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TRUCK AND COMPONENT NOISE LEVELS

FINAL REPORT

MARCH 1979

PREPARED FOR

ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

BY

APPLIED HYDRO-ACOUSTICS RESEARCH, INC.
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1.0 INTRODUCTION

Among the challenges of developing a quiet truck, the problems associated with location, identification, and measurement of component source levels are the most difficult. Various approaches have been utilized by truck and component manufacturers. Each approach is limited by either technical or cost constraints.

Two major approaches have been investigated. These are:

Coherence: Near and far-field microphones are used to compute the contribution of a source by subtracting the near-field levels from the far-field measurement.

Selective Operation: This method requires the silencing of all major sources by lead wrapping and installation of super quiet mufflers and air induction systems. After baseline measurements are obtained, individual components are restored to the original configuration for measurement of the noise level of that component.

A technical problem is associated with the coherence method. When the near-field microphone is placed near one component (i.e. muffler) other components (engine, fan, etc.) are nearby and can contribute to the near-field level. As a result the calculated component source level may be in error. The method of selective operation is, of course, time consuming and expensive because of the requirement to develop enclosures, mufflers, and air induction systems, and the need to conduct extensive before and after tests of each component.

A new approach is discussed in this report. This approach utilizes: a.) a directive array of microphones for location and measurement of sources; and, b.) near-field probes for the identification of the specific source. In particular the report contains a discussion of the directive array approach and the near-field probe approach.

Section 2.0 provides a discussion of the test procedures for component source measurements. The measurement technique has been applied in a test of one truck in order to measure component noise levels as a function of speed and load. Section 3.0 provides a discussion of a test of a Ford heavy-duty tractor. The truck is a model CLT 9000, with a Cummins NTC 350 engine, dual STEMCO mufflers, a viscous fan clutch, and a 13-speed Road Ranger transmission. In addition, Section 3.0 provides a detailed description of the truck, dynamometer, test equipment, test methodology, and the test results. Section 4.0 provides the conclusions and recommendations.

2.0 PROCEDURES FOR COMPONENT NOISE IDENTIFICATION

In preparation for the test and evaluation portion of this effort, wherein the objective is to establish a relative noise ranking of the major truck components as they occur over speed and load range, a thorough literature search was initiated to identify the various methods of obtaining reliable component noise measurements. After the literature search, two procedures were selected and evaluated. These two procedures were: a.) the use of a specially developed directive array for the location and rudimentary identification of truck noise components; and, b.) the use of near field probing for the identification of noise and vibrational components.

2.1 Directive Array Method

The array consists of 20 individual ceramic microphones, which are mounted in a circular arc configuration over an acoustic aperture of approximately 125 feet (45 meters). Electrical signals from built-in microphone preamplifiers are summed in junction boxes to produce a single stationary array beam output. This beam is capable of discrete spatial discrimination of sound from one source in the midst of others. In addition to the 20 microphones with their individual preamplifiers other system components include four remote junction boxes with gain adjustment potentiometers for each microphone, one central junction box, a collection of connecting cables and individual windscreens for each microphone.

2.1.1 Microphone Description

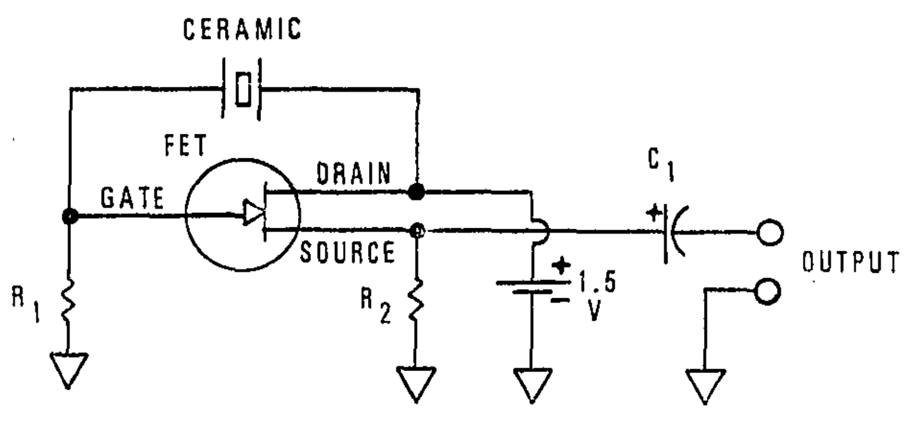
The microphones are Knowles Model BL-1802 ceramic 1/2-inch (12.7 mm) diameter units, manufactured by Knowles Electronics, Inc. of Franklin Park, Illinois.

As stated in the Knowles specification, these microphones have ceramic sensing elements with integral field effect transitors (FET), developed by Knowles laboratories to be used with ANSI Type 2 sound level meters. The measured open circuit pressure response is flat from 20 to 5000 Hz, with a sensitivity of -72 dB relative to one volt per microbar and an A-weighted noise level of 28 dB.

Each sensor including the microphone and preamplifier is housed in a 12-inch (300 mm) rigid plastic tube, with the microphone on one end and the signal output connector on the other.

A source follower circuit recommended by Knowles has been used as the preamplifier. This circuit uses a 1.5 V bias battery to polarize the FET, two resistors and a DC blocking capacitor at the output:

FIGURE 2-1 MICROPHONE PREAMPLIFIER



The basic purpose of this circuit is impedance matching. It transforms from the very high impedance of the ceramic sensing element to a relatively low output impedance that can be used to drive a signal cable without seriously compromising the frequency response. According to Knowles, nominal output impedance of the above preamplifier circuit is 4000 Ω.

Signals from four microphones are brought by individual cables to a junction box and are summed in a simple operational amplifier circuit. The gain applied to each signal is independently adjustable at the input to the summing amplifier. There are five such summing amplifiers, four in the remote junction boxes and one in the central junction box.

Cables connect the four remote junction boxes to the central junction box, where the total summation of all twenty inputs is accomplished in the final summing amplifier. No gain adjustments are available at the inputs to this final summing amplifier.

Bruel and Kjaer AU-0237 polyurethane windscreens are used on the array microphones to shield against wind generated noise.

2.1.2 Description of the Directive Array

The array is deployed in a circular arc formation covering nearly 1/2 of a fifty (50) foot circle. Sensors, consisting of one microphone and preamplifier each, are positioned on the arc, at specific arc length separations. The resulting beampattern is formed by summing all outputs without phase shift to provide a beam response which is focused on the center of the circular arc.

Figure 2-2 presents a schematic diagram of the array, with the diameter, y-axis, normal to the perfect bisector, x-axis, which is the centerline of the array focus. The array utilizes an even number (N=20) of sensors, with odd numbers 1 through 19 to the right

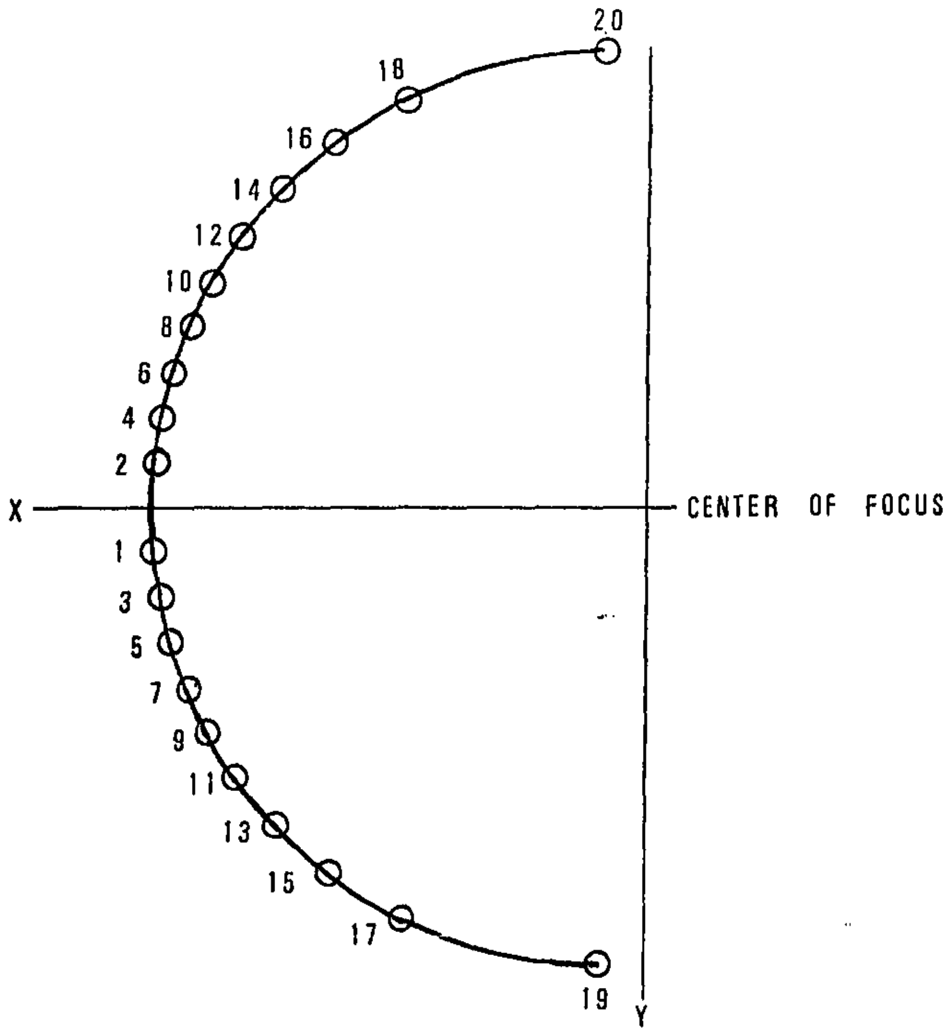


FIGURE 2-2
SCHEMATIC DIAGRAM OF THE DIRECTIVE ARRAY

of the x-axis and even numbers 2 through 20 to the left.

The array broadside beampattern directionality function D, which is the ratio of off-broadside to broadside response is generally written:

$$D(\phi) = \frac{1}{N} \frac{(1-e^{iN\phi})}{(1-e^{i\phi})} \qquad 2\text{-}1$$

where the factor ϕ is a complex function that is related to the frequency, separation between sensors, and the speed of sound.

For the circular arc array geometry the expression for the broadside beampattern is given by:

$$D= \frac{1}{N}\left[\sum_{j=1}^{\frac{N}{2}} (\cos \phi_j+i\sin\phi_j)+\sum_{j=-1}^{\frac{-N}{2}} (\cos \phi_j+i\sin\phi_j)\right] \qquad 2\text{-}2$$

where $\phi_j = (2j-1)\ \pi\frac{fd}{c} \sin\Theta_j$ for $j>o$ 2-3

$= (2j+1)\ \pi\frac{fd}{c} \sin\Theta_j$ for $j<o$

A computer model was developed from Equation 2-2 to look at different array element spacings using a 20-element array at R = 50 feet under isotropic conditions. The computed beampatterns using the model with the spacing parameter

$$d' = \frac{d}{R} \sin^{-1}(j-1/2) \qquad 2\text{-}4$$

where,

d' = non-linear spacing between elements

d = linear spacing between elements (d = 5ft)

provided the required beamwidths as a function of frequency.

The circular geometry of the array is required to accommodate spherical wave front curvature at the 50 feet distance. Therefore, contingent upon the dimensional constraint of the 50 feet radius semi-circular configuration, the sensors were spaced so as to achieve the greatest directivity index (DI). Since DI is dependent on the (linear) length of the aperture, that is, the number of sensors multiplied by the (linear) spacing, the best beamforming results for a constant number of sensors, N (=20), were found with the greatest linear spacing, d, that could be entered into the d' equation and still remain within the confines of the length of the semi-circular arc. This linear spacing was found to be 5 feet. Measured beampatterns for 1/3 octave bands centered at 200, 400 and 630 Hz are shown in Figure 2-3.

Table 2-1 provides the actual microphone locations along the 50 feet semi-circle. Odd numbered microphones are to the right and even numbered microphones are to the left of the array center line.

TABLE 2-1

MICROPHONE LOCATIONS

MICROPHONE NO.	DISTANCE (Relative to C_L)
1 & 2	2'6"
3 & 4	7'6"
5 & 6	12'8"
7 & 8	17'11"
9 & 10	23'4"
11 & 12	29'1"
13 & 14	35'5"

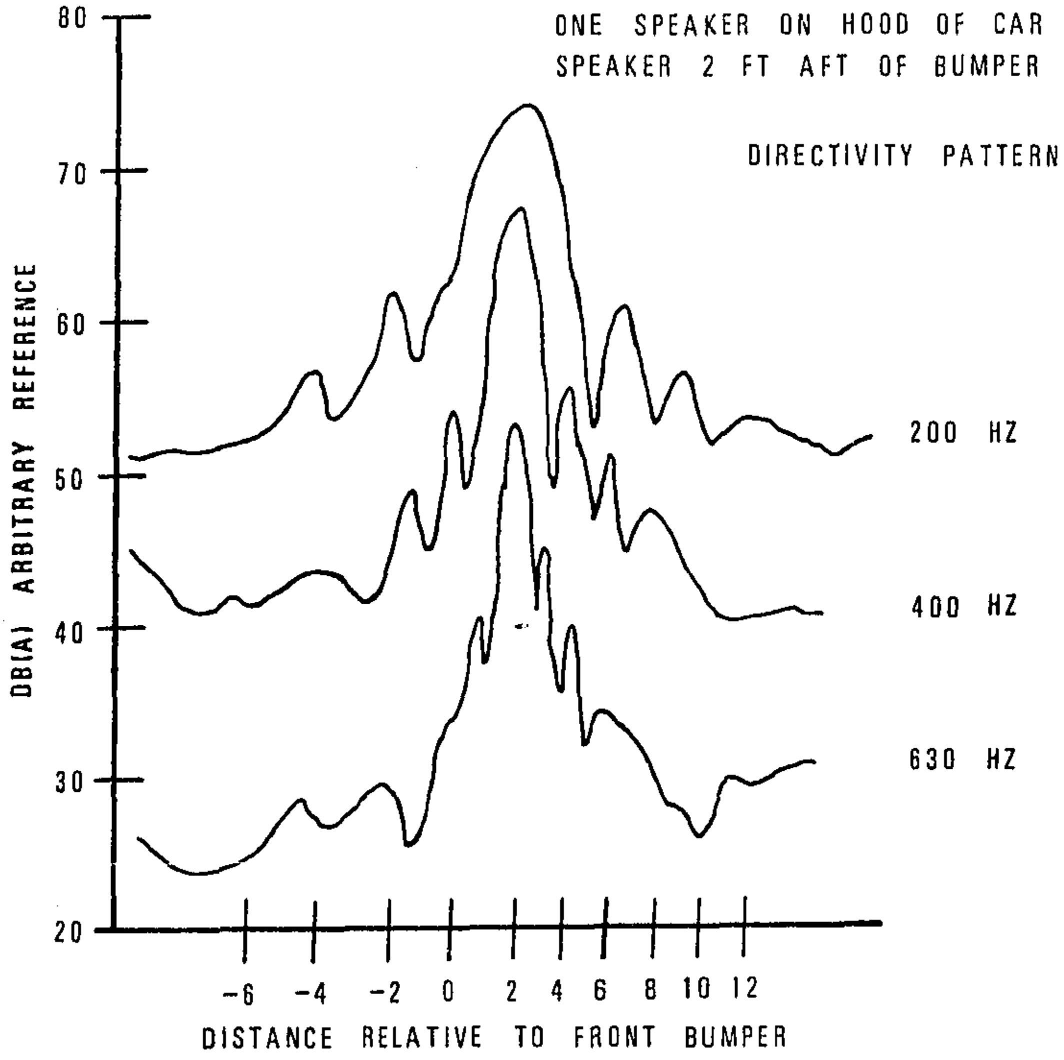


FIGURE 2-3
BEAM RESPONSE LEVEL AS A FUNCTION OF DISTANCE

TABLE 2-1 (continued)

MICROPHONE LOCATIONS

MICROPHONE NO.	DISTANCE (Relative to C_L)
15 & 16	42'5"
17 & 18	50'9"
19 & 20	62'8"

2.1.3 Array Calibration

The array system is calibrated by two methods: (1) using a 1000 Hz tone from a hand-held acoustic calibrator successively on each microphone, adjusting input gain as required; and, (2) comparing the output of the array, with the microphones clustered together, against the output of a single array microphone among the cluster of array microphones, when each is exposed to an identical sound from a known source.

Sensitivity of the complete array to sound received at each of its 20 microphones with the same amplitude and phase will be

$$20 \text{ Log}_{10} \text{ (N=20)} = 26 \text{ dB}$$

higher than when sound is received by only one microphone.

An individual calibrator, such as the Bruel and Kjaer Model 4230, is used to input the same signal into each array microphone in sequence. The gain adjustments are made at the appropriate junction box for each microphone so as to produce the same signal level output from the final summing amplifier. This procedure is repeated for each array microphone.

The second method in calibrating the array is to cluster all 20 microphones together, record the resulting electrical signal output produced by a known sound source, and compare that output level with the level measured with single array microphone at the cluster location. A loud speaker broadcasting broadband pink noise is used so that the array sensitivity can be determined not only at 1000 Hz (a constraint of using calibration method one) but over a wide range of frequencies.

In general, when calibration is performed, the entire data acquisition and in-situ processing system is set up and calibrated. The two calibration procedures are followed to introduce known signals at the microphones of the array. Tape recordings are made of the calibration signals. These are then played back through the same system and displayed on a strip chart.

As a time saving device, when the microphone sensitivities seem stable, calibration between individual experiments/measurements are performed by using the pure tone calibrator on one array microphone, typically (No. 1) at the center of the array, and comparing its output to that of a separate, known microphone, calibrated simultaneously.

2.2 Nearfield Probing

The nearfield probe approach for identification of truck component noise sources consists of nearfield microphones, discriminating sensors, accelerometer probes and narrowband analysis techniques to localize and identify component sources in specified spatial locations as provided by the directive array results. Initial efforts consisted of tests to checkout sensors and to evolve procedures for isolating and identifying component sources.

Table 2-2 presents a matrix of the four nearfield probe tests with details such as data, location, objective, equipment, and results. These four test efforts, coupled with narrowband analysis of the recorded data, have shown that nearfield probing can provide a valuable and sometimes the only input to the identification of truck component noise source.

2.2.1 Test Procedure

The test procedure consisted of four (4) basic steps.

Step #1 involves the use of two identical microphones: one nearfield and hand-held, equipped with a wind screen; the other farfield and mounted on a tripod four feet high, 50 feet from the center line of the truck (See Figure 2-4). For the data acquisition, the truck engine is run up to the governed RPM. The nearfield microphone is then used to probe the various areas of the truck. Data is recorded using a two channel NAGRA tape-recorder.

Step #2 is similar to Step #1, except the nearfield microphone is replaced by an accelerometer. The accelerometer is used to probe the same areas as recorded in Step #1.

In step #3 the nearfield microphone and the accelerometer are used to probe the areas on the truck as in the previous steps. In this test, the accelerometer and nearfield microphone are placed in close proximity to each other.

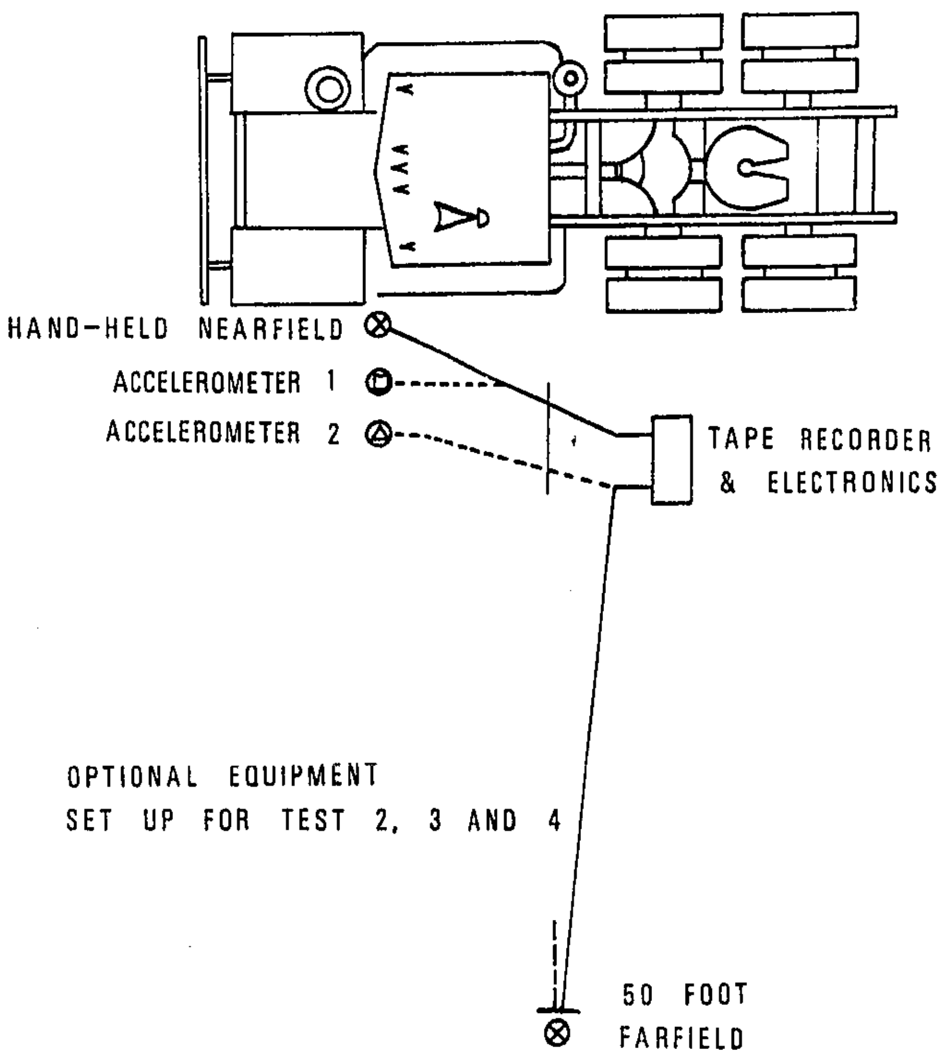


FIGURE 2-4

TEST EQUIPMENT SET UP

TABLE 2-2 Matrix of Nearfield Probe Tests

Date	Location	Objective	Equipment	Results
May 1978	Cheverly, Md.	Checkout nearfield probe sensors	Nearfield Microphones, Accelerometers, NAGRA Tape recorder	Spatial location and identification of components is feasible when data is processed in narrow frequency bins
June 1978	Youngstown AFB, Ohio	Apply method to several trucks	Nearfield Microphones, Accelerometers, NAGRA tape recorder	Engine noise appears at numerous spatial locations on truck, frame rails, oil pan, etc. Oil pan measurements can be used to predict farfield measurements
Oct. 1978	Ft. Lauderdale Florida	Apply to MACK R686ST	Nearfield Microphones, Accelerometers, NAGRA tape recorder	Engine noise appears at numerous spatial locations on truck, frame rails, oil pan, etc. Oil pan measurements can be used to predict farfield measurements
Jan. 1979	Ft. Lauderdale Florida	Apply to FORD CLT 9000	Nearfield Microphones, Accelerometers, NAGRA tape recorder	Engine noise appears at numerous spatial locations on truck, frame rails, oil pan, etc. Oil pan measurements can be used to predict farfield measurements Also driver side exhaust noise levels are 3 to 5 dB noisier than passenger side

Step #4 is similar to Step #3, except the nearfield microphone is replaced by a second accelerometer. This procedure is designed to look at the vibration across the engine mounting brackets and attachments, and from one part of the frame to another.

Figure 2-5 shows the test equipment set up for the four different tests.

In the most recent test of the FORD CLT 9000 (Ft. Lauderdale, January 1979) the probe technique was utilized with the engine operating at a number of speed and load conditions.

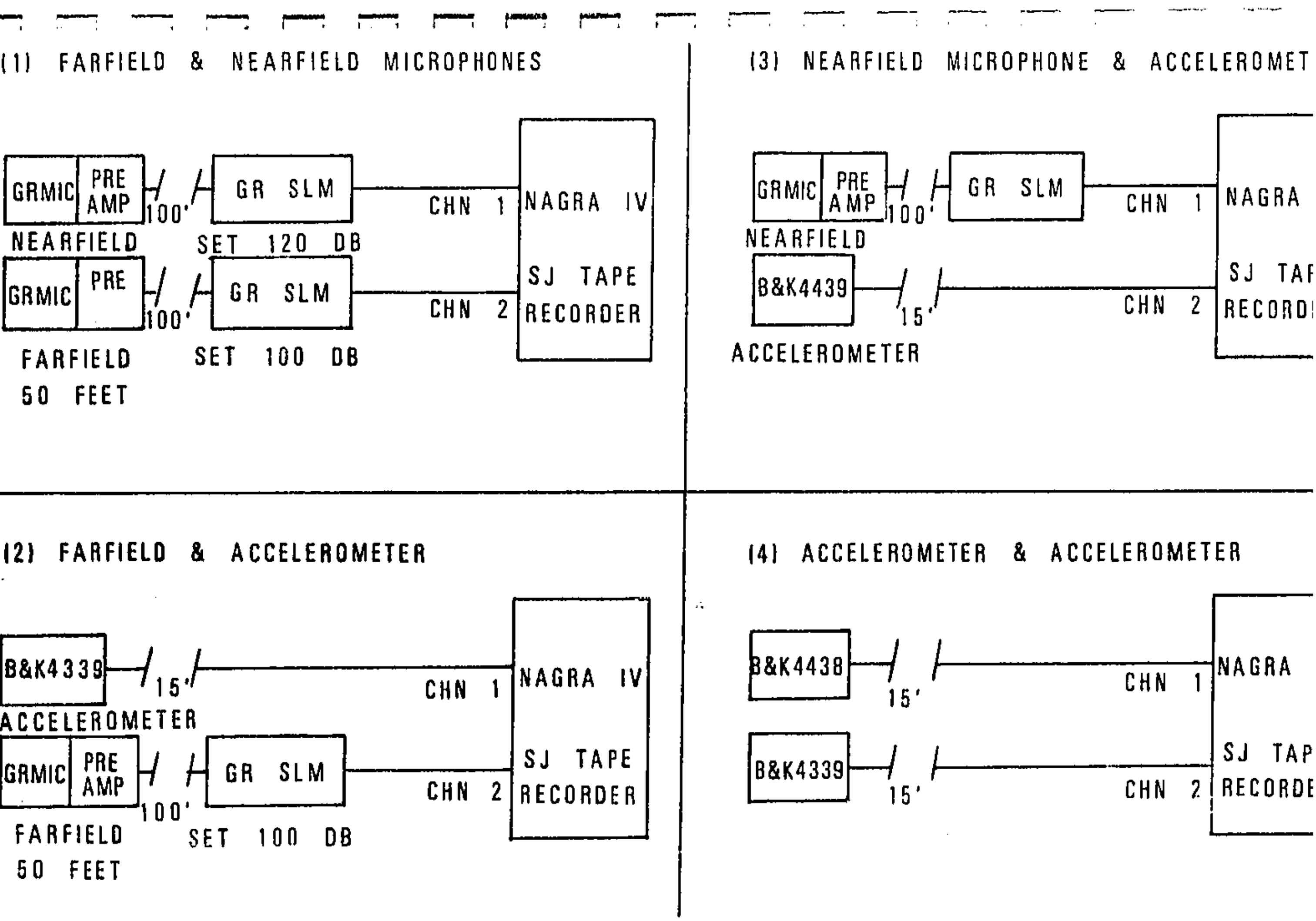


FIGURE 2-5

TEST EQUIPMENT SET UP FOR STEPS 1, 2, 3, & 4

3.0 TEST OF FORD CLT 9000

With the completion of array development and test procedures as reported in Section 2, the selected and developed test methods were then used to measure and evaluate the noise of one heavy-duty truck for the purpose of establishing a relative noise ranking of the major truck noise components as they occur over the engine speed and load range of the truck. The field trial in mid-January 1979, using the directive array on a 1978 Ford CLT 9000 with load being applied by a chassis dynamometer, was the culmination of the test efforts to date.

3.1 Description of Truck

The truck under test is a Ford CLT 9000 owned by the U.S. Department of Transportation. It is a 1978 model which has a manufacturerer's completion date prior to January 1,1978 and, therefore, not equipped with the Ford Noise Emission Control Package requisite for models designed to comply with the 1978 federal truck noise regulation (40 CFR 205).

Figure 3-1 shows a photograph of the truck, along with a listing of specifications taken directly from the truck during the field trial. Detailed specifications and other pertinent information regarding the truck's engine is given in Figures 3-2 and 3-3.

