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THE J-2 ENGINE AS AN ACOUSTICAL NOISE SOURCE

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ABSTRACT

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In the development of the Saturn family of space vehicles, increasing emphasis has been placed upon the operating acoustic environments, because of the increased engineering effort required to design structures and facilities for existence in these environments. As a result, a large number of programs have been initiated to measure the acoustical properties of such engine configurations. However, these usually describe only a very small class of rocket systems-propellants of liquid oxygen and kerosene. The J-2 engine however operates on liquid oxygen-hydrogen propellants and has slightly higher specific impulse and exhaust nozzle exit velocity.

The static firings of the J-2 engine performed by the Rocketdyne Propulsion Field Laboratory at Santa Susana, California, were monitored acoustically by MSFC contractor personnel. It was found that the J-2 was quite similar in acoustic output to the H-1 engine, despite some differences in operating parameters between the two. The acoustic output was found to be about 2.5 million watts with the frequency peaking in the 63 Hertz octave.

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Cont'd)

LIST OF ILLUSTRATIONS (Concluded)

LIST OF TABLES

DEFINITION OF TERMS

Term	Definition
SOUND-FIELD	A region containing sound waves.
NEAR-FIELD	The part of the sound field in the immediate vicinity of the sound source. In general practice, near-field environments are found to be non-linear and dimensions are not large compared to the dimensions of the noise source. Thus the relative dimensions of the noise scurce cannot be considered to approximate a point. In this report, the near-field is somewhat arbitrarily considered to exist within 50 feet of the vehicle.
FAR-FIELD	The part of the sound field where the sound waves are propagated as if in a free-sound field and where the wave front approximates a plane wave. Also, the region is sufficiently far removed from the source that it can be assumed that all the energy originates at a point and is radiated according to classical laws of physics. For purposes of reference, the acoustic far-field is arbitrarily divided into two subregions: the mid-field, which is between 50 and 1500 feet from the source where free-field conditions and inverse square law radiation are most likely to occur; and the far-field, which is beyond 1500 feet where atmospheric heterogeneities and other diffusion effects have a considerable effect on measurement values.
NOISE-FLOOR	The minimum RMS sound pressure level which can be measured because of background acoustic noise or internal electrical noise in the measurement system. In this report, noise floors are analyzed in octave bands and the values are indicated by an X on the center frequency of the individual octave bands.
OCTAVE	A bandwidth in the frequency spectrum where the upper frequency limit is twice the lower frequency, usually identified by the center frequency.

DEFINITION OF TERMS (Concluded)

Term	Definition
SOUND PRESSURE LEVEL (SPL)	The sound pressure level, in decibels, of an RMS sound pressure is 20 times the logarithm to the base 10 of the ratio of this pressure to a reference pressure of 0.0002 microbar.
POWER LEVEL (PWL)	The power level, in decibels, of an acoustic power is 10 times the logarithm to the base 10 of the ratio of the power to a reference power of 10^{-13} watts.

TECHNICAL MEMORANDUM X-53199

THE J-2 ENGINE AS AN ACOUSTICAL NOISE SOURCE

SUMMARY

During the development of the Saturn family of large space vehicles, it was found that the operating acoustic environments contributed materially to the dynamic loading of the structure of the vehicle and its surrounding ground support and test equipment. The noise, now more than the mere annoyance which it has been with smaller engines, had to be taken into account in the design and development of vehicle structures and facilities. As a result, a large number of programs have been initiated to measure the acoustical properties of various large engine configurations. These, in nearly every instance, described only a very small class of rocket systems, propellants of liquid oxygen and kerosene. The J-2 engine, however, operates on liquid oxygen-hydrogen propellants and has slightly higher specific impulse and exhaust nozzle exit velocity. It was therefore important to discover if these differences would affect the performance of the rocket engine as a noise source.

The static firings of the J-2 engine performed by the Rocketdyne Propulsion Field Laboratory at Santa Susana, California, were monitored acoustically by MSFC contractor personnel. The program was patterned after those used for the Saturn S-1 and the H-1 and F-1 engines, although the local terrain caused some modification of transducer placement. It was found that the J-2 was quite similar in acoustic output to the H-1 engine, despite the differences in operating parameters between the two. In fact, the acoustical outputs appeared to be more related to the total thrust than any of the individual engine parameters. The acoustic output was found to be about 2.5 million watts with the frequency peaking in the 63 Hertz octave.

INTRODUCTION

In the development of the Saturn booster vehicles, increasing emphasis has been placed on the operating acoustic environments of the boosters. This situation is a result of the severe nature of large rocket system acoustic environments and the increased engineering effort required to design structures and facilities to exist in these environments. As the design engineering has become more sophisticated, large amounts of information regarding acoustic characteristics have been required. To meet the requirement data describing the acoustical environment generated by the noise mechanism of turbulent rocket exhausts, a large number of measurement projects in support of static test and launch operations have been instituted and a large amount of data have become available (Refs. 1 thru 9).

However, these results usually describe only a very small class of rocket systems (propellants of liquid oxygen and kerosene, specific impulse in a range of 250 to 270, and an exhaust nozzle velocity of approximately 8000 feet per second). A special interest was therefore shown in instituting an acoustical measurement program for the J-2 rocket engine. This engine operates on liquid oxygen-hydrogen propellants at a specific impulse in the 275-290 seconds range with an exhaust nozzle exit velocity of approximately 9000 feet per second. Early in 1963, the engine was in the initial stages of development, and static testing was being performed only at the Rocketdyne Propulsion Field Laboratory located in the Santa Susana Mountains in Ventura County, California. In common with other rocket development, J-2 testing operations were extremely erratic in scheduling, duration, and performance. Moreover, the mountainous terrain in which the test facilities were located posed difficulties in forming acoustical measurement programs to provide meaningful data. Despite these problems, the requirements for acoustical data on high performance, cryogenic engines made an acoustical survey of the J-2 engine necessary, and the results of the survey are included in this report.

It was found that the acoustical environment of the J-2 is similar to the noise generated by liquid oxygen-kerosene rockets (F-1 and H-1 engines and the Saturn I booster). The spectra of the sound pressure levels at 100 meters from the test stand peak in the octave bandwidths centered at 31 Hertz and 63 Hertz; the directivity peaks rather sharply at 45 degrees, and the acoustical efficiency of the jet stream is calculated to be 0.3 percent.

A. INSTRUMENTATION

Measuring the noise levels and acoustic spectra in the vicinity of large rocket engines and space vehicle boosters (at distances up to one kilometer during static testing under a variety of climatic and field conditions with the necessary accuracy, reliability, and format) necessitated the design and testing of a completely new acoustic data instrumentation system (Ref. 10). The data acquisition system shown in Figure 1 consists of a microphone with a preamplifier

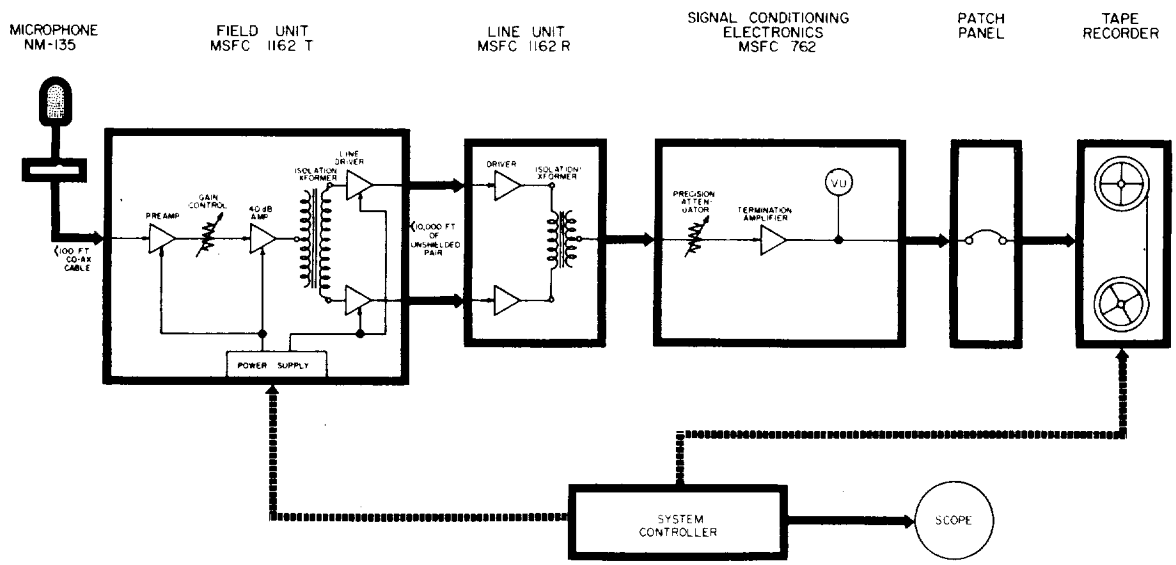


FIGURE 1. BLOCK DIAGRAM OF AUDIO FREQUENCY NEAR-FIELD ACOUSTICAL MEASUREMENT SYSTEM

followed by a step attenuator and decade amplifier. The microphone is a modified hydrophone, Model NM-135, manufactured by the Chesapeake Instrument Company. This microphone consists of a self-generating piezo-electric sensing element that is sealed against precipitation and water vapor leakage. It is mounted on a vibration isolating base and has its signal output through a BNC coaxial connector. Its dynamic range is rated for pressure levels from 80 to over 180 decibels (Ref. 0.0002 microbar). The microphone sensitivity is nominally minus 94 db (Ref. 1 volt per microbar). Its nominal internal capacity is 1600 picofarads. The microphone is connected via a shielded cable to a solid-state preamplifier which acts essentially as an impedance matching unit. It has unity voltage gain and its noise floor is effectively that of the complete system. To maintain adequate low frequency response, the input impedance of the preamplifier must be of the order of several megohms. The output impedance of the preamplifier is low enough to permit the use of a conventional attenuator.

The attenuator has a forty db range and is preset in the field according to the expected range of sound pressure level. A decade amplifier with a fixed gain of 40 db follows and is terminated into a coupling transformer specially designed for adequate low frequency response and signal handling capacity. It is carefully shielded and its secondary winding is balanced with respect to ground. A pair of battery operated, floating ground, solid-state line amplifiers supply the necessary signal power at a maximum signal level of about 2 volts RMS. The electronics thus described comprise the field unit which is placed in its weather proof case in the vicinity of the microphone at the individual measurement position.

For transmission of the signal to the recording facility, standard U. S. Army communication field wire is used instead of the conventional coaxial cable. Use of this field wire substantially reduces cost and results in improved reliability and flexibility in field situations. To conserve signal power, the field wire transmission line is not terminated in its characteristic impedance at the recording facility, but is directly connected to a pair of floating line amplifiers with high input impedance. At the output of these amplifiers there is another coupling transformer to isolate the line from the rest of the equipment and to maintain electrical balance. These components comprise the line unit and are identical with their counterparts in the field unit.

The output of the line unit is connected to the signal conditioning unit which contains a 50 db step attenuator that is adjustable in five db steps followed by a field effect transistor input stage and a solid state buffer amplifier of approximately 10 db voltage gain. A VU meter is provided to monitor the output voltage to the tape recorder. The purpose of the signal conditioning unit is to measure and adjust the signal level for best use of the available dynamic range of the tape recorder units on which the signal is recorded for later analysis. The usual procedure is to adjust the individual channels for full scale levels for any desired reference SPL at the microphone. For this condition, the channel can be adjusted for zero VU at an output signal level of 400 millivolts RMS. Because instrumentation tape recorders are usually calibrated for 100 percent modulation, the channel dynamic range is thus established to be 35 db below any arbitrary reference value of SPL. Considering that the range of noise spectra can often approach this value, it is obvious that care must be taken to normalize the measurement channels to obtain the best performance from the system.

