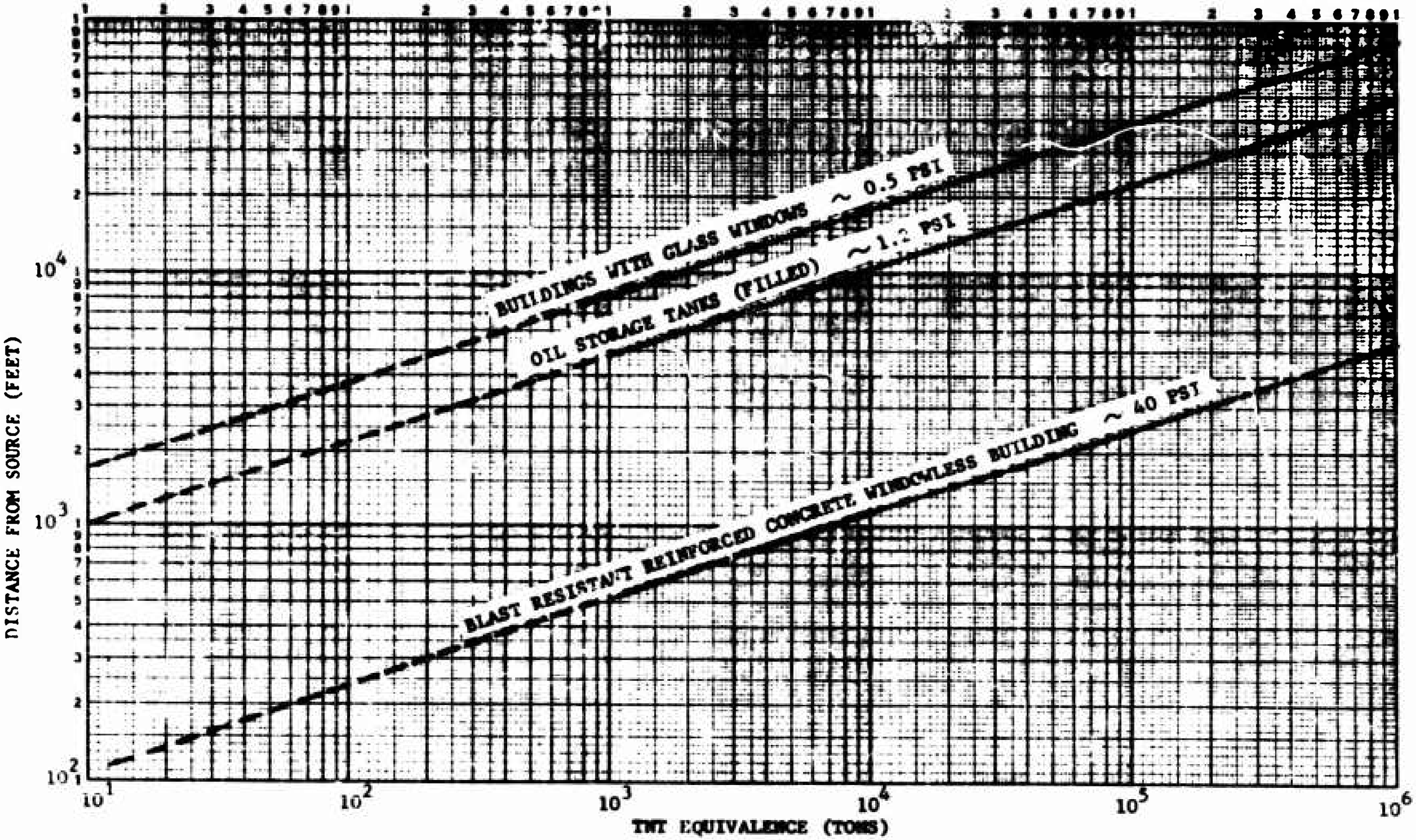


FIG. 4-34 SEPARATION DISTANCES FOR DIFFRACTION TYPE STRUCTURES

Under suitable conditions, window breakage, light structural damage and noise may be experienced at distances from an explosion at which they normally would not be expected. These phenomena are caused by the bending of the blast waves by the atmosphere. This may occur in either of two ways. The first is due to atmospheric conditions of temperature and wind conditions within the bottom six miles of the atmosphere. The second arises from conditions at heights of 25 miles or more above ground.

The peak overpressure for a surface burst depends on the atmospheric pressure. With increasing altitude overpressure at a given distance will generally decrease. The arrival time of the shock front and the duration of the positive phase may be expected to increase.

4.2.2.2 Fragmentation

Explosive fragments of missiles or launch pad structures can create a hazard at greater distances than the resultant overpressure. However, damage from flying debris has a probability of hit which depends upon target densities as a function of distance from the source, and on the fragment trajectories.

The randomness of range for fragments is illustrated in a preliminary report[3] (see Table 5.2-2 therein.) The only practical means of protecting storage tanks seems to be by separation, by erecting barriers, or by utilizing natural barriers. The maximum range of fragments as a function of weight-to-drag ratio and initial velocity are presented here in Fig. 4-35 for certain simple cases.

4.2.3 Table of Distances

The shock wave resulting from an explosion shatters and crushes obstructions as it speeds outward from the source. Its intensity decreases as it travels until it is no longer capable of causing damages. By analyzing the data available from accidental explosions, tables of distances have been established to predict distance at which damage may be expected.

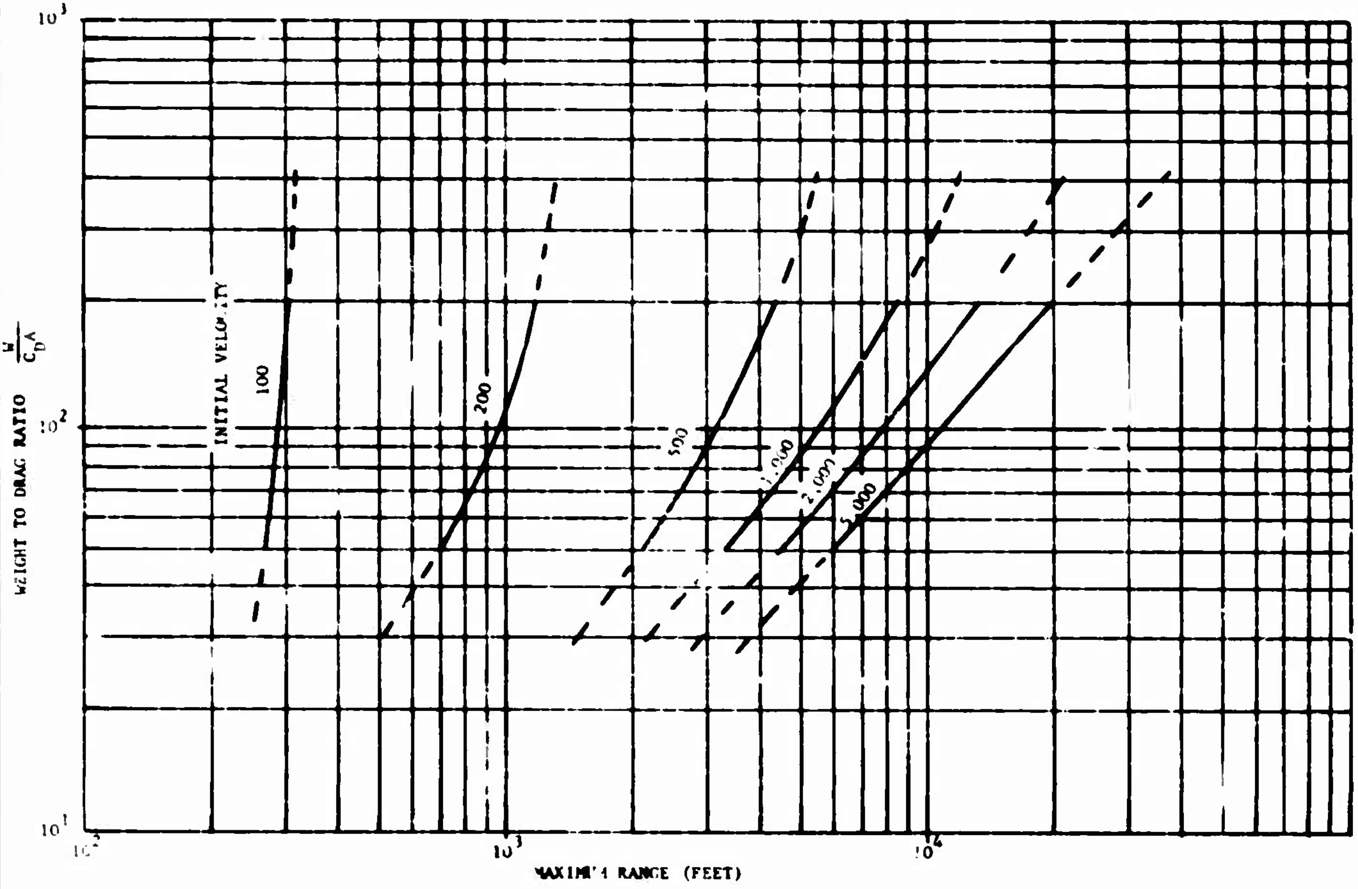


FIG. 4-35 MAXIMUM RANGE OF FRAGMENTS

The "American Table of Distances" was established in 1910 and has served as a basis for state laws and for armed services regulations. This table is based upon and intended primarily for high explosives, and is limited to a maximum weight of explosive of 500,000 pounds (for which the recommended distance is 5,410 feet). The "American Table" specifies greater distances than necessary for small quantities of explosives, but smaller than needed for large quantities[27]. It is thus preferable to look to the recent military regulations for data governing rocket propellants.

Two classes of explosives (Class 9 and Class 10) as defined in the Ordnance Safety Manual[28] are germane. Typical Class 9 items include dynamite, nitroglycerin, solid propellants, and pyrotechnic materials. Included in Class 10 are igniters, JATO units, and high explosive rocket heads. However, both classes, represented by a common quantity distance table, are now employed to govern liquid propellant storage.

The common quantity-distance relationship for Classes 9 and 10 are represented by curves A and B in Fig. 4-36. Curve A gives the separation to inhabited buildings for two conditions; the top fork of the curve applies when no barricades are present, while the bottom curve allows reduced distances when barricades are present. Applicable distances to public railroads and public highways without a barricade would be slightly larger than the distance to inhabited buildings with a barricade.

Curve B defines the intraline separation between storage facilities for unbarricaded conditions. The intraline distance is the minimum required between buildings handling explosives in a single operating or manufacturing line. It is based on the use of a fixed average peak pressure for determining limiting distances for structural damage. Thus, on the basis of this constant peak pressure (average of 2.6 psi), curve B can be extrapolated to larger quantities as shown by the broken-line extension.

Curve B may also be applied in the situation where a barricade is available, simply by reducing the distances by one-half. Barricades are primarily effective in reducing the direct blast damage effects of an explosion. They should not be used to decrease distances when fire or fragmentation hazards are dominent.

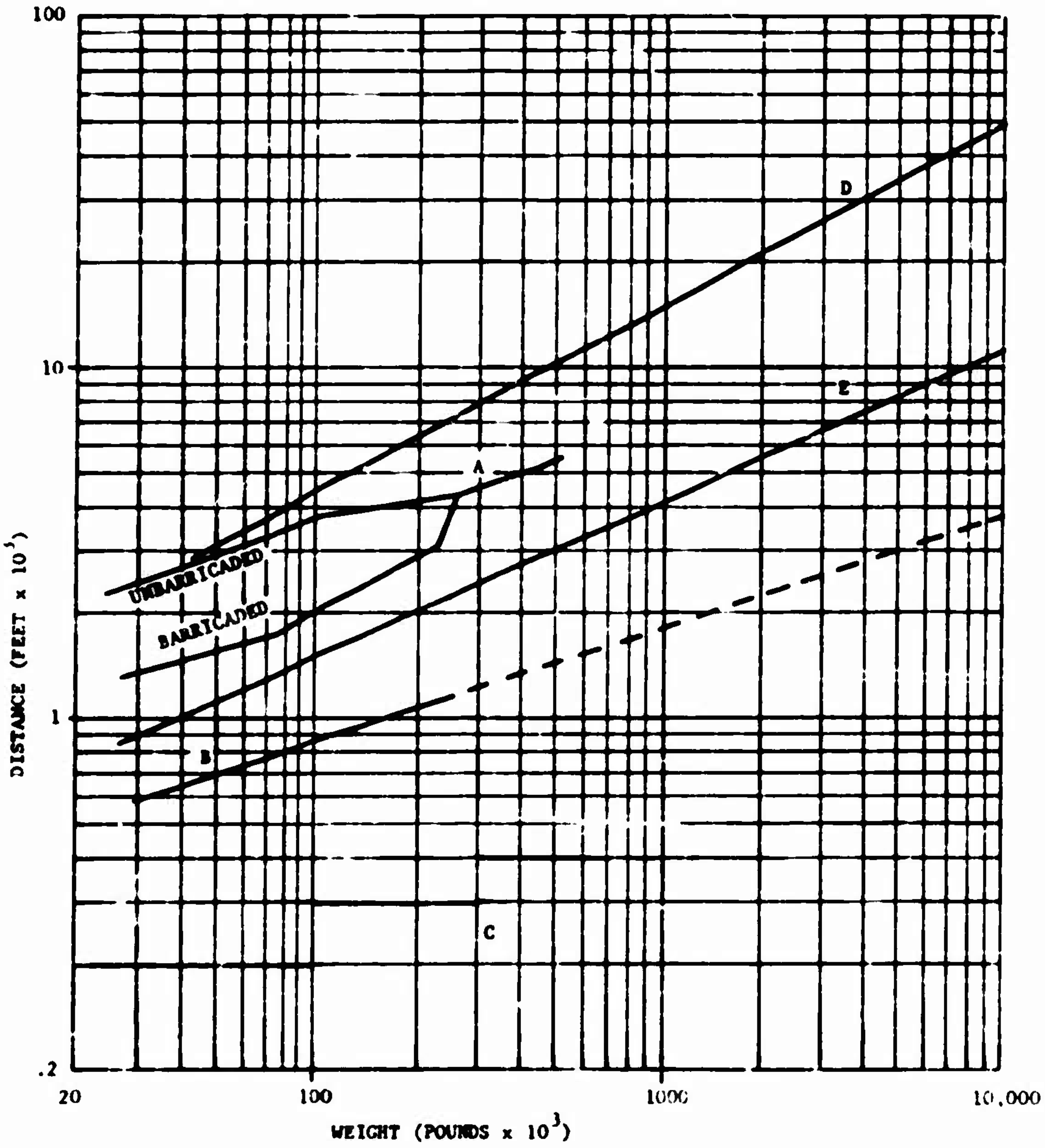


FIG. 4-36 QUANTITY-DISTANCE CURVES

Liquid propellants which are grouped together for the purpose of quantity-distance specification include nitric acid, kerosene, aniline, ethyl alcohol, liquid oxygen, anhydrous ammonia, hydrazine and UDMH. The oxidizers and fuels of this class should be separated in accordance with curve C (consisting of three horizontal segments) of Fig. 4-36 as specified by Ref. 28. These distances may be reduced by one-half if the products are stored in underground tanks. When these substances must necessarily be brought together, their combined weight should be used and the distance equal to one-half that specified for curves A and B will be applicable.

Another grouping of liquid propellants include hydrogen peroxide, diborane, pentaborane, aluminum borohydride, liquid hydrogen, nitromethane and tetranitromethane. The applicable quantity-distance requirements for these materials are also given by curves A and B.

No quantity-distance requirements have yet been determined for liquid nitrogen tetroxide, liquid fluorine and metallic lithium because of such dependent variables as terrain, wind and weather condition. The arbitrary limitation suggested by the Ordnance Safety Manual for these materials is 250,000 pounds in any one location.

Curves D and E were determined[27] from an analysis of a large number of explosion disasters. The former curve represents the greatest distances at which "more serious damage" has been reported from high explosive detonations, while curve E shows the distances up to which "more serious damage" may be expected. Curve D gives possible distances, while the latter curve gives probable distances. "More serious damage" encompasses the range from a structure badly needing repairs to complete demolition.

Manufacturers of liquid rocket propellants also provide tables of recommended distances for their products. However, these relate to storage of materials and not to possible explosions of a fueled missile.

Tables have been derived[29] for liquid hydrogen based on radiation and flame size data. Table 4-V assumes the prevention of formation of shock sensitive mixtures of hydrogen and therefore does not provide protection against detonation.

TABLE 4-V

QUANTITY-DISTANCE TABLES FOR LIQUID HYDROGEN

Distance to inhabited buildings			Distance between storage tanks		
Pounds Over	Pounds not over	Distance (feet)	Pounds Over	Pounds not over	Distance (feet)
0	200	100	0	2,000	50
200	1,000	150	2,000	10,000	100
1,000	5,000	200	10,000	20,000	150
5,000	20,000	250	20,000	40,000	200
20,000	40,000	300	40,000	60,000	250
40,000	100,000	350	60,000	100,000	300

4.3 TOXICITY HAZARDS

Exposure of personnel to toxic fumes is generally associated with propellant spills and leaks, with disposal of waste and residue, and with unforeseen disasters such as tank rupture on the launch pad or missile destruction shortly after launching. For continuous low-level air contamination there are voluntary industry standards known as Threshold Limit Values (or Maximum Allowable Concentrations) which have gained wide acceptance.

Under emergency conditions at the time of a disaster, personnel may inadvertently become exposed to an extent where compensatory body functions begin (such as increased cardiac output or increased respiration). Unfortunately, these critical concentration levels cannot be specified since there are no accepted standards relating to allowable short term exposure.

4.3.1 Maximum Allowable Concentrations

MAC's are the maximum average atmospheric concentration of contaminant to which workers may be exposed for repetitive eight-hour working days without injury to health (Ref. 30 and 31). These values are based on the best available information from industrial experience and experimental studies. Specific numerical values have been adopted for most volatile industrial chemicals, including those materials used as rocket propellants. The values are not fixed but are reviewed annually by a Committee on Threshold Limits of the American Conference of Government Industrial Hygienists. This body is a voluntary association whose membership is open to and includes a large number of professionals and technical administrators in the fields of industrial medicine and public health.

Maximum Allowable Concentrations are guides to good practice and are not regarded as fine lines between safe and dangerous concentrations. Numerical values for rocket propellants are listed in Table 4-VI. These are weighted average concentrations allowable for an eight-hour working shift. In normal industrial practice brief exposures to higher concentrations are anticipated; however, the amount by which the MAC may be exceeded, and the corresponding exposure time depends on the specific propellant.

4.3.1.1 Types of Exposures

At a missile launch site, possible toxic exposures can be grouped into four categories. First, there are those exposures which are sudden, but are expected from time to time and for which protective measures are instantly used. Second, there are those exposures with no forewarning, where a person will evacuate to a fresh air location as soon as he is able, within a matter of minutes. Third are those exposures with some prior warning, where a decision may be made to suffer the exposure (for instance, to meet a schedule) or to evacuate. Fourth are those exposures which may be continuous low-level lingering concentrations, due either to continuous releases of the material or to an air-pollution situation. The first two of these relate to accidental events, while the third and fourth classes are presumed to be somewhat under the regulation and control of the launch site operator.

These four categories of exposure can be distinguished by periods of time: (1) one-minute, (2) fifteen minute, (3) four hour, and (4) continuous exposure. For the last category, continuous exposure, the launch site operator is expected to follow practices which will not expose personnel beyond the MAC values listed in the first column of Table 4-VI.

TABLE 4-VI

VAPOR CONCENTRATIONS USED FOR SITING COMPUTATIONS

(PARTS PER MILLION)

	Chronic Exposure	Acute Exposure			
Propellant	**8 Hr. Industrial Threshold MAC**	24 Hours	4 Hours	15 Minutes	1 Minute
Amine Fuels	5	5	20	50	200
Ammonia	100	100	500	1,000	10,000
Alkyl Boranes	0.01	0.01	1	5	10
Chlorine Trifluoride	0.1	0.1	5	30	250
Ethylene Oxide	50	50	100	500	3,000
Fluorine	0.1	0.1	15	30	250
Hydrazine	1	1	10	100	500
Hydrocarbon Fuels	500	500	500	5,000	20,000
Hydrogen Peroxide	1	1	50	200	3,000
Nitric Acid	5	5	10	40	500
Nitrogen Tetroxide	5	5	10	40	300
Perchloryl Fluoride	3	3	10	25	100
Propyl Nitrate	25	25	50	250	3,000
Tetrafluorohydrazine	0.1	0.1	5	15	300
UDMH	0.5	0.5	5	15	200

The last four columns have no official status and do not represent formal opinion of the Ford Motor Co., the U. S. Navy, or any agency concerned with health and safety practices.

For the short-term exposures, no guide line values have been proposed as yet by industrial health specialists. The importance of these values to missile launch site planning was pointed out in a preliminary report[4]. Lacking any definitive values, basic information in the literature of toxicology was surveyed, from which some arbitrary numbers were developed to serve as a basis for site survey computations. These are listed in Table 4-VI. However, these numerical values should be used cautiously--they have no official status and represent no formal opinion either by the Ford Motor Company, the U. S. Navy or any agency concerned with health and safety practices.

An important aspect of the toxic hazard presented by rocket propellants is their ready detection by smell or nasal irritation. The alkyl boranes, for example, have a mild odor but are highly toxic. Propellants which are both highly toxic and highly irritating include chlorine trifluoride, fluoride, hydrazine, nitric acid, nitrogen tetroxide, perchloryl fluoride, and tetrafluorohydrazine. Those which are irritating, but only mildly toxic include amine fuels, ammonia, and hydrogen peroxide. Lastly, those which are mildly toxic and non-irritating are ethylene oxide, hydrocarbon fuels, and propyl nitrate.

4.3.1.2 Sources of Exposure

With regard to toxic hazards, missile launch site activities can be divided into three classes: (1) propellant storage and transfer relating to ground support activities, (2) the ready condition when a fueled or partially fueled missile is on the launch pad, and (3) the missile in flight.

These launch activities differ with regard to the alertness of personnel to prospective danger, to the means of coping with a spillage or release and to the readiness of personnel to seek protection.

Recommended practices for the ground support activities of propellant storage and transfer are those practices common to the chemical and petroleum industry. Propellants should be handled in closed systems. Expected wastes and residues should be burned or disposed under controlled conditions. Tanks should be surrounded by dikes, with ample containment. A copious water supply should be on hand with adequate distribution to all parts of the premises. Personnel should wear industrial protective clothing at work.

On the missile launch pad, a condition of latent danger exists from the time the propellant is transferred until the missile is launched. Should tanks rupture or valves open, personnel close to the missile will be exposed to flood quantities. To minimize the consequences of a mishap, the number of personnel at the launch pad should be kept at a minimum. Escape routes for everyone should be planned in advance, including rapid transportation to distances beyond the predicted toxicity hazard area.

Toxic hazards associated with the missile in flight are mainly those of transient concentrations, downwind, following the release of either the exhaust products or the unburned propellant vapors. Exhaust products of most rocket propellants can be tolerated for a short time up to a few hundred parts per million. Products of fluorine or borane combustion, however, must always be quite dilute. Suggested allowable concentrations for fluorine or borane exhausts are those which would be allowed for the unburned fluorine or borane propellant. Ground distances between allowable inhabited sites and the flight path can be estimated from the charts in Section 4.3.3. Allowance should be made for flight in unplanned directions.

4.3.2 Atmospheric Diffusion

The diffusion of toxic materials released during normal operation, accidental spills, and system abortions will play a major role in determining the extent of the toxic hazard. Information considered to be important to the toxicologist for evaluation of the hazard are: peak concentration, duration of exposure, and cumulative exposure. Peak concentration is normally considered to be the most important criterion because of the hesitancy in assuming that the eight hour per day maximum allowable concentration (MAC) should be exceeded even for very short durations. The potential value of the two remaining parameters, to the toxicologist, will become important when more is known concerning the effects of "high", short-duration exposures. The integrated concentration and the duration of exposure are also useful parameters for estimating the peak concentration resulting from a finite point source from the available instantaneous point source data.

4.3.2.1 Sutton's Equation

Sutton's equations and modifications thereof provide the most commonly accepted methods of estimating the downwind concentrations to be expected from a release of toxic material. The particular form to be stated here is the result of incorporating modifications resulting from experimental diffusion programs (see Ref. 4). For an instantaneous point source the equation is

$$\chi = \frac{kQ}{\pi^{3/2} C_x C_y C_z (\bar{u}t)^{\left[3-\frac{1}{2}(n_x+n_y+n_z)\right]}} \exp(-\xi) \qquad (4\text{-}19)$$

where

$$\xi = \left[\frac{(d - \bar{u}t)^2}{C_x^2 (\bar{u}t)^{[2-n_x]}} + \frac{y^2}{C_y^2 (\bar{u}t)^{[2-n_y]}} + \frac{(h-V_g t)^2}{C_z^2 (\bar{u}t)^{[2-n_z]}} + \Lambda t \right]$$

χ = concentration on the ground (PPM)

k = constant (PPM - $\frac{\text{Meters}^3}{\text{lb}}$)

Q = quantity release (lb)

C_x = downwind virtual diffusion coefficient (meters)$^{n_x/2}$

C_y = crosswind virtual diffusion coefficient (meters)$^{n_y/2}$

C_z = vertical virtual diffusion coefficient (meters)$^{n_z/2}$

n_x = downwind stability parameter

n_y = crosswind stability parameter

$\bar{u}$ = average wind velocity (meters/sec)

t = time since release (sec)

d = downwind distance (meters)

y = crosswind distance (meters)

n_z = vertical stability parameter

h = source release altitude (meters)

V_g = fallout velocity (meters/sec)

Λ = scavenging rate (sec^{-1})

The usefulness of the foregoing equation is contingent upon a knowledge of values for the various Sutton parameters as well as the applicability of the point source approximation. Ideally the criteria for parameter evaluations would be known on the basis of experimentally determined terrain effects and a constantly monitored atmosphere at the launch site (see Appendix B and Ref. 4). However, for illustrative purposes values for the diffusion parameters can be assumed which are representative of conditions expected at any location. Three typical conditions are listed in Table 4-VII. The atmospheric condition terminology is shown schematically in Fig. 4-37.

TABLE 4-VII

DIFFUSION PARAMETERS

Atmospheric Condition	n (numeric)	C	$\bar{u}$ (meters/sec)
Moderate Lapse	0.20	0.40	5.15
Average	0.25	0.20	5.15
Moderate Inversion	0.35	0.10	3.1

The values listed in Table 4-VII indicate assumptions of isotropic diffusion ($C_x = C_y = C_z = C$, $n_x = n_y = n_z = n$), no fallout ($V_g = 0$), no rainout ($\Lambda = 0$), and a ground level release ($h = 0$). Justification of these assumptions is based upon the following facts:

a. The magnitude of departure from isotropic conditions is not established.

b. A gas normally exhibits only a slight tendency toward fallout.

c. It will most likely not be raining.

d. A ground level release represents the most pessimistic condition for close distances.

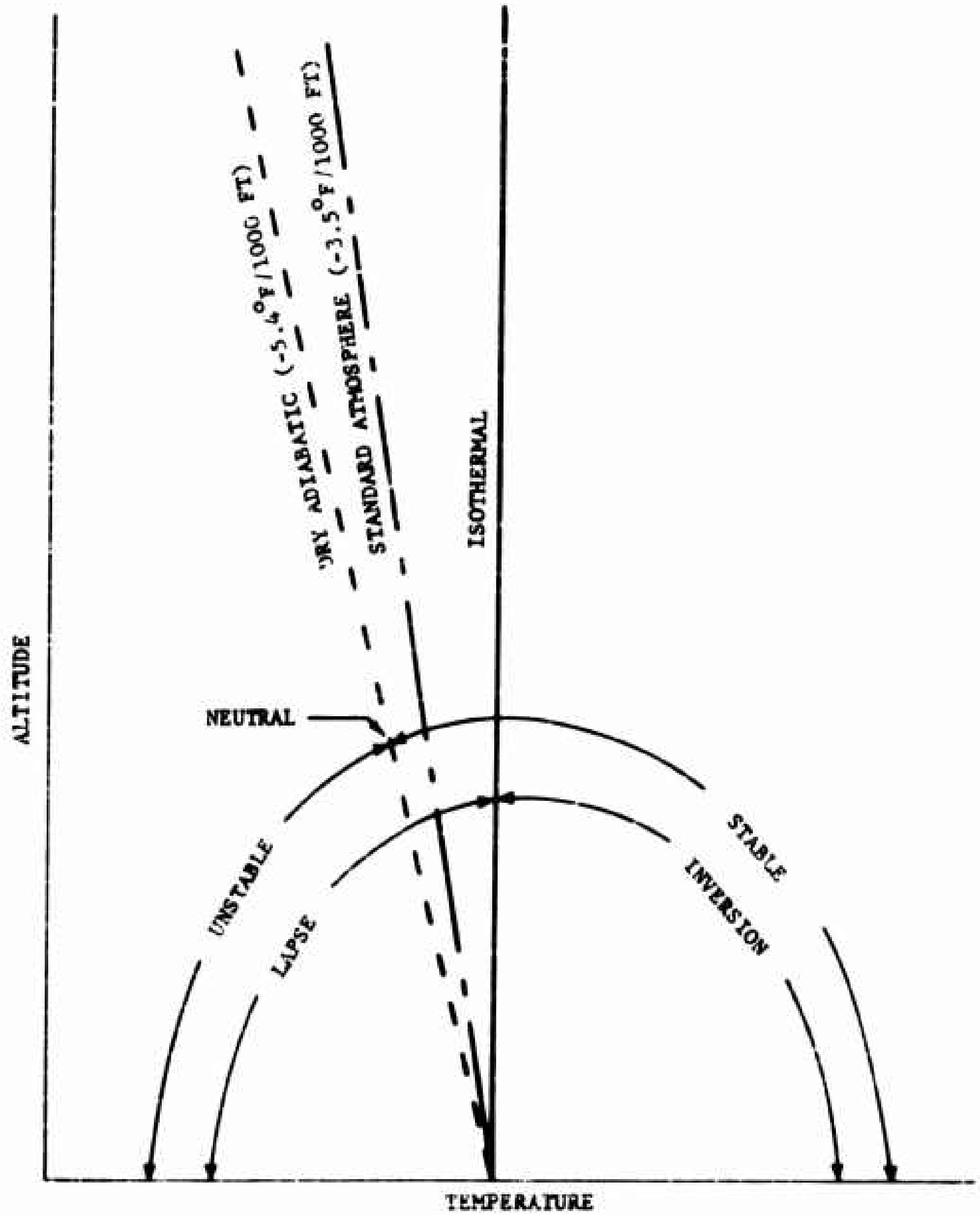


FIG. 4-37 ATMOSPHERIC CONDITIONS (TERMINOLOGY)

4.3.2.2 Machine Program

The usual methods for calculating concentrations by Sutton's equation involve simplifying assumptions. These normally consist of freezing the cloud distribution at a time (t = $\frac{d}{u}$) and not allowing the cloud to diffuse during passage. Simple relationships can thereby be determined for the peak and integrated concentration as a function of distance. However, the actual case, consisting of a constantly diffusing cloud, can be easily treated by use of a machine program. The cloud is frozen only to determine the limits for integration (see Ref. 4).

Equation 4-19 was programmed for an IBM 709 computer and values determined for the parameters listed in Table 4-VII. These values are available in graphical form in a preliminary report[4] and shall not be repeated here.

Numerical calculations indicate a peak concentration which is higher under a diffusion condition than the peak attained at t = d/u, by passage of the 'frozen' cloud. The peak under diffusion conditions leads by a short time the peak under 'frozen' conditions. These differences appear to be small enough, for the parameters listed in Table 4-VII, to be neglected on the basis of comparison.

4.3.3 Concentration Estimates

The approximate equations normally derived from Sutton's equation provides a reasonably accurate method for concentration predictions within the range of parameters given in Table 4-VII.