3.2 Description and Use of Special Test Equipment

3.2.1 Dynamometer

Acoustical data for varying engine load and speed was accomplished through the use of a chassis mounted dynamometer. The

SPECIFICATIONS

TRUCK # DOT **PLACE** Fort Lauderdale, Fl. **RECORDED BY** AHA

VEHICLE

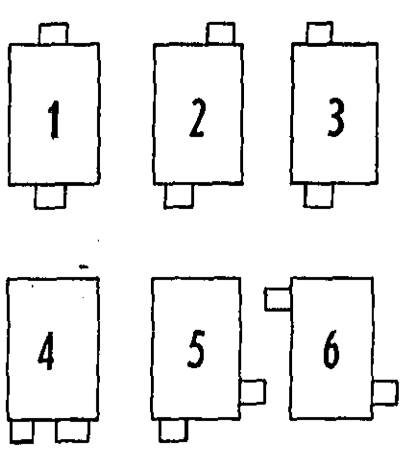
MANUFACTURER Ford Motor Company	OWNER NAME/# DOT
MODEL YEAR/NAME 1978/CLT 9000	VIN# X98LVAG5136
DESCRIPTION Gray Cab	MODEL# CLT 9000
MFGR. CATEGORY# NA	ENGINE TYPE/MODEL IL6/NTC 350
CAB DESIGN COE Sleeper	ENGINE DISPLACEMENT 855 cu. in.
ENGINE MFGR. Cummins	MAX. HP. 350
NO. CYLINDERS 6	MAX. GOV. RPM (TACH) 2385
CYCLE 4	MAX. GOV. RPM (ACTUAL) 2300

AIR INTAKE

TYPE Turbocharged

AIR CLEANER TYPE/MFGR. Dry/Donaldson EBA 09-2011

MUFFLER		FAN	
MFGR & MODEL Stemco 9897		MFGR Unknown	
STACK Vertical	SIDE Both	DIA. 30 in.	BLADES 8
MUFFLER TYPE (SEE BELOW) 1		FAN DRIVE Viscous/Thermatic	



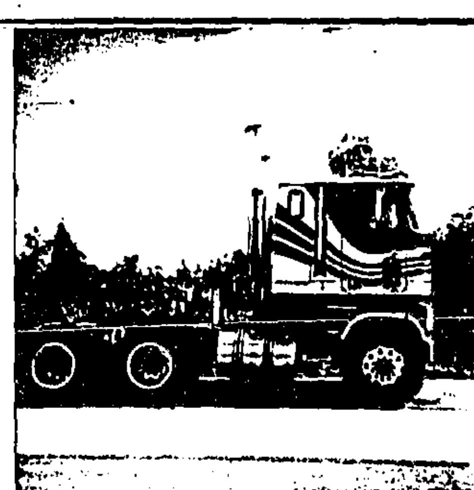
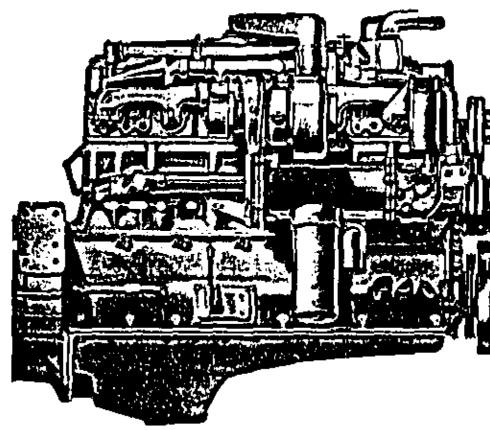


FIGURE 3-1

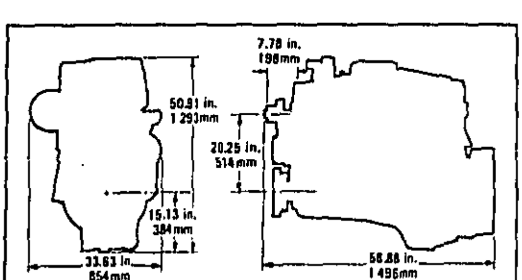
Cummins Diesel NTC-350



Specifications

		Metric
Power Rating	350 bhp	261 kW
Governed RPM	2100	2100
Peak Torque (1400 RPM)	1065 lb.-ft.	1 444 N•m
Nominal Torque Rise	22%	22%
Clutch Engagement Torque	600 lb.-ft.	800 N•m
Number of Cylinders	6	6
Bore and Stroke	5½ x 6 in.	140 x 152mm
Piston Displacement	855 cu. in.	14 *l*
Compression Ratio	14.1	14.1
Operating Cycles	4	4
†Lube System Oil Cap.	11.5 U.S. gals.	43.5 *l*
Coolant Capacity	5.5 U.S. gals.	20.8 *l*
Net Weight with Std. Accessories, Dry	2740 lbs.	1 244 kg
Weight at Rated Power	7.7 lbs./hp	4.7 kg/kW
Installation Diagram Number		3001787

†Bypass filter is included in total.



Design Features

Camshaft: Large 2½ in. (64mm) diameter camshaft controls all valve and injector movement. Induction hardened alloy steel with gear drive.

Camshaft Followers: Roller type for long cam and follower life.

Connecting Rods: Drop forged, 12 in. (305mm) center to center length. Rifle drilled for pressure lubrication of piston pin. Taper piston pin end reduces unit pressures.

Crankshaft: High tensile strength steel forging. Bearing journals are induction hardened. Fully counterweighted.

Cylinder Block: Alloy cast iron with removable, wet liners.

Cylinder Heads: Each head serves two cylinders. Drilled fuel supply and return lines. Corrosion resistant inserts on exhaust valve seats.

Fuel System: Cummins PT™ wear-compensating system with integral flyball type governor. Camshaft actuated Top Stop injectors.

Lubricating Oil Cooler: Tubular type, jacket water cooled, combined with oil filter.

Lubrication: Force feed to all bearings, gear type pump. All lubrication lines are drilled passages, except pan to pump suction line.

Steering Pump Drive: Coupling driven, two bolt flange mounting.

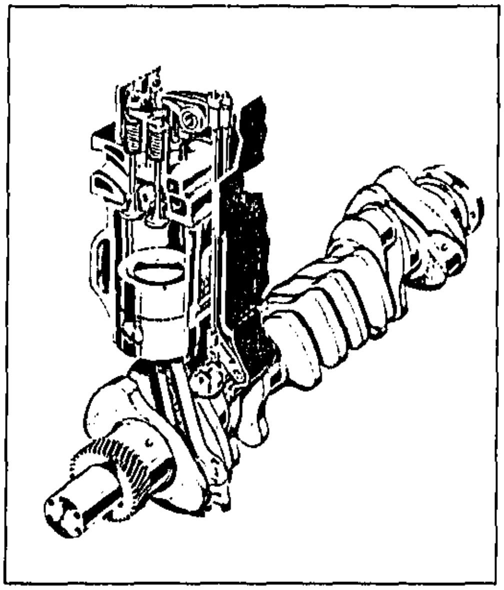
Thermostat: Single unit, modulating by-pass type.

Valves: Dual intake and exhaust each cylinder. Each valve 1⅞ in. (47mm) diameter. Heat and corrosion resistant face on exhaust valve.

Water Pump: Belt driven, centrifugal type, 145 U.S. gpm (549 *l*/min.) @ 2100 rpm, with volute type housing cast in block to provide more efficient flow.

FIGURE 3-2

Internal Design Features



Available Equipment

Compressor, Air: Cummins 13.2 CFM (374 l/min.) one cylinder, coupling driven and pressure charged.

Corrosion Resistor: Spin-on type, mounted. Checks rust and corrosion, controls acidity, and removes impurities from coolant.

Electrical Equipment: 12 and 24 volt starter; 12 and 24 volt alternators of various ampere outputs; and alternator mountings.

Fan: 26 in. (660mm), 28 in. (711mm), 30 in. (762mm), or 32 in. (813mm) diameter, sucker type.

Fan Mounting: Bracket mounted hub and pulley. Hub 20¼ in. (514mm) above crankshaft.

Filters: Lubricating oil, full flow paper element, spin-on type, mounted in combination with oil cooler. Lubricating oil, by-pass type, not mounted. Fuel, paper element, spin-on type, mounted.

Flywheel: For 15.5 in. (394mm) 2 plate clutch to fit various automotive clutches.

Flywheel Housing: S.A.E. No. 1 and 2 cast aluminum with mounting pads.

Governor: Mechanical flyball, limiting speed type.

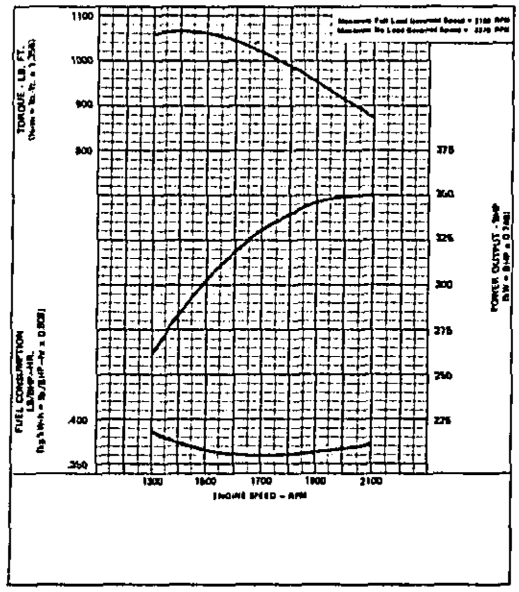
Mounting, Front: Provision for pad type engine support, 6 in. (152mm) diameter trunnion.

Oil Pan: Cast aluminum, 7 U.S. gallon (26.5 l) capacity, optional sump locations.

Turbocharger Location: Low side mounting, low forward mounting.

Other Optional Accessories: Can be provided by Cummins to fit special applications.

Performance



Horsepower, torque and fuel consumption shown by the curves represent performance at SAE standard J816b conditions of 500 Ft. (150m) altitude (29.00 inches (736mm) Hg Dry Barometer), 85°F. (29°C.) intake air temperature and 0.38 in. (9.7mm) Hg water vapor pressure.

Curves represent performance of the engine with water pump, lubricating oil pump, fuel system, compressor (unloaded) and air cleaner; not included are alternator, fan and optional equipment. Curves represent performance with No. 2 diesel or a fuel corresponding to ASTM D2.

Conversion Factors to Metric:

Torque	lb.-ft.	x 1.356 = ______	N•m
Power	bhp	x .746 = ______	kW
Fuel	lb./bhp-hr.	x .608 = ______	kg/kW-hr.

Cummins Engine Company, Inc., Columbus, Indiana 47201
Cummins Americas, Inc., Columbus, Indiana, U.S.A.
Cummins Diesel Australia, Ringwood, Australia
Cummins Diesel International Limited
Cummins Engine Company Ltd., London, England

FIGURE 3-3

unit selected was a Go-Power DT-2000 in-frame dynamometer for use with diesel engines up to 800 HP and 2000 ft.-lbs. of torque. An energy exchange is made through the use of a momentum waterbrake which converts rotating torque to stationary torque. Its operating range is limited to 4000 RPM and has a water requirement of 40 GPM (gallons per minute) at 40 PSI (pounds per square inch).

The Go-Power DT-2000 is mounted on the chassis directly behind the transmission, removing the drive shaft for the dynamometer hookup between the transmission and differential.

During a load test, the transmission is put in the approximate gear as to achieve a 1:1 ratio between engine speed and transmission output shaft speed.

The following equipment was used in support of the Go-Power DT-2000 in-frame dynamometer:

- IFA-TC2000 Adapter System for mounting the DT-2000 to the truck chassis
- C-13-2 Digital Instrument Console with Printer having digital readout and paper printout of engine RPM, Torque and horsepower
- Water Pump (See Section 3.2.2)
- Other miscellaneous equipment such as valves for water flow control, hoses, clamps, etc.

The Go-Power Model C-13-2 digital instrument console unit provided real time measurement and digital recording of engine speed

(RPM) and load (torque and/or horsepower). Calibration of the console unit was performed during the testing period by attaching external known mass to the calibration arm. The calibration showed that the system is capable of torque measurement to within 1% at 460 ft-lb of load. The loading on the dynamometer was controlled by operating a mechanical gate valve located near the dynamometer. The console unit was placed on the rear chassis of the truck to facilitate monitoring and final adjustment of water flow. RPM settings were made with a screw-type throttle value within the cab of the truck. Fine adjustment and regulation of the RPM was accomplished by adjustment of the water flow control valve.

3.2.2 Water Pump

A PACER fluid pump fed canal water into the dynamometer at a flow rate of 45 gallons per minute through 300 feet of plastic hose. The pump is powered by 5 HP gasoline engine providing a pump outlet force equivalent to a 90 foot head for the 3-inch plastic hose used to connect the pump to the dynamometer. An identical section of hose was used to remove the water, after passing through the dynamometer. This hose led to a dumping ground 100 feet away from the measurement area.

3.2.3 Winch

Traversing the truck through the measurement zone required the use of a marine winch. The one selected is a Powerwinch Model 812 C having 2500 lbs line pull (equivalent to straight lift). The winch was placed in an acoustic enclosure approximately 225 feet from the truck so as to remove any contribution to background noise. A 40 foot section of double line ¼" steel rope and approximately 200 feet of 1/8" steel aircraft cable was used as the connection. Because of the large pulling capacity of the winch, fluctuations in truck speed did not occur as a variation in load. Some consistent fluctuations in speed, however, were noticed due to the increasing diameter of cable wrap on the winch drum as the cable is wound in.

3.2.4 Additional Noise Sources

Outfitting the truck with this special test equipment introduced new potential noise sources. Due to its close proximity, the dynamometer was thought to pose problems in source discrimination. Consequent measurements, however, concluded that the dynamometer set well outside the main response axis of the array beam. Another potential source, the water pump, was placed next to the canal, approximately 300 feet from the measurement zone, thus, reducing its contribution to the ambient noise level. Other potentials such as water flow noise through the hoses were found to be negligible.

3.3 Description and Set Up of Test Equipment

A schematic representation of the test equipment set-up, Figure 3-4, shows the various pieces of test equipment in their operational locations.

3.3.1 Test Site

The testing took place at the Miami-Hollywood Drag Strip near Hollywood, Florida, the same test site used in the Florida trial during October, 1978. Figure 3-5 is an aerial sketch of the site drawn with approximate relative dimensions. The drag strips are an asphalt aggregate and bounded on both sides by flat marsh.

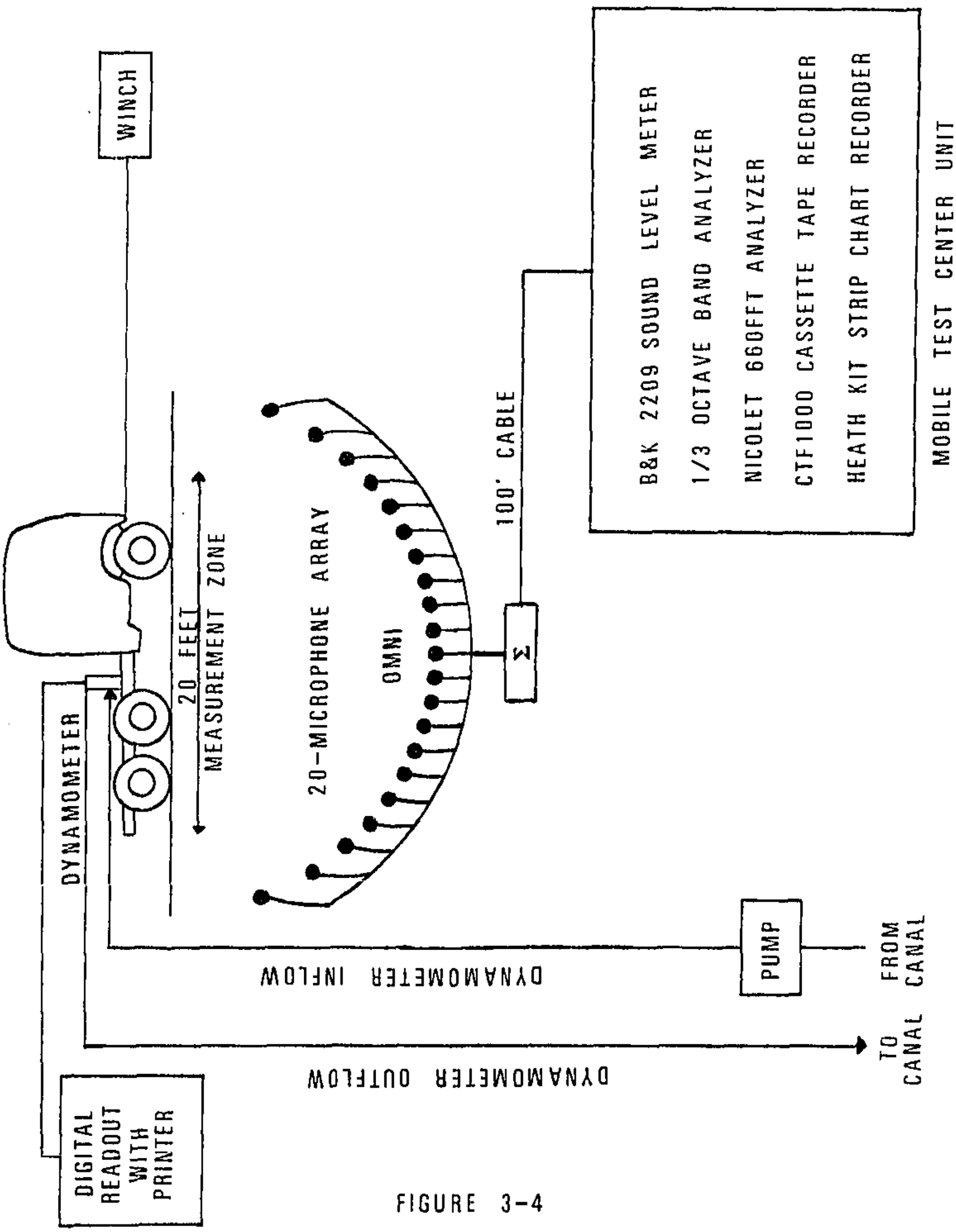


FIGURE 3-4

BLOCK DIAGRAM OF TEST EQUIPMENT

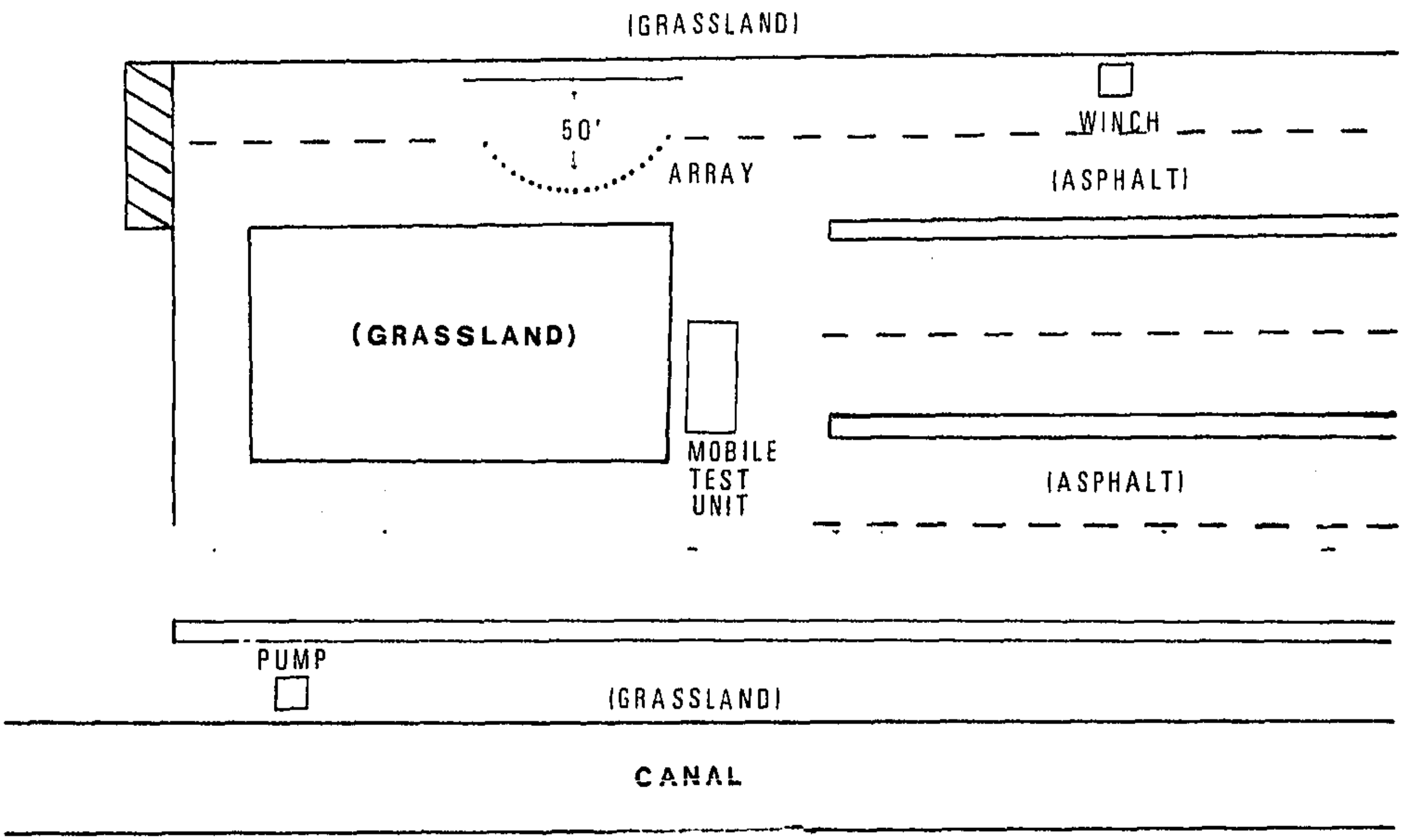


FIGURE 3-5

FLORIDA TEST SITE
AT
MIAMI-HOLLYWOOD DRAG STRIP

There are a few scattered trees between the asphalt and the canal, a separation of approximately 300 feet.

The weather during this test period was good, with temperatures in the 70's and some light precipitation. Ambient noise levels ranged between 50 and 55 dB(A), with a few aircraft fly-over interruptions.

3.3.2 Mobile Test Unit

A TRAVCO motor home was used as a test monitoring station where the measured noise data was recorded and analyzed. It also provided a suitable air-conditioned area for the electronic test equipment.

3.3.3 Recording

Recording of the data from the array and the omni-directional microphone was accomplished with the following equipment:

1 NAGRA IV-S portable stereo analog magnetic tape unit with accessories

1 BRUEL & KJAER Two channel portable condenser microphone and linedriver system

1 BRUEL & KJAER 2209 Type 1 precision impulse sound level meter with accessories

1 PIONEER CT-F1000 cassette tape recorder

The electrical signal output from the 20-microphone array is wired into the B&K 2209 sound level meter by way of a low impedance hermetically sealed cable. The signal passes through the A-weighted filter and is recorded on the left channel of the Pioneer CT-F1000 tape recorder. All data was recorded on TDK-C60 cassette tape. Tape logs were maintained of all runs including run number, rpm, load and other ancillary information.

Simultaneous noise data was recorded with a separate omnidirectional microphone system. A B&K Type 4133 1/2-inch condenser microphone, was placed in the array at the center position, precisely normal to the focal point of the array relative to the measurement zone (See Figure 3-4). The omni microphone powered by a B&K 2619 preamplifier, was connected to a NAGRA IV-S analog magnetic tape unit via a shielded coaxial cable. The electrical signal in NAGRA was passed through an intregal A-weighted filter and then recorded on the left channel of the PIONEER CT-F1000 tape recorder.

3.4 Data Processing & Analysis

Test data was processed in A-weighted bands, one-third octave bands, and in narrowbands. A-weighted and one-third octave band levels were obtained at the output of a B&K 2209 sound level meter equipped with a B&K 1616 one-third octave band filter set. Narrowband data were obtained from a NICOLET 660 dual channel FFT processor. Figure 3-6 provides a block diagram of the data recording and analysis equipment.

FIGURE 3-6

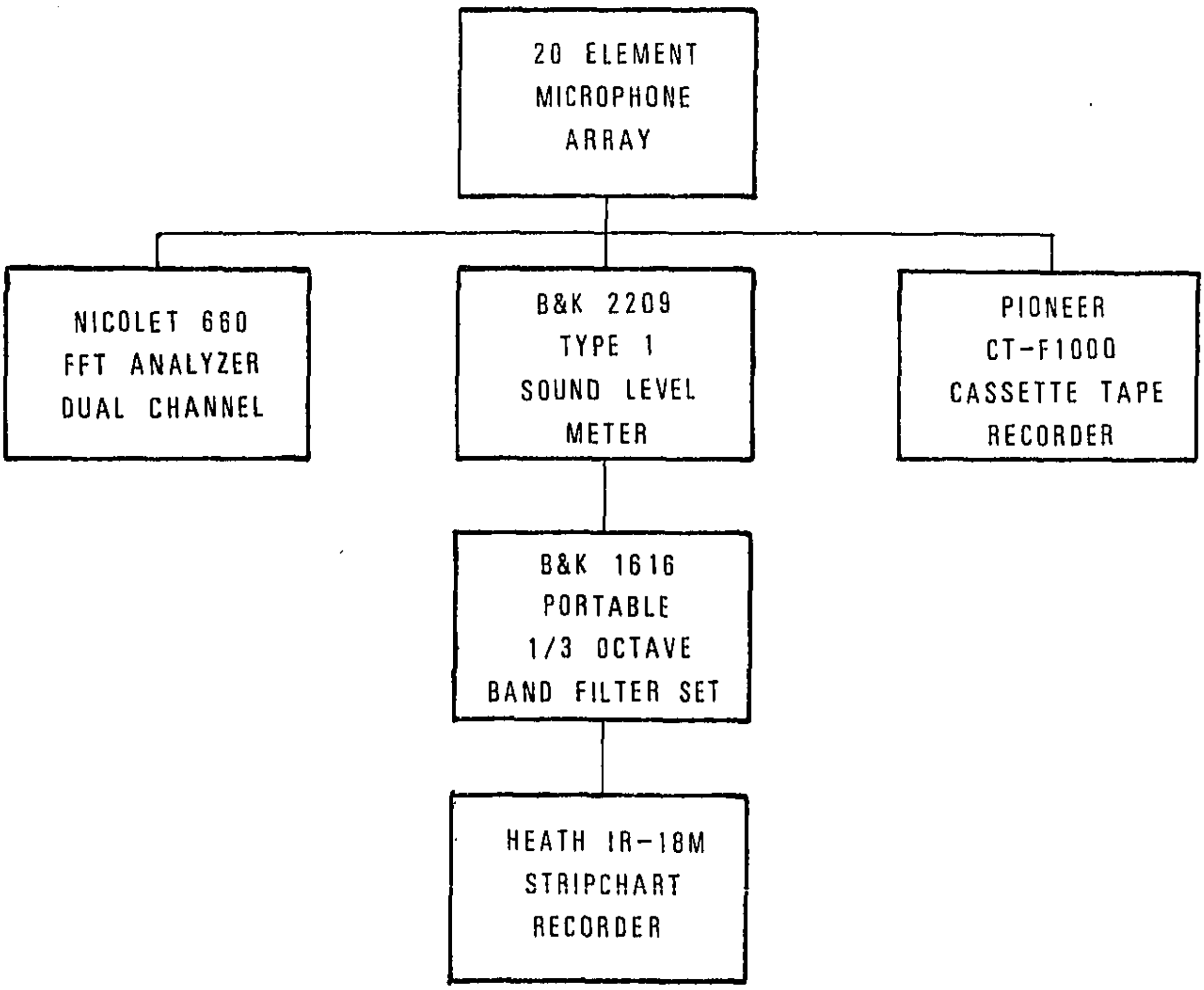


FIGURE 3-6

RECORDING AND ANALYSIS EQUIPMENT

This equipment is listed below:

1 NICOLET 660 FFT dual channel processor with CRT display
1 TEKTRONIX Model 656 X-Y plotter
1 HEATH IR-18M Strip-chart recorder
1 INTRONICS rms and logarithmic converter
1 BRUEL & KJAER 1616 portable one-third octave band signal filter set

A B&K type 1616 one-third octave band signal filter set with a remote frequency band selector switch was connected to the 2209 sound level meter. Set for external filtering, the sound level meter provides real time analog signals. The analog signals are converted to dB with an INTRONICS rms and logarithmic converter. The converted (dB) data was recorded graphically by a HEATH strip chart recorder.

Tape recorded data could be analyzed similarly by playing back data on the PIONEER through the 1/3-octave analysis system (B&K 2209 + B&K 1616), the logarithmic converter, and then recording output levels on the HEATH strip chart.

A NICOLET 660 dual FFT (Fast Fourier Transform) processor was used for narrowband data processing. The NICOLET would process signal data either on-line or from the tape recorder. The NICOLET would process the data for selected frequency ranges and display the results on an integral CRT screen. The display could then be stored for graphic recording on a TEKTRONICS X-Y PLOTTER. The NICOLET 660 provides a dual display showing array and omni data simultaneously, thus permitting real-time comparisons.

