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National Aeronautics
and Space Administration

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SUMMARY

Fifty-two airplane noise recordings have been analyzed to compare the low-frequency noise levels of the Concorde supersonic transport with those of other commercial jet airplanes operating from Dulles International Airport. The other airplanes were grouped into three categories: two- and three-engine, narrow-body; four-engine, narrow-body; and wide-body airplanes. The recordings were made at several locations around Dulles International Airport and have been categorized as close and distant departures and close and distant arrivals. The comparisons of the low-frequency noise levels were made for three noise measures: the sound pressure level in the 1/3-octave band centered at 20 Hz, the total sound pressure level in the 1/3-octave bands with center frequencies less than or equal to 125 Hz, and the total sound pressure level in the 1/3-octave bands with center frequencies less than or equal to 500 Hz. Although the absolute noise levels for the Concorde were found, in general, to be higher than those for the other airplane types, the level of low-frequency noise of the Concorde relative to the perceived noise level (PNL), effective perceived noise level (EPNL), and overall sound pressure level (OASPL) was within the range established by the other airplane types, except for the arrival operations of four-engine, narrow-body airplanes. The measure OASPL was found to be a significantly better predictor of low-frequency noise level than PNL or EPNL.

INTRODUCTION

Operations of the Concorde supersonic transport have been closely monitored since its introduction into commercial service in the United States to determine the environmental impact on communities adjacent to airports which serve the Concorde. The noise impact and the resulting effects of the noise on community annoyance and complaints and on building vibrations have been studied in detail (refs. 1 and 2). The general approach taken in these studies has been to compare the effects of Concorde with those of other subsonic airplanes. To better understand observed differences, at least two issues must be considered. First, the comparative levels and spectral characteristics must be determined. Second, the effectiveness of various noise measures for incorporating the important level and spectral differences must be determined.

The relative effects of the Concorde noise levels in terms of community response, building response, and subjective annoyance are reported in references 1 to 3. Although the results of these studies do not suggest any unique low-frequency effects, the spectral characteristics of the Concorde have not been previously examined in great detail. Reference 4 does present evidence which indicates that under conventional, stabilized, approach conditions at close locations, the Concorde does produce higher low-frequency noise levels than long-range subsonic airplanes. The purpose of the study reported herein is to compare spectra recorded at various locations in the Dulles area for arrival and departure operations. The method of comparison involves the examination of the spectra by means of the ratio of several measures of low-frequency noise to several measures of total noise.

The tape recordings analyzed in the present study were made during the first week of August 1977. The original purpose of the tapes was to provide a set of Concorde noise recordings to be used as stimuli in a subjective annoyance experiment. Consequently, there were some limitations in the data available for the present study. First, no attempt was made to record a large or representative number of operations for each of the other airplane types; for example, relatively few operations of wide-body airplanes were recorded. Second, an insufficient number of modified, decelerating, arrival operations of the Concorde were recorded for inclusion in the analyses. The recordings of all of the airplane types, however, were of sufficient quality to provide data-base information on the relative low-frequency noise level of the Concorde and of the other types of airplanes for different operations and locations.

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DATA ACQUISITION AND ANALYSIS

Test Sites

Figure 1 shows the locations of the recording sites near Dulles International Airport. Site 1 was located approximately 5.2 km from the brake release point on the center line of runway 19L and approximately 1.8 km from the threshold of runway 1R. Site 2 was located approximately 9.5 km from the brake release point on the center line of runway 19L. Site 3 was located approximately 7.3 km down range from brake release and 1.5 km west of the center line of runway 19L. Sites 2 and 3 were used only for recording departures. The flight paths for such departures typically overflew ground points between sites 2 and 3.

Site 4 was located approximately 2.5 km from the threshold on the center line of runway 19L and approximately 5.9 km from brake release on runway 1R. Site 5 was located approximately 6.4 km from the threshold on the center line of runway 19L and was only used for recording arrivals.

Instrumentation

Two mobile units (fig. 2) were used to obtain all the reported recordings. Each unit was equipped with two condenser microphones coupled directly to preamplifiers. Each microphone was equipped with a 0.10-m-diameter, foam-type windscreen on stands 1.2 m above the ground. The two microphones were placed 3 m to 6 m apart. The gain settings on the two channels of the tape recorders were set 10 dB apart to bracket the anticipated levels of the aircraft noises. Calibration signals were recorded on every reel of recording tape. The frequency response for both channels of each recorder was flat within ±1 dB from 20 Hz to 10 kHz. The recorded aircraft noises were analyzed with the system shown in figure 2. These signals were analyzed by means of a 1/3-octave real-time analysis system. The digitized 1/3-octave band levels for each 1/2 sec of the flyovers were stored on digital magnetic tape. These data were subsequently processed by the computer to provide the required calculated acoustical measures for each flyover.

Acoustical Analysis

The data were processed to provide the following measures of noise:

(1) Time histories of each 1/2-sec increment for the sound pressure level of each 1/3-octave band with center frequencies from 20 Hz (referred to as SPL (20 Hz)) to 10 kHz

(2) Time histories of each of the calculated measures: OASPL, PNL, tone-corrected PNL, SPL of all bands with center frequency less than or equal to 125 Hz (referred to as SPL (≤125 Hz)), and SPL of all bands with center frequency less than or equal to 500 Hz (referred to as SPL (≤500 Hz))

(3) Peak values for each of the measures: OASPL; PNL; tone-corrected PNL; and SPL (20 Hz), SPL (≤125 Hz), and SPL (≤500 Hz)

(4) The calculated index EPNL.

RESULTS AND DISCUSSION

The peak values of the measures OASPL, PNL, SPL (20 Hz), SPL (≤125 Hz), and SPL (≤500 Hz) and the calculated index EPNL for each flyover noise are given in tables I to IV. The airplanes are grouped into four categories: Concorde, two- and three-engine narrow body, four-engine narrow body, and wide body. Table I presents the data for departures recorded at the close locations (sites 1 and 4). Table II presents the data for departures at the distant locations (sites 2 and 3). Table III presents the data for arrivals at sites 1 and 4, and table IV presents the data for arrivals at the distant location (site 5). For the flyovers indicated by the footnotes, the maximum SPL levels occurring in 1/3-octave bands during the flyovers are presented in figures 3 to 6.

Tables I to IV show that for any of the noise measures, in general, the levels recorded for the Concorde were greater than for any of the other airplane types. A closer examination in terms of the relative low-frequency noise level is provided in the following section.

Normalization of Low-Frequency Noise Levels

Because of the difficulties in comparing the spectral data across the various airplane, operation, and distance categories, normalizations of the data were performed to examine the relative low-frequency noise levels. These normalizations were based on three commonly used aircraft noise measures: EPNL,

PNL, and OASPL. The relative noise level in the lowest analyzed 1/3-octave band - with a center frequency of 20 Hz - for each airplane, operation, and distance category is presented in figures 7(a) to 7(d). In these figures, the difference between SPL (20 Hz) and the calculated EPNL from tables I to IV is shown in bar graph form. Each horizontal line represents one or more flyovers. A number to the left of the lines indicates the number of flyovers at that relative noise level. Similarly, the relative noise levels normalized by EPNL for those 1/3-octave bands with center frequencies less than or equal to 125 Hz and less than or equal to 500 Hz are presented in figures 8(a) to 8(d) and figures 9(a) to 9(d), respectively. The relative total level normalized by EPNL is presented in figures 10(a) to 10(d). In the same manner the low-frequency and overall noise level measures normalized by PNL are presented in figures 11(a) to 11(d), 12(a) to 12(d), 13(a) to 13(d), and 14(a) to 14(d). The low-frequency measures normalized by OASPL are presented in figures 15(a) to 15(d), 16(a) to 16(d), and 17(a) to 17(d).

The results of these normalizations are summarized in table V. In this table, the normalized low-frequency noise levels of the Concorde relative to the other airplane types are indicated by plus signs if the Concorde produced greater levels and minus signs if the Concorde produced lower levels. Double plus or minus signs indicate that the mean difference in relative low-frequency noise level between the Concorde and the other airplane types was greater than 5 dB and that the range of levels for each type was mutually exclusive. The single plus or minus indicates that the mean difference was at least 3 dB, with mutually exclusive ranges or that the mean difference was greater than 5 dB with non-mutually-exclusive ranges. Zeroes indicate that none of the previous criteria were met and the relative levels are considered indistinguishable.

From table V it can be seen that only when compared with the four-engine, narrow-body airplanes for arrival operations, does the Concorde appear to produce consistently higher relative low-frequency noise levels. For the close arrival operations, there is a trend for Concorde to produce more relative low-frequency noise levels than the two- and three-engine, narrow-body airplanes when normalized by EPNL. The obvious reason for these differences in normalized spectral content is that the EPNL values for all the narrow-body airplanes are established at close distances for arrival operations by high-frequency tonal components due to fan noise. The tonal components also establish the maximum PNL values for the four-engine, narrow-body airplanes. However, for the distant arrival operations, atmospheric attenuation is sufficient to reduce the fan tones of the two- and three-engine, narrow-body airplanes so that their relative low-frequency noise level is similar to that of the Concorde. For the four-engine, narrow-body airplanes with stronger tonal components, however, atmospheric attenuation is not sufficient to prevent the dominance of the tonal noise on the PNL and EPNL measures.

There is evidence from reference 4 that the absolute levels of the Concorde are reduced by 6 dB to 10 dB by using a decelerating approach procedure. Data are presented in reference 4 which indicate that there are also some relative spectral changes at the close arrival location. Although these changes would not appear to alter the total relative low-frequency noise levels significantly in the SPL bands below 500 Hz or 125 Hz, there may be some increase in the relative noise level in the 20-Hz band.

For the departure operations, the Concorde did not consistently produce higher relative low-frequency noise levels than any of the other airplane types. Although the Concorde was found to produce lower relative low-frequency noise levels than wide-body airplanes at the distant locations, this finding should be considered just a trend for arrival and departure operations because of the very few recordings and analyses that were made for wide-body airplanes.

Correlation Between Noise Measures

Linear-least-squares regression and correlation analyses were performed on the set of measured and calculated noise scales for the 52 flyovers presented in tables I to IV. The purpose of these analyses was to determine the best predictor of the various low-frequency noise measures from the set of those scales normally used to describe airplane noise. The results of these analyses are shown in table VI for each of the measures chosen as the dependent variable for the regression analyses. For each dependent variable, the independent variables are listed in order of decreasing correlation (Pearson product-moment correlation coefficient). For each regression performed, the intercept, slope, standard error of the estimate, and correlation coefficient are given.

For the dependent variable SPL (20 Hz), the best predictor was OASPL followed by SPL ($\leq$500 Hz), SPL ($\leq$125 Hz), PNL, and finally EPNL. Table VII presents the results of t-tests performed to determine the significance of the differences between the correlation coefficients (ref. 5). As indicated, OASPL was a significantly better predictor (probability $p \leq 0.01$) than PNL or EPNL; however, there was no significant difference in the predictive ability of OASPL over SPL ($\leq$500 Hz) or SPL ($\leq$125 Hz). The predictor SPL ($\leq$500 Hz) was significantly better than either PNL ($p \leq 0.05$) or EPNL ($p \leq 0.01$); SPL ($\leq$125 Hz) was a better predictor of SPL (20 Hz) than was EPNL ($p \leq 0.05$).

For the dependent variable SPL ($\leq$125 Hz), the best predictor was SPL ($\leq$500 Hz) followed by OASPL, PNL, and finally EPNL. In this case, SPL ($\leq$500 Hz) was found to be significantly better ($p \leq 0.01$) than OASPL, PNL, or EPNL. Again, OASPL was found to be significantly better ($p \leq 0.01$) than PNL or EPNL.

For the dependent variable SPL ($\leq$500 Hz), OASPL was found to be a significantly better predictor ($p \leq 0.01$) than PNL or EPNL.

CONCLUDING REMARKS

Fifty-two airplane noise recordings have been analyzed to furnish information on low-frequency noise levels of the Concorde supersonic transport compared with other commercial jet airplane types operating from Dulles International Airport. Subject to the relatively small number of data points when the airplane types and the recording locations were categorized, the following conclusions were noted:

1. The absolute noise levels for the Concorde were found, in general, to be higher than those for the other airplane types.

2. The low-frequency noise levels of Concorde relative to the overall sound pressure level (OASPL), perceived noise level (PNL), and effective perceived noise level (EPNL) were in general within the range established by the other airplane types.

3. The only consistent conditions at which the relative low-frequency noise levels of the Concorde were greater than those of another airplane type (four-engine narrow body) were for close and distant arrivals. It should be emphasized, however, that this information was obtained only for the standard or stabilized approach procedure. Data from John E. Wesler (J. Sound & Vib., vol. 12, no. 2, Feb. 1978) indicate that although the absolute levels of Concorde arrival noise would be lower for the decelerating approach procedure, the relative low-frequency noise level would be only slightly changed.

4. The relative low-frequency noise levels of Concorde were generally less than or very nearly equal to those of the wide-body airplanes regardless of the measure of normalization.

5. The measure OASPL was a significantly better predictor of the three low-frequency noise measures than was PNL or EPNL.

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August 18, 1978

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3. Powell, Clemans A.: Judgments of Relative Noisiness of a Supersonic Transport and Several Commercial-Service Aircraft. NASA TN D-8434, 1977.

4. Wesler, John E.: Aircraft Noise and Structural Vibration. J. Sound & Vib., vol. 12, no. 2, Feb. 1978, pp. 24-28.

5. Klugh, Henry E.: Statistics - The Essentials for Research. John Wiley & Sons, Inc., c.1970.

TABLE I.- DEPARTURE NOISE MEASUREMENTS AT CLOSE LOCATIONS

Airplane type	OASPL, dB	PNL, dB	EPNL, dB	SPL (20 Hz), dB	SPL (≤125 Hz), dB	SPL (≤500 Hz), dB
Concorde	[a]119.5	125.7	121.7	100.5	113.8	119.2
	131.1	139.1	131.4	103.0	127.0	130.2
	113.1	120.8	120.1	87.8	109.5	113.1
	116.3	124.8	119.8	89.3	112.0	115.6
Two- and three-engine narrow body	[a]101.8	107.7	109.8	75.8	97.9	101.8
	109.0	112.6	109.5	86.7	109.7	108.9
Four-engine narrow body	104.0	107.3	110.1	77.5	97.9	101.8
	[a]105.8	115.0	114.1	82.3	103.4	106.0
	113.0	120.3	116.6	82.5	111.9	113.1
	110.1	122.7	118.4	88.4	108.5	110.1

[a]Maximum 1/3-octave band sound pressure levels for these flyovers are presented in figure 3.

TABLE II.- DEPARTURE NOISE MEASUREMENTS AT DISTANT LOCATIONS

Airplane type	OASPL, dB	PNL, dB	EPNL, dB	SPL (20 Hz), dB	SPL (≤125 Hz), dB	SPL (≤500 Hz), dB
Concorde	98.5 [a]96.0	99.3 104.3	101.2 103.5	74.8 74.8	97.4 94.2	98.5 95.9
Two- and three-engine narrow body	86.1 [a]84.6	90.9 85.3	91.5 86.9	61.5 64.8	85.5 84.0	86.1 84.6
Four-engine narrow body	87.6 92.6 92.9 [a]96.8 90.5 95.3 87.3 89.8	89.0 96.6 95.8 109.2 102.4 103.7 90.2 98.5	92.6 96.4 97.2 107.0 102.9 103.8 94.2 99.4	61.3 66.0 65.3 74.5 63.5 68.8 63.8 66.5	87.1 92.3 86.8 91.4 83.7 88.0 85.0 87.8	87.6 92.6 92.7 96.8 87.8 84.7 87.3 89.6
Wide body	[a]81.0	81.8	79.3	64.8	78.7	81.0

[a]Maximum 1/3-octave band sound pressure levels for these flyovers are presented in figure 4.

TABLE III.- ARRIVAL NOISE MEASUREMENTS AT CLOSE LOCATIONS

Airplane type	OASPL, dB	PNL, dB	EPNL, dB	SPL (20 Hz), dB	SPL (≤125 Hz), dB	SPL (≤500 Hz), dB
Concorde	102.5	109.1	104.9	77.5	94.8	102.1
	[a]112.0	118.9	113.2	86.5	105.6	110.9
	112.8	119.5	115.1	85.5	107.4	111.5
Two- and three-engine narrow body	[a]96.5	107.3	103.4	70.8	87.6	92.5
	97.8	104.7	101.7	75.8	92.4	45.4
	95.5	107.8	104.5	67.8	85.9	91.4
	95.5	107.7	103.7	68.0	87.4	92.0
	92.3	105.2	102.0	64.3	83.4	88.7
	96.3	104.4	102.3	73.3	91.1	95.8
Four-engine narrow body	102.3	116.1	114.1	74.5	90.1	92.8
	[a]103.8	117.9	115.1	75.5	90.5	93.5
	103.5	117.6	115.1	76.3	89.8	93.0
	104.8	118.2	115.6	74.3	89.2	93.0
Wide body	[a]94.3	102.5	99.3	73.8	89.0	93.3

[a]Maximum 1/3-octave band sound pressure levels for these flyovers are presented in figure 5.

TABLE IV.- ARRIVAL NOISE MEASUREMENTS AT DISTANT LOCATIONS

Airplane type	OASPL, dB	PNL, dB	EPNL, dB	SPL (20 Hz), dB	SPL (≤125 Hz), dB	SPL (≤500 Hz), dB
Concorde	[a]99.0	105.6	104.2	71.8	92.8	98.4
	99.0	105.6	104.5	71.8	89.7	98.7
Two- and three-engine narrow body	84.6	85.3	86.9	61.8	84.0	84.6
	85.0	93.3	97.0	65.5	80.6	84.6
	[a]86.0	92.7	94.9	65.5	78.6	81.0
	84.5	93.4	96.2	65.8	80.8	84.4
	80.5	87.2	86.8	62.8	74.0	79.4
	81.8	87.4	87.8	65.3	77.5	81.6
	85.3	95.9	94.6	65.7	77.5	84.8
Four-engine narrow body	83.8	95.5	96.3	63.2	76.3	79.8
	[a]88.8	101.3	101.6	67.3	80.0	81.3
	91.0	101.7	102.1	64.0	78.4	82.2
	89.5	101.6	100.9	69.3	78.9	82.9
Wide body	85.0	91.5	91.5	69.8	81.8	84.4
	[a]84.8	90.7	89.9	66.7	80.2	84.3

[a]Maximum 1/3-octave band sound pressure levels for these flyovers are presented in figure 6.

