Evaluation of Proposed Standards for Aircraft Flyover Noise Analysis Systems

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A unique test is discussed in which identical tape recordings of aircraft flyover noises were analyzed by 12 different organizations in the United States and Europe to determine the degree of uniformity in data analysis that could be achieved. Although all organizations did not use the same analysis system, each system conformed to standard specifications proposed by a Society of Automotive Engineers (SAE) Instrumentation and Analysis Subcommittee. The purpose of the test was to evaluate the proposed standard. The statistical analyses of the test results are presented. Also described are the proposed standard, the elements of the evaluation test, and the analysis systems used.

Introduction

MINIMIZING the differences among organizations in flyover noise levels measured for the same type of aircraft has been a continuing objective. These measurement differences result from both data acquisition and data processing variations. Improved uniformity of techniques and procedures will increase the usefulness of data from different organizations. This uniformity is not easy to achieve because of 1) the complexity of flyover noise, which contains nonstationary random data and fluctuating periodic signals, and 2) the variety of noise measurement and data processing systems employed and the effects of their various operating modes upon the results. As a collective effort to examine this problem, SAE Committee A-21, Aircraft Exterior Noise Measurements, initiated a program to determine the magnitude of measurement differences, identify potential causes, and establish recommended practices to minimize the differences.

A major effort early in this program was a flyover noise test to compare test techniques and results. The tests were conducted in 1968 at Brown Field, Calif. using Boeing 707 and 727 aircraft. Eight different organizations in the aerospace industry recorded and processed data using their own standard methods. Results then were compared to determine the magnitude of the differences and identify potential causes. These results indicated reasonable agreement in some areas, but significant differences in others. It was concluded that the overall level of disagreement was undesirable and that the differences were largely because of data processing technique differences.[1]

The lack of uniformity in data processing techniques was addressed by the A-21 committee by forming an instrument and analysis subcommittee in 1969, whose original charter was to define characteristics of analysis systems to assure uniformity in the analysis of airplane flyover noise. In response to this charter, the subcommittee developed proposed SAE Aerospace Recommended Practice (ARP) 1264, Airplane Flyover Analysis System Used for Effective Perceived Noise Level Computations.[2] This proposed standard deals with the spectrum analysis system used to determine the measured sound pressure levels (SPL) of airplane flyover noise.

In 1973, as part of the evaluation of the proposed ARP 1264, an analog test tape was generated. This test tape consisted of three flyover noise recordings, their calibration signals, and a time code. Fourteen copies of the tape were prepared using strict quality control procedures. These copies subsequently were distributed to the participating organizations, listed in Table 1, for processing with analysis systems conforming to the requirements of proposed ARP 1264. The values reported were in terms of maximum overall sound pressure level (OASPL), maximum perceived noise level (PNLM), maximum tone corrected perceived noise level (PNLTM), and effective perceived noise level (EPNL). The results of the analysis of this tape then were used to verify the specifications defined in the proposed ARP 1264. The uniformity achieved can be considered to be an estimate of the current state-of-the-art.

The procedures specified for calculating the PNLM, PNLTM, and EPNL values were those defined in Federal Aviation Regulation (FAR) Part 36, Noise Standards: Aircraft Type Certification (1969). In order to determine whether the cause of any observed variations from organization to organization were the result of differences in their calculation procedures, sets of tabulated reference one-third-octave-band spectral histories also were distributed to each organization

Table 1 Participating organizations

BOEING COMMERCIAL AIRPLANE COMPANY
BOLT BERANEK AND NEWMAN INCORPORATED WITH 6570TH AMRL, USAF
BRITISH AIRCRAFT CORPORATION, LTD
DOUGLAS AIRCRAFT COMPANY, MCDONNELL DOUGLAS CORP
GATES LEARJET CORPORATION
GENERAL ELECTRIC COMPANY
GRUMMAN AEROSPACE CORPORATION
LOCKHEED CALIFORNIA COMPANY, LOCKHEED AIRCRAFT CORP
NASA LANGLEY RESEARCH CENTER
NOISE AND VIBRATION CONTROL COMPANY
PRATT & WHITNEY AIRCRAFT GROUP, UNITED TECHNOLOGIES CORP
BRISTOL ENGINE DIVISION, ROLLS ROYCE (1971) LTD
DERBY ENGINE DIVISION, ROLLS ROYCE (1971) LTD

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for processing through their computer programs, which provide calculations of PNL, PNLT, and EPNL.

This paper discusses the proposed ARP 1264, the components of the test to evaluate the proposed ARP, the analysis systems used in the evaluation, and the test results. The analyses discussed in this paper are limited to the maximum OASPL, PNLM, PNLTM, and EPNL. For the purposes of this paper, the spectrum analysis system is defined as the equipment utilized to perform the one-third-octave filtering, determine the root-mean-square (rms) of the filtered signals with the proper dynamic response characteristics, and perform the logarithmic conversion on the time-averaged signals. The output of the spectrum analysis system generally is input to a follow-on digital computer program for the calculation of corrected one-third-octave-band SPL's, PNL's, and EPNL's.