The NICOLET processing system was also utilized for processing real time data, of the probe outputs (i.e., nearfield microphones and accelerometers). The nearfield probe data indicated that the left hand side of the truck radiated noise at 0 Ft and 5 Ft which was comparable in level to the right hand side. At 8 Ft however, the nearfield probe data indicated significantly higher levels on the left hand side when compared to the right hand side of the truck.

3.5 Matrix of Test Runs

At the beginning of each day of the test, the array and omnidirectional microphones were set in place and calibrated with the hand held tone calibrator. A single speaker, which broadcasts a broadband noise field was then placed at the center of the array in order to determine array operation. Array beam response and signal gain were measured periodically to assure proper operation of the array.

Test runs designed to locate the component sources consisted of pull-by runs. In this case, the marine powerwinch was utilized to pull the truck past the array. A number of these runs with the truck operating at several engine speeds and several power settings were accomplished in order to determine the component source locations. It was discovered that with the truck positioned at 0 Ft, +5 Ft and +8 Ft distances measured relative to the front bumper, considerably more noise was radiated than at other positions. Time histories of various 1/3-octave band outputs were obtained for each of these runs. These time histories showed peak levels in the vicinity of 0 Ft, +5 Ft, 8 Ft and +11 Ft. At the conclusion of the pull-by runs, a set of stationary runs were accomplished.

These stationary runs were accomplished by positioning the truck at 0 Ft, 5 Ft, 8 Ft and 11 Ft and measuring the noise at the array output as the speed and load parameters were varied from 1000 rpm to max rpm and from no load to max load at several fixed rpm's.

Table 2-1 provides a summary of the stationary runs for each position, rpm, and load condition. The abbreviations are as shown in the legend.

The procedure is as described in the following:

a) Position truck so that array is focused at one location.

b) Adjust initial RPM and initial load and record acoustical data.

c) Increment RPM to next predetermined value while maintaining initial load and record acoustical data.

d) Continue procedure until acoustic data is taken at final RPM and initial load.

e) Adjust to initial RPM and next predetermined load setting and record acoustical data.

f) Continue procedure until data has been taken at all RPM and load settings.

Those test runs shown in Table 3-1 formed the basic data set for characterizing the truck component noise levels as a function of engine speed and load.

TABLE 3-1

SUMMARY RUN MATRIX

TRUCK IN POSITIONS +11, +8, +5, and 0

RPM	TORQUE	HP	POSITION
2400	0	0	P8R
2350	↓	↓	↓
2000	↓	↓	↓
1900	↓	↓	↓
1500	↓	↓	↓
1000	↓	↓	↓
2100	720	288	P8R
2000	770	304	↓
1500	920	263	↓
1400	946	252	↓
800	600	91	↓
2400	0	0	P5R
2100	↓	↓	↓
2000	↓	↓	↓
1500	↓	↓	↓
1000	↓	↓	↓
2250	260	111	P5R
2125	615	249	↓
2100	700	280	↓
2100	245	98	↓
1650	800	251	↓
1500	990	283	↓
1500	770	220	↓
1500	255	73	↓
1000	550	105	↓

RPM	TORQUE	HP	POSITION
2350	0	0	P0R
2100	↓	↓	↓
1500	↓	↓	↓
1000	↓	↓	↓
2100	742	308	P0R
1540	960	290	↓
1420	970	269	↓
2100	0	0	D8L
2100	500	200	↓
2100	750	300	↓
1500	0	0	↓
1500	500	143	↓
1500	869	250	↓
2100	0	0	P11C_L
2100	750	310	↓
1500	0	0	↓
1520	1000	290	↓

KEY

P - Passenger Side
D - Driver Side
R - Right Wheel on C_L
L - Left Wheel on C_L
C_L - Truck C_L on C_L

3.6 Test Results

3.6.1 Torque and Horsepower Measurements

The truck mounted Go-Power Model DT-2000 dynamometer combination was initially tested to determine maximum torque and horsepower ratings for the in chassis Cummins NTC-350 engine. The measured data was found to be slightly lower (see Figure 3-7) than that given by the manufacturer. Reasons for these lowered measured values include:

- losses due to fan operation
- losses due to engine mounted accessories such as the generator, water pump, power steering pump, etc.
- losses through the transmission
- losses through the transfer case of the dynamometer
- losses through the dynamometer itself.

A best fit curve was drawn through the measured values of torque and horsepower showing a measured value 10% lower than the manufacturer specification. There is less scatter on the data points for torque measurements than for horsepower. This may be due to the fact that horsepower is an in-unit calculation.

During the field test, instabilities occurred at or around specific torque and RPM settings prohibiting acoustical data acquisition. These instabilities occurred at 1700-1900 RPM at maximum torque setting and 1450-1600 RPM at 50% torque setting. However, short duration measurements (5-10 sec.) at these points were taken to determine the data shown in Figure 3-7. At the other rpm values long time averages (1 min.) were obtained.

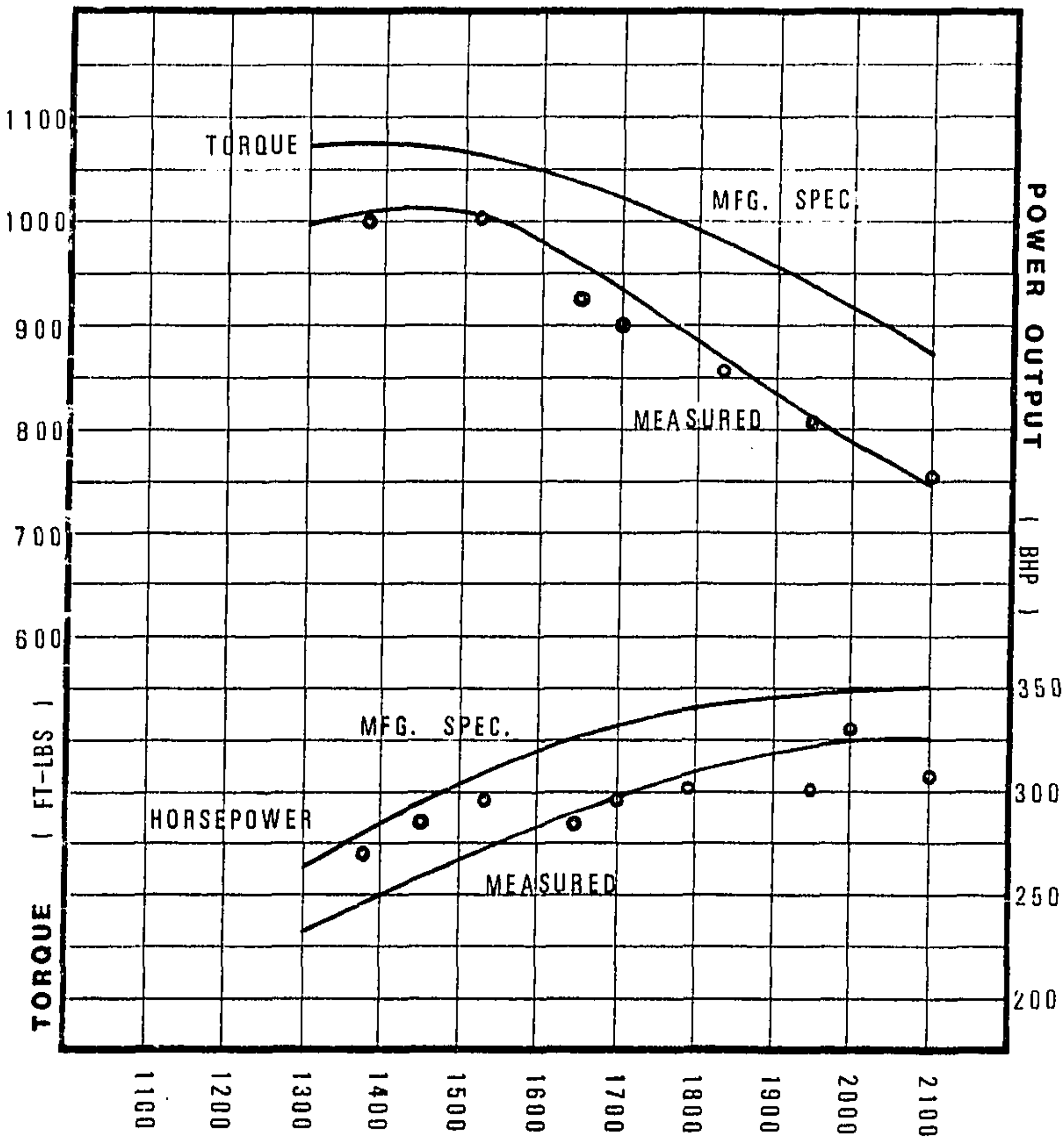


FIGURE 3-7

MEASURED HORSEPOWER AND TORQUE AS A FUNCTION OF RPM

3.6.2 Truck Directivity

Measurements were made of the noise radiating from the CLT 9000 prior to the testing summarized in section 3.5 in order to determine directionality. The measurements, recorded A-weighted with a NAGRA IV-S portable analog magnetic tape unit and a B&K 4133 condenser microphone, were made at various positions along 45° diagonals drawn from the center of the cab.

The results, presented in Figure 3-8, show the noise to be nearly omni-directional with the exception of the measurement at a point directly in front of the truck.

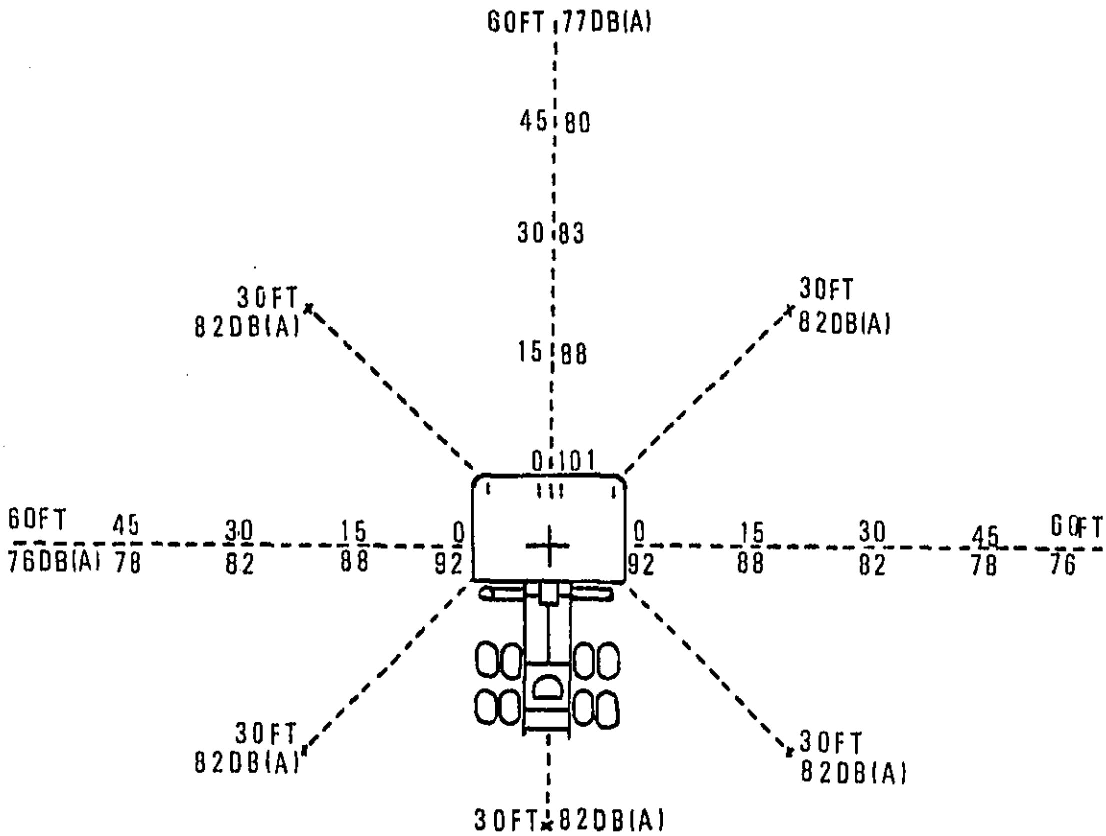


FIGURE 3-8

TRUCK NOISE DIRECTIONALITY
AS MEASURED IN A-WEIGHTED FILTER BAND

3.6.3 Pull-By Runs

The results of the pull-by runs, a procedure outlined in section 3.5, are shown in Figures 3-9, 3-10, and 3-11. These figures are graphs showing noise level vs distance for one-third octave band outputs centered at 200, 400, and 630 Hz for 2100 RPM at no load, 290 ft-lbs. (124 HP) and 770 ft-lbs (305 HP) of torque, respectively.

The figures show general agreement with the occurrence of peaks at zero (0), five (5) and eight (8) foot positions as measured relative to the front bumper of the truck. These positions correspond to the fan/engine, engine and exhaust regions of the truck. Figure 3-12 is a scaled drawing which shows the 0, +5, and +8 locations on the truck, as well as the (+)11 foot location of the dynamometer.

From the spectra, the following general trends are noticed. At 200 Hz:

1. Fan/engine and engine noise dominate for the no load condition.
2. At just over 1/4-load (290 ft -lbs), the peaks shift to engine and exhaust component noise.
3. At approximately 3/4-load (770 ft -lbs), all three noise components are effective with engine noise dominating the peaks.

At 400 Hz:

1. Engine noise (+5) dominates at no load condition with some contribution of exhaust noise (+8).

2. Exhaust noise (+8) singly dominates at 290 ft-lbs, 1/4-load condition.

3. Engine Noise (+5) dominates at 3/4-load (770 ft-lbs) condition with contributing exhaust.

At 630 Hz.

1. At no load condition fan/engine (0) and engine (+5) noise dominate.

2. At 1/4-load condition (290 ft-lbs), no component dominance is present with all peaks contributing equally.

At 1000 Hz:

1. At 3/4-load condition (770 ft-lbs) fan/engine (0) and exhaust (+8) noise dominant.

A major conclusion is drawn from the figures that the primary locations from which noise is radiated to the far-field are at 0 Ft, 5 Ft, and 8 Ft. This result is then used in the set of stationary run-up tests to determine noise level as a function of engine speed and load with the array focused on these positions and with the truck stationary at the center line of the array.

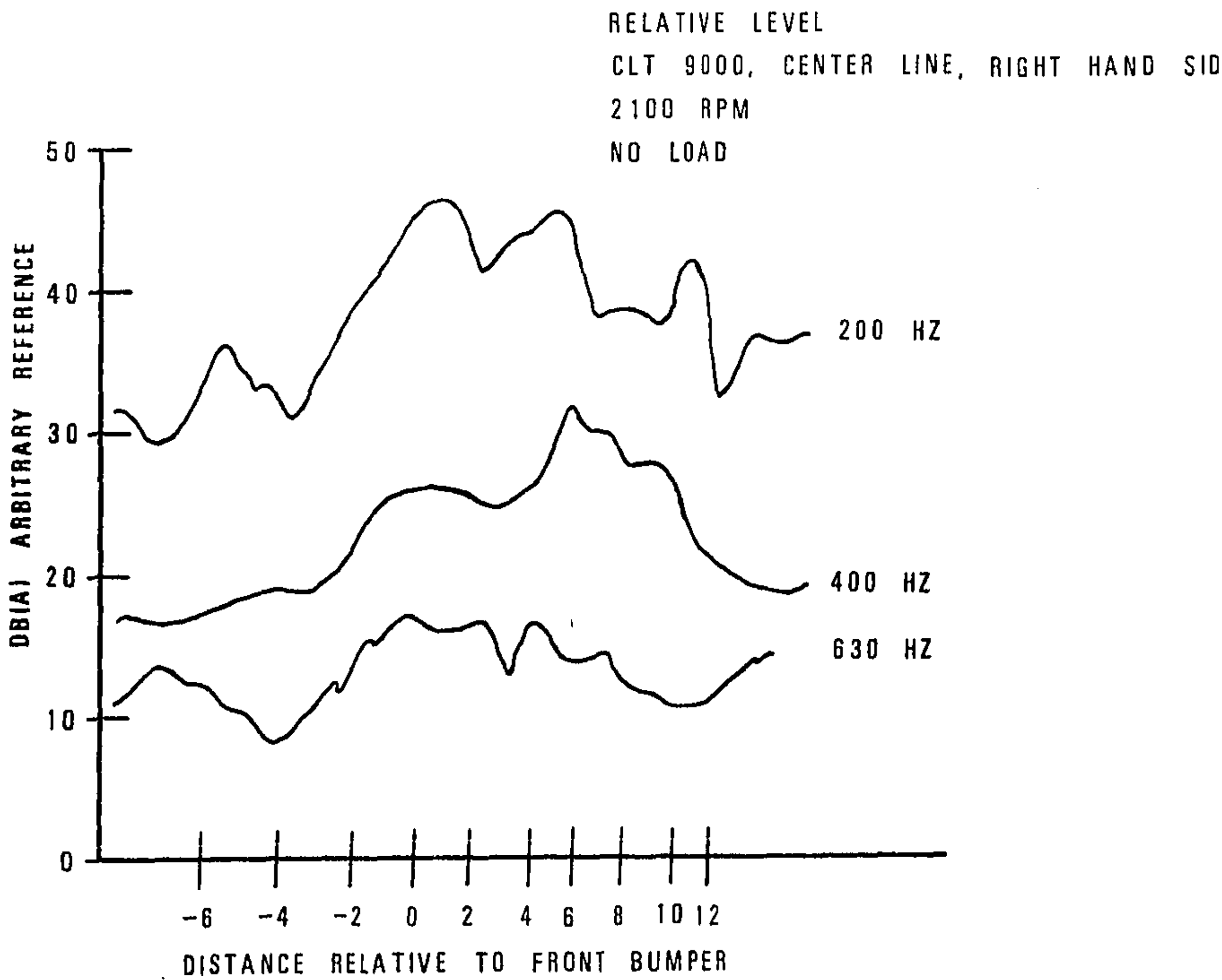
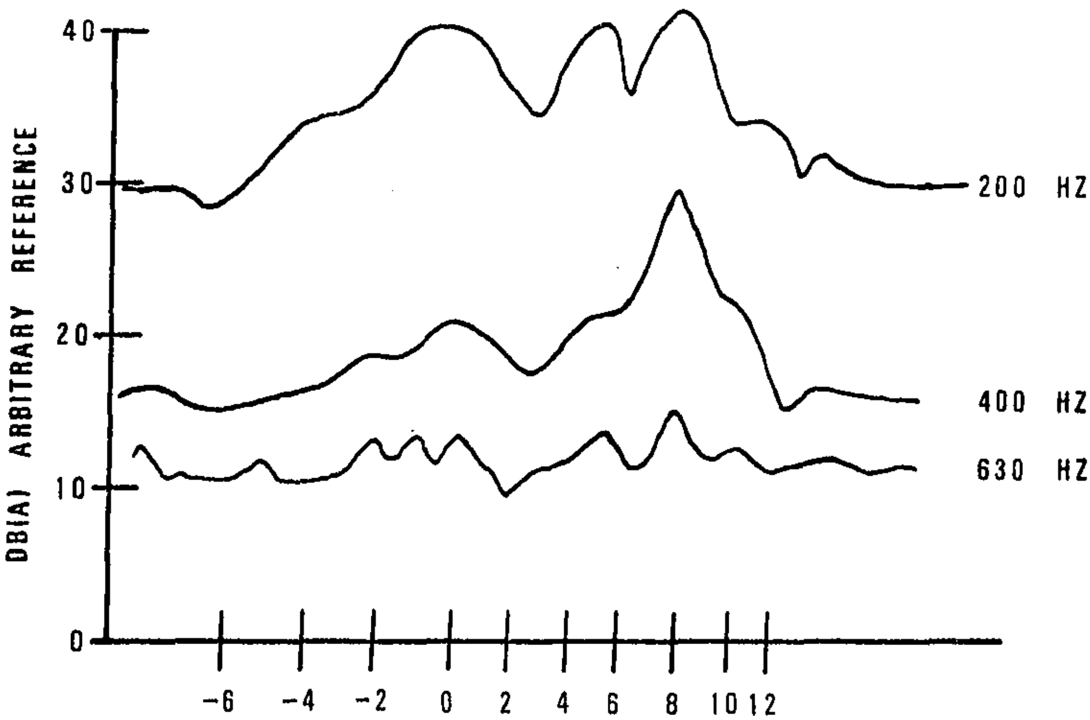


FIGURE 3-9

LEVELS AS A FUNCTION OF POSITION

RELATIVE LEVELS
CLT 9000, RIGHT SIDE
2100 RPM
290 FT-LB
124 HP



DISTANCE RELATIVE TO FRONT BUMPER

FIGURE 3-10

LEVELS AS A FUNCTION OF POSITION

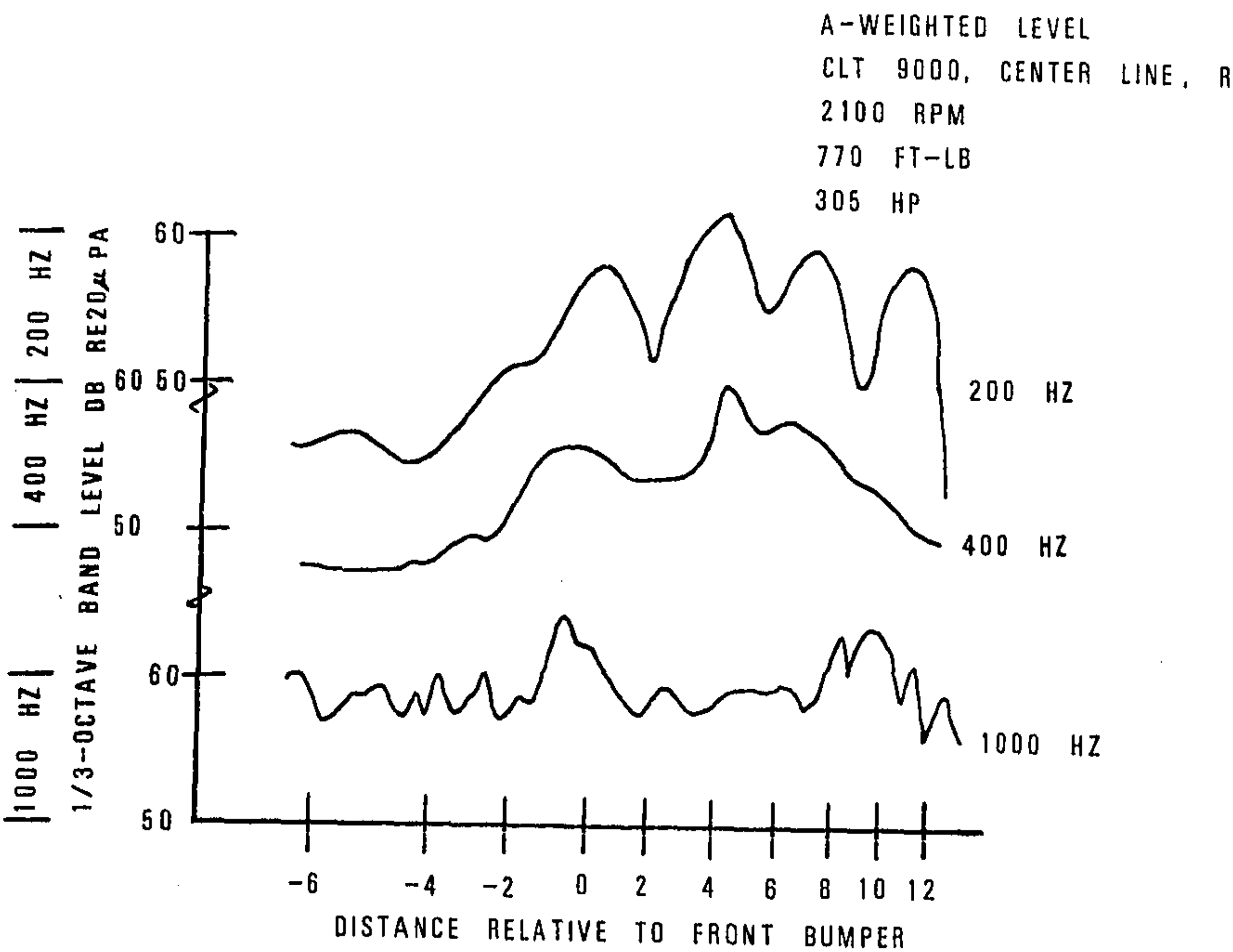


FIGURE 3-11
LEVELS AS A FUNCTION OF POSITION

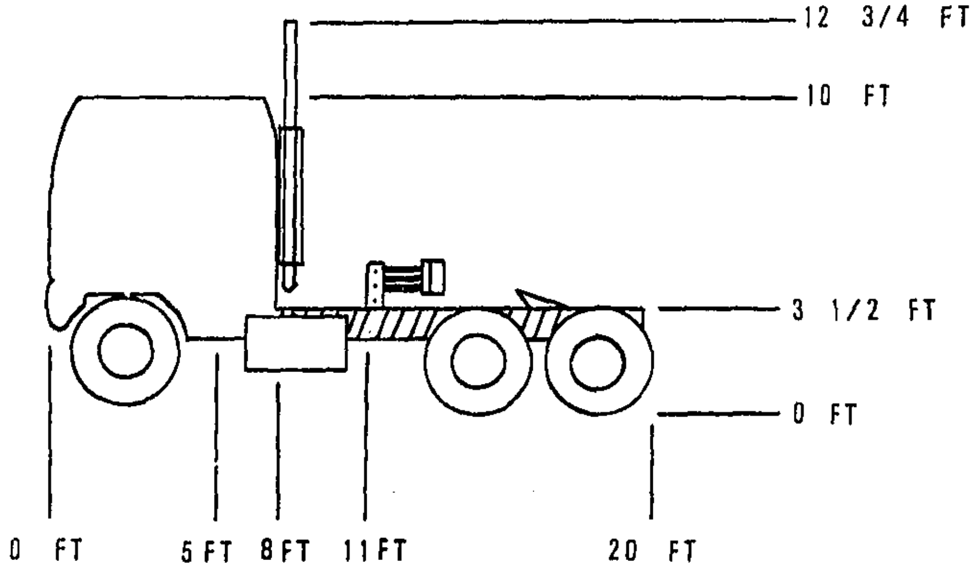


FIGURE 3-12

SIDELINE VIEW OF FORD CLT 9000 TO SHOW THE LOCATIONS (0, 5, 8 & 11 FT)

3.6.4 Component Noise Levels

Measurements were obtained with the truck in position, right side wheels at 50 Ft from the array centerline at engine speeds of 1500, 2000, and 2100 RPM with torque loads of 0, 500, 750, and 960 ft-lb.

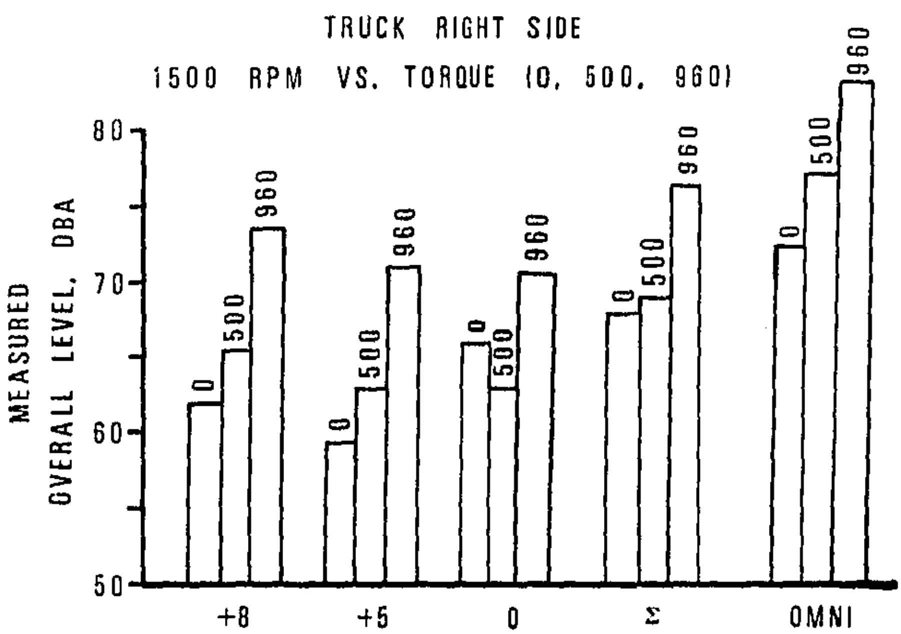
Figure 3-13A and 3-13B present the measured A-weighted array level (dB(A)) and the computed 1/3 octave array level (dB(A)) at 1500 RPM, three torque settings (0, 500, and 960 ft-lb)with the truck at positions +8, +5, and 0. A definition of each measured level is:

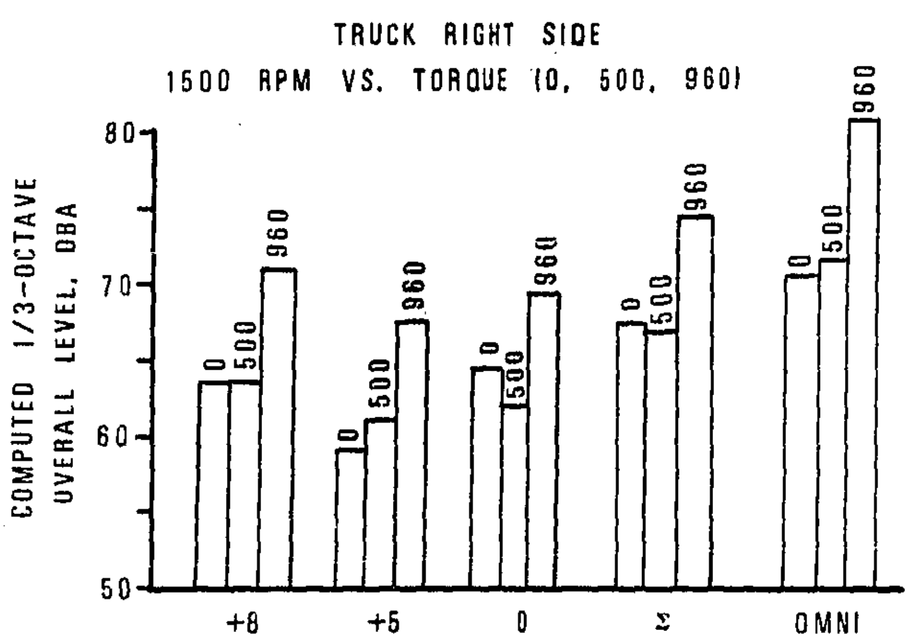
Measured Overall Level - The array output level as measured at the output of an A-weighted filter.