In addition to the instantaneous point source predictions, approximations can be obtained for a finite, constant rate-of-release, point source. Peak concentration for a finite release is determined by calculating the fraction of the equilibrium concentration that is reached as a function of distance from the source. This fraction is obtained from Fig. 4-38 as a function of the ratio of the release time to the duration for integration.

It can be easily shown that the equilibrium concentration is equal to the integrated concentration when the release rate is substituted for the quantity released from an instantaneous point source.

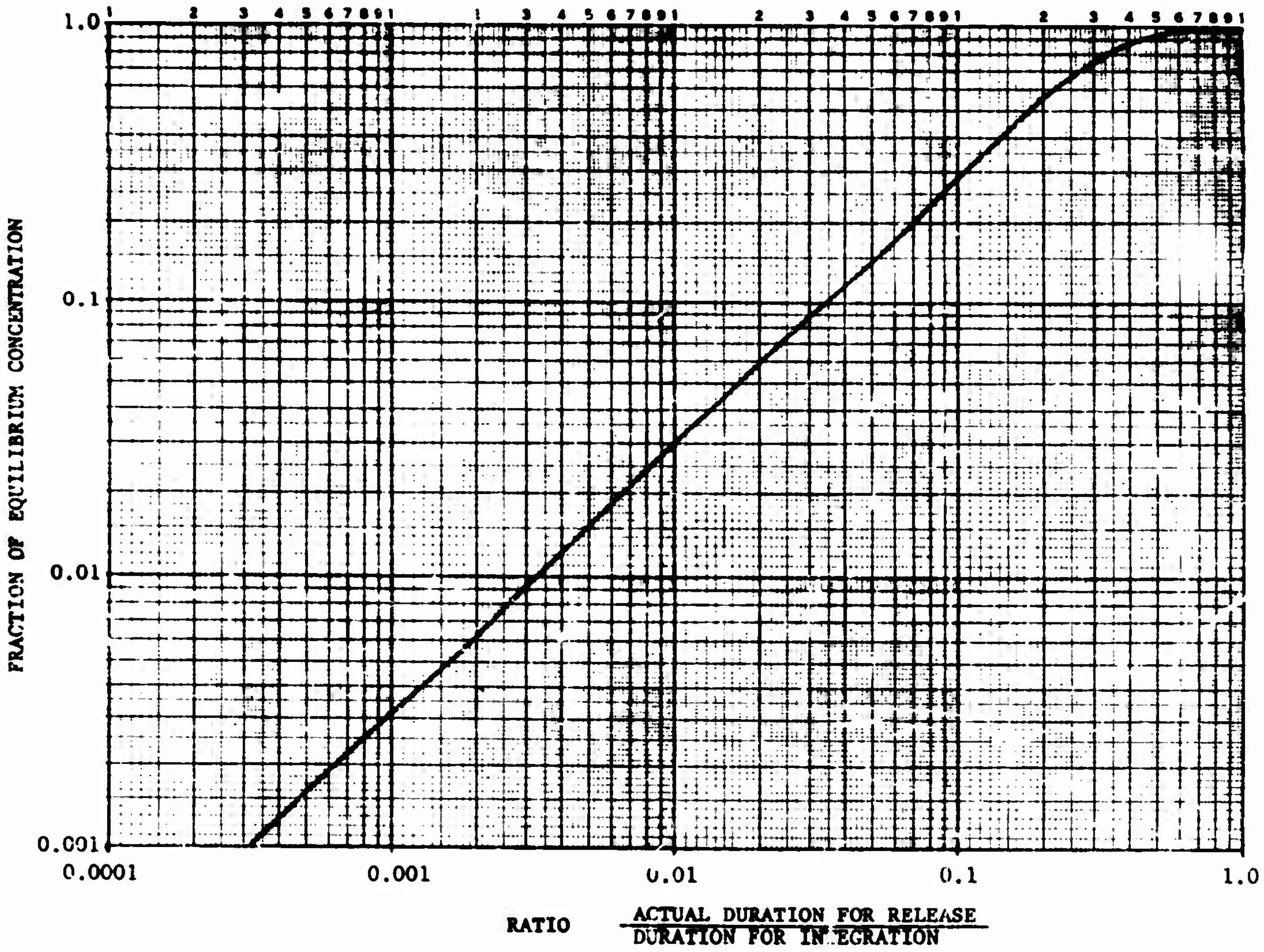


FIG. 4-38 FRACTION OF CONTINUOUS POINT SOURCE EQUILIBRIUM CONCENTRATION (FINITE RELEASE TIME)

The equations applicable for predicting peak concentration, integrated concentration, and duration for integration for an instantaneous point source and isotropic diffusion are the following:

$$\text{Peak Concentration} = \left(\frac{W}{M}\right) \frac{3.62 \times 10^6}{C^3 \phi^3} \exp\left[\frac{-\alpha^2}{C^2 \phi^2}\right] \text{ (ppm)} \qquad (4\text{-}20)$$

$$\text{Integrated Concentration} = \left(\frac{W}{M}\right) \frac{6.37 \times 10^6}{\bar{u}\, C^2 \phi^2} \exp\left[\frac{-\alpha^2}{C^2 \phi^2}\right] \text{ (ppm-sec)} \qquad (4\text{-}21)$$

$$\text{Duration of Integration} = \frac{5.48\ C \phi}{\bar{u}} \text{ (sec.)} \qquad (4\text{-}22)$$

Where $\phi = d^{(1-\frac{n}{2})}$

$\alpha^2 = h^2 + y^2$

M = Molecular weight of toxicant (gm)

W = Toxicant release (lb)

Values for phi (ϕ) are presented graphically, as a function of distance (d) and Sutton's stability parameter (n), in Fig. 4-39.

4.3.3.1 On-Axis Case

From Eqs. (4-20), (4-21) and (4-22) concentration estimates for the on-axis case can be made for any given set of diffusion parameters. On-axis merely describes the special situation for which the point of interest lies directly downwind from the source. For a ground level release the value of alpha is equal to zero while for an elevated source height alpha is equal to the altitude of release.

Graphical representation of the peak concentration, integrated concentration and duration of integration for the ground release, on-axis case can be easily obtained by calculating two points at different distances and plotting the results on log-log graph paper. The results of these plots are all straight lines and easily extrapolated. To facilitate the calculation a curve of phi for two fixed distances as a function of stability parameter have been prepared and presented in Fig. 4-40. This curve represents a cross plot of Fig. 4-39.

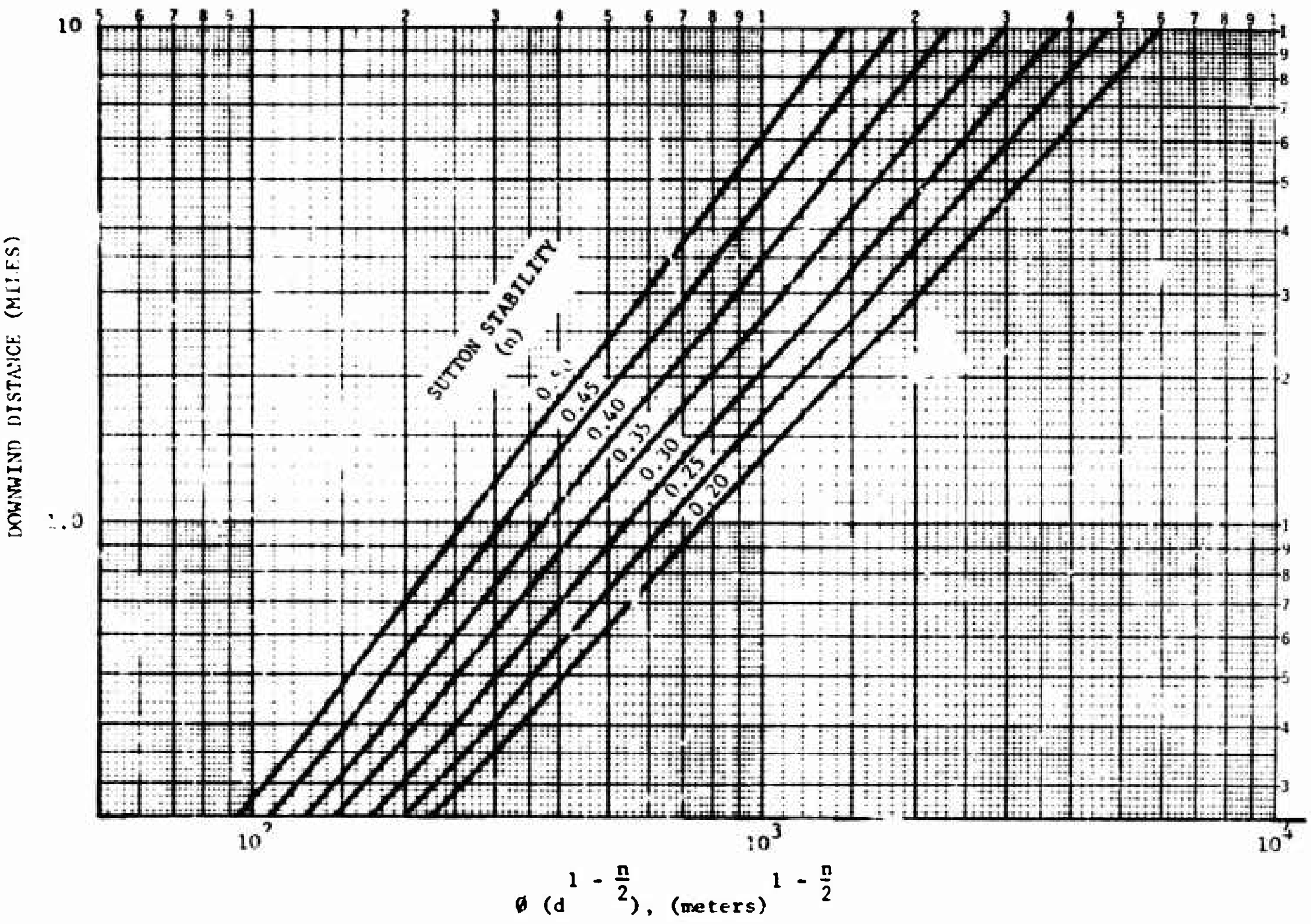


FIG. 4-39 WORKING CURVE FOR DIFFUSION CALCULATIONS

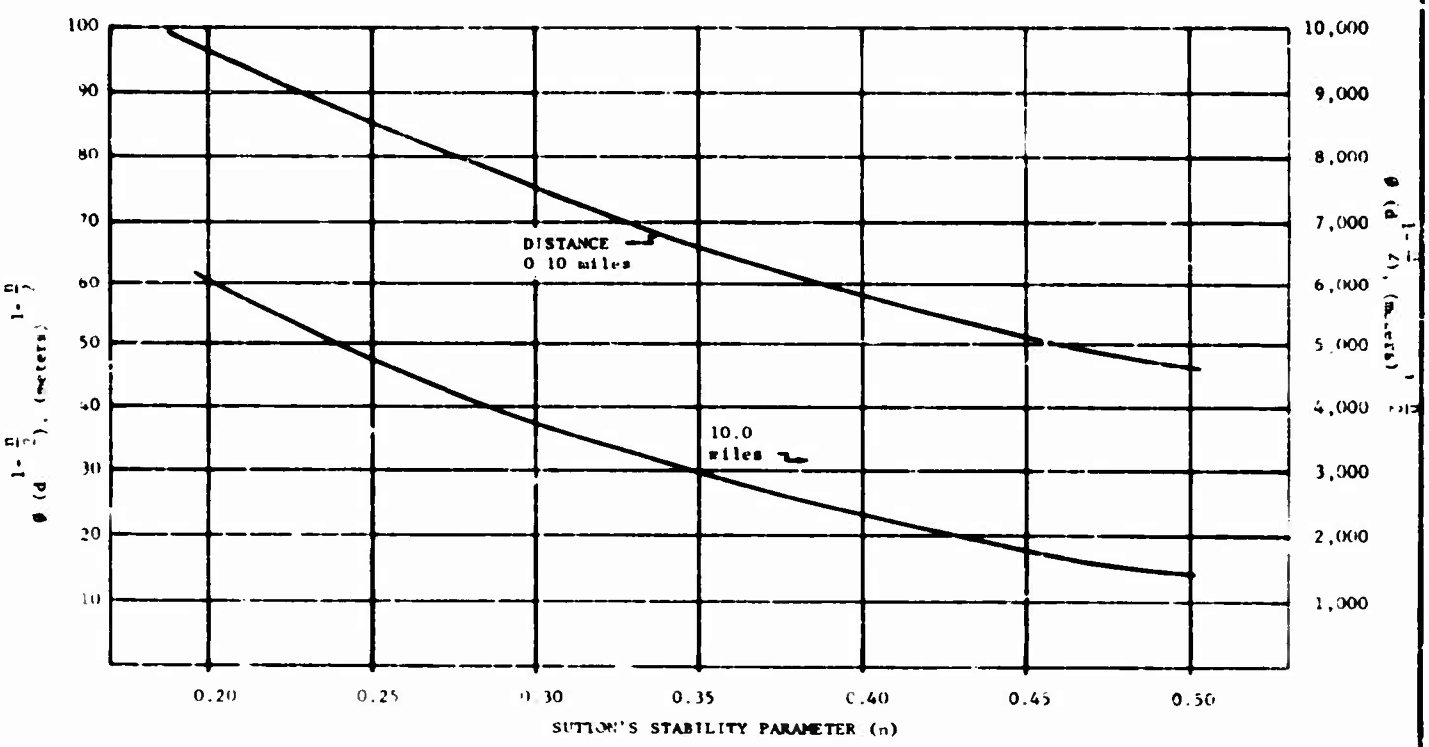


FIG. 4-40 STABILITY EFFECT ON DISTANCE FACTOR (CONSTANT DISTANCE)

With the use of the preceding figures and equations, and assuming or measuring the local values for the virtual diffusion coefficient, the Sutton stability parameter, and the wind velocity; the points to be plotted can be obtained by simple slide rule calculations.

The foregoing is easily illustrated by utilizing the described procedure for average conditions ($n = 0.25$, $C = 0.20$, and $\bar{u} = 5.15$). Values of phi are obtained from Fig. 4-40 for the given stability parameter ($n = 0.25$) at distances of 0.10 miles ($\phi = 85.5$) and 10 miles ($\phi = 4720$). The points to be plotted are given by the following:

Peak Concentration (Average Condition)

$$\chi_{0.1\text{ mile}} = 7.25 \times 10^{2} \quad (\text{ppm} \cdot \frac{M}{W})$$

$$\chi_{10\text{ miles}} = 4.31 \times 10^{-3} \quad (\text{ppm} \cdot \frac{M}{W})$$

Integrated Concentration (Average Condition)

$$\int_t \chi_{0.1\text{ mile}} = 4.24 \times 10^{3} \quad (\text{ppm-sec} \cdot \frac{M}{W})$$

$$\int_t \chi_{10\text{ miles}} = 1.39 \quad (\text{ppm-sec} \cdot \frac{M}{W})$$

Duration for Integration (Average Condition)

$$t_{0.1\text{ mile}} = 1.82 \times 10^{1} \text{ (sec)}$$

$$t_{10\text{ miles}} = 1.0 \times 10^{3} \text{ (sec)}$$

These values are plotted in Fig. 4-41. Corresponding values for the other diffusion parameters listed in Table 4-VII are also given.

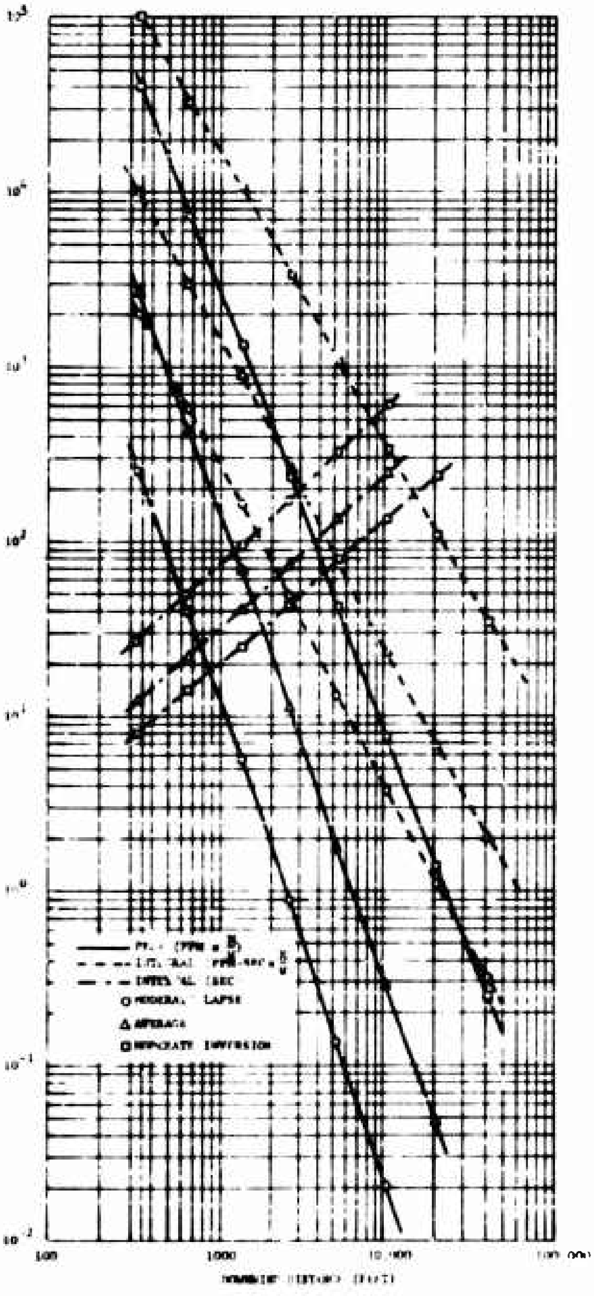


FIG. 6-6. WORKING CURVE FOR ON-AXIS CONCENTRATION ESTIMATES

4.3.3.2 Off-Axis Case

The off-axis case can also be obtained from Eqs. (4-20), (4-21) and (4-22), and represent the conditions for which alpha is not zero. For isotropic diffusion alpha equals the square root of the sum of the squares of the source elevation (h) and the cross wind distance (y); a condition which is not true for non-isotropic diffusion. However, for preliminary siting purposes the degree of anisotropy is not known and isotropy is a reasonable assumption.

When alpha is not zero the peak and integrated concentration values will be a maximum at some distance from the release point and will then decrease (approaching the value obtained for the case where alpha equal zero) as the distance from the point of release increases. The distances at which these maximum values occur are easily obtained by differentiating Eqs. (4-20) and (4-21) with respect to phi and equating the result to zero. This procedure yields the following:

(a) For Maximum Peak Concentration,

$$\chi_{max} = \frac{3.62 \times 10^6}{C^3 \phi^3} \exp\left(-1.5\right) = \chi_{\alpha = 0} \exp\left(-1.5\right) \left(ppm \cdot \frac{M}{W}\right)$$

$$\text{which occurs when } \phi^2 = \frac{2\alpha^2}{3C^2} \qquad (4\text{-}23)$$

(b) For Maximum Integrated Concentration,

$$\int \chi_{max} = \frac{3.67 \times 10^6}{\bar{u}\, C^2 \phi^2} \exp\left(-1\right) = \int \chi_{\alpha = 0} \exp\left(-1\right) \left(ppm\text{-}sec \cdot \frac{M}{W}\right)$$

$$\text{which occurs when } \phi^2 = \frac{\alpha^2}{C^2} \qquad (4\text{-}24)$$

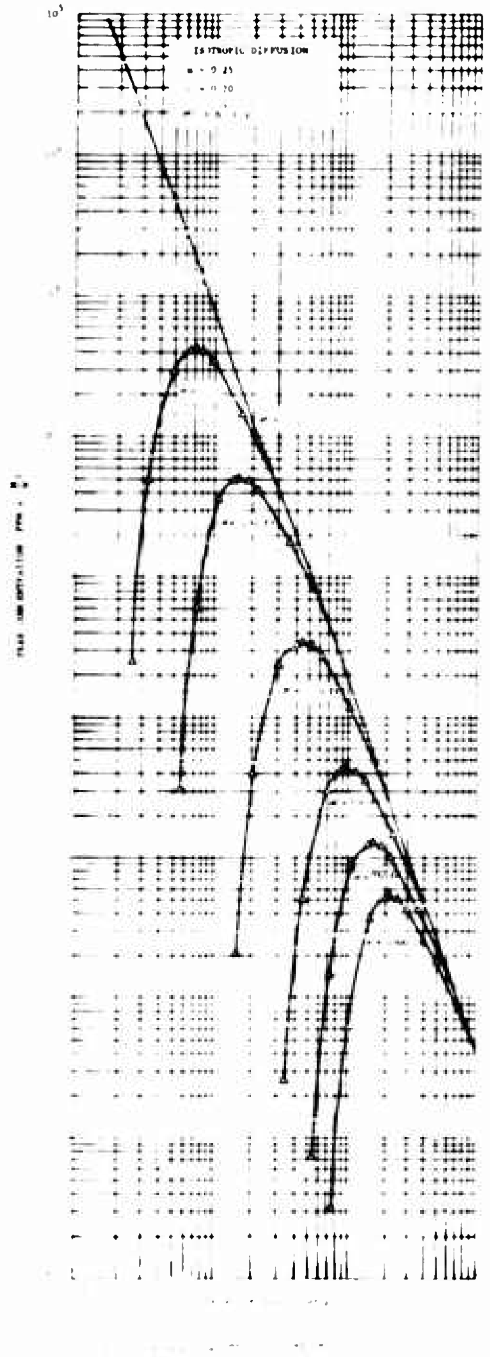
The conditions listed above provide the means for determining the distance at which the maximum concentration will occur. Knowing alpha, the virtual diffusion coefficient, and the stability parameter the value of phi can be calculated and the distance found by utilization of Fig. 4-39.

This procedure has been accomplished for several values of alpha (see Fig. 4-42). Points other than the maximum values were hand calcaulated and are also presented. For convenience, the values of alpha are given in feet; however, to illustrate the procedure the value will necessarily be given in meters. For illustration purposes, one maximum peak concentration will be determined (α = 1000 ft. or 305 meters). From the condition above for maximum peak concentration, and again assuming average weather conditions ($n = 0.25$, $C = 0.20$, and $\bar{u} = 5.15$), phi is determined to be 1.25×10^3. By using this value of phi and the given stability parameter ($n = 0.25$), the distance to maximum ground level peak concentration is determined (from Fig. 4-39) to be 2.15 miles. The concentration at this point is essentially 0.22 ($e^{-1.5}$) times the peak concentration for the average condition ($\alpha = 0$) in Fig. 4-42.

4.3.3.3 Applicability of Results

Results obtained by the methods described herein represent reasonable approximations for purposes of preliminary launch siting studies. Sutton's equation has purportedly been used to accurately predict concentrations at distances up to several kilometers. However, even though the method is questionable at greater downwind distances, it still provides a "best estimate". Such estimates are necessary due to the large propellant inventories associated with large booster systems. It is difficult to be more specific concerning the accuracy of Sutton's equations due to the lack of sufficient experimental evidence over large distances.

When the degree of anisotrophy to be expected is established (as by the gas release and atmospheric diffusion tests described in Appendix B) new estimates can be accomplished by considering phi to be a function of direction (ϕ_x, ϕ_y, ϕ_z) and separating Sutton's equation into three gaussian components. Each can then be treated separately by the approach described here.


ISOTROPIC DIFFUSION
= 0.25
= 0.20
10^5
PEAK CONCENTRATION (PPM

SECTION 5

TYPICAL SITING PROCEDURE

Siting procedure can be based upon the location of a launch pad for a fixed rocket system or upon the determination of vehicle size limitations for a fixed site. For both situations the procedures are dependent upon the same parameters and require the same degree of detail. In determining vehicle size limitation sufficient weather and terrain information would be available so as to require only data collection at the launch pad and immediately adjoining area. A new installation requires estimating and later establishing the necessary terrain and weather information for preliminary and final siting analyses.

In order to include the required criteria for both situations, a Nova-type vehicle was chosen for siting at a new installation. A site location is hypothesized and described along with the prevailing climatic conditions, terrain, and earth structure. Measurement surveys necessary to establish final site desirability are discussed. The analytical procedures of Section 4 are used to estimate the launch hazards for the hypothetical vehicle and launch site. These results are used to specify the location and configuration of the launch complex, and to define the constraints on launching operations.

5.1 HYPOTHETICAL INITIAL CONDITIONS

Hazards evaluation requires somewhat detailed description of the performance of the rocket system to be launched as well as the climatology, topography, hydrology, and geology of the launch site. In addition it is necessary to know the population and location of nearby towns, cities, and housing areas to assess the degree of hazard to the community.

5.1.1 Assumed Launch Vehicle

The hypothetical system is patterned closely after the Nova-type vehicle; the first or booster stage will consist of a cluster of six 1.5-million-pound-thrust F-1 engines utilizing LO_2/RP-1 propellants for a total takeoff thrust of 9 million pounds.

The vehicle has three stages and is capable of placing a large useful payload into orbit. The second stage is assumed to consist of three large engines of the F-1 type, each with a thrust at altitude of 2 million pounds. In order to highlight toxicity hazards, the second and third stages are assumed to utilize nitrogen tetroxide (N_2O_4) as oxidizer and a 50-50 mixture of hydrazine (N_2H_4) and UDMH as fuel. Characteristics of the hypothetical vehicle which are important from the launch hazards standpoint are summarized in Table 5-I.

The hypothetical vehicle will be assumed to have a takeoff weight of 6 million pounds and a ratio of thrust to weight of 1.5. The net initial upward acceleration will be about 0.5g. Figure 5-1 presents the dynamics for the hypothetical vehicle during the early phases of flight which are important for launch hazard considerations

Engine cluster configurations for the first and second stages are shown in Fig. 5-2. An overall diameter of twelve feet per engine has been assumed for the first stage to allow for gimbaling and to eliminate undesirable exhaust interference. The second stage propulsion system would be composed of three engines in a triangular arrangement. The upper stage expansion ratio will be greater than for the booster and therefore requires a larger nozzle area.

The blast deflector configuration for the hypothetical missile is represented by Fig. 5-3. This transversely symmetrical deflector conforms with current designs (Saturn) and offers a predicted substantial reduction in the acoustical power level generated by the booster engines.

TABLE 5-I

CHARACTERISTICS OF HYPOTHETICAL VEHICLE

	FIRST STAGE	SECOND STAGE	THIRD STAGE
Number of Engines	6	3	1
Thrust per Engine* (Pounds)	1.5×10^6	2×10^6	2×10^6
Chamber Pressure (PSIA)	1000	1000	1000
Nozzle Area Ratio	10	16	16
Nozzle Exit Diameter (Feet)	10	12	12
Total Thrust Per Stage* (Pounds)	9×10^6	6×10^6	2×10^6
Oxidizer Type:	LO_2	N_2O_4	N_2O_4
Fuel Type	RP-1	N_2H_4 & UDMH	N_2H_4 & UDMH
Specific Impulse* (Seconds)	263	309	309
Propellant Flow Rate (lb/sec)	5833	5833	5833
Burning Time (seconds)	86	105	115
Mass Mixture Ratio (O/F)	2.35/1	1.05/1	1.05/1
Oxidizer Weight (Pounds)	2,104,000	944,000	343,000
Fuel Weight (Pounds)	896,000	896,000	327,000
Total Propellant Weight (Pounds)	3,000,000	1,840,000	670,000
Volume Mixture Ratio (O/F)	1.63	0.743	0.743
Oxidizer Volume (feet^3)	29,600	10,400	3,790
Fuel Volume (feet^3)	18,200	13,800	5,040

---

*At sea level conditions for first stage and at altitude for second and third stages.

