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STUDY OF THE EFFECT OF DEPARTURE PROCEDURES ON THE NOISE PRODUCED BY JET TRANSPORT AIRCRAFT

TECHNICAL REPORT

March 1965

by

W. J. Galloway
A. C. Pietrasanta
K. S. Pearsons

Bolt Beranek and Newman Inc.
15808 Wyandotte Street
Van Nuys, California 91406

Under Contract FA64WA-4949

for

FEDERAL AVIATION AGENCY

AIRCRAFT DEVELOPMENT SERVICE

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ABSTRACT

The effect of various departure procedures of commercial jet transport aircraft on the noise produced on the ground under the departure path are presented in this report. Noise data at four measurement stations under the flight path of Runway 13R at John F. Kennedy International Airport, New York, were obtained from 300 aircraft departures.

Four different classes of departure procedures, including those specified by current airline operating practices, are compared with the noise produced by a random set of aircraft operations where the departure procedure was unspecified.

Detailed radar observations of the aircraft flights, operational information reported by pilots flying specified procedures, and the measured noise data on all flights observed were used in evaluating the various departure procedures.

The study shows that implementation of a proposed departure procedure could reduce the noise levels on the ground under jet transport takeoffs by as much as 8 PNdB as compared to the noise produced by existing procedures.

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I. INTRODUCTION AND SUMMARY

Noise produced by aircraft in communities adjacent to airports is one of the major problems facing the airline industry today. Many millions of dollars have been spent in research and development on means for quieting jet engines. At the present time most aircraft being flown by the airlines utilize either some form of noise suppressor on the turbojet engines or the quieter turbofan engines. Little additional engine noise reduction seems likely within the present state of the art considering engineering knowledge and economic limitations. However, since the noise exposure under the takeoff path adjacent to airports is directly dependent on the aircraft altitude and engine power setting, it can be materially affected by the type of departure procedure employed. The purpose of this study is to evaluate whether or not changes in current departure procedures would reduce the amount of noise produced on the ground by jet aircraft.

The departure procedures specified by an airline are based not only on aircraft manufacturers' performance data, but also on the particular philosophy employed by the airline in determining the method by which it believes its aircraft should be flown. Each airline develops a recommended procedure for each of the types of aircraft which it flies. These procedures are part of the operational information supplied to the pilot. While the pilot reserves the prerogative of departing from the procedure for safety reasons, or any other reason which he believes warranted, he does, in general, attempt to follow the procedure prescribed by his particular airline.

While many departure procedures are quite similar in nature there are distinct differences in the procedures used by various airlines. One of the goals of the study described in this report is to evaluate the noise produced by aircraft following the standard airline operating procedures employed by a number of different airlines. A second goal is to evaluate the noise produced by several alternate procedures purported to provide less noise on the ground than procedures presently in use. A description of the specific departure procedures employed in this study is provided in Appendix A. In summary, three basic classes of procedures were employed:

Procedure 1: Those procedures which are employed by individual airlines in normal operations at John F. Kennedy International Airport in New York.

Procedure 4: A "minimum noise" procedure suggested by the Federal Aviation Agency.

Procedures 7 and 8: Two procedures, similar in nature, proposed by the Air Line Pilots Association.

Noise data were obtained for the above procedures as well as for a random selection of aircraft in which no particular procedure was specified. This latter group provides, in effect, a control group which is indicative of the general distribution of flight procedures and the noise they produce during normal aircraft departures.

The measurements described in this report were acquired in a community adjacent to Kennedy International Airport in New York. Measurement stations were located at a number of spots along the projection of Runway 13R. These measurement locations span the community between the airport and the southern coast line of Long Island. The field measurement stations used magnetic tape recording equipment to obtain noise data. The tape recorded data were analyzed to obtain the maximum perceived noise level in PNdB occurring at the measurement stations during the aircraft flyovers. Each aircraft observed during the field measurement program had positional data available for its flight path, derived either from a special radar being employed by FAA as part of another study, or through photographic observation of the aircraft from each of the measuring stations.

The aircraft observed during the course of the study consisted of two general classes:

1) Aircraft which were cooperatively participating in the program.

2) Aircraft which were observed at random.

There were 50 participating aircraft designated by the cooperating airlines: American Airlines, Eastern Airlines, Trans World Airlines, United Airlines, and Pan American Airways. The participating aircraft, by prior arrangement through FAA, the Air Line Pilots Association, and the airlines Dispatch Offices flew one of the specified procedures. As discussed in the description of the field measurement program in Appendix B, the ground measurement stations were notified if an aircraft was participating in flying a specific procedure. In addition, the pilot returned a log after his departure in which he answered certain questions concerning his conformance to the procedure which he intended to fly. From a combination of radar or photographic observation and the pilot's report we were able to determine how well the pilot adhered to that procedure. Further information on engine types, power settings, takeoff gross weight, etc. were also included in the pilots logs. For the non-participating aircraft, i.e. those selected at random, only positional and noise data were available.

The field experiment took place during the summer months of 1964, from the latter part of June to the middle of August. During this period, over 300 aircraft were observed. Noise data were obtained at from one to six stations for each of these aircraft. After analysis of the data, and screening of the positional information, the noise data, and the information on the aircraft and its procedures, the initial set of data was reduced to measurements on 80 aircraft following a specified procedure and 94 aircraft not following a specified procedure. A given flight was rejected if it did not have noise measurements for at least two or more ground positions with accurate altitude data on the aircraft during the flight. The final screening of the data resulted in 154 individual noise measurements for the specified procedure flights and 191 noise measurements on the non-specified procedure flights. A summary of the altitudes and perceived noise levels in PNdB for the reduced data employed in the analyses described in this report is provided in Appendix D.

The analyses of the data performed in this study are described in Section II of this report while the conclusions are contained in Section III. In addition to the appendices described above, Appendix C provides pertinent data on aircraft types observed during the study, and Appendix E describes the radar tracking equipment and the analysis of its data performed for this study; and Appendix F illustrates the effect of noise level and duration on noise exposure from jet aircraft departures.

II. ANALYSIS OF DATA

Previous studies[1] classify the noise producing characteristics of commercial jet aircraft by separating the aircraft into two categories, i.e. those using turbojet engines and those using turbofan engines. Within these two classes of aircraft the major differences in noise produced on the ground between one flight and another are functions of two factors: altitude and power setting. The various procedures used by different airlines differ fundamentally in the amount of power utilized during various segments of the departure and in the altitude attained over the community.

In this study we have purposely chosen to analyze only those flights in which the pilot attempted to make a straight-out departure along the projection of Runway 13R. Thus, power changes associated with a turning departure have not been included in our analysis. In this section we discuss the positional (altitude) data for each of the specified procedures and for the non-specified procedures, the noise data produced by the various flights, and the performance information deducible from the radar tracks of the aircraft departure paths.

A. Positional Data

In our analysis we have chosen to consider only the noise data and positional information obtained for flights that flew directly out from the airport, i.e. effectively over or near stations A, B, C, and D. These four stations span the community area from approximately one mile off the airport to the coast line. The stations themselves are approximately one mile apart. Station A corresponds very closely with the Port of New York Authority monitoring station adjacent to the Inwood Country Club. Station A is 900 feet to the side of the prolongation of the centerline of the runway. Stations B and C were directly beneath the flight path. Station D was located as close to the flight path as possible, under the topography limitations of the area; it is positioned 1200 feet to the side of the runway prolongation. The locations of these stations are indicated on Fig. B-1 in Appendix B.

Both slant height and altitude data were obtained during the field measurements by means of radar tracking and photographs. Slant heights, i.e. the distance of closest approach of the aircraft to the measurement stations, could be determined directly from radar tracks and from photographs. Altitudes could also be obtained directly from the radar, but only from those photographs where the aircraft passed directly overhead. Altitudes reported herein represent the heights of the aircraft at the time of closest approach to the individual measuring stations. Hence, an altitude reported for Position A, for example, represents the altitude of the aircraft at its closest point of approach to Position A. All slant height and altitude data used in this analysis are provided in Appendix D. In this section of the report we discuss the results of the analyses of the altitude data only.

The altitude data for flights following each of the four procedures considered in this analysis and for flights where no procedure was specified are plotted in Figs. 1 through 5.* In each figure the mean altitudes as well as the number of samples available are noted for Stations A, B, C, and D. Since every station was not able to obtain a noise measurement for each flight, we have coded on the figures those altitude data for which noise measurements are or are not available. In computing the mean altitude for each procedure we have included all altitude data points, whether or not noise data were available.

A summary of the altitude data for the various departure procedures is contained in Table I. This table lists the mean altitude and the standard deviation computed for data at each of the four measurement stations for Procedures 1, 4*, 7, and 8 as well as for the data corresponding to no specified procedures. Two sets of data are provided: 1) the mean altitude and standard deviation for all observed altitude data, and 2) the mean altitude and standard deviation for the altitude of those flights for which noise data were also available.

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* The data shown in Fig. 2 for Procedure 4 represent data for those flights which the pilots <u>indicated</u> they followed the procedure. Actually very few of the points are representative of a Procedure 4 departure.