Computed 1/3-Octave Overall Level - The array output level as measured in 1/3-octave bands from 100 Hz to 2500 Hz and power summed to provide the total level for this frequency region.

Also shown on Figure 3-13A and 3-13B is the power sum of each source, designated as Σ , and the omnidirectional microphone level. As shown on the figure the Σ level is somewhat less than the level measured at the omnidirectional microphone. There are two possible explanations for this:

1. Array focus affects - The array focuses on an area of the truck radiation and represents only part of the source contribution at each location where as the omnidirectional microphone receives noise from all parts of the truck.


TRUCK RIGHT SIDE
1500 RPM VS. TORQUE (0, 500, 960)
MEASURED
OVERALL LEVEL, DBA
80
70
60
50
0
500
960
+8
+5
0
Σ
OMNI


TRUCK RIGHT SIDE
1500 RPM VS. TORQUE (0, 500, 960)
COMPUTED 1/3-OCTAVE
OVERALL LEVEL, DBA
80
70
60
50
0
500
960
+8
+5
0
Σ
OMNI

2. Dynamometer Contribution - At some load and engine speeds the dynamometer contributes noise to the omnidirectional microphone but not to the array output level and therefore Σ should not be the same level at the measured omnidirectional level.

A conclusion drawn from Figure 3-13 is that the noise level increases with load at the +8 Ft and +5Ft locations but not at the 0 Ft location. For this set of runs the 0 Ft measurements include runs with the fan on and with the fan off. The levels for zero load and 960 ft-lb load are with the fan on whereas the level for 500 ft-lb load is with the fan off. This conclusion is further substantiated by listening to the recorded signal and referring to Figure 3-14. Figure 3-14 shows the A-weighted 1/3-octave band levels in dB relative to 20μPa at the array output with the truck at position 0 Ft. For the 0 ft-lb and 960 ft-lb load conditions the fan is dominating the bands at 160 and 200 Hz. The 500 ft-lb load condition clearly has an absence of fan blade rate noise (160 and 200 Hz) and is generally lower in a number of 1/3-octave bands.

In addition, Figure 3-14 through 3-16 substantiates the general conclusion formed from review of Figure 3-13 that the noise level generally increases with load.

Figure 3-17A and 3-17B present the same bargraph information as Figure 3-13 except at an engine speed of 2000 RPM and torque settings of 0, 500 and 750 ft-lb. In this case the fan is clearly out of the array focus and the levels are increasing with engine load.

Figure 3-18 through 3-20 provide the A-weighted 1-3-octave band spectra at each location, 2000 RPM and varying load.

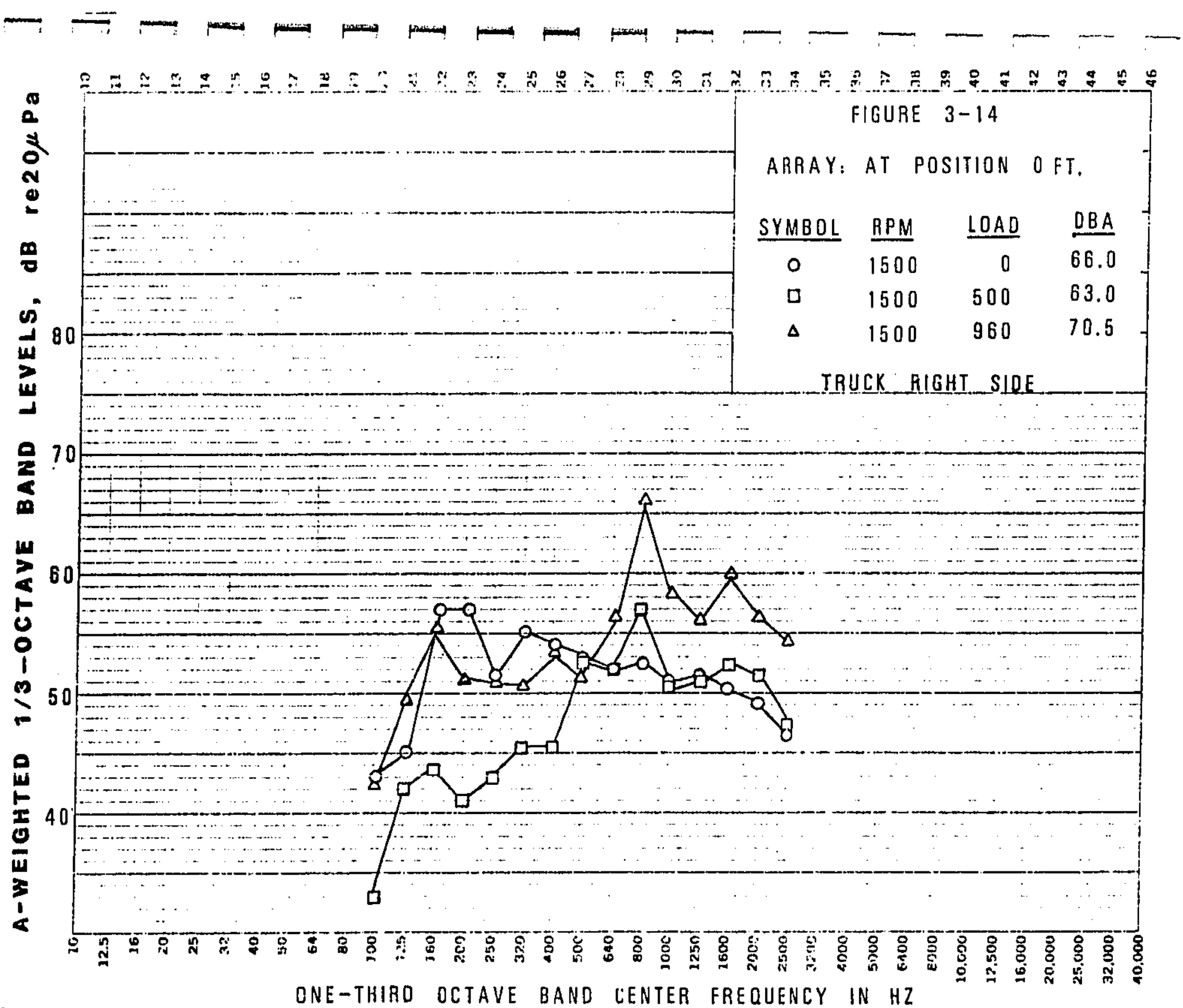


FIGURE 3-14
ARRAY: AT POSITION 0 FT.
SYMBOL RPM LOAD DBA
○ 1500 0 66.0
□ 1500 500 63.0
△ 1500 960 70.5
TRUCK RIGHT SIDE
A-WEIGHTED 1/3-OCTAVE BAND LEVELS, dB re20μPa
ONE-THIRD OCTAVE BAND CENTER FREQUENCY IN HZ

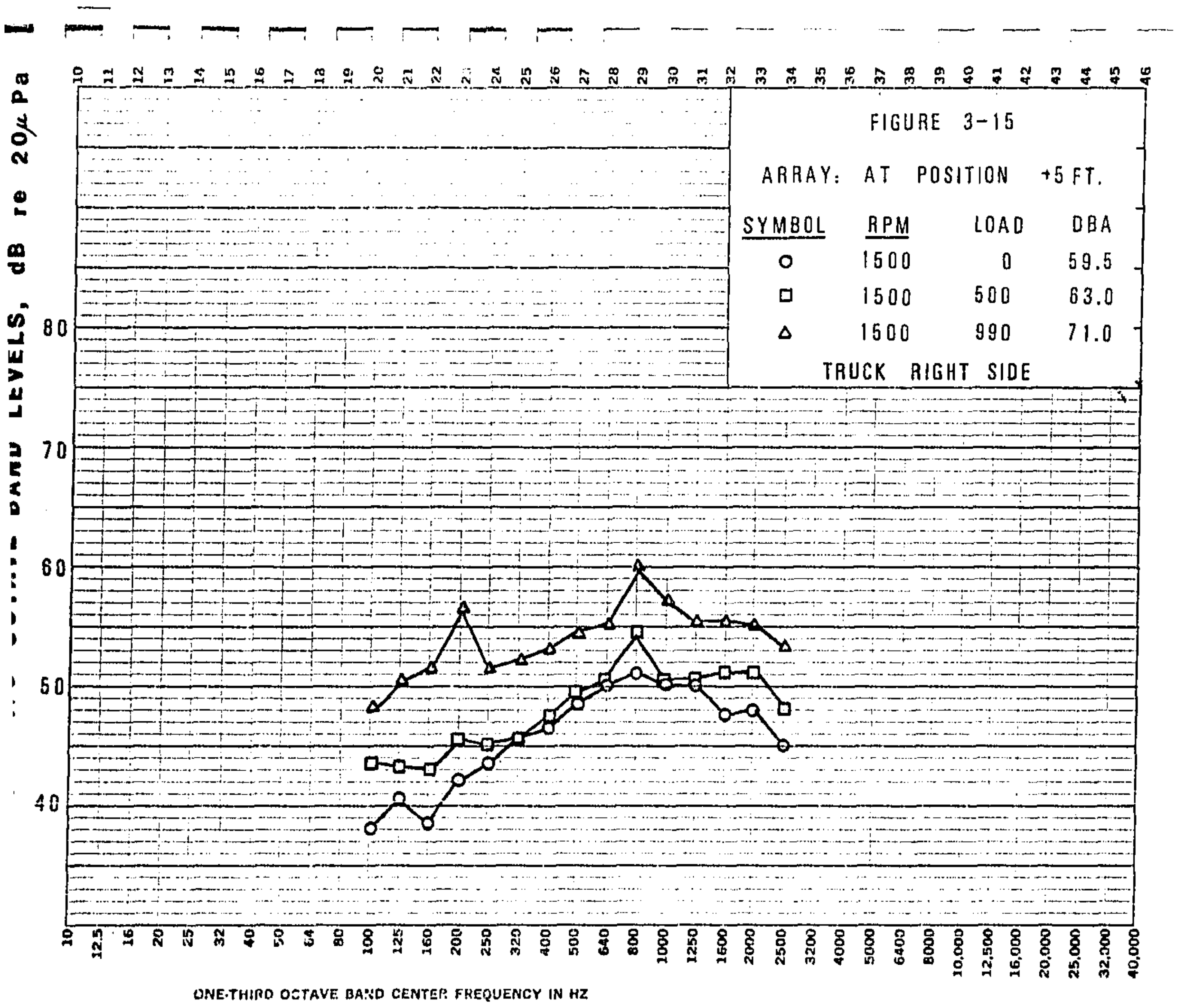


FIGURE 3-15
ARRAY: AT POSITION +5 FT.
SYMBOL RPM LOAD DBA
○ 1500 0 59.5
□ 1500 500 63.0
△ 1500 990 71.0
TRUCK RIGHT SIDE
dB re 20μ Pa
ONE-THIRD OCTAVE BAND CENTER FREQUENCY IN HZ

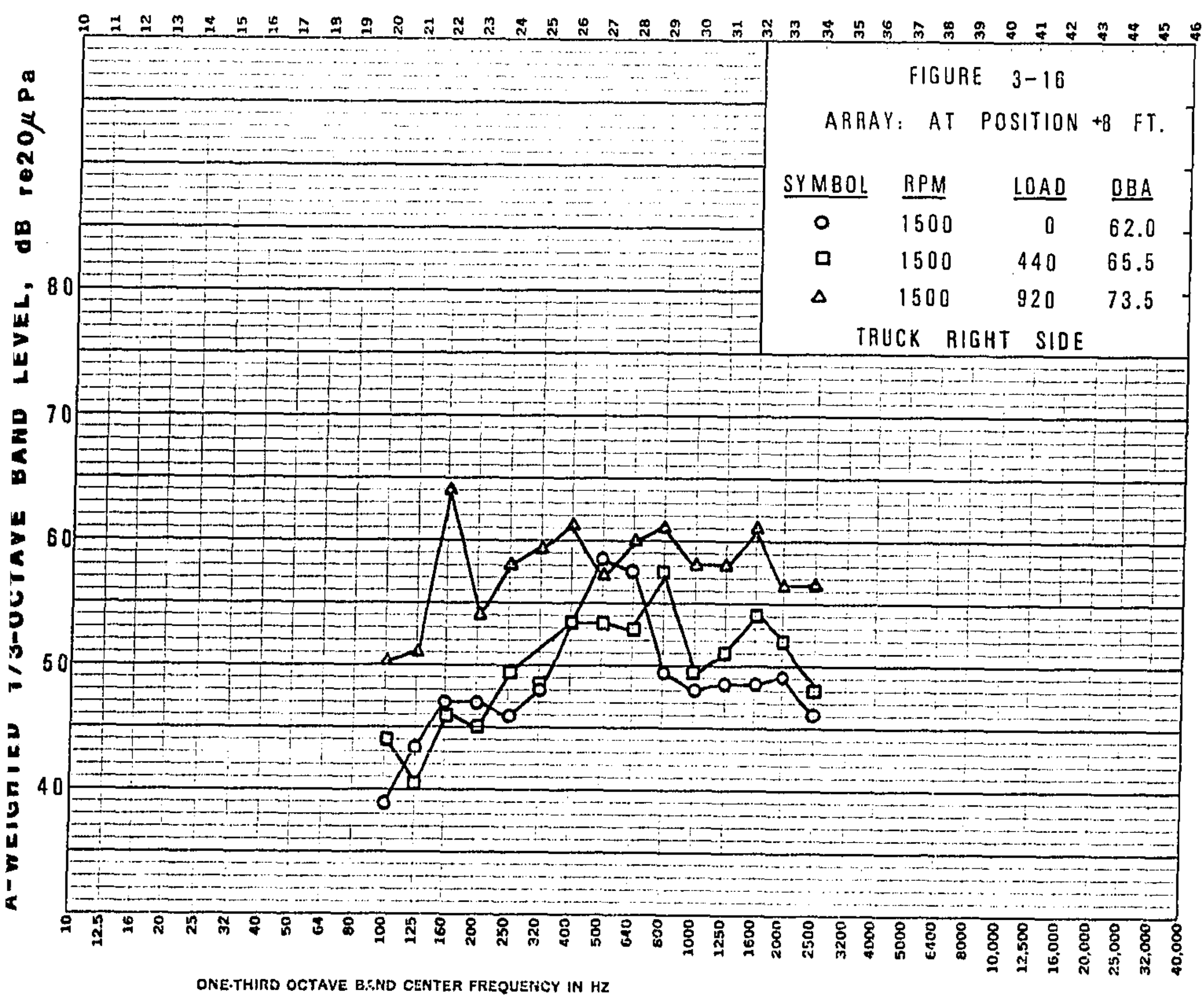


FIGURE 3-16
ARRAY: AT POSITION +8 FT.
SYMBOL RPM LOAD DBA
○ 1500 0 62.0
□ 1500 440 65.5
△ 1500 920 73.5
TRUCK RIGHT SIDE
A-WEIGHTED 1/3-OCTAVE BAND LEVEL, dB re20μPa
80
70
60
50
40
10
12.5
16
20
25
32
40
50
64
80
100
125
160
200
250
320
400
500
640
800
1000
1250
1600
2000
2500
3200
4000
5000
6400
8000
10,000
12,500
16,000
20,000
25,000
32,000
40,000
ONE-THIRD OCTAVE BAND CENTER FREQUENCY IN HZ

FIGURE 3-17A

TRUCK RIGHT SIDE

2000 RPM VS. TORQUE (0, 500, 750)

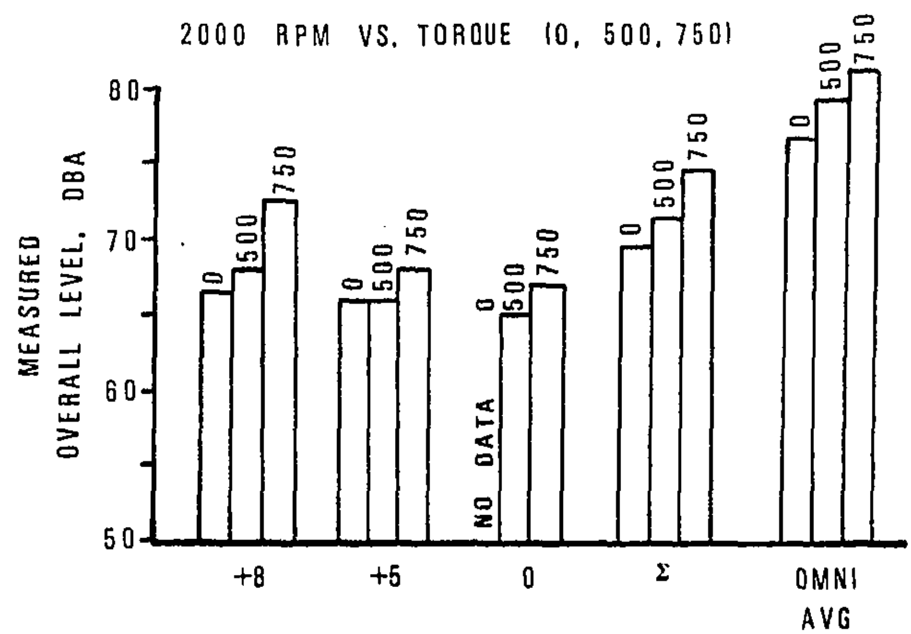
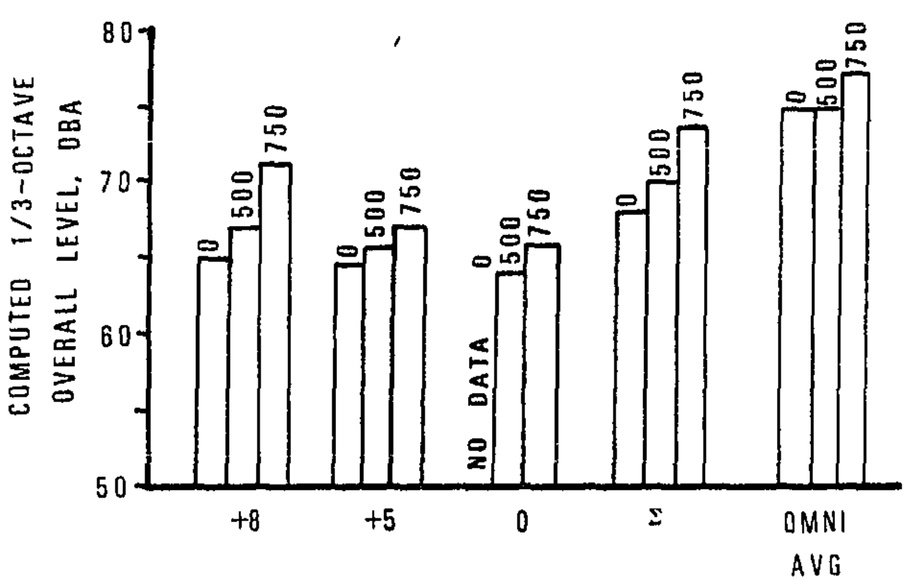


FIGURE 3-17B

TRUCK RIGHT SIDE

2000 RPM VS. TORQUE (0, 500, 750)



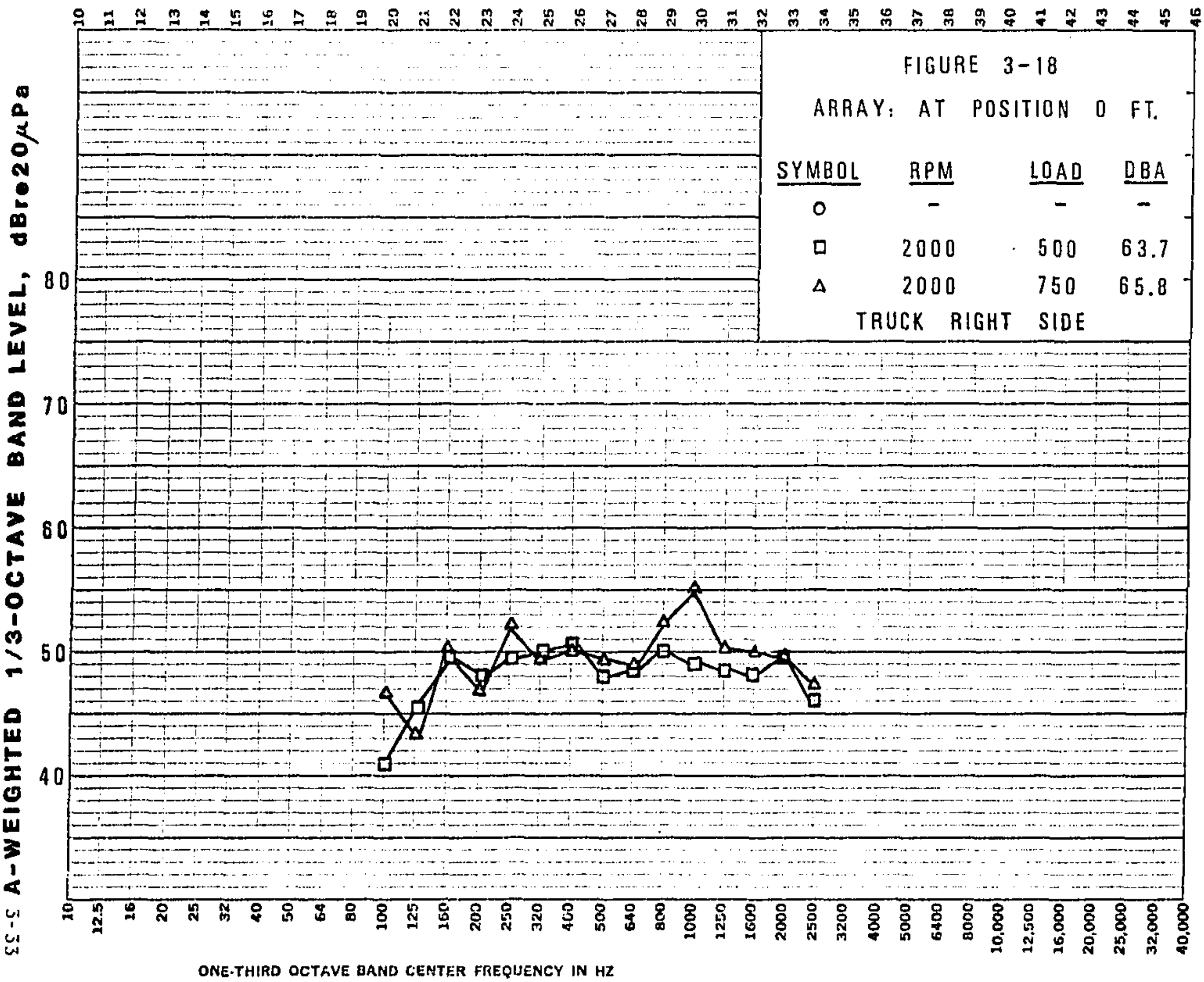


FIGURE 3-18
ARRAY: AT POSITION 0 FT.
SYMBOL RPM LOAD DBA
○ – – –
□ 2000 500 63.7
△ 2000 750 65.8
TRUCK RIGHT SIDE
A-WEIGHTED 1/3-OCTAVE BAND LEVEL, dBre20μPa
ONE-THIRD OCTAVE BAND CENTER FREQUENCY IN HZ

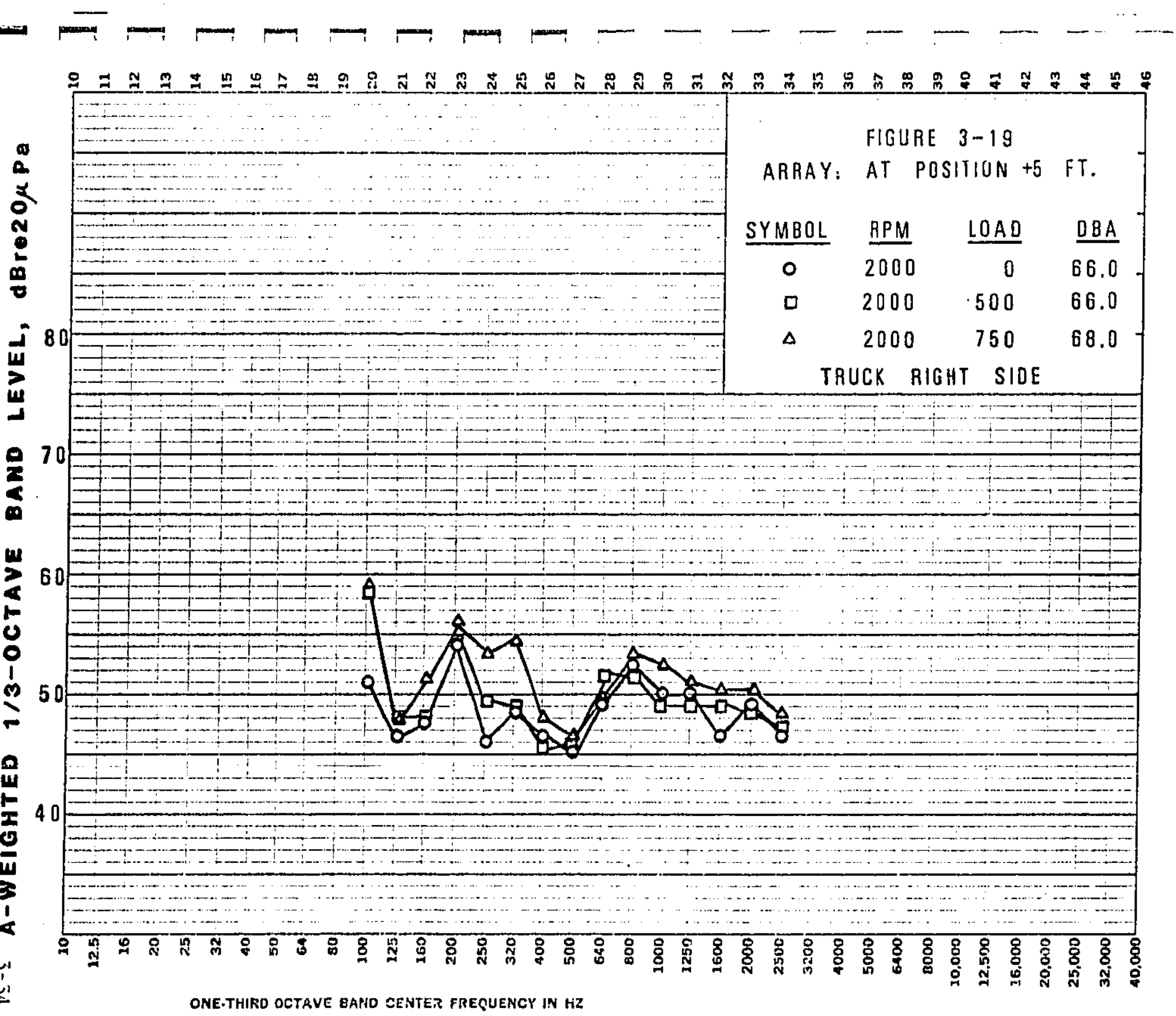


FIGURE 3-19
ARRAY: AT POSITION +5 FT.
SYMBOL RPM LOAD DBA
○ 2000 0 66.0
□ 2000 500 66.0
△ 2000 750 68.0
TRUCK RIGHT SIDE
A-WEIGHTED 1/3-OCTAVE BAND LEVEL, dBre20μPa
80
70
60
50
40
10 12.5 16 20 25 32 40 50 64 80 100 125 160 200 250 320 400 500 640 800 1000 1250 1600 2000 2500 3200 4000 5000 6400 8000 10,000 12,500 16,000 20,000 25,000 32,000 40,000
ONE-THIRD OCTAVE BAND CENTER FREQUENCY IN HZ

Figure 3-20 shows the most dramatic increase in level, and changes in the frequency content, and provides an indication that the truck noise is exhaust system dominated.