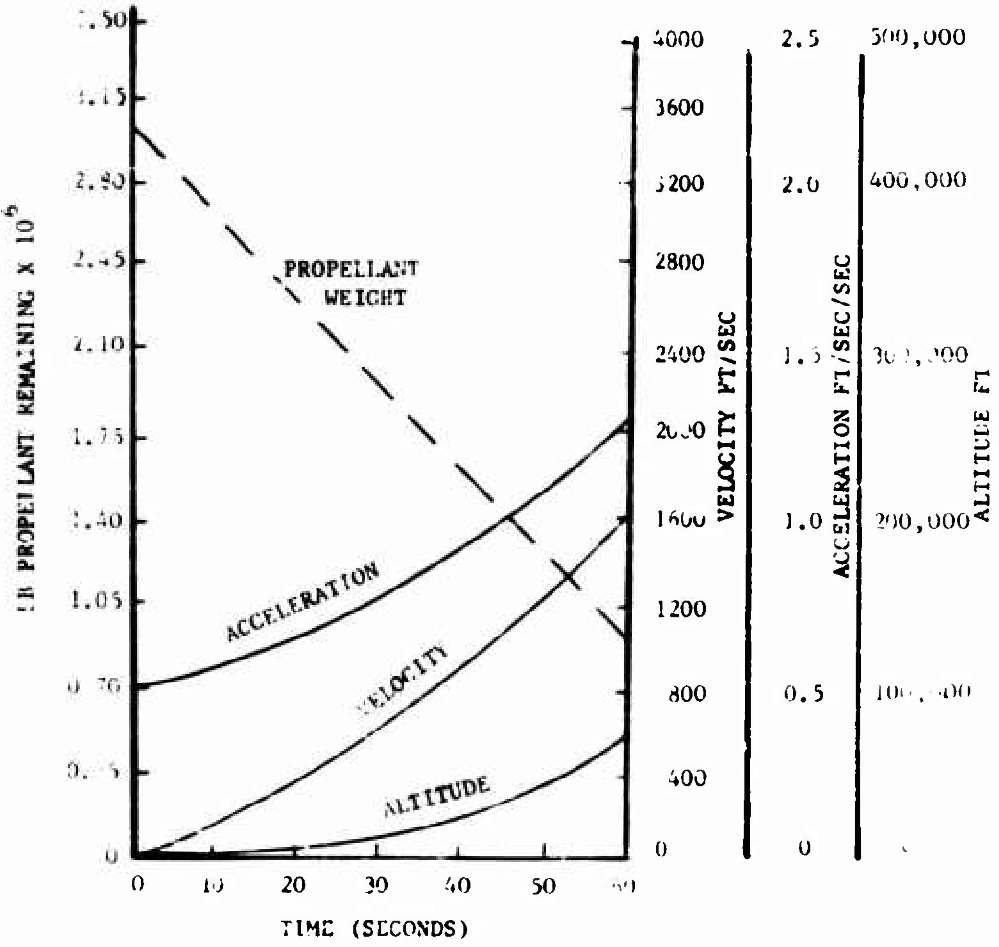
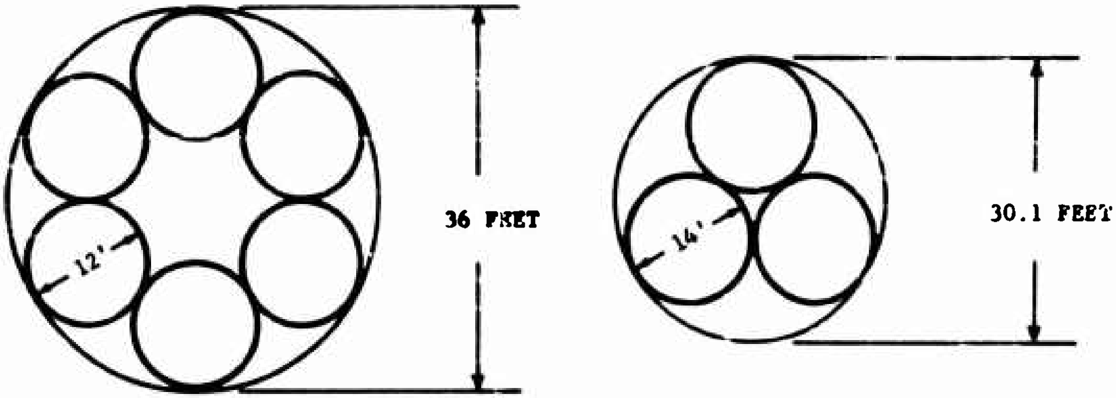


FIG. 5-1 HYPOTHETICAL VEHICLE DYNAMICS



MAIN STAGE

SECOND STAGE

FIG. 5-2 HYPOTHETICAL VEHICLE ENGINE CLUSTERS

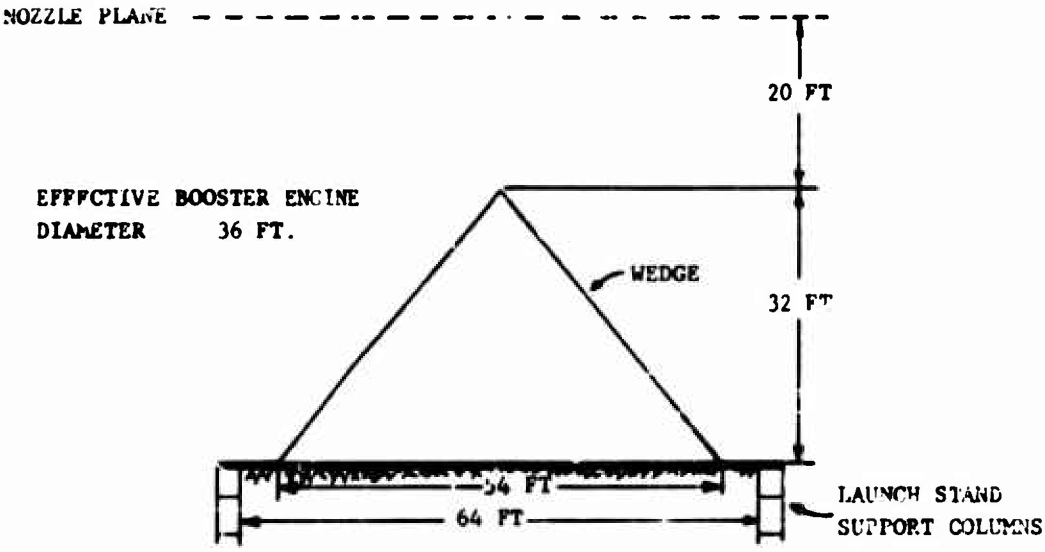


FIG. 5-3 BLAST DEFECTOR CONFIGURATION

5.1.2 Prospective Launch Area

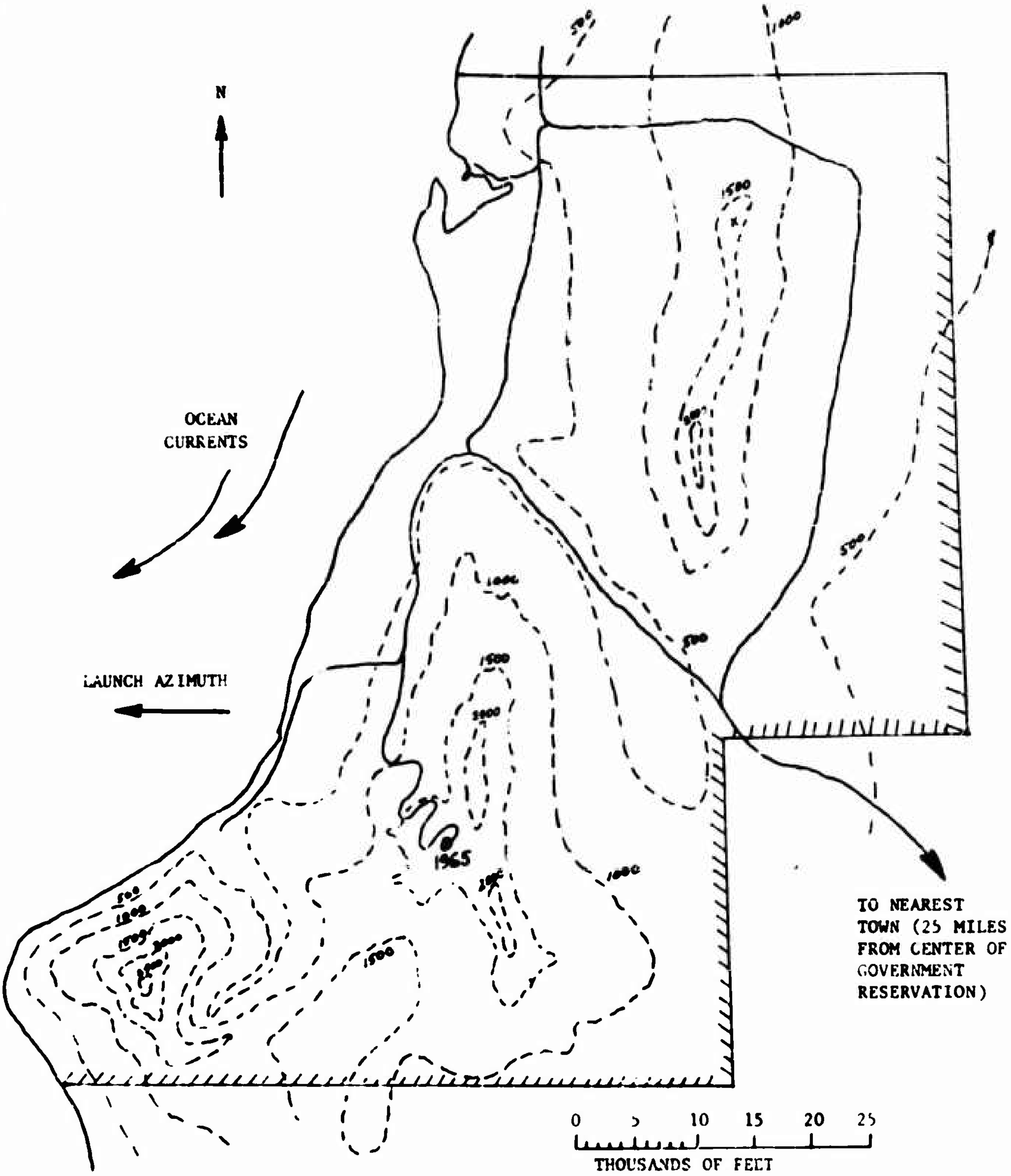
The prospective launch area used for illustration is shown in Fig. 5-4. The area has 20 miles of coastline on the western extremity of a large land mass, and encompasses approximately 140 square miles. The activities within this launch site will be those which are normally required to support launching activities. Administrative and operations personnel will number approximately 800 with only about 50 living within the boundaries. The frequency of launchings is estimated to be 2 per year initially with an eventual increase to 6 per year. The only communities near the site are a city of 50,000 population located 25 miles southeast of the site and a large metropolitan area 100 miles to the north. No offshore islands lie near this prospective launch area.

Access to the site is provided by a harbor and by surfaced roads which enter the reservation from the east. This access road connects 5 miles outside the reservation with a main highway which extends north and south.

The entire area is slashed north and south by a low eroded coastal range. The elevations vary from sea level on the west to 2000 foot hills which recede to a 600 foot valley on the east. The narrow coastal plain is characterized on its southern two-thirds by 50 to 100 foot cliffs while the northern section consists of a narrow sandy beach from which the land rises with a fairly steep slope to 200 feet. The northern landscape continues with the same character for 50 or more miles.

Bedrock in this area is metamorphic rocks of igneous origin and are largely hard, fractured, and jointed granite gneisses and schists. Sedimentary rocks cover the bedrock to depths which vary from 50 feet near sea level to 10-15 feet near the hill tops. The sediment is mostly sandstone, siltstone and conglomerates thereof. Sound velocities assumed for the earth and rock substructure layers are (1) 700 feet/second for the first layer of 5 ft. depth, (2) 2300 feet/second for the second layer of 40 ft. depth, and (3) 15,000 feet/second for the next layer (bedrock) of 325 ft. depth.

The valley which lies to the east is primarily used for farming. With an annual rainfall of only 12 inches per year irrigation is necessary. The population density within a 30 mile radius is 50 to 100 per square mile.



TO NEAREST TOWN (25 MILES FROM CENTER OF GOVERNMENT RESERVATION)

FIG. 5-4 PROSPECTIVE LAUNCH AREA

5.1.3 Climatic Conditions

The ocean represents a constant temperature surface which fluctuates seasonally from 50°F to 70°F. Coastal winds are greatly dependent upon the temperature differential between land and water surfaces. The ocean breezes would be funneled through the regions of lower elevation while the land breeze would return through these passes as well as downward from the peaks. During the transition period between land and sea breeze, the wind would tend to be parallel to the coast.

Prevailing winds for the particular site are from a northerly and northwesterly direction with speeds of 10 to 20 knots varying at times up to 40 or 50 knots. Surface inversions prevail up to 60% of the time during the months of December, January, and February, 20% of the time the lapse rate exceeds 2°C per 100 meters of altitude. During the warmer months inversions are present about 50% of the time between altitudes of 1,000 and 3,000 feet and 20% of the time the lapse rate also exceeds 2°C per 100 meters of altitude. The relative humidity can vary from 90% at the base of the inversion to 50% at the top of the inversion layer with relatively dry air above.

Late night and early morning fog occur frequently, usually clearing before noon.

Summaries of the expected climatic conditions are presented in Figs. 5-5 through 5-10, inclusive. Figure 5-11 represents sound velocity profiles which are expected to occur with a wind from the northwest.

5.1.4 Site Measurement Survey

Once a prospective site has been chosen preliminary hazards analyses can be started by reducing climatological data from surrounding weather stations and estimating site conditions. This would expedite the determination of site desirability since the accumulation of on-site data requires a long time. Also it is doubtful that an on-site weather station would be a realistic assumption as the site will necessarily be remote and somewhat isolated.

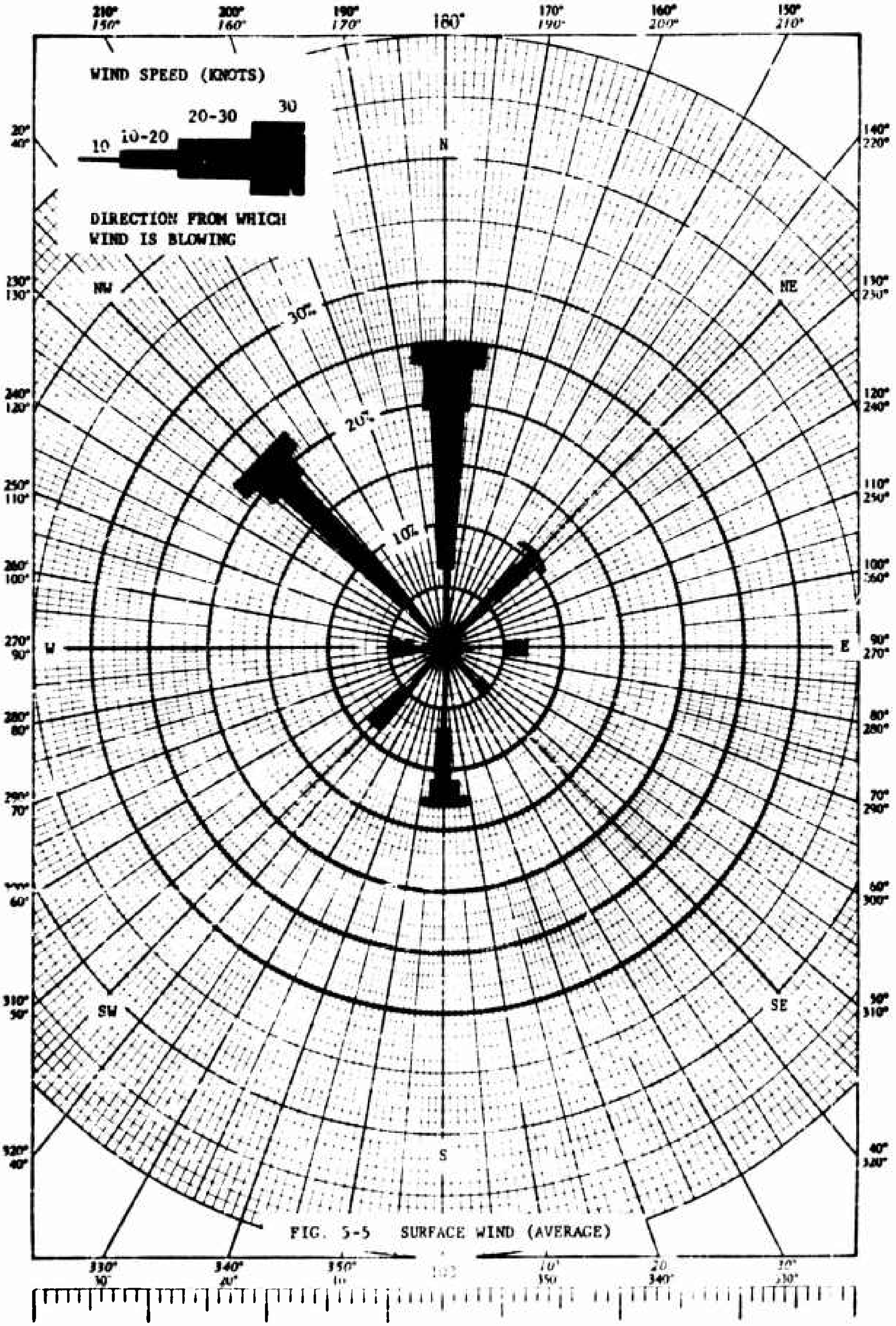


FIG. 5-5 SURFACE WIND (AVERAGE)

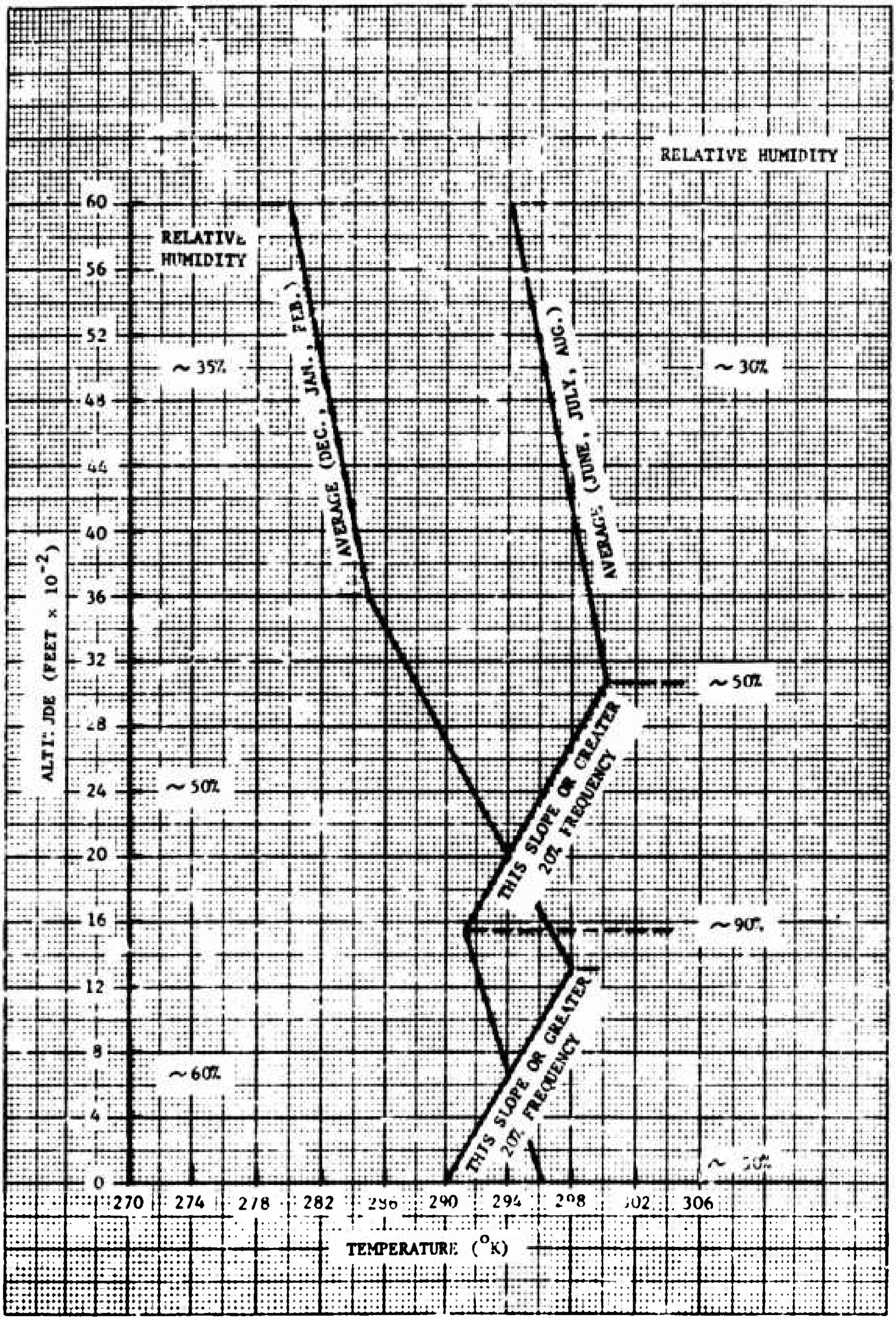


FIG. 5-5 TEMPERATURE VARIATION WITH ALTITUDE

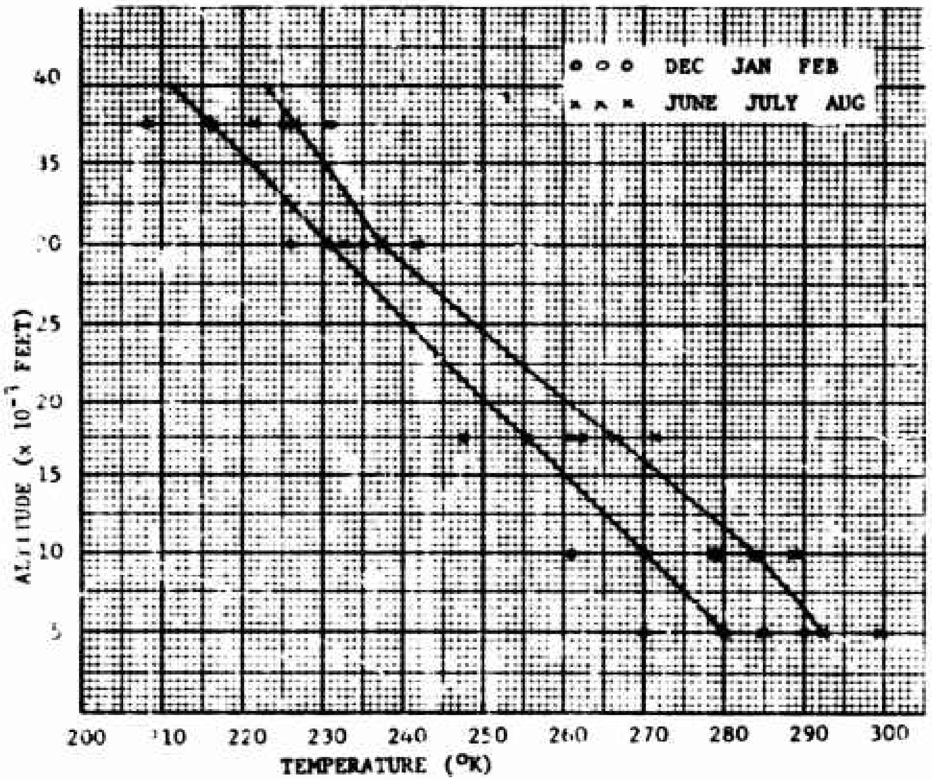


FIG. 5-7 UPPER ATMOSPHERIC TEMPERATURES

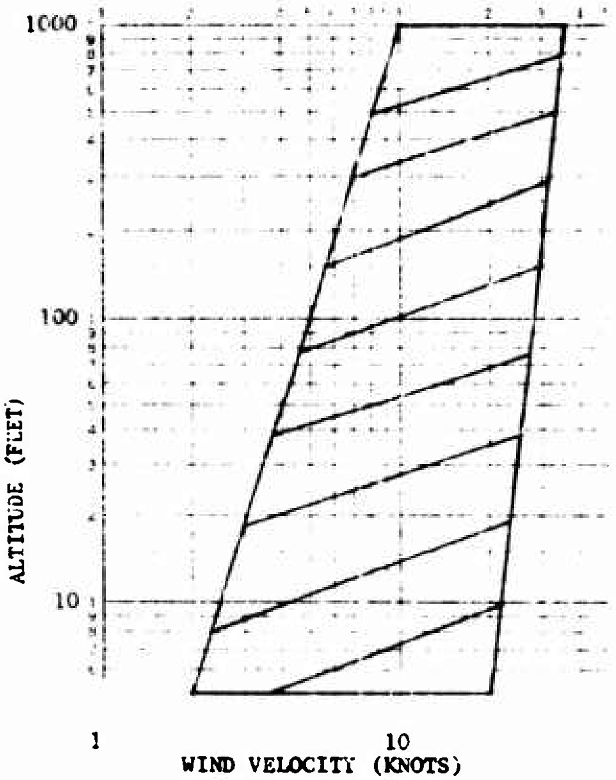


FIG. 5-8 WIND SPEED VARIATION WITH ALTITUDE

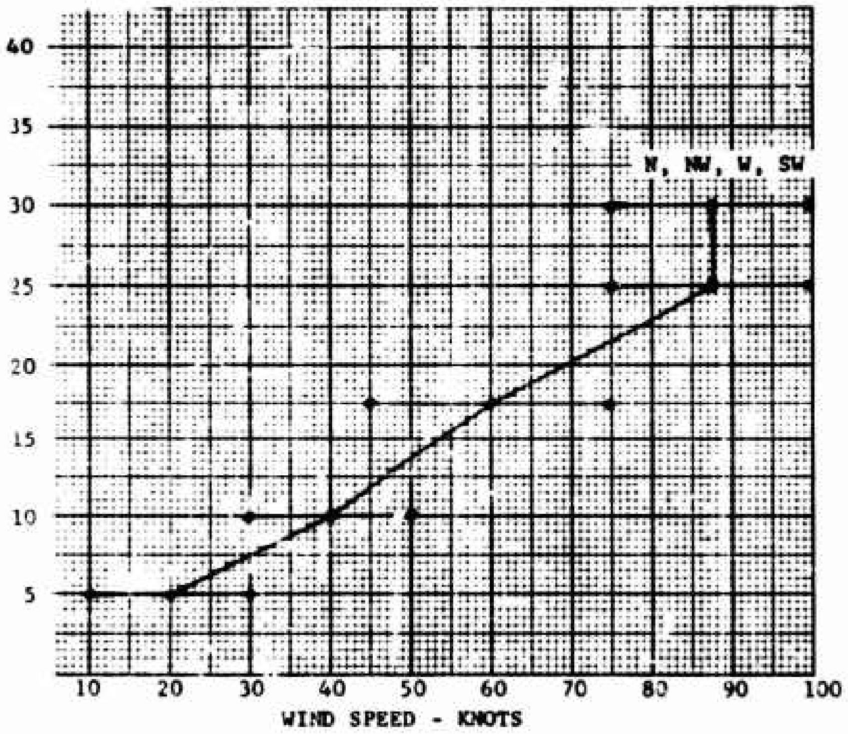


FIG. 5-9 UPPER ATMOSPHERIC WINDS

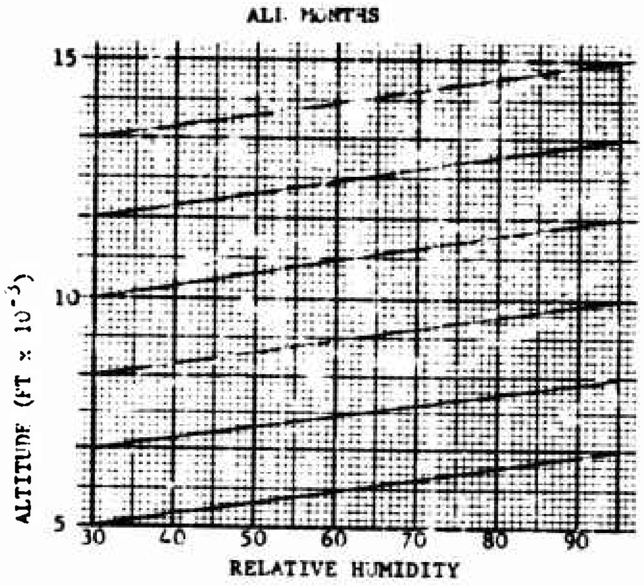


FIG. 5-10 UPPER ATMOSPHERIC HUMIDITY

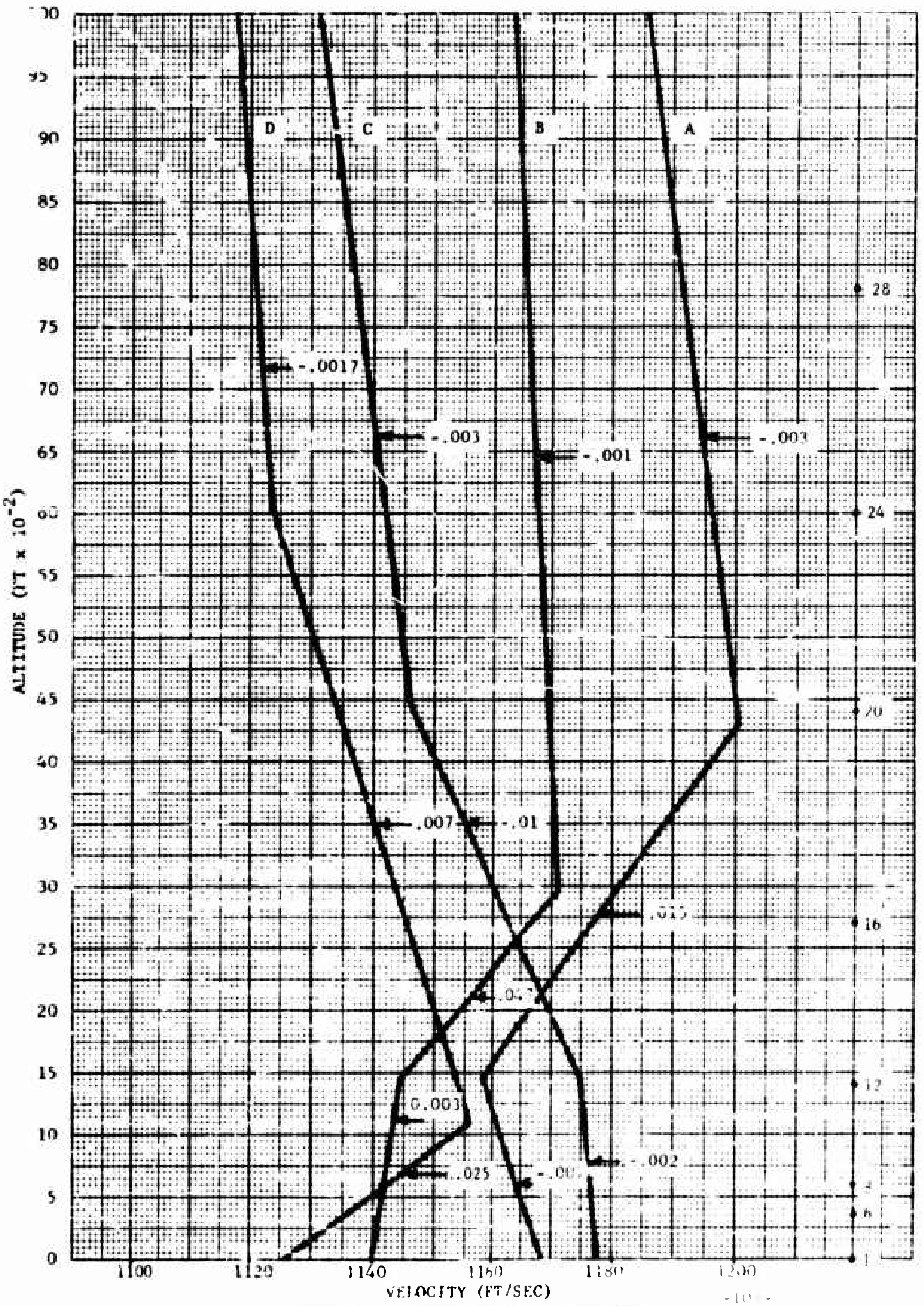


FIG. 5-11 SOUND VELOCITY PROFILES

This section is devoted to a discussion of the site measurement surveys which are necessary and desirable to verify the validity of the selected site. The items to be determined for launch hazards considerations involve those conditions which affect the propagation of sound and shock waves in the air and ground, and atmospheric diffusion of toxic materials. These can be broken down into climatology, topography, hydrology and and geology.

5.1.4.1 Climatology

Climatology of a site is an important factor which is constantly changing with time; however, based upon sufficient data collected over a number of years, extreme and average conditions can be established as a function of seasonal and diurnal fluctuations. Certain atmospheric phenomena create marginal conditions for launch operations. Such phenomena include inversions and weather fronts. Additional weather data required for detailed site analyses include wind, temperature, and humidity (including fog).

Wind measurements are required for the surface and upper atmosphere. The requirements are for direction, magnitude, and frequency as a function of altitude (up to 40,000 feet) for purposes of determining sound velocity profiles. Horizontal and vertical wind velocity fluctuations over short time intervals are necessary in the lower layers of the atmosphere to aid in determining atmospheric diffusion. After a particular launch pad is sited, local (a few to thousands of feet) surface wind fluctuation measurements are required (see Appendix B).

Temperature from the surface to an altitude of 40,000 feet are also required to help determine sound velocity profiles. Temperature gradients are also indicators of atmospheric stability and important to determining atmospheric diffusion.

Humidity has an effect upon sound propagation as it affects attenuation and velocity.

5.1.4.2 Topography

A detailed map relating the altitude contours and description of the local vegetation is required. The location of natural barriers which can be utilized as blast and acoustical shields or suppressors helps to pinpoint suitable launch pads or support facility buildings. The protrusion of vegetation above the surface affects the diffusion of toxic materials.

Off-site topography to surrounding communities is required for determination of its effect upon sound pressure levels, shock wave propagation, and atmospheric diffusion.

5.1.4.3 Hydrology

Hydrological surveys are necessary to establish the natural drainage and flow of underground water supplies. The important factor involved here is to insure against the contamination of local water supplies due to spilled toxic propellants. Soil characteristics need to be determined which affect the ability of a spilled propellant to penetrate to the underground water table. Surface drainage requires considerations for penetration along and at the end point of the natural flow.

In spite of all safeguards taken to preclude contamination of underground water sources, wells and streams, it is desirable to periodically monitor these water sources. In particular, a chemical analysis of the ground water in the vicinity of prospective launch sites should be performed before any possible contaminants are brought on the scene. In this way, evidence will be available to refute unsubstantiated claims of damaging water pollution. The U. S. Geological Survey Office is equipped to sample and analyze the chemical composition of water.

5.1.4.4 Geology

Along with the information obtained from the hydrological survey, a geological survey will give important data for determining acoustic and shock propagation through the ground. Underground rock formations upon which launch stands rest will readily transmit acoustical and blast wave vibrations to surrounding structures.

5.2 LAUNCH HAZARDS EVALUATION

The launch hazards for the rocket system and conditions described in Section 5.1 are evaluated here using the methods discussed in Section 4. Each hazard is treated separately and where possible, numerical values are given which are representative of the hazards expected.

5.2.1 Acoustics

To determine the areas where acoustics is a hazard during the launch of a missile the following calculations are required:

a. The overall and octave band power levels (OAPWL).

b. The overall and octave band sound pressure levels (OASPL) for varying distances, elevation angles to the missile, and azimuth angles to the launch site.

c. The vibration levels transmitted through the ground from the launch site at varying distances and azimuth angles.

d The effects of meteorological conditions on the SPL's The results of these calculations will specify hazardous areas for personnel and structures (missile tracking instrumentation, etc.), and predict the response of surrounding communities to this noise.