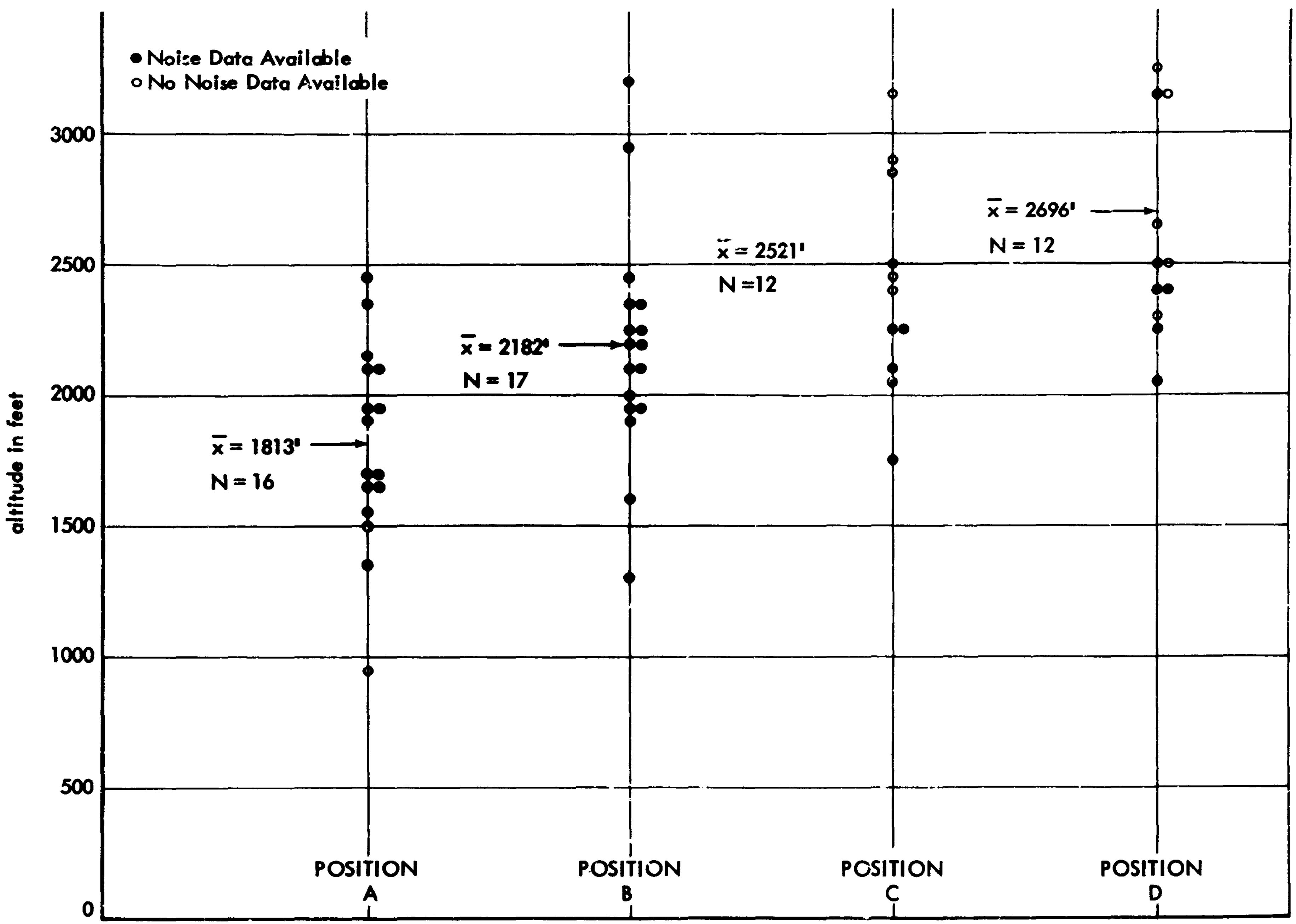

FIGURE 1. DISTRIBUTION OF AIRCRAFT ALTITUDES AT POSITIONS A, B, C, AND D FOR AIRCRAFT USING DEPARTURE PROCEDURE #1

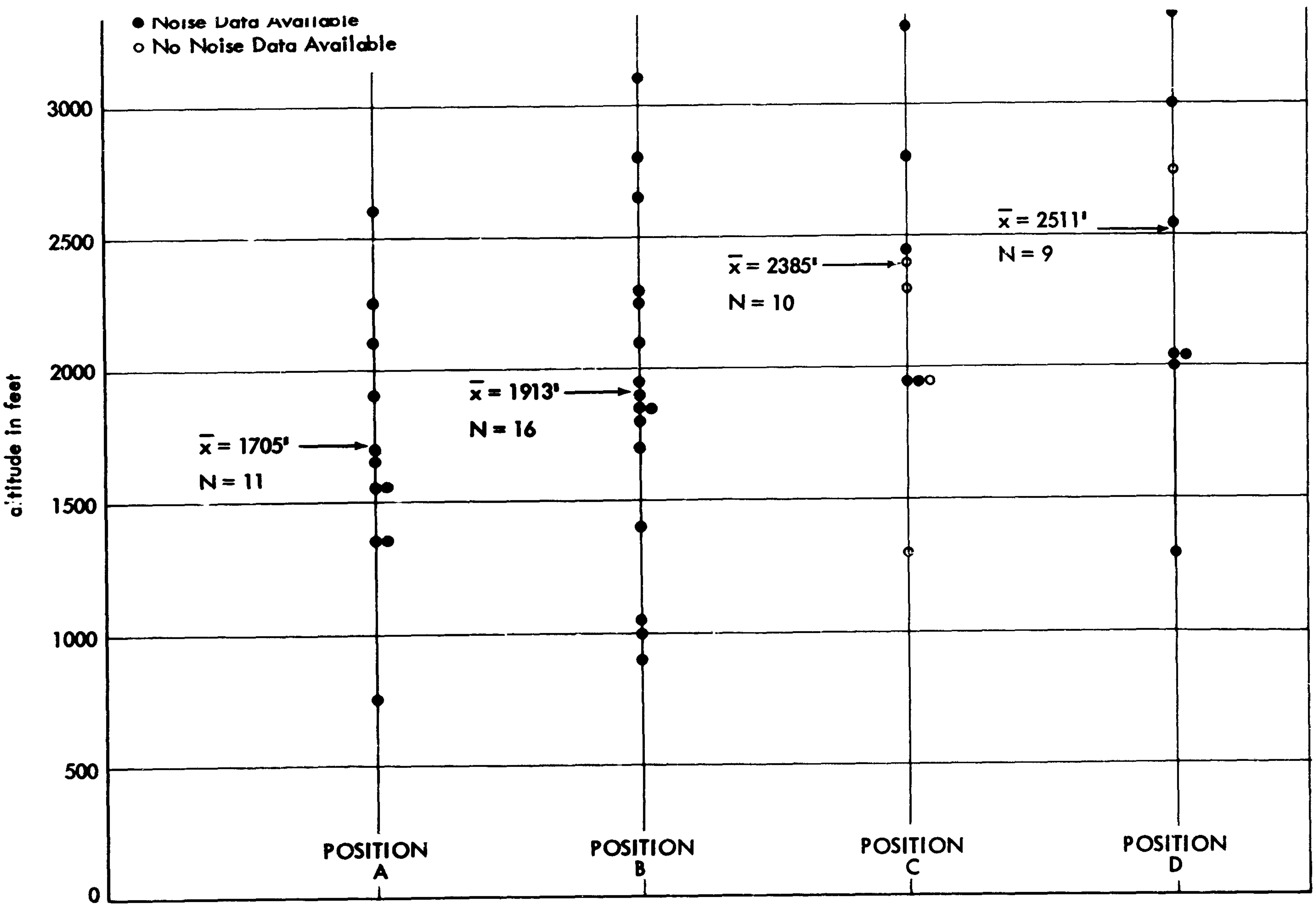

FIGURE 2. DISTRIBUTION OF AIRCRAFT ALTITUDES AT POSITIONS A, B, C, AND D FOR AIRCRAFT USING DEPARTURE PROCEDURE #4

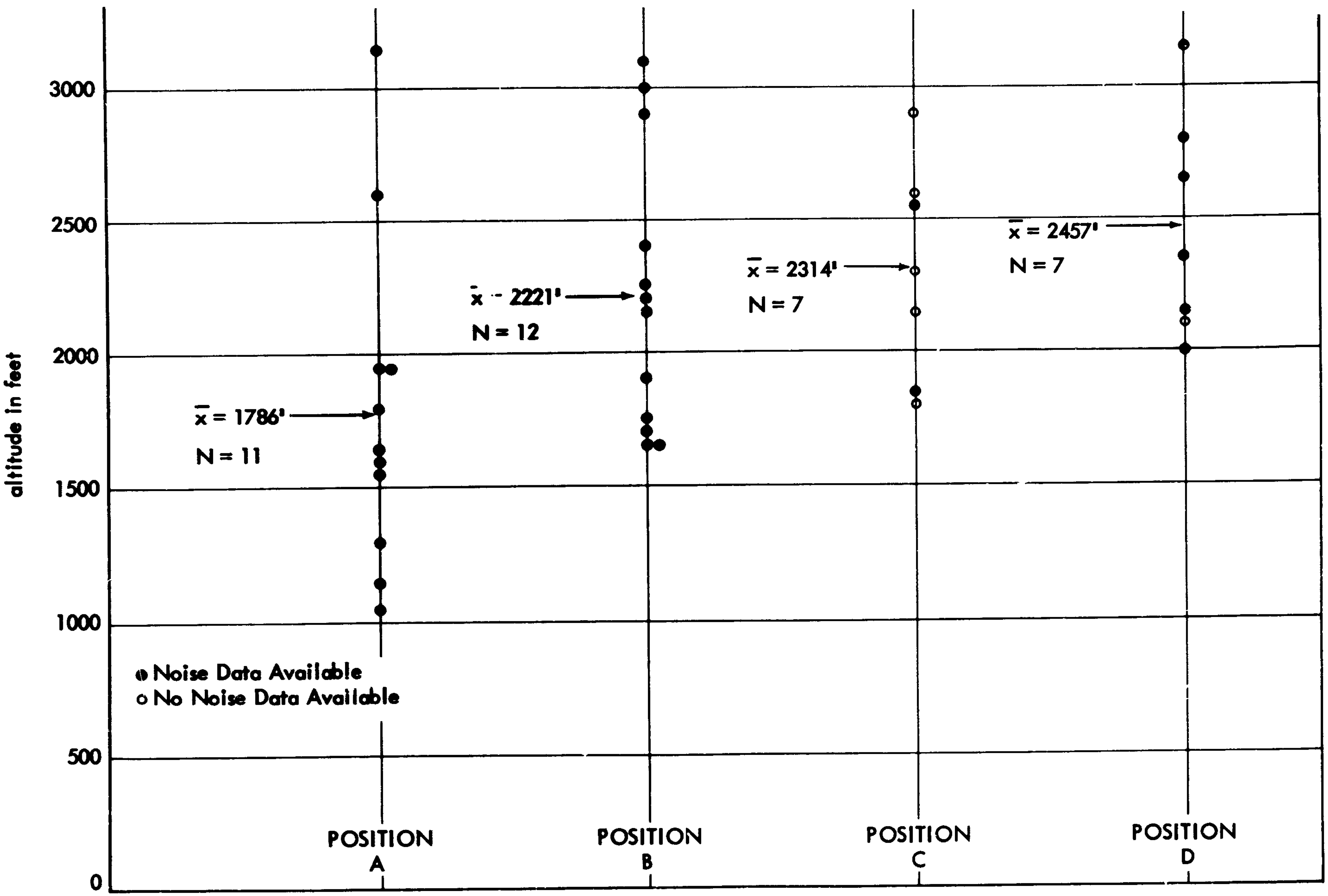

FIGURE 3. DISTRIBUTION OF AIRCRAFT ALTITUDES AT POSITIONS A, B, C, AND D FOR AIRCRAFT USING DEPARTURE PROCEDURE #7

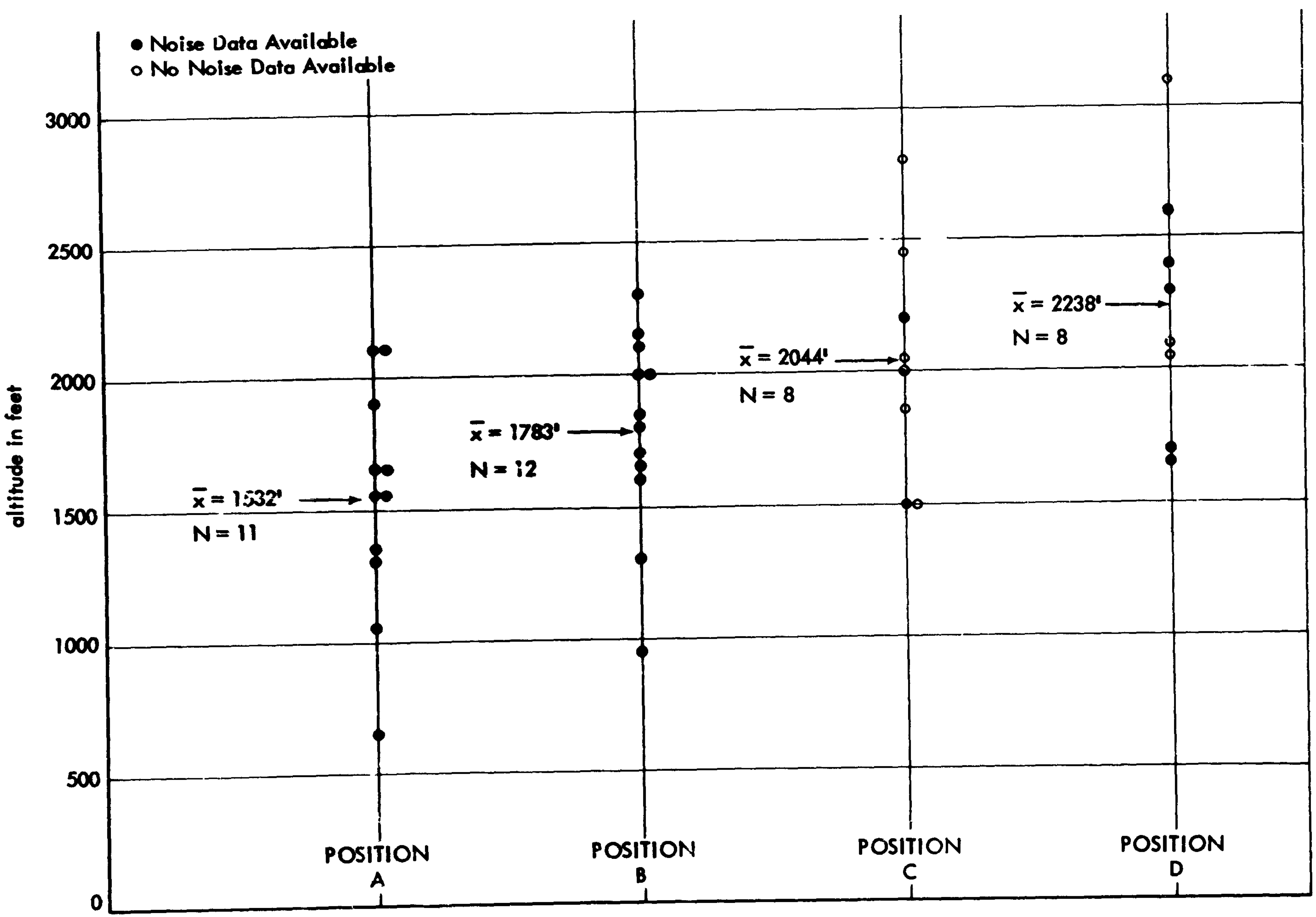

FIGURE 4. DISTRIBUTION OF AIRCRAFT ALTITUDES AT POSITIONS A, B, C, AND D FOR AIRCRAFT USING DEPARTURE PROCEDURE #8

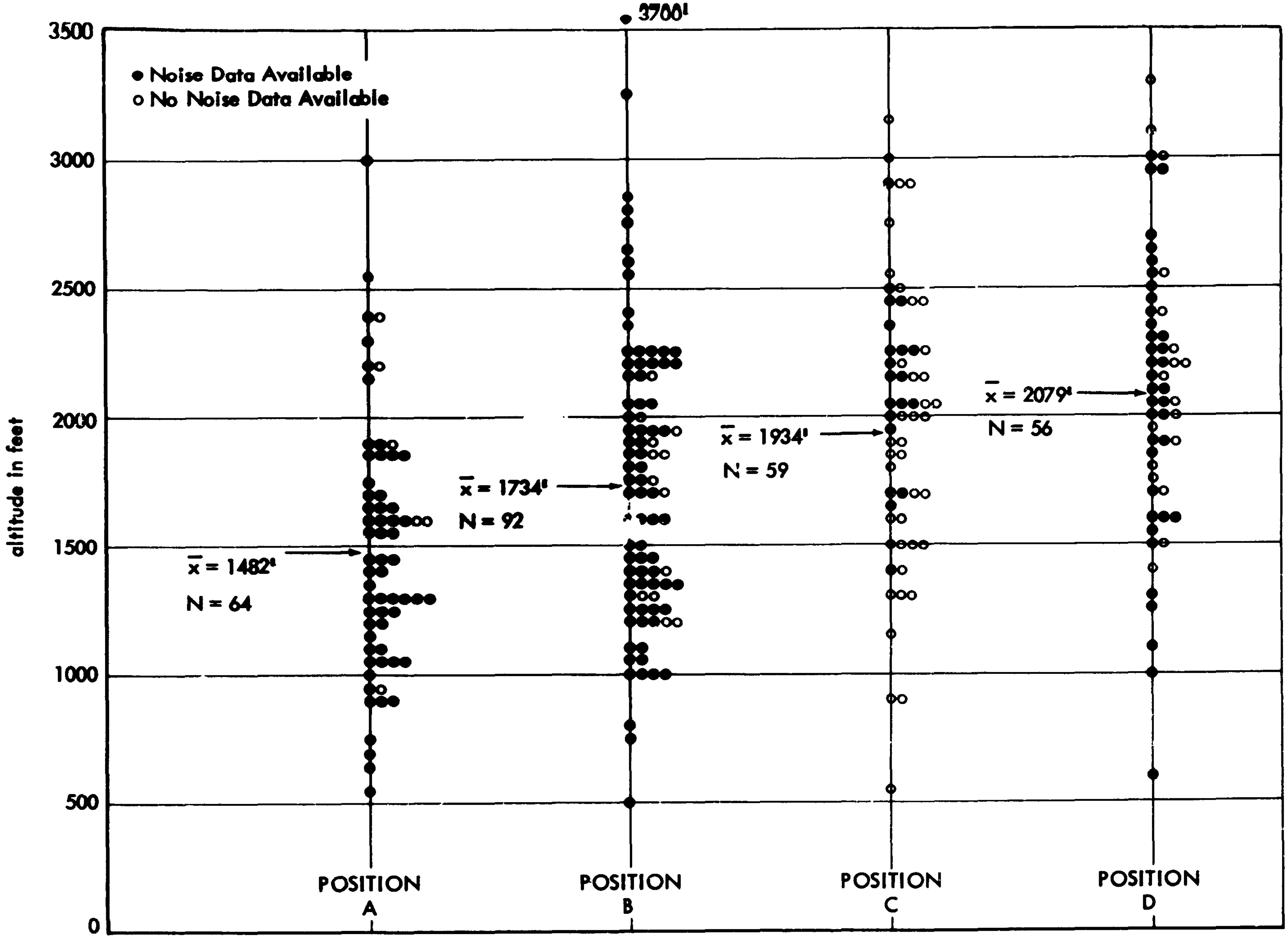

FIGURE 5. DISTRIBUTION OF AIRCRAFT ALTITUDES AT POSITIONS A, B, C, AND D

TABLE I

SUMMARY OF ALTITUDE DATA
FOR VARIOUS DEPARTURE PROCEDURES

PROCEDURE	STATION	ALL OBSERVED DATA			ALTITUDES FOR WHICH PNdB DATA ARE AVAILABLE		
		Number of Samples (N)	Mean Altitude Ft. ($\bar{x}$)	Standard Deviation Ft. (s)	Number of Samples (N)	Mean Altitude Ft. ($\bar{x}$)	Standard Deviation Ft. (s)
1	A	16	1813	386	15	1870	320
	B	17	2182	440	17	2182	440
	C	12	2521	510	7	2400	605
	D	12	2696	510	6	2458	374
4	A	11	1705	501	11	1705	501
	B	16	1913	631	16	1913	631
	C	10	2385	659	5	2490	577
	D	9	2511	727	8	2481	774
7	A	11	1786	620	11	1786	620
	B	12	2221	531	12	2221	531
	C	7	2314	396	2	-	-
	D	7	2457	424	6	2517	430
8	A	11	1532	437	11	1532	437
	B	12	1783	380	12	1783	380
	C	8	2044	446	2	-	-
	D	8	2238	478	5	2130	430
No Specified Procedure	A	64	1482	483	57	1435	460
	B	92	1734	556	77	1727	574
	C	59	1934	586	19	2116	351
	D	56	2079	534	38	2034	548

All calculations employed later in the analysis of the noise data for this study refer to the mean altitudes at each ground measurement station for the various procedures. Comparisons of the standard deviations of the altitudes for the various procedures do not indicate a substantial difference from one to the next. However, as can be observed from the figures, a fairly broad range of altitudes was observed for each set of data. The fact that standard deviations are not substantially different from one procedure to the next would indicate that, for those procedures where limited altitude data are available, the actual distribution for a large number of samples at those points might be somewhat approximated, in terms of range of data, by the type of distribution observed in Fig. 5 for non-specified procedures. The significant element as far as the present study is concerned is that the different procedures do provide somewhat different mean altitudes at various points along the flight path.

Figure 5 provides some interesting insight on the rather broad range in altitudes over the measurement stations of aircraft departures selected at random. Figure 5 indicates that, at any given point along the path, the altitude for different aircraft departures can range from little more than 500 feet to as much as 3700 feet. As will be indicated in the next section, this difference in altitude, combined with differences in engine power settings, can amount to a noise level range of as much as 25 PNdB or more.

B. Noise Data

In this analysis we are attempting to evaluate the noise on the ground produced by aircraft flying directly over a series of measurement points spaced somewhat equi-distant along the departure path. Since two of the four measurement points (A and D) were not directly underneath the straight-out flight path, and since, for various reasons, the aircraft did not always fly precisely straight-out along the center-line projection of the runway, minor corrections must be applied to the measured noise data so that they represent data for aircraft passing directly overhead.

All noise data have been adjusted to provide a "normalized" perceived noise level in PNdB that corresponds to the actual altitude of the aircraft at its point of closest approach.

This adjustment has been performed by applying a correction in PNdB for the difference between the aircraft altitude and its slant height. This correction is obtained from Fig. 6 which is a generalized plot of perceived noise level-versus-distance for turbojet and turbofan aircraft combined.1/* An example of the kind of correction involved can be seen from the following example:

> Assume a measured value of perceived noise level of 110 PNdB for an aircraft whose slant height is 1500 feet. Assume the actual altitude of the aircraft at the point of closest approach would have been 1300 feet. Reference to Fig. 6 shows that a value of 110 PNdB at a distance of 1500 feet would be equivalent to a value of 112 PNdB at a distance of 1300 feet.

The above procedure has been used to obtain "normalized" PNdB for all noise data included in this study. The values thus obtained are listed in the data summary of Appendix D. It is worth noting that this adjustment procedure in general is of minor consequence with typical corrections being of the order of zero to several decibels. The normalizing procedure does, however, provide a consistent basis for further analysis of the data, since the adjusted noise data correspond to a condition where Stations A, B, C, and D are located on the centerline extension of the runway and all aircraft passed directly over all four stations.

The change in the distribution of perceived noise levels when normalized, as compared to the actual observed values, can be seen by a comparison of Figs. 7 and 8. Figure 7 shows the distribution of measured PNdB (without any adjustment for the difference between slant height and altitude). On this figure the range of measured noise levels is 30 PNdB at Station A, 42 PNdB at Station B, 29 PNdB at Station C, and 35 PNdB at Station D. Adjustment of these noise levels for the difference between the slant height and altitude produces the distribution of normalized PNdB in Fig. 8. The The contraction or closer packing of the PNdB data shows clearly from this figure where the range at Station A is now reduced to 24 PNdB, at Station B to 28 PNdB, at Station C to 19 PNdB, and at Station D to 28 PNdB. Thus Fig. 9 is a

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* Air attenuation included in the derivation of this curve complies with the SAE Recommended Practice2/.