The block diagram of the acoustical data reduction system used in the octave band reduction for this report is shown in Figure 2. This system used a fourteen channel instrumentation tape recorder as its input. The tape generated from one or more of the systems outlined above is played from it through a patch

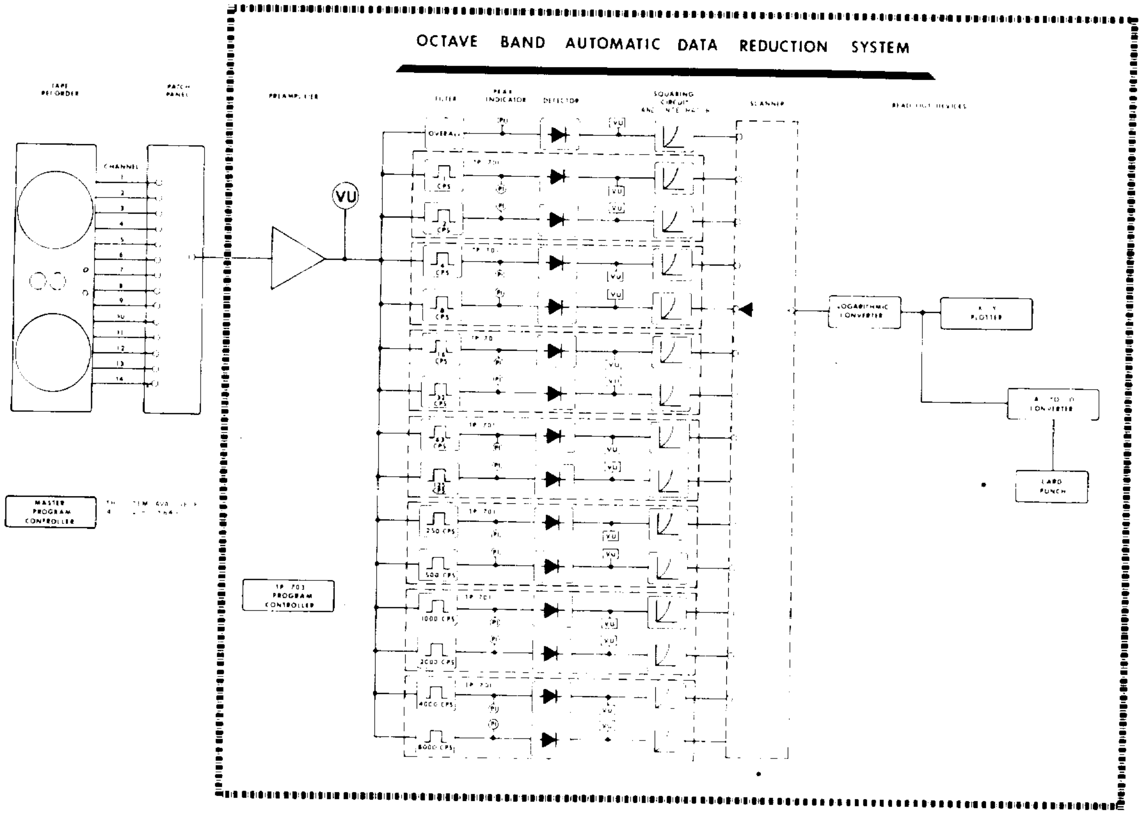


FIGURE 2. BLOCK DIAGRAM OF ACOUSTICAL DATA REDUCTION SYSTEM

panel into the reduction system. One channel at a time is chosen through a pre-programmed patch panel controller and played through a preamplifier. The preamplifier output is then fed into 15 parallel data channels. One channel accepts the overall signal while the other fourteen contain octave band filters from 1 through 8000 Hertz. After passing the filter, the signal is detected, squared, and integrated. Various indicators and VU meters are used to inform the operator that the signal is not being clipped or near the noise floor of the data reduction system. The integrators can be pre-programmed in length of integration time so as not to lose the statistical veracity of the bandwidth-integration time product. An automatic scanning device samples each integrator sequentially and outputs them through a logarithmic converter. At the output of this converter, various data display or recording devices can be used. The two most often utilized are an X-Y plotter which is used to plot sound pressure level versus frequency, and a card punch by which an A to D converter stores, in permanent form, the sound pressure levels of the overall and the fourteen octaves.

B. CALIBRATION

To calibrate the microphone a constant sound pressure level is generated by means of a pistonphone in the frequency range of 0.1 to 50 Hertz. The cavity of the pistonphone is large enough to insure that the transition from adiabatic to isothermal behavior of the gas in the cavity occurs well below 0.1 Hertz. By varying the input resistance of the amplifier, the response of the microphone-amplifier combination at low frequencies could be determined. The tests showed that the open circuit response of the microphone is uniform down to below 0.1 Hertz. Hence, acoustic leakage through the sensitive elements of the microphone is negligible at least down to 0.1 Hertz. When connected to an amplifier of a given input resistance, the response of the combination is determined only by the microphone and cable capacitance and the input resistance of the amplifier (Ref. 10). The response calculated from the known values of capacitance and resistance accounts for the observed drop in response. Since the input resistance of the preamplifier used in the present system is 3×10^8 ohms, the drop of the response at 1 Hertz is less than 1 db. Appropriate corrections to account for this can easily be applied if desired. The open circuit voltage calibration was obtained in a planewave tube below 600 Hertz, and above that frequency in an anechoic chamber. The angle of incidence of the sound field with respect to the axis of the microphone was 90 degrees inside the anechoic room. In the planewave tube the angle of incidence was not important because the directivity of this microphone is negligible below about 1000 Hertz. To obtain appropriate corrections for the deviations of the free-field response of the NM-135 microphone, a number of microphones were tested and appropriate corrections obtained. These corrections were added to the sound pressure levels obtained from analysis of the data recorded from this system. The data show the response of the microphone amplifier system to be flat from one Hertz to 12kHz, plus or minus approximately 1 db.

C. MEASUREMENT PROGRAM

In the evaluation of rocket engines as noise sources, it is necessary to attempt to account for and measure all of the acoustical energy which might be radiated from such a source. One generally accepted measure of this is what is known as the acoustical power level (Ref. 11). This power level investigation, to be rigorous, would require sound pressure measurements on spheres surrounding the sources at different radii. If the radius is large enough that the measurements are made in the acoustic far-field, the total radiated acoustic power of the source is found by integrating the energy flux over the surface of the sphere. In many cases, it is possible to take advantage of the near symmetry of the sound field. Where rotational symmetry around the axis of the sound field may be assumed, measurements may be made only on a semicircle around the sound source. Such conditions are usually assumed to exist when the engine to be tested is located such that either the undeflected flame or the deflected exhaust has its axis within about 30 degrees of the horizontal. The one basic assumption to this procedure is that the sound source is a point located at or near an infinite flat plane whose coefficient of reflectivity is unity. In this case, exact acoustic power measurements would require sound measurements on arcs above the ground plane defined by constant radius R and constant angle θ. The pressures as functions of angle are measured on the ground and assumed to be constant on the arcs in the upper hemisphere. The total power radiated is then given by

$$W_A = \frac{\pi r^2}{\rho c} \int_0^{\pi} p^2(\theta) \sin\theta d\theta$$

Where W_A = Acoustic Power

$P(\theta)$ = rms sound pressure on the ground at radius r, measured from the midpoint of the source

θ = angle between the measurement and the centerline of the exhaust

c = velocity of sound in air

ρ = density of air

In the actual acoustic power level measurement situation,the ideal case is very seldom reached. In the J-2 program, especially, the infinite flat plane did not exist. In fact, as can be seen from Figures 3, 4, and 5, the idealized acoustic point source at or near an infinitely flat reflecting plane was not even closely approximated. However, for reasons already stated, it was necessary to make some measurements of the acoustic spectra and power levels. Since the J-2 static test facility at Santa Susana, California, was built in a natural bowl, it was necessary to compress most of the mid-field measurements, upon which an acoustic power level would be based, into the bowl itself. A 100-meter radius was chosen because of the limitations of the topography. Microphones were placed at 20 degrees from the center line of the deflected exhaust and at 15 degree increments from 30 through 180 degrees. In addition, measurements were made at 10, 20, 40, 50, 80, 150, 200, 300, and 400 meters out the 30 degrees bearing. This allows evaluation of the data collected at the 100 meter radius to be evaluated in terms of whether or not it was collected in the acoustic far-field. This line also can be used to compare with other test configurations on later firings of the J-2 in other areas and with data collected along similar bearings from other large engines. Figure 6 shows the relative locations of the mid-field array around the J-2 static test site. Because of a severe lack of electronic equipment available to the program in this area, it was not possible to simultaneously record at each of the indicated locations. This severely restricted the amount of data which could be collected at any given microphone location and thus restricted the amount of repeatable data which were collected.

Table I shows the measurement location parameters for the 100 meter semicircle. Because of the rocks, boulders, gullies, and other installations in the bowl area, it was not always possible to locate the microphone mount at the exact range and bearing called for. In Table I, both the nominal and actual ranges and bearings are tabulated. Also included in Table I are the microphone elevations in degrees above or below the horizontal plane through the impingement point on the deflector. This then is a measurement of the deviation of the bowl from the assumed horizontal. Table II gives similar information for those measurements which were located along the 30 degree bearing line. Relatively at least, the 30 degree bearing was more uniformly horizontal than was the 100 meter semicircle.

TABLE I

MEASUREMENT LOCATION PARAMETERS - 100 METER SEMICIRCLE

Range From Engine Centerline - Meters		Bearing From Deflected Exhaust Degrees		Elevation Above Horizontal Plane at Impingement Point of Flame Deflector Degrees
Nominal	Actual	Nominal	Actual	
100	99.0	20	21	-3.0
100	99.8	30	30	-2.0
100	101.0	45	46	+3.0
100	97.6	60	55	+4.8
100	106.1	75	70	+9.8
100	100.5	90	86	+10.4
100	98.6	105	104	+12.5
100	105.9	120	118	+13.4
100	104.0	135	133	+10.6
100	99.1	150	148	+14.8
100	101.0	165	164	+19.1
100	103.0	180	177.9	+18.0

For structural reasons, it is quite often necessary to ascertain the sound pressure levels which impinge upon the vehicle at several points along the vehicle's skin. Five such stand measurements were made on this J-2 test program. Their location in range from the engine center line and the height above the nozzle plane are also shown in Table II.

TABLE II

MEASUREMENT LOCATION PARAMETERS - 30° BEARING AND STAND LOCATIONS

Range From Engine Centerline - Meters		Bearing From Deflected Exhaust Degrees		Elevation Above Horizontal Plane at Impingement Point of Flame Deflector Degrees
Nominal	Actual	Nominal	Actual	
10	10.2	30	2[illegible]	+[illegible]
20	20.0	30	30	-6.5
40	39.8	30	3[illegible]	-6.[illegible]
50	49.5	30	30	-4.0
80	80.[illegible]	30	29	-2.[illegible]
100	99.8	30	30	-2.[illegible]
150	152	30	30	-0.[illegible]
200	203	30	2[illegible]	-1.[illegible]
300	2[illegible]	30	3[illegible]	-0.3
400	403	30	30	+3.0
		Height Above Nozzle Exit Plane Meters		
4	4.4	0	0	
4	4.4	4.[illegible]	[illegible].7	
4	4.4	[illegible]	12	
4	4.4	18	3[illegible]	

Table III shows the far-field measurement locations. A range of the measurement in both meters and feet from the engine center line is shown along

TABLE III

MEASUREMENT LOCATION PARAMETERS - FAR FIELD

Range Meters (ft) from Eng. Centerline	Azimuth from T. North	Bearing Degrees from Exh. CW	Elevation Meters (ft) above MSL	Elevation re Nozzle Exit Plane On Stand, Meters (ft)
365 (1200)	63° E	142.5°	609 (2000)	+45.6 (150)
800 (2620)	67.5°E	147°	585 (1925)	+22.8 (75)
1385 (4550)	75° E	154.5°	502 (1650)	-60.8 (200)
780 (2560)	302.5°E	22°	614 (2020)	+51.6 (170)
1300 (4260)	306° E	22.5°	562 (1850)	0
1870 (6130)	305° E	24.5°	556 (1830)	-6.1 (20)

with the azimuths from true north. To conform with the format of the other table, this azimuth has been converted into bearing in degrees from the center line of the exhaust. The elevation of the measurement point is also tabulated above mean sea level and above or below the nozzle exit plane on the stand.

D. EXAMINATION OF DATA

A total of 129 valid measurements were taken during this program which covered 15 static tests of the J-2. Several additional measurements were attempted but were lost due to temporary difficulties with instrumentation or cabling. The valid overall sound level measurements are tabulated in Table IV.

TABLE IV

J-2 ACOUSTICAL MEASUREMENT TABULATION

Overall Sound Pressure Levels
(to the nearest 0.5 dB re: 0.0002 Microbar)

MEASUREMENT LOCATION / Test Number →	126	127	134	157	169	170	171	172	173	192	2	5	6	15	17
10M - 30°					161.0	161.5	160.0	160.0	160.0						
20M - 30°					153.0	154.0	[illegible]	153.5	152.5						
40M - 30°					147.0	147.5	147.0	146.0	145.0						
60M - 30°					146.0	142.5	142.0								
80M - 30°							135.0	135.0	137.5						
150M - 30°							126.0	120.0	120.5						
200M - 30°					122.0	122.0	123.0	122.0	122.5						
300M - 30°					117.0	117.0	117.5	117.5	117.0						
400M - 30°						114.0		115.0	116.5						
100M - 20°					124.5	130.0	129.0	128.5	130.0						
100M - 30°					135.0	135.0	134.5	134.0	134.5						
100M - 45°					143.5	142.5	142.0	142.0	141.5						
100M - 60°		139.0	137.5	140.5	140.5	140.0	139.5		139.5	141.0	140.0	138.5	139.5	141.0	140.5
100M - 75°	136.5	146.0	136.5												
100M - 90°	133.0	133.0	132.5												
100M - 105°	131.5	131.0	128.0												
100M - 120°	126.0	126.0	125.5												
100M - 135°		125.0	122.5												
100M - 150°	123.0	123.0	121.0												
100M - 165°	121.0	121.5	120.0												
100M - 180°	121.5		118.5												
STD #1 (Eng. level)	156.0	159.0		152.0											
STD #2 (4.25M)	150.5	151.5		148.5											
STD #3 (9.15M)	144.5	146.0		146.0											
STD #4 (18.3M)	136.5	137.5		136.5											
STD #5 (Eng. level with Photocon)												155.0	156.0		
780M - 22°										99.0	103.0	100.0	102.5		103.0
1300M - 22.5°										95.0	92.0		98.0	99.0	91.0
1870M - 24.5°										93.0			91.0		93.0
365M - 142.5°										104.0	101.5	100.5	102.5	100.0	102.5
500M - 147°										92.5	94.0	93.5	96.0		94.0
1380M - 144.5°											80.0	86.0	81.0		80.5

Because of the known accuracies of the instrumentation system and of the data reduction equipment, the sound pressure levels are tabulated to the nearest 0.5 decibels. In general, it might be said that there is good repeatability demonstrated in these data from test to test. In each instance, data were taken at the 100 meter 60 degree point so that the consistency of the engine from test to test might be investigated. Since this sound pressure level varied in the overall, from 139.0 thru 141.0, the engine appears to have been acoustically stable. A few points in isolated instances appear to have varied slightly more than did this anchor point. However, it may be said in general that the repeatability of the measured acoustic data was much higher than might be anticipated for a series of R&D firings.