For the launch site and launch vehicle described in Section 5.1 a sample calculation will be made along the 135° azimuth (towards nearby town) to illustrate the factors involved. The calculations will include the first 60 seconds of missile flight and will be made at distances from the launch site of 1000', 2000', 1 mile, 2 miles, 4 miles, and 15 miles.

The acoustical power levels and spectra are determined from the information in Section 4 1.1.1 and are represented by Fig. 5-12.

Assuming a flat earth up to a distance of 4 miles along a 135° azimuth, the space average octave band sound pressure levels may be determined from Eq. (4.1-5). The sound pressure levels at any instant must be corrected for distance from the missile, elevation angle, and meteorological conditions. For example, at T_0 + 1 second the corrections at 1000 feet are represented by Table 5-II and the octave band sound pressure levels by curve (A) in Fig. 5-13. When the jet exhaust no longer impinges on the deflector (T_0 + 6 seconds approximately) the only directional effects are due to the elevation angle of the missile. At 1 mile radius, the source may be considered a point source and the deflector effects ignored completely. Calculations of this type yield the spectra shown in Figs. 5-13 to 5-17.

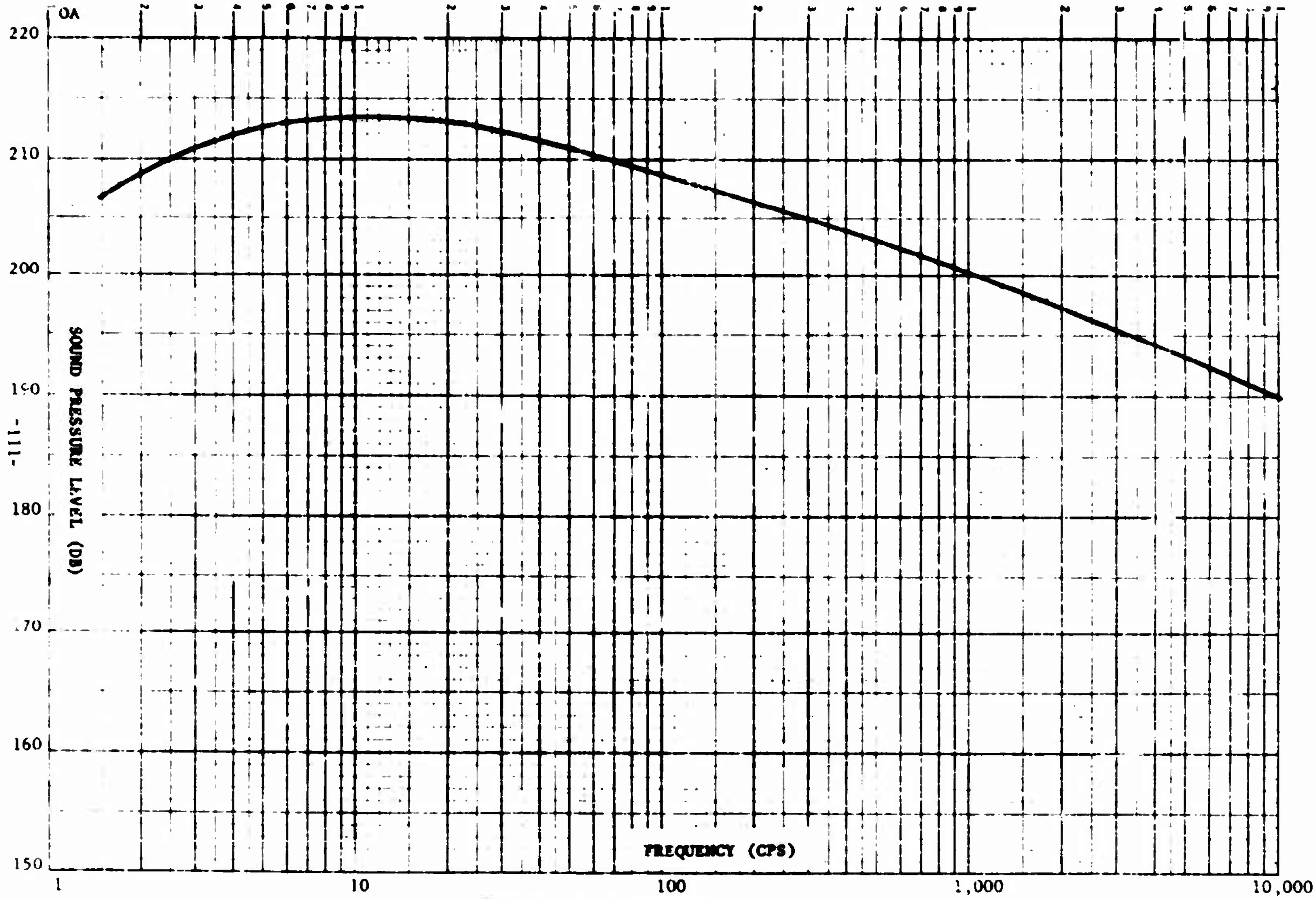


FIG. 5-12 OCTAVE BAND POWER LEVELS

TABLE 5-11

EXAMPLE OF CORRECTIONS TO SPL (dB)

(1000 feet from Launch Site at T_0+1 second)

OCTAVE BAND CENTER FREQUENCY (f_c)	STROUHAL NUMBER f_c D/V	DISTANCE X OF EFFECTIVE SOURCE FROM NOZZLE	HORIZONTAL DISTANCE X_h OF EFFECTIVE SOURCE FROM DEFLECTOR	CORRECTION IN dB DUE TO DEFLECTOR	DISTANCE CORRECTIONS IN dB	DIRECTIVITY CORRECTIONS IN dB		MOLECULAR ABSORPTION (see Fig. 4-9)
						0° (horizontal effective source)	90° (vertical effective source)	
2.0	.012	360	326	-5	65	-6		0
4	.024	326	264	-5	65	-6		0
8	.036	270	236	-5	-66	-6		0
16	.11	198	162	-5	-66	-6		0
32	.22	133	97	-5	-67	-6		0
115	.45	54.5	21.5	-5	-68	-14		0
210	.90	21.6		0	-68		-8	0
420	1.8	12.9		0	-68		+3	0
650	3.66	5		0	-68		-5	0
1730	7.3	2.5		0	-68		-5	-1
3630	14.6	.6		0	-68		+3	-6 (extrapolated)
6800	29.2	.3		0	-68		-2	-15

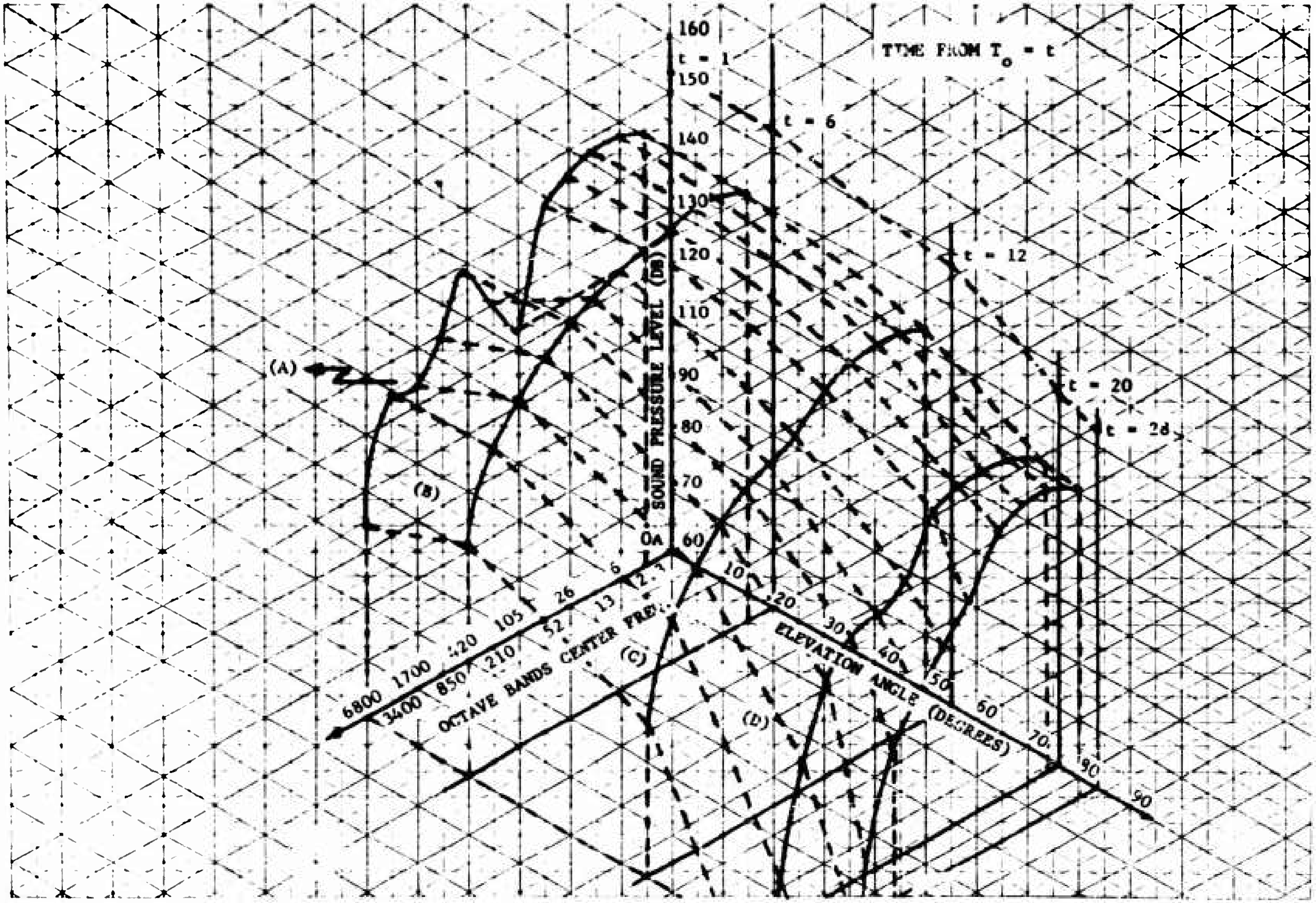


FIG. 5-13 VARIATION OF SPL AT 1000 FEET POSITION

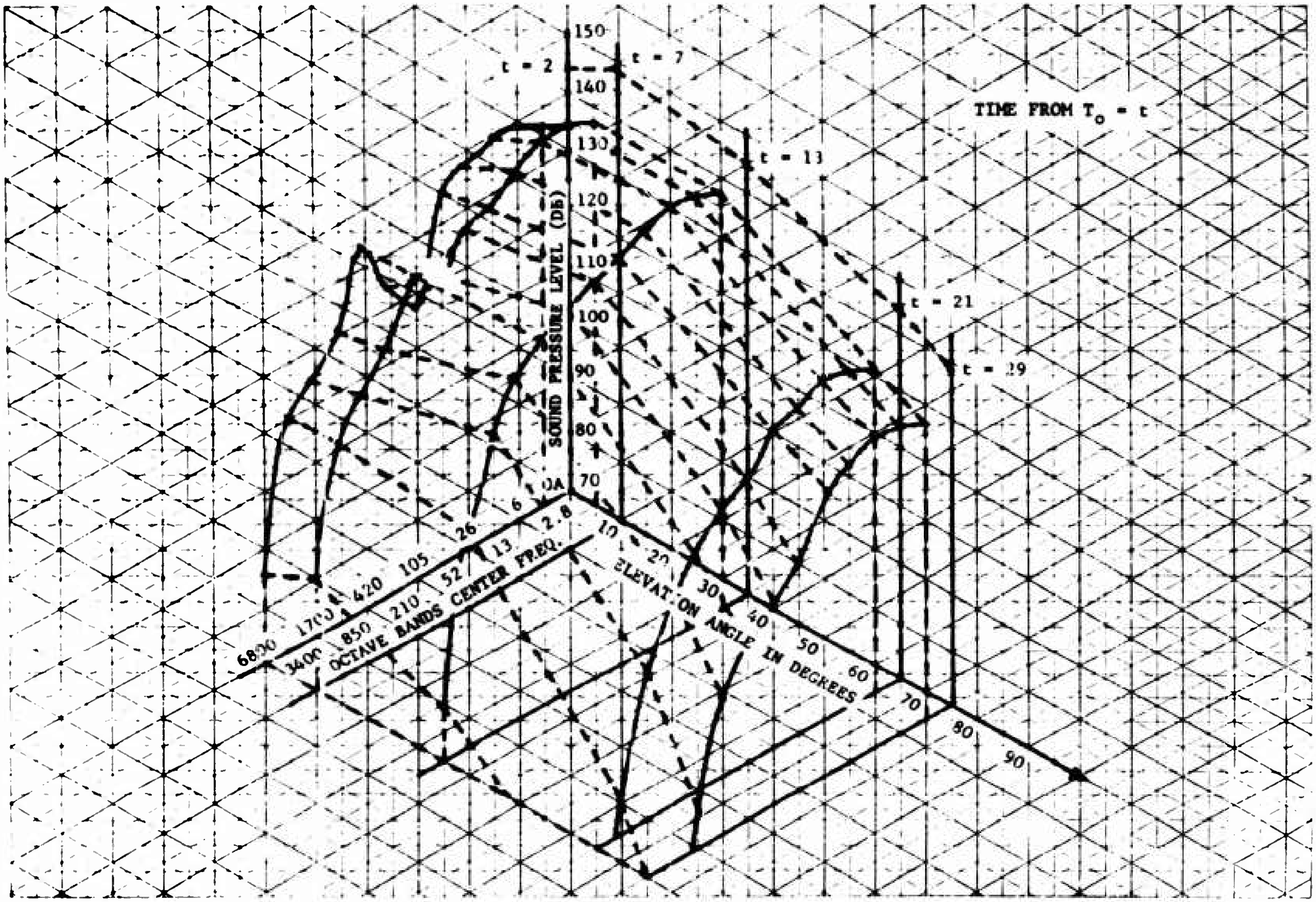


FIG. 5-14 VARIATION OF SPL AT 2000 FEET POSITION

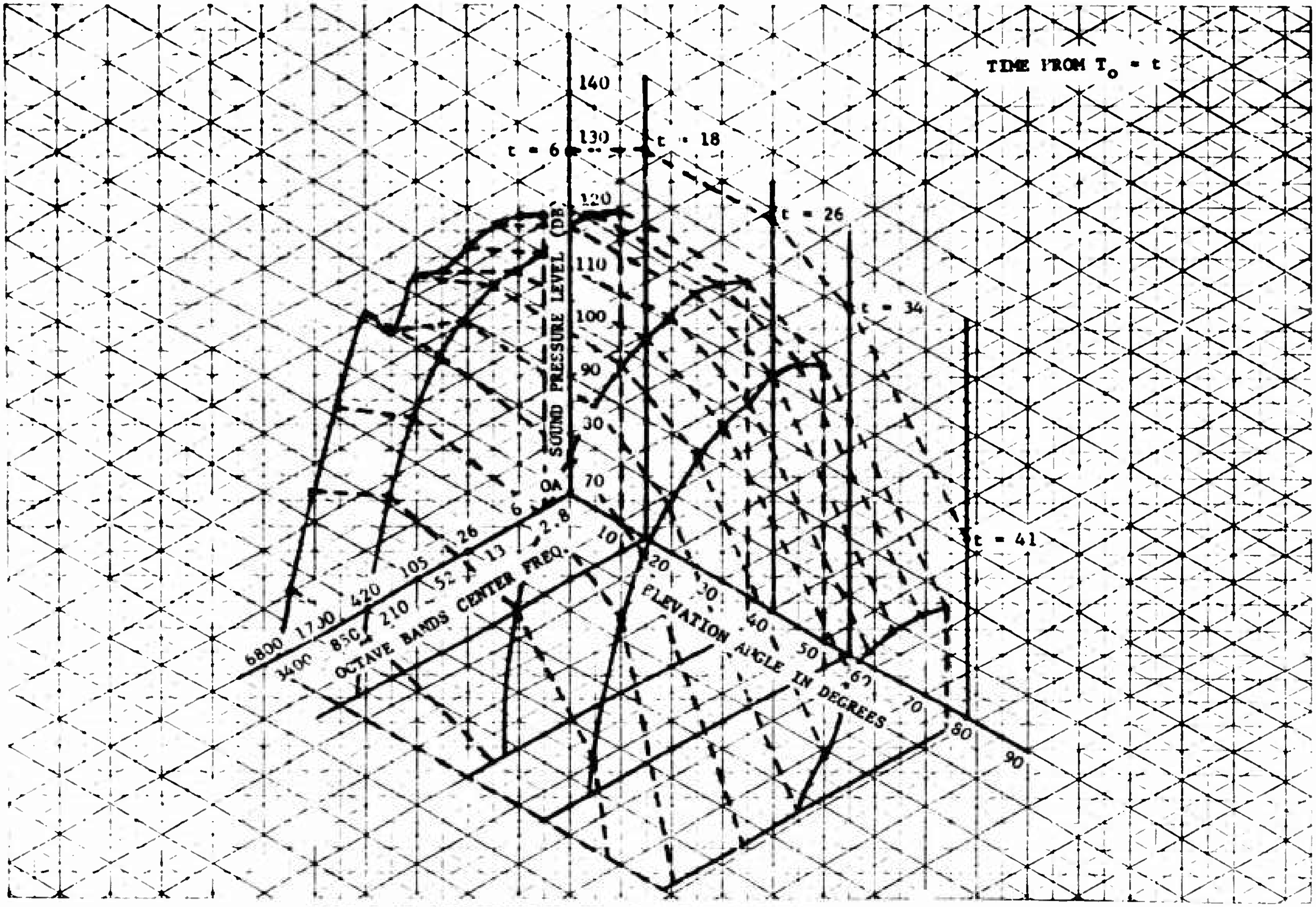


FIG. 5-15 VARIATION OF SPL AT 1 MILE POSITION

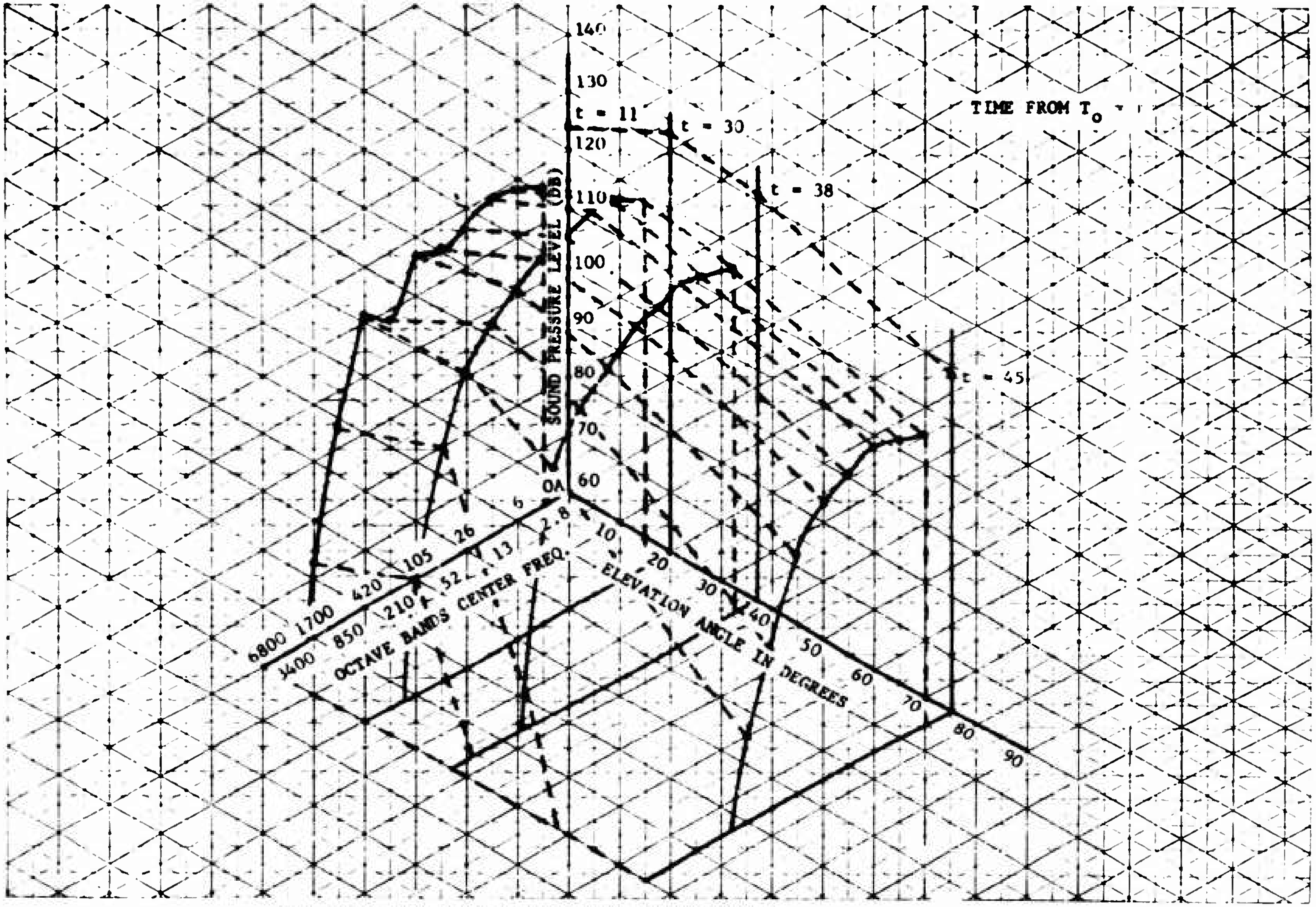


FIG. 5-16 VARIATION OF SPL AT 2 MILE POSITION

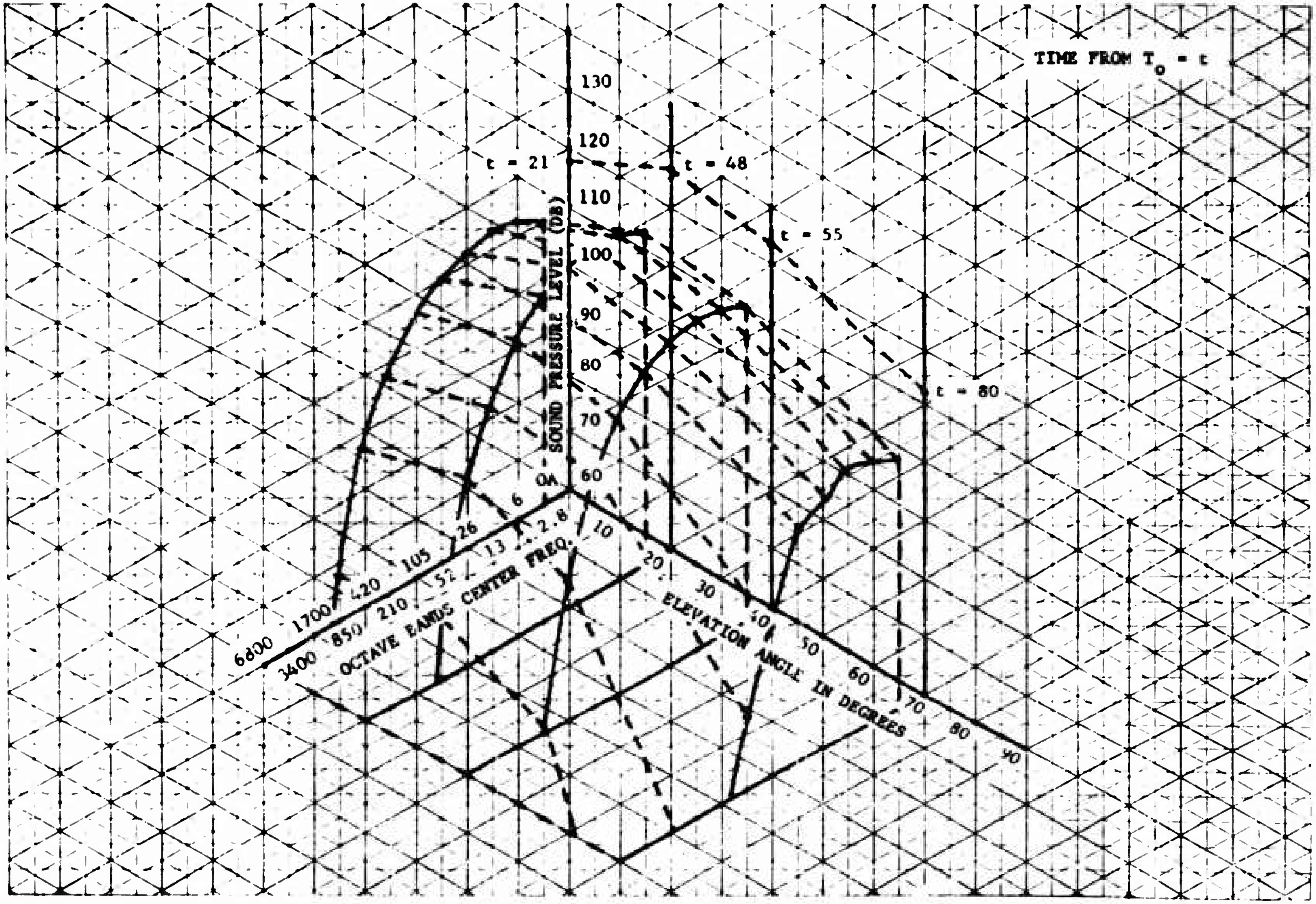


FIG. 5-17 VARIATION OF SPL AT 4 MILE POSITION

The meteorological effects result in the velocity gradients previously shown in Fig. 5-11. For the sound velocity profile labeled as A, the radius of curvature, r (see the geometry shown in Fig. 5-18) can be found by

$$r_i = \frac{c_i}{g_i \cos\theta_i} \qquad (5\text{-}1)$$

where c_i = sound velocity in ith layer

θ_i = angle sound ray makes with horizontal in ith layer

g_i = velocity gradient in ith layer

Note the first gradient will curve the sound upward (0-1500 feet), the second downward (1500-4500), and the third upward (over 4500). Figures 5-18 and 5-19 show that the effect of these gradients is to focus the booster noise at a distance of about 70,000 feet. A slight change in gradient could result in focussing in the vicinity of the town (25 miles distant). The incident noise level would be amplified by as much as 20 to 40 db.

From the initial conditions specified in Section 5.1, the most significant ground vibrations will be generated by direct impingement of acoustic waves on the ground. Figure 5-20 represents estimates of the maximum ground displacements during the hypothetical vehicle lift-off conditions. These values were predicted from Figs. 4-17 and 4-18 and Eq. 4-17 assuming a frequency of 10 cps

From Fig. 5-21 the 150 db contour of equal SPL (maximum SPL to prevent damage to standard structures) may be located at approximately 1400 feet from the launch site and the 135 db contour (maximum allowable SPL for unprotected ears) at approximately 8000 feet from the launch site. Plots of octave band levels as a function of time and distance may also be made by extrapolating the octave band plots of Figs. 5-13 to 5-17. These plots are useful in determining structural hearing damage.

The estimated octave sound pressure levels at the hypothetical town location are plotted in Fig. 5-22. These levels are not expected until approximately T_0 + 12 seconds. This exposure will exist for approximately 60 seconds.