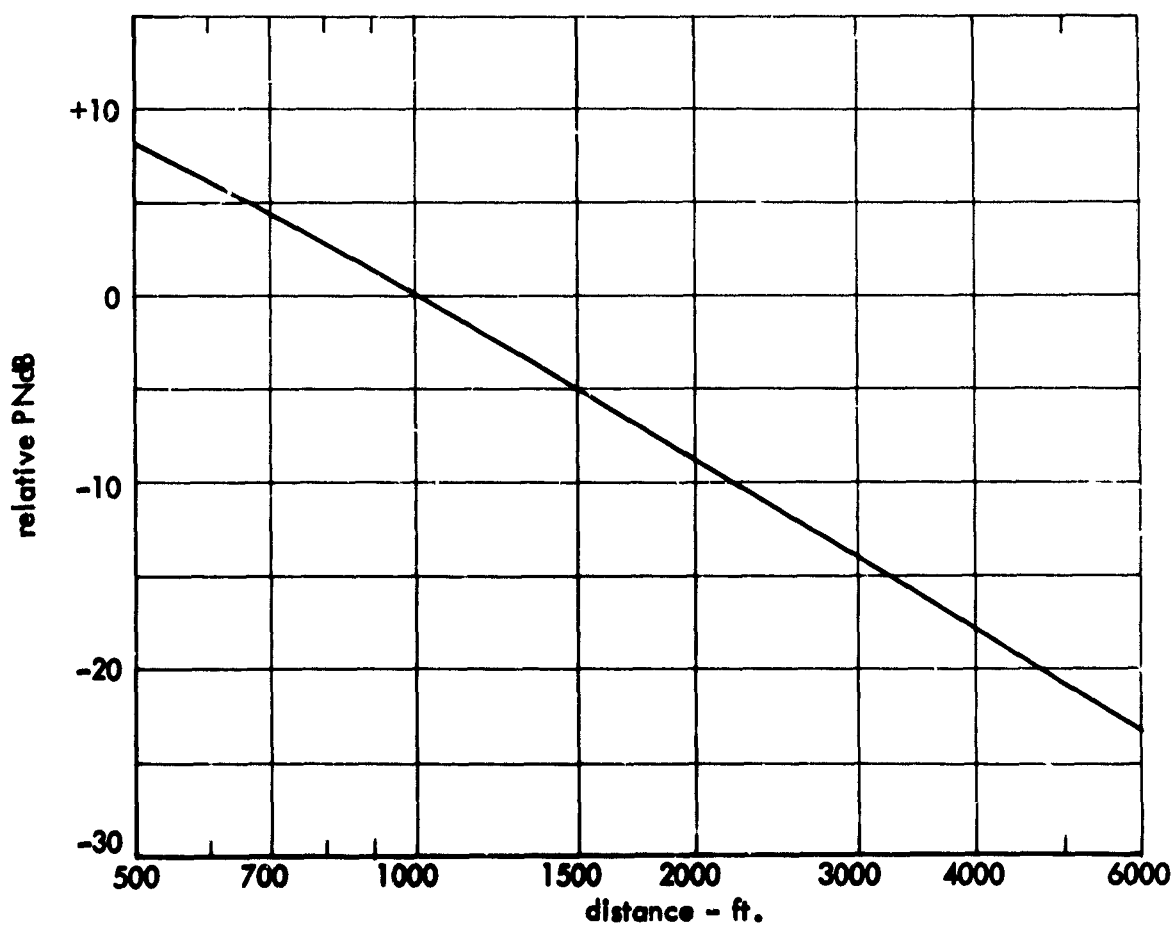


FIGURE 6. RELATIVE PNdB VERSUS DISTANCE FOR FOUR-ENGINE TURBOJETS AND TURBOFAN AIRCRAFT

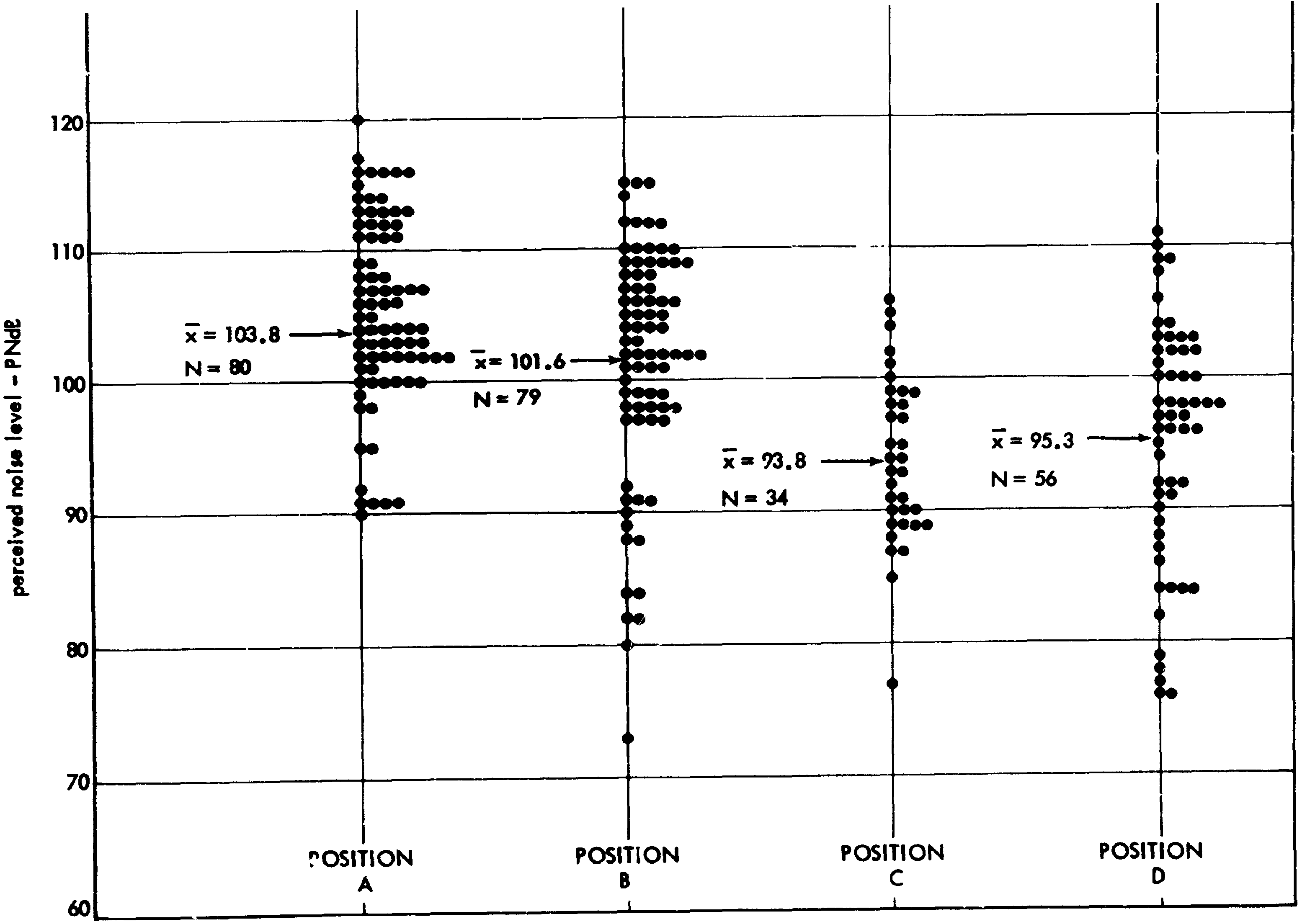


FIGURE 7. OBSERVED PERCEIVED NOISE LEVELS AT POSITIONS A, B, C, AND D FOR NON-SPECIFIED DEPARTURE PROCEDURES

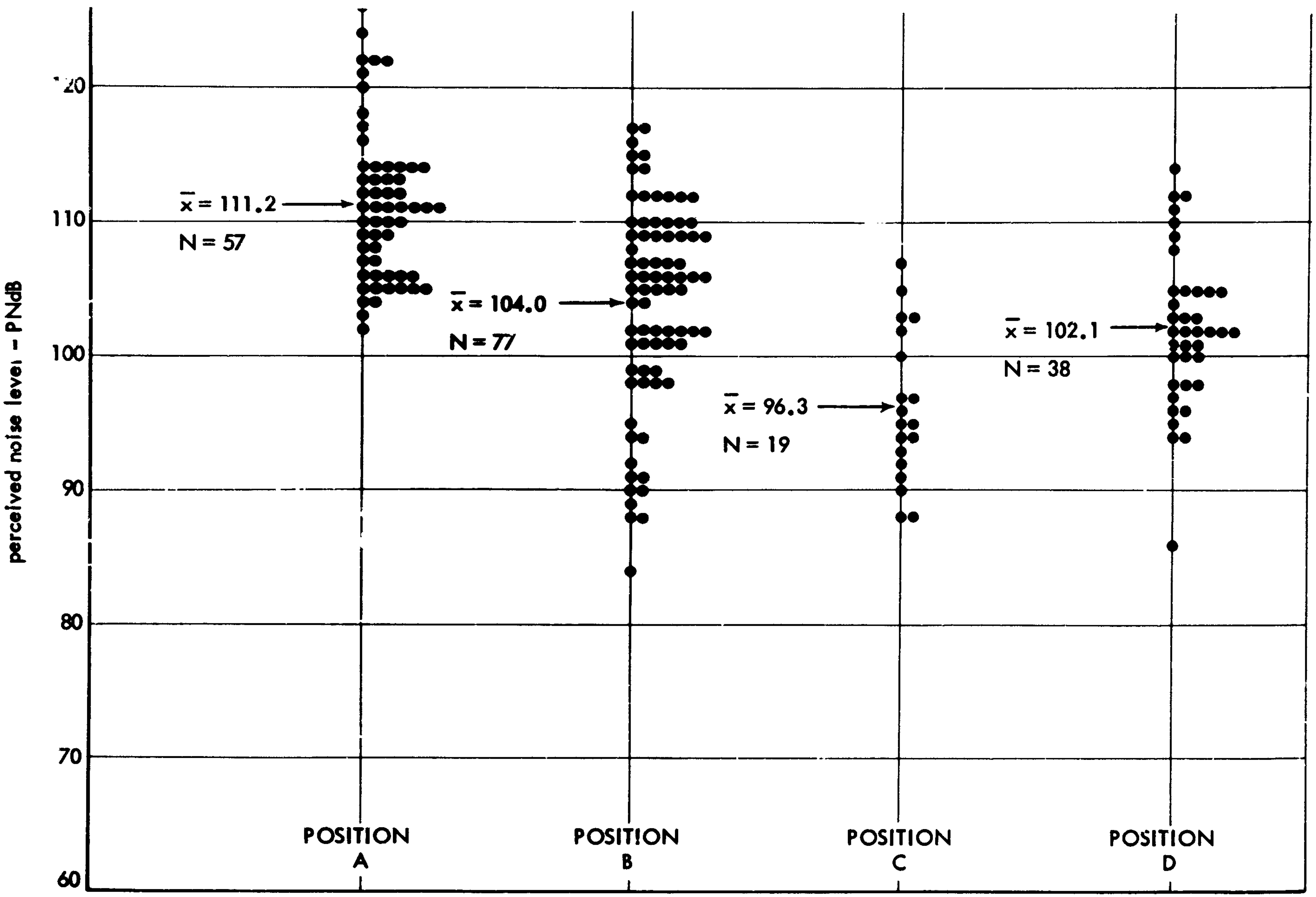


FIGURE 8. PERCEIVED NOISE LEVELS AT POSITIONS A, B, C, AND D NORMALIZED TO ALTITUDE FROM SLANT HEIGHT OBSERVATIONS FOR NON-SPECIFIED DEPARTURE PROCEDURES

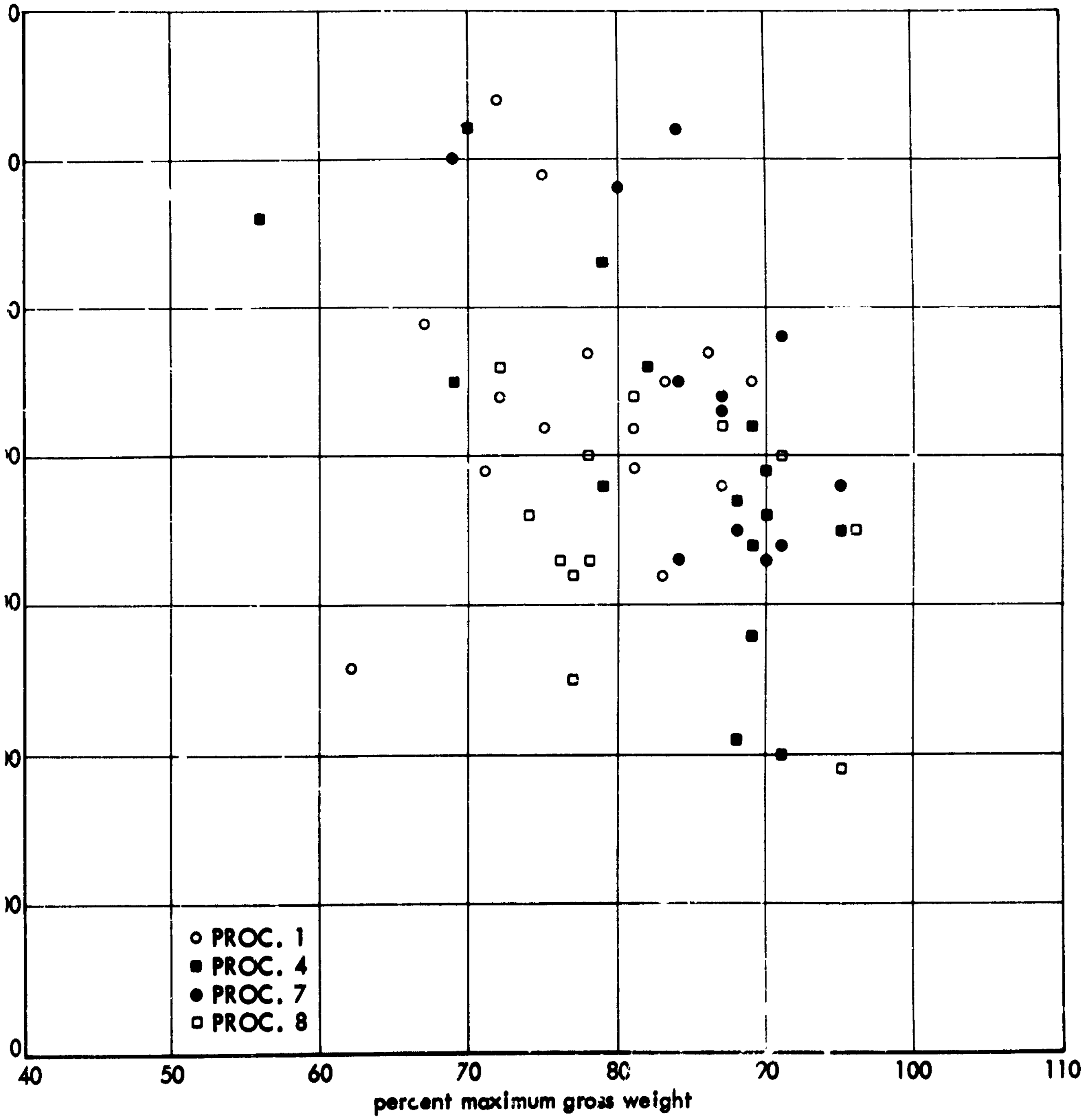


FIGURE 9. ALTITUDE VERSUS PERCENT GROSS WEIGHT FOR DIFFERENT PROCEDURES - POSITION B

good indication of the range of noise levels which would be observed if all aircraft flew directly over the measurement stations. Some data points have been dropped between Figs. 7 and 8 where inadequate altitude or slant height data did not permit a reliable adjustment in PNdB to be made.

The various procedures employed by the airlines specify altitudes for transitions in power setting, aircraft configuration, rate of climb, and speed. For a given power setting the pilot can trade rate-of-climb for acceleration in forward speed. His ability to do this is generally a function of the gross weight of the aircraft. Before proceeding with further analysis of the noise data we questioned whether or not the variation in gross weights of the aircraft influenced the broad range in observed altitudes for the different procedures. One hypothesis might be that, if all pilots followed precisely the same rate of climb and power setting procedure, then differences in altitude would be related to differences in gross weights of the aircraft. If this were shown to be true, then a correction would have to be applied to the data to minimize the effect of weight on the evaluation of the procedures.

We attempted to test this hypothesis by examining the relationship between altitudes and gross weights. For each of the specified procedures, takeoff gross weights were available. On the basis of rated maximum gross weights listed in Appendix C, we have converted the actual gross weight data to percent of maximum gross weight. We then plotted altitudes observed at Position B versus percent of maximum gross weight for aircraft following Procedures 1, 4, 7 and 8, as shown in Fig. 9.

Examination of this figure shows that within each procedure a wide range of altitudes for a given percent gross weight is experienced. While such a range might be expected for Procedure 1, in which several different airline procedures were involved, one would expect that, for Procedures 4, 7, and 8, where all pilots were supposedly following the same type of procedure, aircraft with the about the same percent gross weight would appear roughly at the same altitude. This is certainly not the case. One can argue that the central tendency within this grouping of data would lead one to conclude that the greater the weight of the aircraft, the lower its altitude over Position B. However, the variation in the altitudes for a given percentage gross weight is far more than might be expected. For a given percent gross weight the altitude varies by a factor of two or more. On the basis of this analysis we have assumed that variations in pilot technique and engine power setting are more significant in influencing the noise levels than variations attributable to gross weight of the aircraft during takeoff.

Since turbojet aircraft, in general, produce about 5 PNdB more noise than turbofan aircraft at the same altitude and comparable power settings, the available noise data were separated into two classes, those produced by turbojets, and those produced by turbofans. Further, it is of interest to consider when, and to what extent, aircraft taking off from Kennedy International Airport generally utilize a power cutback when flying over the community. For example, certain airlines follow a procedure whereby a power cutback is initiated prior to the PNYA monitoring station located approximately at Station A. These aircraft maintain the power cutback until clear of the monitoring station (approximately Station B), then may resume power. Other procedures call for reductions in power at various points in the departure procedure.

An indication of the extent of these power cutbacks for either turbojet or turbofan aircraft is contained in Figs. 10 and 11. In Fig. 10 the maximum PNdB observed at Station B are plotted as a function of altitude for turbojet aircraft flying non-specified procedures. The shaded section on the curve indicates the expected range of noise levels for jet aircraft if they maintain takeoff power during their departure[1]. As can be seen from the figure, a large number of the measured values fall below the takeoff power curve, indicating that power cutbacks are in effect, at least in the vicinity of Station B. It is of interest to note that in some cases, this cutback has reduced the noise levels produced with takeoff power by as much as 20 PNdB. Figure 11 provides a similar set of data for turbofan aircraft in the non-specified procedure category as observed at Station B. While it is generally true that one does not expect a significant lowering of noise as a result of cutting back the power on a turbofan engine, as contrasted to a turbojet engine, this figure does indicate that in some instances as much as a 10 PNdB reduction in noise level has been realized by turbofan aircraft through power cutback procedures.

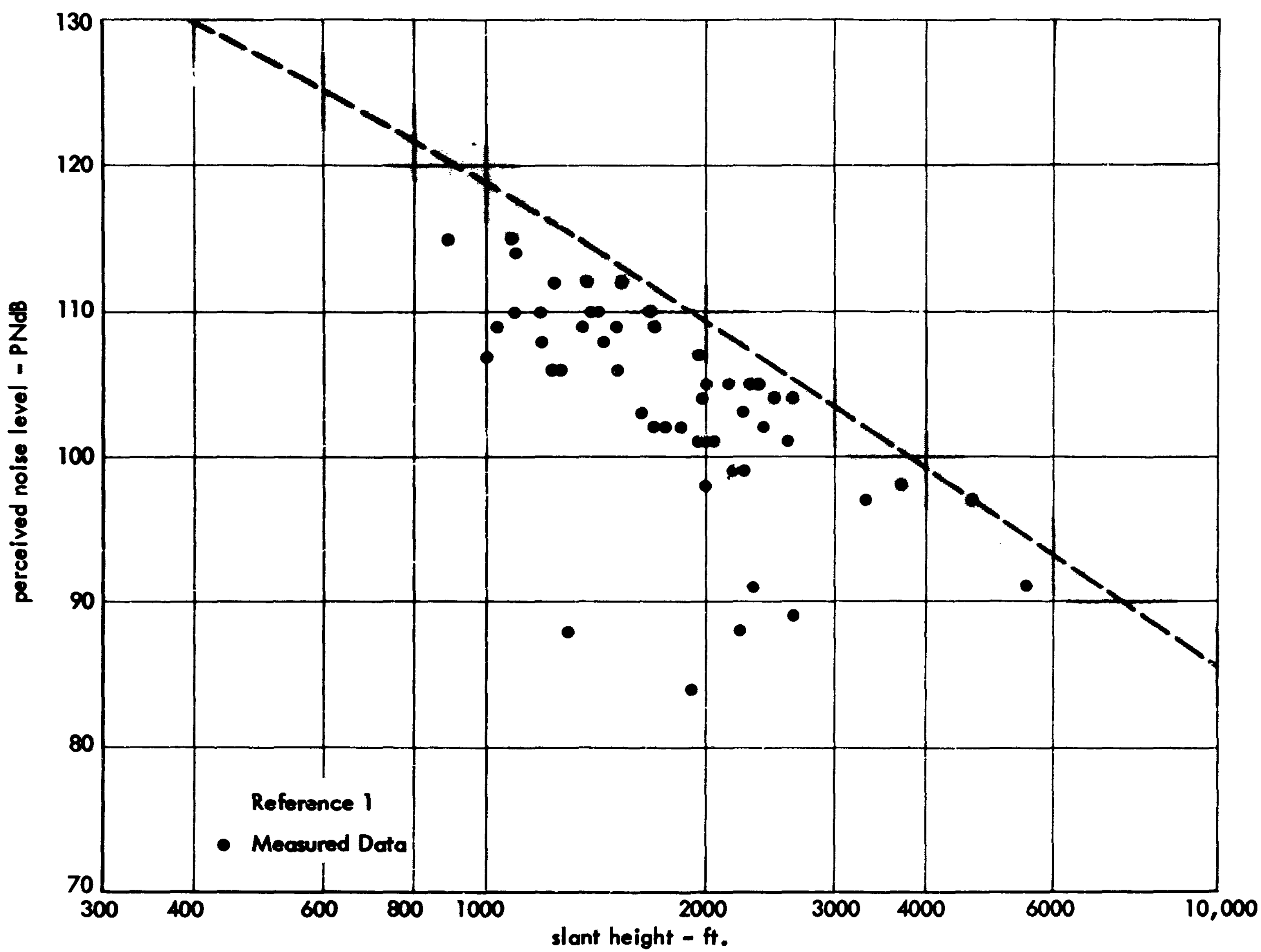


FIGURE 10. PERCEIVED NOISE LEVELS VERSUS SLANT HEIGHT AT POSITION B FOR TURBOJET AIRCRAFT DEPARTURES - NO SPECIFIED PROCEDURE

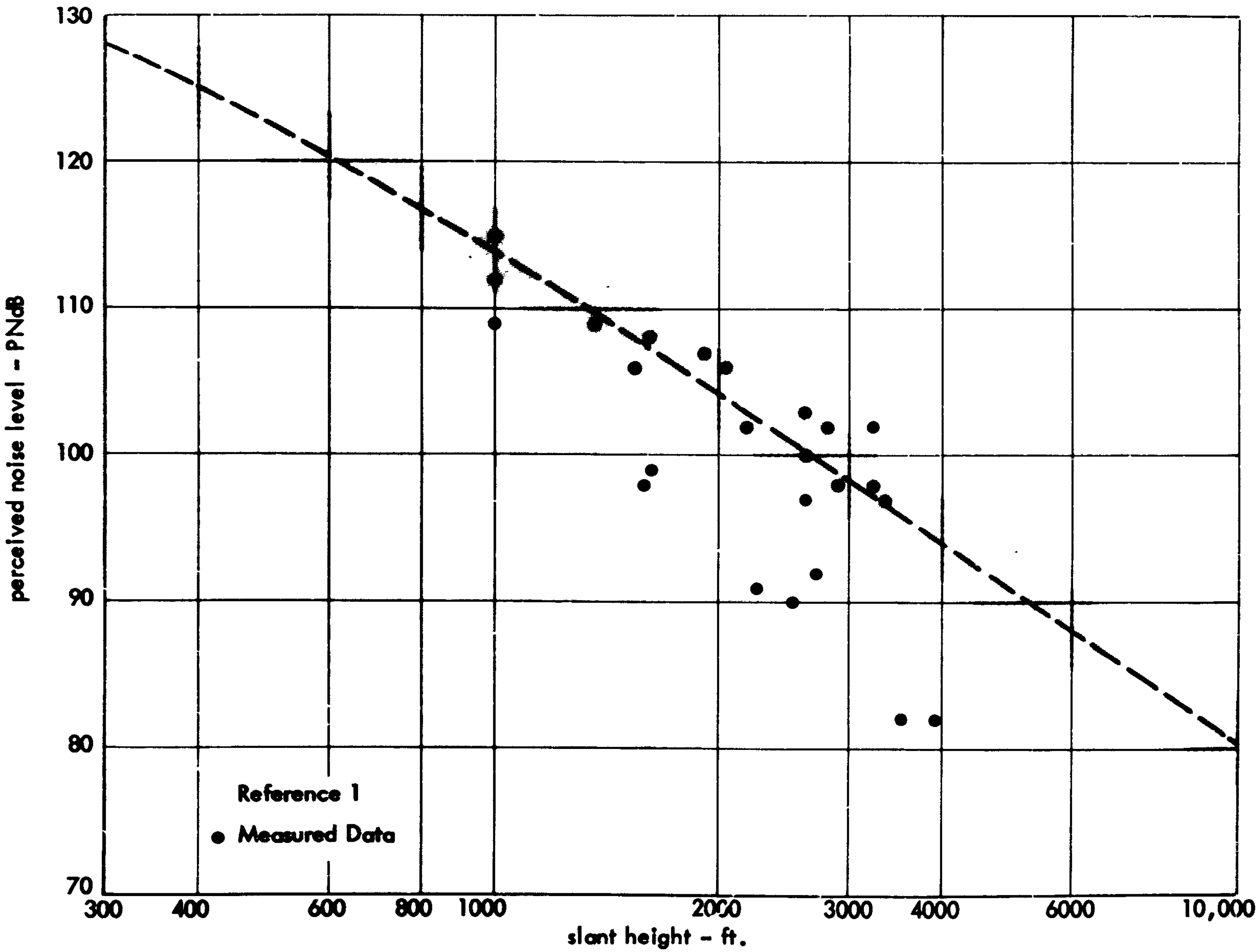


FIGURE 11. PERCEIVED NOISE LEVELS VERSUS SLANT HEIGHT AT POSITION B FOR TURBOFAN AIRCRAFT DEPARTURES - NO SPECIFIED PROCEDURE

C. Radar Data

Data from the radar tracks of aircraft departures have been employed, as noted above, to determine altitudes and slant heights. In the course of the analysis it was observed in many instances that aircraft, presumably following a stable power setting with a stabilized rate of climb, produced abnormal noise levels compared to what would have been expected if the aircraft had actually followed the procedure described. Careful study of the radar tracks for these aircraft revealed reasons why the noise levels would not be as expected. Figures 12 through 17 give an indication of the type of departures that were experienced for different kinds of procedures for different kinds of aircraft. The figures show altitude as a function of distance from the start of takeoff roll as obtained from computer processing of the radar data. Also shown on the figures are the locations for Stations A, B, C, and D (as if they were located directly under the path), along with the corresponding normalized PNdB values.