The measurements which are tabulated in overall sound pressure level in Table IV are averaged and presented in octave band and overall sound pressure levels in Figures 7 through 29. The spectra are shown in terms of octave bands whose center frequencies begin in most cases at 4 Hertz and end at 8000 Hertz. Figure 7 shows the average SPL spectra measured on the J-2 test stand, BTS-2, at Santa Susana, California, at 5.7, 12, and 32 meters above the nozzle plane. These average spectra all show essentially the same characteristics with the exception of a significant shift downward in peak frequency as one moves away from the nozzle plane.

Figures 8-19 present the average sound pressure level spectra measured along the 100 meter radius semicircle from 20 degrees to 180 degrees. The most noticable characteristic of these curves is their dissimilarity. Many of these curves show small peaks or notches which may be the result of reflection or interferences caused by other structures or topographic features in the vicinity of the microphone location. Figure 20 contains the average SPL spectra measured along the 30 degree bearing for each doubling of distance beginning with 10 meters. Thus are presented the data from 10, 20, 40, 80, 150, and 300 meters. These data above 16 Hertz clearly show the effect of increasing range on decreasing high frequency content. They also show the inverse square law to hold true in the overall for about 40 meters. Figure 21 presents the same type of data in the same format but for those measurements along the 30 degree bearing which doubled the distance beginning at 50 meters. The points were: 50, 100, 200, and 400 meters. The average sound pressure level spectra measured in the far-field along the 22 degree and 150 degree bearings are presented in Figures 22 and 23. These show the characteristic lack of high frequency which has been noted from static test firings of other vehicles.

In Figure 24 are seen the data which were taken from points along the 30 degree bearing. These overall data were averaged and plotted against an arbitrary reference.. This scale is the deviation from the classical inverse square law. Because of the extreme unevenness of the ground plane and because of both obstructions and reflecting surfaces in the area, the curve is not at all smooth, as in the idealized case. However, it does slowly fall away from the inverse square law. Also shown in Figure 24 are the deviations of the data taken at each range.

Figures 25, 26, 27, and 28 show the directivity associated with the J-2 as fired at Santa Susana. Figure 25 contains the overall directivity. The maximum lobe occurred quite sharply at 45 degrees. The low frequencies (the octaves from 4 to 32 Hz) had a broader directivity especially behind the test stand (the exhaust jet flow was taken as 0° azimuth), but still in many instances showed a sharp peak at 45 degrees. This is shown in Figure 26. The middle frequencies, or those octaves from 63 through 500 Hertz, have a more sharply defined directivity pattern. They also peak at 45 degrees, although they are, in some instances, more broad out toward 60 degrees. The middle frequencies were especially affected by the test stand itself and show the lowest levels toward 180 degrees. As seen in Figure 28, the higher frequencies, those octaves from 1000 to 8000 Hertz, have the broadest directivity. They, too, show a slight peak at 45 through 60 degrees but come the closest to having a uniform directivity. Since the middle frequencies shown in Figure 28 are, in nearly every instance, the frequencies at which the respective measurement spectra peak, their directivity is that which was most closely followed by the overall.

As was mentioned earlier, there were not enough measurement channels with which to completely instrument the entire program during each test. Therefore, the one microphone at 100 meters 60 degrees bearing was chosen as an anchor point for monitoring the consistency of the acoustical signal from test to test. The average and spread of the measured data values at this location both in the overall and in the octaves from four to 8000 Hertz are shown in Figure 29. The overalls were found to spread approximately plus or minus 1 1/2 decibels. The octave spread in those frequencies above 31 1/2 Hertz was somewhat greater. However both the spread of the data and the general shape of the envelope verified the consistency of the J-2 engine as an acoustical noise source.

The acoustic power level discussed earlier is a very convenient yardstick in the measurement of various classes of rocket and space vehicle engines because it refers directly to the power which is converted to acoustical energy. A sound pressure level measurement on the other hand is expressed in terms of a ratio of pressures at a given point. For quite obvious reasons, it is not always possible to physically occupy identical points around the various test stands and engines. Depending upon the wave length of the peak frequency within the measured spectra, these arbitrary points also may not always fall within the acoustic far-field of the engine being tested. For these and other reasons, the acoustic power level is almost universally accepted as a useful method for the assessment of the noise source. The acoustic power level and the space average sound pressure level from which it is derived for the J-2 engine are shown in Figure 30. In Figure 31 this power level spectrum is again shown, and plotted with it are the corresponding power level spectra from the H-1 and the S-1 configurations. Since the H-1 and J-2 are largely comparable engines in thrust level, it is not surprising that they agree as well as they do. In three of the octaves (16, 31.5, and 63 Hz) there is a wide disparity. This may very likely be the result of the difference in the test configurations from which the respective PWL spectra were obtained. Present plans call for subsequent test series of both the H-1 and J-2 engines to be performed on more identical stands. It is hoped that the questions surrounding these three octaves can be resolved at that time.

The amount of energy which was converted into acoustical noise was calculated from this power level. It amounted to 2.5×10^6 watts which is 0.3 percent of the calculated jet stream energy. This is slightly less than the 0.5 percent found in tests of the S-1 and H-1 engines.

CONCLUSIONS

Despite the difficulties encountered in scheduling, in terrain, and in duration and performance of the engine, this J-2 acoustic test program has contributed significantly to the store of knowledge about rockets and rocket engines as noise sources. On the whole it may be said that the J-2 engine showed a remarkable consistency in performance despite changing engine parameters during this R&D phase. It was found that the acoustical environment of the J-2 is similar to the noise generated by liquid oxygen-kerosene rockets (F-1 and H-1 engines and the Saturn I booster). The spectra of the sound pressure level at 100 meters from the test stand peak in the octave band centered at 31 and 63 Hertz. The overall directivity peaked rather sharply at 45 degrees; however, the spectral directivity is very "frequency" dependent. The acoustical efficiency of the jet stream is calculated to be 0.3 percent. Subsequent tests of the J-2 on other test stands and in other topographic areas will be required to definitively compare the acoustical performance of the J-2 with other types of engines.