TABLE V.- SUMMARY OF COMPARISONS OF RELATIVE LOW-FREQUENCY NOISE LEVELS OF CONCORDE WITH OTHER AIRPLANES[a]

Low-frequency measure	Normalization measure	Close locations: Two- and three-engine narrow body	Close locations: Four-engine narrow body	Close locations: Wide body	Distant locations: Two- and three-engine narrow body	Distant locations: Four-engine narrow body	Distant locations: Wide body
Arrival operations							
SPL (20 Hz)	OASPL	0	0	- -	- -	-	- -
	PNL	0	+ +	-	- -	0	- -
	EPNL	+	+ +	0	- -	0	- -
SPL (≤125 Hz)	OASPL	0	+ +	0	0	0	-
	PNL	0	+ +	0	0	+ +	-
	EPNL	+	+ +	0	0	+ +	-
SPL (≤500 Hz)	OASPL	0	+ +	0	0	+ +	0
	PNL	+	+ +	0	0	+ +	0
	EPNL	+ +	+ +	+	0	+ +	0
Departure operations							
SPL (20 Hz)	OASPL	0	0		0	0	- -
	PNL	0	0		0	+	- -
	EPNL	0	0		0	+	- -
SPL (≤125 Hz)	OASPL	0	0		0	0	0
	PNL	- -	0		0	0	0
	EPNL	0	0		0	+	- -
SPL (≤500 Hz)	OASPL	0	0		0	0	0
	PNL	-	0		0	0	0
	EPNL	0	0		0	0	-

[a]Notations used

+ + mean of Concorde noise level at least 5 dB greater than the mean of other airplane noise level, range of levels mutually exclusive

+ mean of Concorde noise level at least 3 dB greater than mean of other airplane noise level, range of levels mutually exclusive; or, mean of Concorde noise level at least 5 dB greater than mean of other airplane noise level, range of levels non-mutually-exclusive

- - mean of Concorde noise level at least 5 dB less than the mean of other airplane noise level, range of levels mutually exclusive

- mean of Concorde noise level at least 3 dB less than mean of other airplane noise level, range of levels mutually exclusive, or, mean of Concorde noise level at least 5 dB less than mean of other airplane noise level, range of levels non-mutually-exclusive

0 none of the previous criteria apply and relative levels considered indistinguishable

TABLE VI.- RESULTS OF REGRESSION ANALYSES FOR PREDICTION OF LOW-FREQUENCY NOISE LEVELS

Dependent variable	Independent variable	Intercept	Slope	Standard error of estimate	Correlation coefficient
SPL (20 Hz)	OASPL	-6.69	0.822	3.28	0.943
	SPL (≤500 Hz)	-1.79	.790	3.36	.941
	SPL (≤125 Hz)	1.66	.781	3.66	.929
	PNL	.24	.694	4.65	.883
	EPNL	-8.82	.789	5.00	.863
SPL (≤125 Hz)	SPL (≤500 Hz)	-1.59	0.981	2.17	0.983
	OASPL	-3.59	.979	3.85	.893
	PNL	9.86	.777	6.54	.831
	EPNL	-1.91	.899	6.61	.827
SPL (≤500 Hz)	OASPL	-1.51	0.992	3.34	0.956
	PNL	10.58	.802	6.07	.856
	EPNL	-.70	.919	6.30	.844
OASPL	PNL	6.73	0.861	3.41	0.953
	EPNL	-5.82	.991	3.73	.944
PNL	EPNL	-14.01	1.146	2.13	0.986

TABLE VII.- t-TESTS FOR SIGNIFICANT DIFFERENCES

IN CORRELATION COEFFICIENTS

Dependent variable	Independent variable	t-values for comparison independent variable -				
		OASPL	SPL (≤500 Hz)	SPL (≤125 Hz)	PNL	EPNL
SPL (20 Hz)	OASPL		NS0.16	NS0.78	**4.17	**5.19
	SPL (≤500 Hz)			1.35	*2.49	**3.63
	SPL (≤125 Hz)				NS1.78	*2.38
	PNL					NS1.79
SPL (≤125 Hz)	SPL (≤500 Hz)	**23.28			**10.86	**39.14
	OASPL				**3.17	**3.09
	PNL					NS.30
SPL (≤500 Hz)	OASPL				**9.91	**10.02
	PNL					NS.97
OASPL	PNL					NS1.25

NSNot significant.
*Significant at $p \leq 0.05$.
**Significant at $p \leq 0.01$.

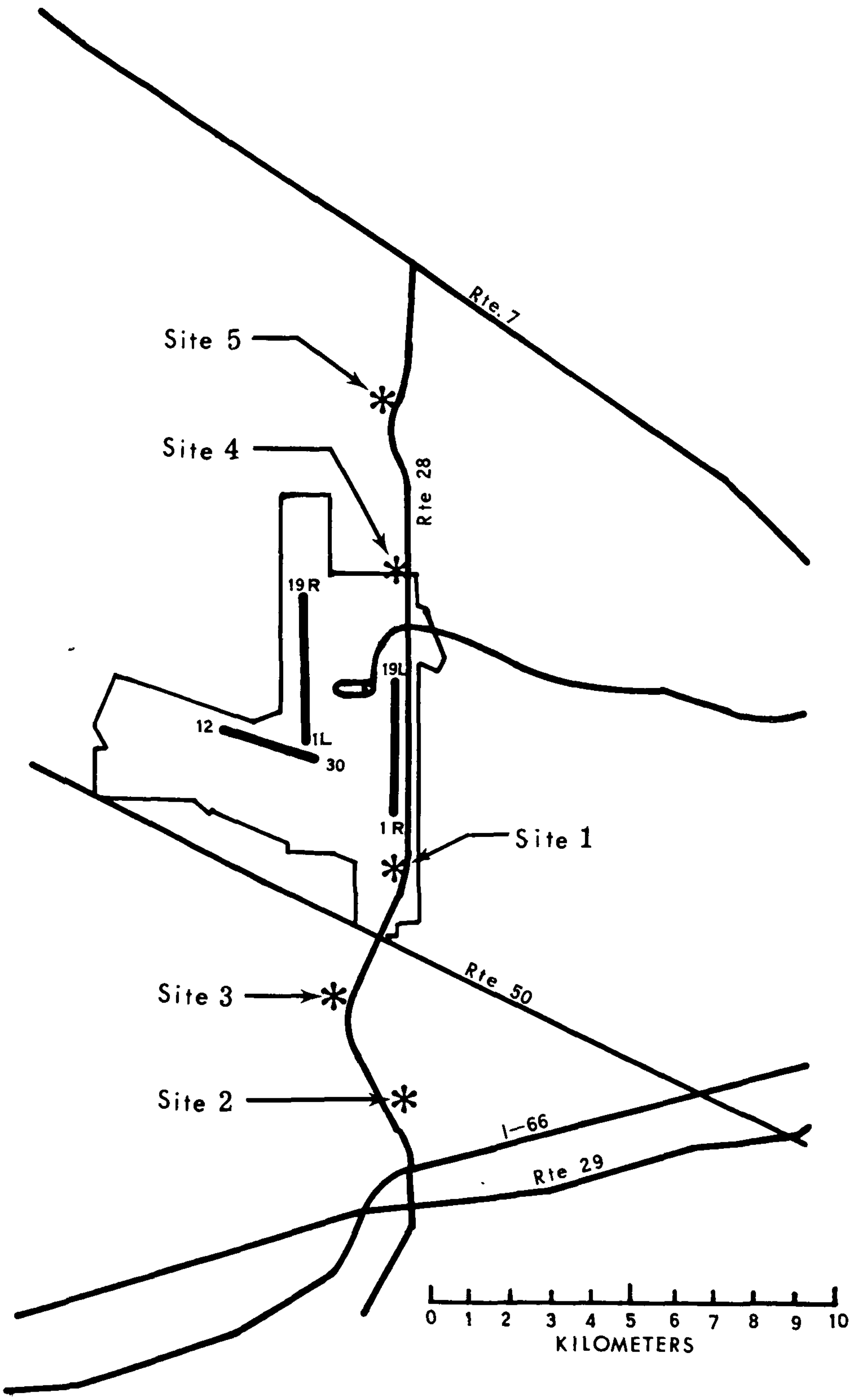


Figure 1.- Map of Dulles International Airport area showing locations of recording sites.

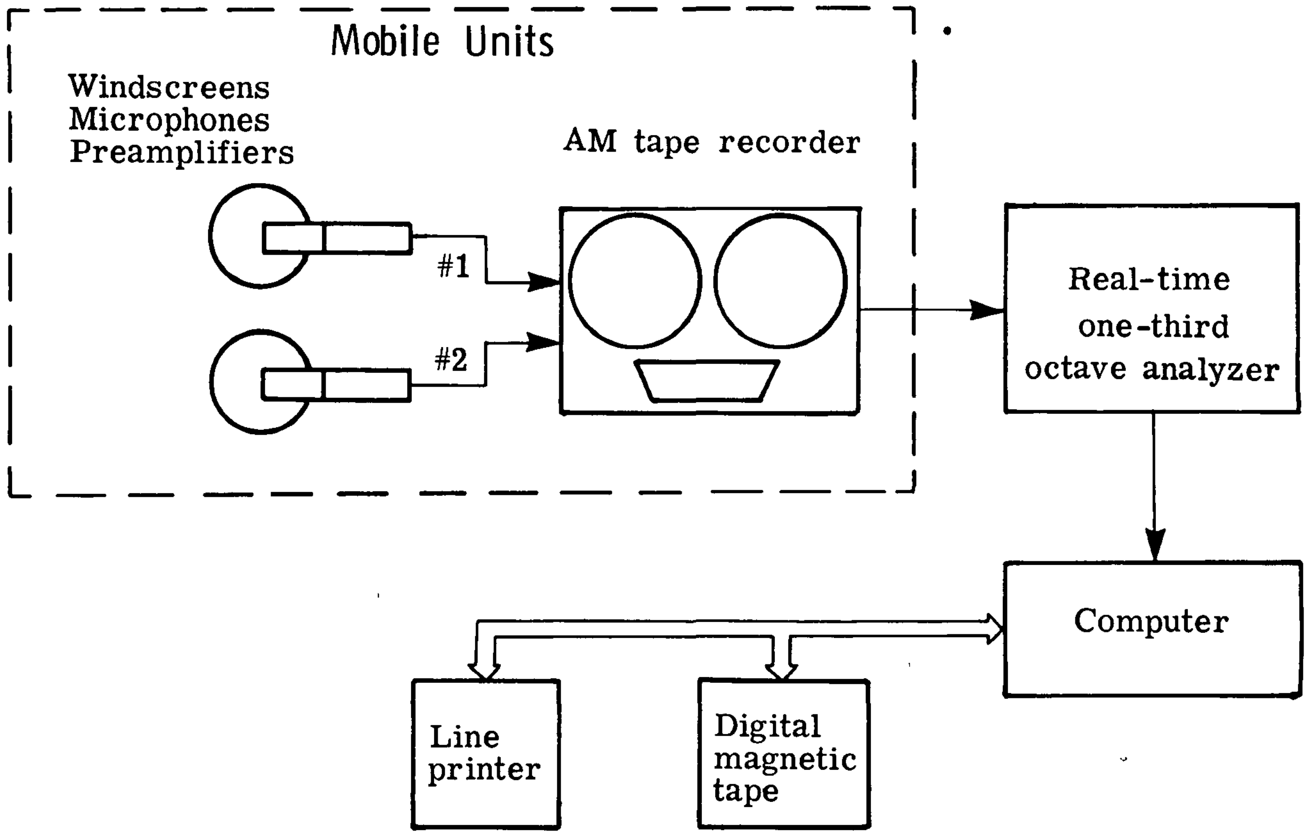
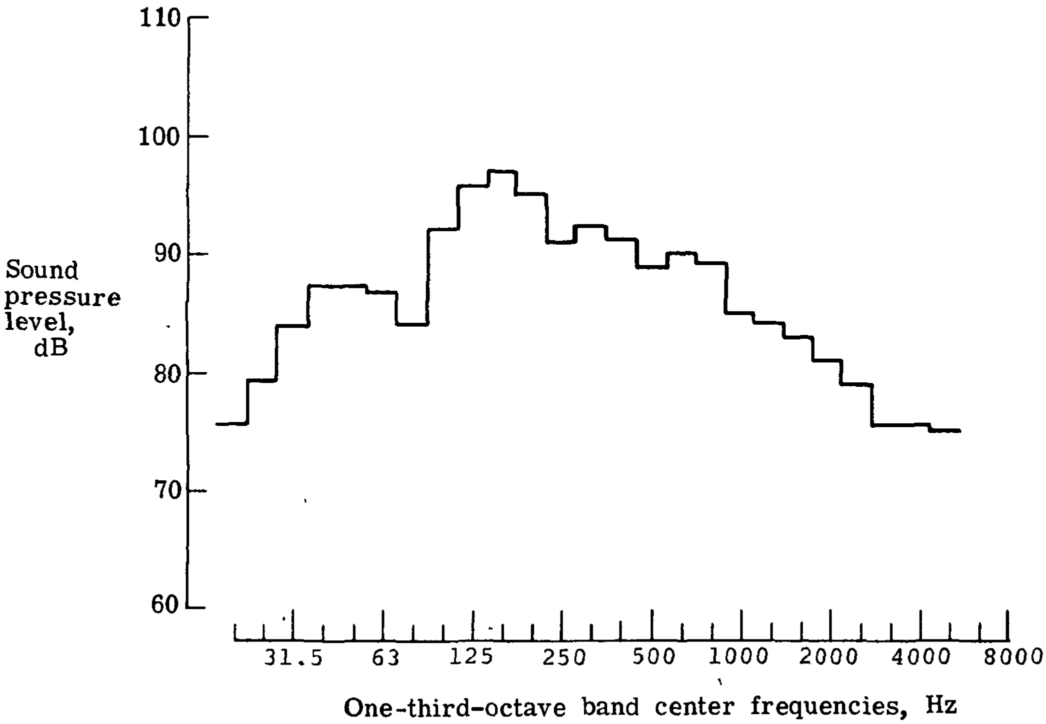


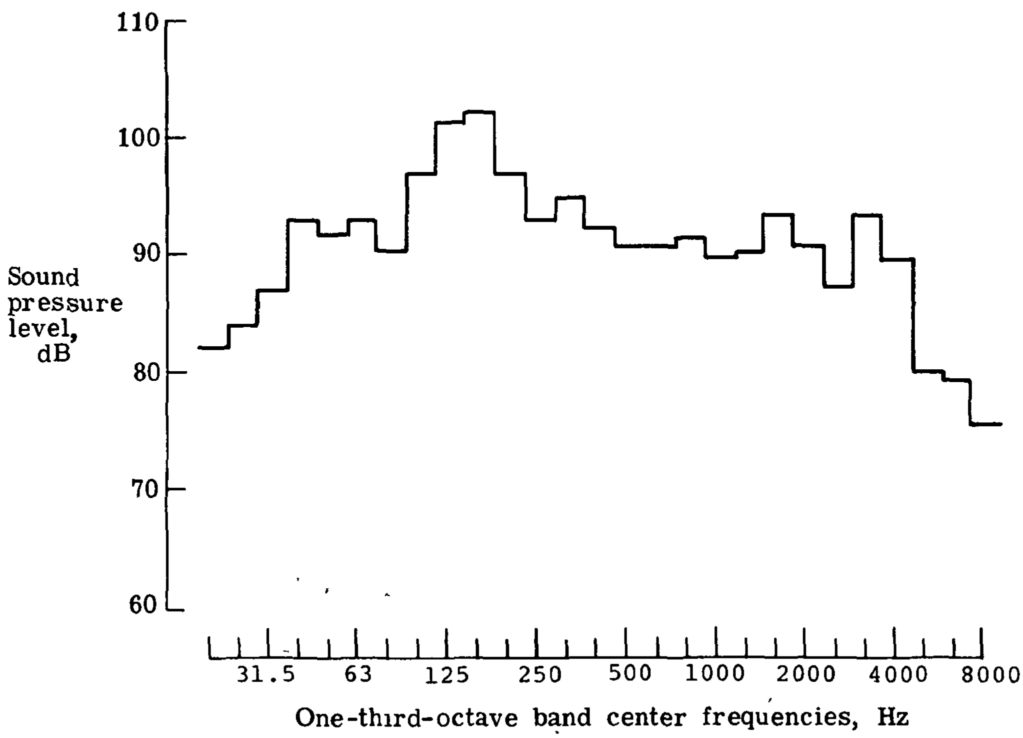
Figure 2.- Diagram of recording and analysis systems.

(a) Concorde.

Figure 3.- Maximum 1/3-octave band sound pressure levels for close departures.

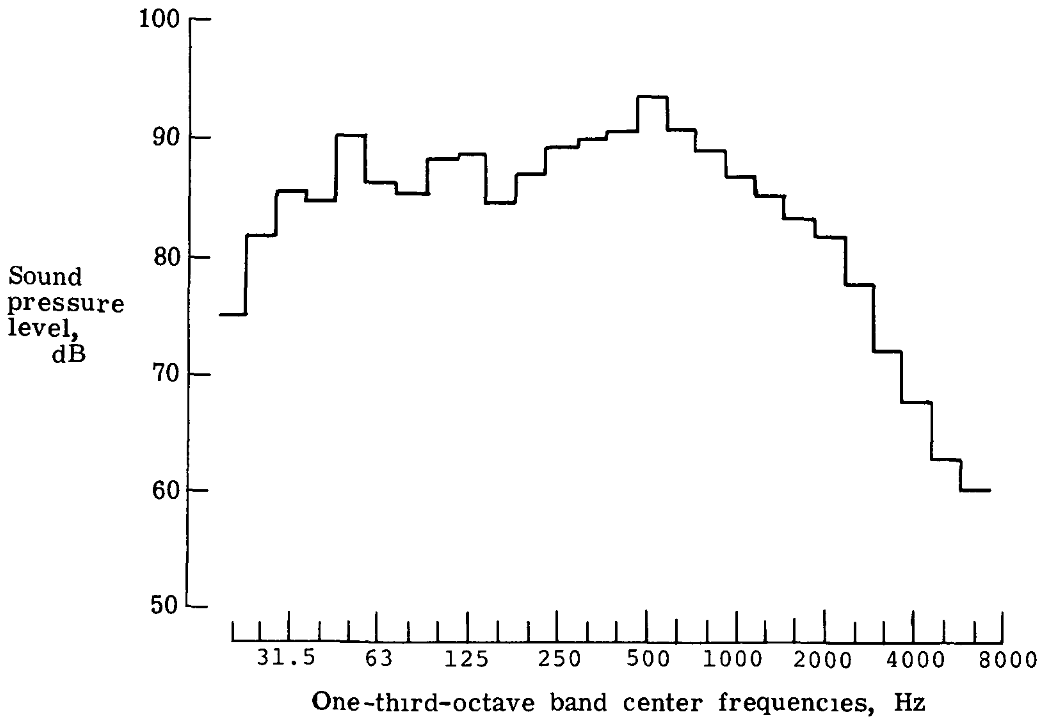


(b) B-727.