Study of the radar data provides insight on one of the major difficulties encountered in this program. Procedure 4, as described in Appendix A, implies that once over the noise sensitive area, the pilot was to maintain a constant power setting and a constant rate of climb. In not one instance did any of the pilots follow the procedure completely throughout the flight. If a constant power setting had been maintained, once the power cutback was performed, the noise levels at Stations B, C, and D would have gradually decreased as the aircraft gained altitude. For example, examine Fig. 12. At first glance the pilot seems to have followed the procedure which calls for a power cutback upon entering the community and a climb rate of a nominal 500 feet per minute. At Station A the noise level was 110 PNdB, while at Station B it was 91 PNdB. The altitude trace then indicates that the pilot apparently applied power shortly beyond Station B to increase his rate of climb, then reduced it again to stabilize back at 600 feet per minute. The increase in power, although of short duration, resulted in a noise level of 104 PNdB at Station C instead of approximately 89 or 90 PNdB which would have been observed if the power setting and climb rate which was established initially had been maintained. Thus, the observed noise levels at C and D were about 14 PNdB higher than would have been experienced if the engine power had not

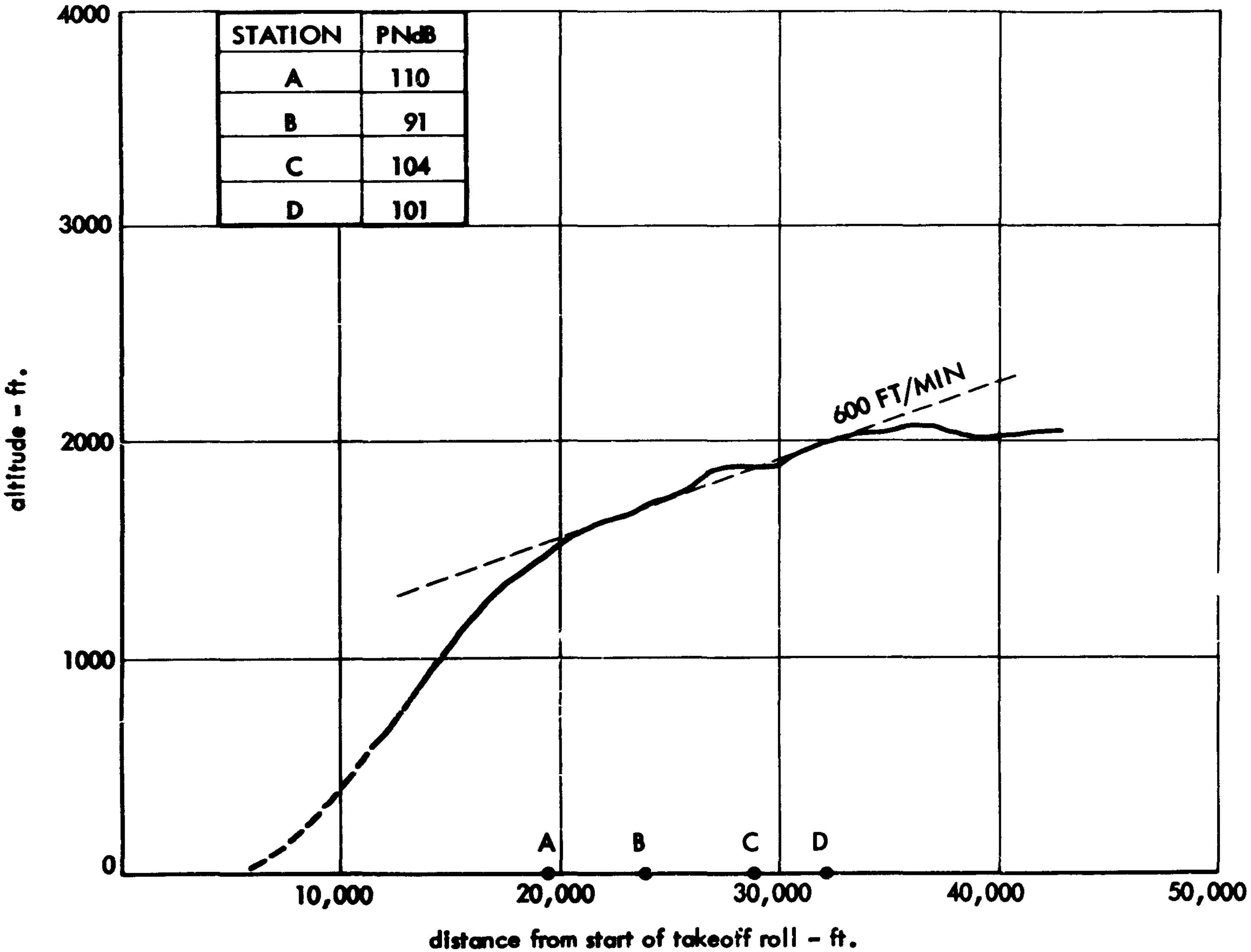
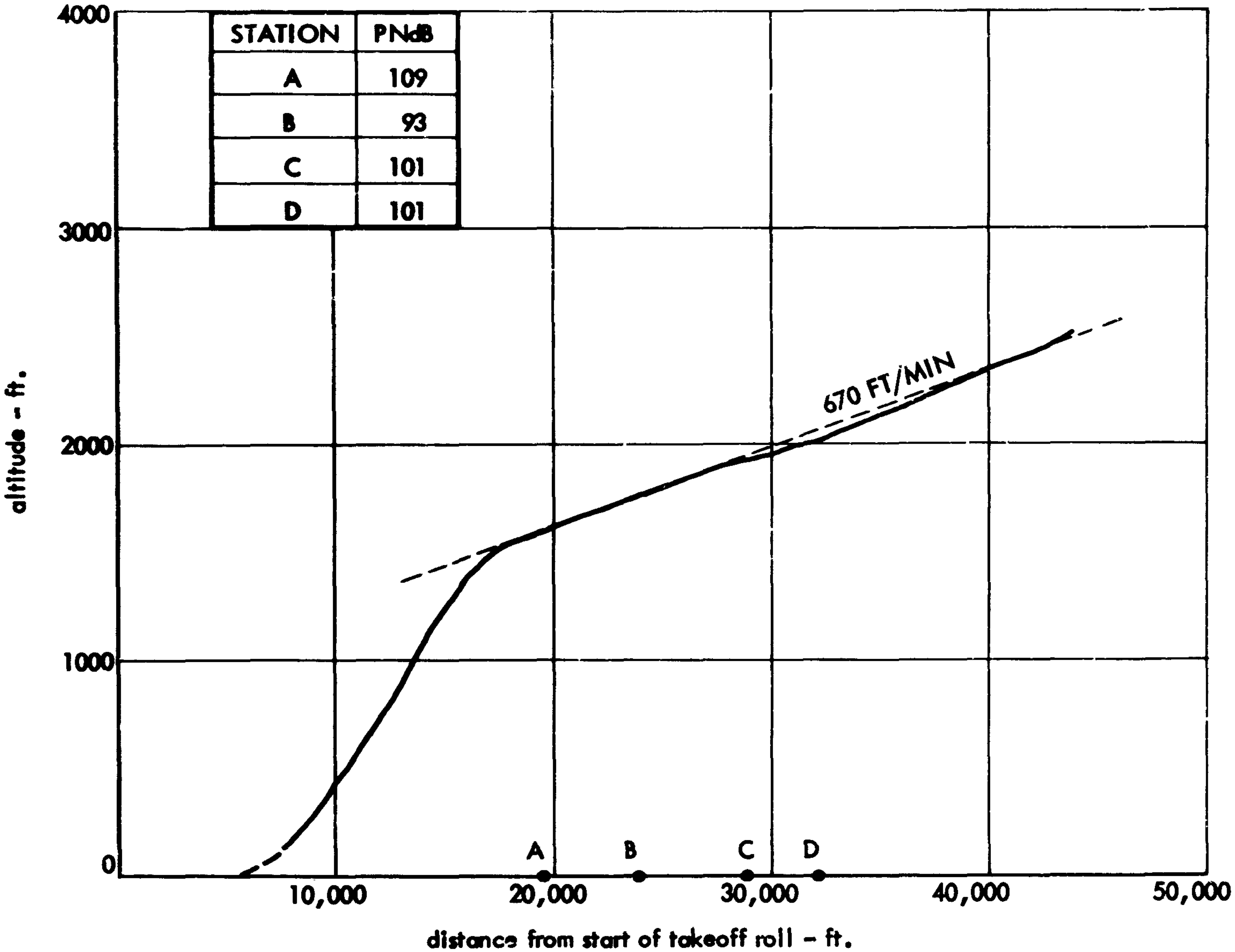


FIGURE 12. RADAR RECORD OF ALTITUDE VERSUS DISTANCE
PROCEDURE NO. 4 - ITEM NO. 4 - DC8-20



STATION	PNdB
A	109
B	93
C	101
D	101

FIGURE 13. RADAR RECORD OF ALTITUDE VERSUS DISTANCE
PROCEDURE NO. 4 - ITEM NO. 7 - 720-B

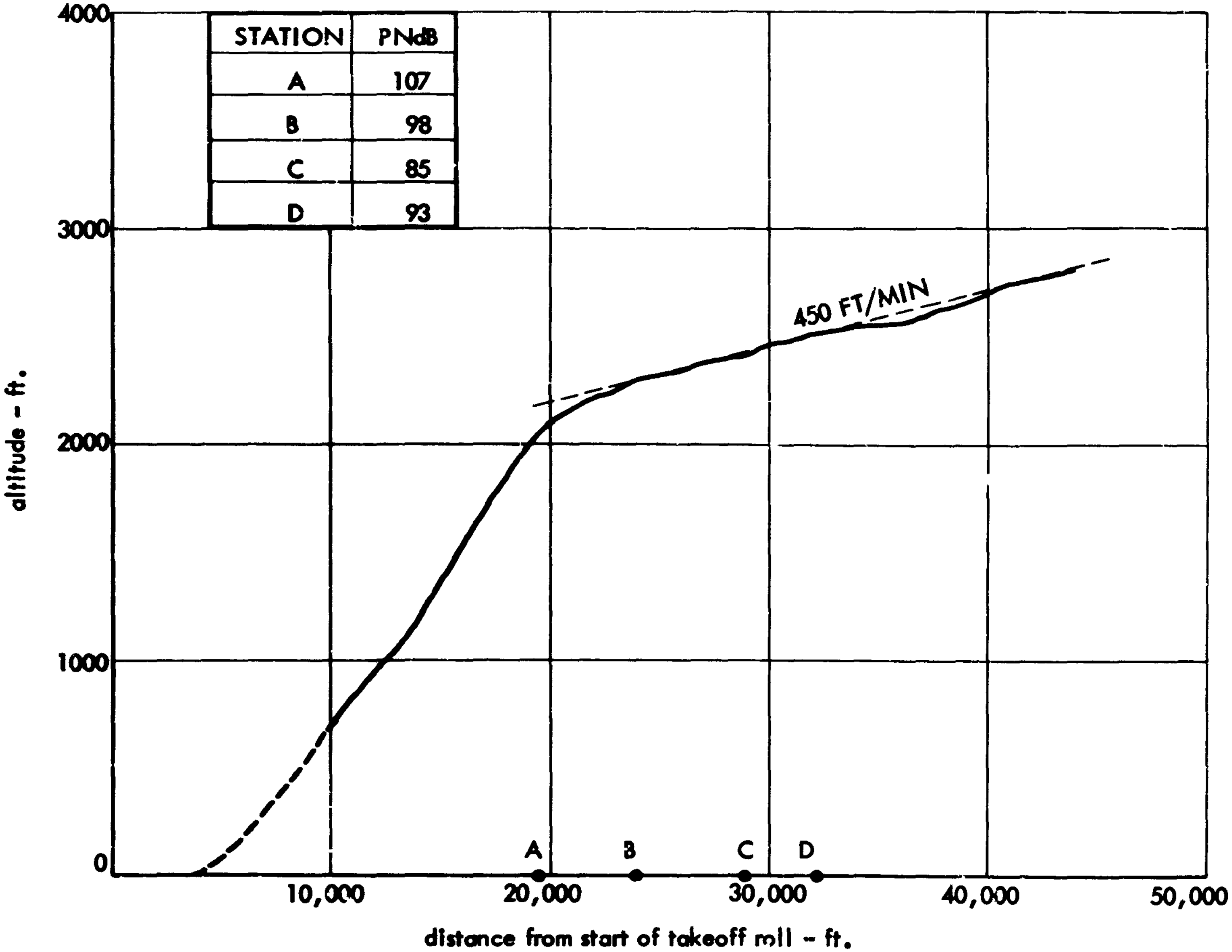
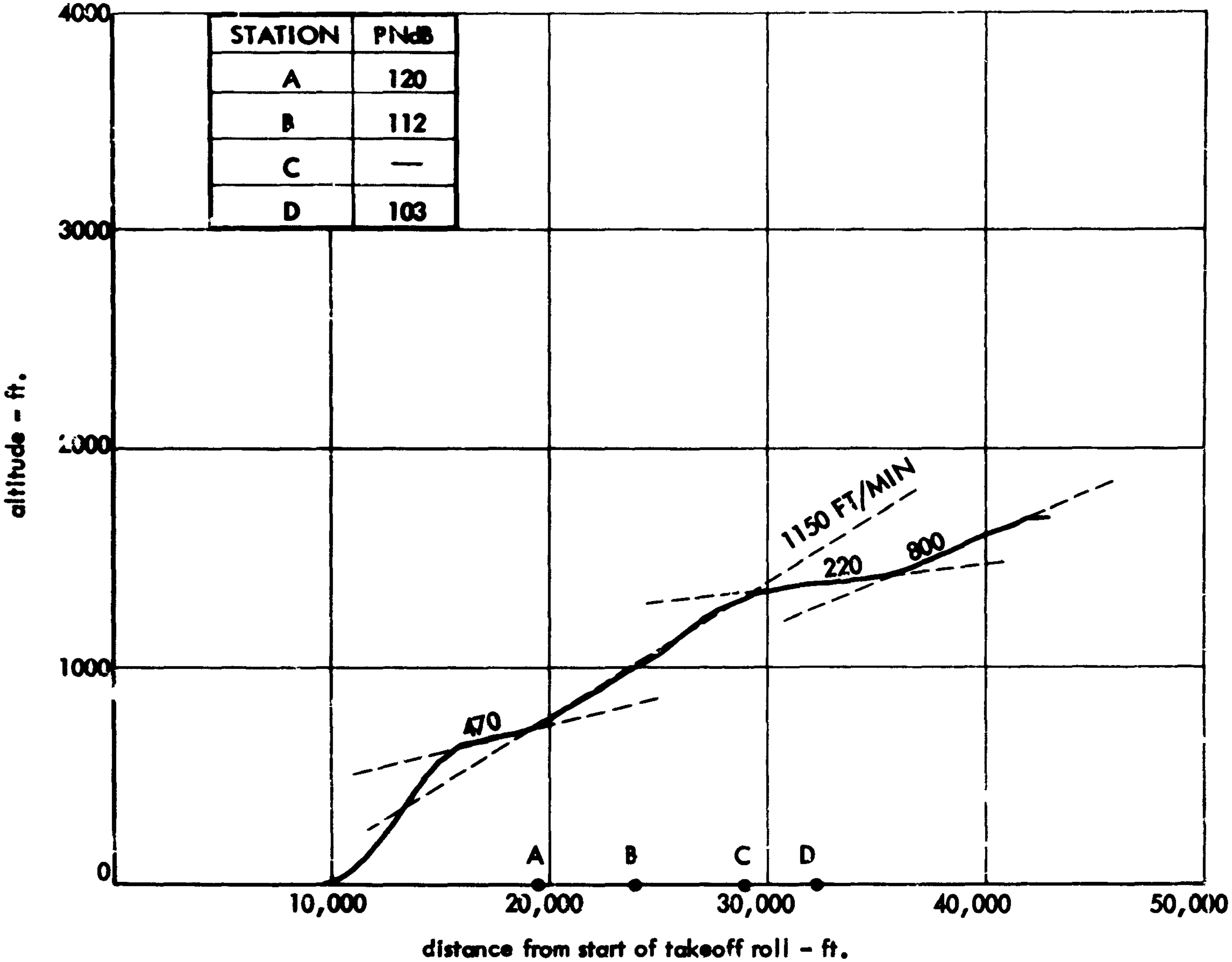


FIGURE 14. RADAR RECORD OF ALTITUDE VERSUS DISTANCE
PROCEDURE NO. 4 - ITEM NO. 10 - DC8-20



STATION	PNdB
A	120
B	112
C	—
D	103

FIGURE 15. RADAR RECORD OF ALTITUDE VERSUS DISTANCE
PROCEDURE NO. 4 - ITEM NO. 21 - 707-320

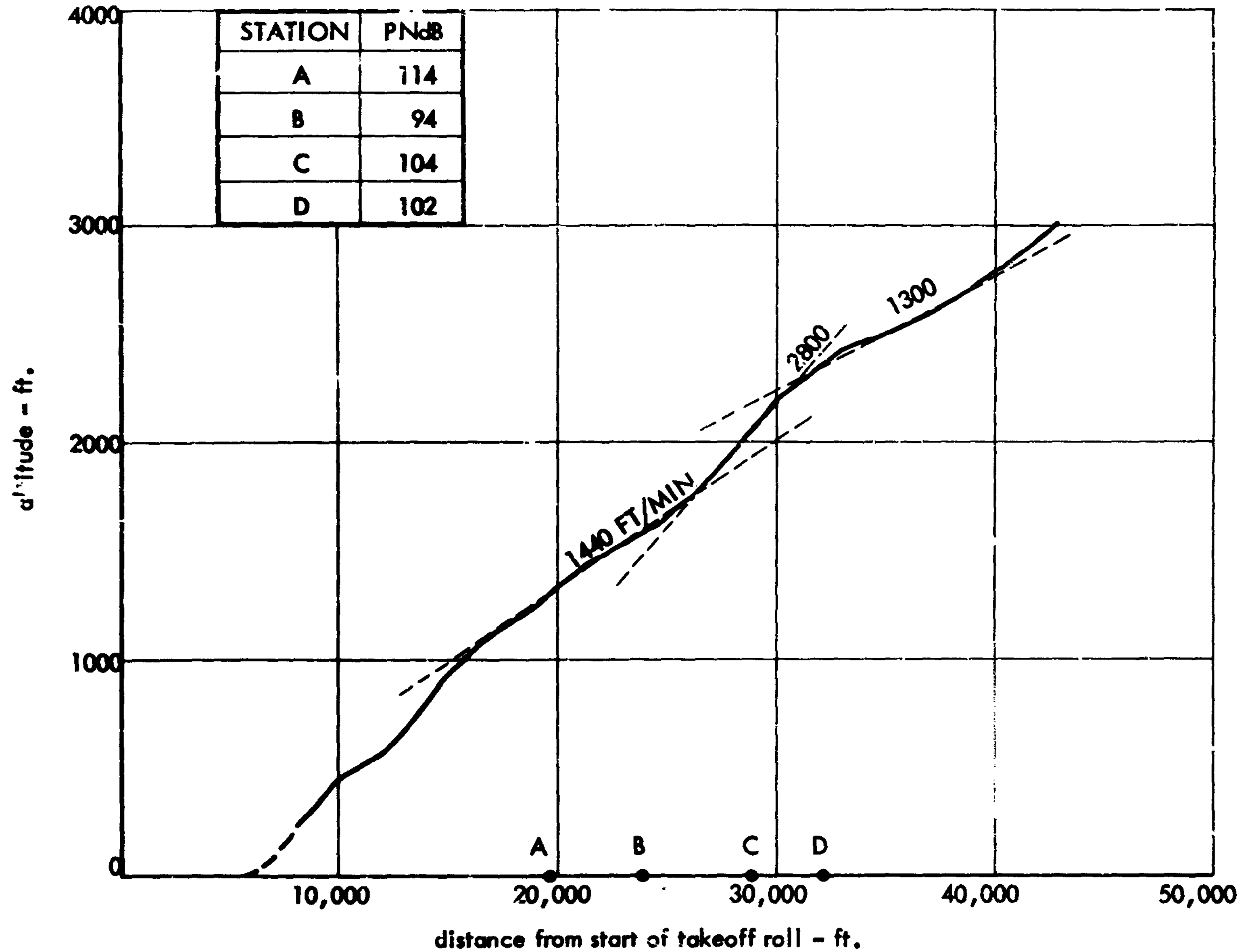


FIGURE 16. RADAR RECORD OF ALTITUDE VERSUS DISTANCE
PROCEDURE NO. 1 - ITEM NO. 2 - 880

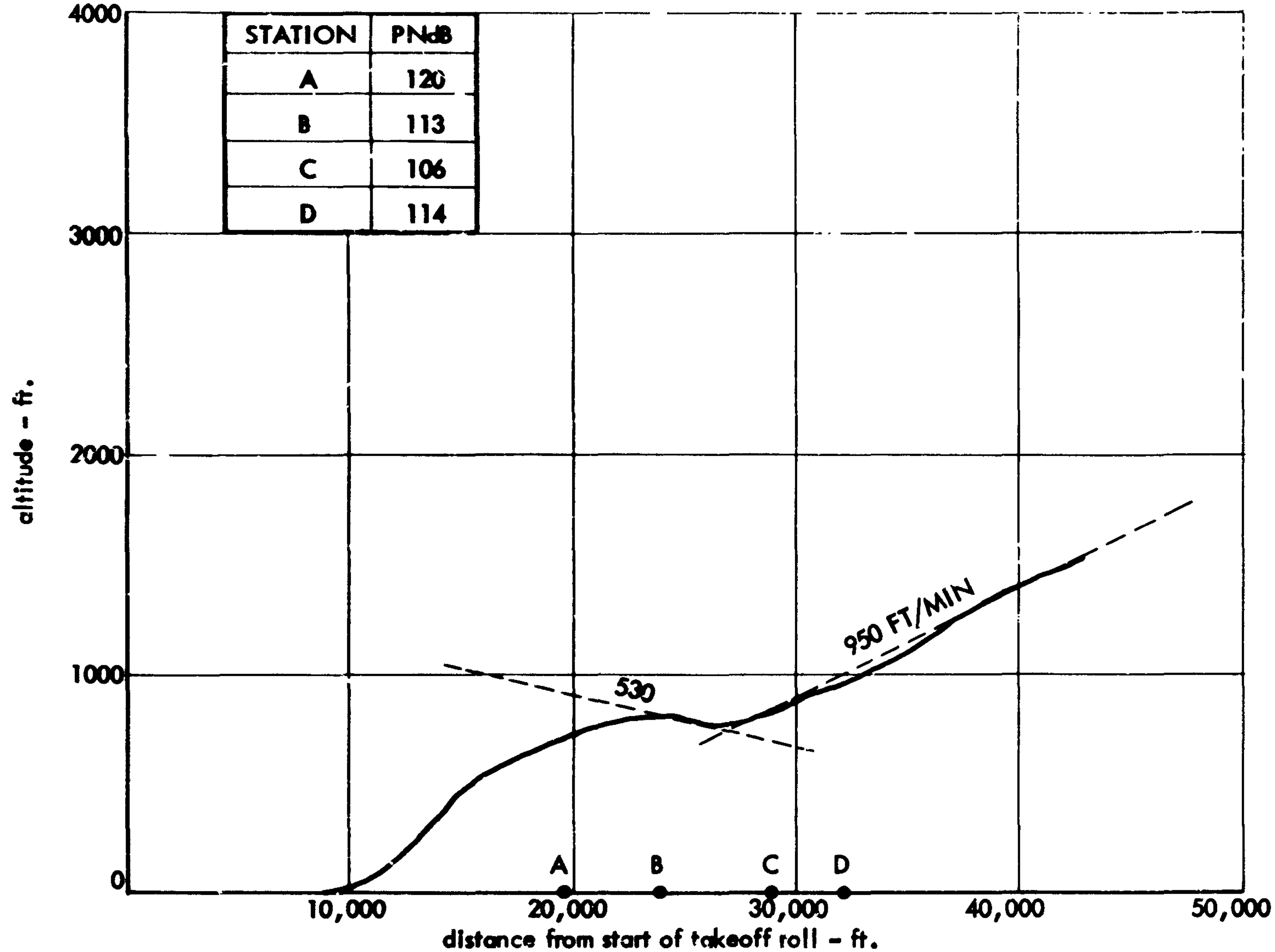


FIGURE 17. RADAR RECORD OF ALTITUDE VERSUS DISTANCE
PROCEDURE NO. 3 - ITEM NO. 2 - 707-320

been changed. The fact that the pilot altered his flight conditions just prior to the coastline is clear from his leveling out to utilize his power for acceleration. The resulting noise produced at Station D was 101 PNdB instead of approximately 88 PNdB which would have been produced if the pilot had maintained his rate of climb and power setting for another half mile.