At an engine speed of 2100 RPM, the situation is similar. Figure 3-21 shows the bargraph results for torque settings of 0, 500 and 750 ft-lb. In this case also, the levels increase with load at each position with the exhaust system the dominant source.

Figures 3-22 through 3-24 illustrate the 1/3-octave band spectra at 2100 RPM and various loads at each truck position.

Test time precluded a full set of measurements in the stationary positions with the truck on the centerline and left hand wheels on the centerline. Nearfield probe results indicated that the levels at 0 Ft and + 5 Ft were comparable in level for both the right and left hand sides of the truck. The nearfield probe measurements at +8 Ft showed that the left hand exhaust was producing considerably more noise than the right hand exhaust at no load and at intermediate load. A set of measurements were then obtained with the truck left side wheels on the array centerline and the focus on the left hand exhaust system. The test results are shown in Figure 3-25. This is the bargraph presentation with the engine speed at 2100 and 1500 RPM, and load settings of 0, 500, 735 and 895 ft-lb of torque. Figure 3-25 shows that the left hand exhaust is nosier than the right hand exhaust at 0 load and at 500 ft-lb of load. The situation is reversed at the maximum load setting for each engine speed.

Appendix A, Figures A-1 through A-5, contain the 1/3-octave band spectra showing comparisons of the right and left side measurements.

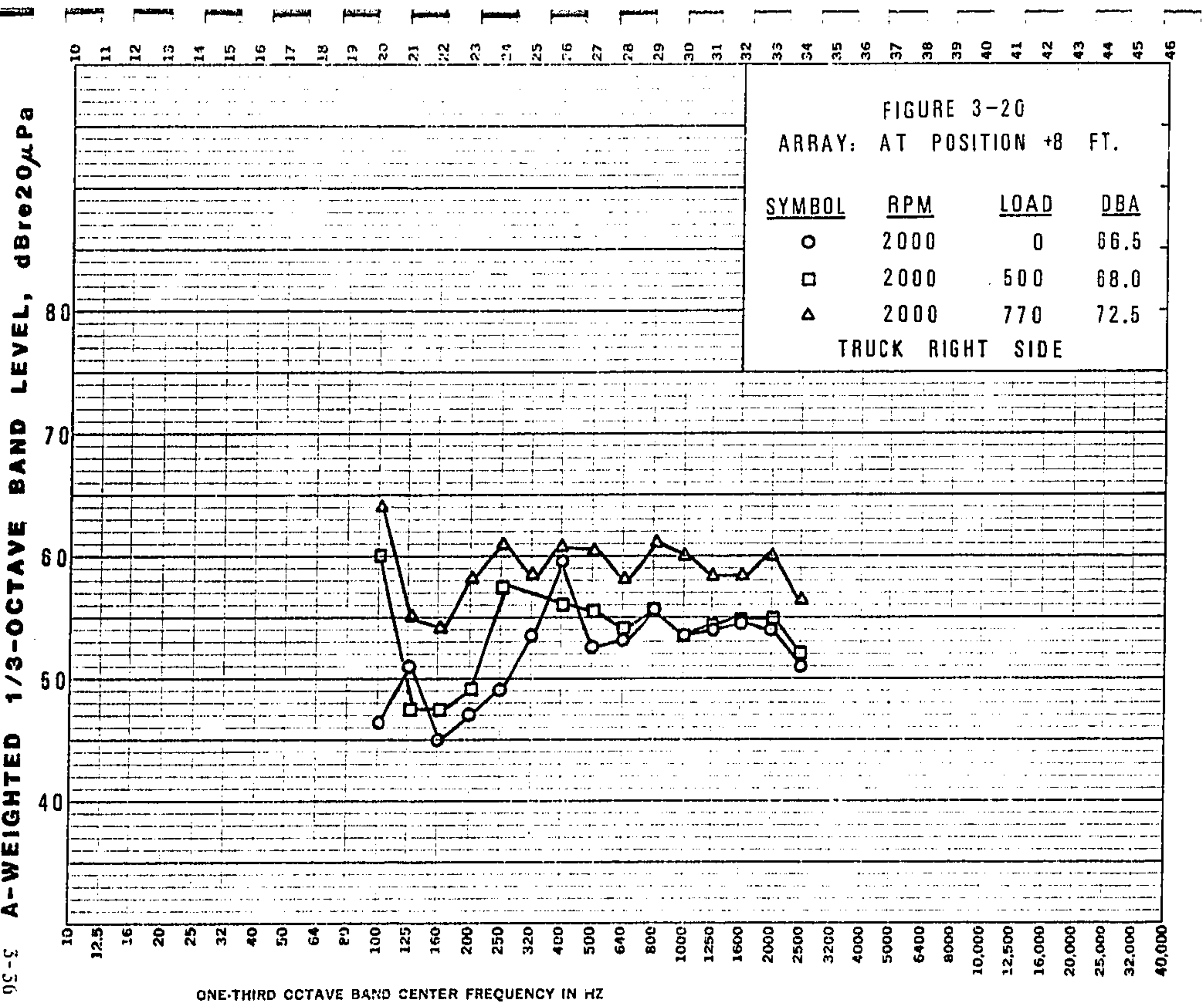


FIGURE 3-20
ARRAY: AT POSITION +8 FT.
SYMBOL RPM LOAD DBA
○ 2000 0 66.5
□ 2000 500 68.0
△ 2000 770 72.5
TRUCK RIGHT SIDE
A-WEIGHTED 1/3-OCTAVE BAND LEVEL, dBre20μPa
80
70
60
50
40
10 12.5 16 20 25 32 40 50 64 80 100 125 160 200 250 320 400 500 640 800 1000 1250 1600 2000 2500 3200 4000 5000 6400 8000 10,000 12,500 16,000 20,000 25,000 32,000 40,000
ONE-THIRD OCTAVE BAND CENTER FREQUENCY IN HZ

FIGURE 3-21A

TRUCK RIGHT SIDE

2100 RPM VS. TORQUE (0, 500, 750)

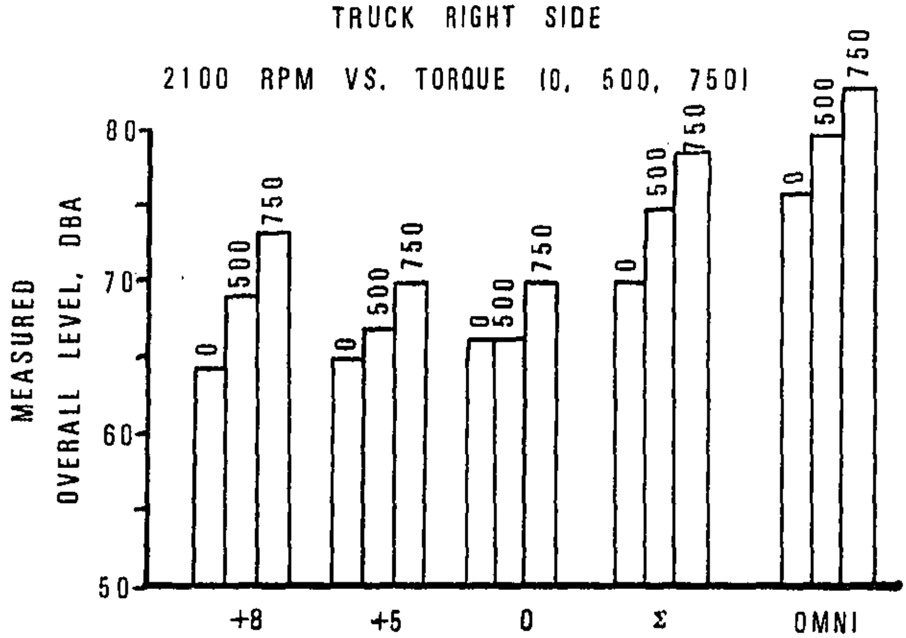
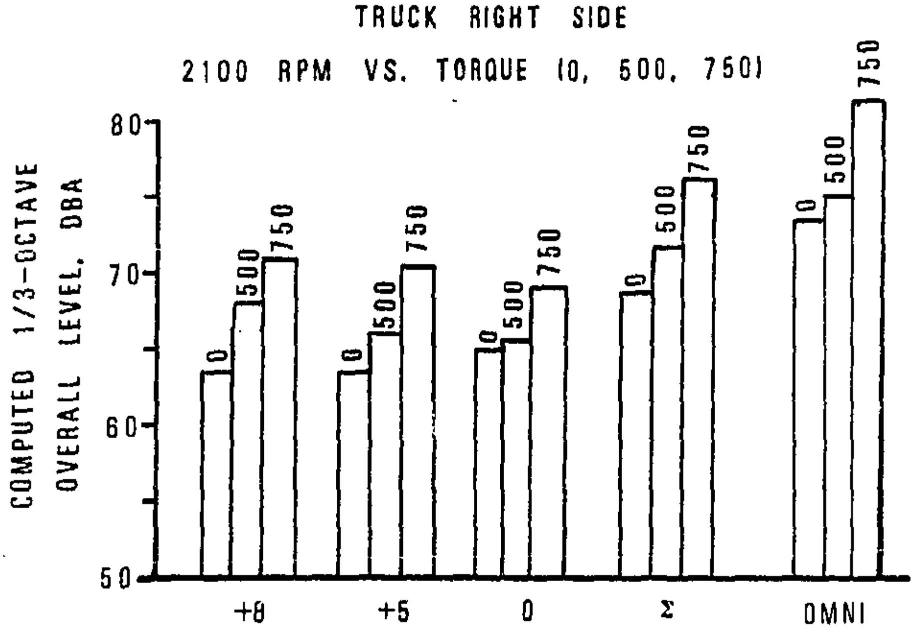


FIGURE 3-21B

TRUCK RIGHT SIDE

2100 RPM VS. TORQUE (0, 500, 750)



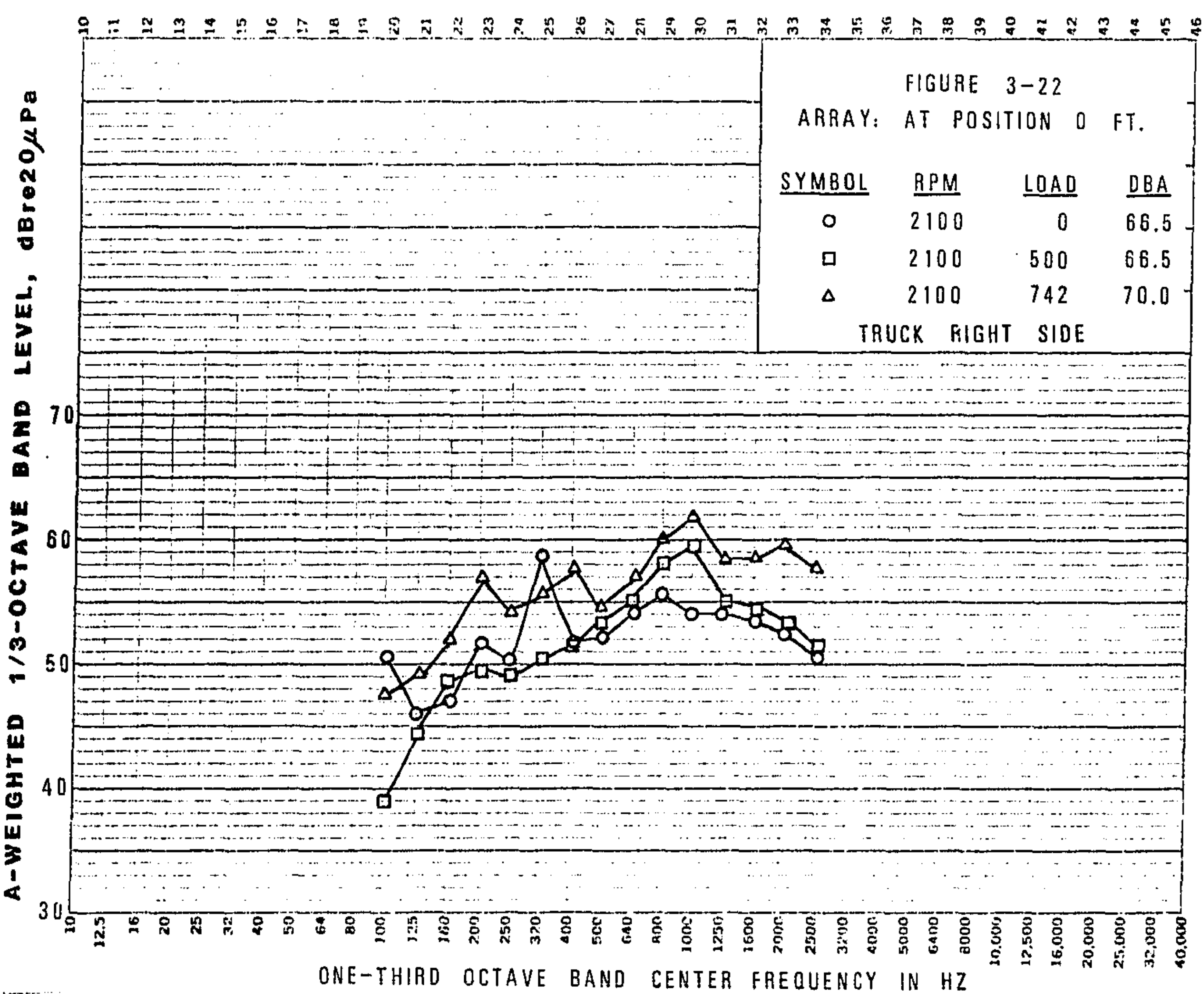


FIGURE 3-22
ARRAY: AT POSITION 0 FT.
SYMBOL RPM LOAD DBA
○ 2100 0 66.5
□ 2100 500 66.5
△ 2100 742 70.0
TRUCK RIGHT SIDE
A-WEIGHTED 1/3-OCTAVE BAND LEVEL, dBre20μPa
30
40
50
60
70
10 12.5 16 20 25 32 40 50 64 80 100 125 160 200 250 320 400 500 640 800 1000 1250 1600 2000 2500 3200 4000 5000 6400 8000 10,000 12,500 16,000 20,000 25,000 32,000 40,000
ONE-THIRD OCTAVE BAND CENTER FREQUENCY IN HZ

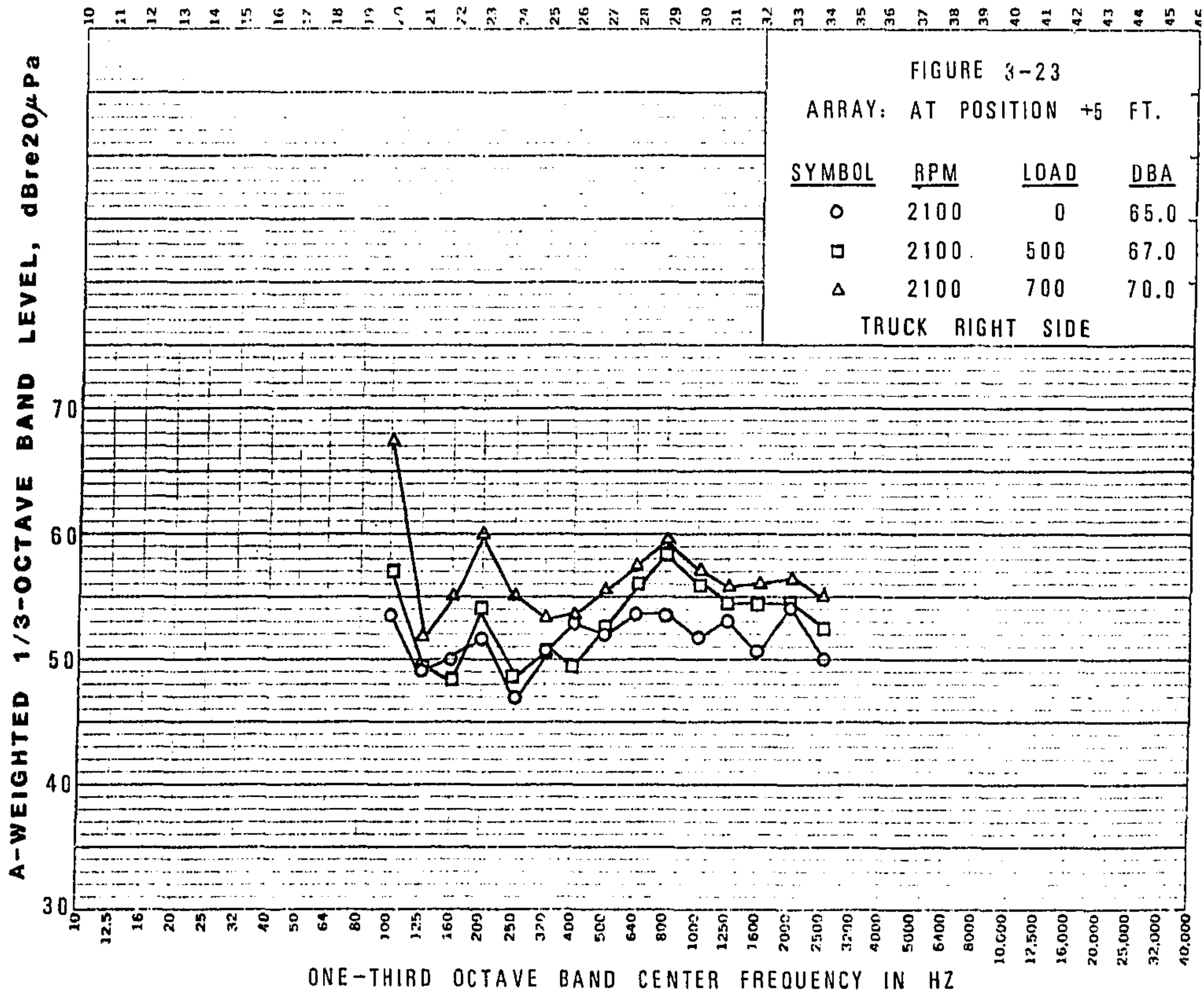


FIGURE 3-23
ARRAY: AT POSITION +5 FT.
SYMBOL RPM LOAD DBA
○ 2100 0 65.0
□ 2100 500 67.0
△ 2100 700 70.0
TRUCK RIGHT SIDE
A-WEIGHTED 1/3-OCTAVE BAND LEVEL, dBre20μPa
ONE-THIRD OCTAVE BAND CENTER FREQUENCY IN HZ
30
40
50
60
70
10
12.5
16
20
25
32
40
50
64
80
100
125
160
200
250
320
400
500
640
800
1000
1250
1600
2000
2500
3200
4000
5000
6400
8000
10,000
12,500
16,000
20,000
25,000
32,000
40,000

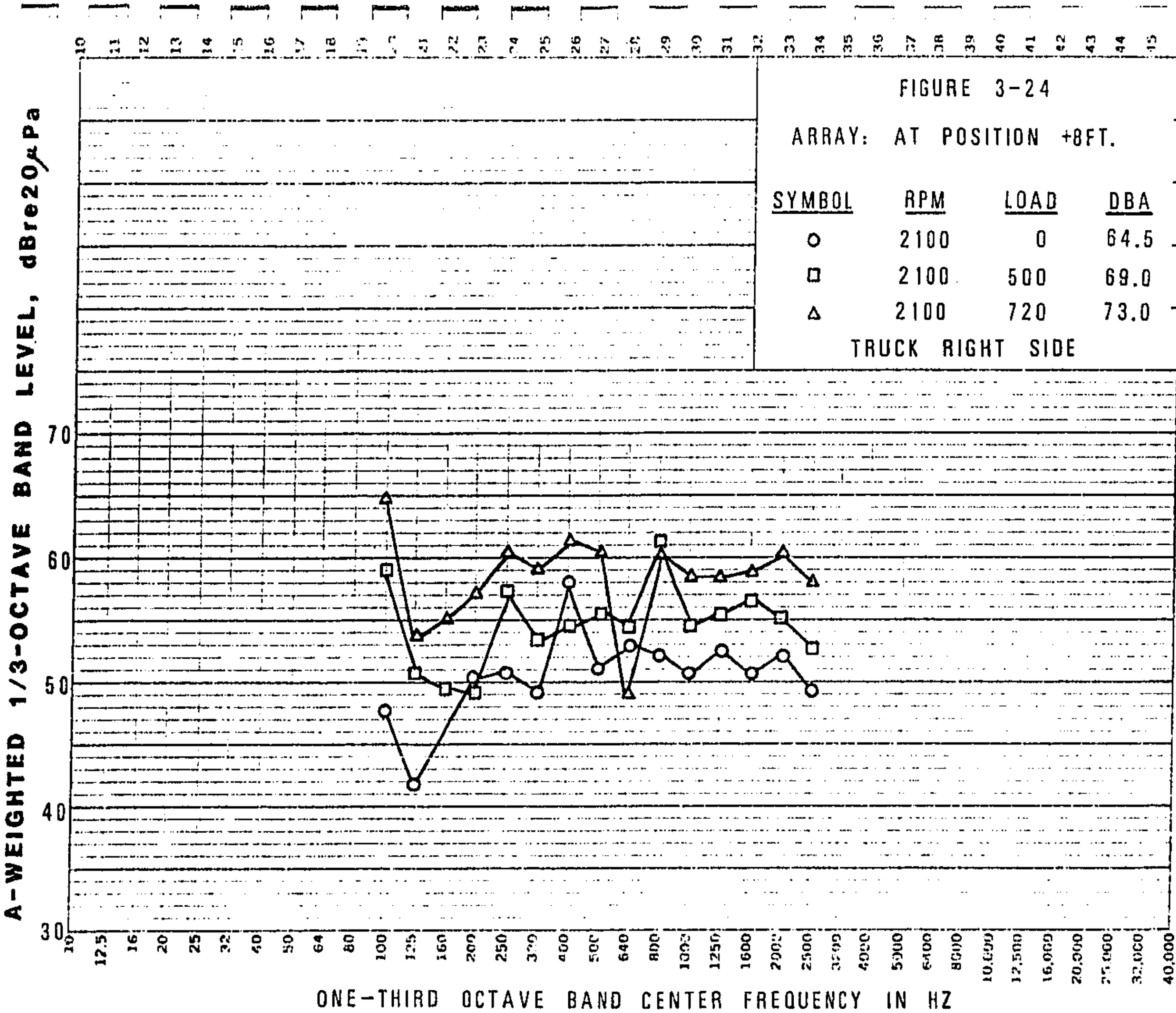


FIGURE 3-24
ARRAY: AT POSITION +8FT.
SYMBOL RPM LOAD DBA
○ 2100 0 64.5
□ 2100 500 69.0
△ 2100 720 73.0
TRUCK RIGHT SIDE
A-WEIGHTED 1/3-OCTAVE BAND LEVEL, dBre20μPa
30
40
50
60
70
10 12.5 16 20 25 32 40 50 64 80 100 125 160 200 250 320 400 500 640 800 1000 1250 1600 2000 2500 3200 4000 5000 6400 8000 10,000 12,500 16,000 20,000 25,000 32,000 40,000
ONE-THIRD OCTAVE BAND CENTER FREQUENCY IN HZ

ARRAY POSITION, 8 FT TRUCK LEFT SIDE VS RIGHT SIDE
RPM (2100, 1500) VS TORQUE (0, 500, 895)

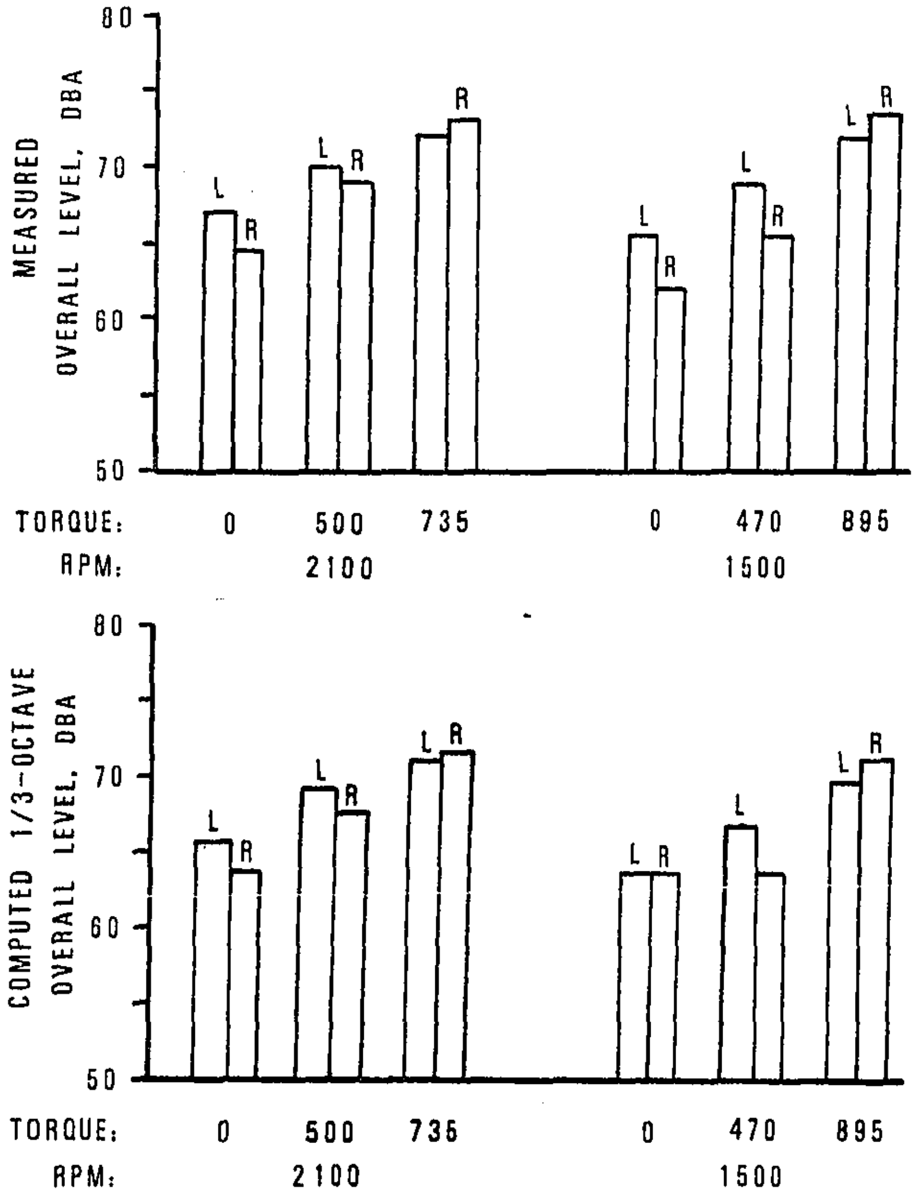


FIGURE 3-25

COMPARISON OF EXHAUST SYSTEM NOISE LEVELS AS MEASURED BY THE ARRAY

3.6.5 One-Third Octave Spectra vs Truck Position

One-third octave results of the measurements obtained with the truck in position, right side wheels at the 50 foot mark, were plotted for 500 ft-lb torque at 1500 and 2100 RPM for the various truck regions.

Figure 3-26 shows the plots of the one-third octave spectra for the 1500 RPM and 500 ft-lb condition at 0, +5, and +8 positions. The plots all have a similar contour with the greatest similarity seen above 630 Hz. At 100 Hz the engine firing rate is observed at +8 and +5, but not at the 0 position. However, the overall noise level in dB(A) at 0 and +5 are the same, with an increase in dB(A) level at the +8 mark. Generally, the +8 spectra dominates the noise level, especially in the bands from 200 to 630 Hz. All three plots show a major peak at 800 Hz, and secondary peak at 1600 Hz.

Figure 3-27 is the graph of the 500 ft-lb load vs position plots at 2100 RPM engine speed, from similar one-third octave band measured results. The basic contour observed in Figure 3-26 has been changed because of firing rate dominance in the 100, 200 and 400 Hz bands. The engine (+5) and exhaust (+8) locations demonstrate dominance of the engine firing rate harmonics in the 100 and 200 Hz bands. A major peak at +8 however appears at 630 Hz, larger at 2100 than 1500 RPM. Other major peaks for +5 and 0, respectively, appear at 800 and 1000 Hz, one-third octave band center frequency.