(c) B-707.

Figure 3.- Concluded.

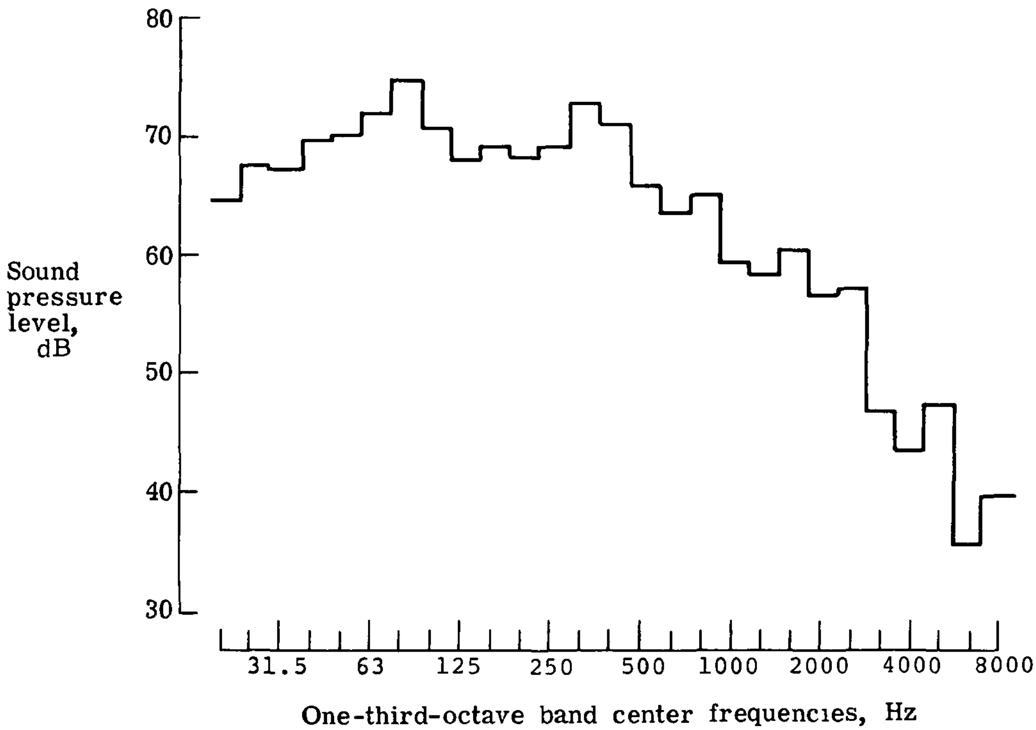


(a) Concorde.

(b) B-727.

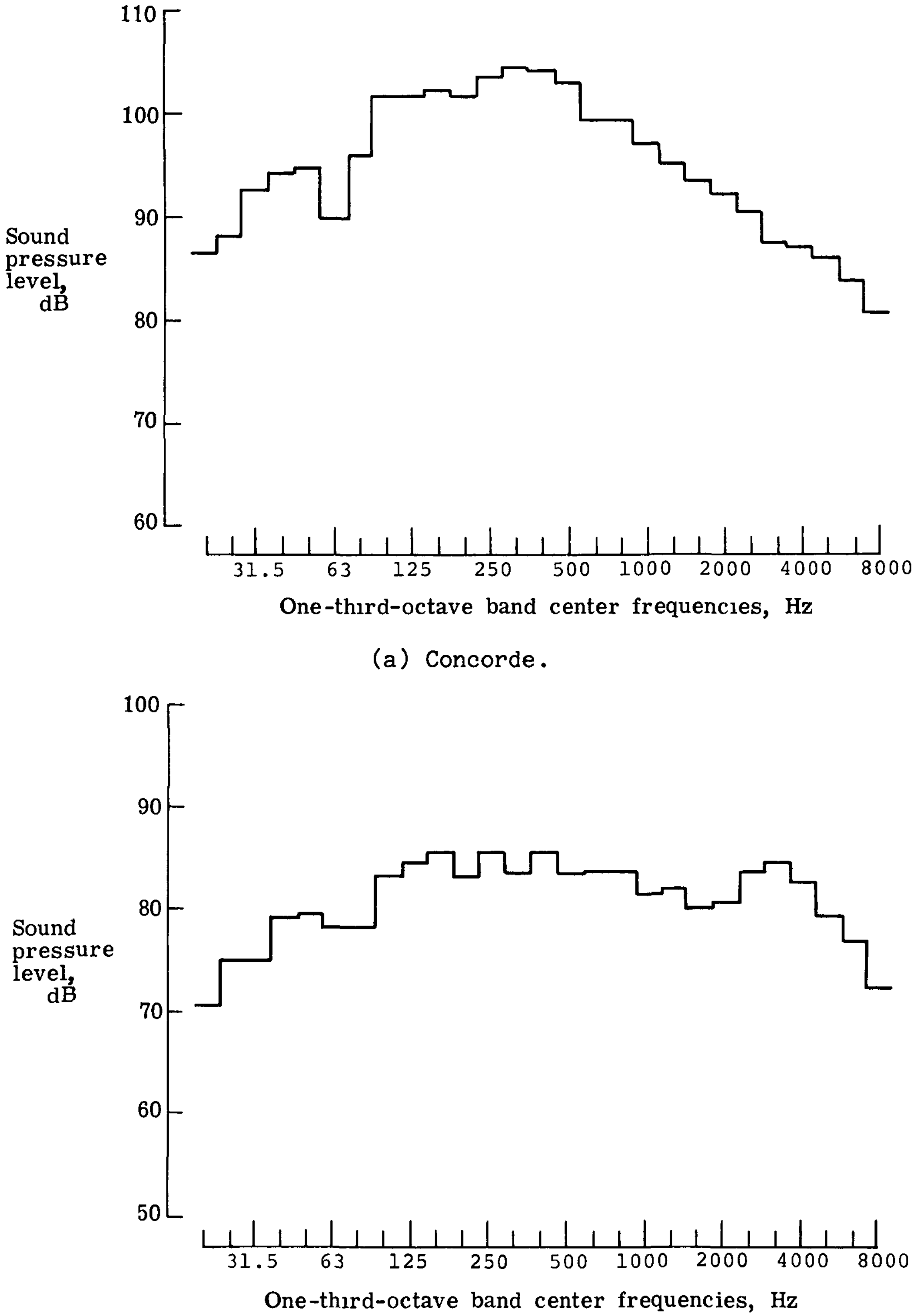
Figure 4.- Maximum 1/3-octave band sound pressure levels for distant departures.

(c) B-707.



(d) DC-10.

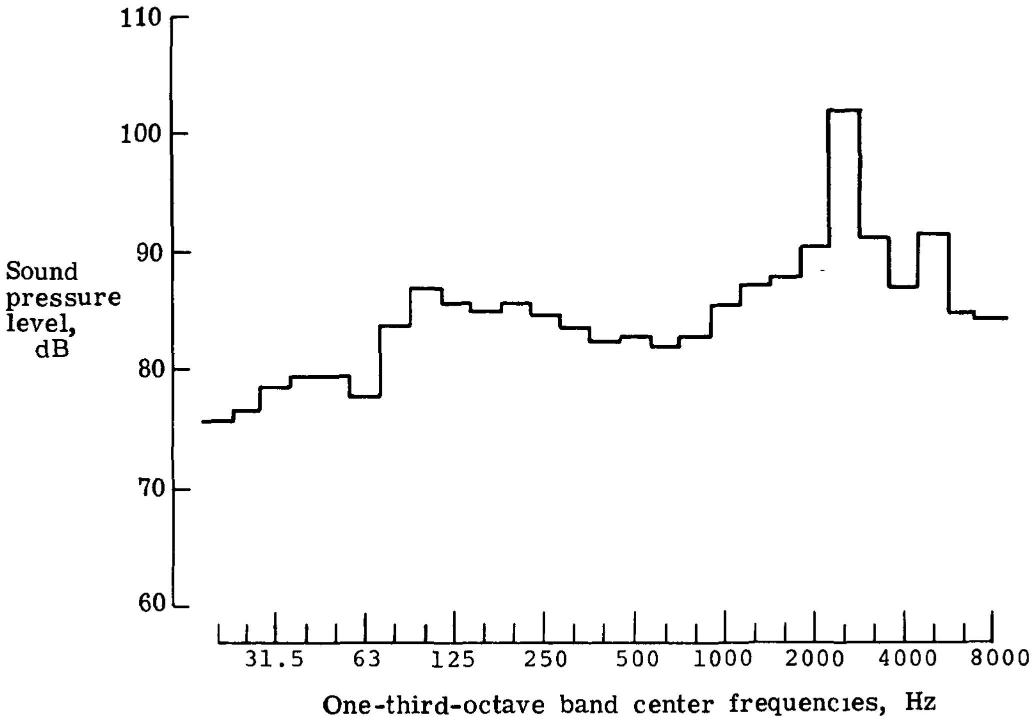
Figure 4.- Concluded.



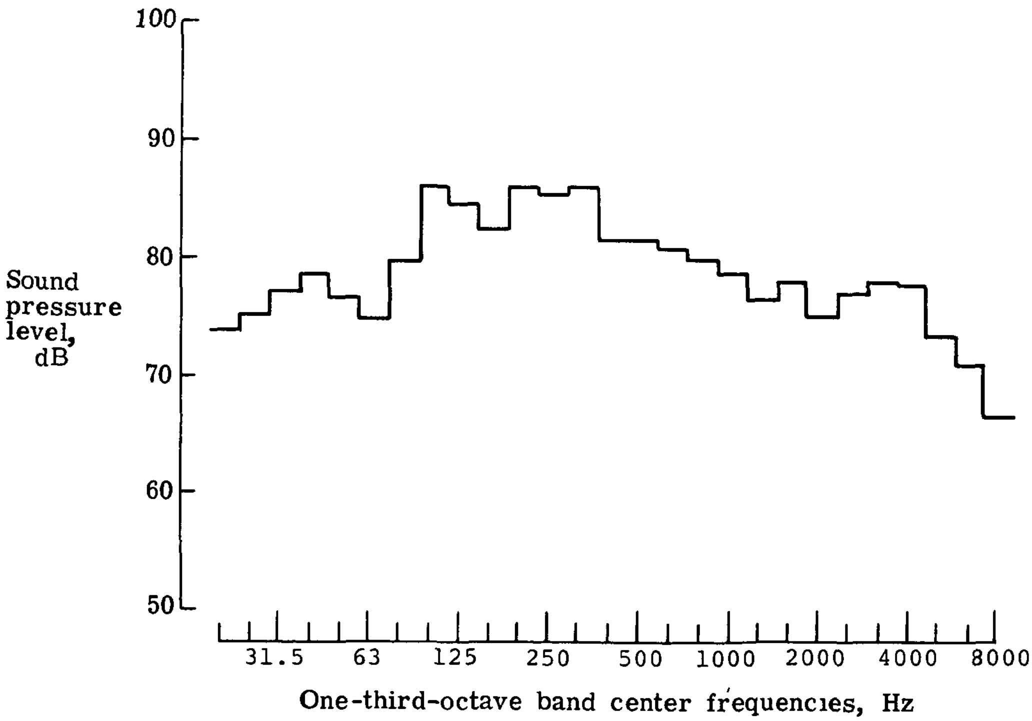
(a) Concorde.

(b) B-727.

Figure 5.- Maximum 1/3-octave band sound pressure levels for close arrivals.



(c) B-707.



(d) DC-10.

Figure 5.- Concluded.

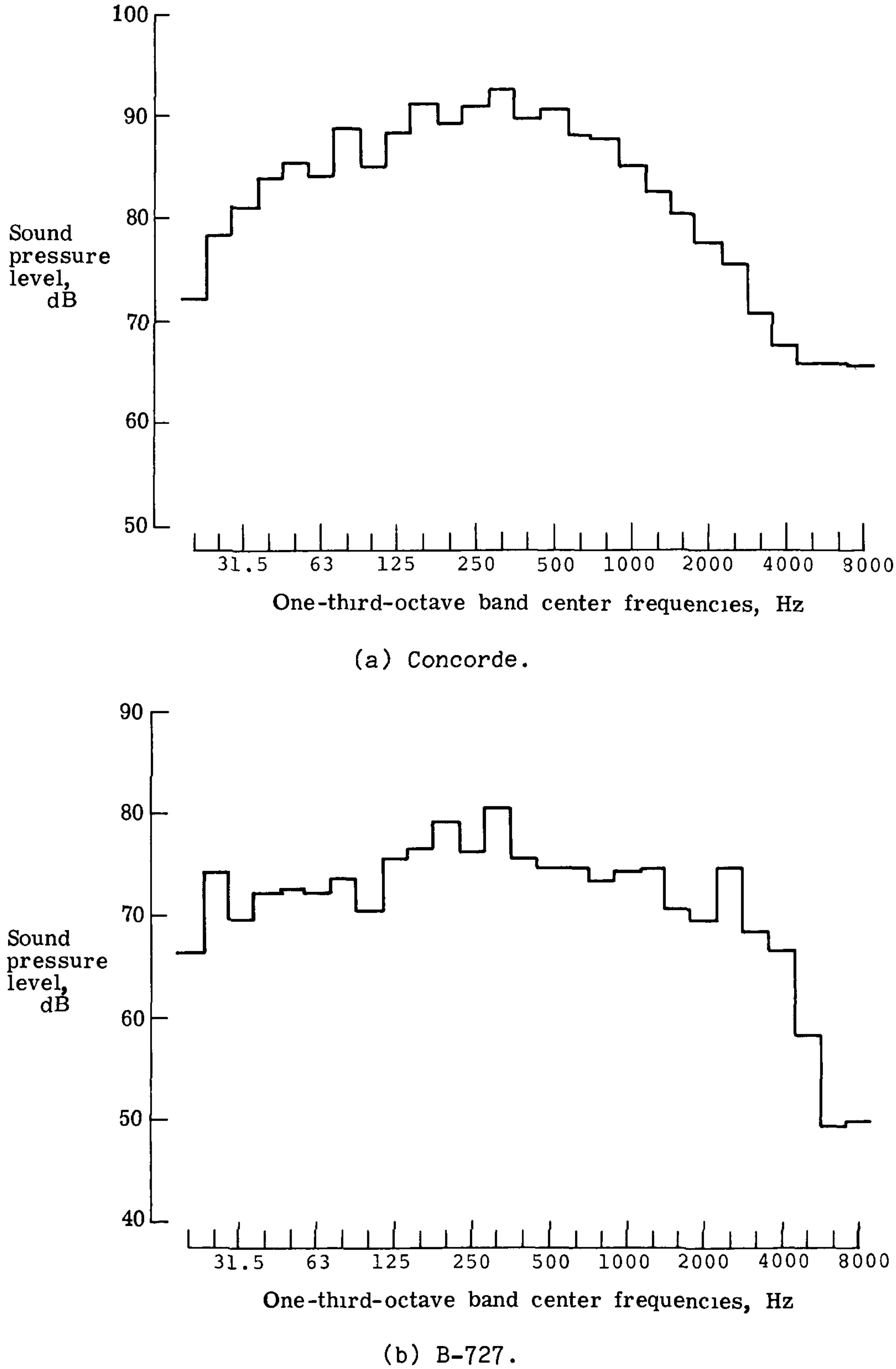
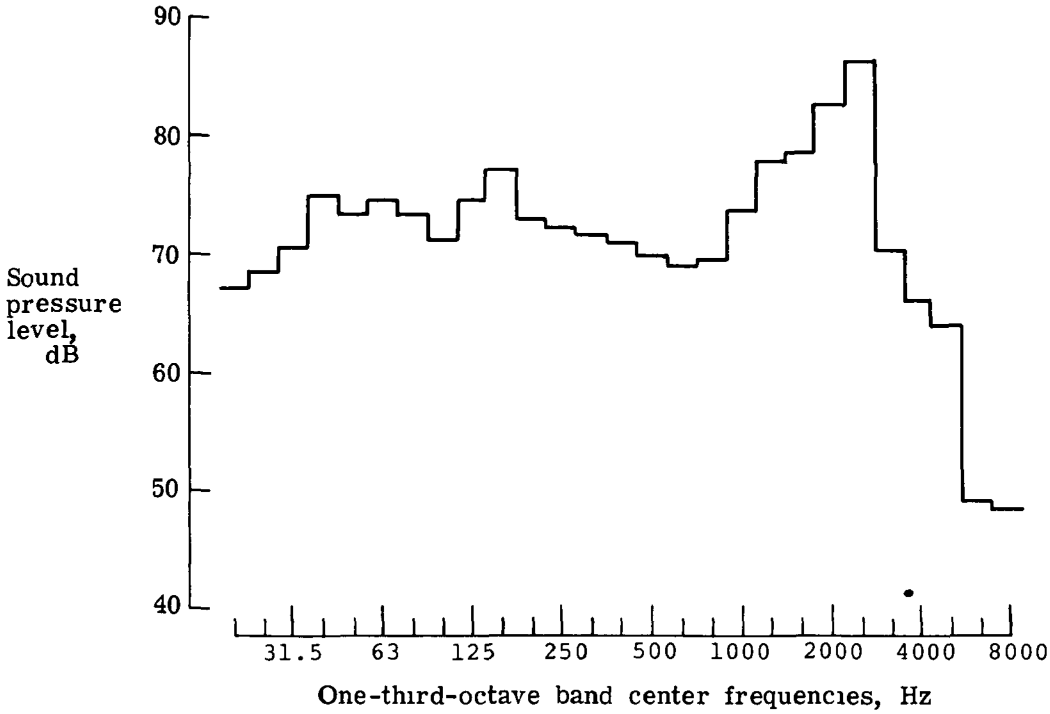
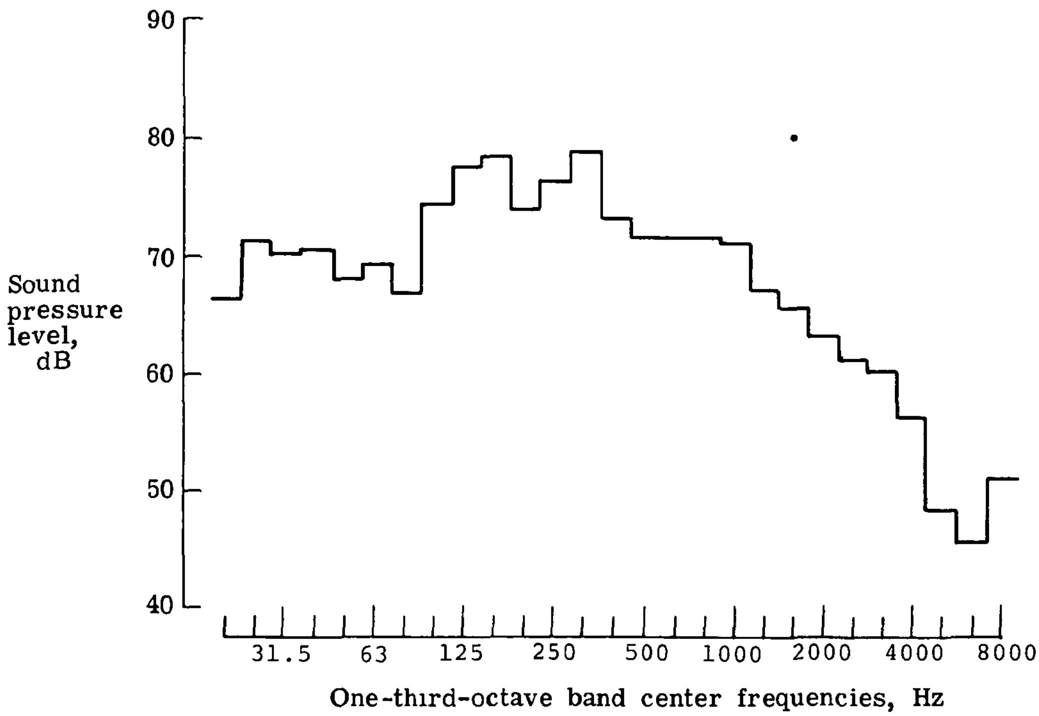


Figure 6.- Maximum 1/3-octave band sound pressure levels for distant arrivals.