Figure 13 illustrates another instance where a slight adjustment of power setting produced a much higher noise level than would be experienced otherwise. The pilot followed the procedure up through Station B, producing 109 PNdB at Station A, and, after his power cutback, 93 PNdB at Station B. The trace indicates that a slight decrease in rate of climb was experienced which the pilot compensated for by a slight adjustment in the throttle to regain his previous rate of climb. This throttle adjustment resulted in an increase of noise level at Stations C and D of 8 PNdB over that at B, instead of a reduction of several PNdB. Thus, noise levels 10 PNdB higher than necessary were caused at Stations C and D because of the throttle adjustment.

The pilot whose flight is shown in Fig. 14 followed the procedure carefully until he got between Stations C and D, at which time he proceeded to make a throttle adjustment similar to those indicated previously and increased his noise level slightly over that at Station C. However, the reduction in noise levels from Station A to Station C is significant, 22 PNdB. This is an indication of the amount of noise reduction that can be obtained through use of a procedure of this nature if no throttle adjustments are applied.

The flight indicated in Fig. 15 is typical of one in which the pilot experienced difficulty in following Procedure 4, even though he stated that he had followed it. This particular flight shows several stages of rate of climb rather than the single climb rate called for in the procedure. It's clear that the pilot did not adhere to his initial power reduction and rate of climb. He increased his rate of climb, then decreased it, and then increased it again. Accordingly, the noise data were of relatively little value in indicating the noise levels which a proper Procedure 4 would yield.

An example of the "Test Able" procedure in which the pilot uses a power cutback prior to passing over Station A, with a resumption of power when clear of the station, is shown in Fig. 16. In this particular instance the pilot did not perform his cutback quite as soon as he might, since he produced approximately 114 PNdB at Station A. However, the power cutback he did use reduced his noise level by 20 PNdB by the time he had reached Station B. It is interesting to note that he still had a climb rate of better than 1400 feet per minute during this operation. Shortly after clearing B, the pilot increased his power to produce a much higher climb rate. This increase in power yielded noise levels of 104 PNdB at Station C, and 102 PNdB at Station D.

A further example of an aircraft following a normal airline procedure is shown in Fig. 17. In this particular example the pilot, with a heavily laden aircraft, was to perform a power cutback on approaching Station A, and then resume his climb power at a later point. In this instance the pilot did not cut back soon enough, with a resultant noise level of 120 PNdB at Station A, and some reduction at Station B -- to 113 PNdB. The altitude plot indicates that the pilot recognized that he had not cut back sufficiently, so he cut back even further, to the point of losing altitude, resulting in 106 PNdB at Station C. Having felt he was close to clearing the populated area, the pilot then proceeded to increase power again to his normal rate of climb. This increase in power increased his noise level so that he produced 114 PNdB at Station D.

Examination of many of the other radar traces indicates very clearly that the power cutback associated with the Test Able procedure often occurs after the Station A position, and just prior to Station B. The reduction in noise levels expected at Station A is not nearly as significant, accordingly, as it is at Station B. One of the other illustrations provided by the radar traces is that often aircraft following this procedure will not only decrease the rate of climb, but will often cut back power sufficiently so that they lose altitude for as much as a half a mile before they resume power to regain their altitude.

One additional observation from the radar traces is that almost without exception, all aircraft do reduce power to some degree over the noise sensitive areas; however they invariably increase power, and hence the noise levels, before reaching the coastline. This is further illustrated by examination of the noise data in Fig. 8 where the noise levels at Station D are averaging approximately 6 PNdB more than those at Station C. This figure supports the conclusion that the pilots are adding power at about the time they approach the coastline, forgetting that adding power at this point will produce much higher noise levels on the ground after the aircraft passes overhead because of the directivity pattern of the jet noise field. Holding the power cutback for another half mile or more would minimize the increased noise level conditions near the coastline.

D. Comparison of Procedures

The data acquired in this study and the analyses described in this section permit us to compare the various procedures and draw certain conclusions on their capability to minimize noise produced on the ground during takeoff operations. The ranges of noise levels, coupled with the relatively similar variances in altitude around the mean altitude for each of the procedures, at each of the stations, suggests that a valid approach to evaluating the procedures is to compare directly their mean noise levels.

For Procedures 1, 7 and 8 the pilots' reports and the radar traces lead us to accept essentially all data from these procedures as being valid for the procedural class specified. On the other hand, the data for Procedure 4 do not indicate that a sufficient number of pilots followed the procedure completely as specified so that little of the observed data beyond Station A can be used meaningfully. Even at Station A only about half of the observed noise levels indicate that a power cutback was employed in accordance with Procedure 4. Typical examples of non-conformance with Procedure 4 have been illustrated above. To arrive at suitable mean values of noise levels for Procedure 4 at Stations B, C, and D, it has been necessary to estimate these values from the data at Station A and from data on individual flights at individual stations where the aircraft appeared to be following the procedure, as indicated by the radar traces and the normalized PNdB values.

The estimation of mean noise levels for Procedure 4 was performed as follows. We examined the noise data at Station A to determine which PNdB values were representative of flights that followed the procedure. Based on this determination we then examined the radar traces and the noise data at Station B to select those flights which were following the procedure over Station B. These data were then assumed to apply for these two positions. We next assumed, as called out in the procedure, that the aircraft would have been climbing at a normal rate of 500 feet per minute from Station A past Station D. Utilizing this rate of climb information we calculated the average change in altitude between Stations B and C, and Stations C and D. Assuming that the engine power over Stations C and D would be the same as that existing over Station B, we calculated the change in perceived noise levels that would result from the change in altitude only, based on Fig. 6. These changes in noise level were then used to extrapolate the noise levels at Station B to Stations C and D. In all instances there are sample flights during which the pilot followed the procedure for at least two points along the path so that we verify that such noise levels were achieved during that part of the flight.

A summary of the mean perceived noise levels in PNdB for the different procedures and for the non-specified departures is provided in Table II-A. The estimated noise levels at each of these stations, if takeoff power had been maintained continually over the flight path, and the aircraft were at the mean altitude indicated for the non-specified procedural path, have also been listed in Table II-A. In each instance the data have been separated into turbojet and turbofan aircraft categories.

To assist in comparison of the various procedures the differences in PNdB between the various specified procedures and the non-specified departures, at each of the four stations, is shown in Table II-B. The table also indicates the difference in PNdB between the non-specified departures and the values estimated for continuous takeoff power. The average of the differences in PNdB between the various procedures and the non-specified procedures are given in the last columns of the table. It is worth observing that all procedures, as well as the random selection of departures with no specified procedure, show an average noise reduction compared to the takeoff power condition of the order of 5 PNdB.

TABLE II

COMPARISON OF PERCEIVED NOISE LEVELS UNDER TAKEOFF PATH FOR SEVERAL DEPARTURE PROCEDURES

A) Mean Perceived Noise Level in PNdB

Procedure	Station A		Station B		Station C		Station D	
	Jet	Fan	Jet	Fan	Jet	Fan	Jet	Fan
1	114	104	108	97	104	96	107	98
4	105	100	95	94	93	92	91	90
7	108	101	104	97	103	96	102	96
8	111	109	103	103	102	102	105	101
No Spec.	113	109	105	103	97	95	104	99
T.O. Power (Est.)	113	108	111	106	108	105	109	105

B) Difference in PNdB Between Specified Procedures and Non-Specified Departures

Proc.	Station A		Station B		Station C		Station D		Avg. of Diff.	
	Jet	Fan	Jet	Fan	Jet	Fan	Jet	Fan	Jet	Fan
1	+1	-5	+3	-6	+7	+1	+3	-1	+3.5	-3.8
4	-8	-9	-10	-9	-4	-3	-13	-9	-8.8	-7.5
7	-5	-8	-1	-6	+6	+1	-2	-3	-0.5	-4.0
8	-2	0	-2	0	+5	+7	+1	+2	+0.5	+2.3
T.O. Power (Est.)	0	-1	+6	+3	+11	+10	+5	+6	+5.5	+4.5

C) Difference in PNdB Between Various Procedures and Procedure 4

Proc.	Station A		Station B		Station C		Station D		Avg. of Diff.	
	Jet	Fan	Jet	Fan	Jet	Fan	Jet	Fan	Jet	Fan
1	+9	+4	+13	+3	+11	+4	+16	+8	+12.3	+4.8
7	+3	+1	+9	+3	+10	+4	+11	+6	+8.3	+3.5
8	+6	+9	+8	+9	+9	+10	+14	+11	+9.3	+9.8
No Spec.	+8	+9	+10	+9	+4	+3	+13	+9	+9.3	+7.5
T.O. Power (Est.)	+8	+8	+6	+12	+15	+13	+18	+15	+11.8	+12.0

These data indicate that, if Procedure 4 is followed completely, it provides a substantial noise reduction over the other specified procedures and over the average values of the non-specified procedures. To illustrate the relative differences between these procedures and Procedure 4, the PNdB differences are summarized in Table II-C.

Computations of statistical variance were performed for all normalized PNdB values for each set of procedures at each of Stations A, B, C, and D where enough data were available. These analyses showed standard deviations ranging from about 5 to 8 PNdB, with the exception of that for Procedure 1 at Station B which was 11.8 PNdB. No substantial difference was found, with this exception, among the variances in PNdB at any of the stations for Procedures 1, 7, 8, and the non-specified procedure data. No usable calculations could be made for Procedure 4.

The much larger number of samples available for the non-specified procedures leads us to believe that it provides a useful indication of the variance to be expected in the noise data from random takeoffs. For comparison of the variance for all the useful noise data with that for the non-specified procedure data we combined all of the data at each measurement station to compute an overall standard deviation at each station, giving proper weighting to the sample sizes of each set of data. These standard deviations, compared with those for the non-specified procedures, are listed in Table III.

We conclude from these results that standard deviations of from 5 to 8 PNdB are characteristic for noise levels at points directly under the takeoff path in the vicinity of an airport regardless of departure procedures employed. It is worth noting that, on the basis of altitude variance alone, only from 2 to 4 PNdB can be attributed solely to altitude variations. Thus, as might be expected, the combined effect of such items as power setting, aircraft type, gross weight, and pilot technique constitute a major component of the variance in noise levels.

TABLE III

STANDARD DEVIATIONS OF NOISE LEVEL IN PNdB
FOR NON-SPECIFIED PROCEDURES AND FOR ALL DATA

STATION	NON-SPECIFIED PROCEDURES		ALL DATA	
	Number of Samples (N)	Standard Deviation (s)	Number of Samples (N)	Standard Deviation (s)
A	57	5.8	105	6.1
B	77	7.6	134	7.7
C	19	5.7	31	7.6
D	38	5.7	63	5.2

III. CONCLUSIONS

On the basis of the analysis and results described in the previous section, we conclude the following:

1) The perceived noise levels associated with all departure procedures being employed at Kennedy International Airport today (which will be referred to as the "control group")* average 5 PNdB less over the noise sensitive communities than would be produced by aircraft flying with full takeoff power.

2) Turbojet aircraft following procedures outlined by the participating airlines (Procedure 1) produced approximately 3.5 PNdB more noise than the average of all turbojets in the control group. However, turbofan aircraft following Procedure 1 produced an average of 3.8 PNdB less than the average of all turbofan aircraft in the control group.

3) Turbojet aircraft following the Air Line Pilots Association proposed procedures (Procedures 7 and 8) provide a negligible average difference in noise levels when compared with turbojet aircraft in the control group. However, in the case of turbofan aircraft, those following Procedure 7 yield a net reduction in noise level of 4 PNdB compared with turbofan aircraft in the control group, while those following Procedure 8 produce approximately 2.3 PNdB more noise than the control group.

4) Aircraft following an accurate Procedure 4 would yield an average reduction in noise level in the community of 7.5 PNdB for turbofans and 8.8 PNdB for turbojets compared to the control group.

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* In these conclusions we consider that the random sample of non-specified departures are representative of all departure operations at Kennedy International Airport today. This sample includes essentially every jet aircraft type and airline operating procedure employed at the airport and thus constitutes a control group against which other operations can be compared.

5) All aircraft procedures which include a power cutback of some degree over some portion of the noise sensitive area permit the pilot to increase power prior to departing the community. This resumption of power produces an increase of 5 PNdB to 10 PNdB over the noise levels that would be experienced if the power cutback were maintained until clear of the noise sensitive area.

6) During a power cutback condition, small increases in the rate of climb brought about by increases in engine power can increase the noise levels on the ground as much as 10 to 15 PNdB more than would be observed if the throttle setting had been maintained.

REFERENCES

1. Bolt Beranek and Newman Inc., Technical Report "Land Use Planning Relating to Aircraft Noise", FAA (October 1964). Also published by Dept. of Defense as AFM 86-5, TM 5-365, NAVDOCKS P-98, "Land Use Planning with Respect to Aircraft Noise".

2. SAE ARP 866, "Standard Values of Atmospheric Absorption as a Function of Temperature and Humidity for Use in Evaluating Aircraft Flyover Noise", (1964).

3. Kryter, K. D and K. S. Pearsons. "Some Effect of Spectral Content and Duration on Perceived Noise Level." JASA 35:866-883, No. 6, June 1963.

APPENDIX A

DESCRIPTION OF DEPARTURE PROCEDURES

This appendix summarizes briefly the departure procedures that were employed during this study.

Departure Procedure No. 1

This procedure represents the normal departure procedure as outlinedin Company Flight Manuals for each airline. We list below brief descriptions of some of the normal departure procedures for the airlines whose aircraft participated in the majority of observations obtained during the field measurements. These descriptions are by no means complete nor do they include all of the aircraft in use by each of the airlines. They are included simply to give an indication of the types of departure procedures employed.

American Airlines - (707-123 B and 720 B Operating Manual)

After lift-off the aircraft accelerates to V_2 + 20 kts. After reaching 2000 ft the aircraft accelerates to V_2 + 50 kts. As soon as conditions permit the aircraft accelerates to normal climb speed (300 kts.).

Eastern Airlines - (Flight Manuals)

DC-8 - Takeoff power is maintained to 1000 ft at which time the engine power is reduced to approximately 2.0 EPR. At 2000 ft the power is reduced to climb power and the aircraft accelerates to climb speed.

B707/B720 - Takeoff power is employed to 1000 ft at which time the power is reduced to 2.1 EPR for the B720 and 1.9 EPR for the B707. At 2000 ft the power is reduced to climb power and the aircraft accelerates to climb speed.

B727 - Takeoff power is maintained to 1000 ft. Beyond 1000 ft maximum continuous power is employed; at 2000 ft the aircraft accelerates to climb speed at the same power setting.

Trans World Airlines

Noise abatement departure procedure for all jet aircraft is to employ takeoff power (at V_2 + 10 kts.) until just before reaching the "Test Able" site (Position A of this study). Engine power is then reduced and maintained at the reduced rate until approximately 10 seconds beyond "Test Able." Power is then resumed as necessary and the normal departure is resumed.

United Airlines

Aircraft climb at V_2 + 10 kts. to 2000 ft at presumably takeoff power. Aircraft then accelerates at presumably reduced power.

Pan American Airways

Aircraft climbs out at V_2 + 10 kts. and takeoff power. At or just before the critical noise area the engine power is reduced to a specified amount depending upon the aircraft. Reduced power is maintained for 8 to 10 seconds after passing the sound monitoring position; engine power is then increased to rated thrust. If aircraft is still over the noise critical area, the thrust is increased gradually as altitude is gained.

Departure Procedure No. 3

A normal takeoff will be made with a climb to 800 ft at V_2 + 10 kts. and 30° of flaps. At 800 ft, the speed will be increased to V_2 + 20 kts., the flaps raised to 20°, and the power reduced to that necessary for a 500 ft per minute rate of climb.

Departure Procedure No. 4

Make normal takeoff and proceed as follows:

(A) Climb at V_2 + 10 kts. to 400 ft.

(B) Accelerate to V_2 + 20 kts. (B707/720 retract flaps to 20°) and maintain T.O. flap configuration. (V_2 + 30 kts. if maneuvering is required).

(C) Maintain this configuration with T.O. power and V_2 + 20 kts. until initial penetration of noise sensitive area.

(D) Reduce climb gradient to that resulting from 500 ft/min. Rate of climb, holding same airspeed and flap position.

(E) Maintain this configuration until

1. Noise sensitive area(s) are cleared, or at least
2. 3000 ft altitude is reached, then

(F) Proceed according to normal (SOP) flight plan.

Departure Procedure No. 7

(A) Normal takeoff and climb to 400 ft.

(B) Accelerate to maneuvering speed for following flap configuration:

Boeing 707/720	20°	(example: V_2 + 30 kts.)
Convair 880	20°	
DC-8	15°	
Boeing 727	15°	

(C) Continue climb at maneuvering speed for above flap configuration utilizing takeoff thrust to 2000 ft.

(D) Proceed according to normal operating procedures.

Departure Procedure No. 8

(A) Normal takeoff and climb to 400 ft.

(B) Accelerate to maneuvering speed for following flap configuration:

Boeing 707/720	20°
Convair 880	20°
DC-8	15°
Boeing 727	15°

(C) Continue climb at maneuvering speed for above flap configuration utilizing takeoff thrust to 1000 ft.

(D) Reduce to climb thrust and continue climb at maneuvering speed to 2000 ft.

(E) Proceed according to normal operating procedures.

Additional procedures were proposed by the Aviation Development Council in New York in conjunction with FAA representatives. Procedure 2 is the normal procedure employed by TWA and PAA and thus is Procedure 1 for these airlines. Procedures 5 and 6 were not specified by any airline during the test and were not requested to be performed by FAA.

APPENDIX B

SUMMARY OF FIELD MEASUREMENT PROGRAM

The main purpose of the field measurement program was to acquire sufficient noise and positional data to permit a satisfactory comparison of the noise exposure produced by several "specified" departure procedures, not only with each other but also with general departure procedures in use today. J. F. Kennedy International Airport was selected as the site of the measurements. It was decided, in conjunction with the FAA, to obtain data at several locations off the end of the runway at Kennedy International Airport. To acquire the necessary data on each of these several departure procedures that were to be employed, as well as on a large number of departures operating under no specified procedure, it was planned to make three field trips of two to three days duration. However, due to weather and coordination problems, four trips of three to five days duration were eventually necessary.