Proposed Analysis System Specifications

The purpose of proposed ARP 1264 is to provide for uniformity in one-third-octave-band spectral analysis of airplane flyover noise when EPNL is to be the major result of the analysis. Elements of the spectrum analysis system that are covered by the document include: 1) one-third-octave-band filter characteristics, 2) detector accuracy, 3) dynamic response characteristics, 4) data sampling interval, 5) amplitude resolution, 6) overall system accuracy, and 7) dynamic range. ARP 1264 allows for the use of either analog or digital techniques for filtering and averaging of the noise signals as long as the required specifications are met. Table 2 summarizes the spectrum analysis system characteristics specified in the proposed standard.

The calculation of EPNL from the one-third-octave-band sound pressure level histories is not covered in the document, but is described in Ref. 3. Also, the characteristics of the microphones, tape recorders/reproducers, calibrators, and other components of the field data acquisition portion of the total measurement system are not considered.

Evaluation Test Components

Each participant in the test to evaluate proposed ARP 1264 was provided with three items: 1) a tape recording consisting of calibrations and three aircraft flyovers, 2) tabulations of one-third-octave-band sound pressure levels in 0.5-sec increments for three aircraft flyovers, similar but not identical to those on the tape recording; and 3) a set of test instructions and standard data reporting forms.

Table 2 Noise analysis system characteristics required by ARP 1264

PARAMETER	SPECIFICATION
FILTERS	1/3-OCTAVE, 50- TO 10,000-Hz CENTER FREQUENCY MEET SPECIFICATIONS OF ANS-S1.11, 1966 (CLASS III)
DETECTOR ACCURACY	APPROXIMATE ROOT-MEAN-SQUARE OF INPUT SIGNALS WITH CREST FACTORS OF 3 TO WITHIN THE FOLLOWING TOLERANCES: TOLERANCE — LEVEL RELATIVE TO FULL SCALE OF ANALYZER ±1 dB — 0 TO −30 dB ±1.5 dB — −30 TO −55 dB
DYNAMIC CHARACTERISTICS	ANALOG OR DIGITAL AVERAGING TECHNIQUES APPROXIMATING A "SLOW" RESPONSE AS DEFINED BY IEC 179.
OUTPUT INTERVALS	0.5 SECOND. ALL 24 1/3-OCTAVE LEVELS SAMPLED WITHIN 50 MSEC. NO MORE THAN 5 MSEC OF DATA OF ANY 0.5-SECOND PERIOD TO BE EXCLUDED.
AMPLITUDE RESOLUTION	±0.3 dB
OVERALL SYSTEM ACCURACY	±1 dB
DYNAMIC RANGE	55 dB

Test Tape Recording

Aircraft Flyover Noise Signals

In selecting the flyover noise recordings, the objective was to provide a range of signals that contained as many as possible of the signal characteristics that could be expected from a flyover of a conventional jet transport aircraft. The principal characteristics of interest were spectral content, including tones and broadband noise, and the rise and decay rates of the signals. In order to obtain the variety of desired characteristics, three recordings of a commercial transport powered by low-bypass-ratio turbofan engines were selected. These recordings were made with the microphone located 1) directly under the takeoff flightpath, 2) approximately 2100 ft to the side of the takeoff flightpath, and 3) directly under the flightpath during a landing approach. It can be noted that these microphone locations are consistent with those required in aircraft noise certification tests. Each recording had unique characteristics that can be summarized as follows:

Takeoff Centerline: This signal was of moderate duration; the noise level in terms of PNLT remained within 10 PNdB of the maximum level for a period of approximately 6.5 sec. During this period, the higher frequency tones, which propagate forward from the engine inlet and rearward from the fan discharge, dominated the signal until the airplane passed overhead and the low-frequency roar of the jet exhaust masked out the tones. The doppler shift of the tone frequency also was quite apparent.

Takeoff Sideline: This signal was of relatively long duration having a period of approximately 21.5 sec during which the PNLT was within 10 PNdB of the maximum level. The long duration resulted in a relatively slow rise and decay of the signal. Because of the long distance from the airplane to the microphone, the higher frequency tones were substantially attenuated and this flyover signal was dominated by low-frequency broadband noise.

Approach Centerline: This signal had a very short duration because of the close proximity of the airplane to the microphone, less than 400 ft, as it passed overhead. The period in which the signal was within 10 PNdB of the maximum level was only approximately 3.5 sec. Higher frequency tones strongly dominated the spectra with extremely rapid rise and decay rates.