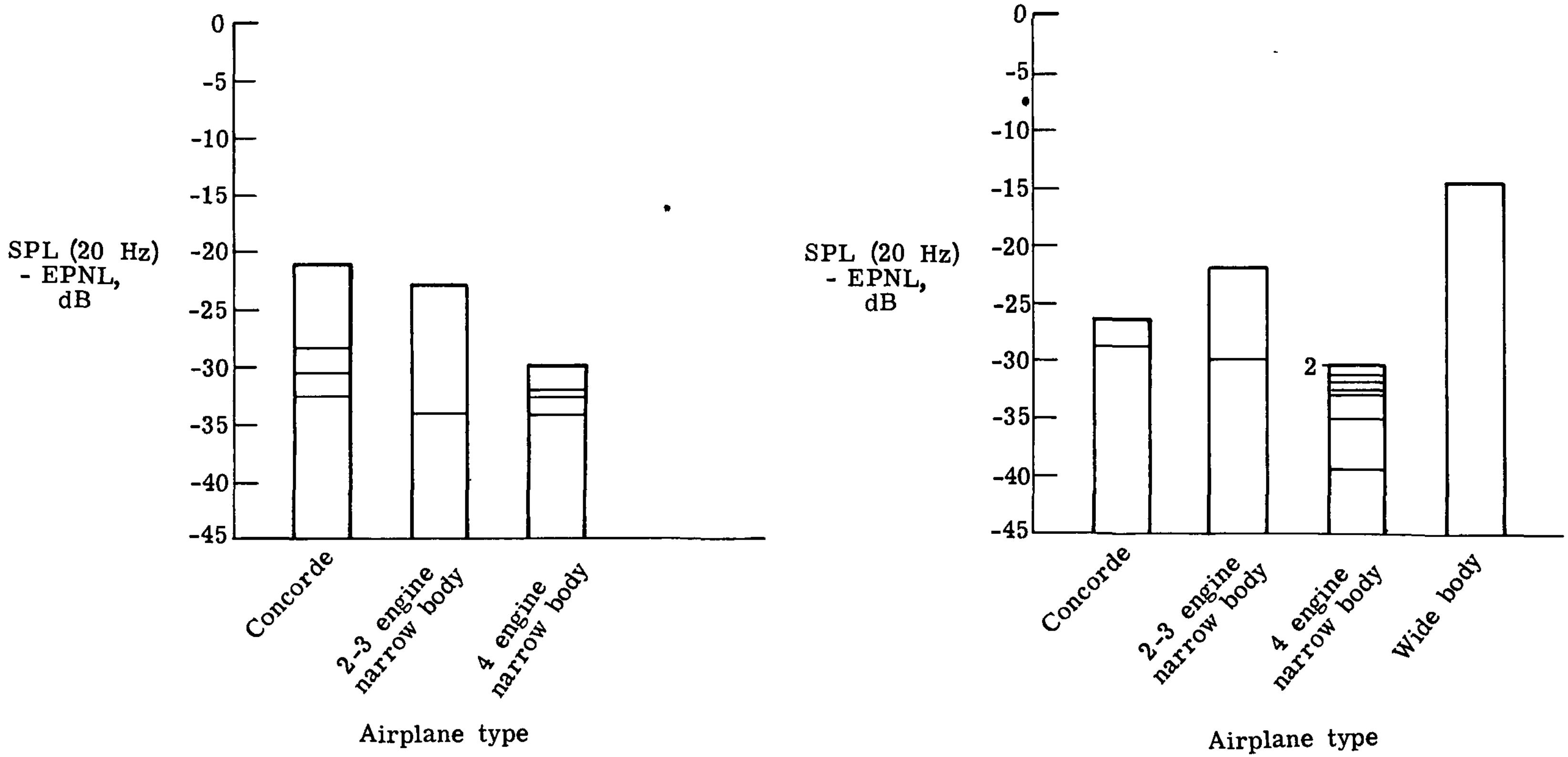


(c) B-707.



(d) DC-10.

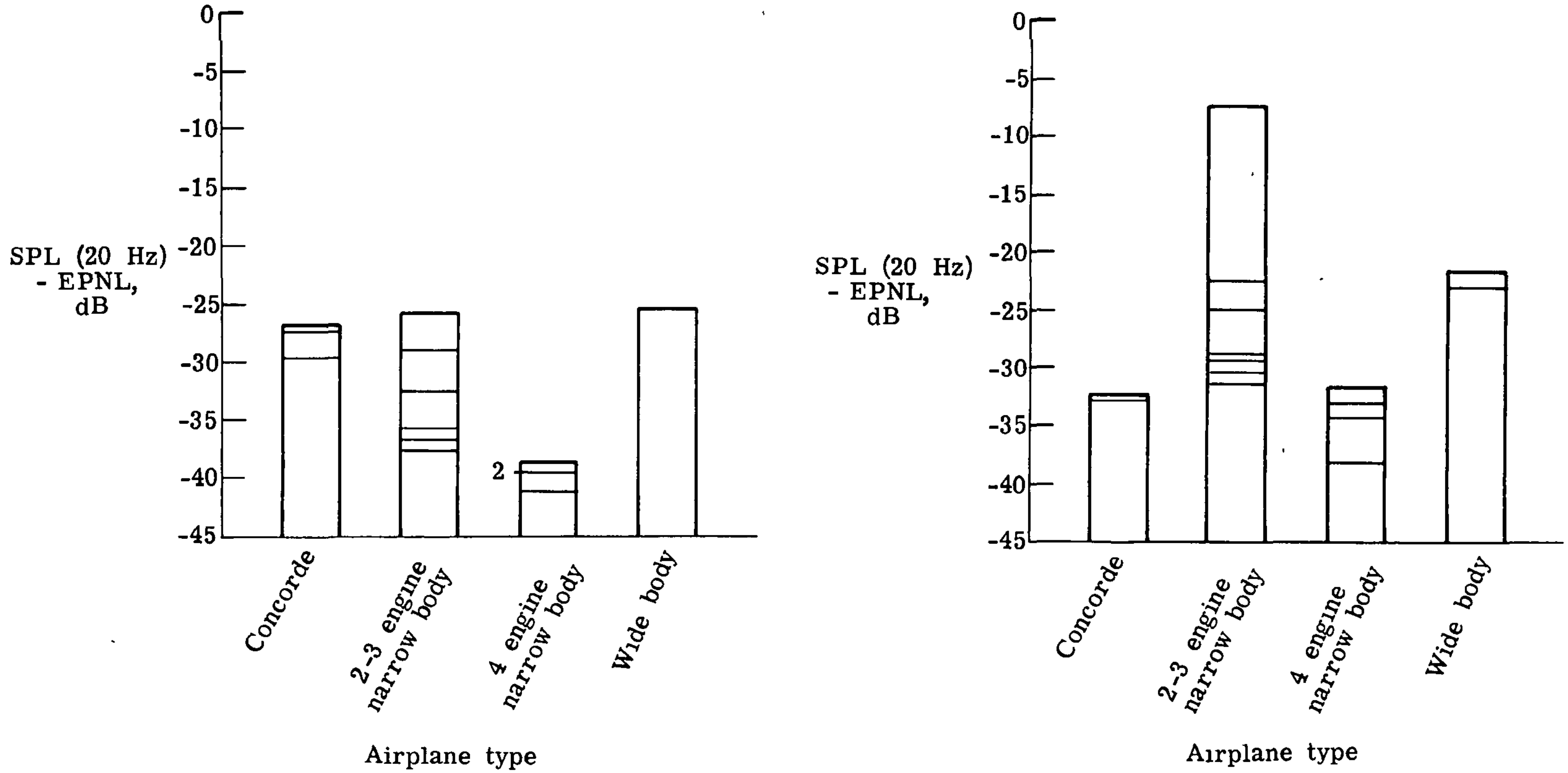
Figure 6.- Concluded.



(a) Close departures.

(b) Distant departures.

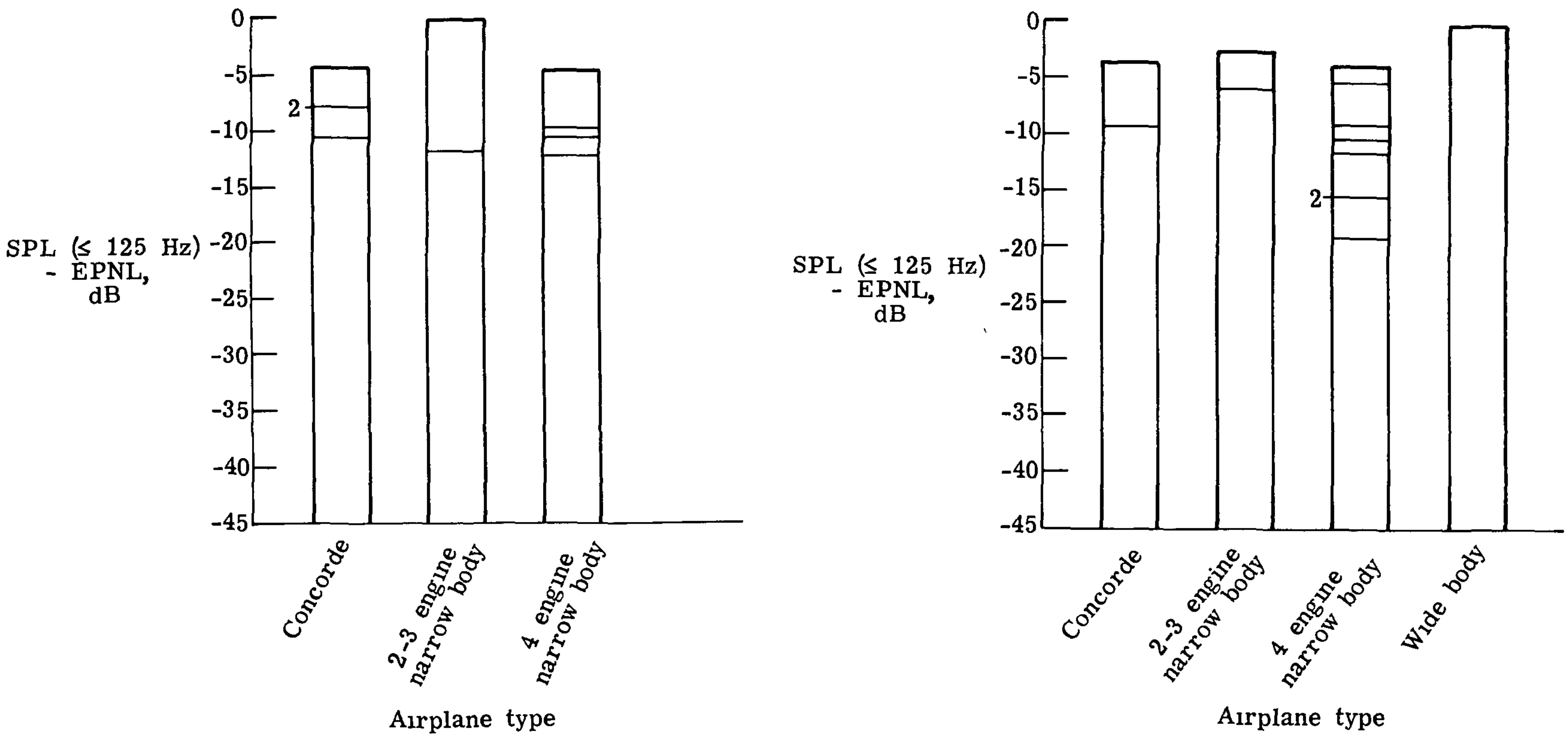
Figure 7.- Sound pressure levels in 20-Hz 1/3-octave band relative to EPNL.



(c) Close arrivals.

(d) Distant arrivals.

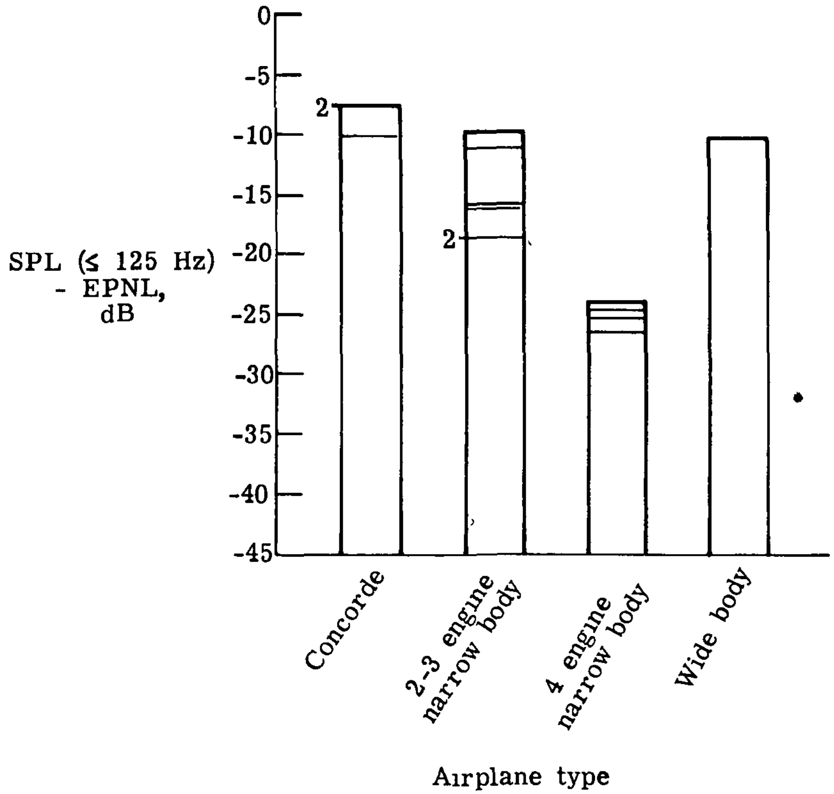
Figure 7.- Concluded.



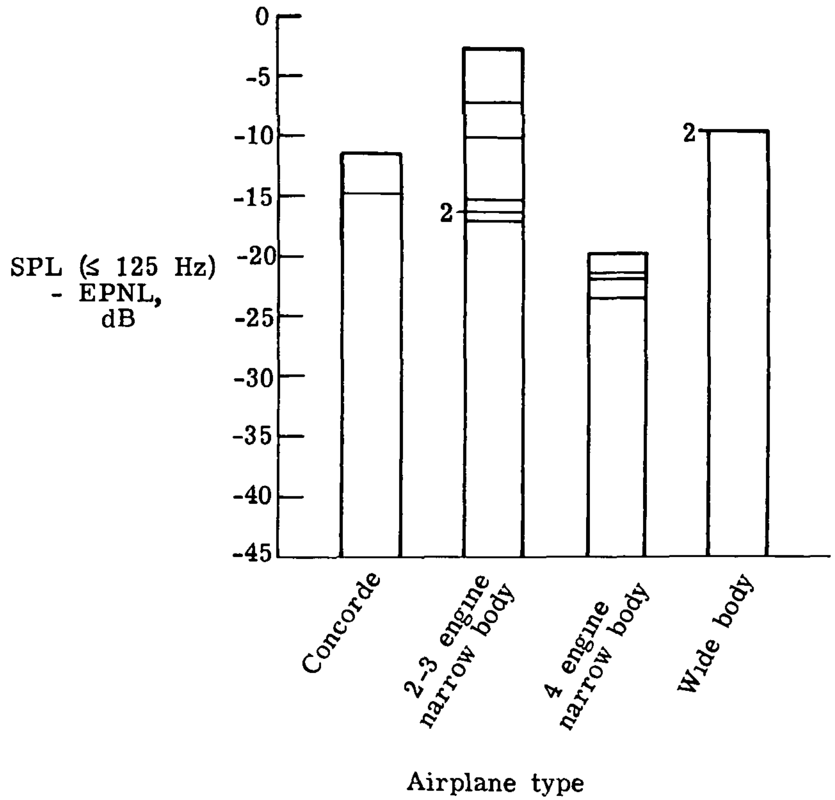
(a) Close departures.

(b) Distant departures.