In this appendix we discuss the planning for the field survey trips, list the equipment that was employed, and go over in some detail the measurement procedures used in the field and the manner in which the data were reduced. Inherent in making simultaneous measurements at several different locations are problems of communications and coordination which are also covered in this appendix. Finally, a brief chronological summary of each of the field trips is presented along with some recommendations for future measurements of a similar nature.

A. Planning for the Surveys

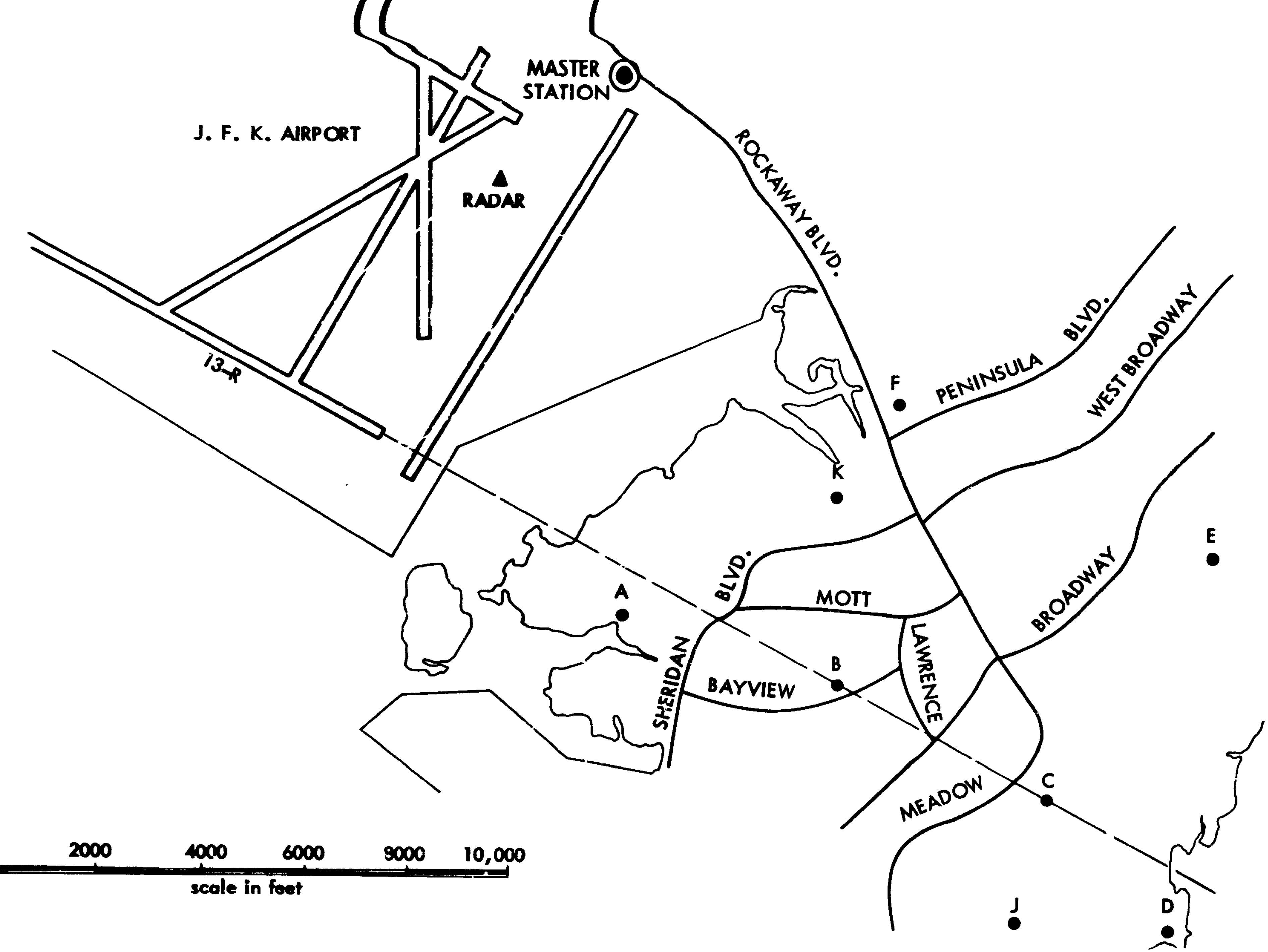
Following the selection of Kennedy International Airport as the site of the measurements, it was necessary to decide how many runways were to be monitored. This decision was influenced primarily by two considerations. First, the problems of coordination and additional man-hours associated with moving several measuring crews and their equipment to different locations around the airport suggested strongly that the number of runways to be monitored be kept to a minimum, and, if possible, to just one.

Secondly, it was fortuitous that at the time we were planning this study the FAA was planning a series of studies of traffic distribution by means of a modified military radar. The FAA had already selected Kennedy International Airport as the site of their first series of measurements and made arrangements to provide continuous positional data on the departures observed during our study. The fact that the radar equipment could not be easily shifted from location to location on the airport also suggested that only one runway should be selected for the monitoring operation.

The selection of the runway was made jointly with FAA personnel since they had agreed to operate the radar exclusively for us during our measurement survey periods. The primary factor influencing the selection of the runway was the runway utilization during the summer months since the surveys were planned for June and July. On the basis of runway use information for this time period during the previous several years, Runway 13R was chosen. Other factors in its favor were that it is the longest runway at Kennedy International Airport and that a straight-line extension of the runway passes through areas adjacent to the airport best suited for making acoustical measurements.

To provide for efficient utilization of time in the field, and to obtain the greatest number of departure observations in the shortest time, it was necessary to select that part of the day best for monitoring operations on Runway 13R. This runway usually becomes active during these months around 11:00 a.m. to 12:00 noon. Based on a study of takeoff traffic density on this runway, it was decided to monitor takeoff operations from 12:00 noon to 8:00 p.m. on each of the survey days.

Initially, six measuring positions were chosen, four approximately along the straight-line extension of Runway 13R (Positions A, B, C, and D) and two about one mile to the side of the path (Positions E and F). These positions are noted on Fig. B-1. Position A was located near the


MASTER STATION
J. F. K. AIRPORT
RADAR
13-R
ROCKAWAY BLVD.
PENINSULA BLVD.
WEST BROADWAY
BROADWAY
MOTT
BLVD.
LAWRENCE
SHERIDAN
BAYVIEW
MEADOW
A
B
C
D
E
F
J
K
0
2000
4000
6000
9000
10,000
scale in feet

Port of New York Authority noise monitoring point since this is the portion of the community closest to the airport and also the point at which some airlines reduce power on takeoff. The other locations were approximately equally spaced from the start of the community to the shoreline.

In selecting the measurement positions, care was also taken to provide an open view of the aircraft during a good part of the time they were in the vicinity of the measurement station to provide ease in aircraft identification and to prevent any acoustical shielding of the aircraft noise. The measurement positions located one mile to the side of the flight path (Positions E and F) were originally chosen to provide monitoring at points in the community other than just under the flight path. Later these positions were replaced by Positions J and K located one-half mile to the side of the flight path. However, Positions A, B, C, and D were maintained throughout the entire survey.

In addition, a master station was positioned as shown in Fig. B-1. The operator of this station was in contact with the radar station, in full view of the airport, and was monitoring the tower radio. He was also in communication with the measuring stations and coordinated the operations of the entire measurement survey. He would notify the measuring crews when participating aircraft were taking off and would also instruct them regarding the monitoring of other operations.

B. Equipment

A complete data recording system was located at each of the selected measurement positions. Each system was operated by one man and consisted of the following items:

1) Bruel and Kjaer sound level meter, Model 2203

2) Bruel and Kjaer 1/2-inch microphone, Model 4133

3) Electrovoice polyfoam wind screen adapted for use with 1/2-inch microphone

4) Tripod for supporting the sound level meter

5) Bruel and Kjaer pistonphone calibrator, Model 4220

6) Kudelski tape recorder, Model Nagra III

7) Shure microphone Model 98108 with "push-to-talk" switch for annotating data

8) Pair of crystal headphones for data monitoring

9) Bulova Accutron Wristwatch

10) Portable table for supporting the measuring equipment

11) 35-millimeter camera with telephoto lens (not at all stations)

12) Data Log Book

13) Aircraft Identification Sheets

14) Two-way radio to provide communication with other stations. (Later replaced with operator's telephone headset.)

A block diagram of the above equipment is shown in Fig. B-2.

There were a total of seven systems assembled, one for each measuring station and a spare to replace any malfunctioning equipment. Each system was carefully calibrated before each field trip, and equalized so that all of the data could be played back on one master data reduction machine. The frequency response of each system was within +1.5 dB from 40-12000 cps when played back on the master data reduction machine. Field calibration was performed with the pistonphone calibrator at least once during each data reel. To check further on the stability of the measuring system, the internal calibration of the sound level meter was recorded several times throughout each reel of tape.

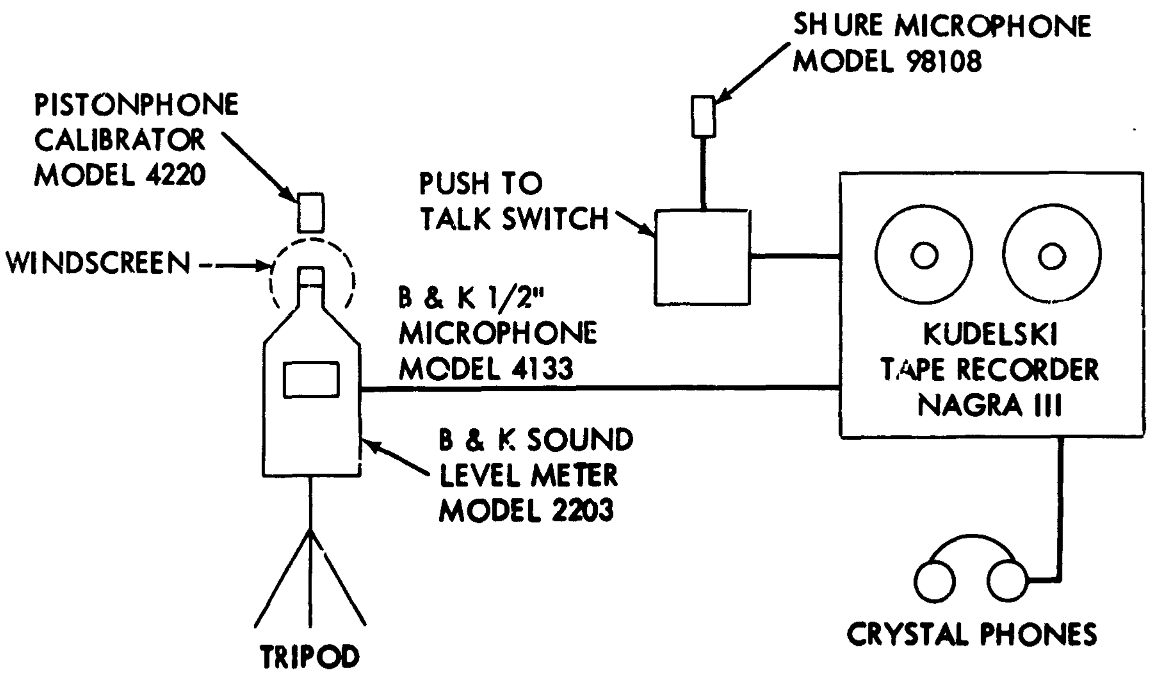


FIGURE B-2. DATA RECORDING SYSTEM FOR AIRCRAFT NOISE

C. Measurement Procedure

The basic measurement procedure was for each station to record on magnetic tape those flyovers prescribed by either the master station or Position A. Selection of the flights to be monitored was based on whether the pilot was flying one of the proposed takeoff procedures, or whether the aircraft flight path appeared to be a straight-line extension of the runway. Before adequate communications were available between measurement positions, monitoring personnel were instructed to record all flyovers. Flyovers were identified, insofar as possible, by airline, type of aircraft, and an accurate account of the time the aircraft passed over the measuring station. This information was tabulated on a log sheet, a sample of which is shown in Fig. B-3.

Although many of the field crew had made measurements in the field previously, a detailed operating procedure was provided so that data acquisition would be uniform at all stations, thus simplifying the task of data reduction. In this regard trial field measurements were performed adjacent to Logan International Airport in Boston. This was done both to familiarize the personnel with the specific measuring equipment to be employed, and to check out the measuring procedure itself and make improvements as necessary.

The detailed measurement procedures given to each person recording data were as follows:

SET UP AND OPERATING PROCEDURE

Set Up

1. Set up equipment as shown in block diagram with sound level meter vertical. Make sure tape speed is 15 i.p.s. During calibration sound level meter should be beside tape recorder. During measurements sound level meter should be at least 10 to 15 feet from car, in an open area, away from buildings or other obstructions.

Reel________ Team (System)________ Initial________ Position ________ Date________

Event No.	Time at Flyover Hr.	Min.	Sec.	Atten.	Airline	Flight No.	Aircraft Type	Cal. Ref and Additional Comments or Description		Photo No.

FIGURE B-3. SAMPLE OF DATA LOG SHEET

2. Check batteries in tape recorder (switch to playback) and SLM. If in doubt, replace batteries.

3. Thread tape recorder.

4. Fill in information required on back of tape reel box and top of data log sheet.

5. Switch tape recorder to "TEST."

6. Activate push-to-talk microphone and test for tape recorder dB meter reading. Should read about -10 to -20 dB with raised voice.

7. Switch tape recorder to "HI-FI RECORD" and talk in material on back of tape reel box,* with additional comments about the weather or any information which you feel may affect the data. Give name in place of initials. Switch tape recorder to TEST.

Calibration**

8. Turn on sound level meter to "SLOW METER" and "LIN."

9. Switch attenuator to 100 dB, making sure CLEAR KNOB is full clockwise, and place calibrator gently over microphone. Turn calibrator on and monitor with earphones. Make sure calibrator batteries are operating by switching calibrator to "CHECK" and noting rise in pitch. (If no change occurs during this procedure, then ask for replacement batteries as soon as convenient.)

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* After first reel of the day, time may not permit talking all information onto tape. In this case, put reel number, team position and date only. In an emergency, even this information may be added later in the tape. However, if this is done, please note the fact on the tape reel box.

** Except for first reel of the day, this procedure may be done once at any convenient time during each reel of tape.

10. Switch calibrator to "MEASURE" position. SLM should read 109 ± 1 dB. Tape recorder meter should read -10 dB as noted on recorder.

11. With calibrator still on, switch tape recorder to "HI-FI RECORD" and record for 30 seconds.

12. Remove calibrator and switch attenuator to "REF" for 10-15 seconds; talk the necessary information on tape, using push-to-talk mike. Write this information on the log sheet, including the SLM reading to the nearest 0.1 dB.

13. Turn off recorder.

14. Check SLM by talking into it with attenuator on 70 dB.

15. Set attenuator on value such that flyovers will not overload instruments for your position. This means sound should not exceed "0" on SLM. (Estimates of expected overall sound pressure levels will be provided.)

16. Put wind screen in place and put tripod with SLM in measuring position, leaving sound level meter on throughout the day.

17. Wait for signal from radio or some clue, either visual or aural that an aircraft is approaching.

Measurement

18. At signal from radio or other clue, turn on tape recorder. For far out positions, experience may dictate a more optimum time for turning on tape recorder.

19. If you have a camera, photograph the aircraft when it passes overhead or is passing perpendicular to your line of sight, then immediately note time to nearest second. If you do not have a camera, note time to nearest second, etc.

20. If possible, note SLM reading during peak. If it is greater than 0 dB, then change to next higher attenuator setting for subsequent measurements.

21. Try to note any descriptive details about the aircraft on the log sheets.

22. After noise of aircraft is equal to background, then use push-to-talk mike to put required information* on tape.

23. Turn off tape recorder and await signal from radio.

24. Return to Item 18.

Following each day's data acquisition, common event numbers were assigned to each flight. This procedure provided the correlation among the data for the different stations necessary for data reduction. The third trip, for the most part, did not require this correlation of events since the communication system was adequate enough to accomplish this in the field.

To provide checks on the radar data and to obtain slant height information for those flights not tracked by the radar, cameras were issued to personnel at certain measuring stations. Accompanying instructions stated that photographs were to be taken only when the observer's line

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* Required information consists of all data to the left of the triple line on the log sheet. If time does not permit this, then try to record at least information to the left of the double line.

of sight was perpendicular to the flight path of the aircraft. The distance to the aircraft was determined from the image size on the negative, lens focal length, and aircraft length according to the formula:

$$\text{slant height} = \frac{(\text{aircraft length})\ (\text{focal length})}{(\text{image size})}$$

For ease in measuring image size, a film strip projector was employed to enlarge the image on the film by a known magnification.

D. Communication and Coordination

Good communications between stations in the field was essential to the efficient conduct of the measurement surveys. The FAA was to provide adequate radio communication between each measuring station or at least to provide a transmitter at one and receivers at the other five. A receiver to monitor tower radio was also to be included. These were necessary both for identifying a given flight at all six measuring positions, and for advising all stations of those flights to be measured. An additional advantage of the two-way communication system would be to provide emergency communication in case of malfunctioning equipment. Radio transmitters and receivers were provided. However, during the first series of tests, it was clearly demonstrated that insufficient signal strength was available from the transmitters. Only the tower radio monitor was adequate. Since no other radio communications could be obtained from FAA, it was decided to install a temporary commercial telephone tieline to connect each measurement location.

It was also desirable to have a telephone line connected to the radar van. This was impossible since a cable could not be placed across any of the taxiways surrounding the radar. Although originally it was planned to locate the master or coordinating station at Position A, the master station was finally located on the airport as shown in

Fig. B-1, in the interest of providing communication to the radar. Communications were then provided to the measuring stations by the tieline and to the radar van by short range two-way radio.

The time available between the first trip and second trip did not permit the telephone company to complete the phone system in its entirety. Enough of the system was completed, however, to provide communication between some of the field measuring stations. Due to Position D's inaccessible location with respect to a telephone pole, radio communication was employed between Position C and Position D. Between the second and third field trips, Positions E and F were replaced by Positions J and K; this meant that new phone lines had to be installed. One of these locations did not have telephone communication for the first portion of the measurements on the third trip. However, communication was provided to this location as well as Position D by Portable Citizens Band Radio. By the middle of this trip, with all the communications working, the measurement procedure became much more efficient.

Considerable coordination was necessary throughout the program to insure that:

1) the pilots were flying prescribed takeoff procedures

2) the radar was tracking the participating aircraft

3) the measuring stations were recording the aircraft flyovers.

Before any measurements could be made, the pilots had to be briefed on which procedure they would be flying; the radar station had to be alerted to prepare for tracking on Runway 13R; and the field personnel had to go to their measuring stations and set up their equipment in preparation for the aircraft noise recording.

When the radar van and the master station were ready to proceed, they would notify the tower. Then, weather conditions permitting, and as soon as Runway 13R became active, the tower would notify each airline that the program was commencing. At this time the sound measuring stations were also notified by the tower through the master station located on the field. Confirmation was also relayed either directly from the tower or from the master station to the radar that flights would be commencing. However, there was usually a delay of at least one hour after the airlines were notified because the pilots were briefed at least one hour before their scheduled takeoff. This timing created a problem if, when all else was ready, the runway being used was not 13R; when runway usage did change to 13R there would be at least an hour's delay in starting the program. The problem would be further complicated if, before the hour was up, the wind changed enough to dictate the use of another runway. If this occurred, another hour's delay would be incurred when the runway use again reverted to 13R.

During the field surveys the only indication that either the radar or the master station had that the pilot was participating in the program was by monitoring tower radio. The pilot of a participating aircraft was to indicate his participation when he contacted the tower. If he failed to do this, we would not know until the pilot's logs were returned, days or even weeks later, whether or not the pilot was participating. One difficulty in this regard was that the pilot sometimes reported his participation to clearance delivery, rather than to the tower, and therefore we had no way of knowing that he was indeed participating in the program.

During the early trips immediate knowledge of an aircraft's participation was not really necessary since both the radar and the sound measuring stations were recording almost every flight taking off on 13R. This practice resulted in acquiring mostly data on those aircraft which were not participating in the program of flying any special takeoff procedure. Therefore, it became desirable to be more selective . the flights which were to be recorded to obtain an adequate number of flights for each of the different departure procedures employed.

E. Data Reduction

Aside from some spot checking of the data in the field, the majority of the data was reduced in our laboratories. The data reduction system consisted of an Ampex tape recorder with playback equalized to be compatible with the Kudelski tape recorders used in the field, a sound level meter, an octave band filter set, a PNdB filter, and a Bruel and Kjaer graphic level recorder. A block diagram of the system is shown in Fig. B-4.

Since the flyover data were to be reported in maximum perceived noise level in PNdB, it was expedient to attempt to obtain values of PNdB directly. Hence, the PNdB filter mentioned above was employed. Its frequency response is equivalent to the inverse shape of the 40-Noy curve of perceived noise. It was calibrated by calculating perceived noise levels from 20 octave band spectra chosen from data taken at the four positions along the flight path. This method has been used successfully in the past when large amounts of perceived noise level data are reduced. The accuracy with which this method predicts the perceived noise level is indicated by the standard deviation of 1.3 PNdB for the differences between calculated and "filtered" PNdB as shown in Table B-1. This correlation is consistent with that obtained during previous studies.