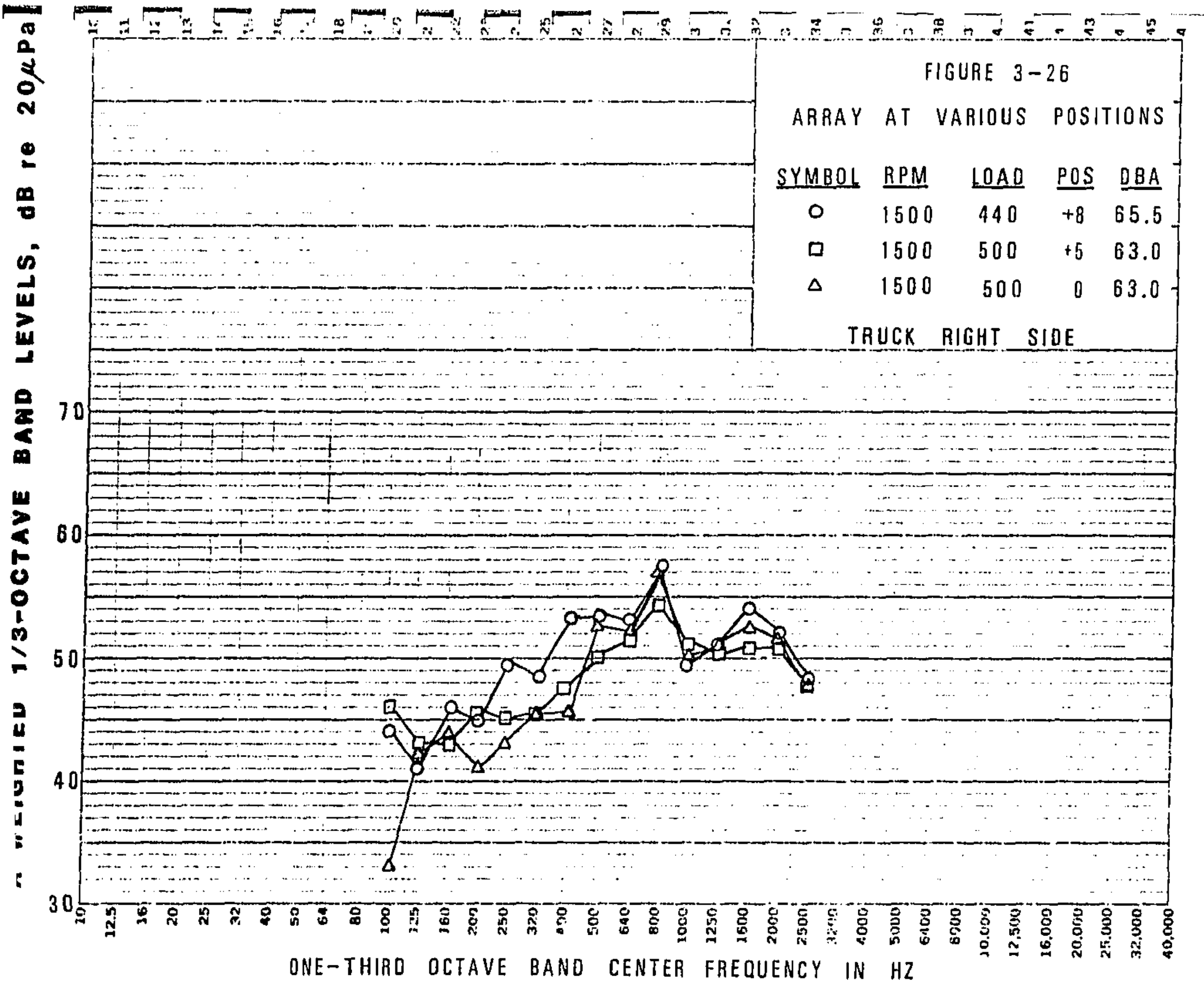


FIGURE 3-26
ARRAY AT VARIOUS POSITIONS
SYMBOL RPM LOAD POS DBA
○ 1500 440 +8 65.5
□ 1500 500 +5 63.0
△ 1500 500 0 63.0
TRUCK RIGHT SIDE
A-WEIGHTED 1/3-OCTAVE BAND LEVELS, dB re 20μPa
70
60
50
40
30
10 12.5 16 20 25 32 40 50 64 80 100 125 160 200 250 320 400 500 640 800 1000 1250 1600 2000 2500 3200 4000 5000 6400 8000 10,000 12,500 16,000 20,000 25,000 32,000 40,000
ONE-THIRD OCTAVE BAND CENTER FREQUENCY IN HZ

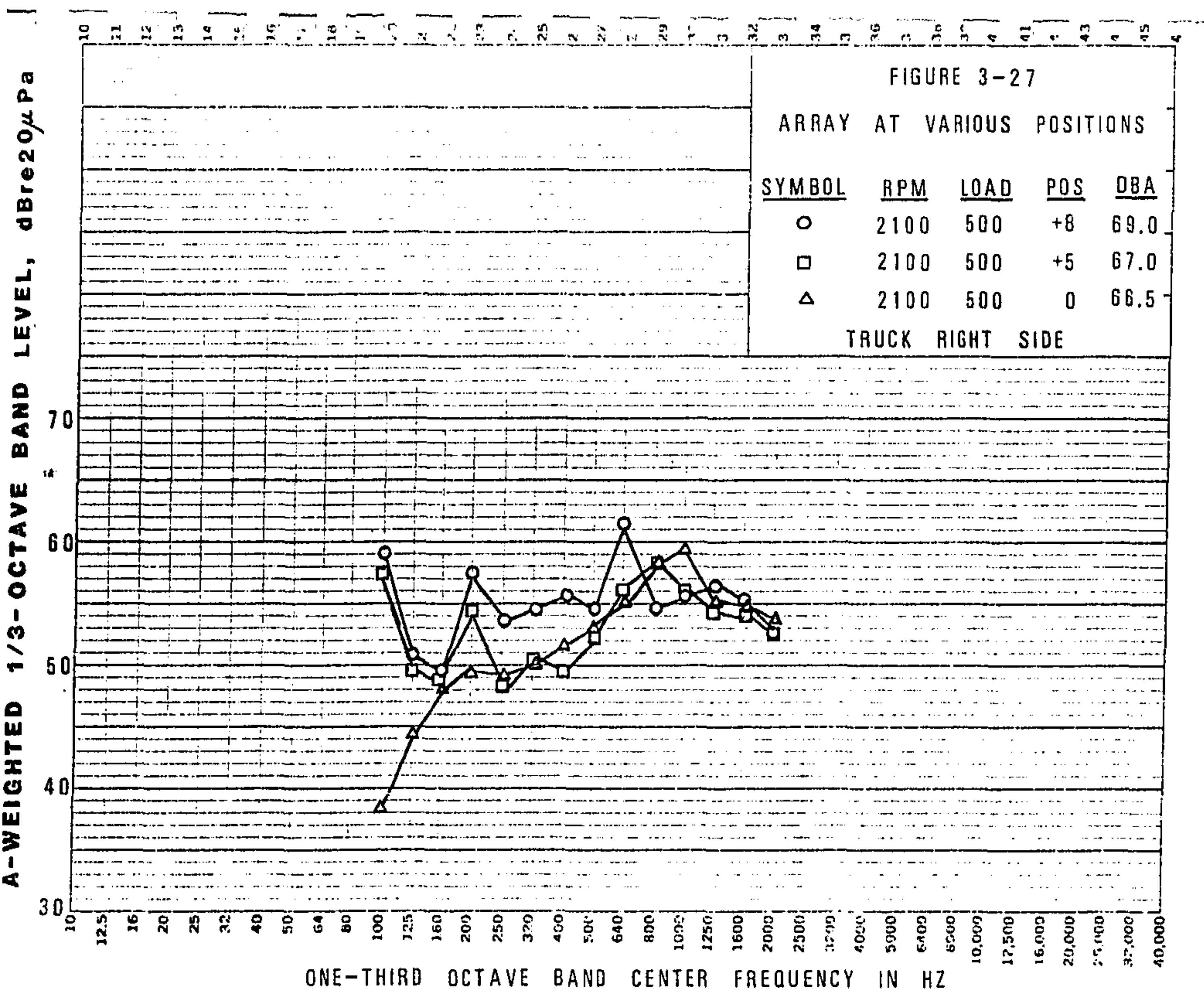


FIGURE 3-27
ARRAY AT VARIOUS POSITIONS
SYMBOL RPM LOAD POS DBA
○ 2100 500 +8 69.0
□ 2100 500 +5 67.0
△ 2100 500 0 66.5
TRUCK RIGHT SIDE
A-WEIGHTED 1/3-OCTAVE BAND LEVEL, dBre20μPa
70
60
50
40
30
10
12.5
16
20
25
32
40
50
64
80
100
125
160
200
250
320
400
500
640
800
1000
1250
1600
2000
2500
4000
5000
6400
10,000
12,500
16,000
20,000
40,000
ONE-THIRD OCTAVE BAND CENTER FREQUENCY IN HZ

3.6.6 Levels vs RPM and Load

Measured levels of the omnidirectional microphone and array outputs have been plotted as a function of RPM for each load condition. Measured torque in the ranges 440 to 615 ft-lb, 700-800 ft-lb, and 850 to 1000 ft-lb are considered to represent 1/2, 3/4 and full load. Figure 3-28 presents the A-weighted omnidirectional microphone levels as a function of RPM at various loads. Figures 3-29 through 3-31 present the same data for the array output with the truck at position +0, +5, and +8 Ft, respectively. Each of these figures show that the level is an increasing function of RPM at fixed load for all load conditions except full load. At full load there is only a slight increase in level as RPM is increased. In addition, the figures show that at fixed RPM the levels increase as load increases from no load to full load.

Figures 3-32 through 3-35 present the data for the summed A-weighted 1/3-octave bands in the frequency range from 100 Hz to 2500 Hz. These figures substantiate the same conclusions as discussed for the measured A-weighted levels.

In addition, Appendix A, Figures A-6 through A-9 present 1/3-octave spectra for the no load runs at each RPM. These curves show how the spectra and dominant 1/3-octave bands change as the RPM is varied from 1000 to maximum engine speed.

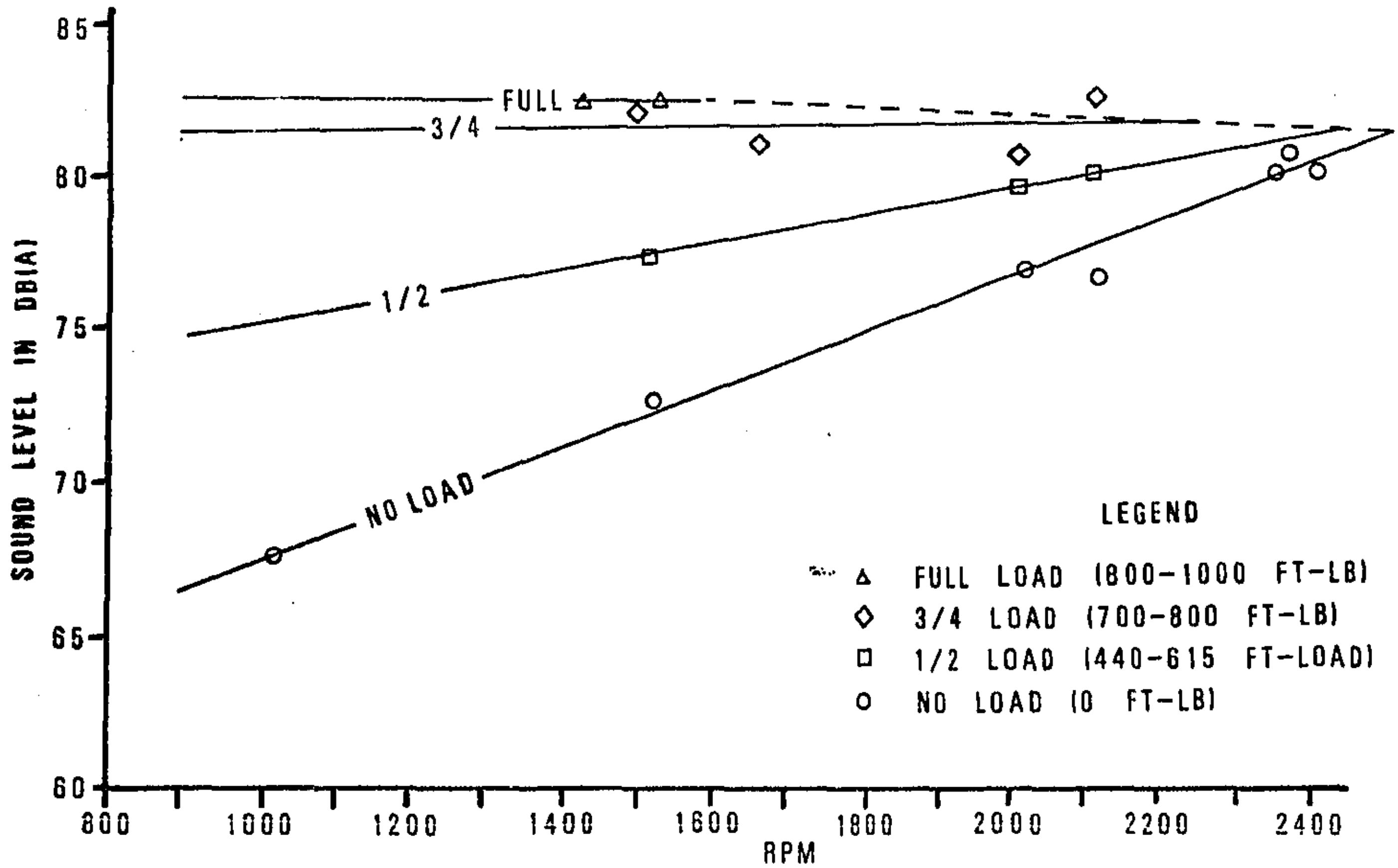


FIGURE 3-28

OMNI DIRECTIONAL MICROPHONE SOUND LEVEL AT VARIOUS LOADS VS. RPM

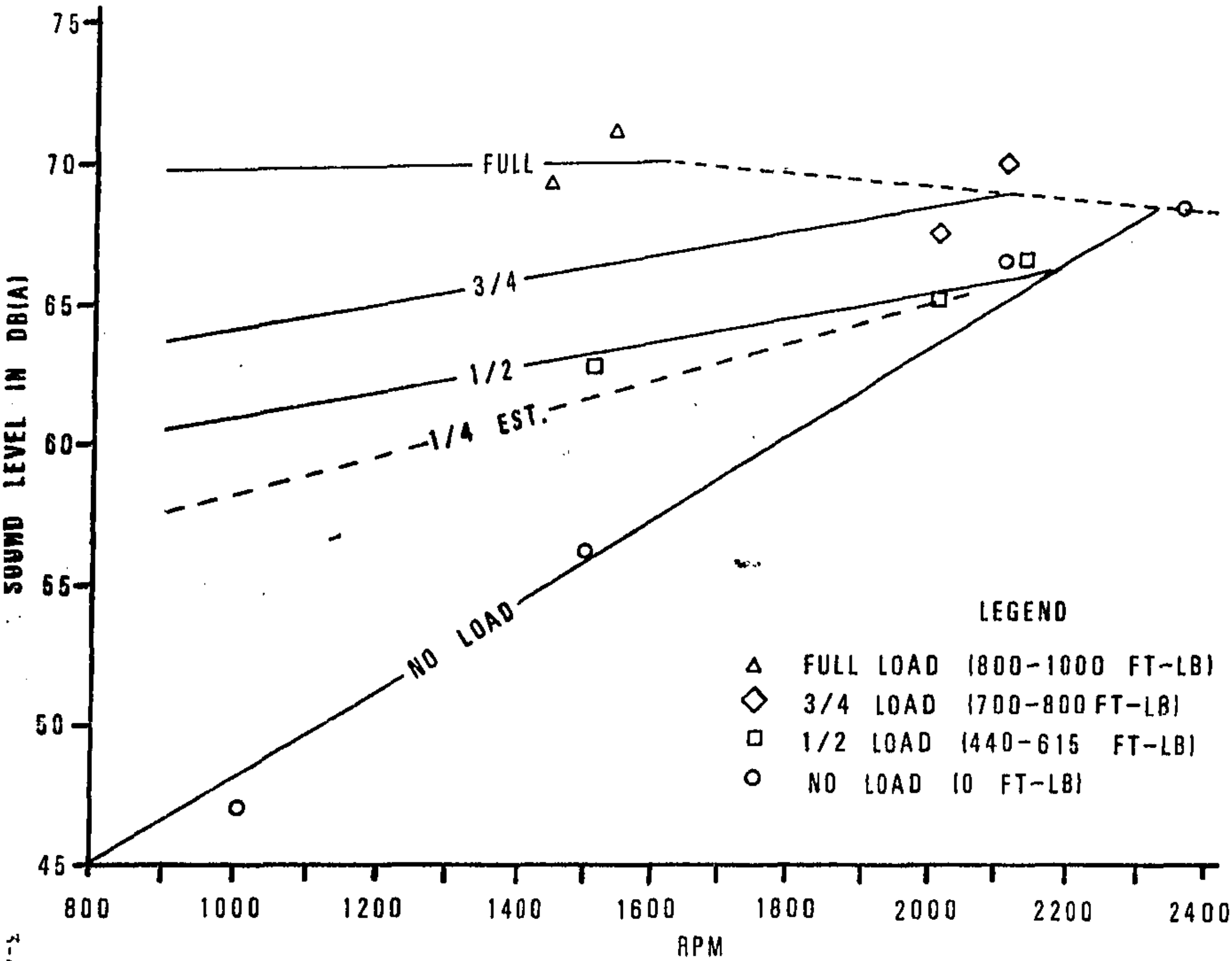


FIGURE 3-29
ARRAY SOUND LEVELS AT POSITION Ø (BUMPER) FOR VARIOUS LOADS
PASSENGER SIDE, RIGHT WHEEL AT CENTER LINE

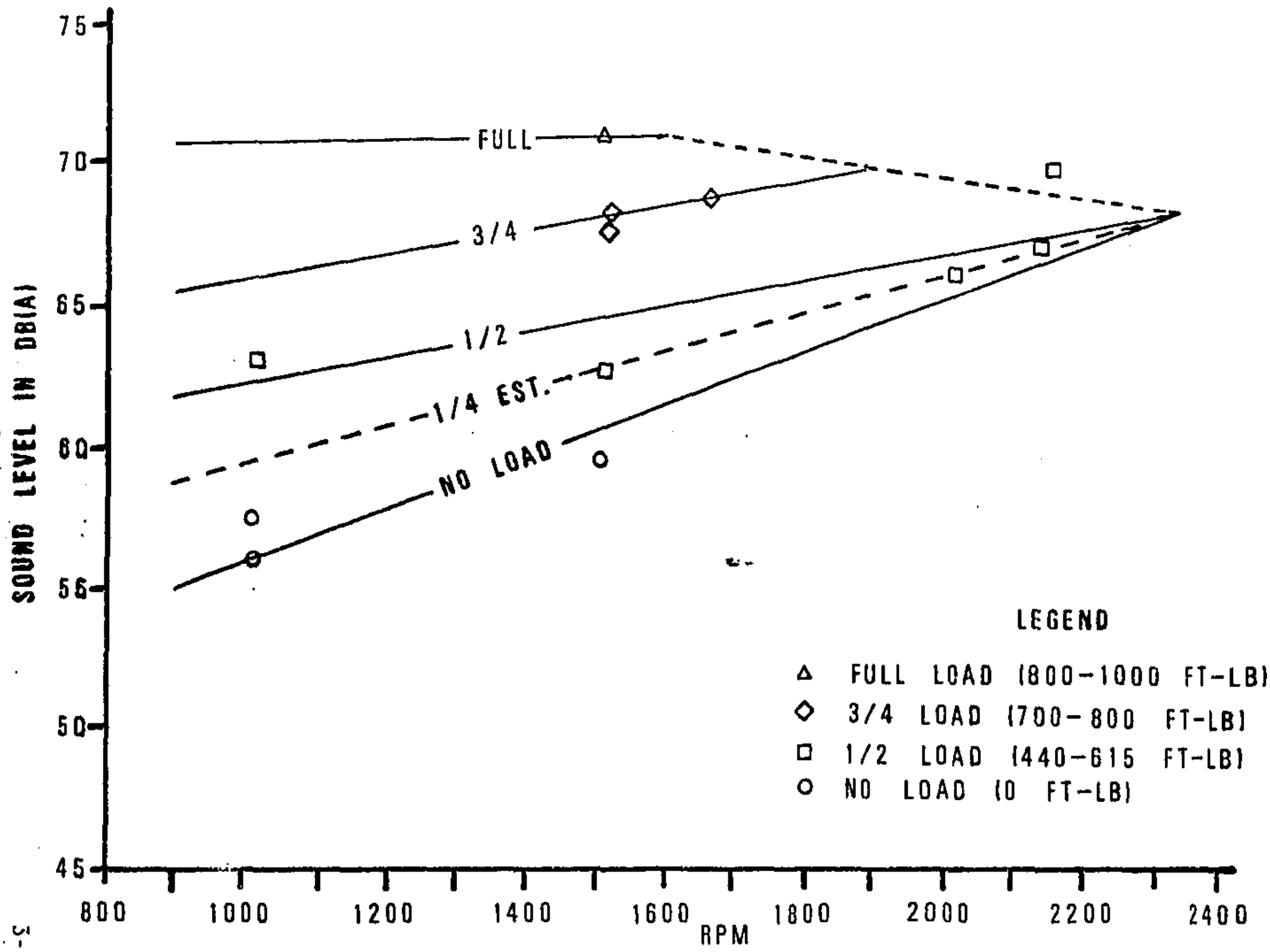


FIGURE 3-30
ARRAY SOUND LEVELS AT POSITION +5 (ENGINE) FOR VARIOUS LOADS VS. RPM
PASSENGER SIDE, RIGHT WHEEL AT ARRAY CENTER LINE

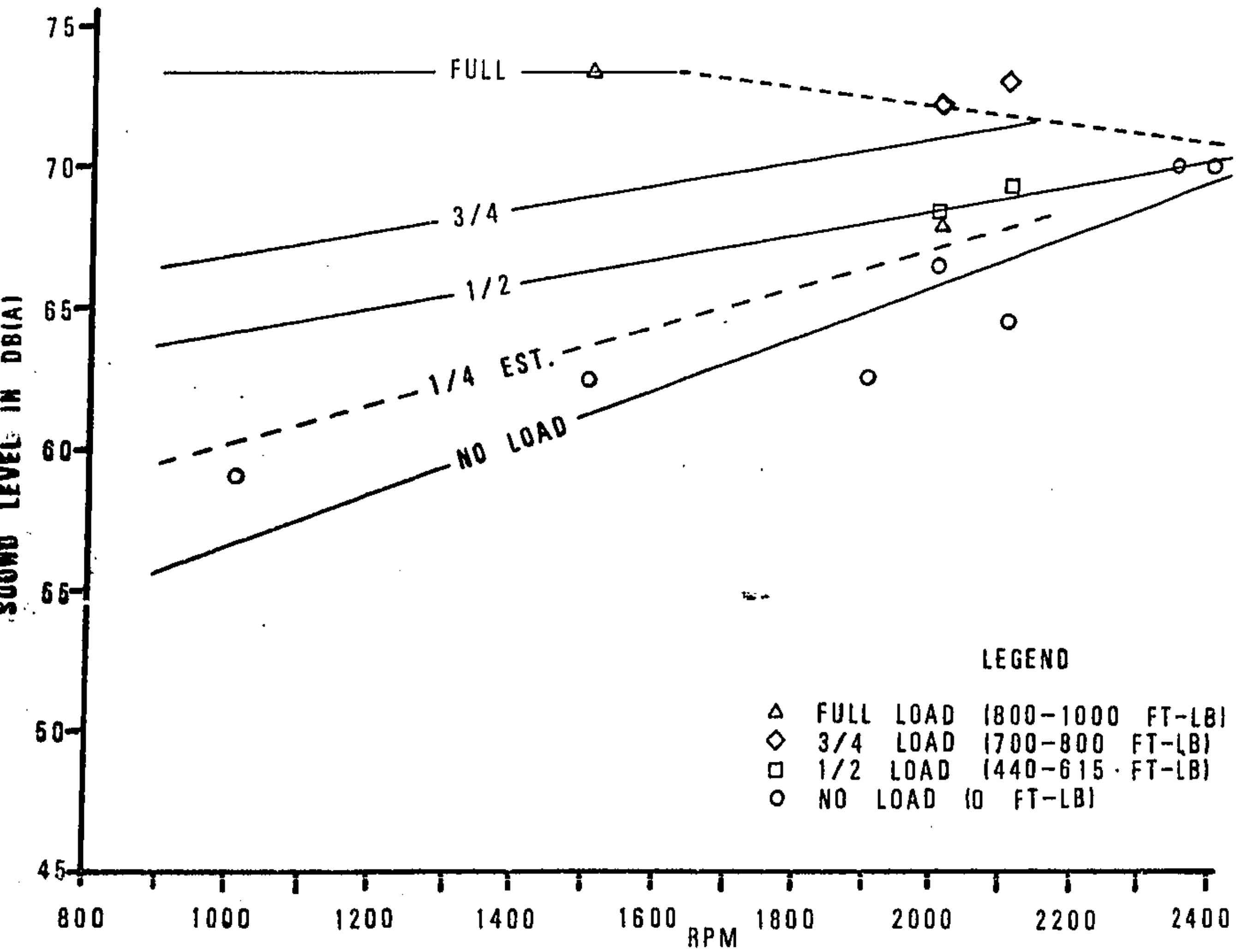


FIGURE 3-31

ARRAY SOUND LEVELS AT POSITION +8 (EXHAUST) FOR VARIOUS LOADS VS. RPM

PASSENGER SIDE, RIGHT WHEEL AT ARRAY CENTER LINE

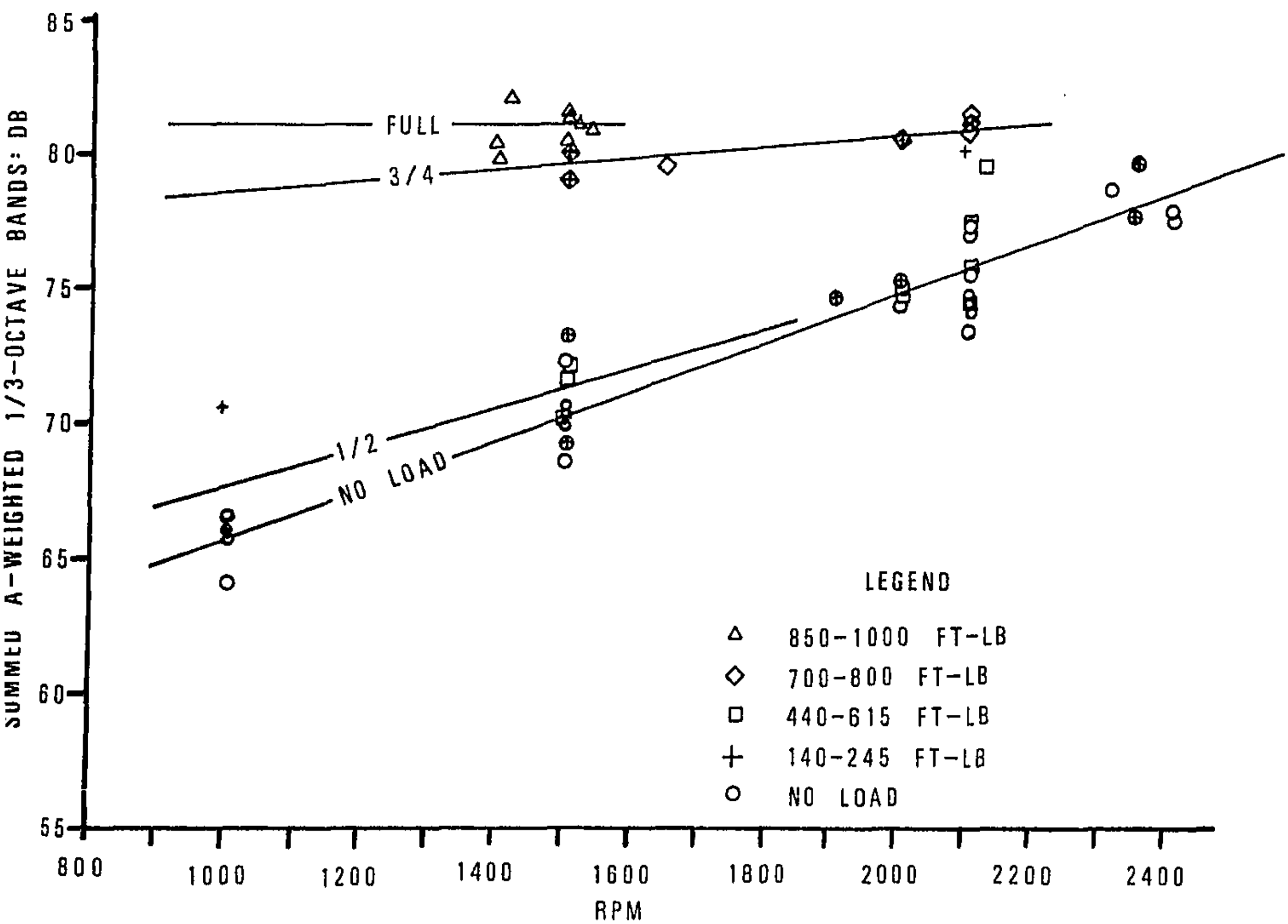


FIGURE 3-32
OMNIDIRECTIONAL MICROPHONE SUMMED A-WEIGHTED
1/3-OCTAVE BAND (100- 2.5K) SOUND LEVELS VS. RPM

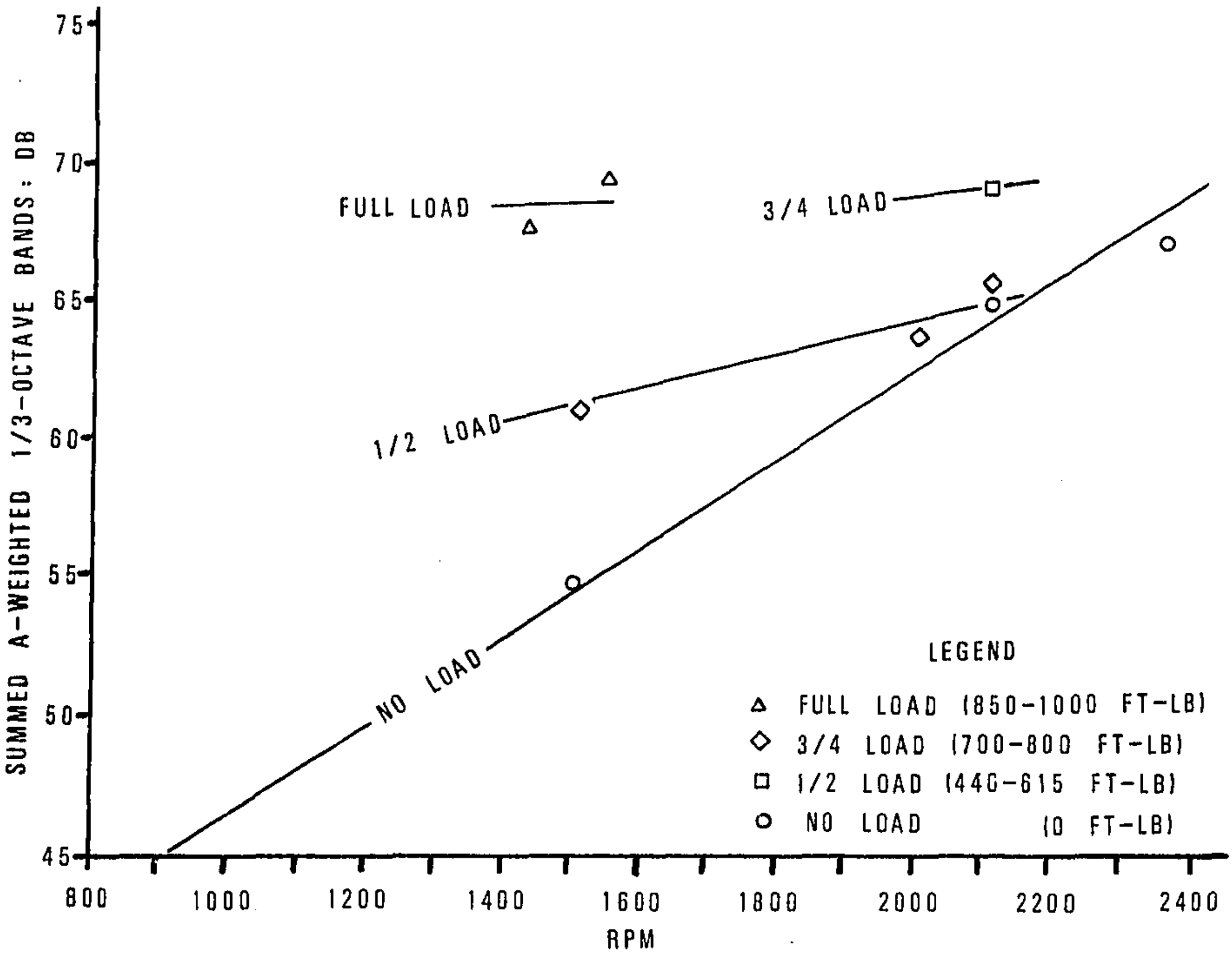


FIGURE 3-33

ARRAY MICROPHONES SUMMED A-WEIGHTED 1/3-OCTAVE BANDS (100-2.5K)