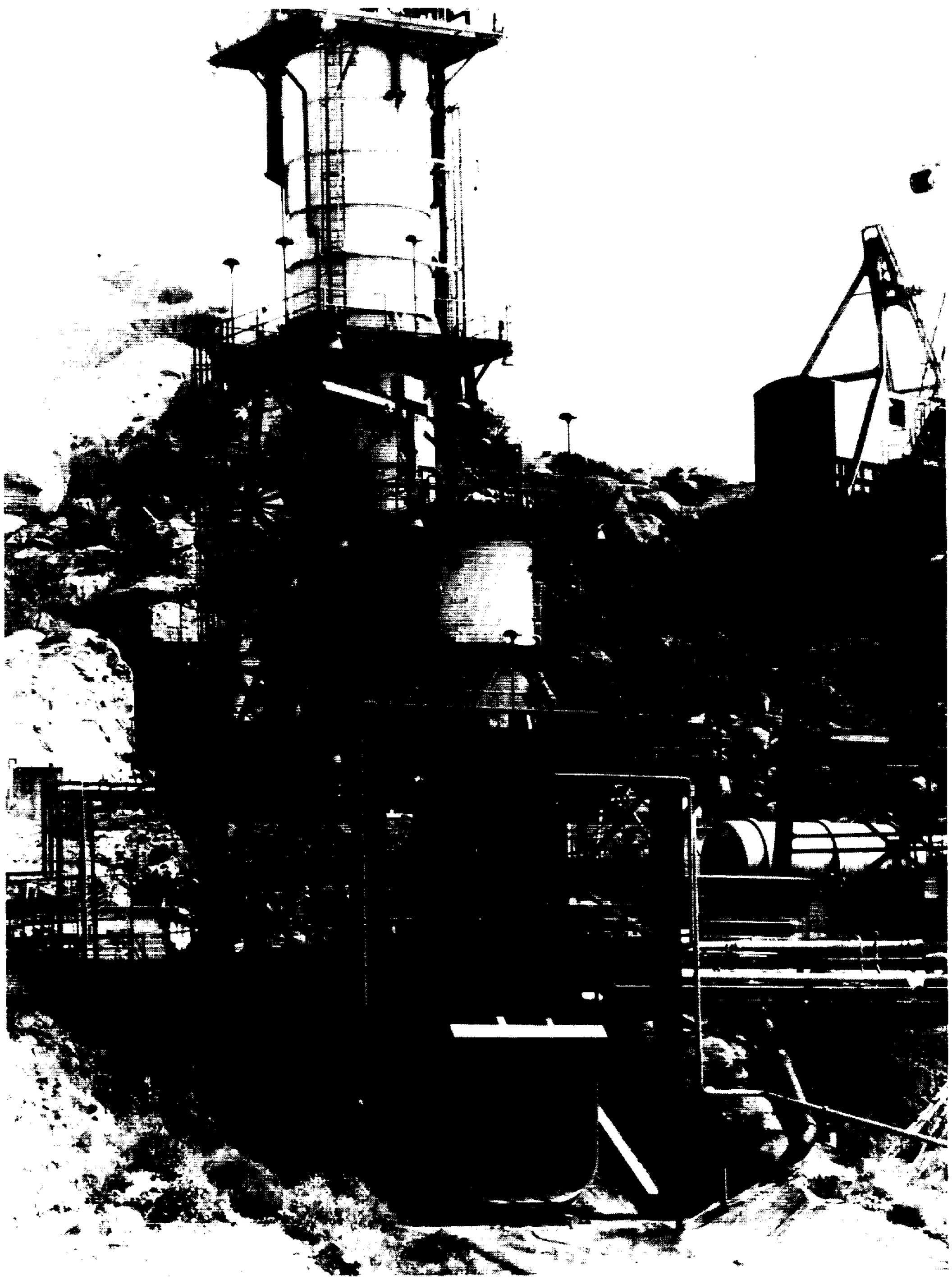


FIGURE 3. PHOTO OF VTS-2 SHOWING NEAR-FIELD LOCATION AND TERRAIN

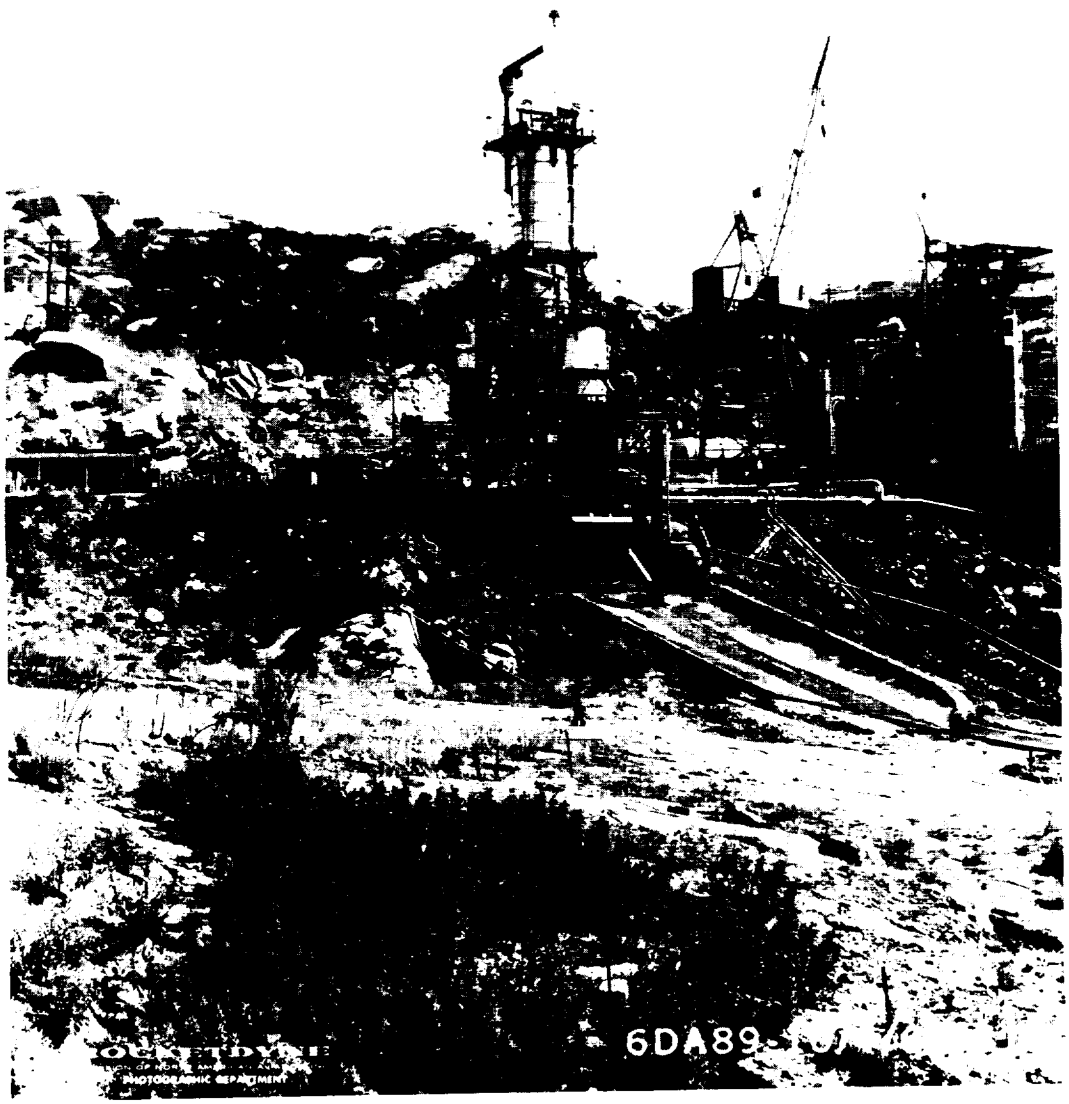


FIGURE 4. PHOTO OF VTS-2 AND MID-FIELD LOCATIONS AND TERRAIN

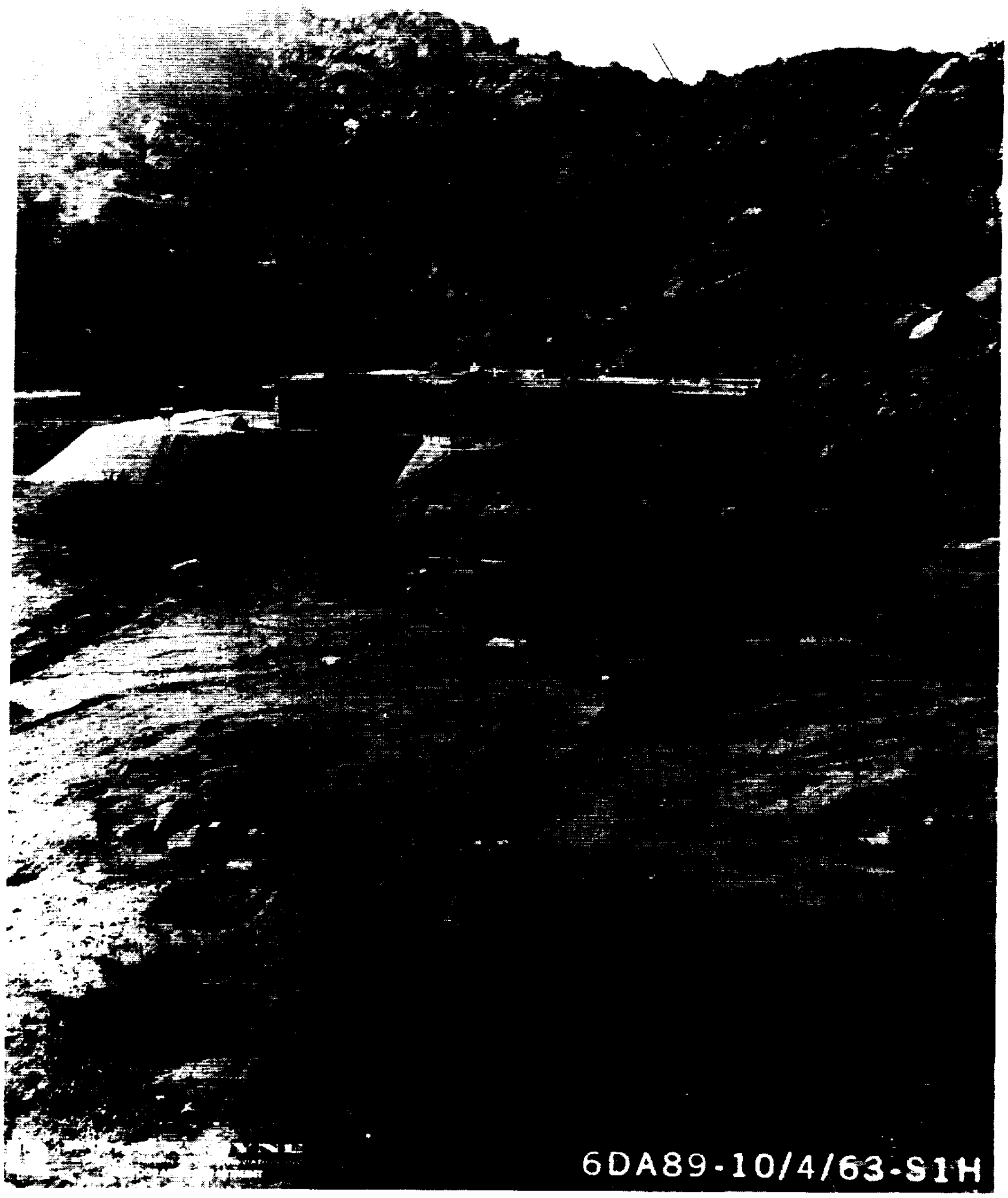
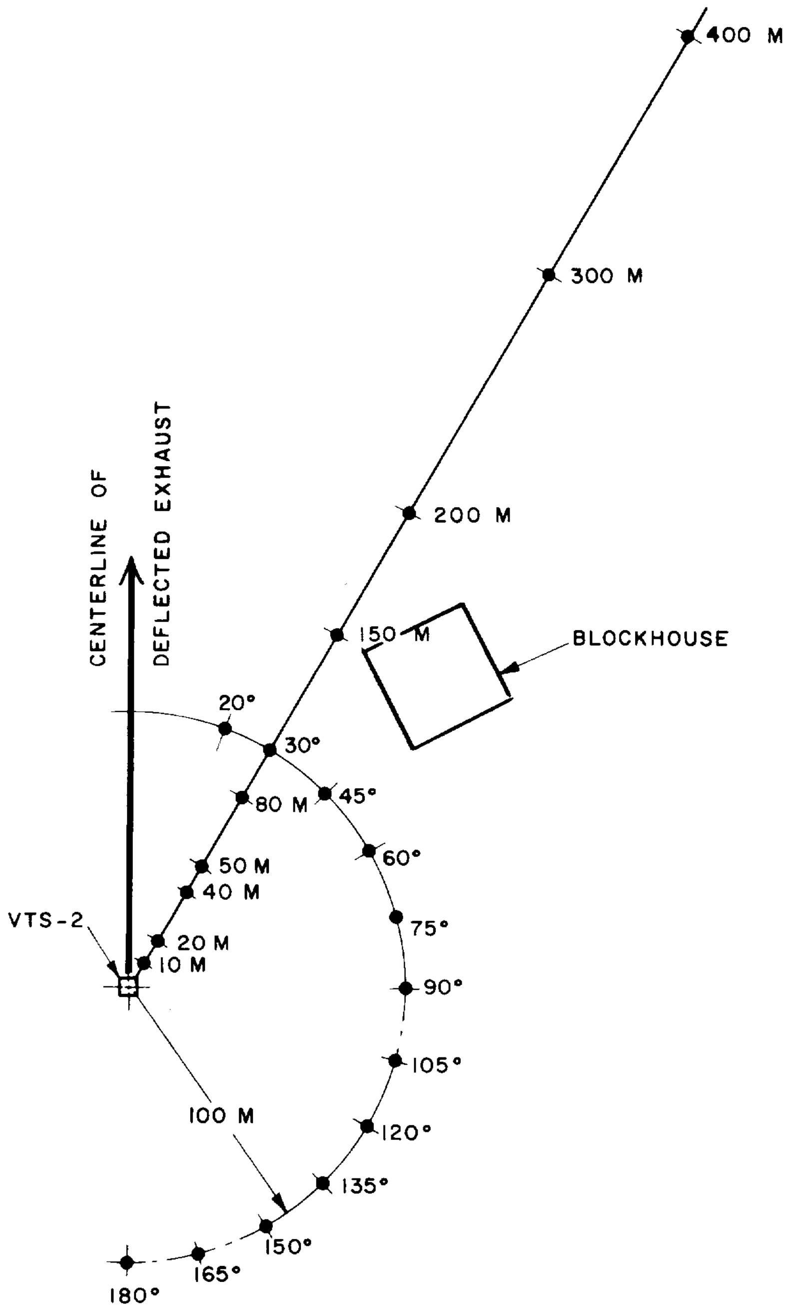