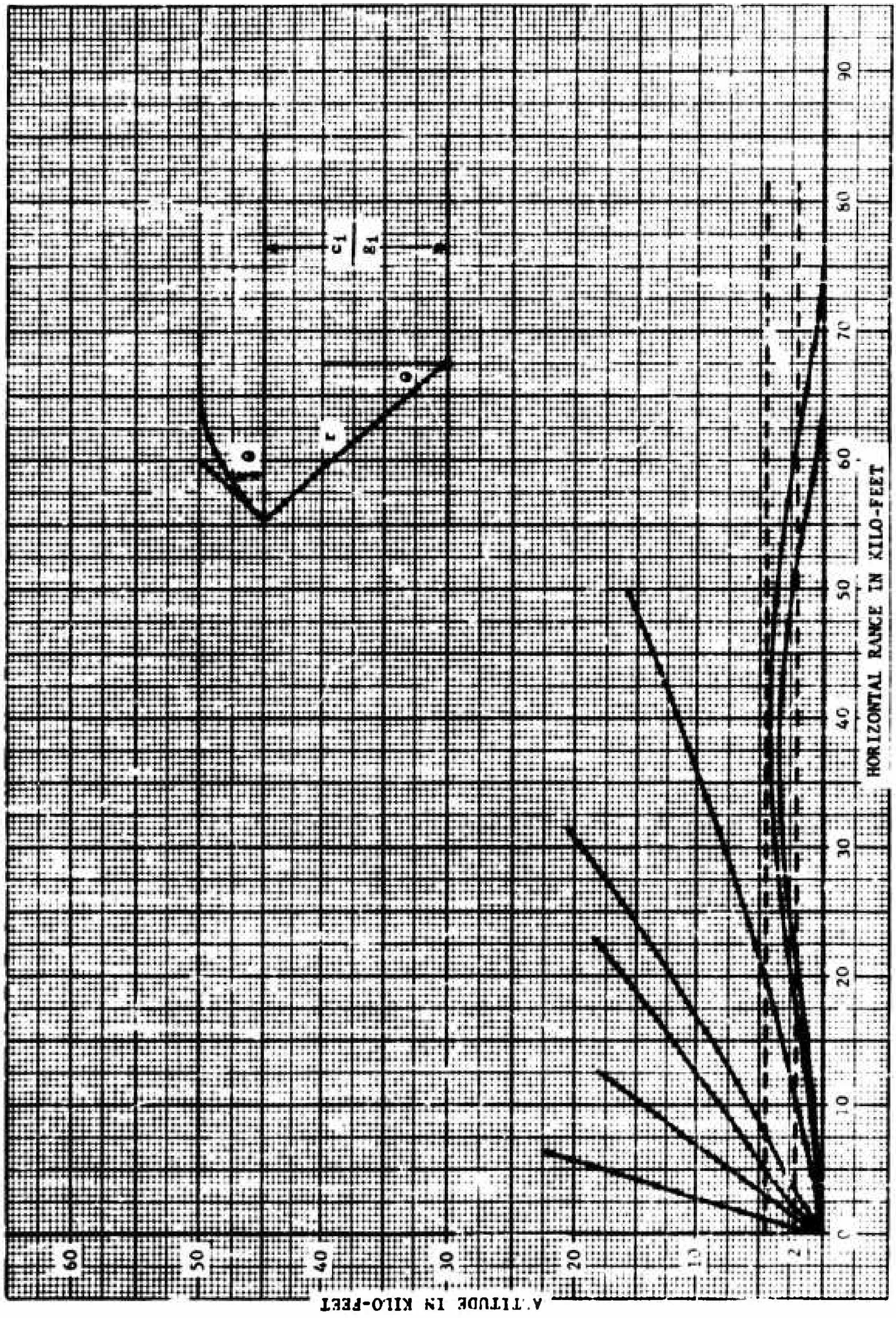


FIG. 5-18 EFFECT OF VELOCITY GRADIENT (ZERO ALTITUDE)

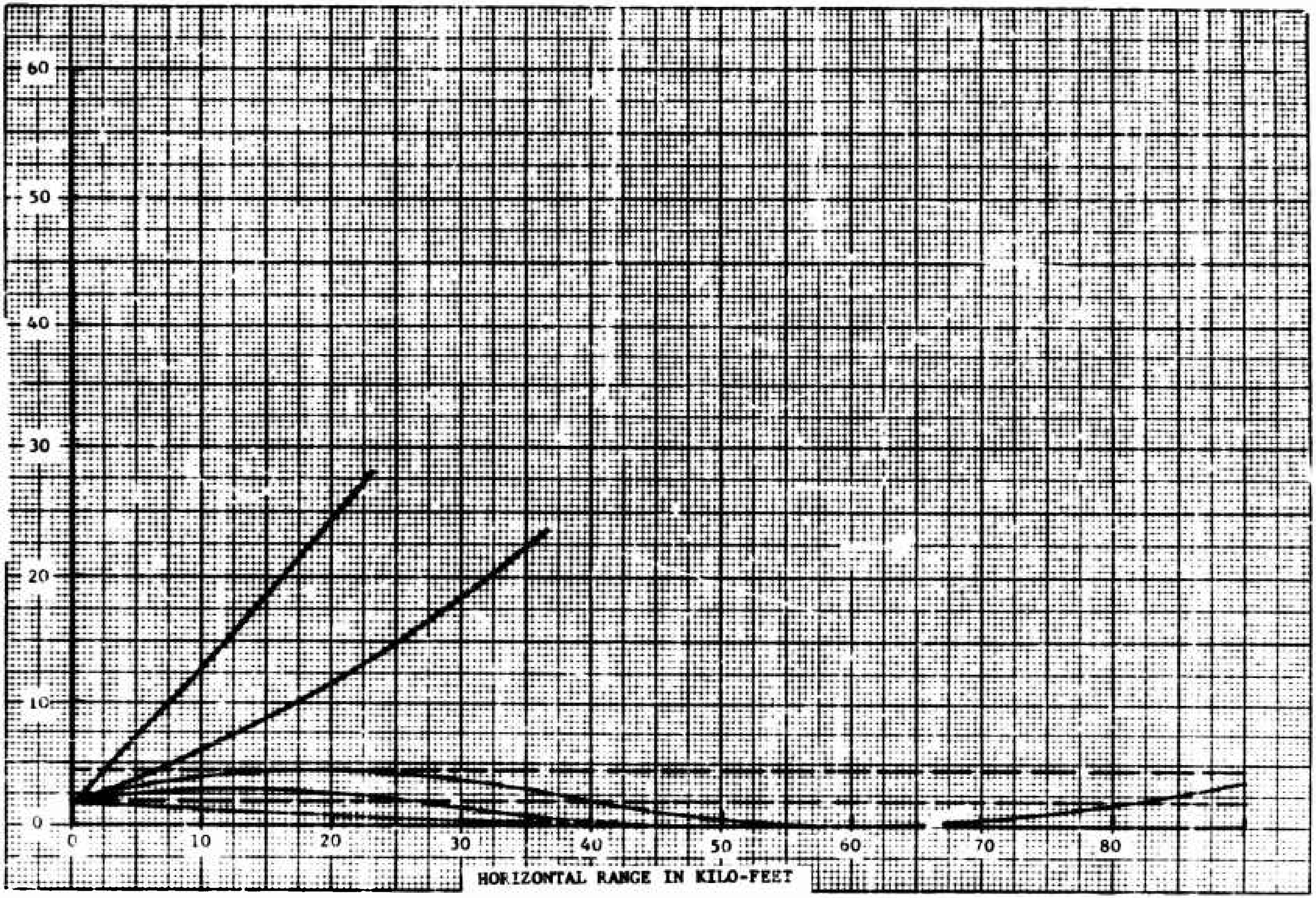


FIG. 5-19 EFFECT OF VELOCITY GRADIENT (1500 FEET ALTITUDE)

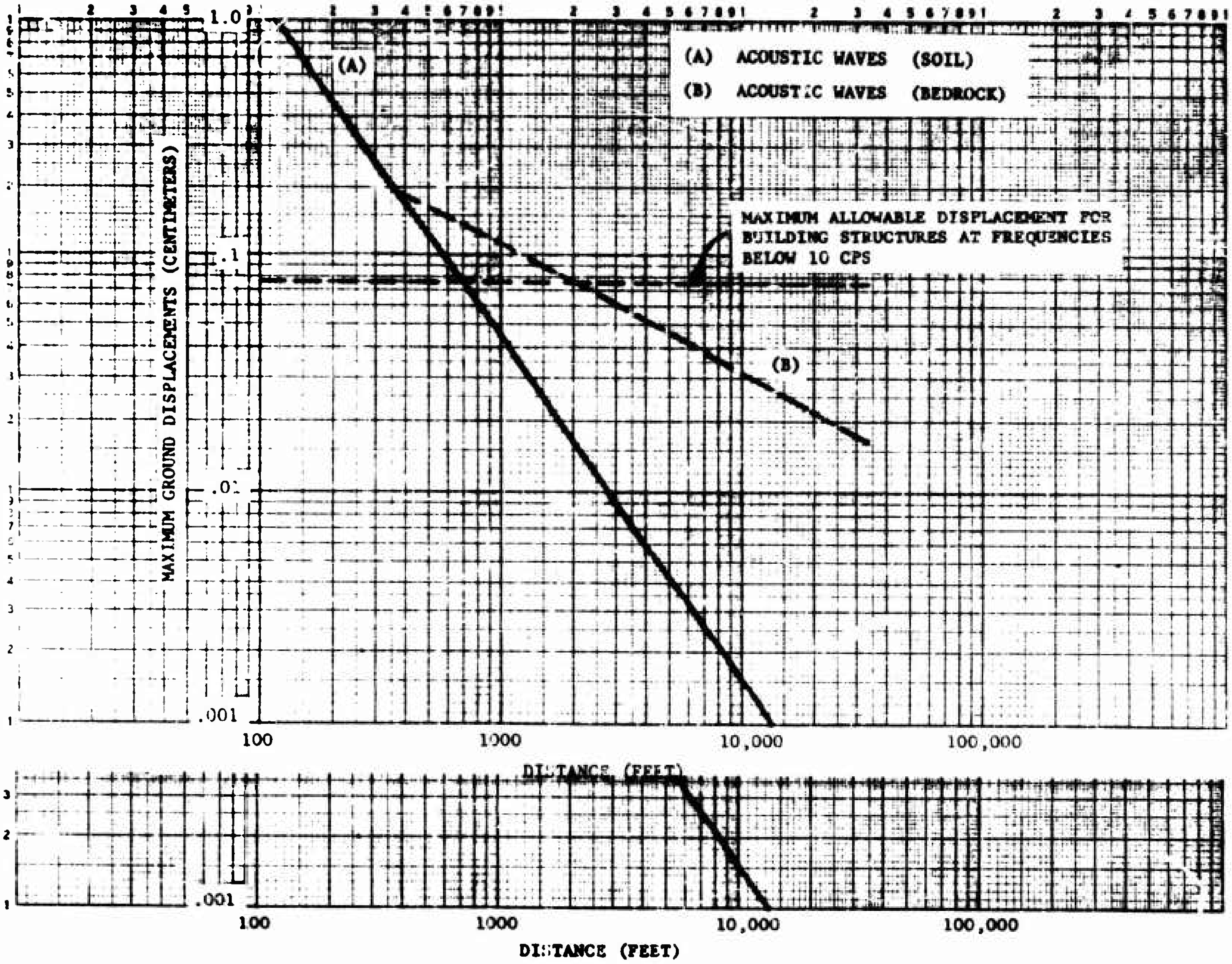
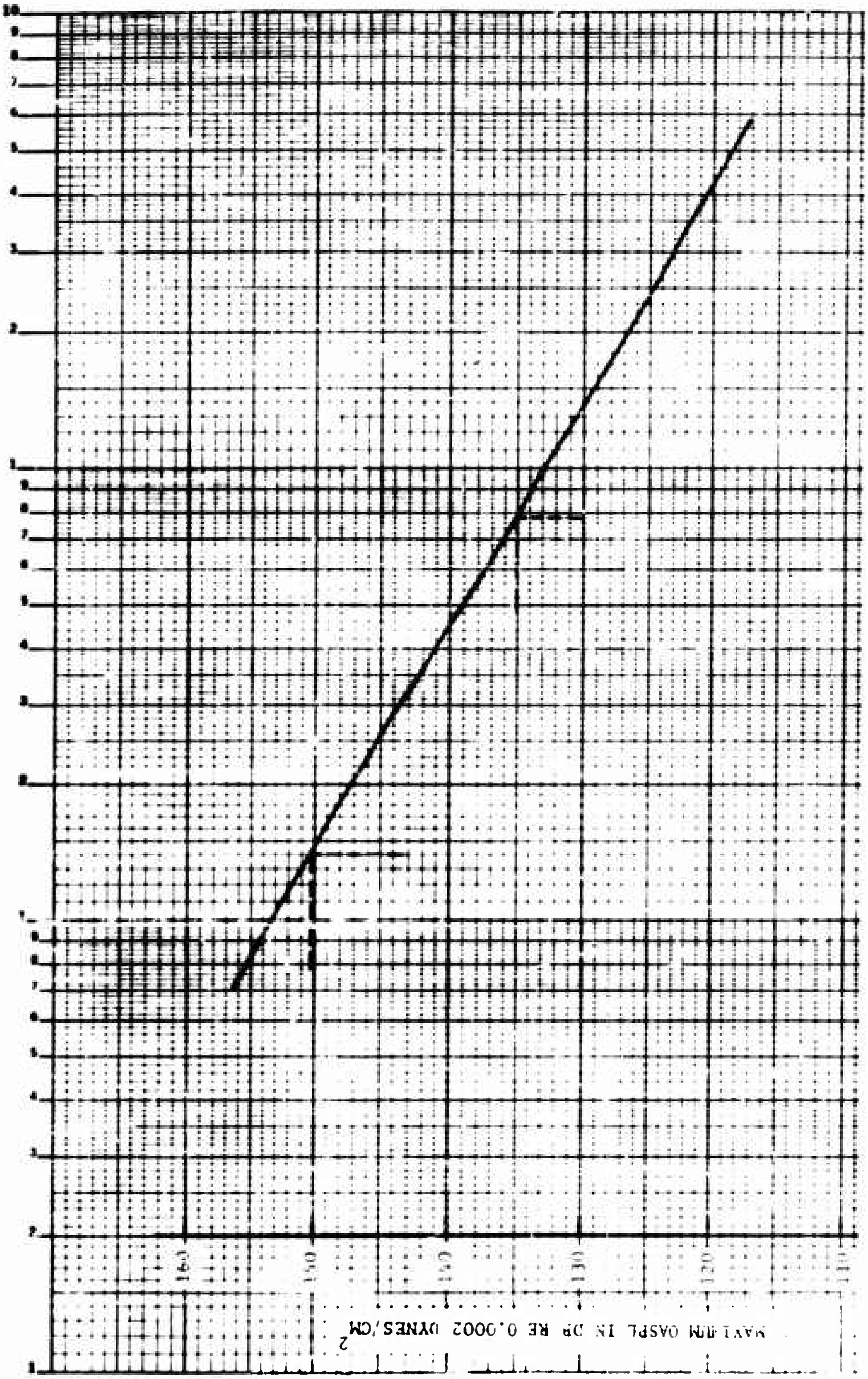


FIG. 5-20 ESTIMATED MAXIMUM GROUND DISPLACEMENTS


10
9
8
7
6
5
4
3
2
1
9
8
7
6
5
4
3
2
1
9
8
7
6
5
4
3
2
1
160
150
140
130
120
110
MAXIMUM OASPL IN DB RE 0.0002 DYNES/CM^2

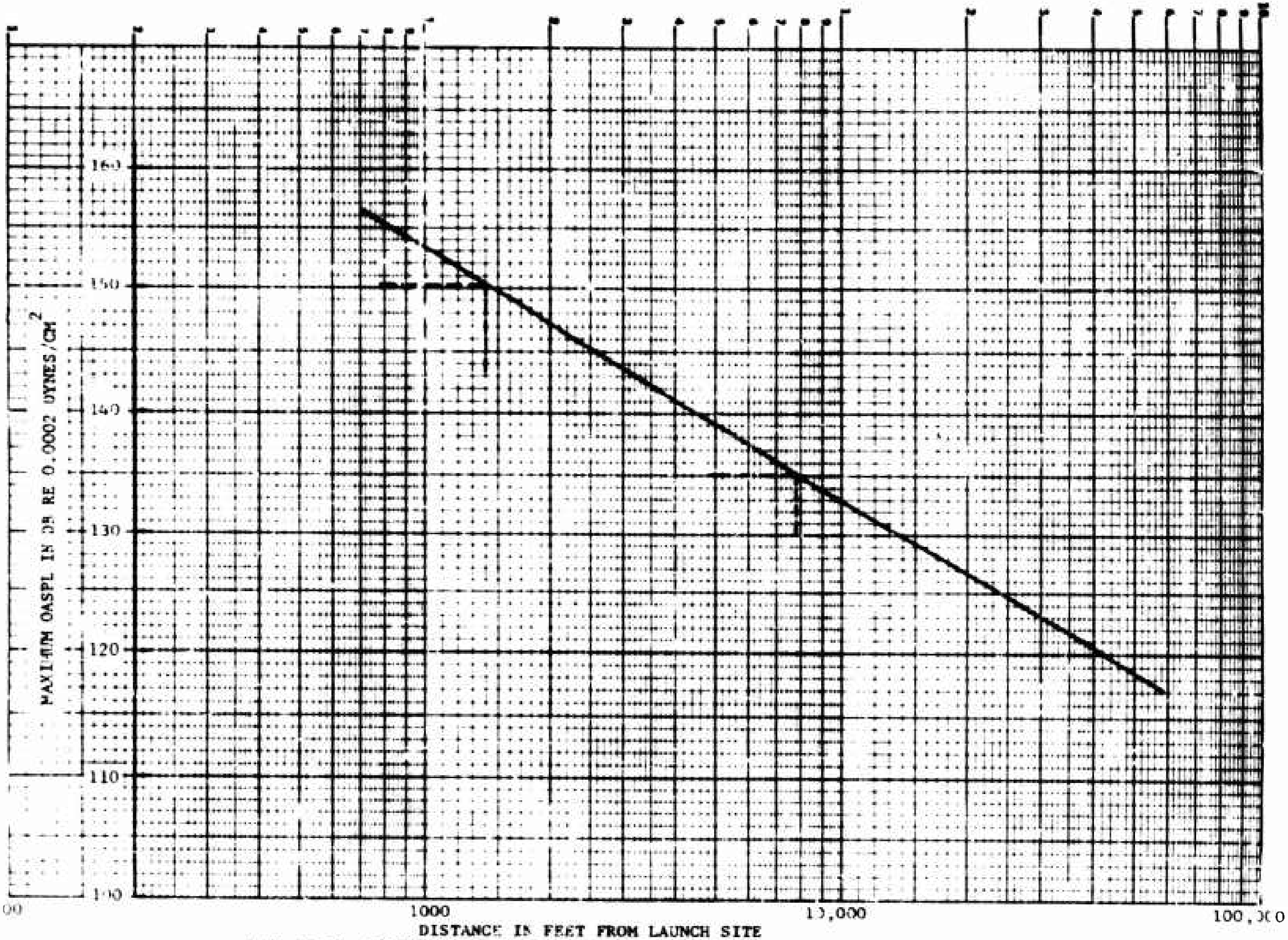


FIG. 5-21 ESTIMATED MAXIMUM OVERALL SOUND PRESSURE LEVELS

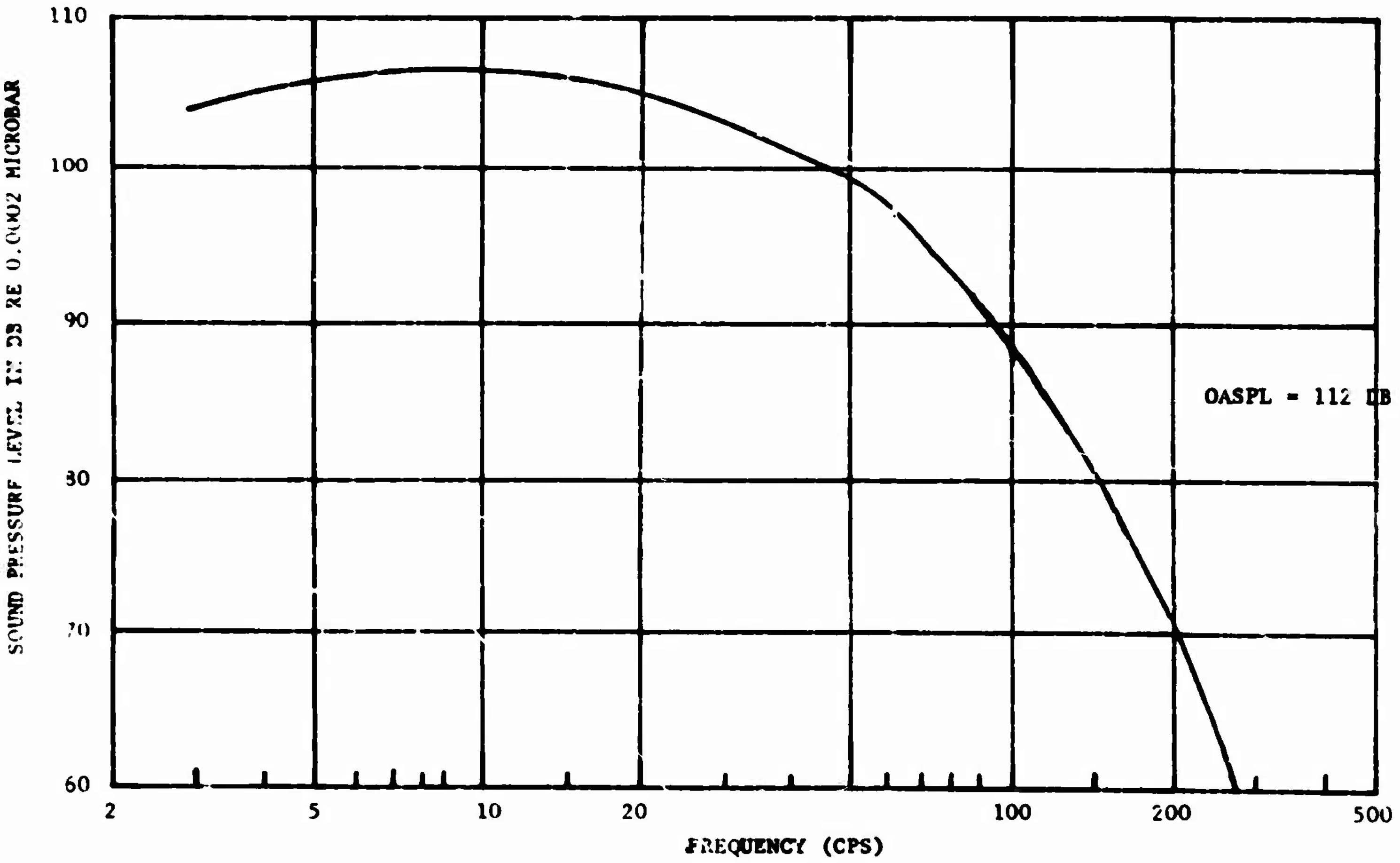


FIG. 5-22 ESTIMATED OCTAVE BAND SOUND PRESSURE LEVELS INCIDENT ON COMMUNITY

The equivalent sound pressure level in the 300/600 cps band is 86 db (using Fig. 4-27) and the equivalent noise exposure (ENE) 104 db. Similarly (from Fig. 4-29) the incident noise spectrum is adjusted -5db for 1 minute exposure and results in level rank J.

The ENE indicates that, at the same location, one-base housing would be acceptable; however, for off-base housing, the level is marginal. The level rank indicates that vigorous complaints and legal action might result from the noise levels incident in the community. Prevailing climatic conditions may either lessen or increase the sound pressure levels in the community.

5.2.2 Explosions

A vehicle explosion while on the ground and an explosion in the air will have different consequences. In a surface explosion, when a vehicle collapses just as it leaves the pad, the propellant tanks of the booster stage would burst with subsequent mixing of oxidizer and fuel. The mixed propellant would explode upon ignition and the remainder of the fuel would burn intensely. The second stage propellant tanks would be engulfed in flame and would soon rupture to spill their contents into the flaming pool of propellant. The upper stage propellants would not be mixed upon entering the flames and the reaction should be limited to burning rather than a second explosion.

The explosive hazard of this series of events is determined by the quantity of mixed propellant and its energy of explosion. Without experimental data, planning of site layout for this possible event is based on two separate concepts: (1) arbitrary designation of 10% TNT equivalence, and (2) a fourth root function derived from scale model tests. Ten percent TNT equivalence is the judgement used in Saturn launch site planning[25] and represents a conservative estimate. The fourth root function was derived by Space Technology Laboratories[32] from experimental data obtained by Broadview Research Corporation on Atlas configurations. The mixing problems and arrangement of propellant tanks on the Atlas are radically different than those proposed for the Saturn and Nova-type vehicles so that the results of Atlas tests are also thought to be conservative. Figure 5-23 shows the overpressures obtained by the two different methods.

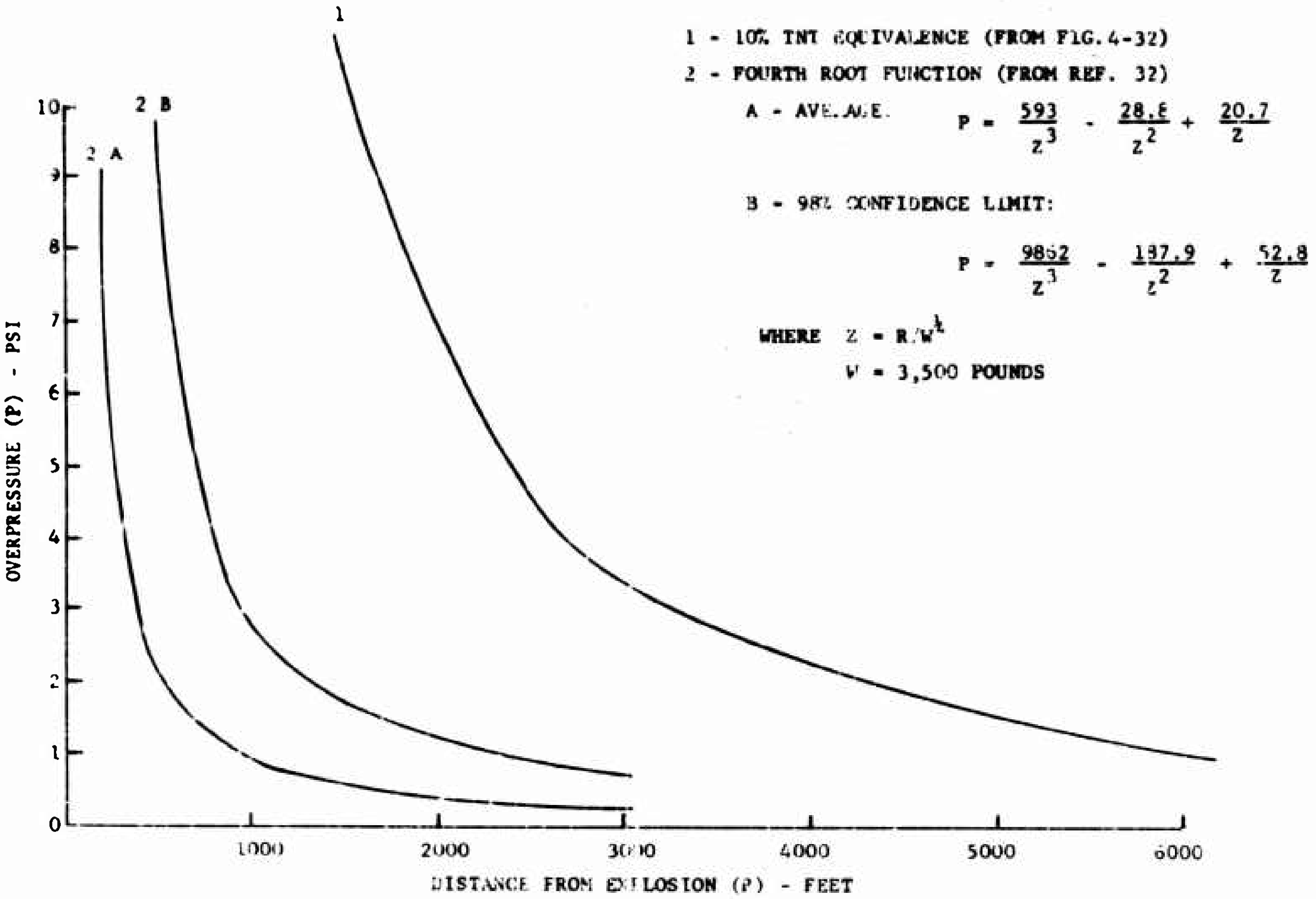


FIG. 5-23 OVERPRESSURES EXPECTED FROM A BOOSTER EXPLOSION ON THE SURFACE

FIG. 5-23 OVERPRESSURES EXPECTED FROM A BOOSTER EXPLOSION ON THE SURFACE

An explosion on the launch pad leads to the highest possible overpressures at ground level near the source. Cratering of the earth and ground shock phenomena will also occur. Figure 5-24 shows the crater dimensions which result from a surface explosion based upon a burst of TNT over dry soil. For a hard rock or concrete surface the effects will be about 80% of these in dry soil. The crater dimensions to be expected for a Nova-type vehicle will be:

Apparent crater diameter	(D_a)	96 ft.
Depth	(H_a)	16 ft.
Diameter of Rupture Zone	($D_r = 1.5\ D_a$)	144 ft.

The diameter of rupture zone is considered to be the limit of ground damage. Figure 5-25 gives the relationship between shock velocity, peak wind velocity, dynamic pressure and reflected pressure following an explosion near the ground.

The second type of accident which can occur is a vehicle explosion in the air shortly after launching. Figure 5-1 illustrates the relationships between velocity, acceleration, altitude and fuel consumption during the first ten seconds of vertical flight. These curves were computed assuming constant thrust for successive one second intervals. The vehicle conditions at 500 and 1000 ft. are:

Altitude	500 ft.	1000 ft.
Time to reach this altitude	7.5 sec.	10.2 sec.
Propellant remaining	3.235×10^6 lbs.	3.140×10^6 lbs.
Velocity	130 ft/sec	175 ft/sec
Acceleration (net)	0.570g	0.595g

Unburnt fuel would complicate and increase the toxic hazards of the incident. Certain aspects of the problem can be qualitatively defined without complete information regarding the accident. The liquid propellants will be subject to dispersion prior to explosion as well as after. Figure 5-26 shows a reasonable distribution of particle sizes of globules during the mishap.

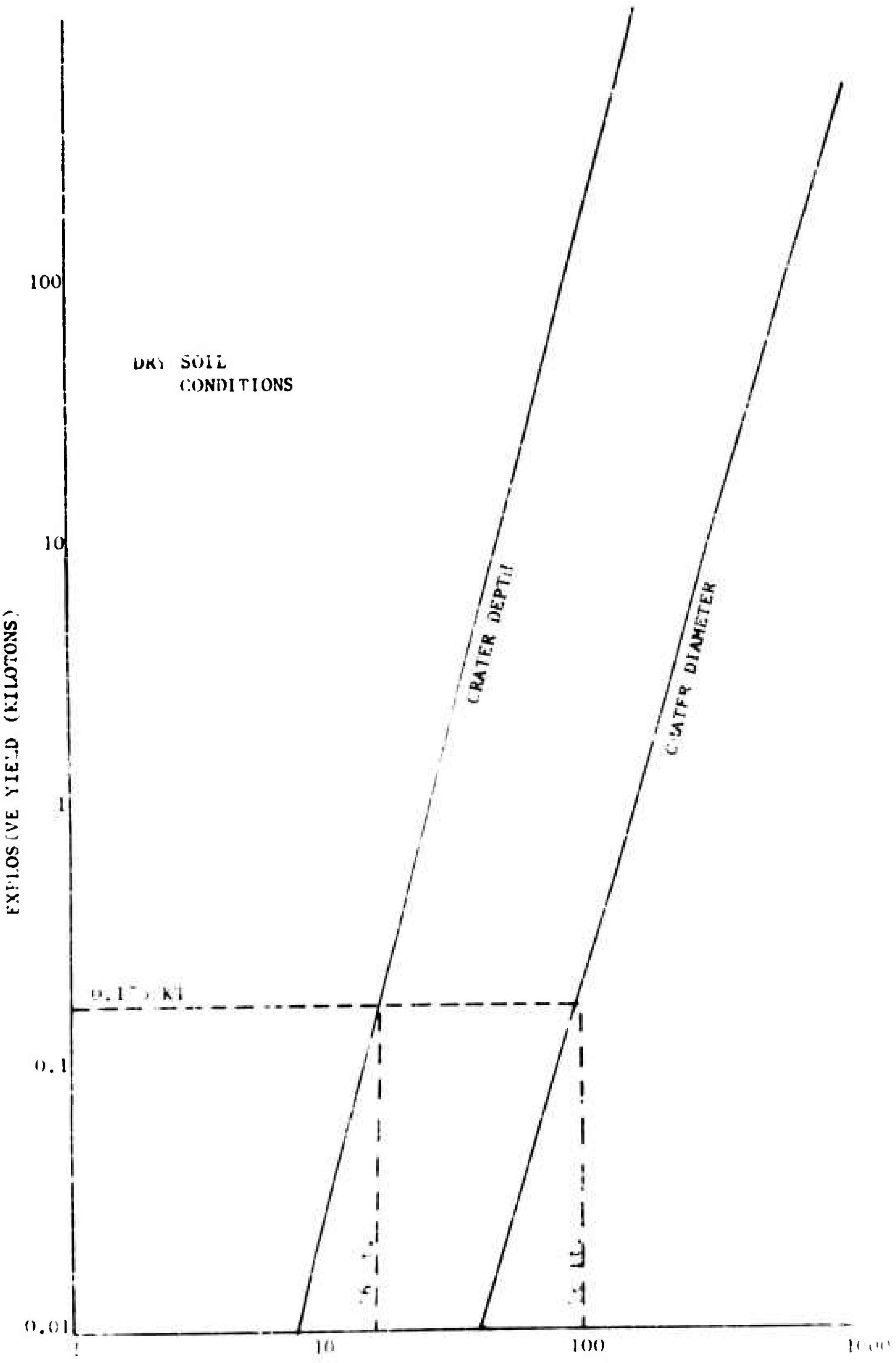


FIG. 5-24 CRATER DIMENSIONS FOR A CONTACT SURFACE BURST

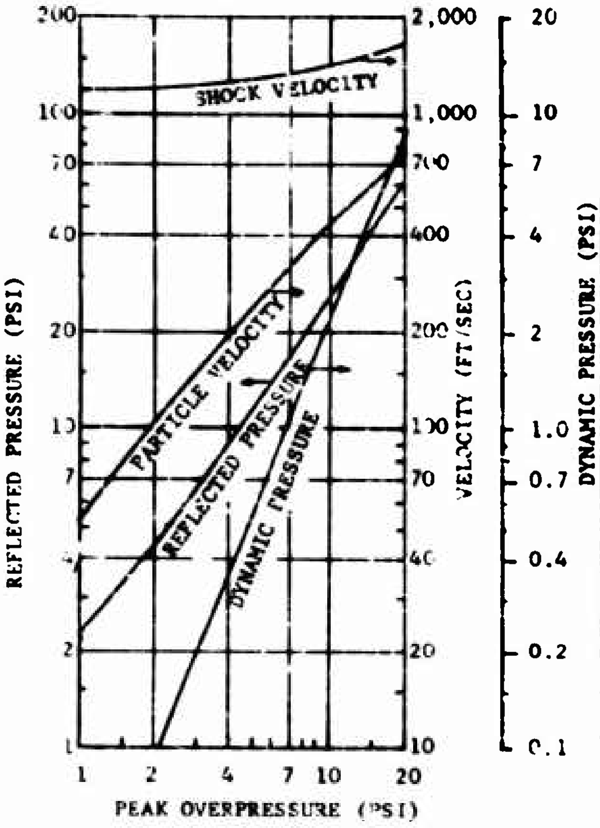


FIG. 5-25 BLAST WAVE CHARACTERISTICS AT THE SHOCK FRONT[23]

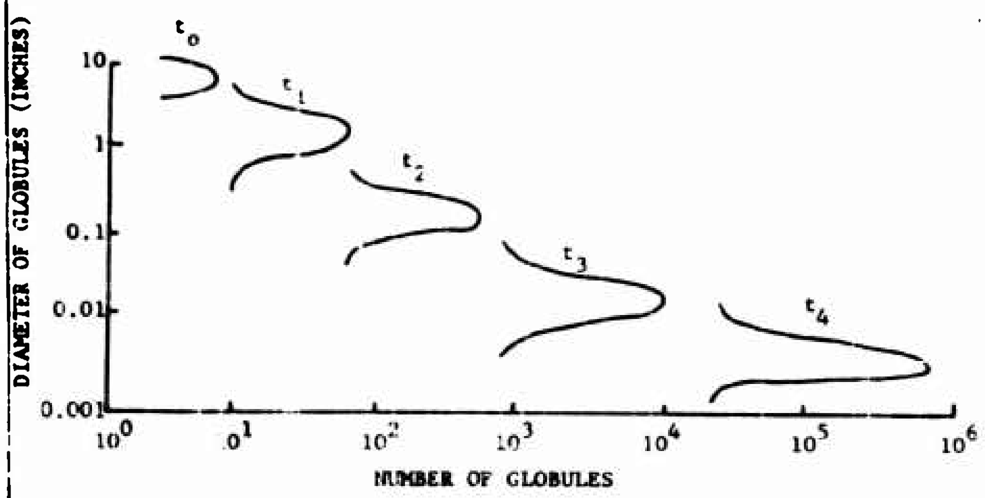


FIG. 5-26 GLOBULE SIZE DISTRIBUTION

The time intervals correspond to the following stages

t_o	Prior to accident ($t = 0$)
t_1	Immediately following destruction
t_3	Immediately following explosion of mixed propellant
t_4	Particles remaining unburned at this time

Only about one per cent of the propellant will mix prior to an explosion. As the tanks rupture, the velocity of the air past the vehicle will break the liquid into globules of a wide size range. and it will also cause air intermixing of oxidizer and fuel particles. Fuel which comes into contact with the ignition source will burn and in turn ignite any masses of mixed propellant which forms. Considering the short interval of time involved, a reasonable assumption of the quantity contributing to an explosion is one percent.