0' FT. POSITION (BUMPER) SOUND LEVEL VS. RPM

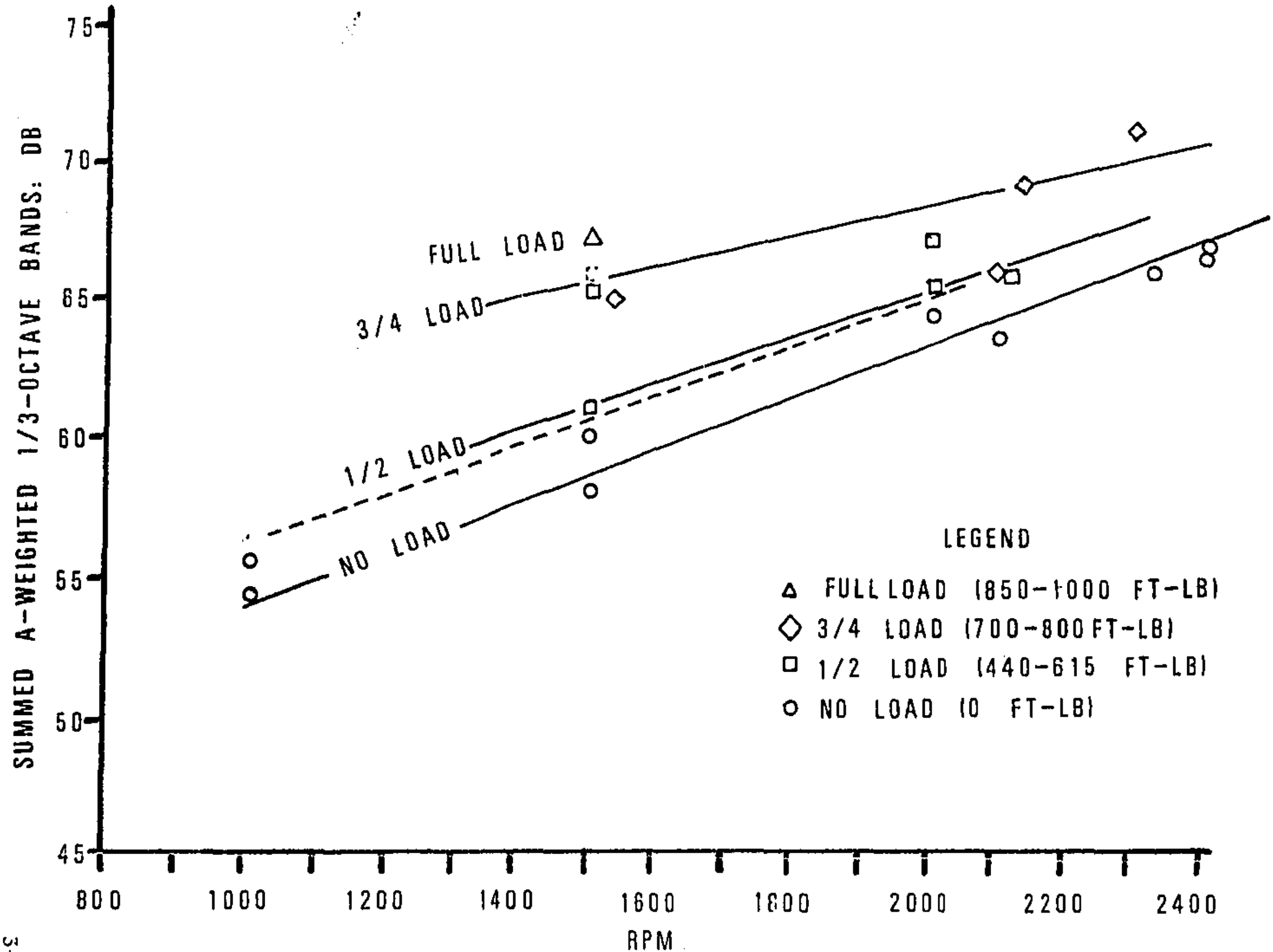


FIGURE 3-34

ARRAY MICROPHONES SUMMED A-WEIGHTED 1/3-OCTAVE BANDS (100-2.5K)
5 FT. POSITION (ENGINE CENTER LINE) SOUND LEVEL VS. RPM

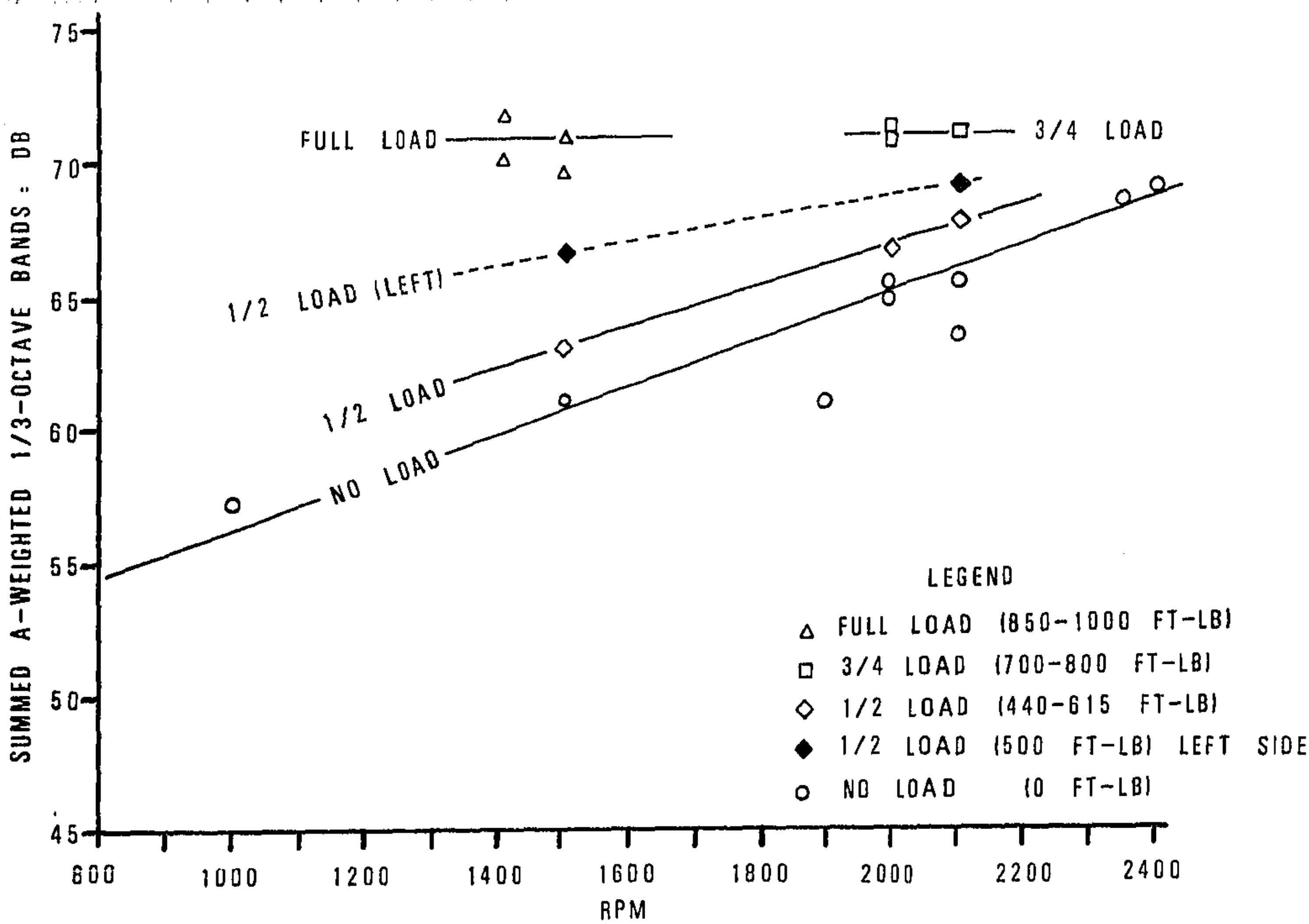


FIGURE 3-35

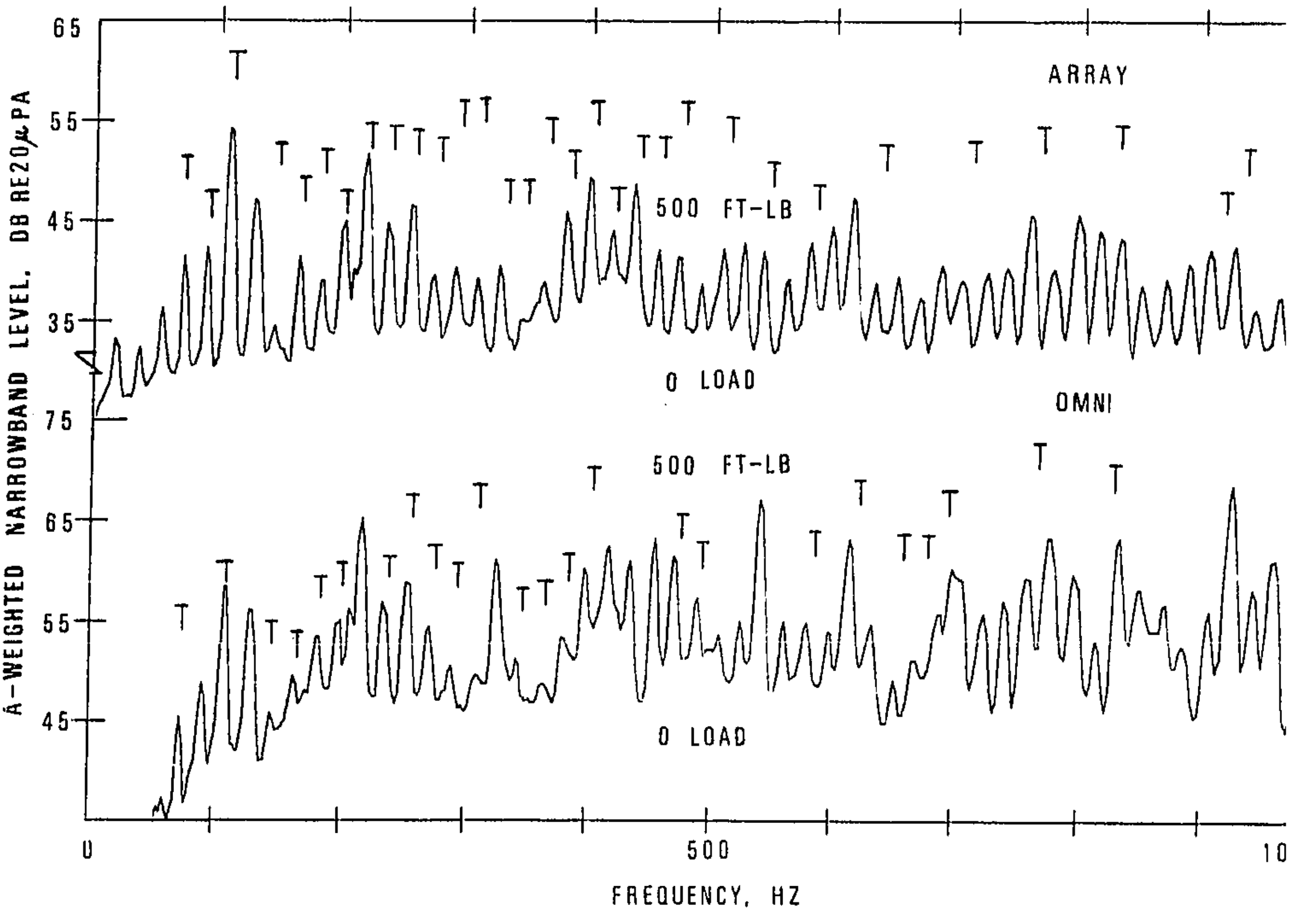
ARRAY MICROPHONES SUMMED A-WEIGHTED 1/3-OCTAVE BANDS (100-2.5K)
8 FT. POSITION (MUFFLERS) SOUND LEVEL VS. RPM

3.6.7 Narrowband Levels

A-weighted narrowband levels were measured with the truck at the +8 Ft position. Omnidirectional and array output levels were measured for no load and 500 ft-lb of load at an engine speed of 2100 RPM. Figure 3-36 shows the results of the narrowband measurement. The upper half of the figure is the array measurement while the lower half of the figure is the omnidirectional microphone measurement. The solid curves represent the no load measurement and the tee marks (T) represent the increase in level for that frequency component at 500 ft-lb of load. The level increase for each line component ranges from 0 dB to 20 dB with an average increase in the vicinity of 8 to 10 dB.

FIGURE 3-36

TRUCK POSITION 8 FT LHS 2100 RPM



4.0 CONCLUSIONS AND RECOMMENDATIONS

This report provides a description of a new approach to truck component noise identification and measurement. The approach consists of a directive array for location/measurement, near field probes for identification and test procedures which can be used in the field to locate, identify and measure truck component noise. A successful application of the approach was demonstrated in a test of one Ford CLT9000 heavy duty truck.

Noise levels for the Ford CLT9000 have been measured at the locations of component sources and for various engine speeds and loads. The following conclusions can be derived from the measured data:

- o The truck radiated noise in the vicinity of four locations/sources. These are at 0 Ft (engine and fan), 5 Ft (back of engine), 8 Ft (exhaust system and transmission), and 11 Ft (dynamometer.)
- o A-Weighted and 1/3-octave band sound levels are an increasing function of engine speed at fixed load and an increasing function of load at fixed engine speed.
- o The data indicate that the dominant source is the exhaust system (8 Ft). In addition, the left side levels at 8 Ft are 1 to 3 dB higher than the right side with no load and 500 ft-lb of load, while at 735 and 895 ft-lb the right side is 1 to 2 dB higher than the left side.

- o At the 0 Ft location (engine and fan), the fan noise dominates when the fan is required to run at high speed to cool the engine. In other instances the fan is running slowly, and engine noise dominates. This conclusion is substantiated by Figure 3-14.
- o Dynamometer noise and/or truck noise transmitted through the dynamometer transfer case contributed to the omnidirectional microphone levels at some engine speeds and loads. However, the array is capable of discriminating against the noise associated with the dynamometer installation.

A set of recommendations are provided in the following:

a. Future tests of the Ford CLT9000 should be accomplished after installation of 1978 model year quiet mufflers, and noise insulation applied to the underside of the engine tunnel.

b. Engine side shields could be designed to prevent engine and fan noise from radiating at the 0 Ft and 5 Ft locations.

c. Future tests with the dynamometer installed should be accomplished after designing a barrier to prevent dynamometer noise from contributing to the far field omnidirectional microphone level. In addition, a set of rubber isolation mounts could be designed to eliminate the sound short from the transfer case to the frame rails.

APPENDIX A

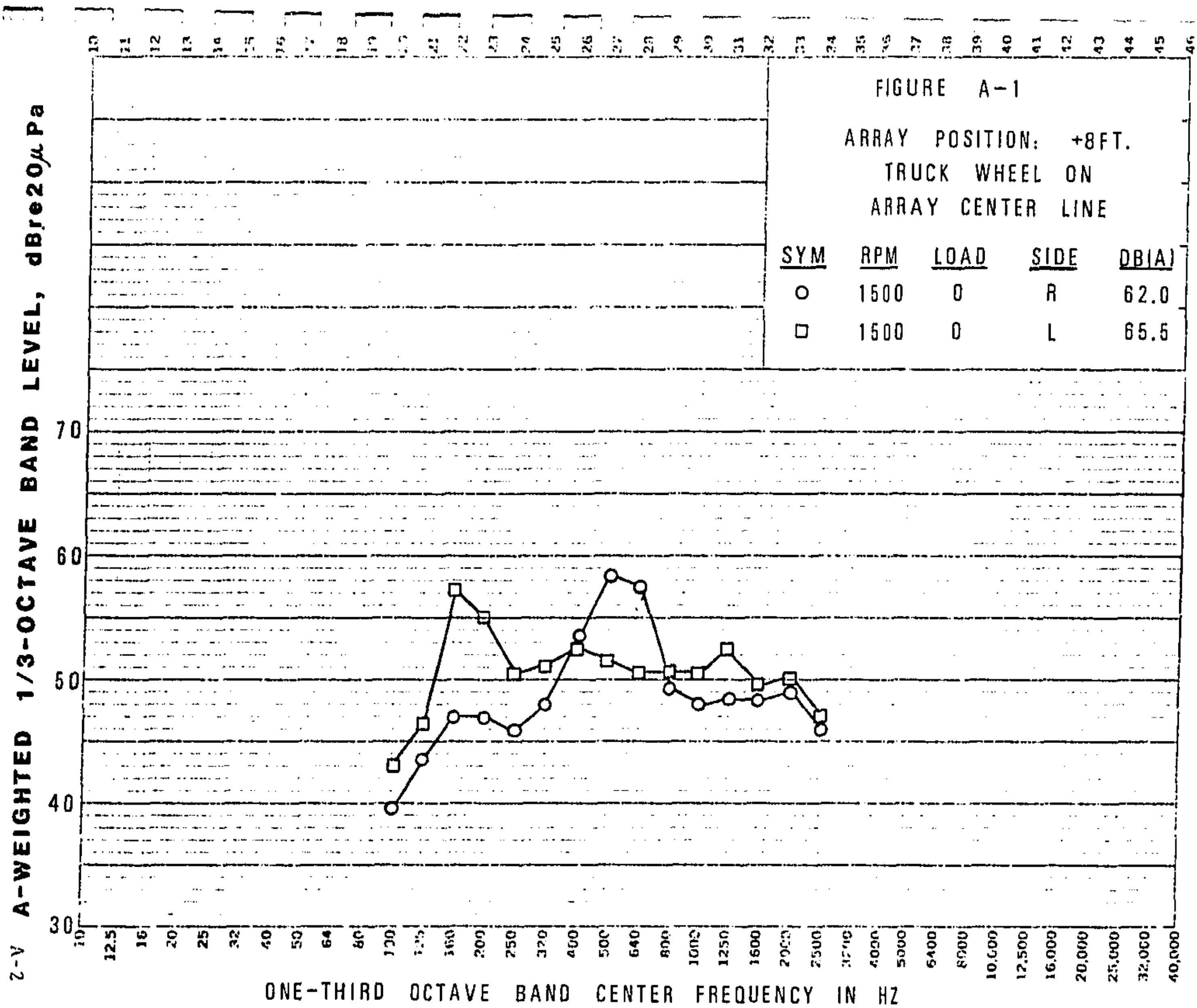


FIGURE A-1
ARRAY POSITION: +8FT.
TRUCK WHEEL ON
ARRAY CENTER LINE
SYM RPM LOAD SIDE DB(A)
○ 1500 0 R 62.0
□ 1500 0 L 65.5
A-WEIGHTED 1/3-OCTAVE BAND LEVEL, dB re 20μPa
ONE-THIRD OCTAVE BAND CENTER FREQUENCY IN HZ

Z-V

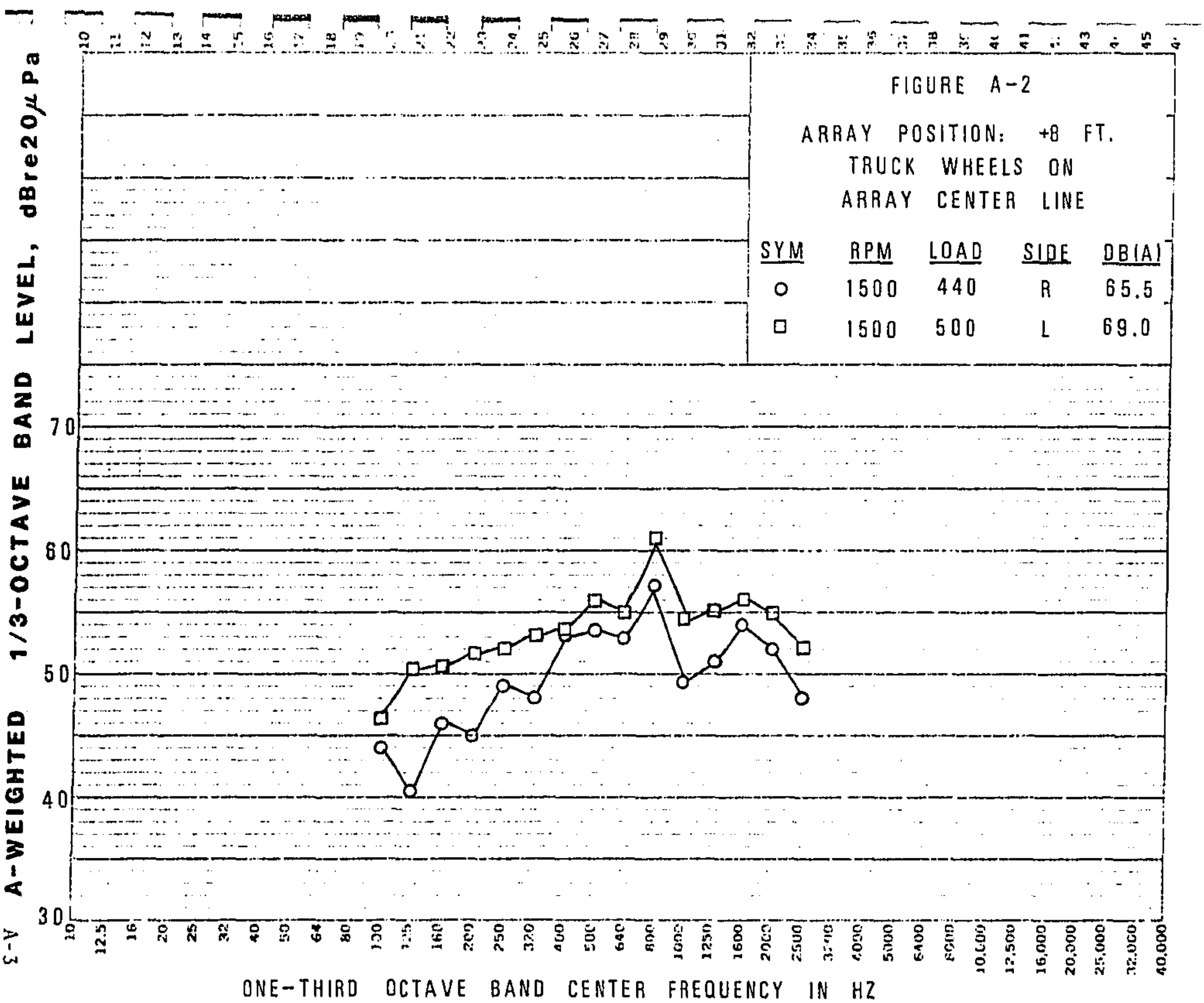


FIGURE A-2
ARRAY POSITION: +8 FT.
TRUCK WHEELS ON
ARRAY CENTER LINE
SYM RPM LOAD SIDE DB(A)
○ 1500 440 R 65.5
□ 1500 500 L 69.0
A-WEIGHTED 1/3-OCTAVE BAND LEVEL, dBre20μPa
70
60
50
40
30
10
12.5
16
20
25
32
40
50
64
80
100
160
200
250
320
400
500
640
800
1250
1600
2000
2500
4000
5000
6400
10,000
12,500
16,000
20,000
25,000
32,000
40,000
ONE-THIRD OCTAVE BAND CENTER FREQUENCY IN HZ