FIGURE 5. PHOTO OF VTS-2 BLOCKHOUSE AND TERRAIN



MEASUREMENT ARRAY OF MIDFIELD MEASUREMENTS

FIGURE 6. DRAWING OF MEASUREMENT ARRAY OF MID-FIELD MEASUREMENTS

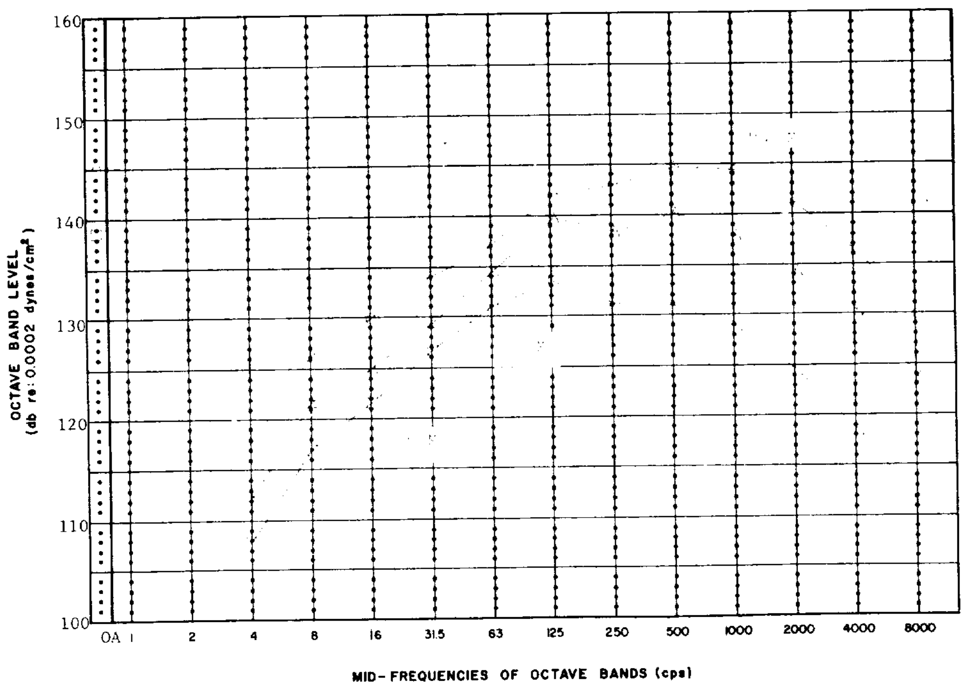


FIGURE 7. AVERAGE SPL SPECTRA MEASURED ON J-2 TEST STAND

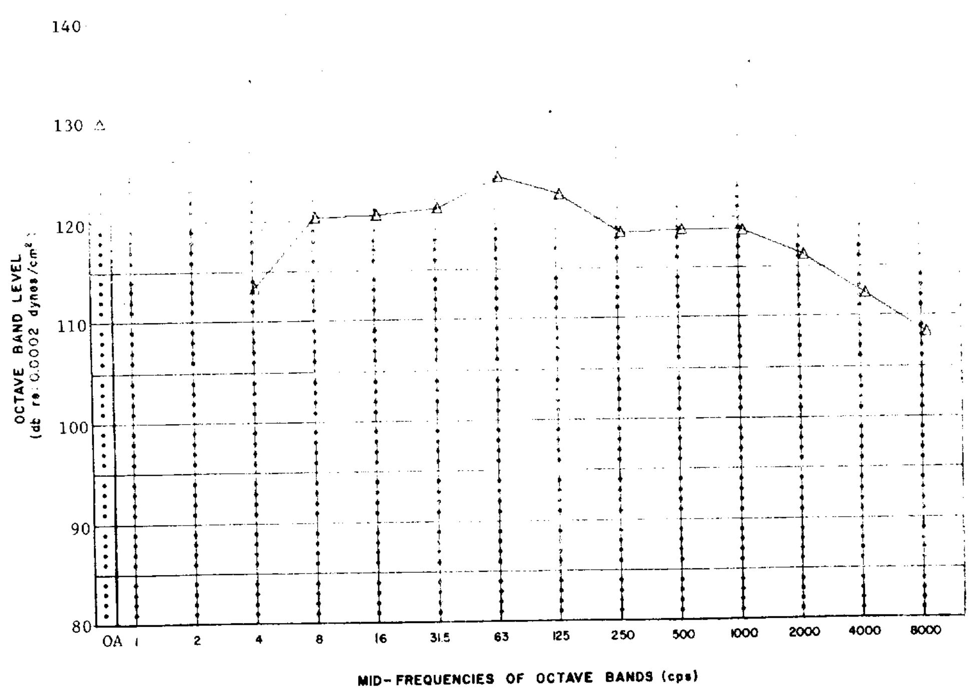


FIGURE 8. AVERAGE SPL SPECTRA MEASURED AT 100 METERS, 20 DEGREES

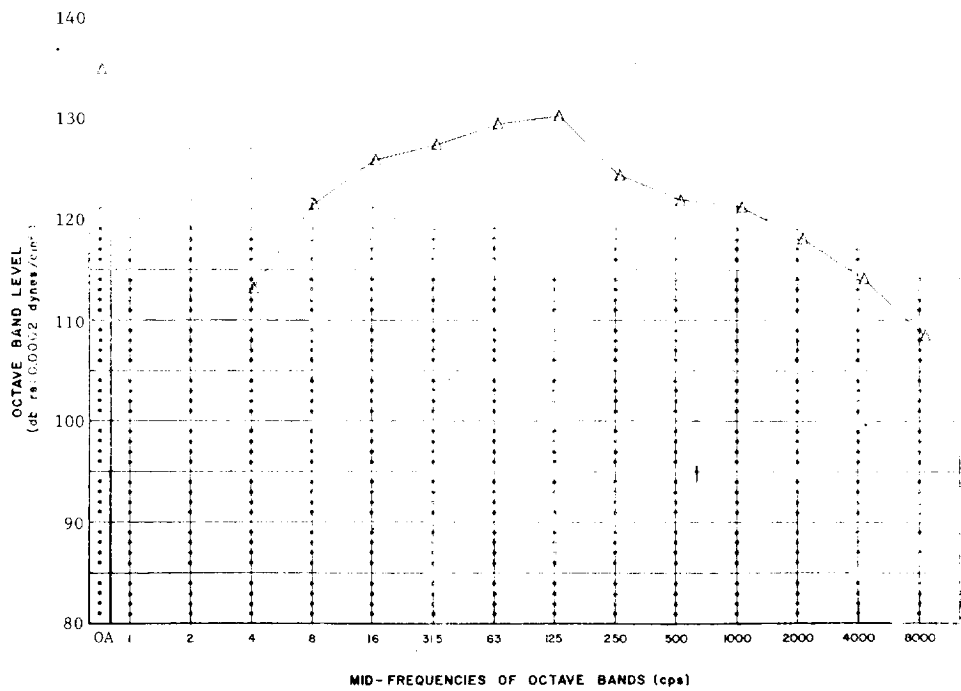


FIGURE 9. AVERAGE SPL SPECTRA MEASURED AT 100 METERS, 30 DEGREES

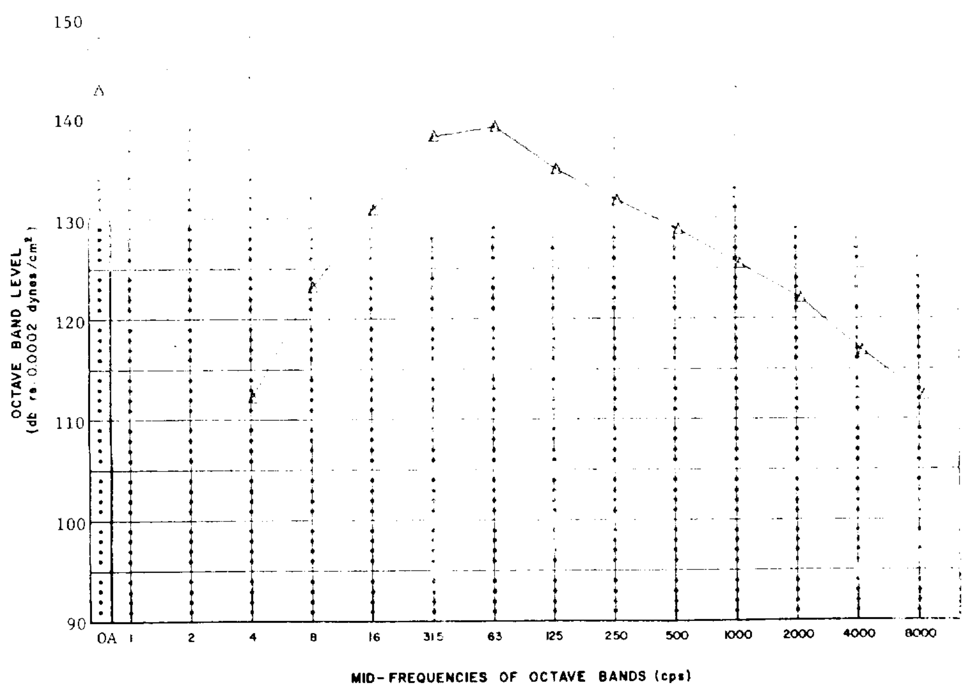


FIGURE 10. AVERAGE SPL SPECTRA MEASURED AT 100 METERS, 45 DEGREES

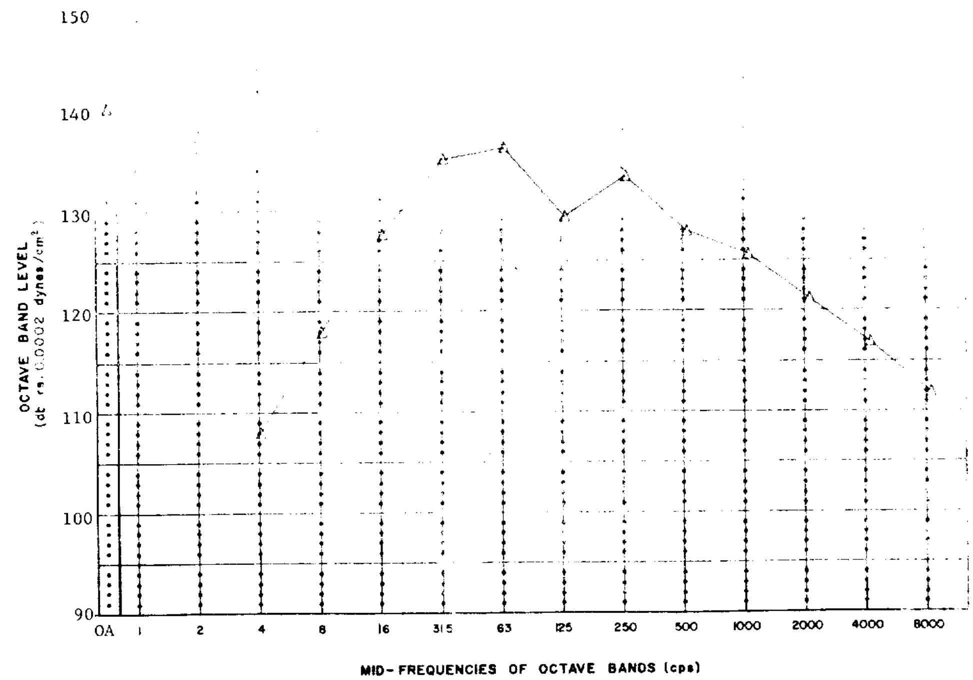


FIGURE 11. AVERAGE SPL SPECTRA MEASURED AT 100 METERS, 60 DEGREES

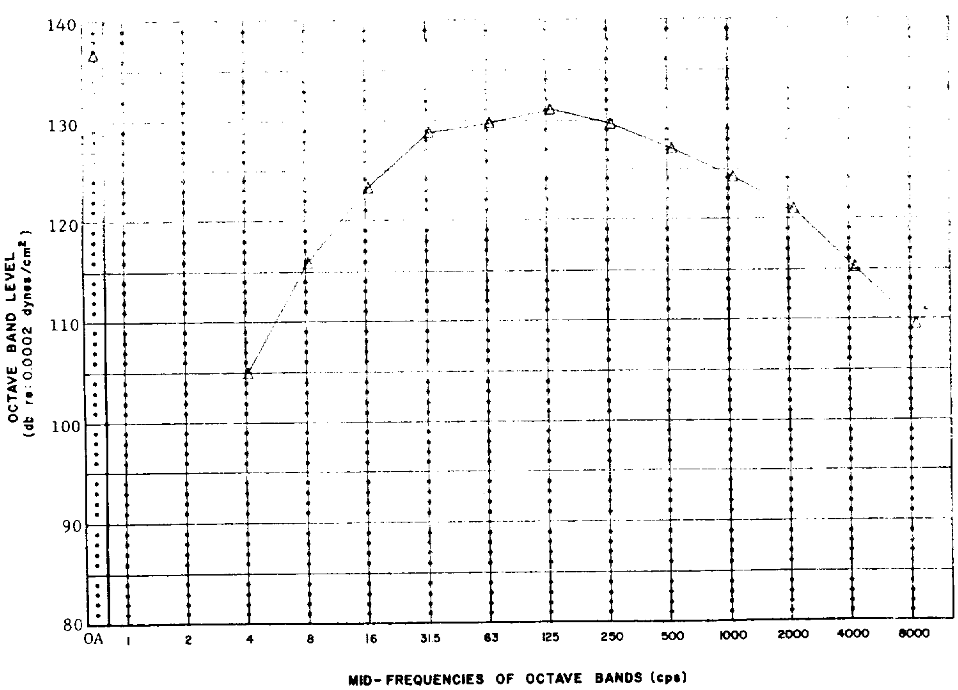


FIGURE 12. AVERAGE SPL SPECTRA MEASURED AT 100 METERS, 75 DEGREES

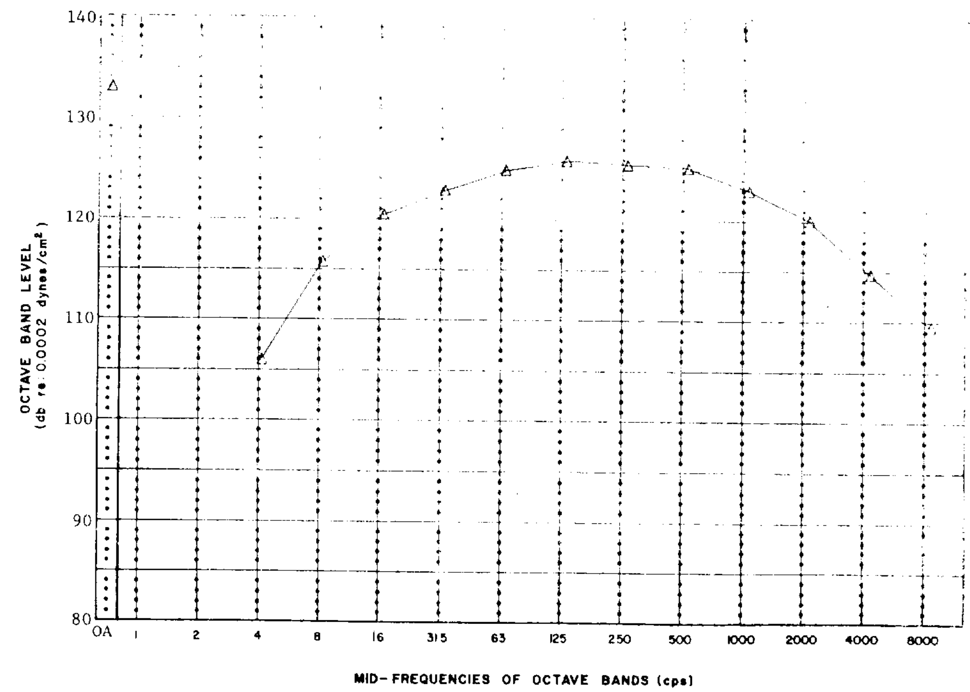