An explosion of a vehicle in the air may result due to a malfunction within the vehicle or from a destruct signal originating in range control. The latter case is more likely after the vehicle has reached an altitude of 500-1000 feet. The destruction device would presumably cause the propellant tanks to rupture and also provide a source of ignition. A fire would likely begin in the fuel, burning in air or oxidizer vapor, and would initiate the explosion of the mixture of oxidizer and fuel. The heat from the subsequent explosion would create convection currents above it and propel flaming liquid masses through the unburnt propellant. The heated air above the explosion would speed the evaporation of any particles. Particles which are too large to completely vaporize would fall back into the flames and burn. All this time the propellant is traveling upwards.

Using Fig. 5-26 the numerically predominating particle size after explosion will be about 0.01 inches in diameter. Based upon experimental relationships determined by the U. S. Bureau of Mines[33], the RP-1 requires 1 second to burn (0.3 in/sec), the hydrazine requires 7.6 seconds (0.04 in/sec) and the UDMH about 2 seconds. During this time the burning particles will have ignited other particles in their path.

Explosions at 500 or 1000 ft. above the launch pad will result in a shower of both burning and unburned propellant onto the pad. This deluge will fall well within the boundaries of explosive hazard dictated by the surface burst. The principal hazard of an air burst is deemed to be the flaming propellant falling on the pad.

5.2.3 Toxicity

Toxicity hazards for the hypothetical launch vehicle will be primarily due to utilization of the storable propellants in the second and third stages. The first stage liquid oxygen--RP-1 propellant combination does not represent a toxic hazard. On the other hand nitrogen tetroxide, hydrazine, and UDMH are all quite toxic having MAC's of 5, 1, and 0.5 ppm respectively.

Figures 5-27, 5-28 and 5-29 represent Sutton equation estimates for the downwind concentrations resulting from the release of 50,000 pounds of each of the upper stage propellants for moderate inversion and average atmospheric conditions and various modes of release. The validity of the Sutton's equation over such great distances is questionable, but it is considered to be the best possible estimate at this time.

The missing link is an indication of the maximum incident which can or would possibly occur. A malfunction of the first stage system could lead to the expulsion of all of the second and third stage propellants. This would be the worst case and involve scaling up the peak concentration values presented in Figs. 5-27, 5-28, and 5-29 by factors of 26, 12, and 12 respectively, and utilization of the instantaneous source.

The energy released during malfunction would probably be sufficient so that a great deal of the fuel would be burned. UDMH and hydrazine would continue to burn due to the presence of atmospheric oxygen. The hazard involved can be classed with the one previously discussed for RP fuel since both have about the same volatility. On the other hand N_2O_4 is quite volatile and could readily be vaporized to NO_2 as the result of partial reaction with spilled hydrazine-UDMH or from first stage detonation. The uncombined vaporized oxidizer would be dispersed by the atmosphere. The greatest toxic hazard likely to occur is an instantaneous release of all of the N_2O_4 within the second and third stages.

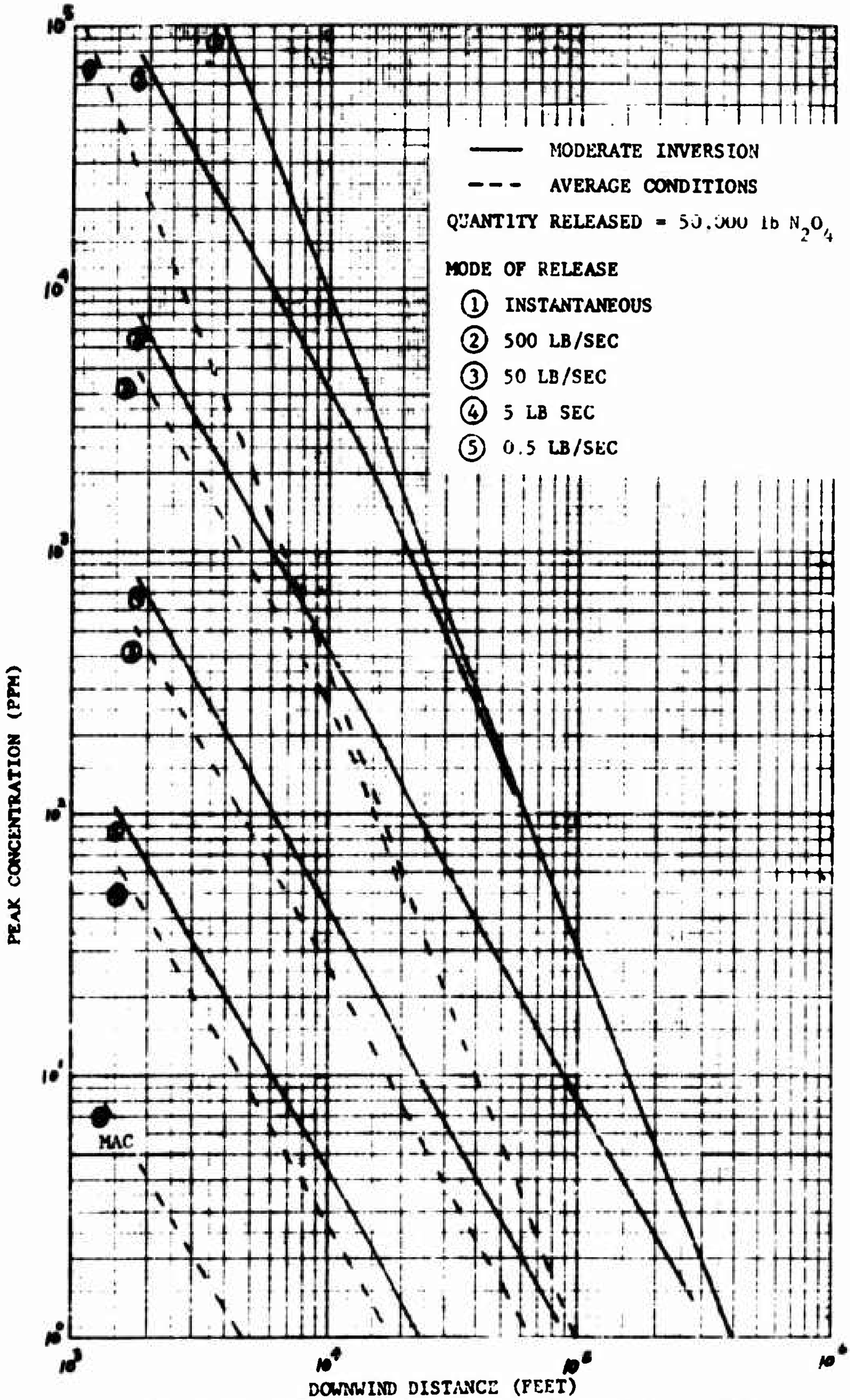


FIG. 5-27 PEAK CONCENTRATIONS FOR NITROGEN TETROXIDE

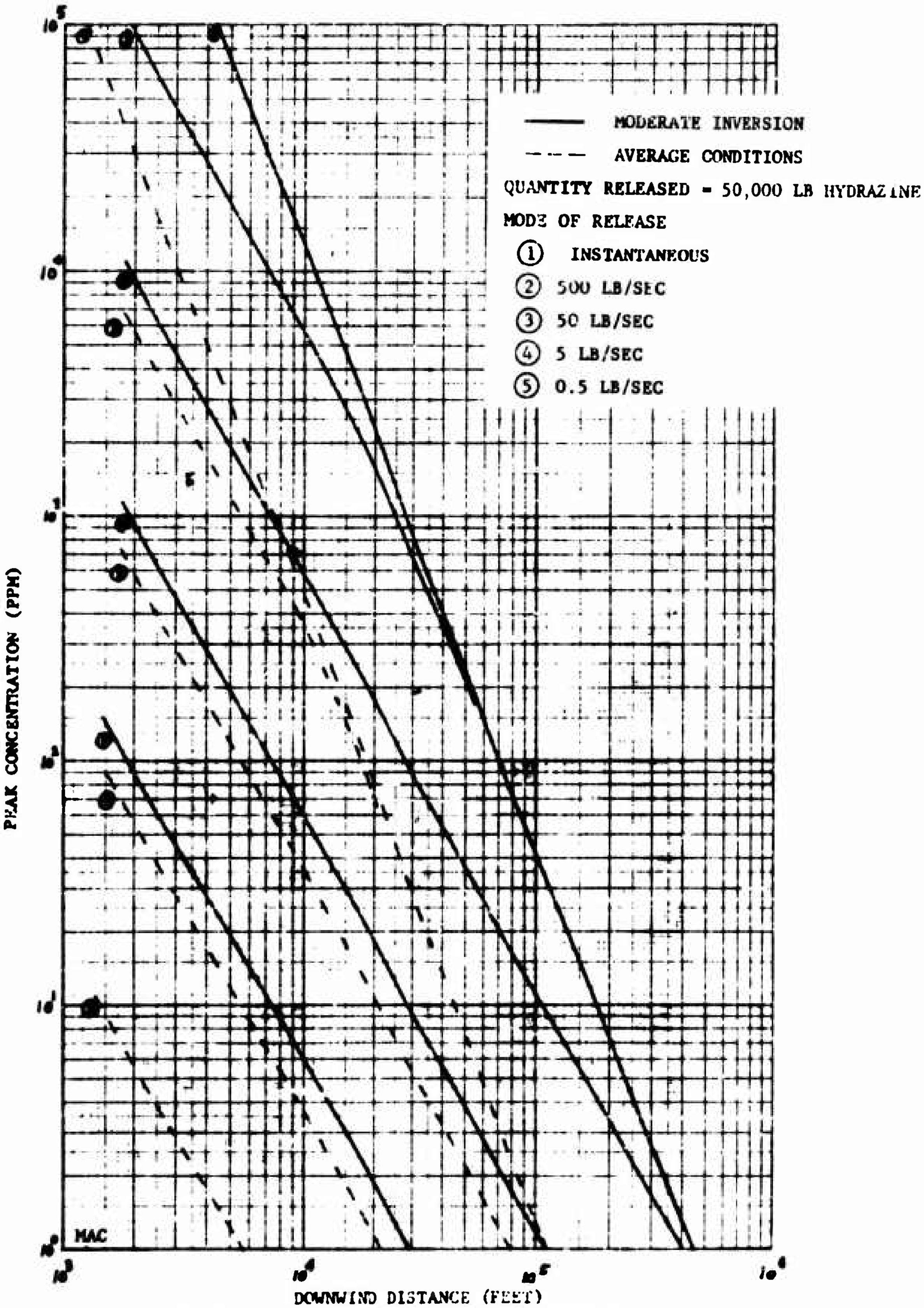


FIG. 5-25 PEAK CONCENTRATIONS FOR HYDRAZINE

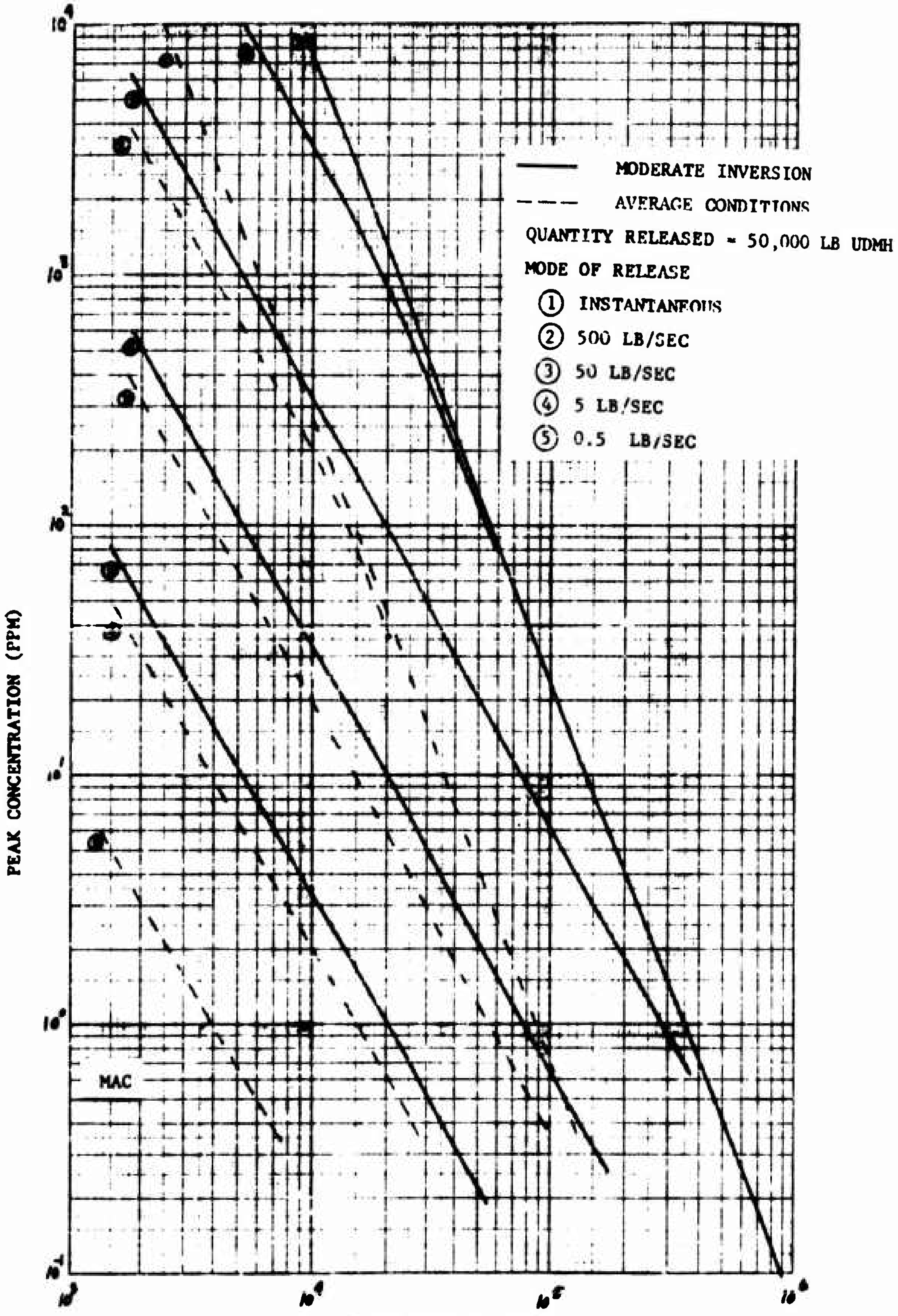


FIG. 5-29 PEAK CONCENTRATIONS FOR UDMH

From Fig. 5-27 and the scaling factor of 26 it is obvious that the quantity of N_2O_4 to be utilized within the hypothetical rocket system presents a hazard to the nearby town (25 miles or 132,000 feet). Here the instantaneous release of all the N_2O_4 could result in a peak concentration of about 390 ppm for a moderate inversion or 9 ppm for average atmospheric conditions. The durations of exposure (obtained from Fig. 4-41) for each of these conditions are approximately 1000 and 2000 seconds, respectively. Assuming that the eight hour MAC exposure (1.44×10^5 ppm-sec) could be received on the basis of a single emergency exposure during the indicated times, both conditions would be tolerable at 25 miles. However, the shorter duration and higher concentration during the inversion makes launch inadvisable under this condition.

If the vehicle has left the pad and obtained an altitude of greater than 250 feet prior to the release of all the N_2O_4, an additional dilution will be evidenced. The expected dilution will vary from zero to a factor of 3 for a 1,000 foot release. This indicates that any initial source rise due to heat content would be ineffective in reducing the concentration at the town. However, an altitude release (1000 ft) would reduce the predicted concentration to about 5 ppm which is the MAC.

For a toxicity standpoint launch should be confined to lapse or average atmospheric conditions with provisions made for evacuation of the near off-site inhabitants downwind of the launch site.

5.3 SELECTION OF LAUNCH SITE

The hypothetical initial conditions were purposely chosen to make the task of site selection difficult. The hypothetical government reservation considered for a launch site is marginal insofar as the safety of the nearby town (25 miles) is concerned. This situation typifies site isolation requirements for the larger vehicles of the future. The major threats to the civilian community stem from the large quantities of toxic propellant carried aboard the vehicle and from focussing of high intensity sound. The available reservation will accomodate a launch complex for the hypothetical vehicle, but certain constraints upon launching operations are required.

It is necessary to repeat at this point that all of the material in Section 5 is presented purely to illustrate the important hazard considerations in the siting process. This presentation should not be construed as the complete site selection procedure. Economic, legal, and logistic factors will also influence site selection. Section 4 of this report together with the preliminary Aeronutronic reports (Refs. 1, 2, 3, and 4) provide the background data for a more thorough hazard evaluation.

5.3.1 Location of Launch Facilities

In addition to the launch complex itself, which is specified in the next section, a host of supporting facilities are required at the launch site. These facilities include a vehicle assembly building, instrument calibration and repair shops, liquid oxygen generating plant, administration building, technical and biomedical laboratories, personnel services building, toxic propellant storage area, fuel storage area, electrical power generating station and/or substation, instrumentation for range safety, communication trunk lines, water storage tanks, and other related logistic facilities. Tolerable locations for some of these facilities are determined from the results of the hazards evaluation.

Before considering facility locations it is necessary to postulate the worst probable accident, and to estimate the damage to surroundings. This will essentially be a matter of conjecture since the events following an abrupt total loss of a vehicle can only be imagined.

A maximum accident on the launch pad is conceived as a sudden collapse of the fully tanked missile such that all tanks discharge under pressure their contents (3.0 million pounds) as overlapping pools on a flat surface. The propellants ignite instantly, engulfing the missile with flames within a few tenths of a seconds. Although the liquid oxygen from the booster vaporizes quickly, the fuel will cause a severe fire. The pools of propellant are turbulent. A distinct fireball will form and will be aggrevated by the release and combustion of the upper stage fuel. After a short period of time, the structural members of the vehicle may ignite and burn at a much higher temperature than the fuel fire. The thermal effects of the fire will prevail for several minutes.

A detonation can be presumed to occur at approximately three seconds, with a TNT equivalence of 10 per cent of the propellant weight. Any structure hardened to less than 40 psi overpressure will be damaged within a radius of 500 feet. At 2500 ft., structures designed for less than 2 psi will be damaged, and a damaging overpressure of 0.5 psi will be felt at 5000 feet. A 150 ft. crater will be created, with debris and flaming propellant thrown in all directions.

Toxic fumes from the upper stage propellants will pollute the area. The bulk of the fumes, primarily NO_2, will be driven upward in a chimney of hot gases, blossoming outward at altitudes above 500 feet.

Even during a normal launching it will be necessary to contend with the critical sound pressure levels of 135 db and 150 db at distances of 8000 ft. and 1400 ft., respectively. Acoustically-induced ground displacements will require that building structures be situated at least 2000 ft. away from the launch stand to avoid structural damage.

The storage of propellants appears to be one of the least hazardous aspects of launch operations. Filled or pressurized propellant storage tanks should not be subjected to overpressures greater than about 1.2 psi. Thus, a minimum separation of about 3000 ft. is required between any propellant tanks and the launch stand regardless of the quantity stored, unless blast resistant barriers are employed.

The only practical means of protecting storage tanks from fragmentation is by dispersion and separation of tanks or by utilizing natural barriers when possible. Since fragments having the maximum range will strike at an elevation angle of about 45 degrees, or higher for an altitude burst, the barriers would have to be very tall. Increased separation appears as a more reasonable alternative.

The ready storage areas are located within the launch complex and are discussed in the next section. Bulk storage requirements, for purposes of illustration, are assumed to be approximately twice the vehicle requirements; or essentially 4 million pounds of liquid oxygen, 2 million pounds of RP-1, 1.5 million pounds each of hydrazine and of UDMH, and 2.5 million pounds of nitrogen tetroxide.

Quantity-distance data (derived from Fig. 4-30 for the bulk storage of propellants is given in Table 5-III. The quantity of liquid oxygen required demands an on-site generating plant which should be farthest removed of any of the propellant storage areas from the launch complex. Official quantity-distance data for nitrogen tetroxide provide for only one-tenth of actual requirements. Separation distances between adjacent fuel and oxidizer storage areas should be a minimum of 7500 feet. The distance adopted for separation between the non-toxic storage areas and buildings, roads or other places of habitation is 1000 feet. For toxic propellant storage, the required separation is dependent upon terrain and weather conditions.

TABLE 5-III

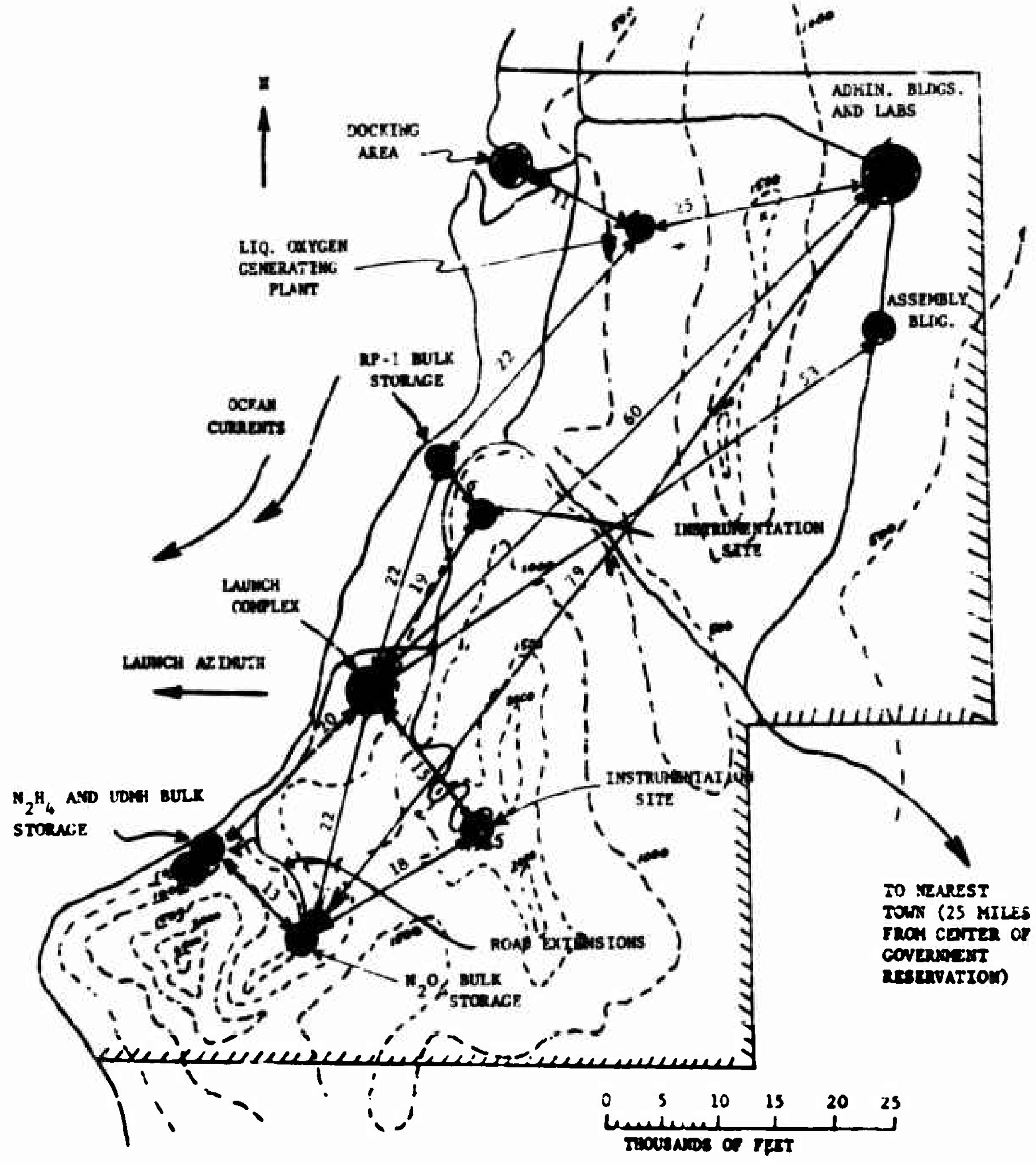
BULK PROPELLANT STORAGE

Bulk Storage Area	Individual Tank Capacity (million lbs)	No. of Tanks	Separation Between Tanks (ft)	Distance from Launch Complex (ft)
N_2O_4	0.25	10	300	7500
N_2H_4	0.50	3	400	6500
UDMH	0.50	3	400	6500
RP-1	0.50	4	400	7000
LO_2	1.0	4	500	8000

The locations chosen for the various launch facilities are indicated in Fig. 5-30. Substantial safety margins were included where possible and careful consideration was given to terrain features and to predominant weather patterns.

5.3.2 Launch Complex Specifications

The launch complex consists of the launch pedestal and blast deflectors, umbilical tower, track mounted service tower, launch control blockhouse, ready storage tanks for each propellant, replenishing tanks for each cryogenic propellant, propellant transfer systems, holding ponds, and instrumentation for range safety, launch control, and preflight vehicle checks. Tentative separation distances based upon the preliminary hazard evaluation, and natural barriers are shown in Fig. 5-31. The construction features of the complex would be specified by an architect-engineer after the final siting is accomplished. The location of the whole complex is as shown in Fig. 5-30.



DISTANCES SHOWN REPRESENT THOUSANDS OF FEET

FIG. 5-30 FACILITY LOCATIONS

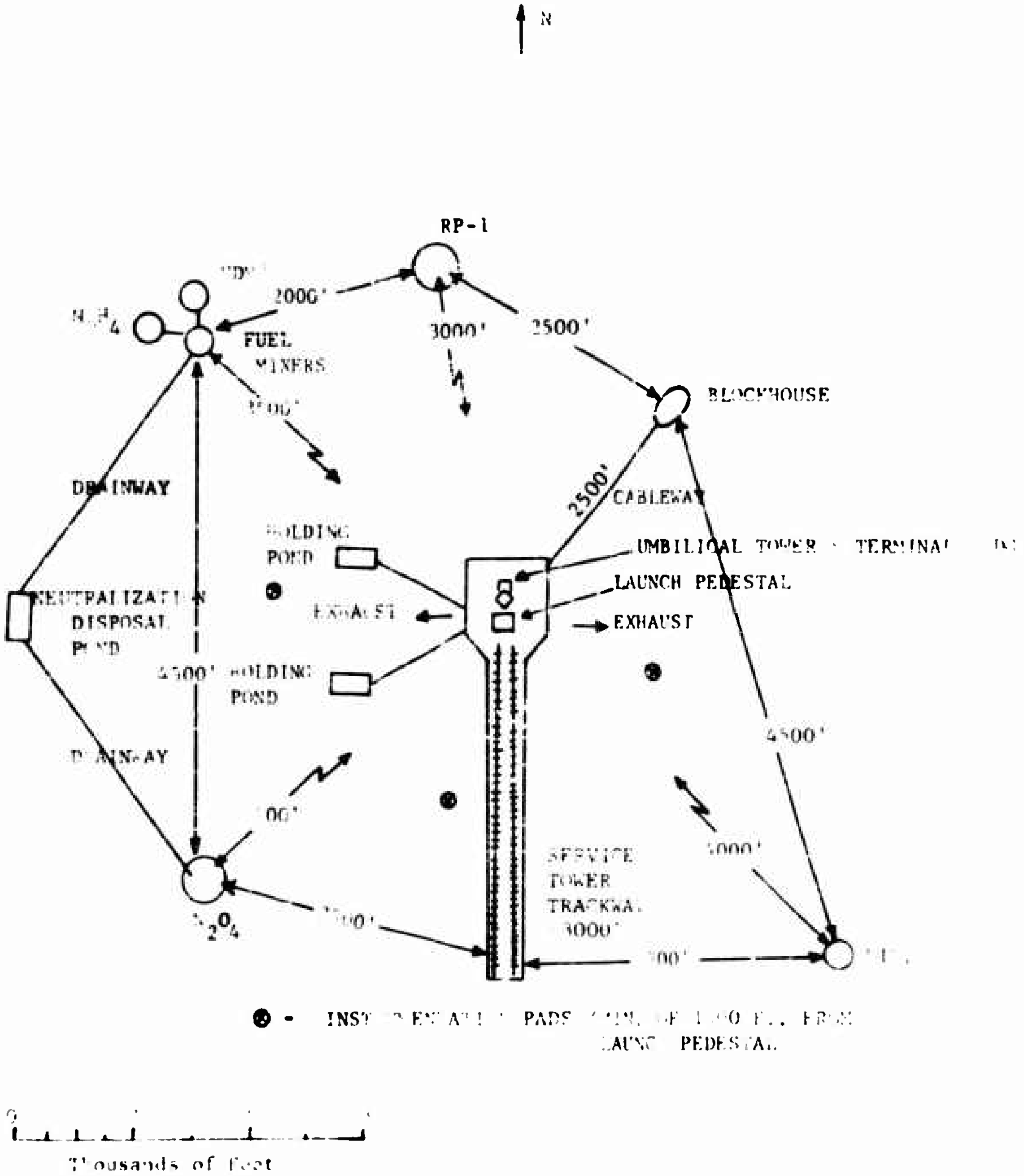


FIG. 5-31 LAUNCH COMPLEX

The launch pad is located on a downgrade from the blockhouse so that a major accident with extensive fuel spills would not endanger blockhouse personnel. The concrete apron on the launch pad slopes downward from the center to facilitate drainage or washdown in the event of spills. The launch pedestal is constructed so that the thrust load is distributed among structural members resting on bed rock. The umbilical tower is designed to withstand a normal launching operation, but is considered expendable in launch pad disasters. Supporting facilities both within and external to the launch complex are not in line with the exit directions of the flame deflector.