An example of the graphic level plot from which maximum perceived noise level was determined is shown in Fig. B-5. Notice that the writing speed has been adjusted to eliminate the need for visual averaging.

F. Comments of Field Trips

Trip No. 1 - 15-18 June 1964

Although we had hoped to obtain useful data on the first trip, its main function became that of providing a good "shakedown" for personnel and equipment. The first day of the trip, 15 June, revealed that communication by the radios provided by the FAA was inadequate. Because of a misunderstanding, the radar facility discontinued tracking

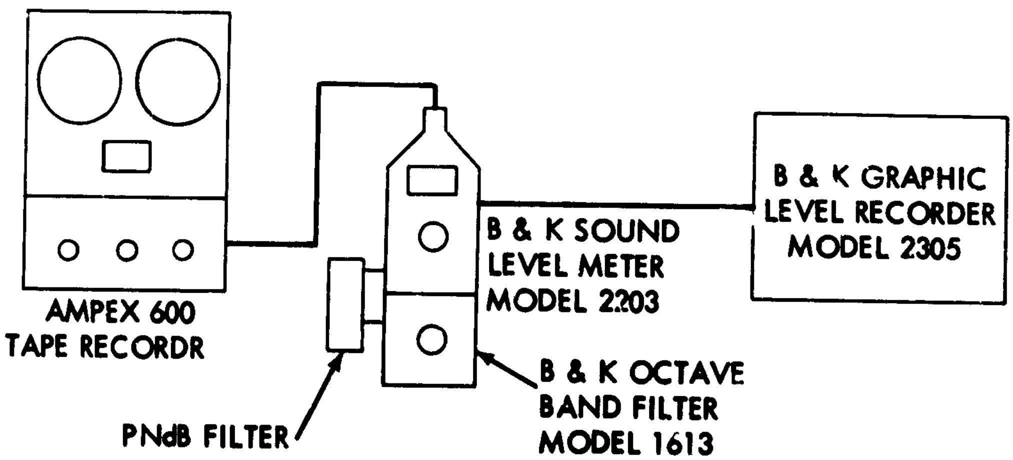
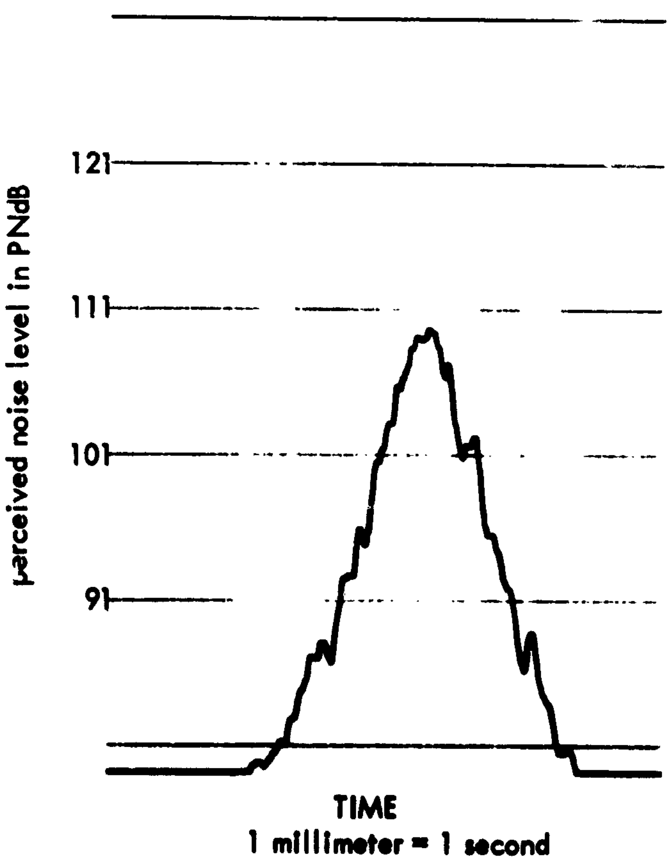


FIGURE B-4. DATA REDUCTION SYSTEM

TABLE B-I

COMPARISON OF MAXIMUM PERCEIVED NOISE LEVELS OBTAINED WITH PNdB FILTER AND BY CALCULATION FROM OCTAVE BAND DATA

Date	Position	Perceived Noise Level (PNdB)		Difference (PNdB)
		Filtered	Calculated	
7-29-64	A	114	115	-1
"	C	106	107	-1
"	A	110	110	0
"	B	107	107	0
"	C	104	105	-1
"	A	105	106	-1
"	B	103	103	0
"	C	96	96	0
7-31-64	A	99	99	0
"	B	95	92	+3
"	A	117	118	-1
"	B	118	115	+3
"	D	105	105	0
"	A	107	108	-1
"	D	95	95	0
"	A	114	114	0
"	B	112	113	-1
"	D	110	112	-2
"	A	114	115	-1
"	B	112	113	-1
Mean Difference = -0.2 PNdB Standard Deviation = 1.3 PNdB				



RECORDED AT POSITION B
6 JULY 1964
NO SPECIFIED PROCEDURE
ITEM NO. 18

FIGURE B-5. TYPICAL PLOT OF PERCEIVED NOISE LEVEL FOR AIRCRAFT FLYOVER after 2:00 p.m. We learned later that afternoon that the pilots were not flying any of the specified procedures for this exercise. As a result, we ceased field operations at 5:30 p.m. The following two days, 16 and 17 June, weather precluded operations on 13R. The last day, 18 June, about ten flights were monitored. However, there were no radar tracks and none of these flights included participating aircraft. In summary then, the first trip mainly indicated the need for the following improvements:

1) better communications between field measuring stations

2) closer coordination with the radar operators and

3) increased effort on the parts of the airlines and pilots to provide the specified procedures.

Trip No. 2 - 6-8 July 1964

The second trip was somewhat more fruitful than the first. Measurements were obtained every day. The number of flights monitored totaled 84 the first day, 55 the second day, and 30 the last day. However, on the first day, only 5 of the 84 flights were reported as participating aircraft. (The actual number of participating aircraft was greater as later revealed by the pilots' logs.) Similarly, on 7 July only 7 aircraft reported that they were participating aircraft and of these 7 only 2 reported they employed Procedure No. 4, the main procedure of interest. On 8 July 11 were reported as participating and only 2 of these were reported as Procedure No. 4. The reason for this increase in participating aircraft on 8 July, relative to the total number of aircraft monitored, was that the tower was relaying information that the pilots had given to clearance delivery.

The number of flights which were used for analysis, after the pilots' logs were all available, was 41 participating flights and 48 miscellaneous flights (no specified procedure). On the basis of the preliminary information gathered in the field, and the pilots' logs that were available at the time, we decided to concentrate on obtaining data only on Procedure No. 4 (for participating aircraft) for the next trip. Further, we decided that fewer recordings would be made of those aircraft not participating in the program. It should be stressed that weather played an important role in determining the amount of aircraft which could be monitored. Even on 6 July when 84 flights were recorded, measurements did not start until 4:00 p.m. because of winds which precluded the use of Runway 13R.

Trip No. 3 - 27-31 July 1964

On 27 July 27 flights were monitored, of which 5 were participating aircraft. On 28 July only 8 flights were monitored and none of these were participating aircraft. Rain halted any further measurements on that day. On 29 July 21 flights were monitored, of which six were participating aircraft, as determined from the pilots' logs. No measurements were made on 30 July and, because the weather reports for the next day indicated that Runway 13R would not be used, many of the measurement team returned home. However, Runway 13R was active the next day, and a portion of the field crew was immediately recalled and sent into the field. Because of the short notice, and because of the probability that Runway 13R would not be used for the entire day, only Positions A, B, and D were monitored. On 31 July 76 flights were monitored; of these 26 were participating aircraft according to the pilots' logs.

In summary, for the third trip the total number of flights used for analysis consisted of 39 with specified procedures and 46 with no specified procedures. In reviewing the pilots' logs and the radar information it appeared that the pilots were not following Procedure No. 4 as instructed even though they reported that they had. Several pilots reported that the procedure was difficult to follow, which may have had some bearing on whether or not it was done precisely. Since more data on Procedure No. 4 was deemed necessary, a fourth trip was planned.

Trip No. 4 - 17-21 August 1964

For the entire week of this trip weather prevented any recording of aircraft noise. At the end of the week it was mutually agreed by FAA and BBN, that since insufficient funds were available for further field trips BBN would cease measurements in the field and proceed with analysis of the data already obtained.

G. Recommendations for Future Studies

Probably the most important recommendation that could be made would be that of insuring, prior to the actual measurements, adequate communication between field stations. Because of the possibility that the communication system might break down it is also important that accurate time recording be employed to allow data correlation, independent of the communication system.

A better method should be found to determine, without waiting for the pilots' logs, whether

a) the pilots planned to follow a specific takeoff procedure -- this could be done immediately following the pilots' briefing by calling the master station and relaying merely the flight numbers and the corresponding procedure numbers.

b) the pilots did, at least in their opinion, fly the specified procedure -- availability of this information by the end of each day would mean that the following day's measurements could be planned much more efficiently.

Although the measurement of slant distance using photographic methods was adequate, it could be improved by adding some measure of the aircraft's angle of elevation when the photograph is made. Further, it would have been useful to reduce more data in the field. This was difficult to accomplish during this program, since the communication conditions that existed required that much of the time that might have been spent on data reduction be spent on correlation of data among measuring positions.

APPENDIX C

PERTINENT DATA ON COMMERCIAL JET TRANSPORTS

Aircraft	Engine	Fan/Jet	Maximum Gross Weight in Lbs.
707-120	JT3C-6	Jet	258,000
707-120B	JT3D-1	Fan	258,000
707-220	JT4A-3	Jet	248,000
707-320	JT4A-9	Jet	316,000
707-320B	JT3D-3	Fan	328,000
707-320C	JT3D-3	Fan	328,000
707-420	Conway 508	Jet	316,000
720	JT3C-7	Jet	230,000
720B	JT3D-1	Fan	235,000
727	JT8D-1	Fan	153,000
DC-8-10	JT3C-6	Jet	273,000
DC-8-20	JT4A-3	Jet	276,000
DC-8-30	JT4A-11	Jet	315,000
DC-8-40	Conway 12	Jet	315,000
DC-8-50	JT3D-3	Fan	315,000
DC-8F	JT3D-3	Fan	315,000
880-22	CJ805-3	Jet	184,000
880-22M	CJ805-3B	Jet	193,000
990A	CJ805-23B	Fan	255,[illegible]0

APPENDIX D

SUMMARY OF SLANT HEIGHT, ALTITUDE, AND NOISE DATA

The data that have been utilized in performing the analysis discussed in this report are summarized in the tables on the following five pages. All data for each departure procedure have been grouped together and separated from all data for "No Specified Procedure". Data in the latter category represent a sampling of normal departures from Kennedy International Airport. For Procedure 4 we have listed data for all flights for which the pilots indicated they were following Procedure 4. However, as discussed in the body of the report, in most of these instances Procedure 4 was not followed either throughout the entire departure or in the vicinity of one or more of the field measurement positions.

Within each data set the data are numbered consecutively for purposes of identification. The "Date" column indicates the day on which the field measurement was obtained. All data were collected during July 1964. The gross weights are those reported on the pilots' log for the participating aircraft. No gross weight data are available for the "No Specified Procedure" data since these departures were selected randomly in the field and no pilots' logs were obtained.

The remaining sixteen columns in the tables represent the noise, slant height, and altitude data for field measurement stations A, B, C, and D.

> Measured PNdB - These are the actual maximum perceived noise levels recorded at Stations A, B, C, and D for each departure whether the aircraft passed overhead or off to one side.
>
> Slant Height - These values represent the distance to the aircraft at the point of closest approach to the field recording station. For aircraft that passed directly overhead the value would be equivalent to the altitude. These data were obtained either from an analysis of the radar data or from an analysis of photographs taken at the measurement stations.

Altitude - These values represent the actual altitude of the aircraft at the point of closest approach to the measurement position. These data were obtained primarily from an analysis of the radar information, but also include data from photographic observations where the aircraft passed directly overhead.

Normalized PNdB - These values represent the perceived noise levels that correspond to the altitudes listed in the previous columns. These PNdB values have been estimated by adjusting the measured PNdB for the difference in PNdB that corresponds to the difference between the slant height and the altitude. These PNdB differences have been estimated from the PNdB-vs-distance curve shown in Fig. 6.

As an example of the calculation, refer to Item No. 2 under Procedure 1. The measured perceived noise level at Position A is 110 PNdB which corresponds to an observed slant height of 1836 ft. Analysis of the positional data indicates that the aircraft passed off to one side of Position A. At its point of closest approach, its altitude was 1333 ft. From Fig. 6 we see that the difference in PNdB between 1333 ft and 1836 ft is approximately 4 PNdB. This value has been added to the observed value of 110 PNdB to obtain the value of 114 PNdB which corresponds to the maximum perceived noise level that would have been observed on the ground underneath the aircraft when it passed overhead at an altitude of 1333 ft.

No.	Date	Aircraft	Gross Wt. $x10^3$ Lbs	Measured PNdB A	Measured PNdB B	Measured PNdB C	Measured PNdB D	Slant Height-Ft. A	Slant Height-Ft. B	Slant Height-Ft. C	Slant Height-Ft. D	Altitude-Ft. A	Altitude-Ft. B	Altitude-Ft. C	Altitude-Ft. D	Normalized PNdB A	Normalized PNdB B	Normalized PNdB C	Normalized PNdB D
PROCEDURE 1																			
1	7-6	707-120	237	113			96	1893		2272	3155								
2	7-7	880	153	110	94	104	101	1836	1641	2106	2596	1333	1594	2076	2422	114	94	104	102
3	7-7	990	184	99	89	97		2272	2200	2776		2080	2200			101	89		
4	7-7	DC8-10		116	98	111		1767	2010	2019		1510	2010			119	111		
5	7-7	720B	182	103	87	93			3200										
6	7-7	707-120B	223	97	82	89	86	3590	4052	4639	5841	1720	1921	2247	2406	106	92	99	98
7	7-7	990		104	89	85		2244	2403	2955	3891	1954	2353	2828	3144	106	89	86	
8	7-8	720		101	103		92												
9	7-8	DC8-50		104	101		102	2524											
10	7-8	990	185	99	100			3499	3650	4570	6556	2443	2950	3139	3253	104	102		
11	7-27	DC8-30	195		116	97	101	1714	1641	2531	4215	946	1297	1765	2025		119	102	111
12	7-29	DC8-20	223	110	107	104		2152	2058	2577	3667	1633	1951	2265	2299	113	108	106	
13	7-29	707-120B	184	97	101	93		3314	3661	4171	5079	2352	3192	3546	3756	101	102	95	
14	7-29	DC8-50	224	108	107	102	96	1863	1976	2147	3370	1573	1943	2049	2249	110	107	103	101
15	7-31	DC8-50	212	103	103		95	2246	2509	3038	3117	2138	2453	2881	3130	103	103		95
16	7-31	720	172	108	104			2650	2100		3029		2100				104		
17	7-31	DC8-20	229	110	108			2227	2264	2529	2665	1898	2252	2487	2630	112	108		
18	7-31	DC8-20	246	112	109			2145	2250		2776	1950	2250			113	109		
19	7-31	DC8-20	232	111	108			2016	2111	2410	2970	1651	2090	2395	2480	114	108		
20	7-31	DC8-10		111	110		99	2395	2335	2954	5030	1707	2194	2460	2474	115	111		109
21	7-7	990	198	100	90	96		2272	2350	3155		2080	2350			101	90		
22	7-7	707-120	189	106	84		94		4000										
PROCEDURE 3																			
1	7-6	880	155		101	90				2398									
2	7-6	707-320		111	111	103	104	1461	963	1050	2068	712	821	811	965	120	113	106	114
3	7-7	707-120B	224	104	99	105	102	1893	1460	1514	2019		1460				99		
4	7-8	707-120	188	107	103		101	1690	1710	2001	2575	1525	1679	1971	2241	109	103		103
5	7-27	707-320	296	108	115		112	1136											
PROCEDURE 4																			
1	7-6	720B	205	114	106			1641	1850	2272		1360	1850	2272		117	106		
2	7-6	707-320B	184	103	94	83	92	2398	2834	3355	3358	2252	2797	3277	3352	104	94	83	92
3	7-6	DC8-30	277	113	99	98			1035				1035				99		
4	7-7	DC8-20	244	109	90	101	101	1716	1821	2319	2121	1529	1710	1886	2026	110	91	104	101
5	7-7	880	127	99	87	96	94	2794	2776	3522	4774	1872	2255	2775	3121	104	90	99	100
6	7-7	880	146	102	94	102	100		1900	2145	2903		1900				94		
7	7-7	720B	220	106	93	101	97	1980	1814	2044	2825	1635	1765	1941	2062	109	93	101	101
8	7-8	707-120B	232	100	99		90	2903			4822								
9	7-27	880	147		105					2272									
10	7-27	DC8-20	212	106	93	85	91	2294	2328	2485	3069	2108	2315	2434	2547	107	98	85	93
11	7-27	707-320	297	112	116	102	110	802	680	883	1010								
12	7-29	707-120	180	105	103	96	95	2272		3407	3155								
13	7-31	DC8-20	244	106	106		102	1640	1410			1360	1410			109	106		
14	7-31	707-120	186	103	100		92	2776	3200										
15	7-31	707-120B	228	106	96			1930	2090	2453	2903	1722	2076	2417	2774	107	96		

APPENDIX D (Cont.)

No.	Date	Aircraft	Gross Wt. x10^3 Lbs	Measured PNdB A	Measured PNdB B	Measured PNdB C	Measured PNdB D	Slant Height-Ft. A	Slant Height-Ft. B	Slant Height-Ft. C	Slant Height-Ft. D	Altitude-Ft. A	Altitude-Ft. B	Altitude-Ft. C	Altitude-Ft. D	Normalized PNdB A	Normalized PNdB B	Normalized PNdB C	Normalized PNdB D
16	7-31	707-120		100	106			1893	1620										
17	7-31	DC8-20	247	108	105		97	1665	1939	2532	2432	1538	1789	1944	2049	109	106		99
18	7-31	707-120	181	98	95		91	2631	3184	3659	3705	2602	3115	3458	3548	98	95		91
19	7-31	880	145	103	102		100	2903	2650				2650				102		
20	7-31	707-120B	232	107	104		96		1950		2650		1950				104		
21	7-31	707-320	287	114	112		102	1209	1046	1403	1537	763	1004	1324	1394	120	112		103
22	7-6	DC8-?	297		111				900				900				111		
PROCEDURE 7																			
1	7-6	727	146	106	88		80	1717	4206	6719	7505	1536	1906	2137	2149	107	98		96
2	7-7	727	128	88	78		80	2935	4363	7441	10335	1933	2232	2585	2783	93	87		97
3	7-7	707-120	232	103	97	106		1752	1732	1937	2635	1156	1660	1870	2083	109	97	107	
4	7-7	707-120	227	95	103	106	100	1388	1750	2019	2524	1040	1750			98	103		
5	7-7	707-120B	225	91	90	94	95	1926	2333	3044	2915	1822	2188	2530	2638	91	91	96	96
6	7-8	727	140	99	97		83	3027	3178	4102	5682	1931	2413	2911	3155	105	101		91
7	7-8	880	131	107	98		96												
8	7-8	707-120	232	116	108														
9	7-29	707-120	215	111	111		101	1695	1684	1835	2470	1309	1656	1791	1977	114	111		104
10	7-29	707-120B	224	108	107		100	1650	2262	2557	2359	1585	2141	2279	2350	108	107		100
11	7-31	727	128	99	97		93	3281	3100			3140	3100			99	97		
12	7-31	880	128	104	104		95		3000				3000				104		
13	7-31	707-120	235	108	104			1893	1700		2524	1650	1700			110	104		
14	7-31	880	148	108	105		95	2776	2900		3660	2620	2900			109	105		
PROCEDURE 8																			
1	7-6	707-120	200	113	104			1923	1675	1946	2660	1318	1586	1858	2062	118	104		
2	7-6	707-120	199	111	104		92	2391	2294	2888	4170	1030	1270	1490	1643	121	112		104
3	7-6	DC8-20	215		100		100		1980	2272	2650		1980				100		
4	7-6	727	148	105	103	92	98	1783	1825	2222	2831	1343	1775	2178	2495	108	103	92	100
5	7-7	720	179	106	96	104		1893	1650	2145	2902	1650	1650			108	96		
6	7-7	720	175	101	95	105	100	2238	1780	2041	2465	1555	1675	2007	2320	106	95	105	101
7	7-7	727	133	92	87	88	86	3281	3100	3912	5048								
8	7-8	707-120B	234	107	103		99	1749	2027	2489	3267	1536	2005	2443	2589	109	103		102
9	7-31	720	174	97	96		97	3029	2600										
10	7-31	880	140	99	95		100		3000										
11	7-31	707-120	190	104	104			1915	1836	2101	2143	1663	1825	2035	2115	106	104		
12	7-31	707-120	225	102	102			227*	2100		3534	2080	2100			103	102		
13	7-31	720	196	106				1893											
14	7-31	DC8-20	224	104	105		98	2272	2150		2650	2080	2150			105	105		
15	7-31	727	139	103	102		95		2250		4669								
16	7-31	DC8-20	198	105	104			2018	2372	3603	4141	1901	2319	2800	3123	105	104		
17	7-31	707-320	299	117	108		105	1313	1028	1583	2396	628	950	1511	1717	126	109		109

APPENDIX D (Cont.)