Figure 8.- Sound pressure levels in 1/3-octave bands with center frequencies less than or equal to 125 Hz relative to EPNL.

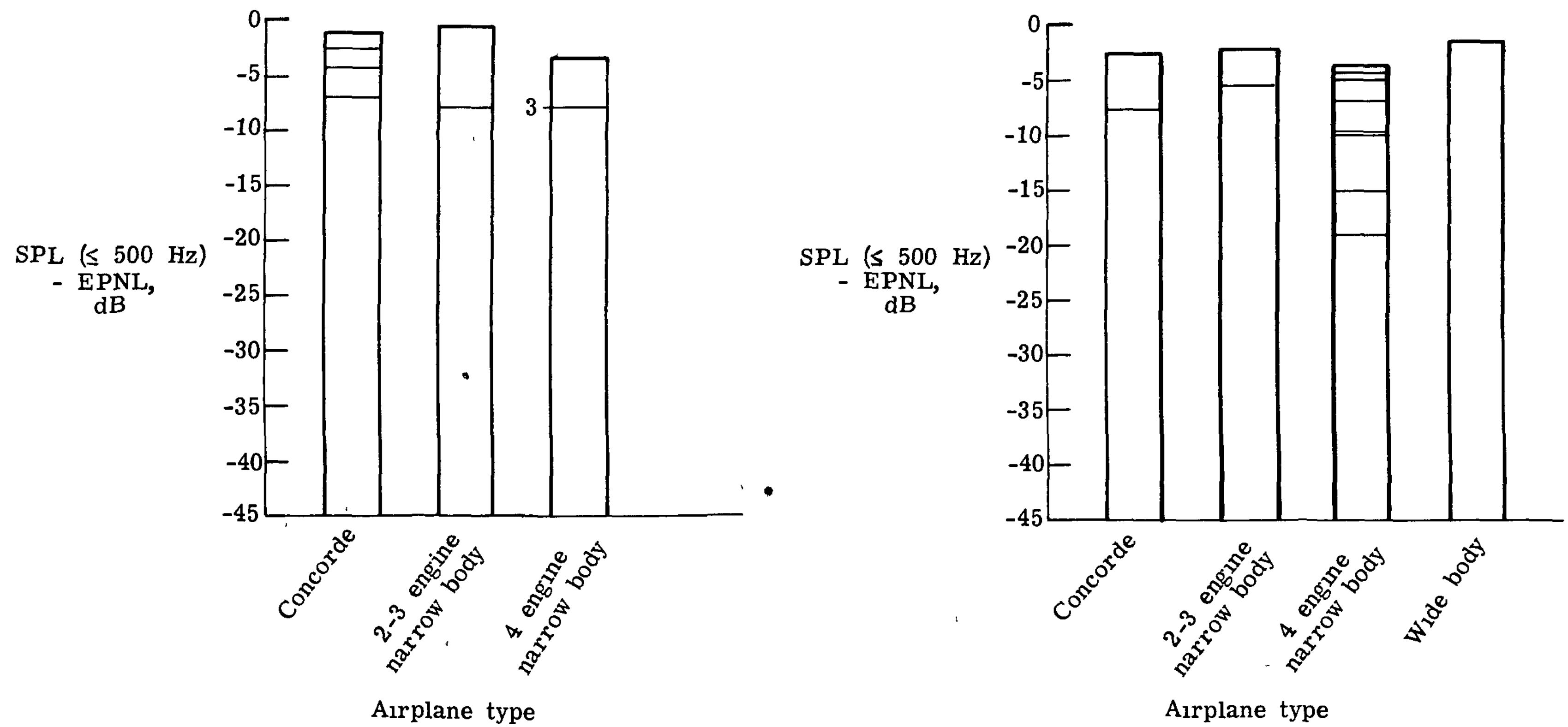


(c) Close arrivals.



(d) Distant arrivals.

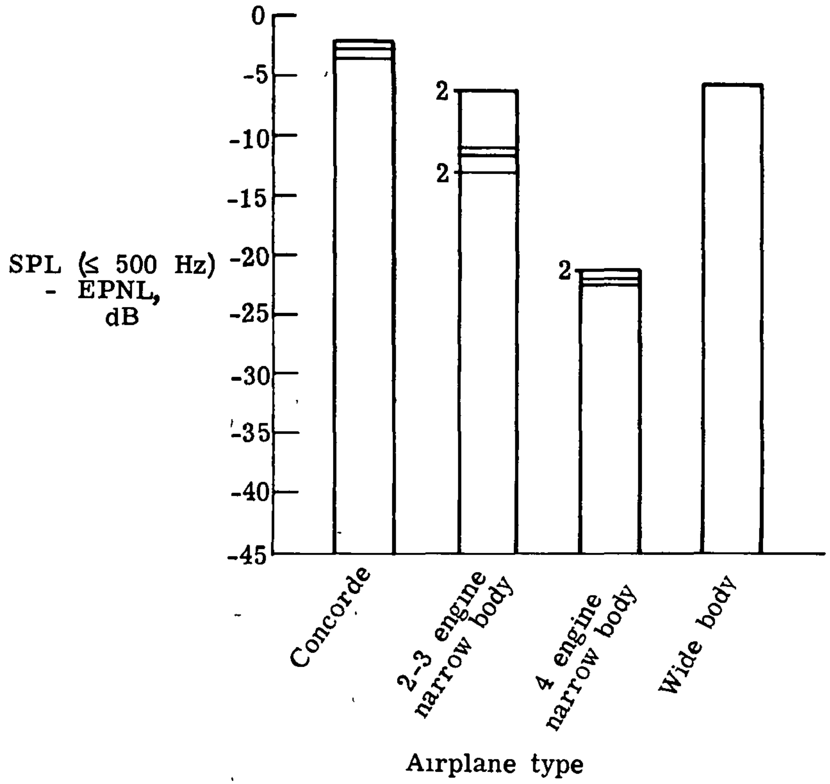
Figure 8.- Concluded.



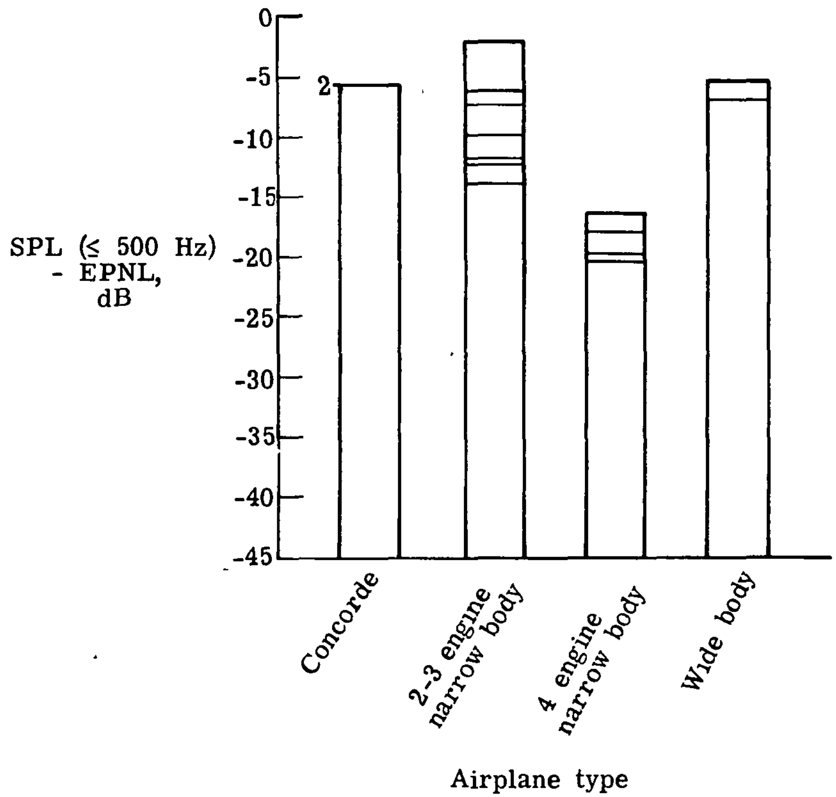
(a) Close departures.

(b) Distant departures.

Figure 9.- Sound pressure levels in 1/3-octave bands with center frequencies less than or equal to 500 Hz relative to EPNL.

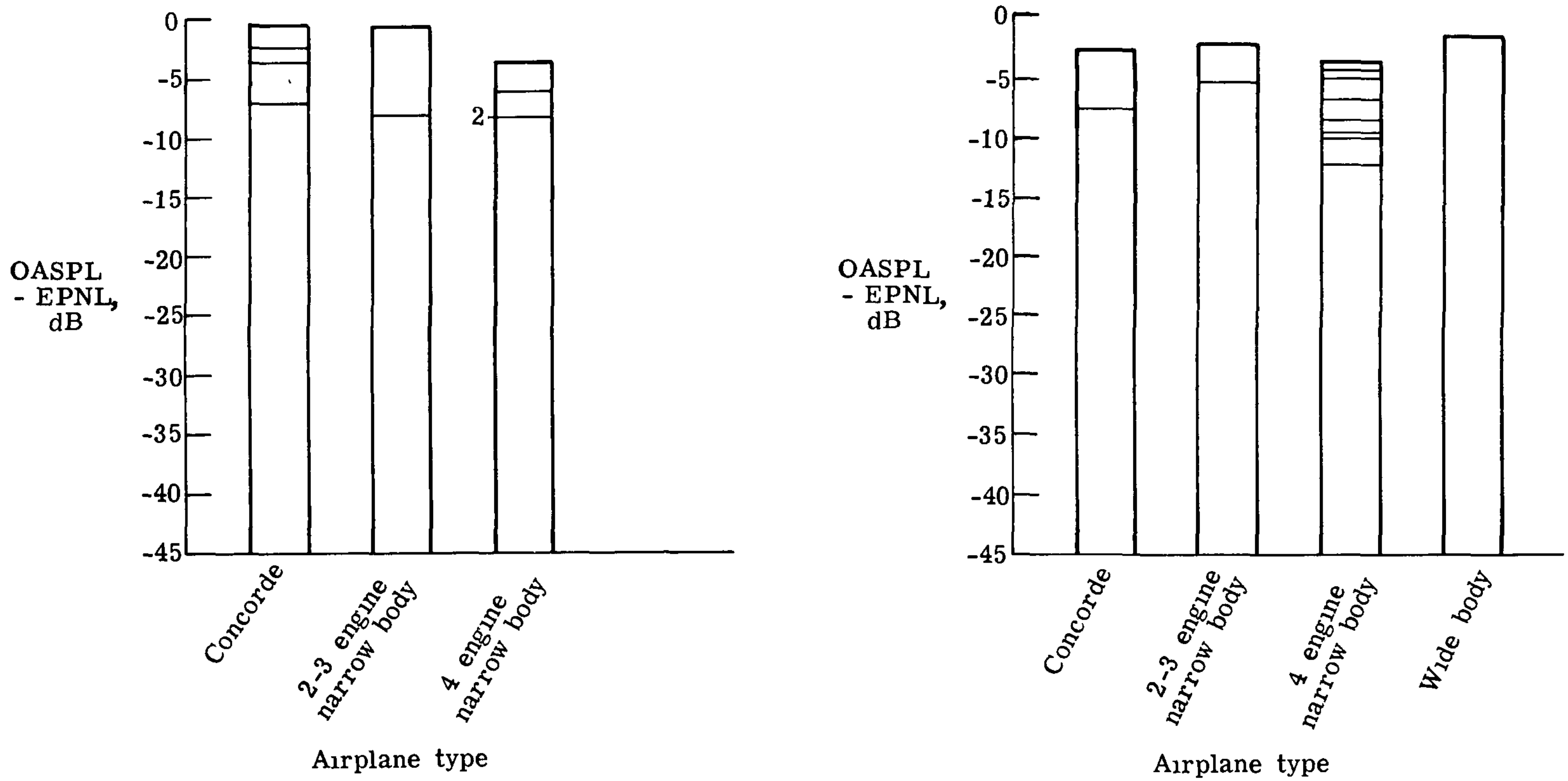


(c) Close arrivals.



(d) Distant arrivals.

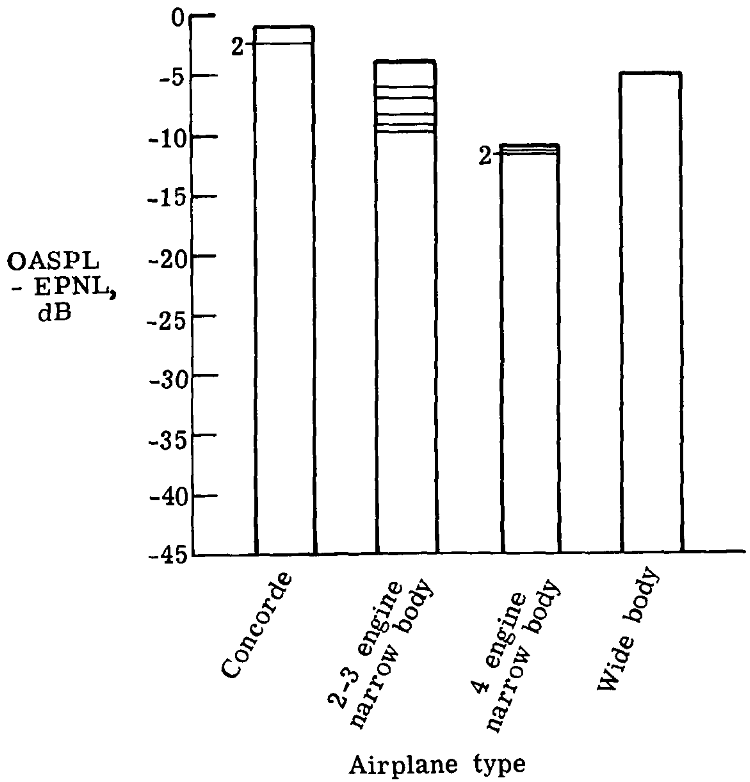
Figure 9.- Concluded.



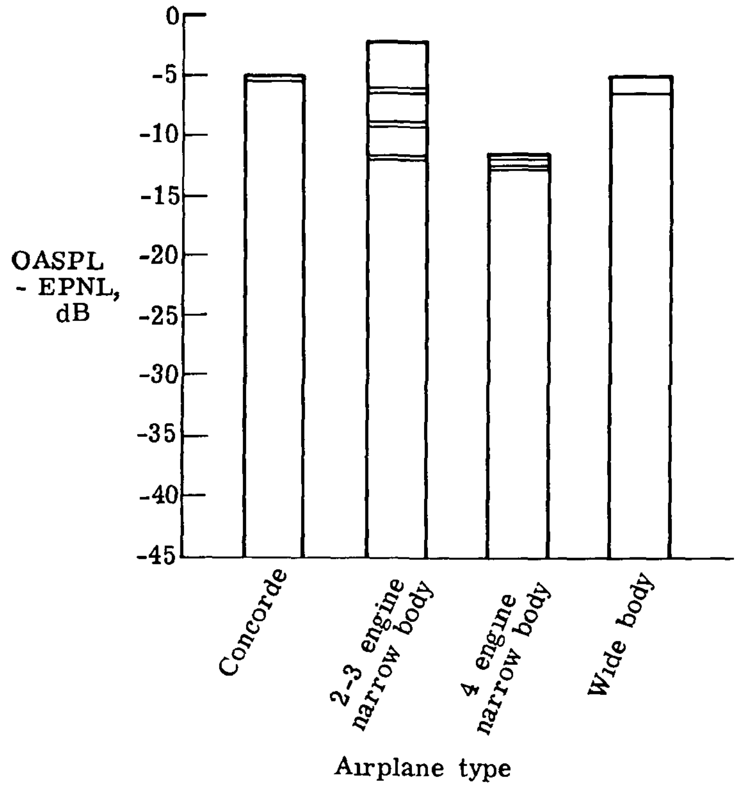
(a) Close departures.

(b) Distant departures.

Figure 10.- Overall sound pressure level relative to EPNL.

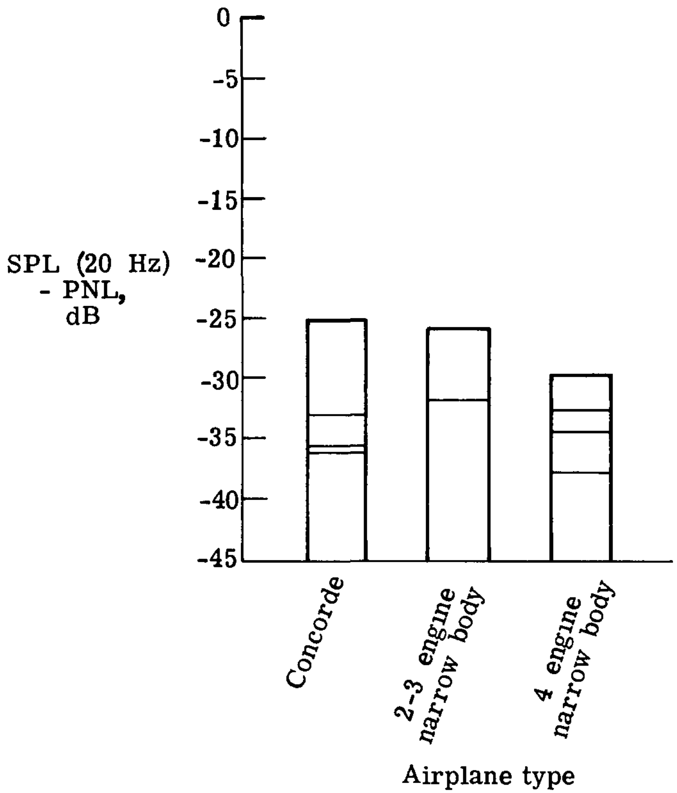


(c) Close arrivals.