FIGURE 13. AVERAGE SPL SPECTRA MEASURED AT 100 METERS, 90 DEGREES

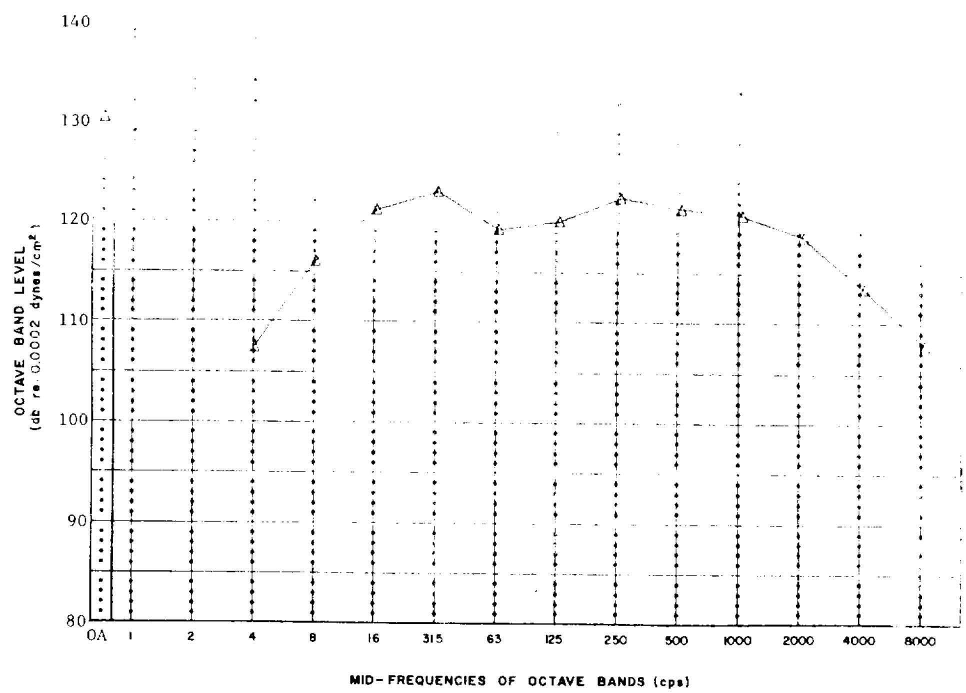


FIGURE 14. AVERAGE SPL SPECTRA MEASURED AT 100 METERS, 105 DEGREES

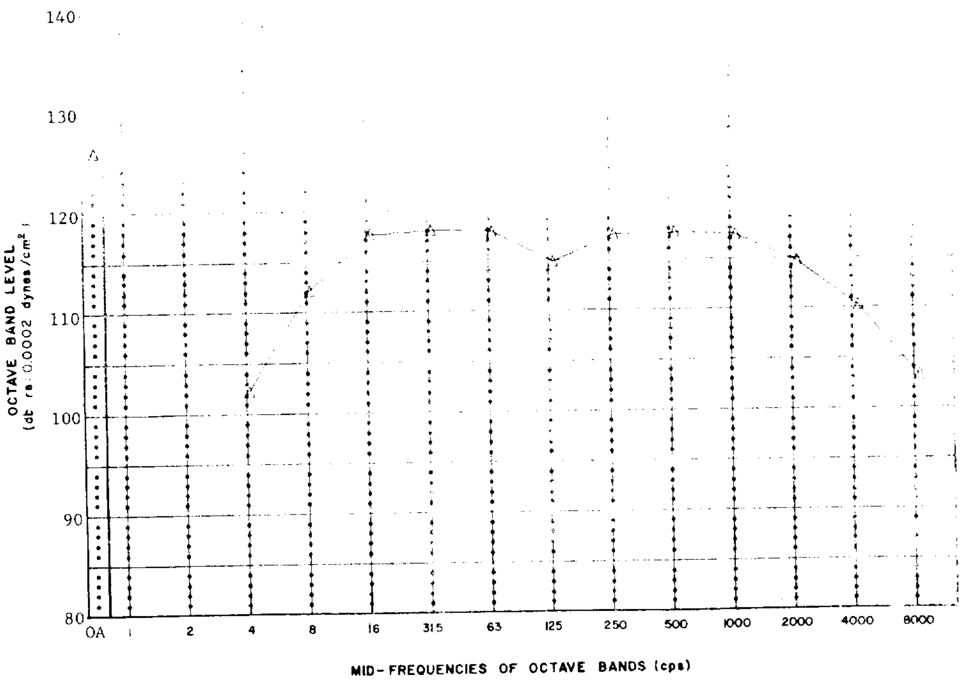


FIGURE 15. AVERAGE SPL SPECTRA MEASURED AT 100 METERS, 120 DEGREES

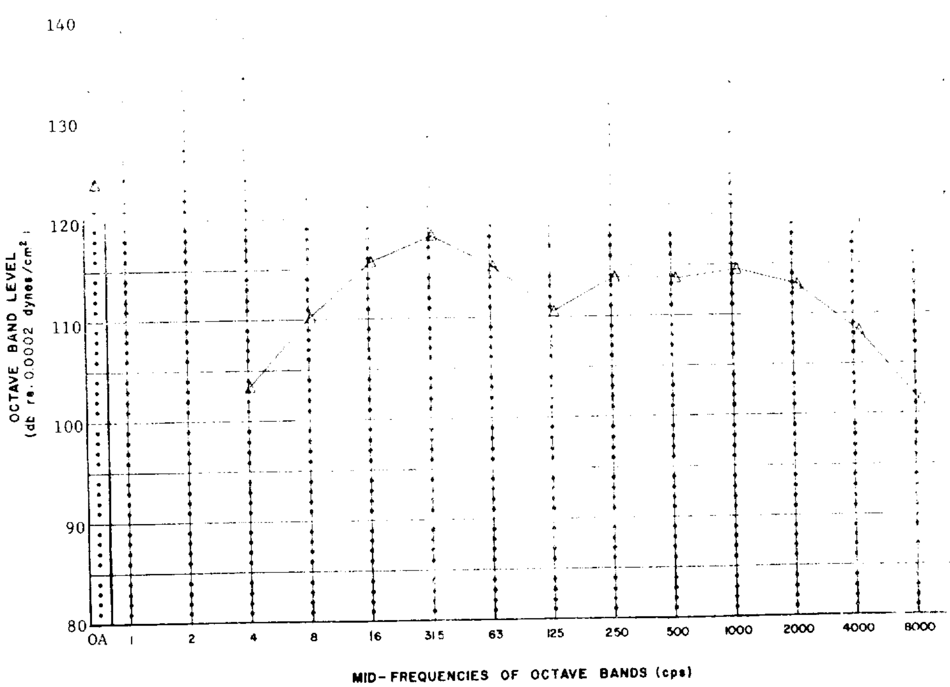


FIGURE 16. AVERAGE SPL SPECTRA MEASURED AT 100 METERS, 135 DEGREES

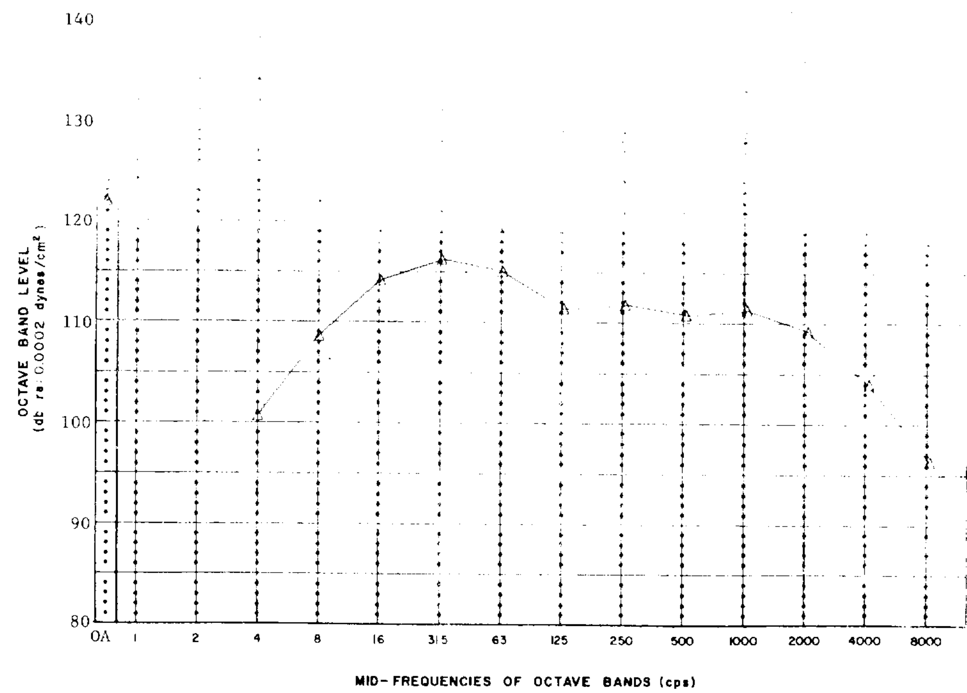


FIGURE 17. AVERAGE SPL SPECTRA MEASURED AT 100 METERS, 150 DEGREES

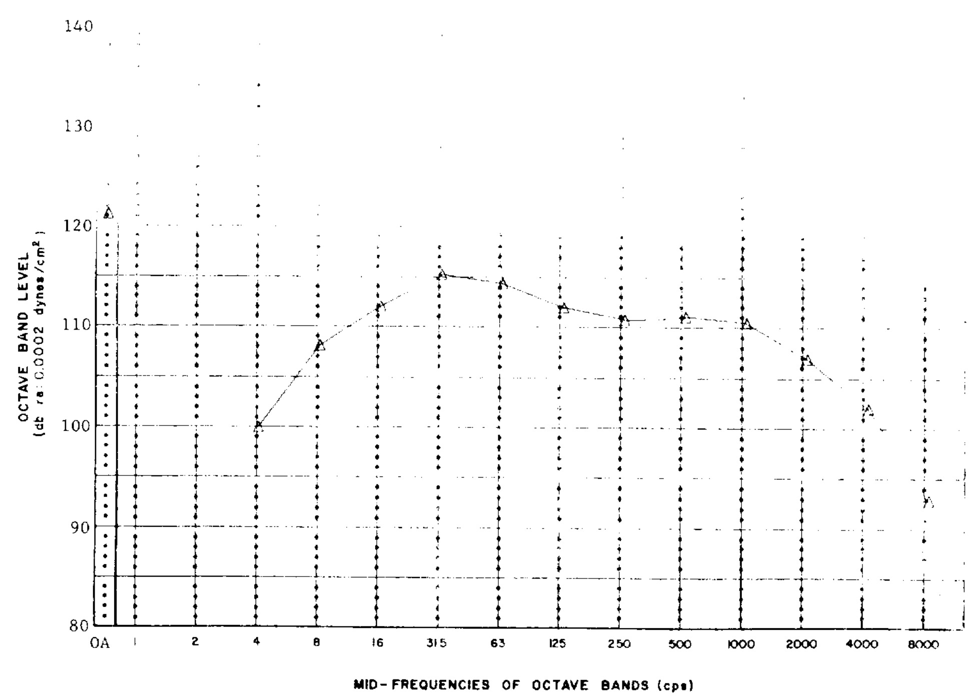


FIGURE 18. AVERAGE SPL SPECTRA MEASURED AT 100 METERS, 165 DEGREES

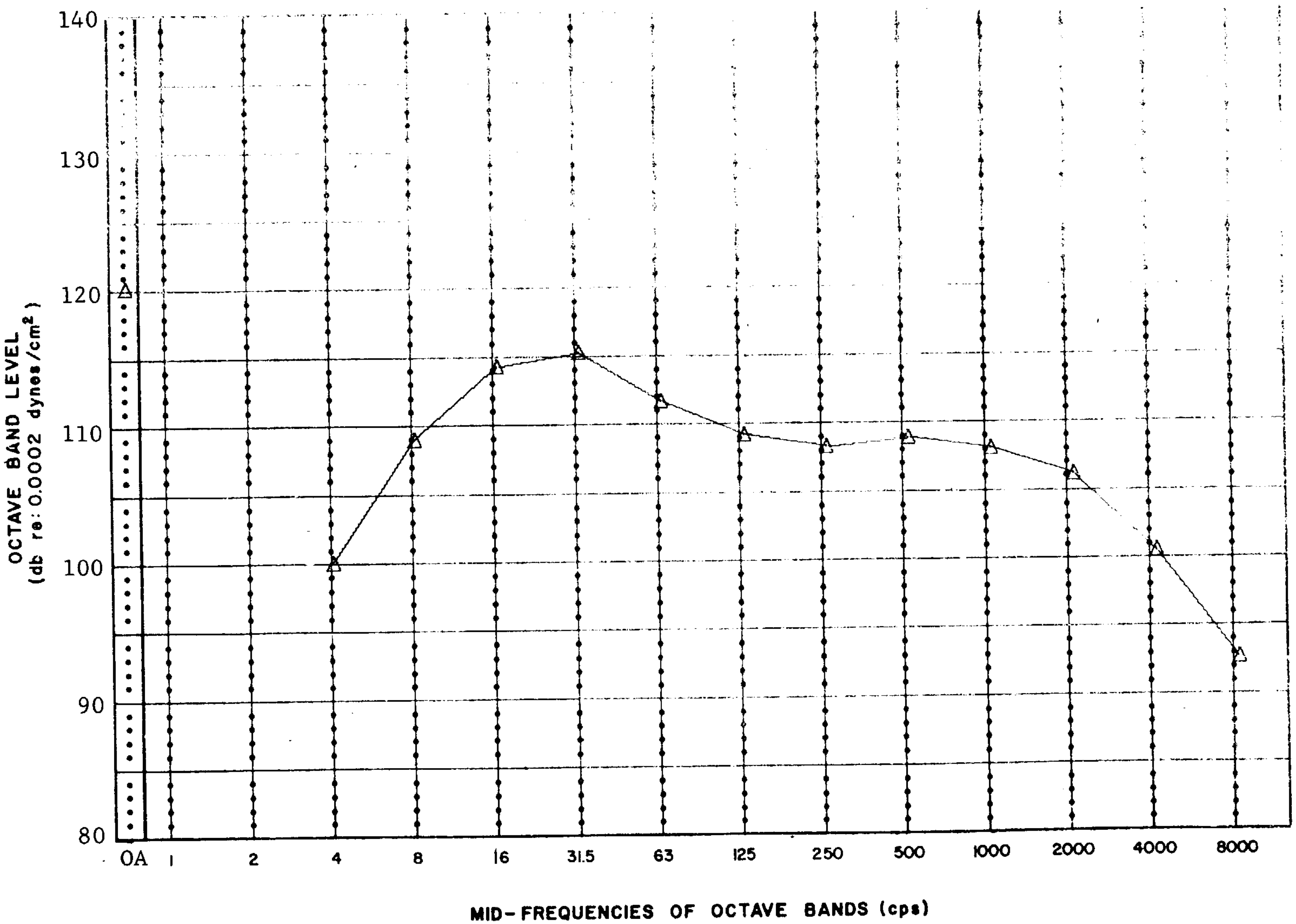


FIGURE 19. AVERAGE SPL SPECTRA MEASURED AT 100 METERS, 180 DEGREES

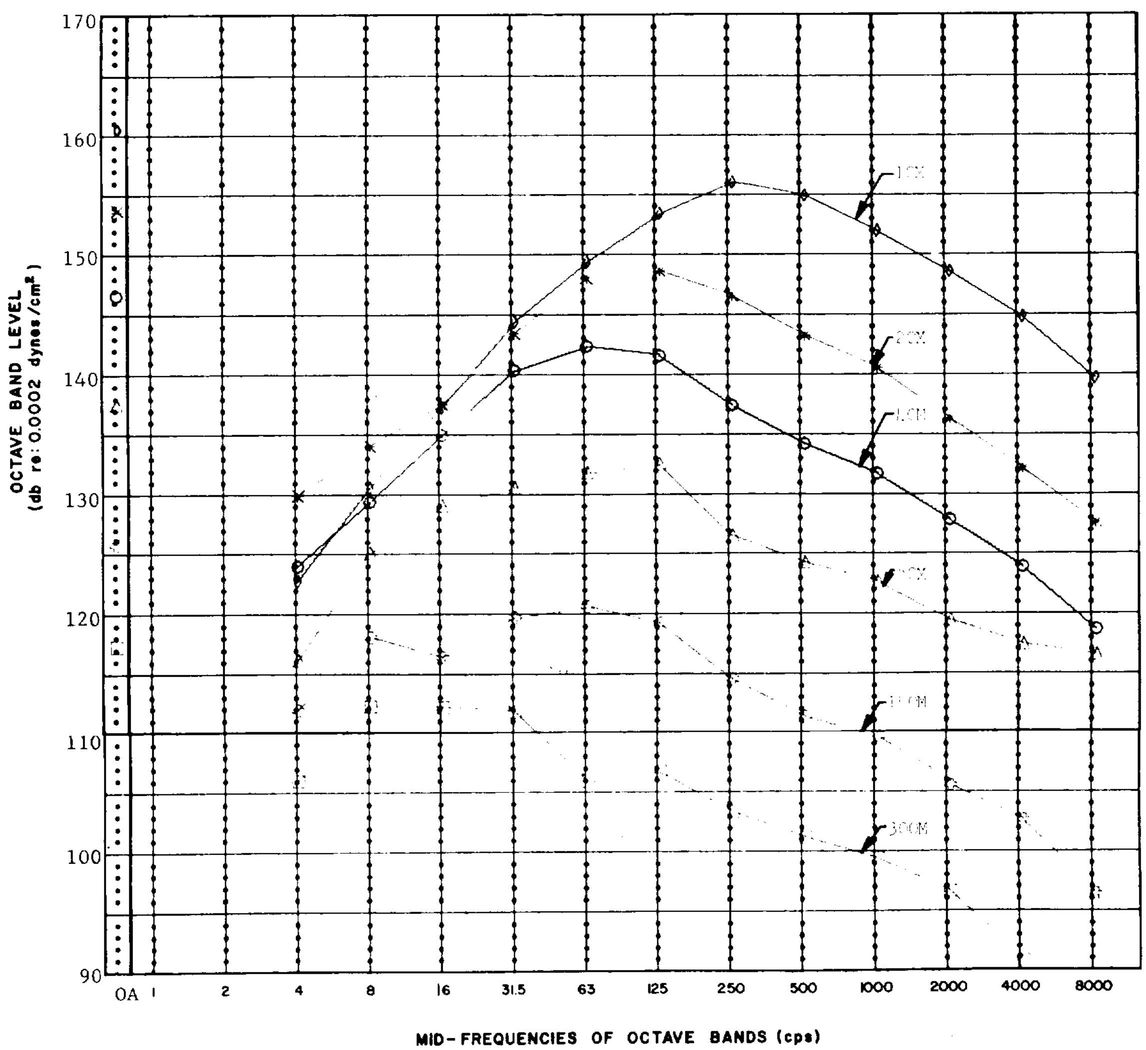