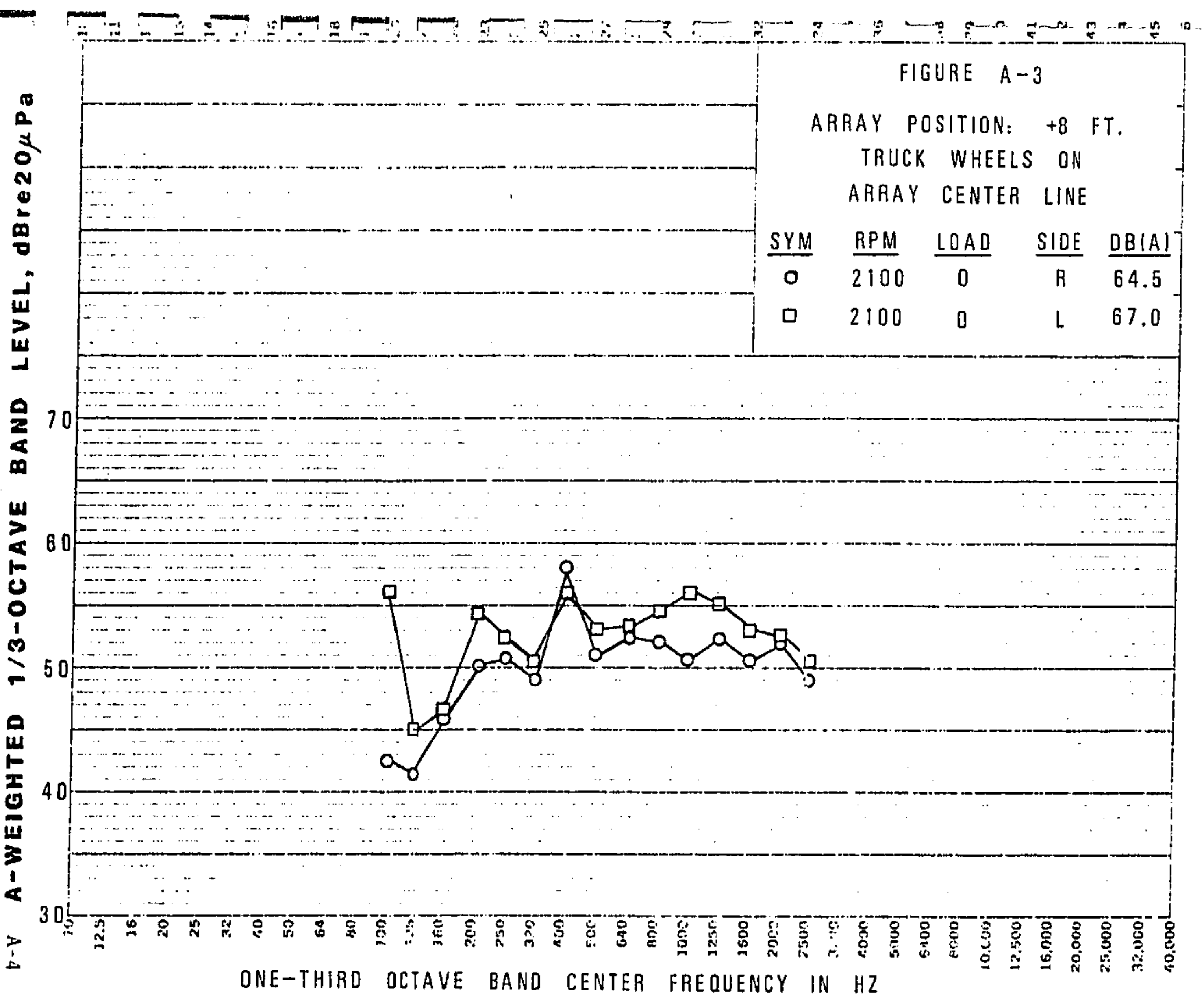


FIGURE A-3
ARRAY POSITION: +8 FT.
TRUCK WHEELS ON
ARRAY CENTER LINE
SYM RPM LOAD SIDE DB(A)
○ 2100 0 R 64.5
□ 2100 0 L 67.0
A-WEIGHTED 1/3-OCTAVE BAND LEVEL, dBre20μPa
70
60
50
40
30
12.5
16
20
25
32
40
50
64
80
160
200
250
400
640
800
1000
1250
1600
2000
2500
4000
5000
6400
8000
10,000
12,500
16,000
20,000
25,000
32,000
40,000
ONE-THIRD OCTAVE BAND CENTER FREQUENCY IN HZ

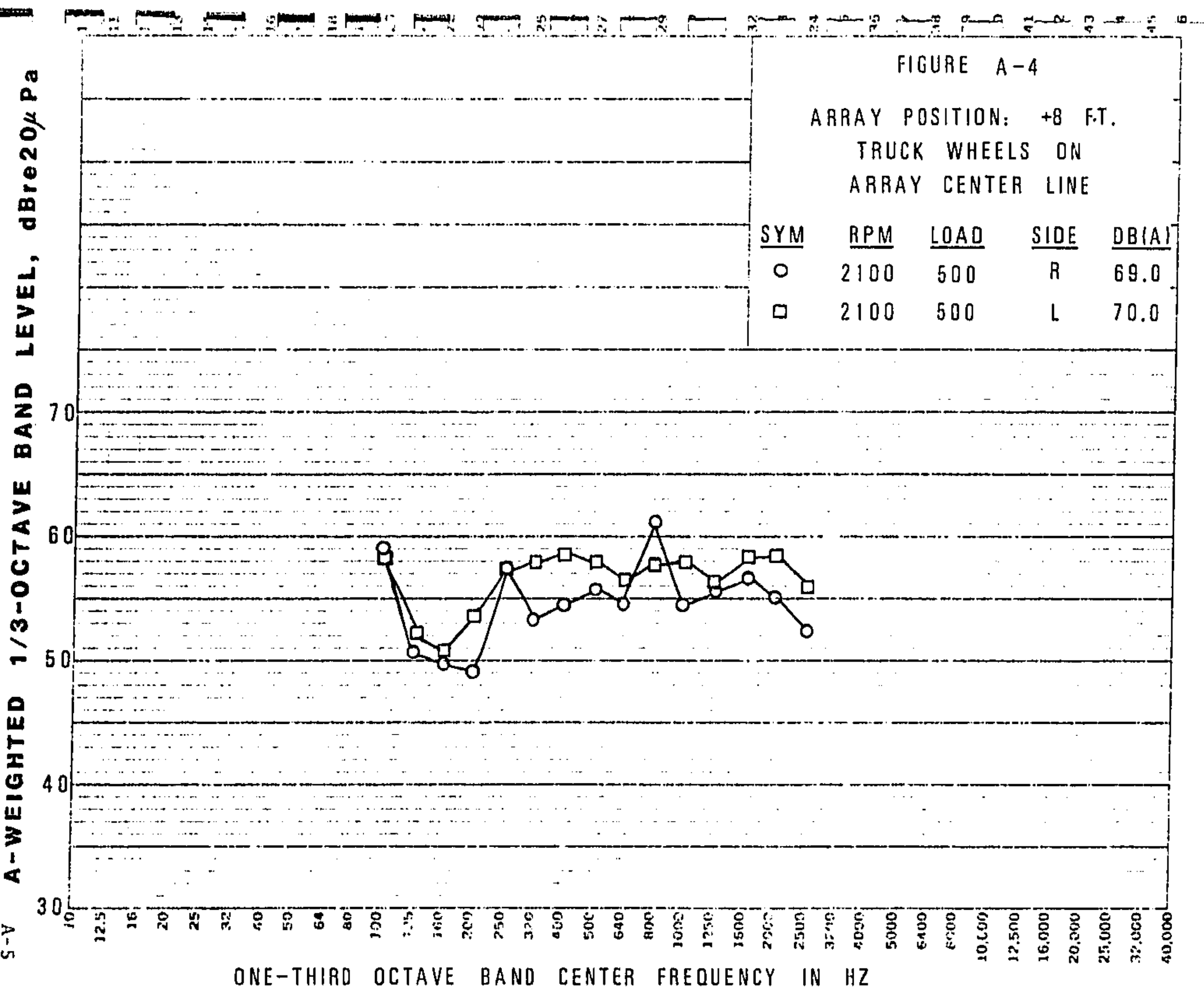

ARRAY POSITION: +8 FT.
TRUCK WHEELS ON
ARRAY CENTER LINE
SYM RPM LOAD SIDE DB(A)
○ 2100 500 R 69.0
□ 2100 500 L 70.0
A-WEIGHTED 1/3-OCTAVE BAND LEVEL, dBre20μPa
ONE-THIRD OCTAVE BAND CENTER FREQUENCY IN HZ

FIGURE A-4

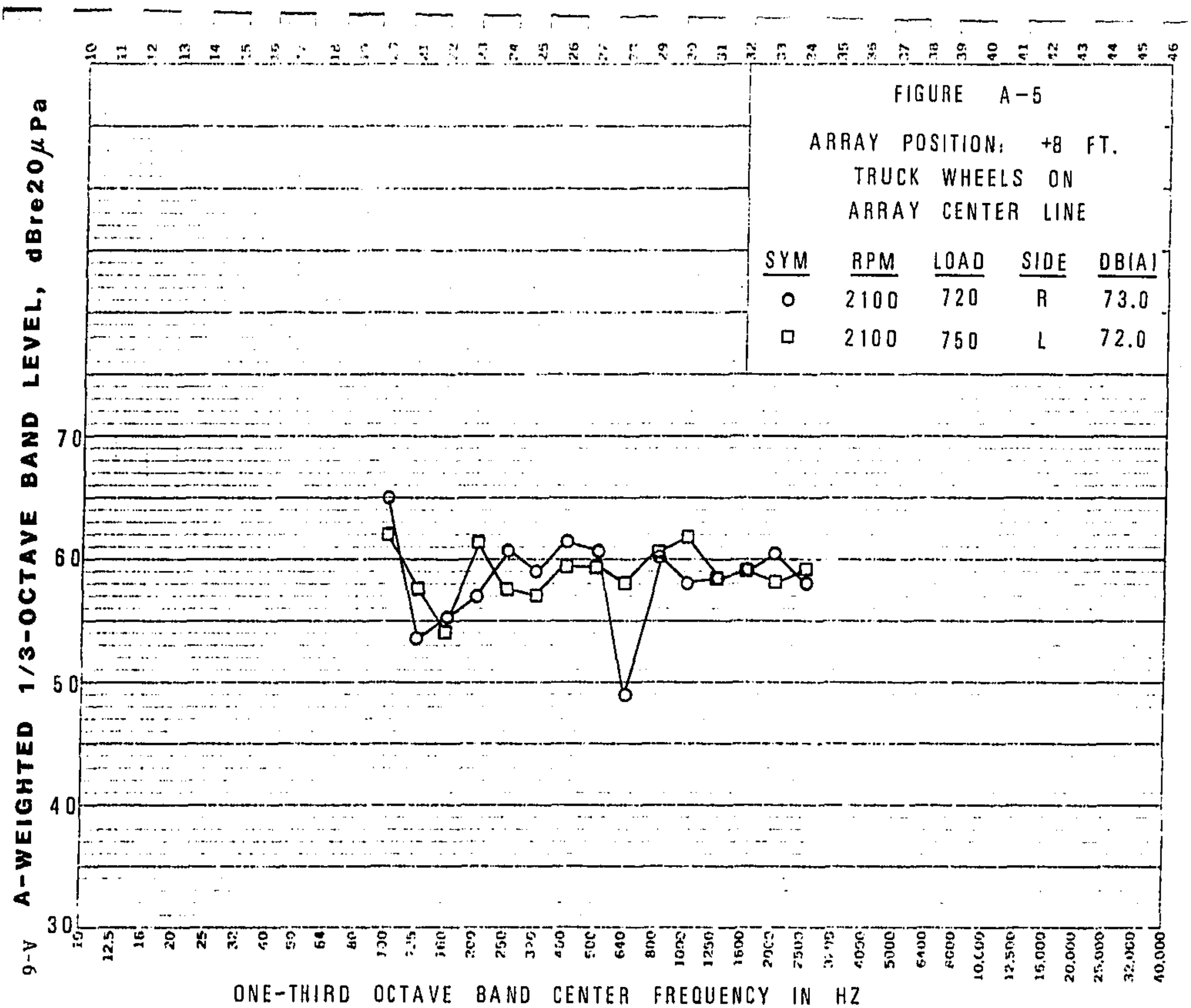


FIGURE A-5
ARRAY POSITION: +8 FT.
TRUCK WHEELS ON
ARRAY CENTER LINE
SYM RPM LOAD SIDE DB(A)
○ 2100 720 R 73.0
□ 2100 750 L 72.0
A-WEIGHTED 1/3-OCTAVE BAND LEVEL, dBre20μPa
ONE-THIRD OCTAVE BAND CENTER FREQUENCY IN HZ

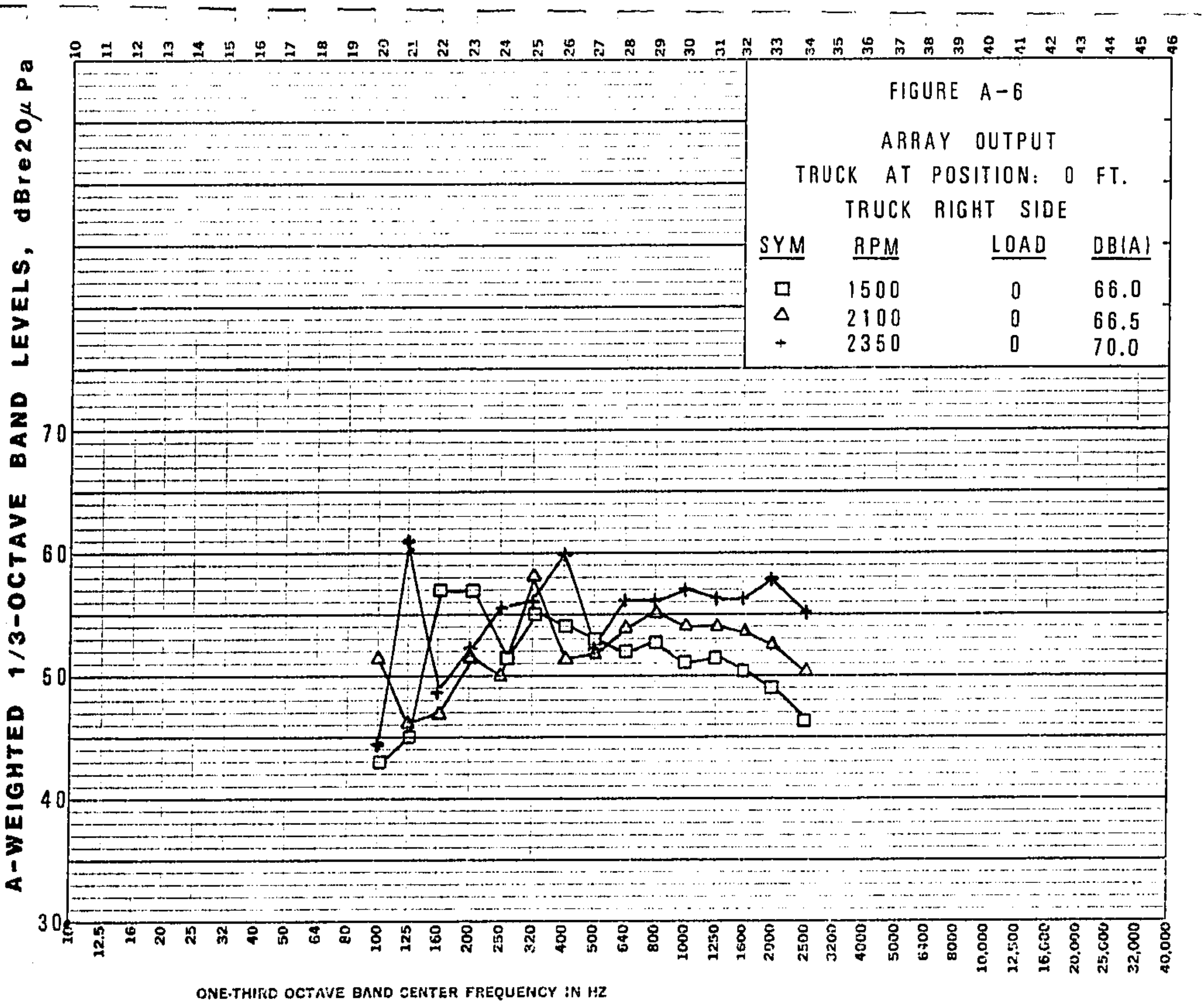


FIGURE A-6
ARRAY OUTPUT
TRUCK AT POSITION: 0 FT.
TRUCK RIGHT SIDE
SYM RPM LOAD DB(A)
□ 1500 0 66.0
Δ 2100 0 66.5
+ 2350 0 70.0
A-WEIGHTED 1/3-OCTAVE BAND LEVELS, dBre20μPa
70
60
50
40
30
10
12.5
16
20
25
32
40
50
64
80
100
125
160
200
250
320
400
500
640
800
1000
1250
1600
2000
2500
3200
4000
5000
6300
8000
10,000
12,500
16,000
20,000
25,000
32,000
40,000
ONE-THIRD OCTAVE BAND CENTER FREQUENCY IN HZ

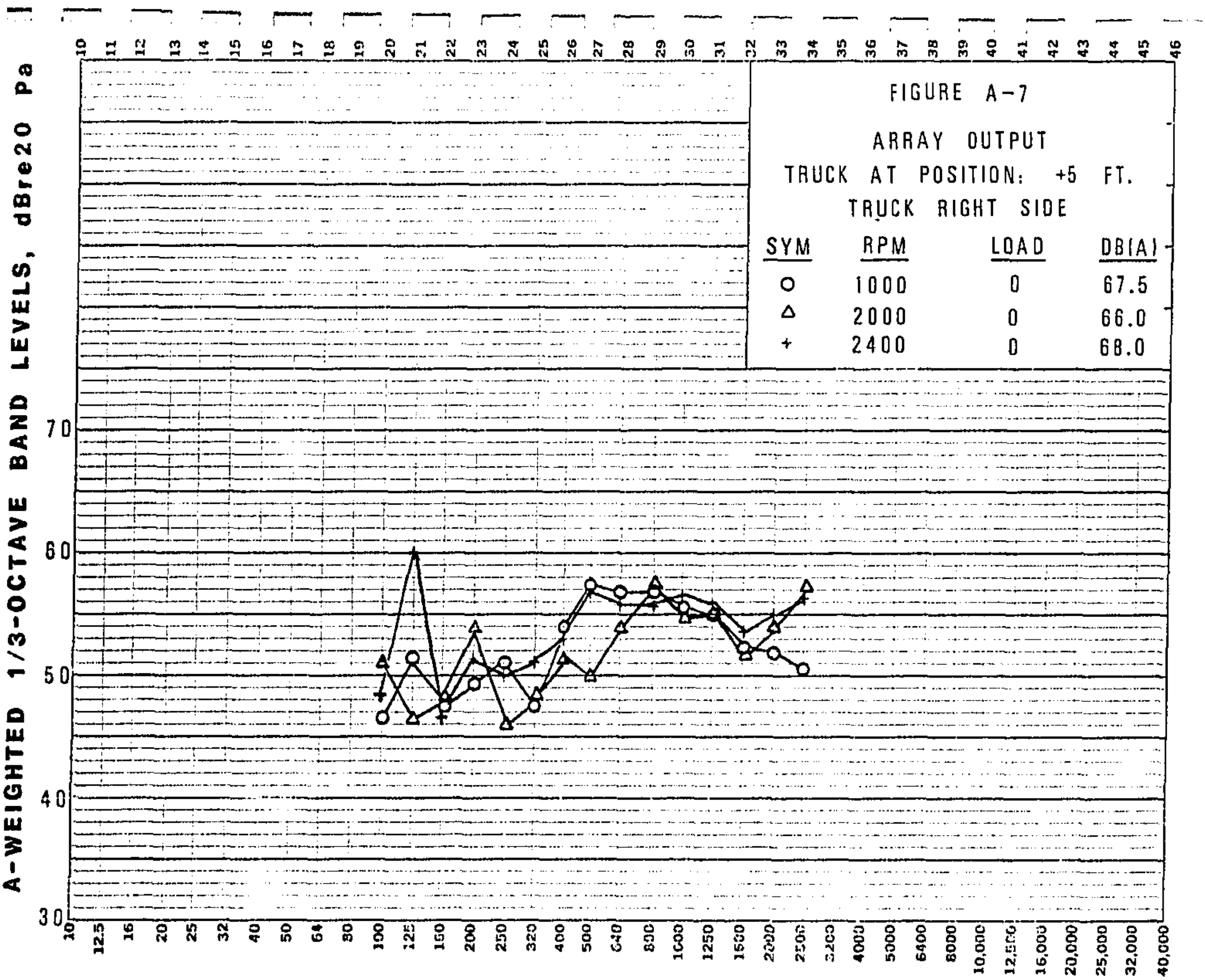


FIGURE A-7
ARRAY OUTPUT
TRUCK AT POSITION: +5 FT.
TRUCK RIGHT SIDE
SYM RPM LOAD DB(A)
○ 1000 0 67.5
△ 2000 0 66.0
+ 2400 0 68.0
A-WEIGHTED 1/3-OCTAVE BAND LEVELS, dBre20 Pa
70
60
50
40
30
10 12.5 16 20 25 32 40 50 64 80 100 125 160 200 250 320 400 500 640 800 1000 1250 1600 2000 2500 3200 4000 5000 6400 8000 10,000 12,500 16,000 20,000 25,000 32,000 40,000
ONE-THIRD OCTAVE BAND CENTER FREQUENCY IN HZ

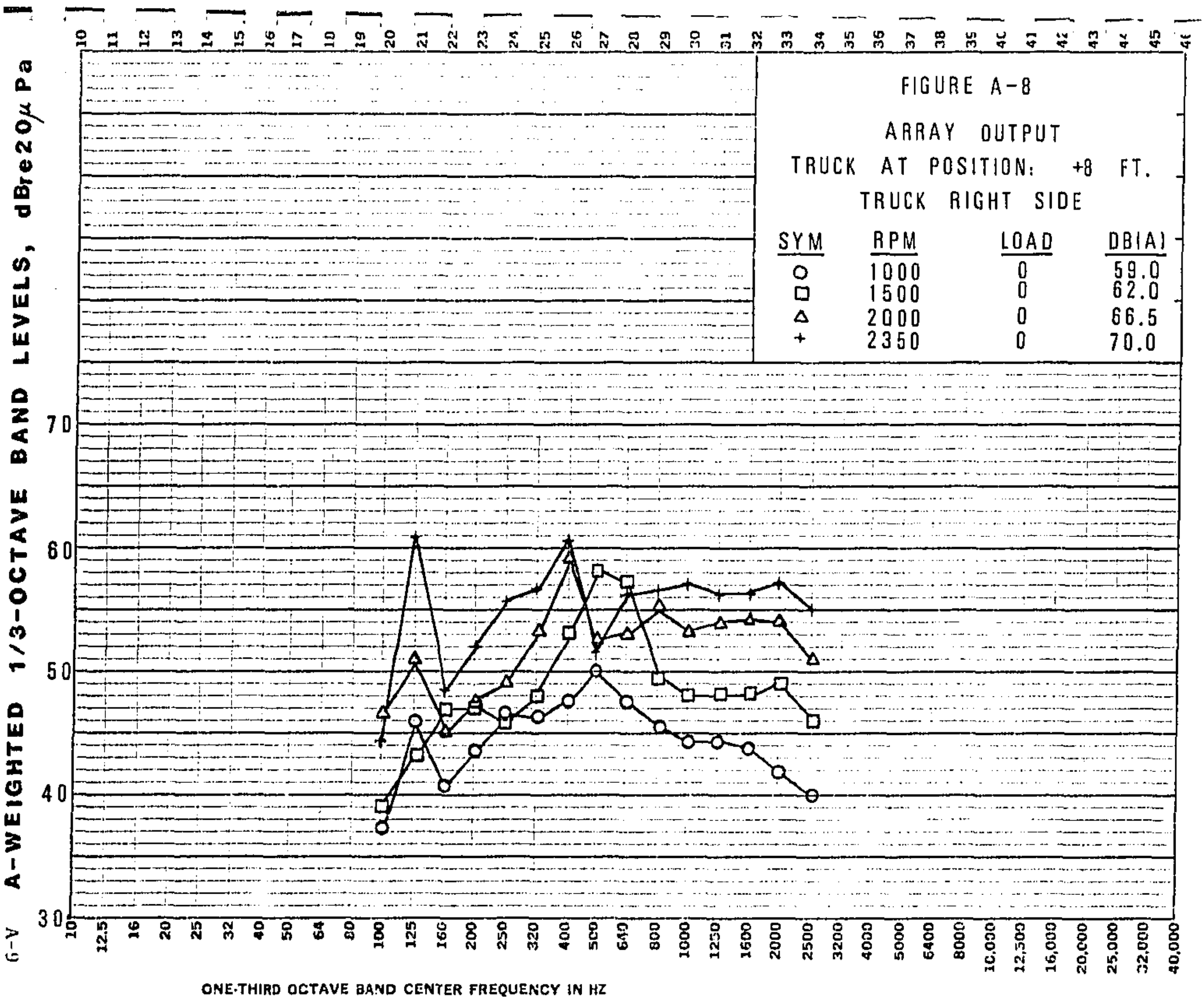


FIGURE A-8
ARRAY OUTPUT
TRUCK AT POSITION: +8 FT.
TRUCK RIGHT SIDE
SYM RPM LOAD DB(A)
○ 1000 0 59.0
□ 1500 0 62.0
△ 2000 0 66.5
+ 2350 0 70.0
A-WEIGHTED 1/3-OCTAVE BAND LEVELS, dB re 20μ Pa
ONE-THIRD OCTAVE BAND CENTER FREQUENCY IN HZ

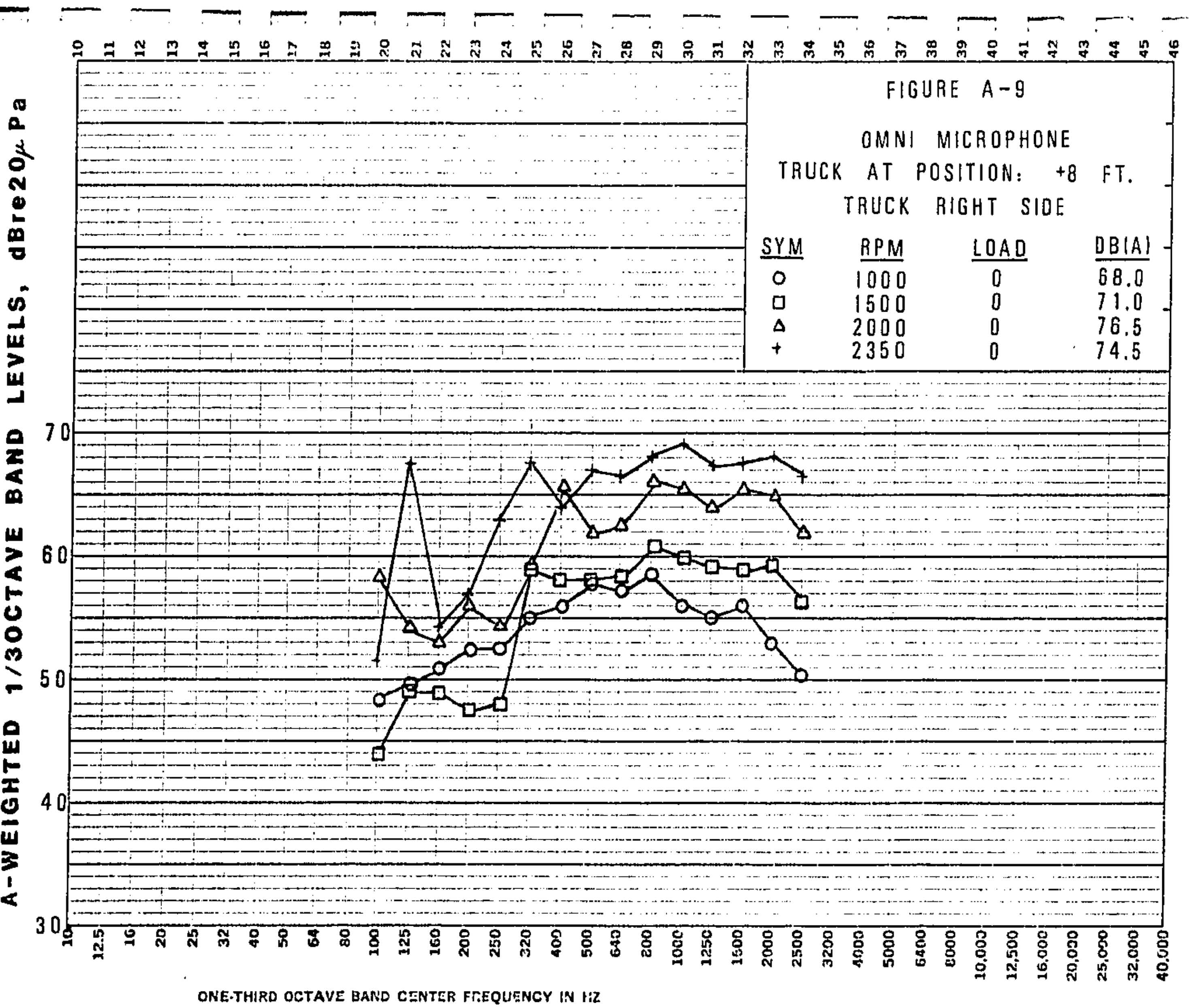


FIGURE A-9
OMNI MICROPHONE
TRUCK AT POSITION: +8 FT.
TRUCK RIGHT SIDE
SYM RPM LOAD DB(A)
○ 1000 0 68.0
□ 1500 0 71.0
Δ 2000 0 76.5
+ 2350 0 74.5
A-WEIGHTED 1/3OCTAVE BAND LEVELS, dBre20μPa
30
40
50
60
70
10 12.5 16 20 25 32 40 50 64 80 100 125 160 200 250 320 400 500 640 800 1000 1250 1500 2000 2500 3200 4000 5000 6400 8000 10,000 12,500 16,000 20,000 25,000 32,000 40,000
10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46
ONE-THIRD OCTAVE BAND CENTER FREQUENCY IN HZ