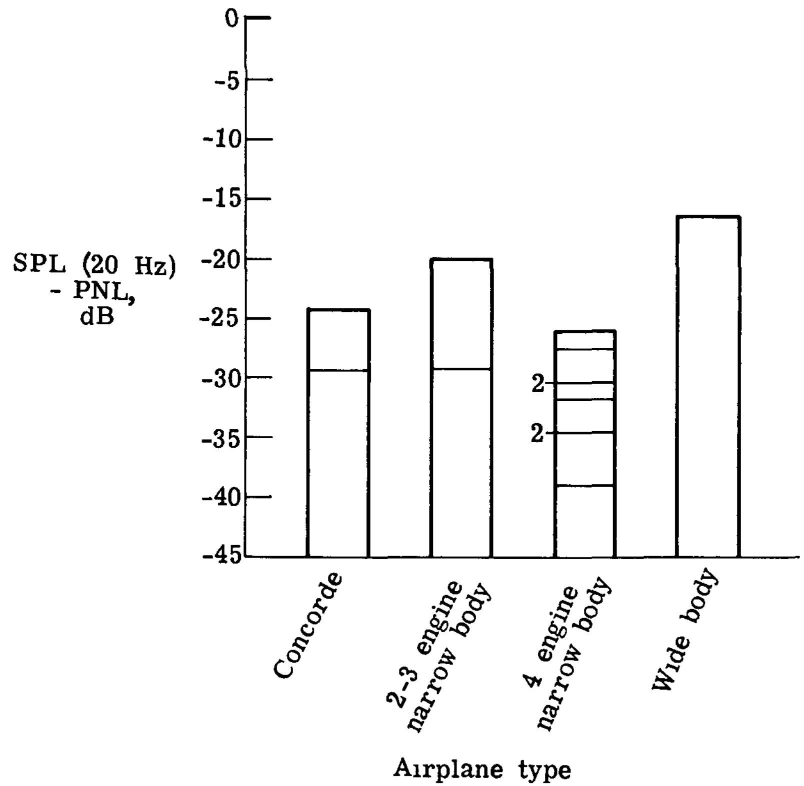


(d) Distant arrivals.

Figure 10.- Concluded.

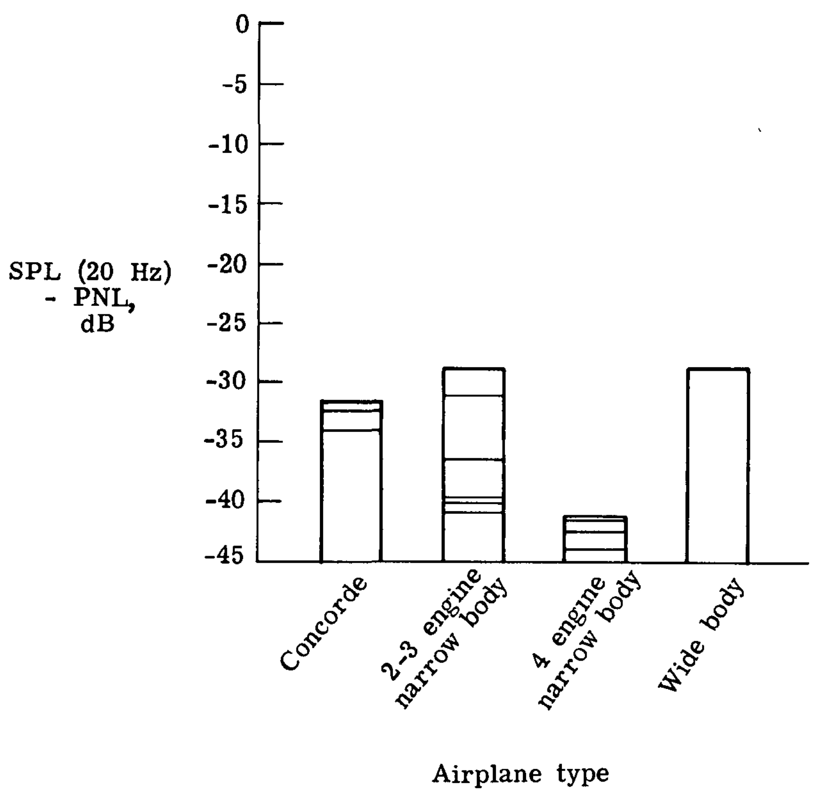


(a) Close departures.

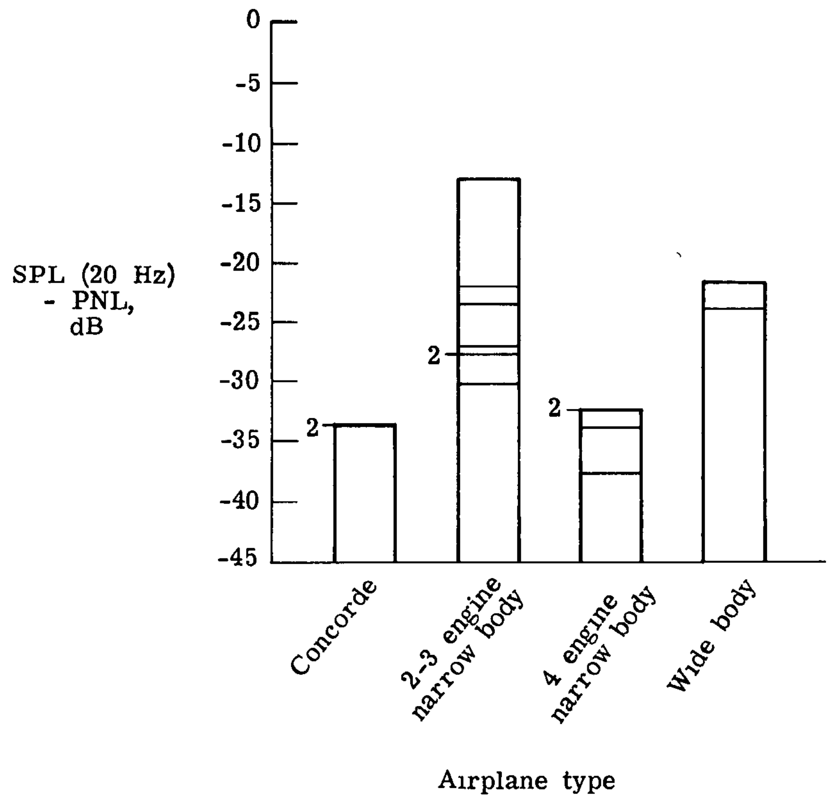


(b) Distant departures.

Figure 11.- Sound pressure levels in 20-Hz 1/3-octave band relative to PNL.

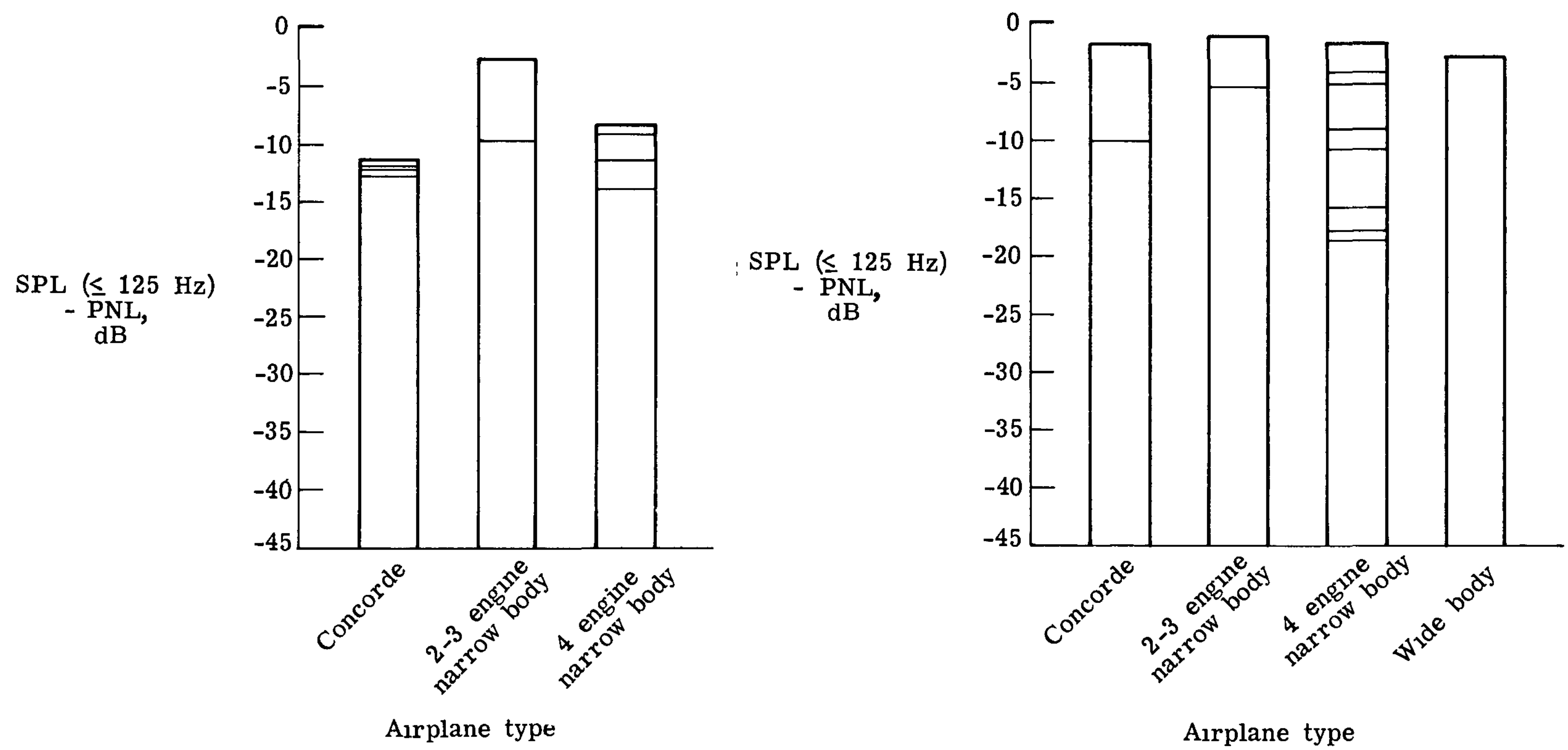


(c) Close arrivals.



(d) Distant arrivals.

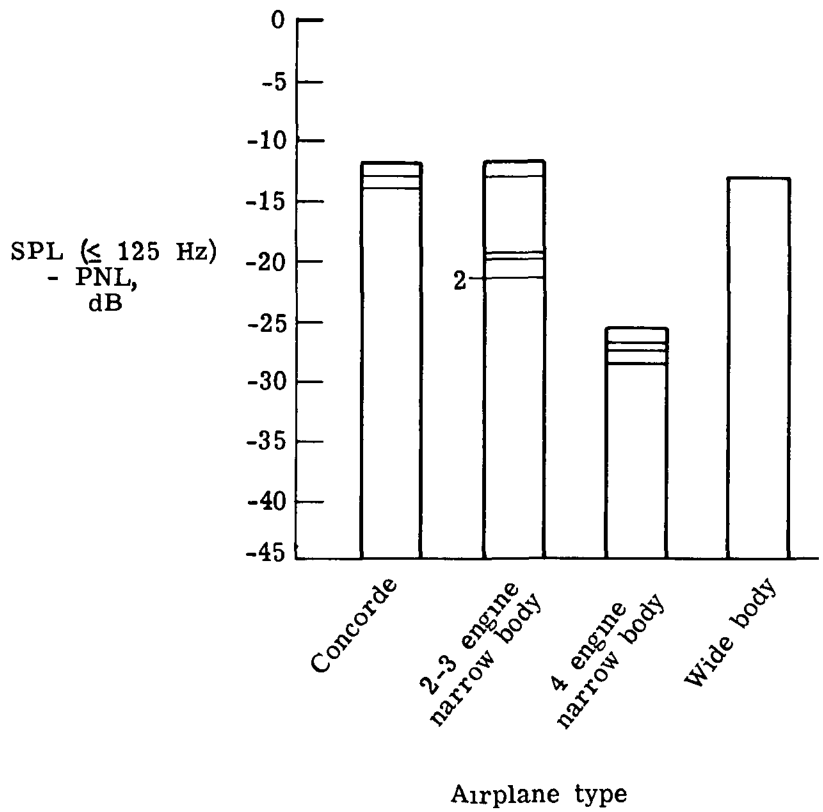
Figure 11.- Concluded.



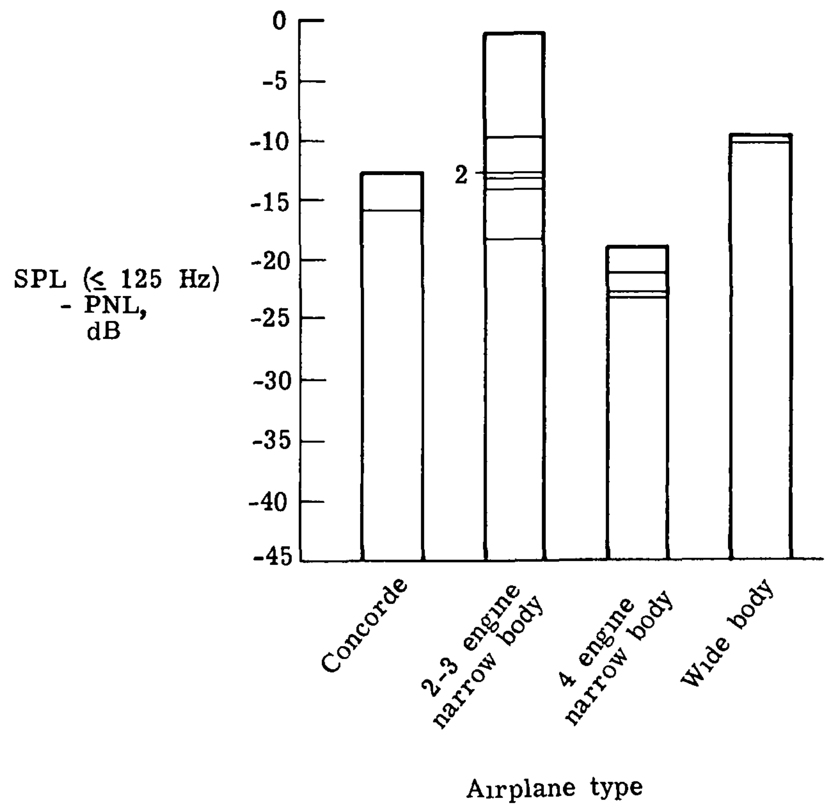
(a) Close departures.

(b) Distant departures.

Figure 12.- Sound pressure levels in 1/3-octave bands with center frequencies less than or equal to 125 Hz relative to PNL.

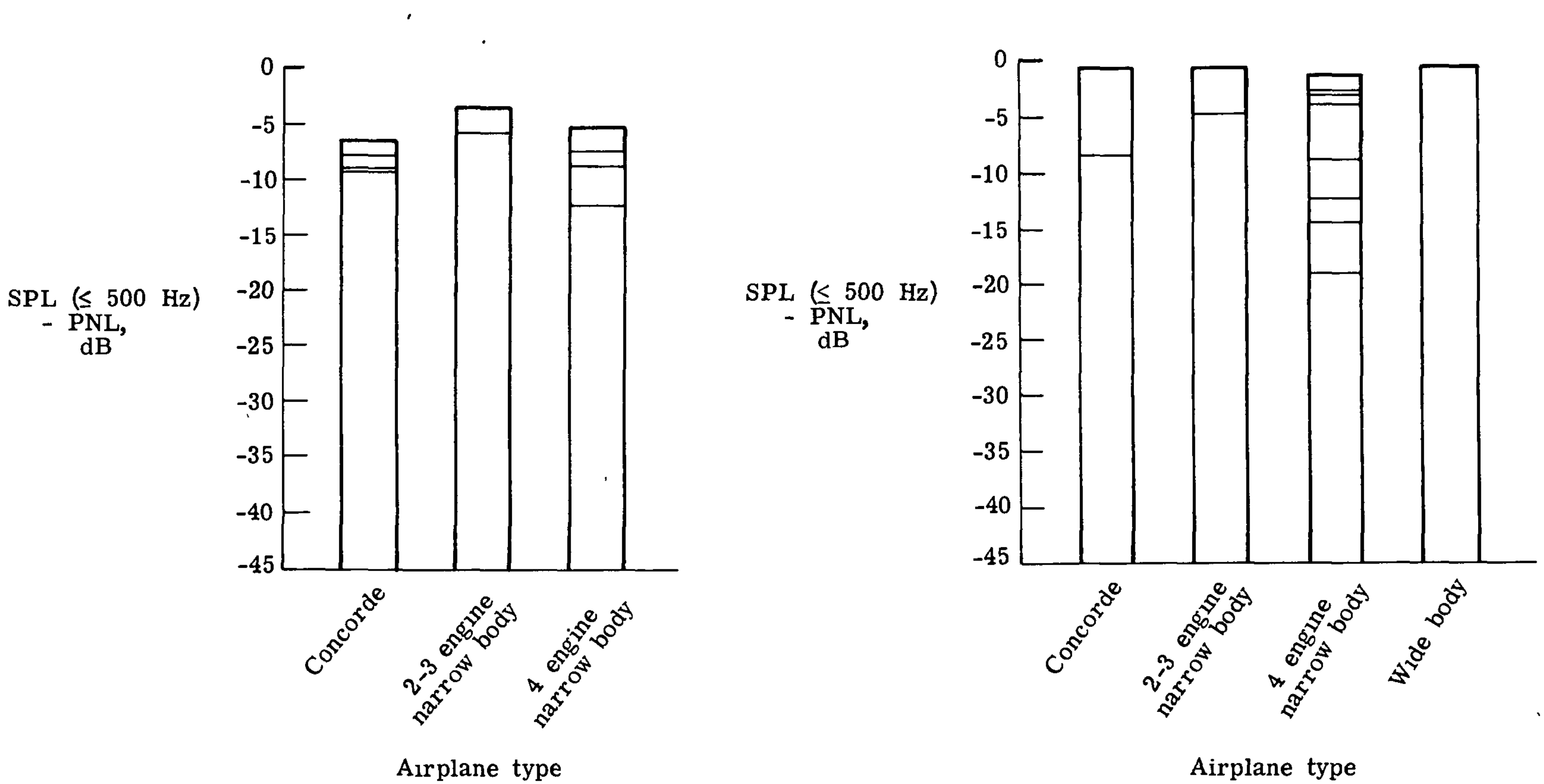


(c) Close arrivals.



(d) Distant arrivals.