FIGURE 20. AVERAGE SPL SPECTRA MEASURED ALONG 30 DEGREE BEARING FOR EACH DOUBLING OF DISTANCE BEGINNING WITH 10 METERS

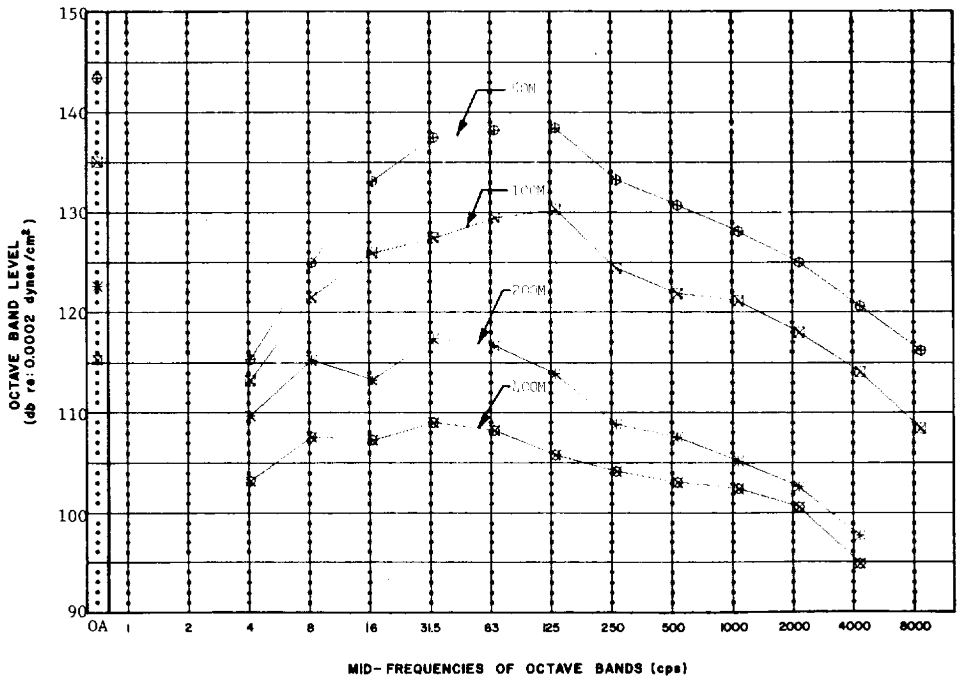


FIGURE 21. AVERAGE SPL SPECTRA MEASURED ALONG 30 DEGREE BEARING FOR EACH DOUBLING OF DISTANCE BEGINNING WITH 50 METERS

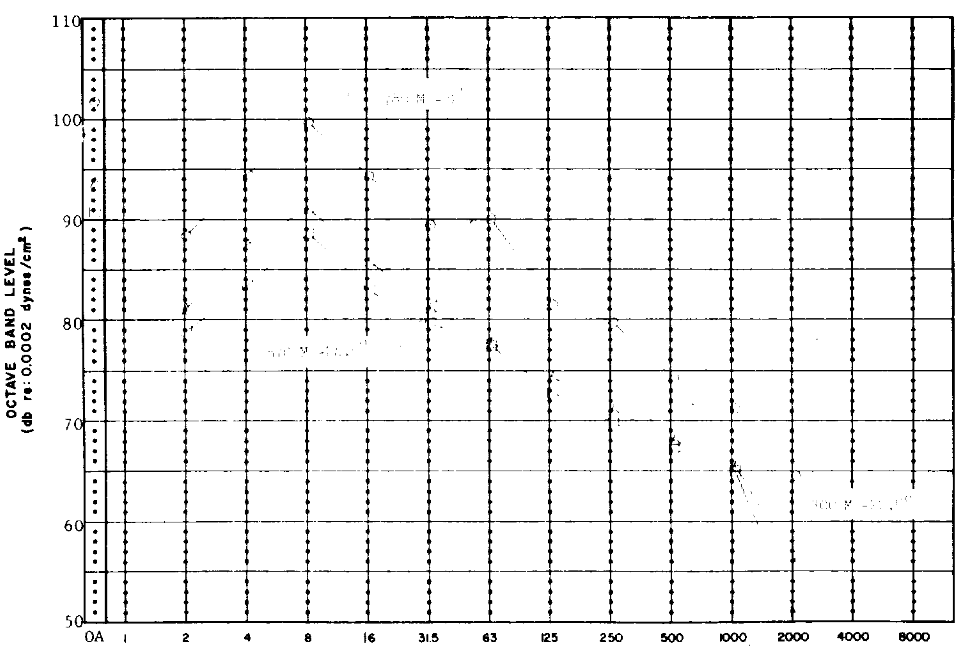


FIGURE 22. AVERAGE SPL SPECTRA MEASURED AT THE FAR-FIELD LOCATIONS ALONG 22 DEGREE BEARING

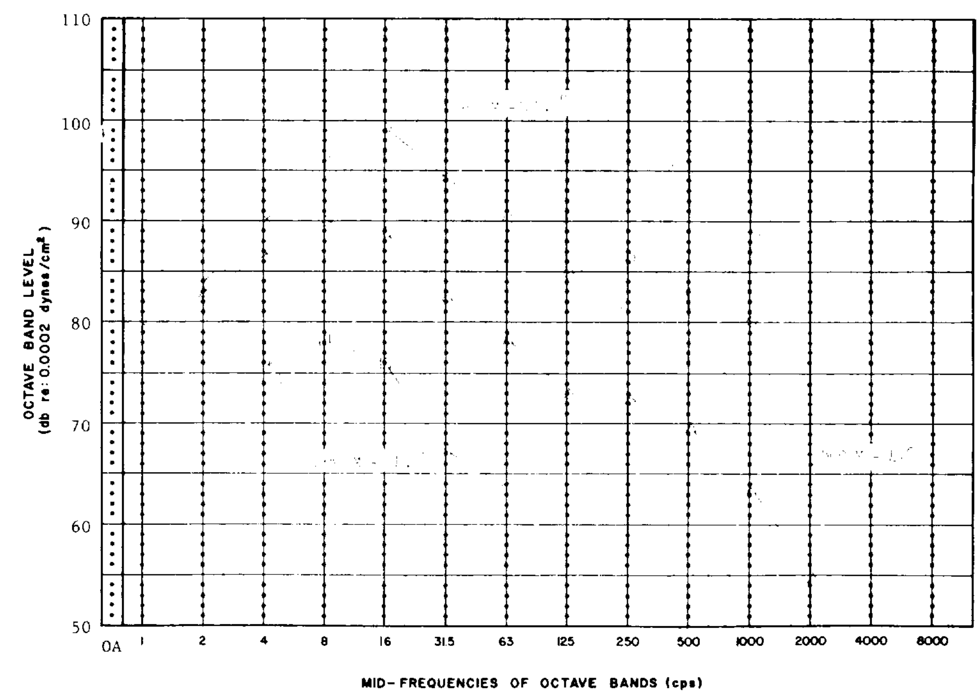


FIGURE 23. AVERAGE SPL SPECTRA MEASURED AT THE FAR-FIELD LOCATIONS ALONG 150 DEGREE BEARING

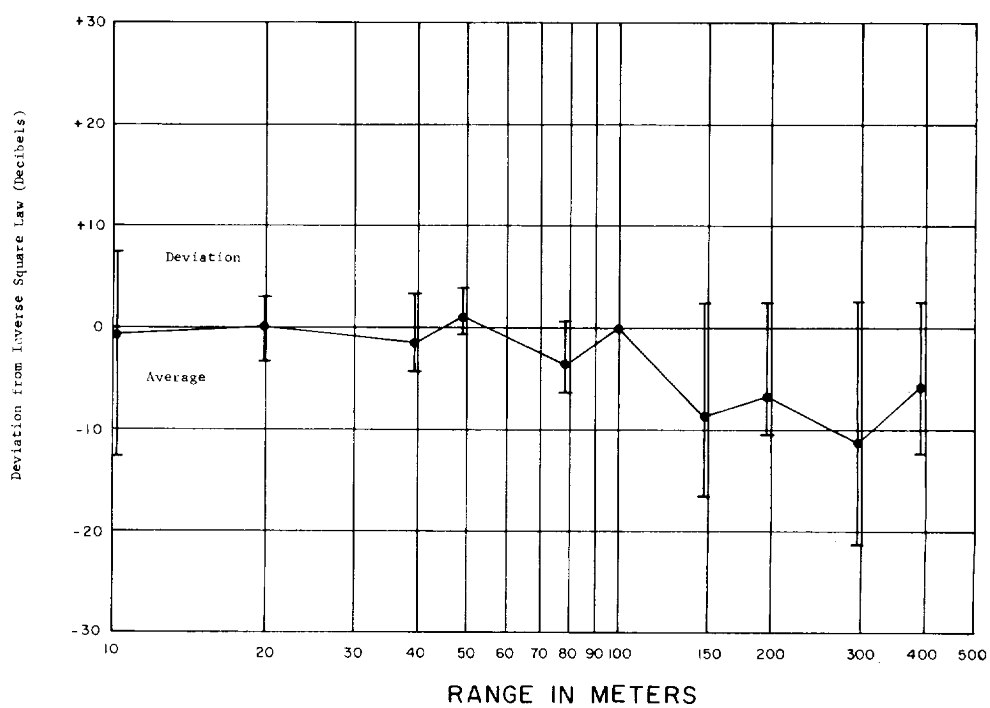


FIGURE 24. AVERAGE AND RANGE OF DEVIATIONS FROM INVERSE SQUARE LAW PROPAGATION ALONG 30 DEGREE BEARING

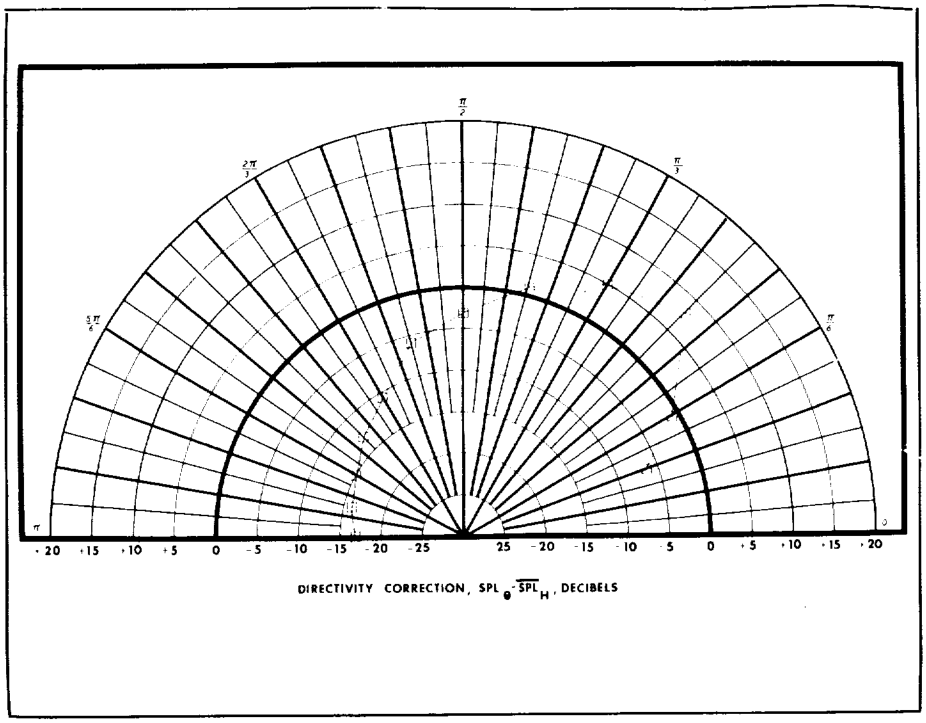


FIGURE 25. OVERALL DIRECTIVITY PLOT AROUND VTS-2 TEST STAND

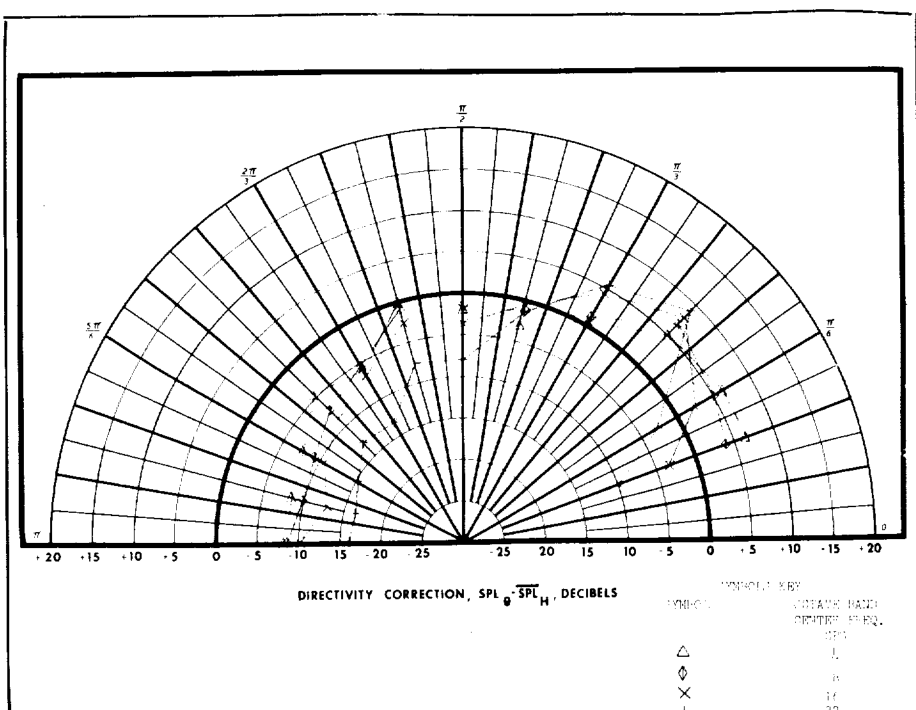


FIGURE 26. LOW FREQUENCY DIRECTIVITY PLOTS (OCTAVE)