No.	Date	Aircraft	Measured PNdB A	Measured PNdB B	Measured PNdB C	Measured PNdB D	Slant Height-Ft. A	Slant Height-Ft. B	Slant Height-Ft. C	Slant Height-Ft. D	Altitude-Ft. A	Altitude-Ft. B	Altitude-Ft. C	Altitude-Ft. D	Normalized PNdB A	Normalized PNdB B	Normalized PNdB C	Normalized PNdB D
NO SPECIFIED PROCEDURE																		
1	7-6	707-420	113			92	1985	1813	2222	3567	1025	1270	1309	1290	122			105
2		707-420	111	109		92	1526	1033	1572	3122	532	509	587	601	124	117		112
3		DC8-50	111			82	2066	4794	7459	8159	1684	2003	2492	2717	113			96
4		720	108	102	93	100	1893	1760	2181	2528	1526	1760	2148	2395	111	102	93	100
5		DC8-20	107	102	90	98	2147	1850	3163	3609	1617	1781	1993	2123	111	102	96	105
6		707-320B	91				5363	4900			1057	2149			112			
7		DC8-20	98			79	4317	6483			1396	1683			113			
8		880	104	98		100	1891	1984	2385	2551	1659	1950	2234	2582	106	98		100
9		990	95				2872	6381	9734	10847	990	1171	1473	1825	109			
10		707-320	106	99														
11		DC8-10	120	107		104	1893	1960	2145	2524	1650	1960			122	107		
12		720		105		102		2150				2150				105		
13		707-420	116	110				1180				1180				110		
14		720	116	102	88		2398	2400	2903		2200	2400	2900		117	102	88	
15		DC8-50		102	91			2180	2524			2180	2520			102	91	
16		707-220		109	89			1700				1700				109		
17		DC8-30		88	98			1290				1290				88		
18		DC8-20	115	109	98	106	1262	1360	1893	2019	870	1360	2020		120	109		
19		707-320B	112	112	101	103		1000				1000				112		
20		707-320	116	114	100	103	1136	1100		2524	670	1100			122	114		
21		DC8-50	104	106	95	101		1550				1550				106		
22		707-320B	105	109				1000				1000				109		
23		707-320	111	107	94			1000				1000				107		
24		DC8-30		106	99			1230				1230				106		
25	7-7	DC8-50	100	90	95	92	2732	2513	3006	4188	1306	1613	2026	2257	110	96	100	101
26		720	100	73		84	2398	5022	7133	7560	1117	1370	1715	1913	110	90		102
27		DC8-50	90			76	5188	8766	11309	11242	1624	1855	1980	2309	105			96
28		DC8-20	109	88	102	100	2213	2212	2434	2785	1905	2181	2426	2485	111	88	102	101
29		707-320C	92			78	3373	6297	8800	9539	921	1224	1301	1515	109			102
30		DC8-20	91	84	99													
31		707-320B	101	82			7445	3528	6484	9469	1300	1390	1673	1756	109	94		
32		880	91				4041	7057	9690	10507	1274	1395	1600	1697	106			
33		720					6685	8935	12340	15446	1572	1819	2141	2214				
34		707-120B	103			77	2967	2739	2694	3884	1535	1932	2009	2046	111			86
35		707-420	102	80		84	2329	4676	6691	6944	1895	2226	2450	2549	105	90		97
36		707-420				76	5221	8561	11420	12127	2174	2327	2573	2939				94
37		707-320C					3508	6073	8391	8889	2522	2836	2912	3019				
38		DC8-20	91	84	99			1890				1890				84		
39		707-320C		98	106		1893	1580	1388			1580				98		
40		DC8-20	95	99	105			2180				2180				99		

APPENDIX D (Cont.)

No.	Date	Aircraft	Measured PNdB A	Measured PNdB B	Measured PNdB C	Measured PNdB D	Slant Height-Ft. A	Slant Height-Ft. B	Slant Height-Ft. C	Slant Height-Ft. D	Altitude-Ft. A	Altitude-Ft. B	Altitude-Ft. C	Altitude-Ft. D	Normalized PNdB A	Normalized PNdB B	Normalized PNdB C	Normalized PNdB D
41	7-7	DC8-50	102	91	87			2250				2250				91		
42	7-8	DC8-50	113	108		108	1382	1618	1822	1702	1233	1470	1604	1701	114	109		108
43		DC8-20		104			2543	2477	2500	3075	1868	2185	2073	2048		106		
44		727	102	92		94	2131	2703	3000	3103	2125	2647	2971	2936	102	92		95
45		DC8-20	106	101		98	2085	1948	2214	3099	1585	1863	2153	2258	109	101		102
46		DC8-20		99			2649	2246	2251	2611	1600	1851	2177	2223		101		
47		720	102	91			3090	5480	7378	7618	1453	1746	2061	2168	112	106		
48		720B		98			2796	2893	3434	4411	2409	2730	3145	3325		99		
49	7-27	880		115			1218	1086	1285	1978	943	1072	1276	1375		115		
50		707-320B	114	97		84	1103	3341	5684	6232	1061	1330	1862	2107	114	109		98
51		707-320	100	104	89	98	2438	1987	2803	3150	1758	1952	2209	2282	105	104	92	102
52		DC8-20	108	110	94	102	1667	1425	1688	2302	1192	1410	1672	1923	112	110	94	105
53		DC8-30	103	104	87	91	2426	2638	4151	6662	1846	2137	2328	2439	106	107	95	104
54		727	104	97	77	90	1273	2605	4277	3734	1277	1446	1927	1980	104	105	88	98
55		707-120B	108	103	85	97	1972	2604	3530	3331	1847	2264	2447	2635	109	105	90	100
56		DC8-30	107	108	93	96	1658	1449	1926	3125	1126	1264	1398	1532	112	110	97	105
57		707-120	103	103	89	91	2251	2247	3361	4912	1663	1814	2229	2262	107	107	95	101
58		880	99	105	91	96	2498	2345	2762	3909	1837	2029	2128	2151	103	107	94	103
59		707-120B	103	106	92	103	2524	2040	2916	2398		2040				106		
60		707-320B	116	115	97	104		1000	1514	2272		1000				115		
61	7-29	727	102		97		1829	1877	2263	2699	1413	1842	2248	2405	105		97	
62		880	100		90		2439	5148	7111	7192	1266	1774	2058	1981	108		106	
63		720	114		90		1234	3154	4755	4698	1208	1305	1699	1914	114		103	
64		990	102	82	89		1625	3901	5934	6200	1294	1531	2026	2191	105	94	103	
65		DC8-20	106	110	104	100	1935	1672	2139	2773	1314	1449	1695	1843	111	112	107	105
66		727	100	100		89	2520	2609	3243	4381	1726	2264	2755	3019	105	102		94
67	7-31	720	111	97		86	1257	3306	5500	6004	1230	1368	1485	1585	111	109		103
68		DC8-20	112	97		87	1903	4618	7130	7826	1549	1922	2245	2334	114	109		103
69		DC8-50	107	99		98	1645	1627	1962	2270	1451	1583	1879	2208	109	99		98
70		DC8-20	104	89			2363	2636	3002	3098	2313	2550	2883	3097	104	89		
71		707-420	102	104			1970	1636	1820	2016	1463	1604	1807	1930	106	104		
72		880	113	109			1250	1504	2336	1928	1145	1178	1399	1513	114	112		
73		DC8-20	112	105			1993	2319	2730	2573	1860	2206	2454	2557	113	105		
74		DC8-50	113	109		96	1210	1358	2428	2664	951	1197	1491	1587	116	110		102
75		707-320	112	108		109	925	1190	1846	1300	769	741	920	1075	114	114		111
76		DC8-50	104	107		98	2250	1913	1960	2722	1588	1702	1779	2003	108	108		102
77		990	107	102		95	1338	3232	5748	6508	1334	1502	1901	2045	107	112		110
78		DC8-30	114	112		110	1489	1368	1499	1778	1068	1353	1490	1588	118	112		112
79		DC8-30	117	112		102	1891	1537	1872	3185	900	1050	1169	1251	126	117		114
80		707-420	116	115		109	1023	887	1168	969	675	825	873	990	121	116		109

APPENDIX D (Cont.)

No.	Date	Aircraft	Measured PNdB				Slant Height-Ft.				Altitude-Ft.				Normalized PNdB			
			A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
81	7-31	DC8-20	104	91		102		2320				2320				91		
82		707-120	107	102		96		1700				1700				102		
83		DC8-10	105	98		98	3155	3700			2980	3700			106	98		
84		DC8-30	113	101		88	2650	2580			2380	2580			114	101		
85		707-420	102	101				1960				1960				101		
86		707-320	107	106				1520				1520				106		
87		DC8-30	103	110			1767	1090		2524		1090				110		
88		880	101	105				2000				2000				105		
89		707-120	109	110		103	1893	1400				1400				110		
90		707-120	98	101		97		2050		2650		2050				101		
91		707-120B	104	102				2800				2800				102		
92		707-320B	100	98		84		3230				3230				98		
93		720	105	106		97	883	1260		3281		1260				106		
94		707-320		112		111		1230				1230				112		

APPENDIX E

COMPUTER GENERATION OF TAKEOFF PLOTS

The radar data utilized in this study were obtained from analysis with BBN's Digital Equipment Corporation PDP-1 computer. Our analysis was performed with programs we prepared to operate on a reformatted version of the digital tape produced by the FAA radar tracking facility at Kennedy International Airport.

The digital tape generated by the FAA tracking radar provides seven parameters (3 cartesian position coordinates, 3 corresponding velocities, and time) at increments of 1/10 of a second during a tracked takeoff. Our program for producing the plots used in our analyses selects from this large quantity of data position information at increments of 1000 feet along the horizontal projection of the aircraft flight path. The program then transforms the origin of coordinates from the radar location to the start of the takeoff runway. In addition, we compute the aircraft velocity vectors from the observed time and position information, rather than using the velocities recorded by the radar system. (This has the advantage of smoothing somewhat the velocity profiles.)

Frequently the radar does not acquire the target aircraft until the aircraft has moved some distance down the runway and actually taken off. In these cases the computer programs insert "artificial" flight path information back to the start of the takeoff runway. This is done to simplify our computations, but it is obvious that the "artificial" path information is not meaningful.

The output of the computer analysis is presented graphically on a Calcomp Model 560 digital plotter. Calibrated transparent overlays are available for detailed study of the data. For each takeoff, five different plots were obtained:

> Horizontal projection of the aircraft flight path in X and Y coordinates. The X coordinate is along the axis of the takeoff runway, and the Y coordinate is normal to X on the lefthand side of the aircraft. The scales are in feet.

Altitude of the aircraft in feet as a function of distance along the flight path in feet. (The abscissa here, and on the remaining three plots, is the distance along the horizontal projection of the flight path. This is equal to the X distance on the first plot only for "straight-out" takeoffs.)

Aircraft speed in feet per second versus the distance along the horizontal projection of the flight path. This function, like rate of climb versus horizontal distance is computed from the distance and time information at 1000-ft intervals. Being derivatives of quantized functions, these two calculations show short-term variations which may not be meaningful. The short-term variations could have been eliminated by conventional digital low-pass filtering of the functions, but this did not seem justified for our limited applications of the data.

Time in seconds as a function of distance along the horizontal projection of the aircraft flight path. The actual time that the radar acquired the target aircraft is indicated just to the left of the origin in hours, minutes, and seconds.

Of these data, the altitude-horizontal distance plots were most useful for interpretation of the noise data. Samples of these data are shown in Figs. 12-17. In addition, the horizontal track data were used to screen departures to determine those which were essentially straight-out flights along the projection of the runway center line. Time-versus-distance plots were also used in evaluating the rate-of-climb for a number of the flights. The availability of the radar data in the compact form described above was extremely valuable in determining the correlation of aircraft performance with associated noise levels, providing additional insight to the analysis not available to us in prior studies.

APPENDIX F

COMBINED EFFECT OF NOISE LEVEL AND DURATION ON NOISE EXPOSURE FROM JET AIRCRAFT DEPARTURES

Laboratory research indicates that noises of different time duration may produce different subjective reactions for the same maximum perceived noise level in PNdB. It is of interest to compare the maximum PNdB and durations of noise levels produced by different departure procedures. The data acquired in this study have been used to compute the maximum noise levels in PNdB and the time duration in seconds for which the noise exceeds a level 10 dB below the maximum PNdB produced on the ground for various takeoff procedures. The results of the calculations are tabulated in Table F-I for turbojet aircraft flying the three different altitude profiles shown in Fig. F-1. The middle curve, (2), is consistent wi. the mean profile for non-specified departures; while the upper (1) and lower (3) curves correspond to ±1.65 times the standard deviation about the mean altitude for these procedures (the 90% range for a normal distribution). Noise levels, and durations listed in Table F-1 are computed for stations A, B, C, and D of the current study. The locations for these stations are indicated on the figure.

The maximum noise levels in PNdB have been calculated for turbojet aircraft using three departure procedures:

I) Maximum takeoff power, Profile 1, 160 knots mean IAS.

II) Power cutback similar to Procedure 4, Profile 2, 160 knots mean IAS.

III) Maximum takeoff power, Profile 3, 200 knots mean IAS.

The effective perceived noise level is computed from the expression 3/:

TABLE F-I

EFFECTIVE PERCEIVED NOISE LEVELS FOR THREE DEPARTURE PROCEDURES

Departure Procedure	Station A			Station B			Station C			Station D		
	PNdB	Δt	$PNdB^{*}_{eff.}$	PNdB	Δt	$PNdB_{eff.}$	PNdB	Δt	$PNdB_{eff.}$	PNdB	Δt	$PNdB_{eff.}$
I	107	28	109	105	33	108	104	36	108	103	37	107
II	105	18	104	95	22	96	93	24	95	91	26	93
III	123	7	116	121	8	115	119	9	114	117	12	114

* $PNdB_{effective} = PNdB + 15 \log_{10} \frac{\Delta t}{t_{ref}}$

where Δt is the duration in seconds that the noise exceeds a level 10 dB below the maximum PNdB, and

t_{ref} is chosen arbitrarily equal to 20 seconds.

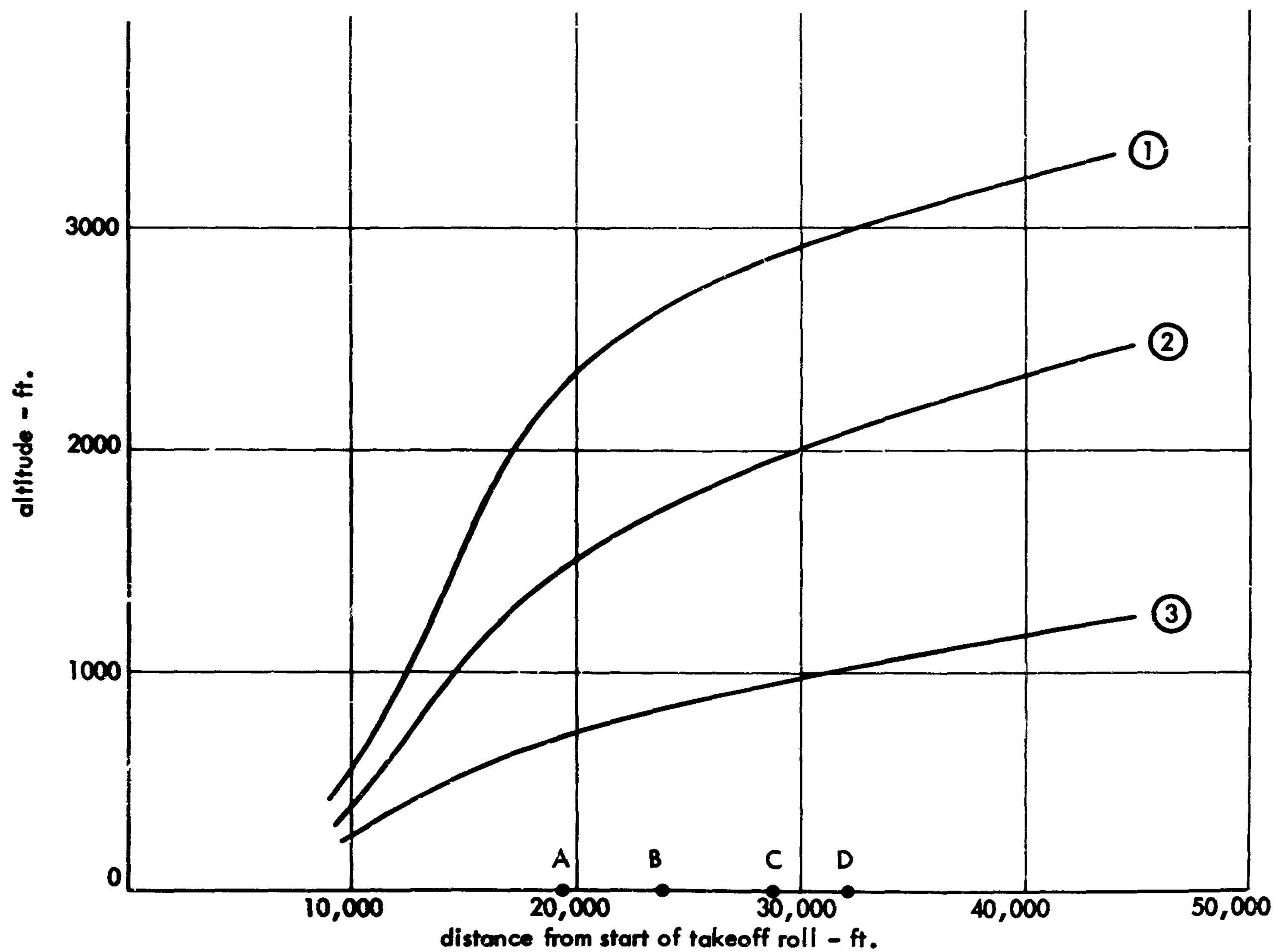


FIGURE F-1. TAKEOFF PROFILES USED IN ANALYSIS OF DURATION EFFECTS

$$PNdB_{effective} = PNdB + 15 \log_{10} \frac{\Delta t}{t_{ref}}$$

where: PNdB is the maximum noise level during the flyover

Δt is the duration in seconds that the noise exceeds a level 10 dB below the maximum PNdB.

t_{ref} is a reference time; taken arbitrarily as 20 seconds for this example.

Similar comparisons can be approximated for turbofan aircraft by reducing the noise levels for Procedures I and III by 5 PNdB while maintaining those for Procedure II as listed in Table F-I. To a first approximation, the durations for turbofan takeoff noise levels are considered to be the same as for turbojet. More refined computations will require further analysis of the time durations of noise data from both turbojet and turbofan aircraft.

It is apparent from these calculations that shorter duration flyovers can ameliorate somewhat the higher noise level conditions by as much as 7 PNdB. However, the effect of power cutbacks in lowering the maximum noise levels far outweighs the compensating effect of corrections for duration in determining an effective perceived noise level.

Bolt Beranek and Newman Inc., Los Angeles, California
STUDY OF THE EFFECT OF DEPARTURE PROCEDURES ON THE NOISE PRODUCED BY JET TRANSPORT AIRCRAFT, by W. J. Galloway, A. C. Pietrasanta, and K. S. Pearsons, Technical Report, March 1965, 84 pp., incl. illus., 3 refs.
(Contract No. FA64WA-4949, Report No. ADS-41)

Unclassified Report

The effect of various departure procedures of commercial jet transport aircraft on the noise produced on the ground under the departure path are presented in this report. Noise data at four measurement stations under the flight path of Runway 13R at John F. Kennedy International Airport, New York, were obtained from 300 aircraft departures.

Four different classes of departure procedures, including those specified by current airline operating practices, are compared with the noise produced by a random set of aircraft operations where the departure procedure was unspecified.

Detailed radar observations of the aircraft flights, operational information reported by pilots flying specified procedures, and the measured noise data on all flights observed were used in evaluating the various departure procedures.

The study shows that implementation of a proposed departure procedure could reduce the noise levels on the ground under jet transport takeoffs by as much as 8 PNdB as compared to the noise produced by existing procedures.

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