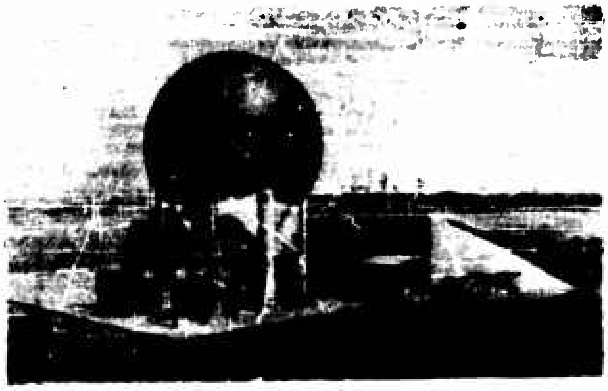
The inhabited blockhouse is separated 2500 feet from the launch pad, and is designed to withstand a peak overpressure of at least 50 psi. Instrumentation signal cables are routed to the launch pad through an underground tunnel sloped to preclude drainage of spilled propellants toward the blockhouse.

Toxic propellant detectors are installed in all areas frequented by personnel, and particularly in and around the blockhouse, cableway, launch stand, service tower, propellant storage areas, and propellant disposal pits. These instruments detect N_2O_4, N_2H_4, and UDMH vapors in air to levels below the respective MAC's of 5, 1, and 0.5 ppm. Equipment is provided in the blockhouse to monitor all of the detectors continuously. This console also contains indications of the local micrometeorological conditions.

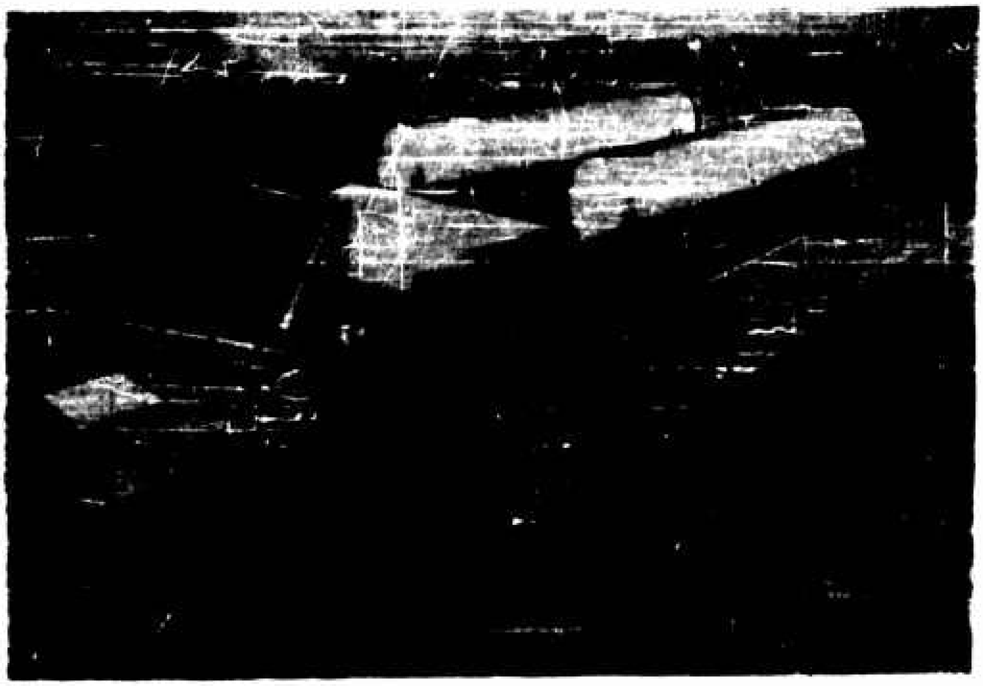
From a safety standpoint, the transfer of propellant from bulk storage to ready storage areas is best accomplished by pipeline. Transfer from ready storage to the vehicle is also by pipeline via the umbilical tower, and is automated so that the process may be initiated and controlled from the blockhouse propellant loading panels.

Each propellant ready storage area is enclosed by a retaining wall to contain 125% of the volume of the tanks in case of rupture. This retaining wall is earth reveted on the side exposed to the launch pad. The tanks are insulated and partial weather protection is provided for the transfer system consisting of pumps, valving and associated plumbing. An illustration of propellant storage areas planned for the Saturn launch complex are shown in Fig. 5-32.

Fortunately the probability of a large propellant spill is low during routine storage and transfer conditions. Although some spillage is inevitable it will be in small quantities or at slow rates so that, for toxic propellants, the MAC will only be exceeded, if at all,



A. LIQUID OXYGEN



B. RP-1 FUEL

FIG. 5-32 SATURN PROPELLANT STORAGE AREAS[34] within a very small area downwind of the spill, and probably for only a short period. Personnel in these areas will normally be expected to wear protective clothing and to be familiar with emergency procedures requiring rapid evacuation and/or wearing of respirators.

The safety precautions to be observed in handling the propellants are well defined by the Liquid Propellant Information Agency and have been summarized in preliminary Aeronutronic reports[3,4]. This advice includes such matters as toxic propellant neutralization, waste disposal, respirators, protective clothing, eye showers, fire fighting, vapor detection systems, ear protectors, and warning devices.

Water is required for cooling the jet exhaust deflector, for neutralization of toxic propellant spills, for safety showers and general domestic use, for a deluge and sprinkler system and for fire-fighting equipment. Water should be available in amounts ten to fifty times the possible spillage of toxic propellant.

5.3.3 Launching Constraints

In the study of launch site hazards, it was found that the safety of the off-site civilian population is strongly dependent upon local meteorological conditions. The primary hazard stems from the huge quantities of toxic propellant involved, and the fact that the probability of a catastrophic spill increases greatly after the vehicle is fully loaded. The other effect is the focussing of acoustical energy and is a potential hazard on every normal vehicle launch.

The presence of on-site personnel can be regulated, protective equipment can be made available, and safety procedures can be enforced as necessary. Similar remedies are not practical for protecting off-site personnel. Consequently, it is necessary to restrict launch operations to times of favorable weather conditions.

The weather parameters which influence the off-site toxicity problem are atmospheric stability and wind direction. Conditions favoring vertical convective currents are favored to enhance the diffusion process and thus preclude the formation of a persistent cloud of high concentration. However, even when the lapse rate is not ideal for cloud dispersion, the town may still be safe when the wind is 30 degrees or more off course from the direction to the town.

The focussing, and resultant amplification, of sound energy into the nearby town is caused by the variation of sound velocity with altitude. It was shown in the hazards evaluation that for the weather conditions which occur most frequently, sound energy would most likely be focussed at a point about 15 miles from the launch area. However, it is necessary to monitor the local temperature and wind gradients for comparison with precomputed profiles that are known to cause the undesired focussing 25 miles into town.

Personnel movement and the conduct of normal activities will be constrained because of potential hazards at the launch site. Two sets of land use boundaries are considered: the launch hazard area and the missile hazard volume. The launch hazard area is defined as a semicircular area in back of the launch stand to a radius R and the 2R wide launch path which widens downrange for a limited distance by θ degrees on each side. Only authorized operating personnel are permitted inside the launch hazard area during launch. The boundaries for this area are chosen on the conservative side with some exceptions for expediency. For the illustrative example, reasonable choices are a radius R of 15,000 feet and an angle θ of 10 degrees, with the instrumentation site on the hilltop excluded. Personnel in the launch hazard area must be restricted to distances greater than 8000 feet from the vehicle during launch operations unless they are in the blockhouse, or otherwise protected.

When toxic propellants are used, the launch hazard area also includes a sector defined by the wind direction plus or minus ϕ degrees originating at the launch stand and extending X miles downwind. Both ϕ and X are strongly dependent upon atmospheric stability. For average atmospheric conditions (dry adiabatic lapse rate) ϕ and X may be chosen as 20 degrees and 10 miles, respectively. This area usually extends off of the reservation and must be cleared prior to vehicle propellant loading if the wind speed is great. For low wind speeds there may be sufficient time to evacuate and/or protect off-site personnel after a disaster has occurred.

The missile hazard space is defined as the volume originating at the launch point within which a vehicle or its fragements will be contained either as a result of its maxium aerodynamic/ballistic capacity or controlled flight termination. This space is based primarily upon the expected effects of destruct explosion on the number, weights, velocity, and trajectory of pieces, and upon the explosion effects on remaining fuel. The projection of the missile hazard on the ground normally would be expected to lie within the conservatively chosen launch hazard area, but could be larger.

REFERENCES

1. Oslake, J. J., Haight, N. L., Oberste, L. J., Acoustical Hazards of Rocket Boosters, Vol. I - Physical Acoustics, Aeronutronic Technical Report No. U-108:96, Nov. 1960.

2. Oslake, J. J., Haight, N. L., and Oberste, L. J., Acoustical Hazards of Rocket Boosters, Vol. II - Effects on Man, Aeronutronic Technical Report No. U-108:97, Nov. 1960.

3. Oslake, J. J., Getz, R. J., Romine, R. A., and SooHoo, K., Explosive Hazards of Rocket Launchings, Aeronutronic Technical Report No. U-108:98, Nov. 1960.

4. Oslake, J. J., Dobrin, S., and Romine, R. A., Toxic Hazards of Rocket Propellants, Aeronutronic Technical Report No. U-108:99, Nov. 1960.

5. Aldrich, D. E., and Sanchini, D. J., The Development of High-Thrust Engines for Large Vehicles, American Rocket Society Paper 1414-60, Presented at the ARS Fifteenth Annual Meeting, Washington, D. C., Dec. 5-8, 1960

6. Cole, J. N., Von Gierke, H. E., Kyrazis, D. T., Eldred, K. M., and Humphrey, A. J., Noise Radiation from Fourteen Types of Rockets in the 1,000 to 130,000 Pounds Thrust Range, Technical Report, WADC 57-354, Astia AD 130794, Dec. 1957.

7. Chobotov, V., and Powell, A., On the Prediction of Acoustic Environments from Rockets, Astia Document AD 217 248.

8. Dorland, W. D., Noise Radiated from Single and Multi-Engine Tests of a Rocket Motor Developing 500 Pounds of Thrust, ABMA RPT DTR-TM-1-59, 16 Nov. 1959.

9. Sutherland, L. C., Future Trends in Acoustic Environment of Manned Space Vehicles, Paper Presented at 60th Acoust. Soc. Am. Mtg., Oct. 1960.

10. Cole, J. N., England, R. T., and Powell, R. G., Effects of Various Exhaust Blast Deflectors on the Acoustic Noise Characteristics of 1,000 Pound-Thrust Rockets, (Unpublished WADD Technical Report 60-6), Aug. 1960.

REFERENCES (CONT'D)

11. Bolt, Beranek and Newman, *Estimate of the Sound and Vibration Fields During Static Firing of a Saturn Vehicle and Analysis of the Damage Problem*, RPT. 679, Jan. 1960.

12. Ingard, U., *The Physics of Outdoor Sound*, Fourth Annual Noise Abatement Symposium, 4, 11 (1953).

13. Perkins, B., Lorrain, P., and Townsend, W., *Forecasting the Focus of Air Blasts Due to Meteorological Conditions in the Lower Atmosphere*, BRL Rpt. 1118, Oct. 1960.

14. Sabine, H. J., Raelson, V. J., and Burkhard, M. D., *Sound Propagation Near the Earth's Surface as Influenced by Weather Conditions*, Technical Report, WADC 57-353, Part III, Aug. 1959.

15. Nyborg, W. L., and Mintzer, D., *Review of Sound Propagation in the Lower Atmosphere*, Technical Report, WADC 54-602, Contract AF 33 (616)-340, Project No. 7212, Aero Medical Laboratory, May 1955.

16. Willis, D. E., and Wilson, J. T., *Maximum Vertical Ground Displacement of Seismic Waves Generated by Explosive Blasts*, Bul. of the Seismological Soc. of Am., 50, No. 3, p. 455, July 1960.

17. Harris, C. M., *Handbook of Noise Control*, McGraw-Hill Book Co, Inc.

18. Purcell, J. B., *Control of Airborne Sounds by Barriers*, Noise Control, Vol. 3, No. 4, July 1957.

19. Von Gierke, H. E., and Pietrasanta, A. C., *Acoustical Criteria for Working Spaces, Living Quarters, and Other Areas on Air Bases*, WADC TN 57-248, Nov. 1957.

20. Cole, J. N., and Von Gierke, H. E., WADC Technical Report No. 57-547, Sept. 1957.

21. Beranek, L. L., *Acoustics*, McGraw-Hill Book Co., Inc., New York, 1954.

22. Yuill, C. H., et. al., *Missile/Space Vehicle Launch Site Fire Protection Study*, Southwest Research Institute, June 1959, WADC Technical Report 59-464.

23. Glasstone, S., *The Effects of Nuclear Weapons*, U. S. Atomic Energy Commission, June 1957.

REFERENCES (CONT'D)

24. Cook, M. A., The Science of High Explosives, Reinhold Publishing Corp., 1958.

25. Hall, C. J., A Committee Study of Blast Potentials at the Saturn Launch Site, Report No. DMM-TR-9-60, ABMA, Redstone Arsenal, Alabama.

26. Private communciation with Mr. F. S. Forbes, Edwards AFB, 1 Feb 1961.

27. Robinson, C. S., The Present Status of the American Table of Distances, Army-Navy Explosives Safety Board Tech. Paper No. 1, Washington, D. C., 1 July 1945.

28. Ordnance Safety Manual, ORD M7-224, 15 May 1958. Ordnance Corps, Dept. of Army.

29. Research on the Hazards Associated with the Production and Handling of Liquid Hydrogen, U. S. Bureau of Mines, WADD Technical Report 60-141.

30. Patty, F. A., Industrial Hygiene and Toxicology, Vol I, General Principles, 2nd Rev. Ed., Interscience Publishers, Inc., New York, 1958.

31. Committee on Threshold Limits, American Conference on Government Industrial Hygienists, Threshold Limit Values for 1958, AMA Arch. Indus. Health, 18, p. 178, Aug. 1958.

32. Smalley and Anderson, The Explosive Potential of Liquid Oxygen in RP-1 Missiles, Space Technology Laboratory, Jan. 1959, Confidential.

33. Research on the Fire and Explosion Hazards Associated with New Liquid Propellants, Annual Report 1959-1960, U. S. Bureau of Mines.

34. Von Tiesenhausen, G., Ground Equipment to Support the Saturn Vehicle American Rocket Society Paper 1425-60, Presented at the ARS Fifteent Annual Meeting, Washington, D.C., Dec. 5-8, 1960.

35. Magill, P. L., Holden, F. R. and Ackley, C., Air Pollution Handbook, McGraw-Hill, Inc., New York, 1956.

36. Fission Products Field Release Test II, Air Force Special Weapons Center, TR-60-26, Kirtland AFB, New Mexico, Sept. 1960.

APPENDIX A

ACOUSTICAL FIELD MEASUREMENTS AT ROCKET LAUNCH SITES

A well-planned acoustical and vibration measurement program is an integral part of the site selection procedure for high-thrust rocket launch pads. The resultant data are also used to establish the physical separation and the structural characteristics of launch support and instrumentation facilities associated with the launch complex. Although generalized prediction techniques are satisfactory as a starting point, they are of limited accuracy in forecasting sound propagation phenomena at specific geographic locations. An experimental approach is invariable necessary to determine the propagation characteristics of the rocket noise spectrum as a function of the local soil, terrain and weather conditions.

Acoustical and vibration field measurements require the use of relatively sensitive laboratory equipment under generally adverse conditions. These measurements must be conducted concurrently with measurements of specific weather variables. A suggested program for obtaining the necessary field data is described in this appendix. Due consideration is given to transducer and recorder requirements, calibration and measurement techniques, and methods of processing and analysing the recorded data.

A three-phase measurement program is recommended.

Phase I measurements would yield the following acoustical characteristics of the subject rocket booster engine(s).

1. Far-field sound pressure levels (SPL)

2. Noise spectrum

3. Directivity patterns

4. Near-field SPL including pressure transients

<u>Phase II</u> measurements would be conducted to determine the following sound propagation characteristics in the vicinity of the subject launch site(s):

1. Atmospheric sound attenuation between a ground based noise source and preselected receiver positions for various meteorological influences.

2. Same as above except for an airborne noise source at preselected elevation angles.

3. Vibration damping characteristics of the ground and the resultant ground displacement at preselected locations.

<u>Phase III</u> measurements would be conducted during launch operations of the subject vehicle(s) to provide a history of

1. Near and far-field sound pressure levels.

2. Ground vibration level

3. Structural or equipment vibrations.

4. Sound pressure levels in nearby communities.

Phase I measurements are usually a necessary part of the missile or space vehicle development program and these data may be available from the systems contractor. However, some of these data, if obtained during static tests at the engine development site, may not be applicable because of high water/propellant ratios and possible differences in blast deflector configuration. Phase II data are quite critical in their influence on the final results. Phase III represents the challenge of obtaining a vast amount of meaningful data in a short period of time.

Large scale acoustical and vibration measurements are seldom conducted without limiting conditions which either control the methods of test and/or substantially influence the confidence in the resulting data. Typical limiting conditions are as follows:

1. Model scale data must be used due to the limited number of full scale tests available.
2. Acoustical and vibration measurements are considered secondary objectives during both static firings and launch operations.
3. Adverse weather conditions affect the instrumentation used in making the measurements.
4. Data are often obtained by personnel with little experience in this type of measurement.
5. Data acquisition systems must be operated by remote control.
6. Sound sources other than rocket engines must be used for propagation studies.
7. Community response is subjective and not always directly proportional to the noise exposure.

Because of these factors it is mandatory that the responsible test engineer maintain a complete record of all conditions which do not conform with good instrumentation practice as determined from a special pre-test check list.

Instrumentation Systems

Transducer requirements for Phases I, II, and III are described separately in the following paragraphs. Data recording and data analysis equipment are specified as part of a mobile instrumentation van which is used for all three phases.

The basic instrumentation system components for Phase I measurements are indicated in Fig. A-1. The sound pressure level is converted to an analog electrical signal by a microphone.

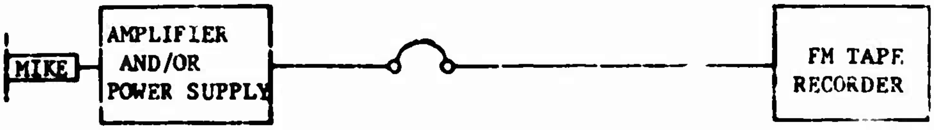


FIG. A-1 TYPICAL MICROPHONE RECORDING SYSTEM

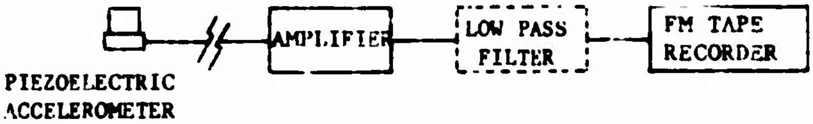


FIG. A-2 TYPICAL ACCELEROMETER RECORDING SYSTEM

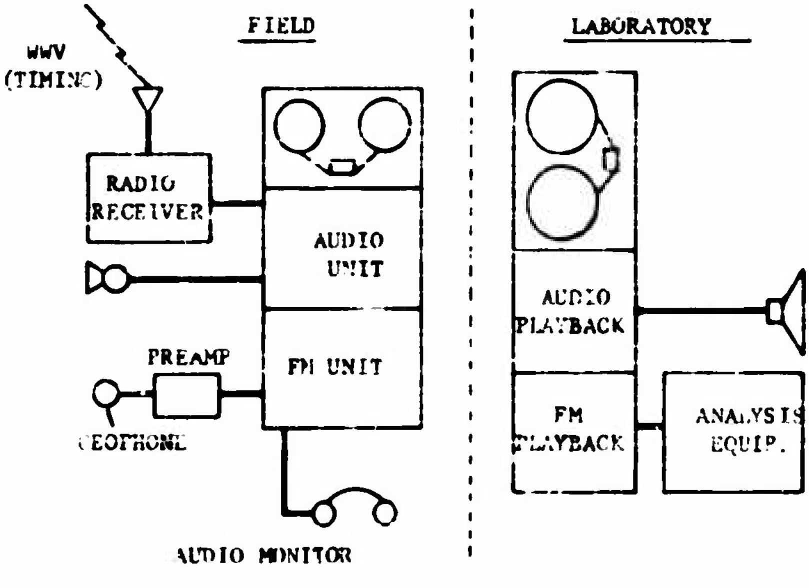


FIG. A-3 SEISMIC TAPE RECORDING SYSTEM

Microphones are to have a frequency response within ± 2 db from 5 to 10,000 cps. Several types with different sensitivities are necessary so that sound pressure levels ranging from 70 to 170 db can be measured. The linear dynamic range should be at least 50 db for each type. If suitable microphones are available that do not need special power supplies other than batteries, a large amount of cabling can be eliminated in making field measurements. Wind screens are also necessary.

For Phase II measurements, the following additional instrumentation systems are required:

1. Accelerometers and associated amplifiers.
2. Meteorological balloons and/or radiosondes.
3. Sound generating system.
4. Temperature gradient measuring system.
5. Wind speed gradient measuring system.
6. Turbulence measuring system.
7. Various standard weather instruments.
8. Seismic recording system.
9. Portable tape recording system.

A block diagram of an accelerometer system is shown in Fig. A-2. Lightweight piezoelectric type accelerometers and transistorized amplifiers are most satisfactory for operation in high intensity sound fields. The accelerometers should respond to vibration excitation irrespective of their orientation.

The sound generating systems should consist of controlled charges of different weights and capable of being ignited at various altitudes up to approximately 10,000 ft. Other missiles with less thrust and operating near the proposed site are also satisfactory sound sources.

The temperature gradient measuring system should consist of a series of temperature sensing devices (thermocouples) spaced logarithmically in height on 50 foot portable meteorological towers and connected in pairs so as to measure the temperature differences between adjacent levels on the tower.

The wind speed gradient system consists of high-speed cup anemometers located at approximately the same positions on the towers as the temperature instruments.

Wind fluctuations in speed and direction due to turbulence are to be detected by the combination of three transducers, a wind direction vane, a thermister anemometer and a high-speed cup anemometer.

Meteorological balloons should provide wind and temperature data at intervals of 500 feet from the surface to 12,000 feet altitude.

The standard weather instruments required include wind speed and direction indicators, temperature sensors, relative humidity and barometric pressure recording units, and maximum and minimum thermometers (including a sling psychometer) all located in a standard meteorological shelter.

A block diagram of a suitable seismic tape recording system is shown in Fig. A-3. The system should be capable of recording signals from quarry blasts and from ground vibrations generated by acoustic signals from surface explosions.

The instrumentation systems required to conduct Phase III measurements are essentially the same as those for the Phase II systems except that the sound source is now an accelerating rocket booster engine. In addition, strain gage transducers must be used with the accelerometers to measure strain and vibration of nearby structures and/or of sensitive vehicle tracking equipment. Strain gages must be small rosettes having a minimum resistance to ground of 10 megohms and a gage factor of at least 2. All strain gage installations must be weatherproofed.

Calibration equipment should consist of insert voltage devices for all systems. Oscillators, oscilloscopes, electronic counters, and VTVM's should be available for monitoring the various input and output voltages and frequencies. Acoustic sensitivity calibrators for all microphones are also necessary. Accelerometers should be periodically calibrated on a shake table to check their sensitivity. Block diagrams for calibration of microphones and accelerometers are given in Fig. A-4. Portable tape recorders (Ampex 600, or 351, etc.) and microphones are also necessary for recording the incident noise in communities surrounding the missile base.

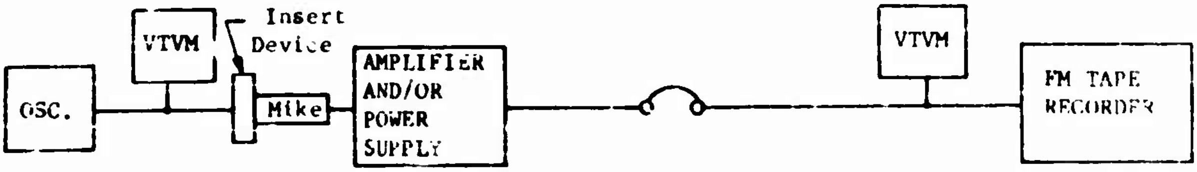
Data recording and data processing equipment should be installed in a mobile instrumentation van. The van itself should have the following capabilities:

1. Transportable by air (usually a semi-trailer)
2. Constructed for adequate noise reduction plus durability
3. Contain work benches, storage space, and equipment racks
4. Heated and air-conditioned
5. Contain observation windows and flood lights for night operation
6. Self-contained electrical power source

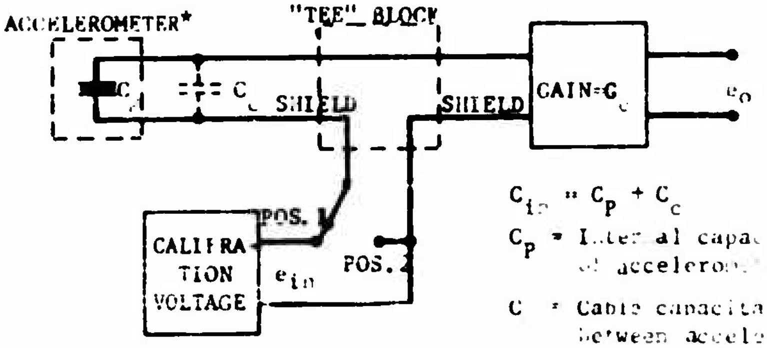
The essential components of the data processing system are discussed subsequently. The most important units housed in the trailer for recording purposes are the magnetic tape recorder, amplifiers and power supplies, calibration equipment, cable reeling devices and cables, and radio receiver for timing detection (WWV).

The data recorder must be a high quality FM magnetic tape recorder and have a dynamic range of at least 40 decibels (e.g., Ampex Series FR 600). Speed-lock and timing should be available along with facilities for voice annotation on the tape. Tape loop mechanisms are also necessary for data reduction.

Amplifiers and power supplies for all microphones, accelerometers, and strain gages must be available in racks in the instrumentation van. These units however, should be mounted for easy removal if necessary. The gain of the amplifiers should be controllable in calibrated steps with a large enough dynamic range to accomodate any situation which may arise.



(a) MICROPHONE CALIBRATION SYSTEM



$C_{in} = C_p + C_c$

C_p = Internal capacitance of accelerometer

C_c = Cable capacitance between accelerometer and "tee" fitting

Switch
POS. 1 - Calibrate
POS. 2 - Operate

*(Accelerometer must be isolated from ground)

As shown, above, the accelerometer acts only as a passive capacitance when it is driven by the oscillator.

The equation for input vs. output is as follows: $\frac{e_o}{e_{in}} = G_e \times C_{in} \times 10^{-3}$

where
e_o = Output voltage in volts
e_{in} = Input voltage from calibrate source in volts
G_e = Charge gain in millivolts per micromicrocoulomb
C_{in} = Input capacitance in micromicrofarads which includes the accelerometer and input cable between the accelerometer and "tee" coupling for the calibration circuit.

(b) ACCELEROMETER CALIBRATION SYSTEM

FIG. A-[illegible] CALIBRATION SYSTEMS

Measurement Procedures

Achievement of the field test program goals is best assured by taking the systematic approach and carefully outlining test procedures. The initial step is to prepare a suitable test directive which defines the exact kind and amount of the measurements to be made during the test. Liaison between the various groups concerned with the measurement program must be established and maintained throughout the program. Qualified field engineers and technicians must be obtained to make the measurements.

Next, a laboratory evaluation of the measurement system is necessary to determine the following properties and characterisitcs.

1. Free-field calibration of microphone systems

2. Pressure calibration of microphone systems

3. Response of all transducer systems to vibration and acoustic excitation

4. Effects of temperature, temperature gradients, electromagnetic radiation, magnetic fields, humidity, rain, and wind on the transducers and measurement systems

5. Effects of transient overload and power supply voltage variations

Microphones for the Phase I measurements should be positioned by using a surveyor's transit. Line arrays of transducers should be placed at selected intervals originating from the launch point and extending out to about 2 miles. A reference microphone should be maintained if more than one launching is required to complete this array. These arrays are to be spaced at 15° azimuth intervals to determine the directional characteristics of the sound source; however, examination of the launch configuration may indicate certain symmetrical properties which will make some measurement arrays redundant. Microphones should be mounted so that adverse effects due to ground reflection and non-parallel incidence of the sound waves on the microphone diaphragm are minimized.

Microphone preamplifiers are to be located in as near an ambient environment as possible, however, should this prove to be impractical, vibration isolation, acoustic absorption, and temperature shielding should be provided as necessary.

Prior to the test, each microphone system should be checked for frequency response, linearity, sensitivity, dynamic range, and signal-to-noise ratio. The frequency response and sensitivity should be recorded on the magnetic data tape, however, the sensitivity check, made by using an acoustic calibrator, should be placed on the tape as near to the time of the test as is possible. Also, the sensitivity of the system should be chosen so that the rms value of the expected input signal to the FM tape recorder does not exceed 36% of full scale modulation. Sensitivity calibrations are also needed at the conclusion of the test.

The following meterological data must be determined prior to the test:

1. Wind speed and direction, wind gradient

2. Temperature (wet and dry bulb) and temperature gradient

3. Relative humidity

4. Amount of turbulence

These data are to be measured at the portable towers and shelter near the instrumentation van. However, additional data, available from the missile base meterological group should also be obtained.

In Phase II the ground to ground and air to ground sound propagation measurements require a sound source of sufficient intensity to be identified at fairly remote areas (up to 15 miles). This source must also be mobile enough to be placed at various elevation angles above the ground. The ground vibration source must also be of sufficient intensity to be detected over these ranges but need not be mobile.

Line arrays of microphones are necessary as for Phase I. Ground vibration measurements will be made with arrays of seismic pickups similar to those of the microphones. A reference voltage should be placed on the magnetic data tape for all vibration pickups in lieu of the acoustic sensitivity check. The meteorological data specified for Phase I is also required for Phase II.

Microphones for the Phase III measurements should be positioned about the missile tracking equipment or structure on which the vibration is to be determined. Microphone arrays should also be located in both the near and far field position similar to Phase I and Phase II.

Accelerometers should be placed on sensitive areas of the equipment but care must be taken so that the transducer weight does not affect the vibration response of the item. Measurement should be made in three axes and where possible, all accelerometers set into place with a torque of 20 inch-lbs.

All strain gages must be thoroughly bonded to the test specimen and weatherproofed. Resistance to ground should be above 10 megohms and a gage factor of 2 is required.

Meteorological data as previously noted is also required for Phase III.

Sound pressure level surveys will be made in the surrounding communities with microphones and portable tape recorders during launch operations. A community survey questionnaire will also be circulated to determine the response to this incident noise.

Data Processing and Reduction

The measured data from all microphones will be processed in octave and/or 1/3 octave bands. The vibration pickups and strain gage data will be processed in narrow bands. Data reduction equipment should be available in the instrumentation van.

Equipment for reduction of microphone signals will consist of octave and 1/3 octave filters with center frequencies ranging from 1 to 10,000 cps. A graphic level recorder is needed which has the frequency response and pen ballistics capable of accurately recording both high and low frequency data. A multichannel visicorder or oscillograph should be available for reducing data channels simultaneously with suitable time scales. A polaroid camera is required and must be adaptable to an oscilloscope. Autocorrelation devices are required for comparing data at separate locations. All equipment must be calibrated frequently to insure compliance with the manufacturer's specifications.

Equipment for narrow band reduction should consist of a manual and an automatic sweep system. Equipment for determining the statistical distribution of the amplitude of the data are also necessary.

Data should be reduced from a duplicate of the original data magnetic tape to avoid damaging the master tape. Analyses of the percentage of modulation on each track are to be made prior to reduction to note the possibility of non-linear effects in the recording. Frequency calibration and reference tones are to be played back through the reduction equipment and recorded on the graphic level recorder prior to reducing the data. Any difference between the reference calibrations and the data must be noted. Dwell time for all narrow band data must be a minimum of one second per cycle.