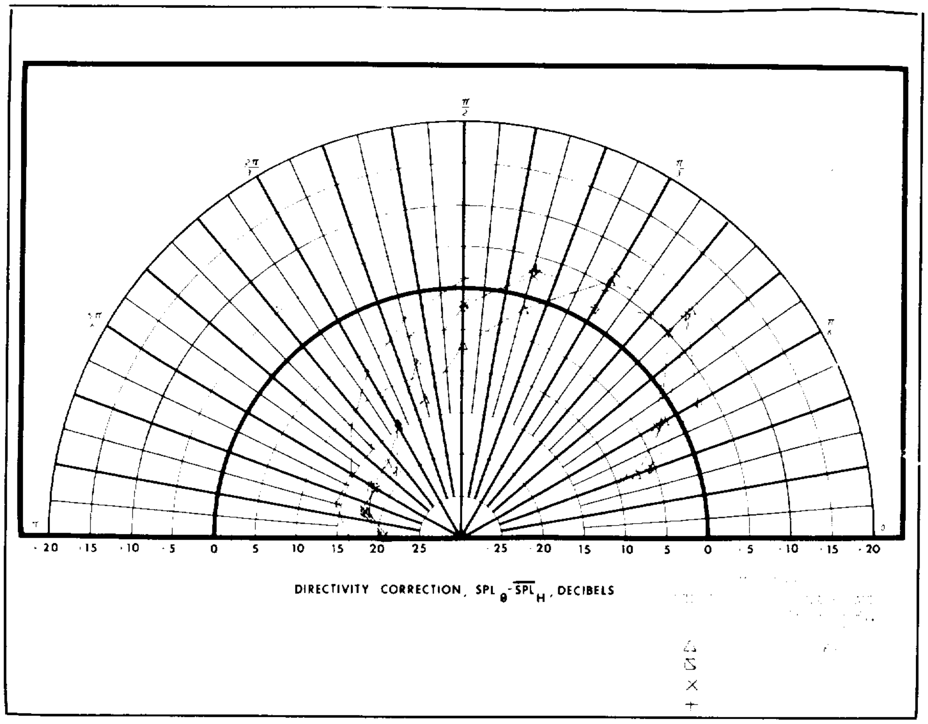


FIGURE 27. MIDDLE FREQUENCY DIRECTIVITY PLOTS (OCTAVE)

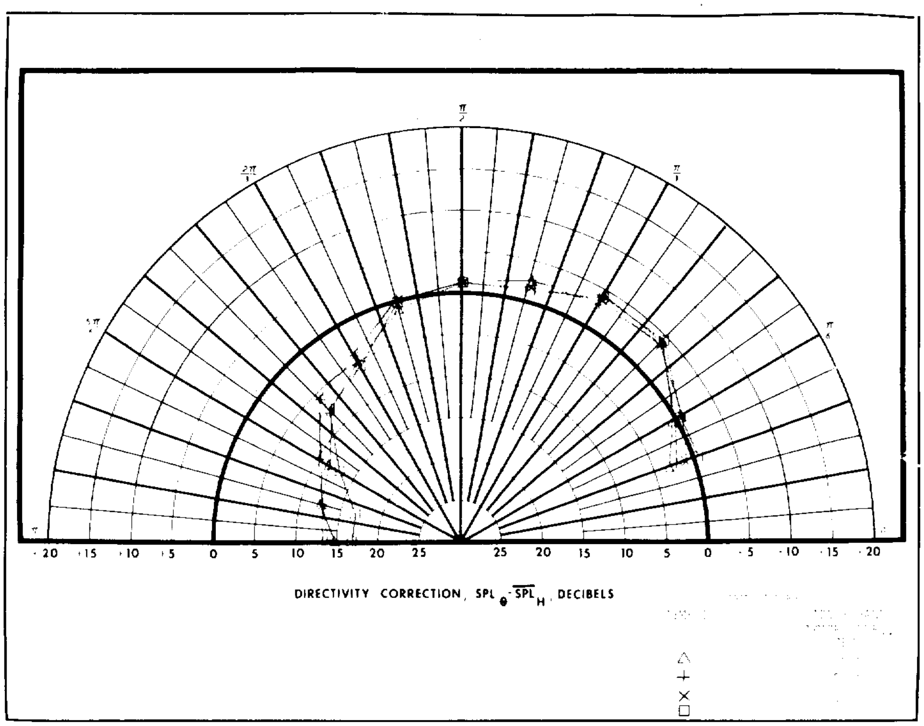


FIGURE 28. HIGH FREQUENCY DIRECTIVITY PLOTS (OCTAVE)

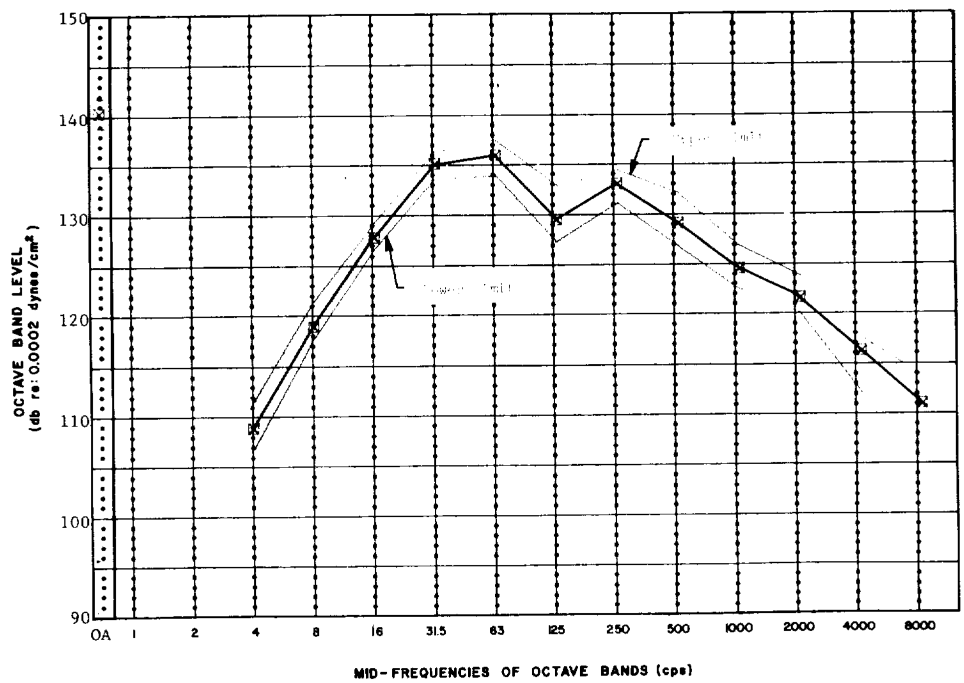


FIGURE 29. AVERAGE AND SPREAD OF DATA VALUES MEASURED AT 100 METERS, 60 DEGREES FOR 13 TESTS

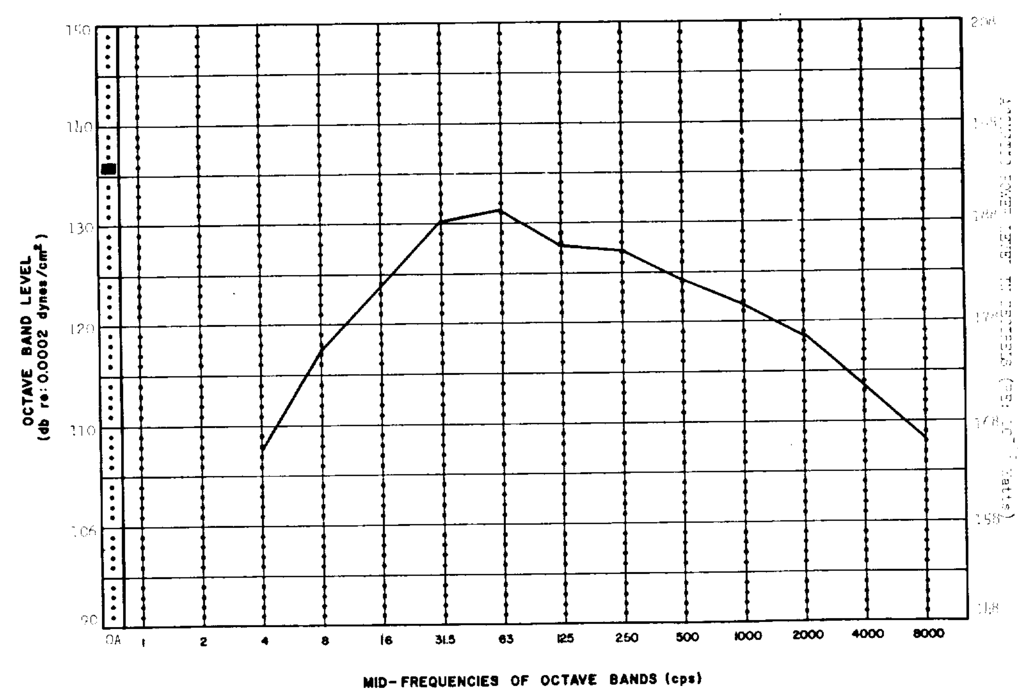


FIGURE 30. SPACE AVERAGE SOUND PRESSURE LEVEL SPECTRUM AT 100 METERS RADIUS

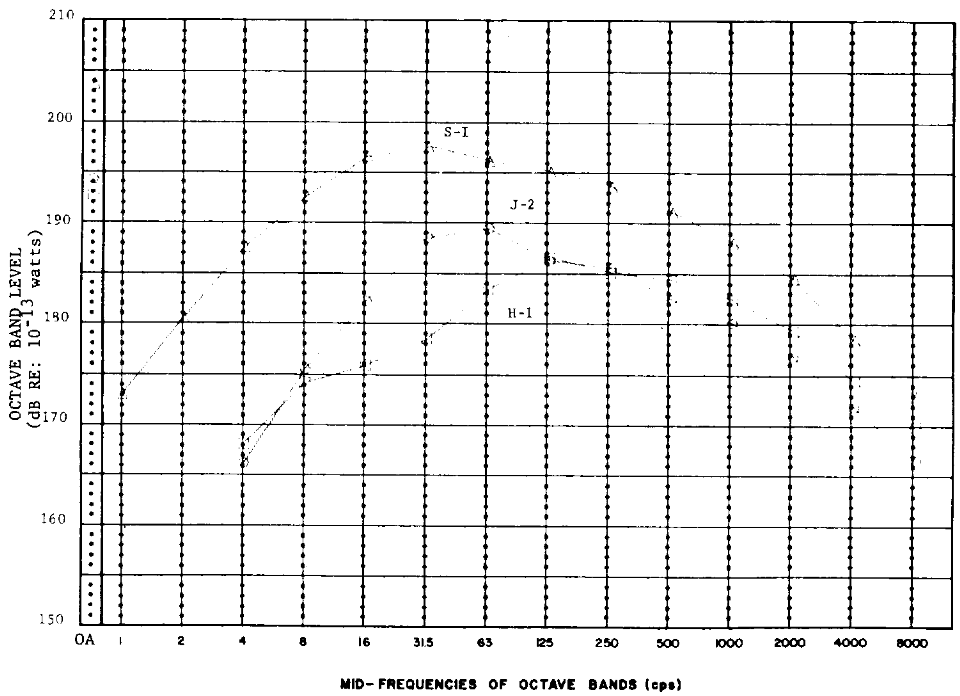


FIGURE 31. ACOUSTIC POWER LEVELS FROM J-2, J-1, and S-1 ENGINES

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Approval

The J-2 Engine As An Acoustical Noise Source

By

Richard N. Tedrick
Charles C. Thornton
Wade D. Dorland

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This report also has been reviewed and approved for technical accuracy.

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