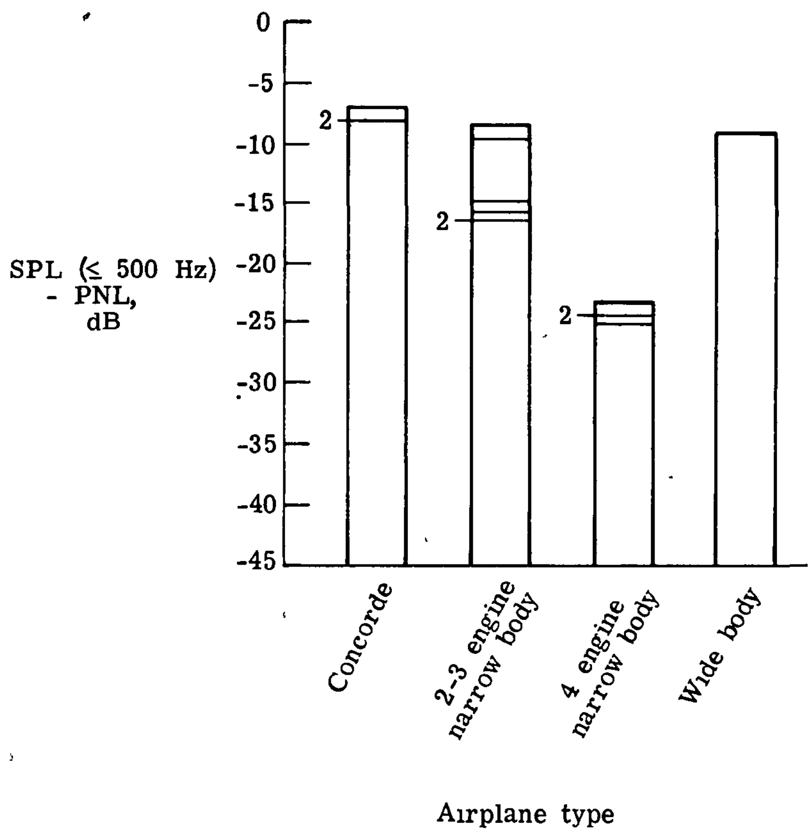
Figure 12.- Concluded.



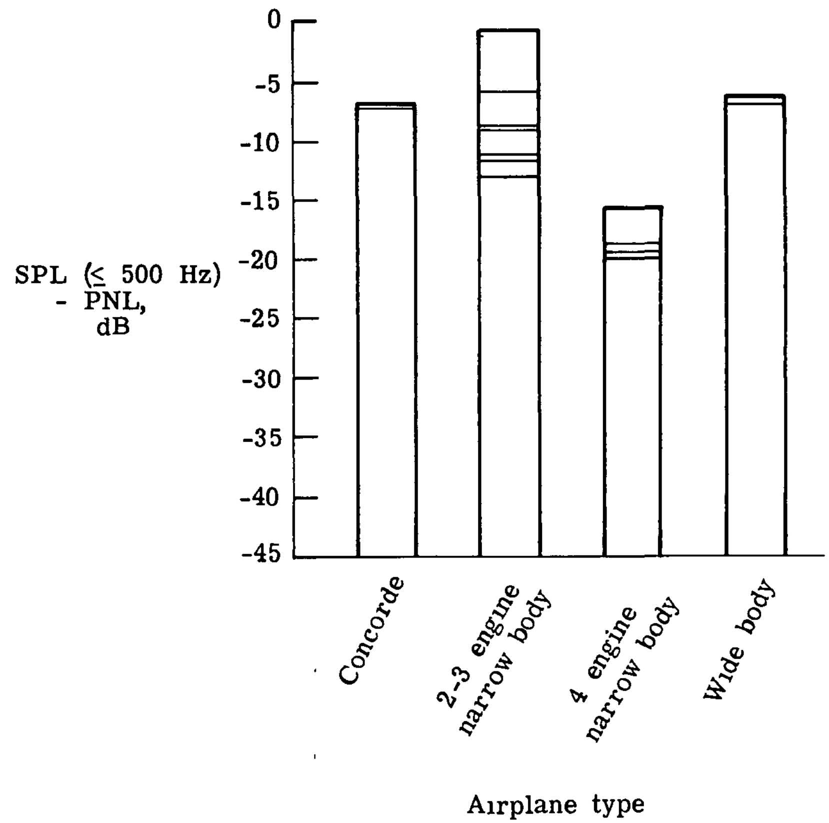
(a) Close departures.

(b) Distant departures.

Figure 13.- Sound pressure levels in 1/3-octave bands with center frequencies less than or equal to 500 Hz relative to PNL.

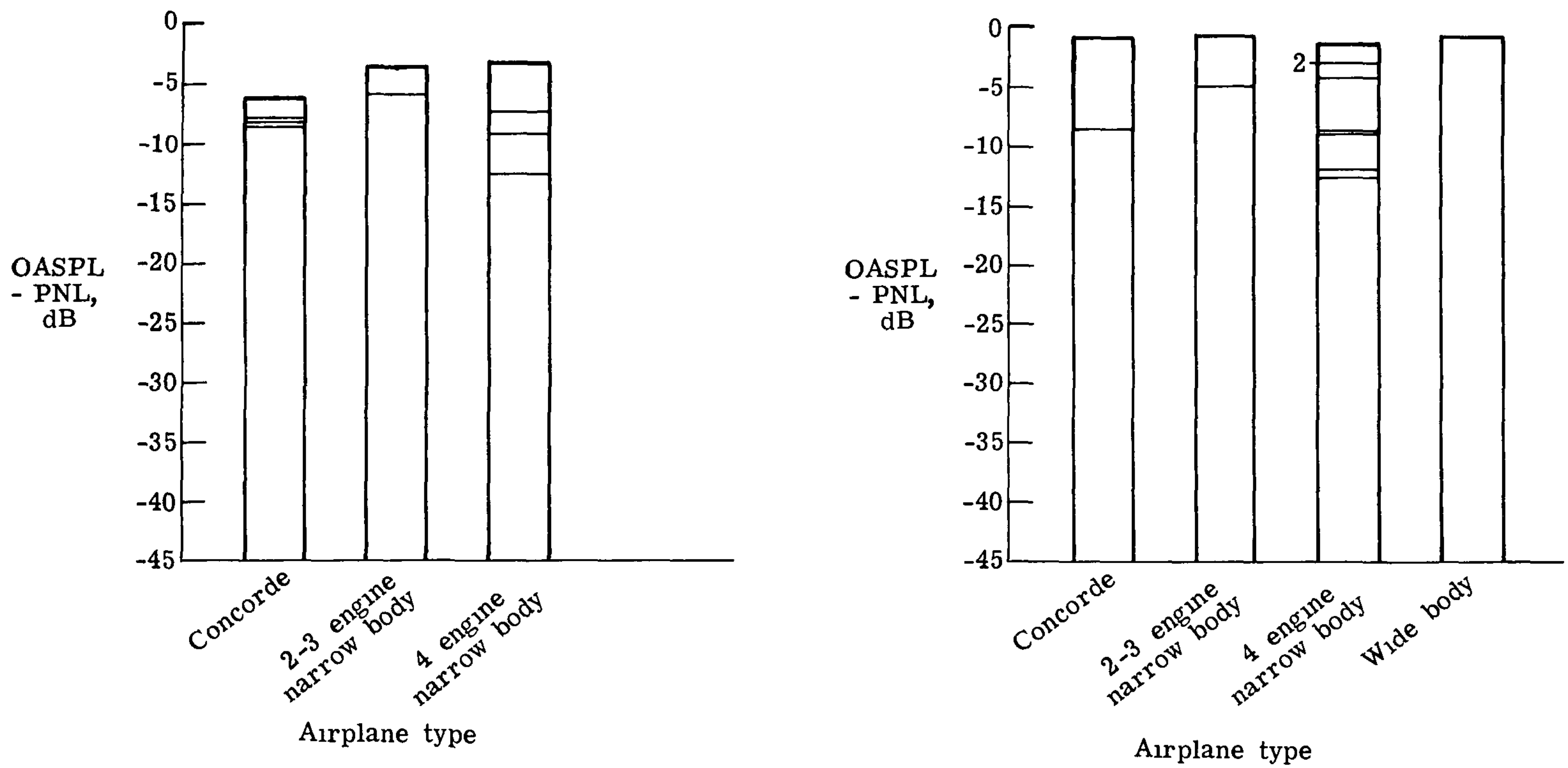


(c) Close arrivals.



(d) Distant arrivals.

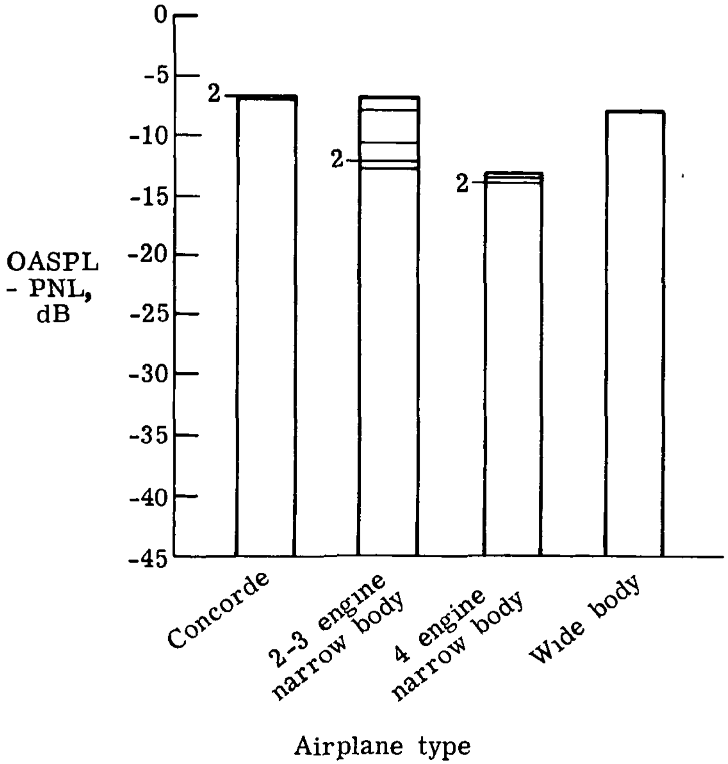
Figure 13.- Concluded.



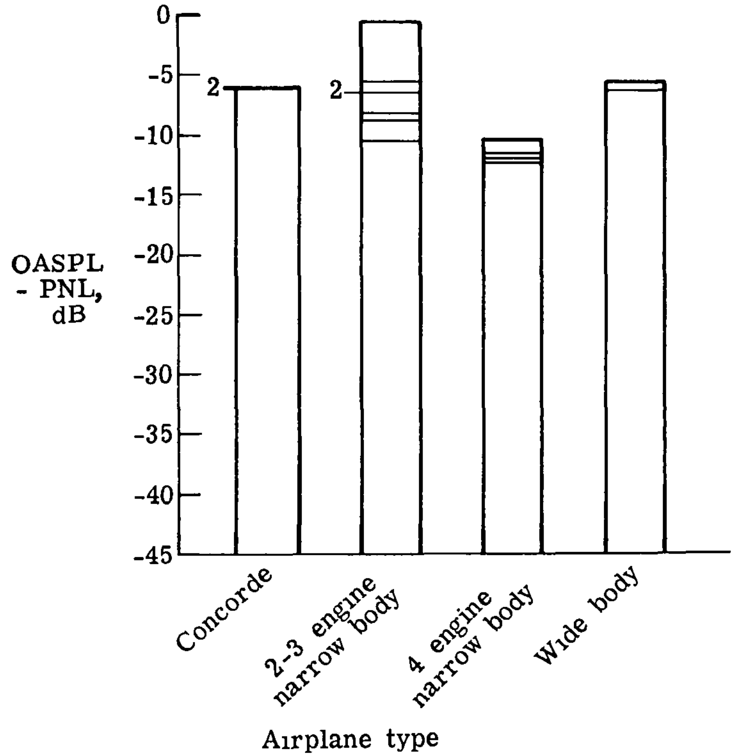
(a) Close departures.

(b) Distant departures.

Figure 14.- Overall sound pressure level relative to PNL.

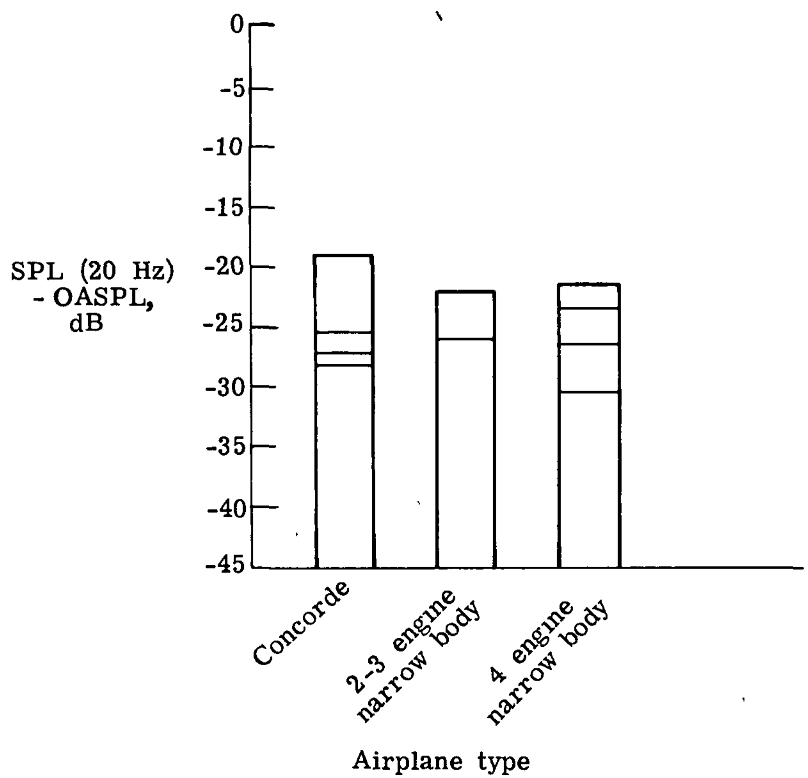


(c) Close arrivals.

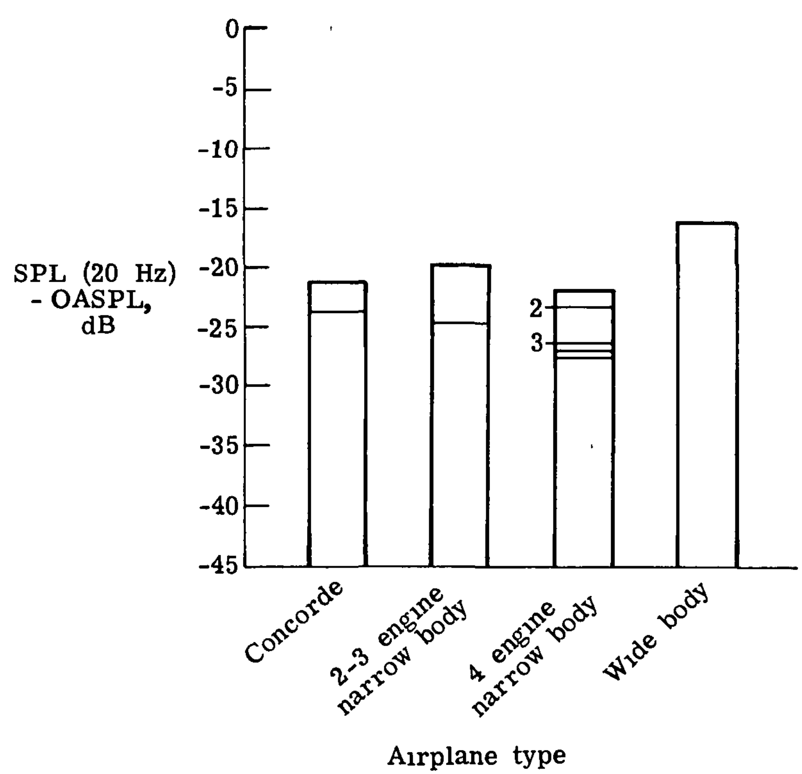


(d) Distant arrivals.

Figure 14.- Concluded.

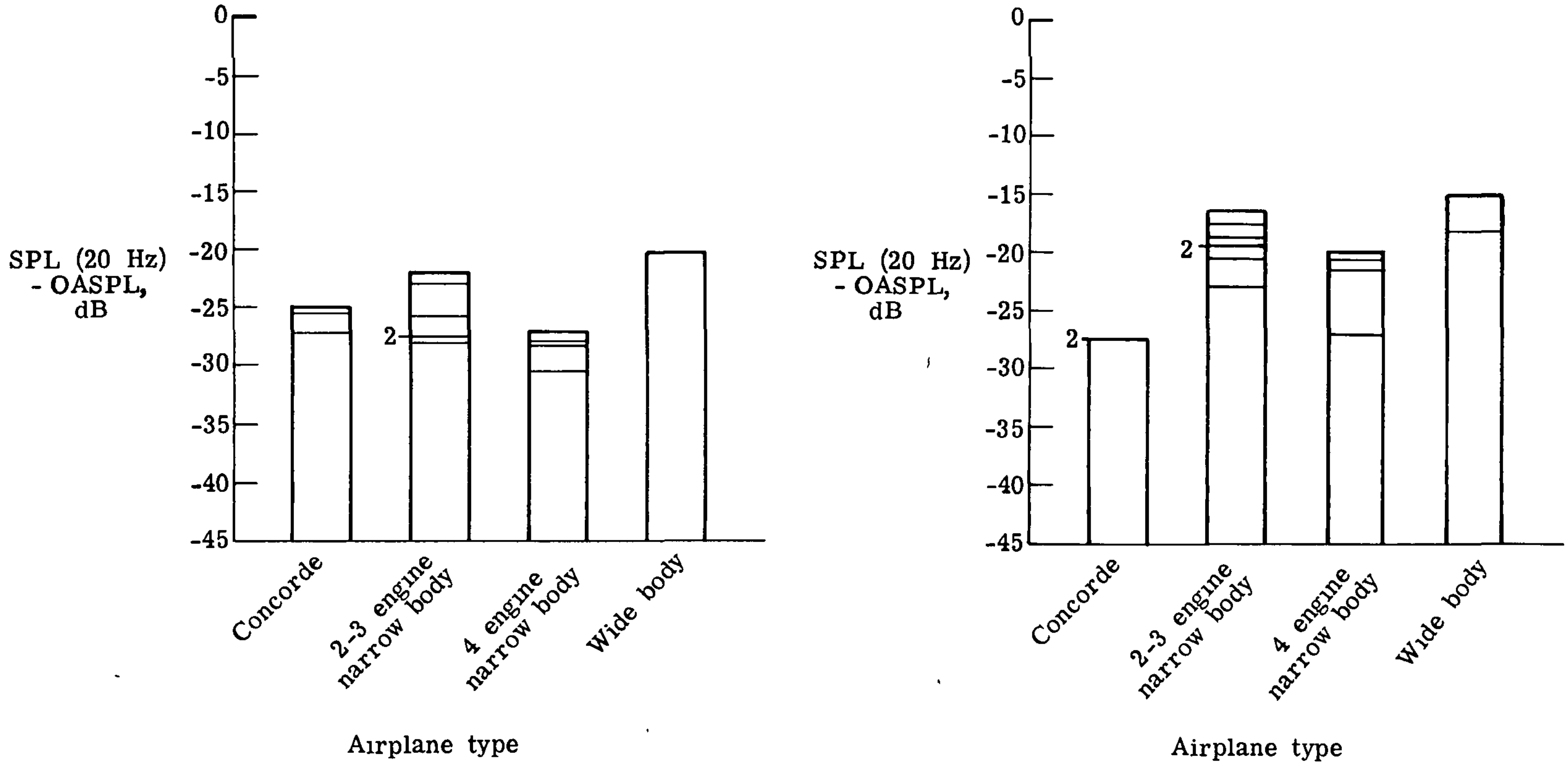


(a) Close departures.