Acoustic data should be reduced in overall and one-third octave band levels from 16 to 10,000 cps versus time for each filter, accelerometer data in g's or g^2 per cps from 10 to 2,000 cps, and strain gage data in strain levels from 5 to 2,500 cps. The output signals from the filters should be recorded on a graphic recorder. In order to minimize errors or deviations in the data due to its statistical nature, it is necessary to broaden the filter bandwidth, or increase the dwell time per cycle when processing data of short duration. For very short durations of data, digital methods will be used to obtain the frequency spectra.

Analyses of Data

The data, having been reduced from the magnetic tape to recorder strip charts, is now ready for analyses.

The data obtained during the Phase I measurement program consists of near and far field acoustics generated during the vehicle launching. From these data the power level, directivity of the source as a function of time from T_0, and the 150 db, 135 db, 110 db, and 87 db contours of equal sound pressure level can be determined and plotted. Plots of amplitude, frequency, and elevation angle plotted for various azimuth angles and locations on isometric orthographic paper will show the changes in the noise characterisitcs about the vehicle during the launch and early flight phase.

Similar characteristics of the ground borne vibrations are to be plotted and the 1/3 g contour determined. Ground displacement plots as a function of distance and time are to be plotted also

The data obtained during Phase II determine the propagation characteristics of the air and ground about the launch site as a function of temperature, humidity, soil type, etc. These characteristics are to be plotted as a function of attenuation or amplification (focussing) per 1000 feet, frequency, and other pertinent parameters. Indicated areas of large amplification should be defined as well as possible. Attenuations determined from the measured propagation data are then to be applied to data obtained from Phase I measurements.

Data from Phase III will define the incident excitation and the response of various vehicle tracking equipment and nearby structures during actual launch operations. Plots of amplitude vs time and amplitude vs frequency are to be compared to determine this response. Community response may also be calculated more accurately

After the contours of equal SPL, 1/3 g, and critical displacements have been determined, the probable damage that will occur to personnel and structures located within these areas may be assessed. The comparison of the theoretical calculations, modified by the measured propagation characteristics, with the actual data will also reveal the accuracy of these calculations in predicting hazardous areas in the future. The physical damage or instrumentation error caused by vibration in critical equipment will also reveal existing hazard areas. Comparison of predicted and actual community response will show to what extent this response is due to actual incident noise or personal bias against the rocket base.

APPENDIX B

GAS RELEASE AND ATMOSPHERIC DIFFUSION TESTS

The atmospheric dispersion and diffusion of propellant vapors has not been tested in any definitive manner. Some measurements of propellant vapor concentrations have been made in conjunction with other work but instrumentation for this purpose has been limited. Some insight into the mechanisms of atmospheric dilution has been gained from field tests of other contaminants

A survey of prior work indicated that of the tests made, very few were adequately planned with regard to properly situated sampling stations and choice of release conditions. Most of the practical lore on atmospheric diffusion has developed from visual observation of smoke patterns from stacks and chimneys (Ref. 35). The diffusion of airborne radioactive particles was examined from planned releases for a few months in 1958 and 1959 (Ref. 36). Projections of this information to the needs of launch site planning is judged to be inadequate.

Two categories of information are required to characterize the toxic hazard of a potential launch site: (1) test data relating to the injection of vapors into the atmosphere and (2) test data relating to atmospheric diffusion.

Specifically, these data are developed from spill tests, using toxic vapor detectors, and from measurements of atmospheric turbulences. Spill tests and atmospheric turbulence tests may be performed separately but both are recommended for proper documentation of the expected hazards.

The Dilution Process

If the air is still and temperature gradients are stable, there is no strong tendency for vapors from a pool of liquid to disperse. This condition often prevails within a few feet of the ground even though at the time there may be winds aloft. The intermingling of air masses develops when turbulence is created, either by the "tumbling" of the air as the wind blows, or by "boiling" as heated air flows upward from the ground. The eddy patterns of air turbulence can sometimes be seen when dust or smoke is in the air.

On a large scale, the dilution of vapors released from a point can be pictured as a process of uniform diffusion even though the actual mechanism involves discrete inhomogeneous masses of air. The usual mathematical model of the dilution process has as its basis the fundamental law of diffusion

$$\frac{d\chi}{dt} = K\left[\frac{\partial^2\chi}{\partial x^2} + \frac{\partial^2\chi}{\partial y^2} + \frac{\partial^2\chi}{\partial z^2}\right]$$

which relates the instantaneous concentration at any point x, y, z as a function of the concentration gradients and the elapsed time, t. The diffusion coefficient, K, must be developed from many meteorologic variables, of which the principal ones are the velocity and temperature profiles of the air and characterizations of wind gustiness.

However, even the most sophisticated mathematical analyses require the use of gross assumptions and approximations. Sutton's equation is a derivation based on a description of the wind velocity profile by a simple formula with a numerical constant chosen to represent the atmospheric lapse rate. The equation is pertinent for a smooth unobstructed ground surface with a uniform wind and with stable atmospheric conditions as is common during the after-dawn or after-sunset hours.

For other situations, there is no general formula which will apply. An empirical gas release test, or a series of tests, at a specific site would supply the needed information. However, to duplicate a full-scale vehicle malfunction for the sake of dispersion analysis seems impractical. The alternative, therefore, is to perform sub-scale tests and develop a table of meteorological parameters correlated with familiar climatic conditions at a specific site from which to assess the downwind concentrations following a release

For illustration, Fig. B-1 is a contour map of the bluff area at the foot of the Santa Ynez Mountains near Point Pedernales on the NMTPA, an area which has been suggested as a launch site for a multi-million lb. launch vehicle. The map shows an area 2.0 x 2.5 miles in extent with the western edge at sea level and the faces of the mountains up to typical elevations of 750 ft. The ridge line of the mountains is a short distance to the east at a nominal elevation of 1000 to 1250 ft. The total air mass over this area is 296 billion pounds. The amount below 1000 ft. is about 5 billion pounds.

Even this enormous amount of air would dilute a 5 million lb. spill of propellant only to <u>1000 parts per million</u> if the mixing were instantaneous and thorough. Following an actual spill, fumes will flow in channels over the crest of the mountains eventually to be diluted by the unobstructed air mass passing above 1000 ft. The flow pattern through and beyond the mountains is not known. Furthermore, as shown in Fig. B-2, the local wind and the point of release will affect the downwind concentration.

Spill Tests

The objective of performing spill tests is to provide numerical values of vapor concentrations in air within a few thousand feet of the point of release. Diffusion of vapors in the region beyond can then be estimated from knowledge of atmospheric turbulence.

Of the two propellant systems seriously considered for multimillion pound thrust engines, liquid oxygen and hydrocarbon rate low as toxic agents but nitrogen tetroxide, hydrazine, and UDMH rate high. Tests are therefore designed for the latter propellant system.

Spills of fuel-into-oxidizer, oxidizer-into-fuel, and side-by-side are recommended in each case to measure the cloud formation, cloud size, direction of travel, bouyance effects, and duration of burning. Tests should be made in high and low wind, and in stable and unstable air. Sampling stations around the point of release will define the cloud by its vapor concentrations

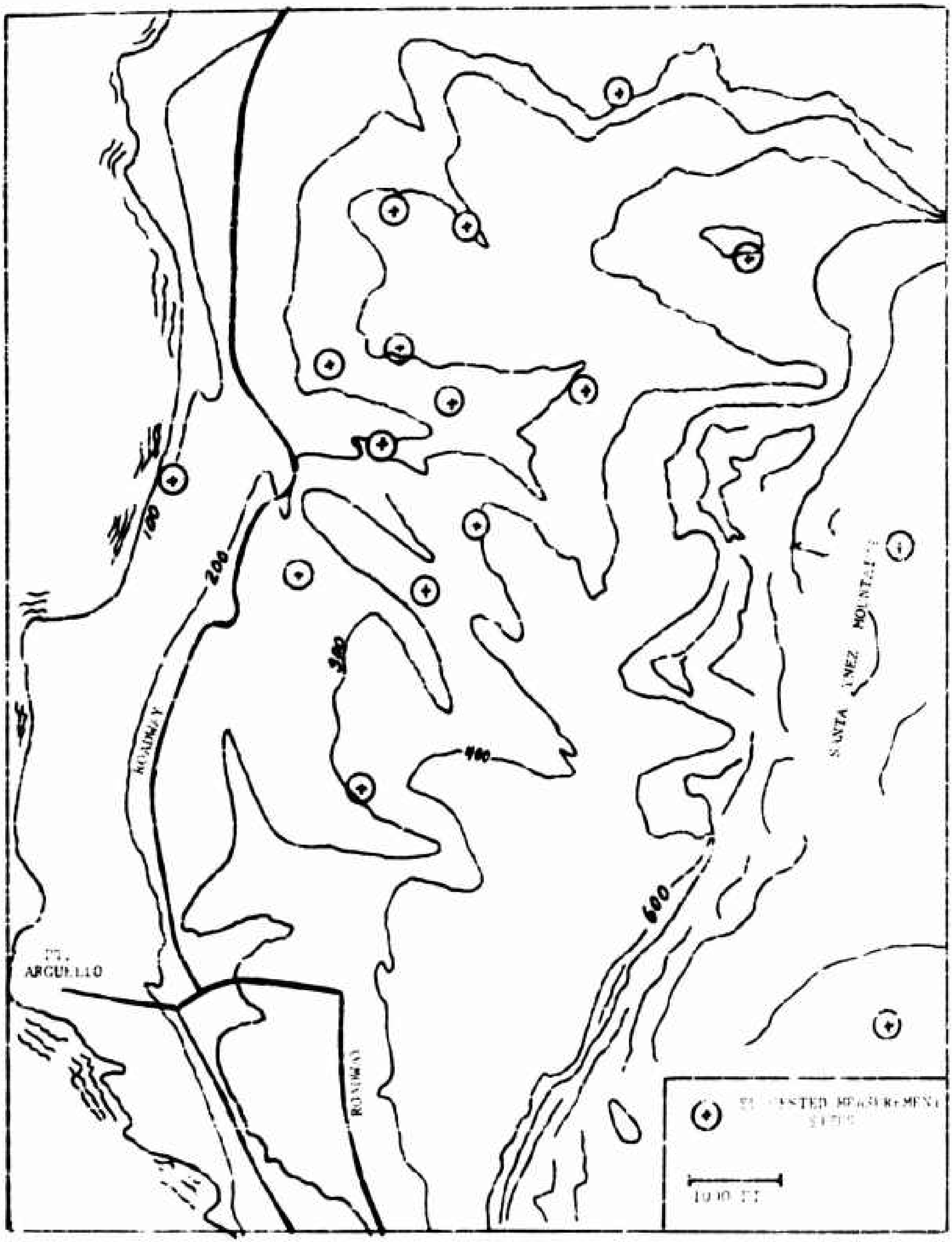
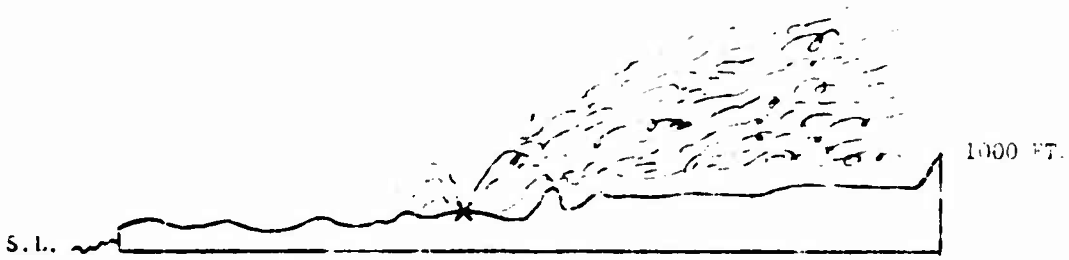


FIG. B-1 CONTOUR MAP



GROUND RELEASE AFTERNOON

AIR RELEASE AFTERNOON

GROUND RELEASE, MORNING

AIR RELEASE, MORNING

2 MILES

FIG. B-2 PLUME PATTERNS FROM GAS RELEASE

The spill tests should be started using relatively small quantities of propellant. The following tests are recommended initially.

(1) Ten gallons of fuel released into a 100 gallon shallow pool of oxidizer.

(2) Ten gallons of fuel released into 100 gallon deep pool of oxidizer

(3) Ten gallons of oxidizer released into 100 gallon shallow pool of fuel

(4) Ten gallons of oxidizer released into 100 gallon deep pool of fuel

(5) Fifty gallons of fuel released on fifty gallons of oxidizer, both in flimsy drums.

(6) Fifty gallons of oxidizer released on fifty gallons of fuel, both in flimsy drums

(7) Fuel and oxidizer sprayed in separate streams at one gallon per sec. on a common spot

Approximately four tests of similar character to the smaller ones should be conducted using ten times the initial quantities. These tests should be chosen to best extrapolate the <u>useful</u> information.

At least one test involving approximately 10,000 gallons of propellant should be conducted using a tankage configuration similar to what may be expected for the larger size vehicles. The test conditions should be chosen to simulate a loaded vehicle on a launch pad.

Instrumentation for the spill tests would consist of a toxic vapor concentration detector network. This network is conceived as a series of detector devices and a central data recorder, with accessory power packs, data links, amplifiers, comparative references and signal selectors. The recommended detector is the null point coulometric cell which, adapted either for oxidizer or fuel, registers a continuous signal in millivolts proportional to the toxic vapor concentration. Other elements suggested for the transmission and recording system are shown in the block diagram of Fig. B-3.

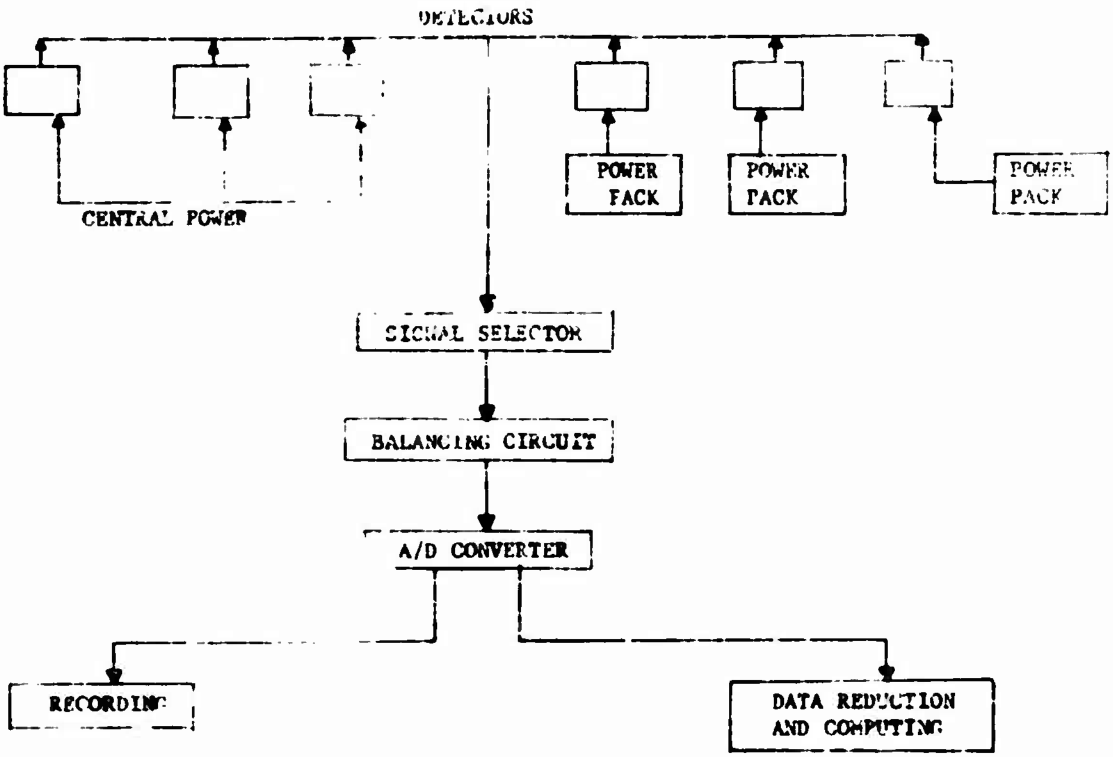


FIG. B-3 BLOCK DIAGRAM OF INSTRUMENTATION SYSTEM

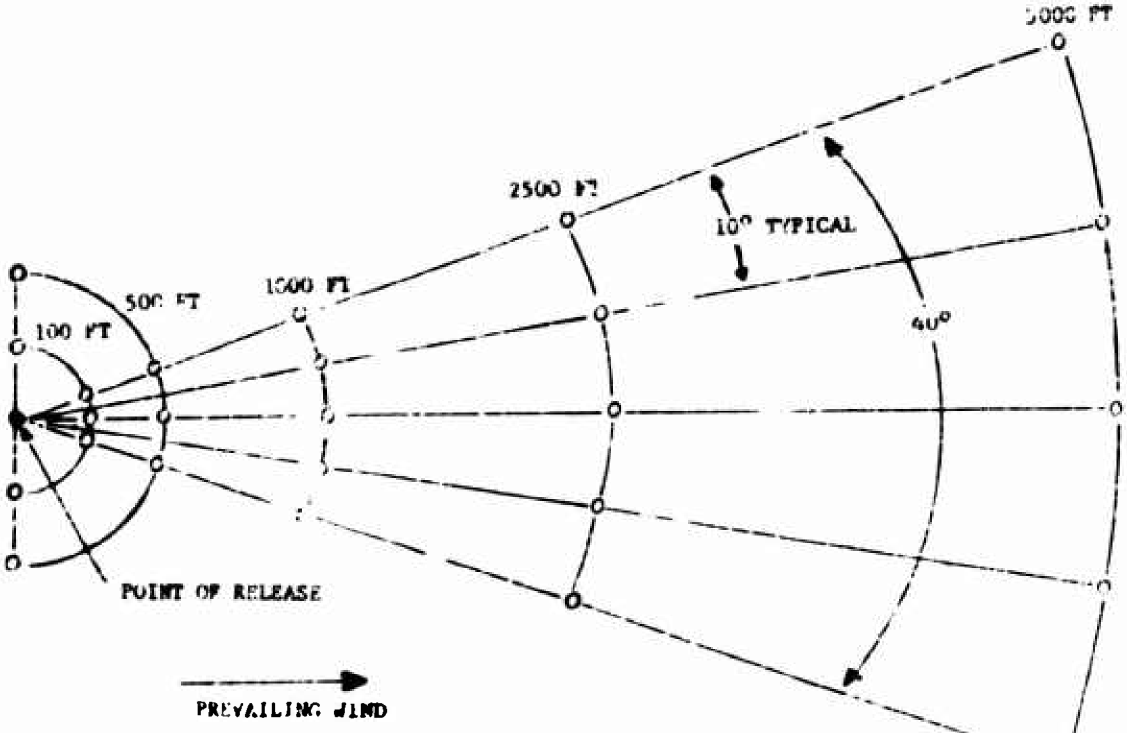


FIG. B-4 SA[illegible] STATION LOCATIONS

Figure B-4 suggests a pattern for sampling station locations. The pattern is merely illustrative and not necessarily optimum for the number of instruments employed. Each station requires two pairs of detectors, one pair (for fuel and oxidizer) near the ground, and another at 100 ft. elevation.

Atmospheric Turbulence Tests

The data required are obtained from instruments such as anemometers and vanes to record continuously the short term and long cycle wind fluctuations. These must be placed on hilltops, in gullies, in the passes through the ridge line, on the lee sides of hills, and on upwind slopes. The object of such measurements is to identify the random turbulence at each station and to characterize the turbulence numerically in such a manner as to correlate the disturbances with the more obvious weather indicators.

Disturbances of the air at each station can be considered in terms of frequencies and amplitudes. In a continuous record over a long time, there will be high frequency cycles from gusts, longer cycles from breezes, cycles associated with daylight and darkness, tendencies of a week's duration and longer tendencies which repeat yearly. Obviously the seemingly random and erratic nature of air turbulence can be treated only statistically. Practically, test period will be for representative short time intervals, long enough to establish average values and frequent enough to detect changes with changing climatic conditions.

For a thorough survey, several spots should be studied, chosen in such a manner as to typify the complete character of the terrain. Instruments should be mounted on masts at elevations from 4 ft. to 150 ft. above ground. Each instrument cluster should provide for the measurement of both horizontal and vertical wind velocity and direction, with undamped anemometers and vanes (time constant 0.5 sec) and damped ones (time constant 5 to 15 sec). In addition, data is needed on local air temperature, barometric pressure and soil temperature. The daily and hourly climate of the area will be correlated with the observations of turbulence.

In order of importance the information to be collected each weather station is:

1 Horizontal wind velocity near the ground (low response)

2. Horizontal wind velocity at a height (low response)

3. Vertical wind velocity near the ground (high response)

4. Horizontal wind velocity near ground (high response)

5. Horizontal wind velocity at a height (high response)

6. Vertical wind velocity at a height (high response)

7. Air temperature

8. Differential temperature with height

9. Barometric pressure

10. Soil temperature

Instrumentation for each of these measurements is recommended, but not necessarily a complete array for each station of the test network. Elaborate instrumentation would be a burdensome expense, and tremendous quantities of raw data will obscure the purpose of the tests.

The following items are recommended for a 16 station network:

NO.	ITEM
16	Masts
32	Anemometer
3	Vertical Wind Meter
6	Horizontal Wind Meter (high response)
6	Air Temperature Indicator
6	Differential Temperature Indicator
6	Barometric Pressure Transducer
6	Soil Temperature Indicator

Transmission equipment and recording components are also required.

PHYSICAL PROPERTIES AND CHARACTERISTICS OF PROPEL

PROPERTY	UNITS	AMMONIA	ANILINE	CHLORINE TRIFLUORIDE	DIBORANE	ETHYL ALCOHOL	ETHYLENE OXIDE	FLUORINE	HYDRAZINE	HYDR
MOLECULAR FORMULA		NH_3	$C_6H_5NH_2$	ClF_3	B_2H_6	C_2H_5OH	C_2H_4O	F_2	N_2H_4	CH
MOLECULAR WEIGHT		17.03	93.1[illegible]	92.46	27.69	46.068	44.052	[illegible]	32.048	10
BOILING POINT @ 1 atm pressure	°F	-28	364	52.[illegible]	-134.5	173	50.[illegible]	-306	[illegible]	50
MELTING POINT	°F	-108	[illegible] 24	-1[illegible]	-265.9	-174	[illegible]	-364	3[illegible].5	
CRITICAL TEMPERATURE	°F	270	798	3[illegible].2	6[illegible]	470	376		[illegible]	-
CRITICAL PRESSURE	psia	1639	768	837.0	581	928	1041	-	2145	-
CRITICAL VOLUME	ft³/lb	0.068	0.0472	-			-		0.069	-
DENSITY, GAS @ 0	lb/ft³	0.0[illegible]	0.159	0.250	[illegible] @ 32°F	0.10	-	0.1	0.0342	-
HEAT CAPACITY, GAS @ 50°F	BTU/lb °F	0.[illegible]		0.162	[illegible]	.38	0.2[illegible]		0.36	0.
DENSITY, LIQUID @ 60°F	lb/ft³	38.10	63.79	113 @ B.P.	2[illegible] @ B.P.	49.2[illegible]	56.[illegible]3	93.[illegible] @ B.P.	62.96	49
HEAT CAPACITY, LIQUID @ 60°F	BTU/lb °F	1.125	0.495	0.3[illegible] @ B.P.	0.67 @ B.P.	0.57	0.472	0.37 @ B.P.	0.736	0.
VAPOR PRESSURE, LIQUID @ 60°F	psia	125	< 0.02	21.6	513 @ 58°F	0.85	21	23.6 @ 290°F	0.206	-
VISCOSITY, LIQUID @ 60°F	cps	0.319	4.4	0.43	5.0x10⁻⁵ @ [illegible]	1.20	0.270	0.24 @ B.P.	0.976	2
COEFFICIENT OF THERMAL EXPANSION @ 60°F (CUBICAL)	1/°F	.0013	-	-		0.0006	0.0008[illegible]	-	-	
HEAT OF VAPORIZATION @ B.P.	BTU/lb	589.3	205	129	223	361	249.3	74	540	1
HEAT OF COMBUSTION	BTU/lb	8000	15,200	N.A.	31,300	12,800	12,350	N.A.	5,346	10,[illegible]
SOLUBILITY IN WATER		Very sol	Sl. sol	Reacts	Reacts	Very sol	Very sol	Reacts	Very sol	Inso
EXPLOSIVE LIMITS IN AIR	%	15 - 28		N.A.	[illegible]	2.8 - [illegible]	3 - 100	N.A.	5 - 100	0.[illegible]
FLASH POINT (OPEN CUP)	°F	N.A.	195	N.A.	-	[illegible]	< 0	N.A.	126	110°
FIRE POINT	°F	N.A.	985	N.A.			[illegible]	N.A.	126	
AUTOIGNITION TEMPERATURE	°F	1204	141[illegible]	N.A.		[illegible]	[illegible]	N.A.	518	4
EXPLOSIVE HAZARDS (OTHER THAN FUEL-AIR MIXTURES)		Forms explosive mixtures with mercury	-	With fuel vapors	Vapor with CO_2 liquid with CCl_4	-	Polymerizes violently in presence of acids or bases	Vapor with fuels - pressure [illegible]		Liqu mixt fuel
FIRE HAZARDS		Ignition temp of vapor lowered by presence of fuel vapor	Not easily ignited	Extremely reactive	Pyrophoric	Fuel, liquid	Wide range of flammable vapor/air mixtures	Extremely reactive	May ignite on contact with metallic oxides	Vapo mixt
FIGHT FIRE WITH		Water fog or spray	Water fog or spray	Water fog or dry powder with slow even [illegible] of [illegible]	Water fog or inert gas expander mechanical foam	Alcohol resistant foams or water	Water fog or spray on small fires - water dilution on large fires	Water fog	Dilution	-
TLV	ppm	100	5	0.1	0.01	-		-	1	
TOXIC BY		Inhalation	[illegible]	Inhalation	Inhalation	-	-	Inhalation	Inhalation	
DECONTAMINATE WITH		Water	Detergent [illegible]	Water fog or [illegible] soda ash	Small amounts with water-methanol mix	Water	Water	Water fog	Water dilution	Det
DISPOSE OF BY		Vaporization	Burning	Vaporization	Burning	Vaporization	Vaporization	Burning	Neutralize with H_2O_2 or bleach in solutions	Bur

*N.A. - NOT APPLICABLE

1

APPENDIX C

PROPERTIES AND CHARACTERISTICS OF PROPELLANTS

	FLUORINE	HYDRAZINE	HYDROCARBON RP-1	HYDROGEN	HYDROGEN PEROXIDE 90%	NITRIC ACID	NITROGEN TETROXIDE	OXYGEN	OZONE	PENTABORANE	[illegible]	[illegible] NITRATE	[illegible]
	F_2	N_2H_4	[illegible]	H_2	H_2O_2-H_2O	HNO_3	N_2O_4	O_2	O_3	B_5H_9	[illegible]	[illegible]	[illegible]
	38.00	[illegible]	100	2.016	31.26	63.02	92.016	-	48	63.[illegible]	[illegible]	[illegible]	[illegible]
	-306.[illegible]	236	[illegible] - 525	-42[illegible]	285	159.6	70	-297.[illegible]	-169.[illegible]	13[illegible]	-53	236.9	[illegible]
	-360.[illegible]	34.[illegible]	-40	-434.6	11.[illegible]	-42.00	12	-362	-315.[illegible]	-50.1	-146.[illegible]	-15[illegible]	[illegible]
	-200.6	716	-	-399.8	65[illegible]	-	316.[illegible]	-182	10.2	[illegible]	+31.[illegible]	506.[illegible]	[illegible]
	808.29	2135	-	188.1	3,[illegible]45		1470	731	807.[illegible]	-	[illegible]	588	[illegible]
	-	1.069		0.511	-		[illegible]	[illegible]	[illegible]366	-	[illegible].0152	[illegible]	
	0.3[illegible]2	0.6349	-	-	-	-	-	[illegible]2766	-	-			
	[illegible]	0.36	0.37	-	0.[illegible] @ [illegible]°F	-	0.20	0.2[illegible]	[illegible]	0.30 @ [illegible]°F		-	
	73.[illegible] @ B.P	[illegible]	68.6	4.15 @ B.P.	86.5[illegible] @ 77°F	96.1	30.5	[illegible] @ B.P.	[illegible] B.P.	39.3 @ [illegible]°F	6[illegible].52	[illegible]	
	0.37 @ A.P.	[illegible]	[illegible]	2.26 @ B.P.	0.660	0.418	0.206	0.399 @ B.P.	0.156 @ B.P	0.57 @ [illegible]°F		[illegible]	
	21.6 @ -299°F	[illegible]	-	[illegible]	[illegible]	[illegible]920	[illegible]	611.8 @ -190°F	602 [illegible]	[illegible]	160	[illegible]	
	0.24 @ B.P.	[illegible]	2		1.[illegible]	[illegible]	-	0.[illegible]	[illegible] 20 @ -3[illegible]°F	0.36 @ [illegible]°F	[illegible]	[illegible]	[illegible]
	-			-	[illegible]	[illegible]	-	0.00[illegible]	0.00111 @ [illegible]		[illegible]	[illegible]	
	260	560	150	.75	700	216.[illegible]	170	61.62	11[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	N.A.	[illegible]	18,500	51,571	N.A.	N.A.	N.A	N.A.	N.A	30,[illegible]	N.A.	N.A.	
ol.	Reacts	Very so[illegible]	Insol	N.A.	Very sol	Very sol	Very [illegible]	[illegible]	N.A.	[illegible]	[illegible]	[illegible]	
0	N.A.	[illegible] - 100	0.8 - [illegible]	[illegible]	N.A.	N.A.	N.A	N.A.	N.A.		N.A.	N.A	
	N.A.	126	[illegible]10° closed cup	< -423	N.A.	N.A.	N.A	N.A	N.A	-	N.A.	N.A	
	N.A	[illegible]	-		N.A.	N.A	N.A.	N.A.	N.A.		N.A	N.A	
	N.A.	518	480	[illegible]085	N.A.	N.A.	N.A.	N.A	N.A.	-	N.A	N.A	
[illegible]	Vapor with fuels [illegible] explosions		Liquid mixtures with fuels	Solid with solid O_2. Pressure explosions	Explosive decomp. with proper catalysts	Explosive in contact with hydrazine or furfuryl alcohol	Forms impact sens. mist with liquid fuels	Forms impact sens. mist with liquid fuels-Pressure explosions	Shock sens.	Mixtures with [illegible] are [illegible] sensit.	Forms impact sens. [illegible] solid fuels. Press. exp.	[illegible]	
[illegible]	Extremely reactive	[illegible] ignites in contact with metallic oxides	Vapor-air mixtures	Volatile with wide range of flammability	Decomposes with evolution of suff. heat to ignite material	Fumes liberated on heating [illegible]	Strong oxidizer	Strong oxidizer	Strong oxidizer	Pyrop[illegible]	Strong oxidizer	[illegible]	
[illegible]	Water [illegible]	[illegible]	Water fog or foam	CO_2 for small fires	Water dilution	Water dilution	Water dilution	Fight fuel fire	Fight fuel fire	Water fog [illegible]	Water dilution	[illegible] with water	[illegible]
		1	500	-			5	-	0.1	0.[illegible]	[illegible]	[illegible]	
	Inhalation	Inhalation	-		Inhalation	Inhalation	Inhalation	-	Inhalation	[illegible]		[illegible]	
	Water [illegible]	Water dilution	Detergent sol	-	Water	70% sodium bicarbonate sol followed by water dilution	Water	-	-	Flush with water or [illegible]	[illegible]	Water	[illegible]
[illegible]	Burning	Neutralize [illegible] or bleaching solution	Burning	Vaporization	Decomposes upon standing	Reaction with [illegible] sol	Vaporization	[illegible]	[illegible]	Burn[illegible]	[illegible]	Burning	[illegible]