(b) Distant departures.

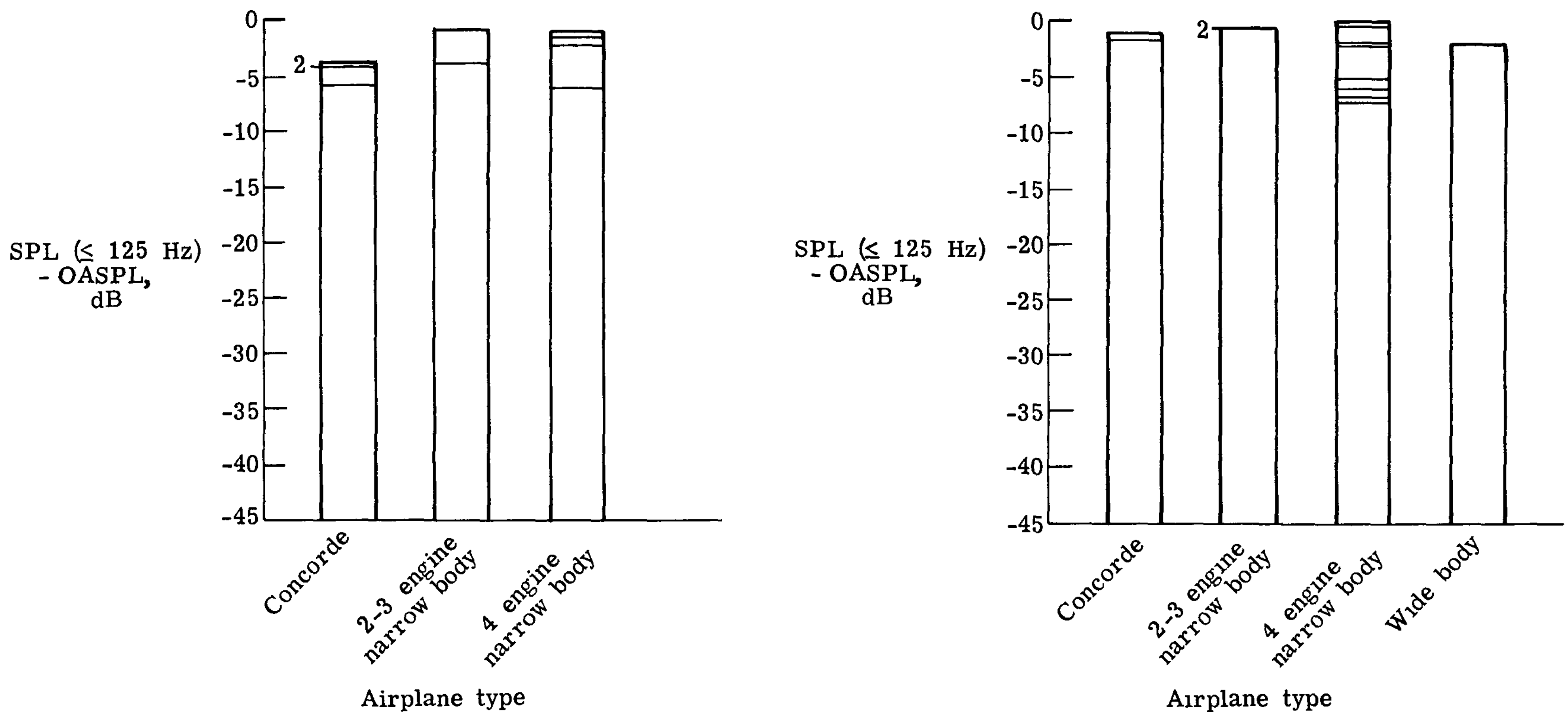
Figure 15.- Sound pressure levels in 20-Hz 1/3-octave band relative to OASPL.



(c) Close arrivals.

(d) Distant arrivals.

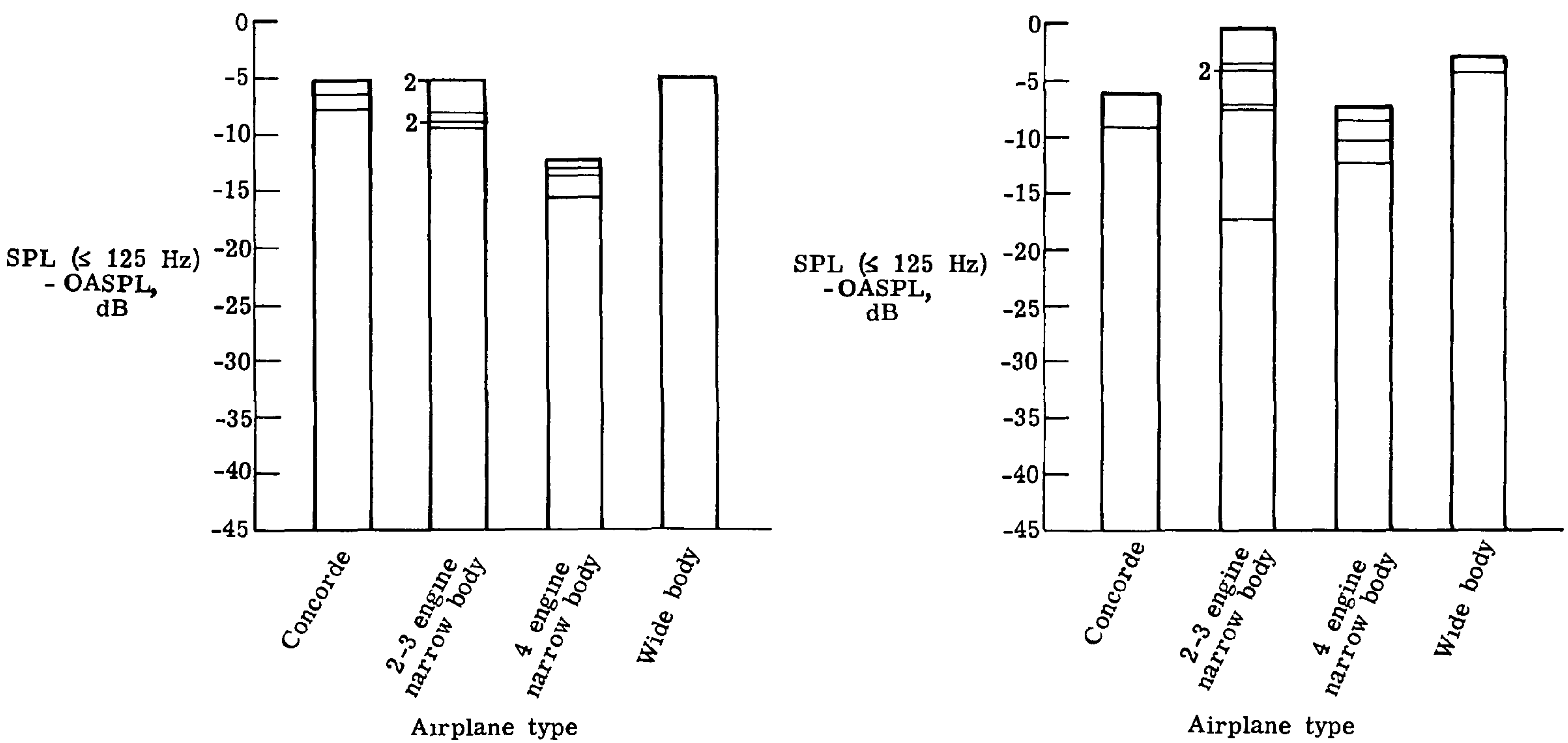
Figure 15.- Concluded.



(a) Close departures.

(b) Distant departures.

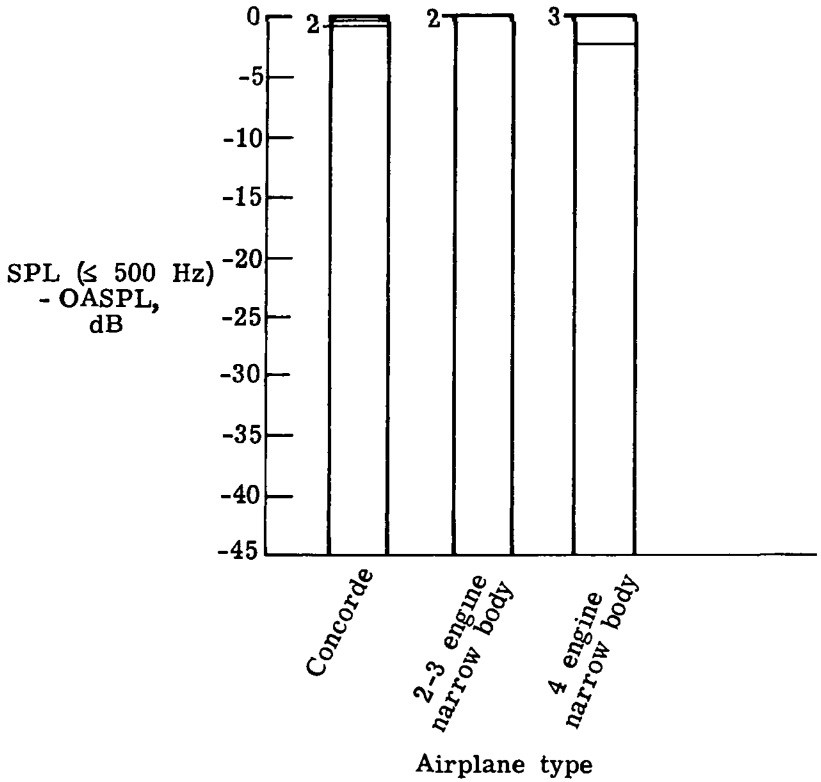
Figure 16.- Sound pressure levels in 1/3-octave bands with center frequencies less than or equal to 125 Hz relative to OASPL.



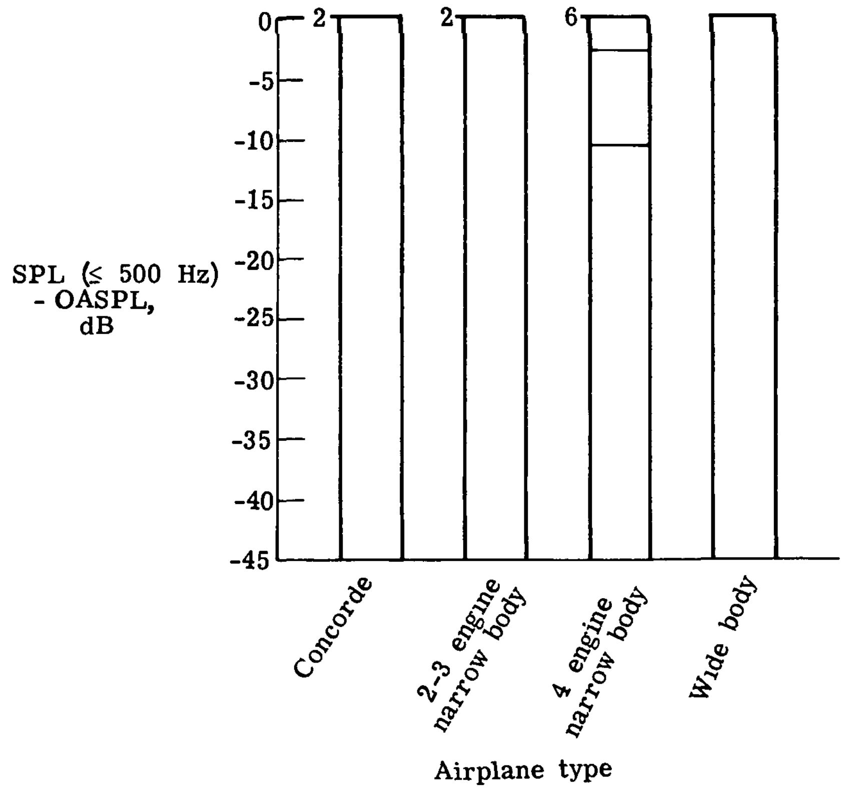
(c) Close arrivals.

(d) Distant arrivals.

Figure 16.- Concluded.

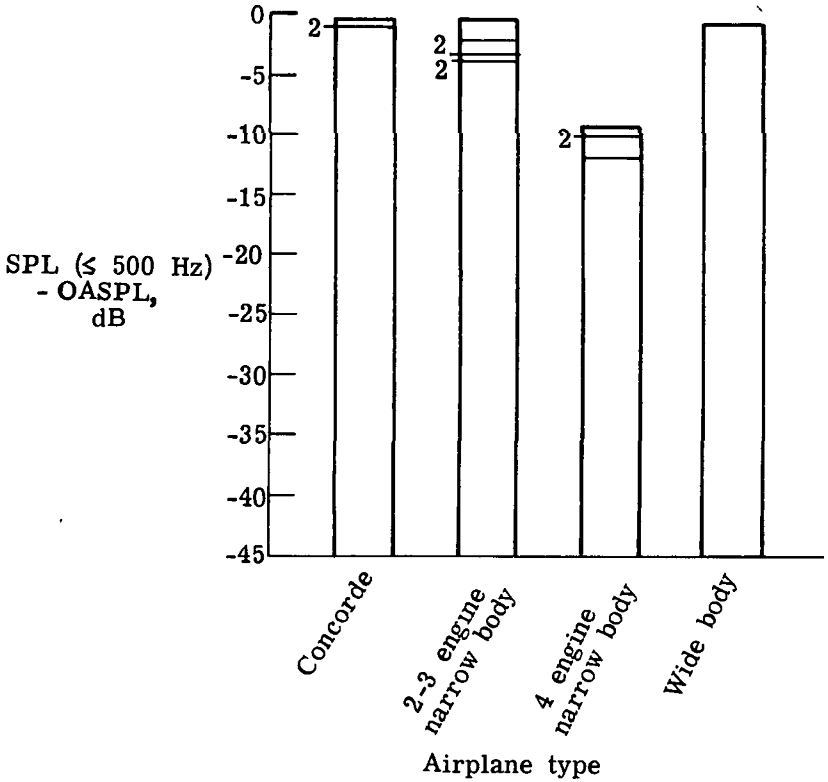


(a) Close departures.

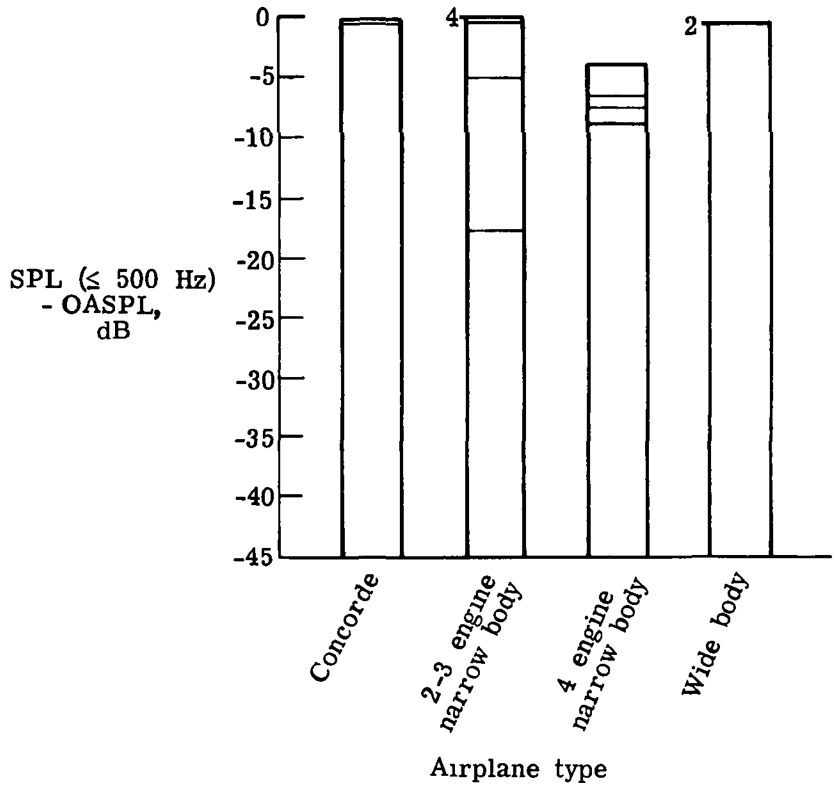


(b) Distant departures.

Figure 17.- Sound pressure levels in 1/3-octave bands with center frequencies less than or equal to 500 Hz relative to OASPL.



(c) Close arrivals.



(d) Distant arrivals.

Figure 17.- Concluded.

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15. Supplementary Notes

16. Abstract

Fifty-two airplane noise recordings, made at several locations around Dulles International Airport, were analyzed to compare the low-frequency noise levels of the Concorde supersonic transport with those of other commercial jet airplanes. Comparisons of the relative low-frequency noise levels which were produced at close and distant locations for departures and arrivals were made for three noise measures: the sound pressure level in the 1/3-octave band centered at 20 Hz, the total sound pressure level in the 1/3-octave bands with center frequencies less than or equal to 125 Hz, and the total sound pressure level in the 1/3-octave bands with center frequencies less than or equal to 500 Hz. Although the absolute noise levels for Concorde were found, in general, to be higher than those for the other airplane types, the level of low-frequency noise of the Concorde relative to the perceived noise level (PNL), effective perceived noise level (EPNL), and overall sound pressure level (OASPL) was within the range established by the other airplane types, except for the arrival operations of four-engine, narrow-body airplanes. The measure OASPL was found to be a significantly better predictor of low-frequency noise level than PNL or EPNL.

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