Test Tape Preparation and Uniformity

The selected flyover signals and the calibration signals were recorded on a master tape by an Ampex 1800 tape recorder in the FM mode at a tape speed of 30 in./sec and a 54,000-Hz carrier frequency. A standard IRIG B time code was recorded on a separate channel. Fourteen copies of the master tape were made using a direct record process in which the FM carrier was copied directly to assure that all tapes were

Table 3 Tape recording contents

RUN	DATA (CHANNEL 4)	TIME CODE (CHANNEL 6) MIN	SEC
1.	PLAYBACK ALIGNMENT CHECK — 1-VOLT, 1000-Hz SIGNAL	13 TO 13	23 43
2.	AMPLITUDE CALIBRATION TONE — 250 Hz, 104 dB	13 TO 14	50 04
3.	FREQUENCY RESPONSE CALIBRATION SIGNAL (PINK NOISE)	14 TO 14	10 30
4.	AIRCRAFT FLYOVER — TAKEOFF CENTERLINE	14 TO 15	40 10
5.	AIRCRAFT FLYOVER — TAKEOFF SIDELINE	15 TO 15	15 49
6.	AIRCRAFT FLYOVER — APPROACH CENTERLINE	15 TO 16	54 12
7.	REPEAT ALIGNMENT CHECK — 1-VOLT, 1000-Hz SIGNAL	16 TO 16	18 38

Table 4 Measured uniformity of test tape copies

FLYOVER	VARIATION (2σ) OASPL (dB)	PNLTM (PNdB)
TAKEOFF CENTERLINE	±0.3	±0.5
TAKEOFF SIDELINE	±0.3	±0.3
APPROACH CENTERLINE	±0.3	±0.9

Table 5 Example of variation introduced by FAR Part 36 tone correction procedure

1/3-OCTAVE-BAND CENTER FREQUENCY (Hz)	SOUND PRESSURE LEVEL (dB) SPECTRUM 1	SPECTRUM 2	DIFFERENCE (dB) (1 MINUS 2)
50	74.7	74.7	0
63	67.2	67.2	0
80	71.2	71.2	0
100	78.7	78.7	0
125	83.5	83.5	0
160	86.5	86.5	0
200	77.7	77.7	0
250	84.2	84.2	0
315	84.0	84.0	0
400	82.5	82.5	0
500	82.5	82.5	0
630	82.5	82.5	0
800	80.5	80.5	0
1,000	82.5	82.5	0
1,250	84.2	84.2	0
1,600	81.7	81.7	0
2,000	84.3	84.2	0.1
2,500	102.2	102.2	0
3,150	93.7	93.7	0
4,000	83.2	83.2	0
5,000	88.7	88.7	0
6,300	81.5	81.5	0
8,000	79.7	79.7	0
10,000	71.2	71.2	0
PNL (PNdB)	118.2	118.2	0
PNLT (PNdB)	121.7	122.6	−0.9

identical. The contents of the test tape are summarized in Table 3. Ampex 1800 tape machines were used in the copying process, and the machines were checked before use to confirm that they complied with the manufacturer's specifications.

In order to provide further assurance that all of the test tape copies were identical, each copy was analyzed before distributing the copies to the test participants. This analysis was performed with a General Radio 1921 system using a 0.5-sec integration time with no additional smoothing. A summary of the results of this analysis is shown in Table 4. Compared in this table are variations among the copies in OASPL and PNLTM for each flyover. Considering that the resolution of the analyzer is 0.25 dB, the OASPL variations from copy to copy are within measuring accuracy.

It is interesting to note in Table 4 that, for the approach flyover, the variance in terms of PNLTM is significantly larger than the variance in OASPL. A peculiarity in the tone correction procedure was identified as the source of the increased variance. This peculiarity results from the use of a step function to define when the change in slope of the noise spectrum is large enough to identify a potential tone and require averaging of adjacent one-third-octave bands to establish a background level (i.e., when the change in slope is greater than 5). An example of the variance created by the tone correction procedure is shown in Table 5. In this table, two sets of one-third-octave-band spectra are shown. The tone occurs in the one-third-octave band having a center frequency of 2500 Hz. The two spectra are identical except for the 2000-Hz band, where the sound pressure levels differ by 0.1 dB. The PNL's calculated from the two spectra are identical, 118.2 PNdB. However, when the tone correction procedures of Ref. 3 are used, the spectrum with the 0.1 dB *lower* level in the 2000-Hz band produces a 0.9-PNdB *higher* tone correction and tone-corrected perceived noise level. In effect, the calculation procedure identifies the level in any one-third-octave band as a potential tone when the change in slope of the noise spectrum, as determined by the procedure, is greater than 5 dB. In the example shown in Table 5, the 0.1-dB higher level in the 2000-Hz band provided just enough difference to result in a change of slope greater than 5 (5.1 to be precise), consequently producing the significantly larger (0.9 PNdB) tone correction. Thus, apparently insignificant differences in the sound pressure levels obtained from analysis systems can be expanded into substantial differences in PNLT by the calculation procedure.

Tabulated Reference One-Third-Octave-Band Spectral Histories

In order to investigate the possibility that variances between organizations in their analysis of the test tape in terms of EPNL could have arisen because of calculation procedure differences rather than analysis system differences, sets of one-third-octave-band spectra were provided. Participants were instructed to calculate PNLM, PNLTM, and EPNL values from these supplied spectra using the same calculation procedures used to calculate these values from their test tape analysis. Although specific procedures for calculating EPNL, PNL, and PNLT values were specified, it was possible that procedures used by each organization were not identical. This nonuniformity in the calculation procedures possibly could result from several sources including 1) their interpretation of the defined procedures and 2) computer roundoff techniques used when programming the procedures. One-third-octave-band spectra were provided in 0.5-sec increments in the form identical to the output of the analysis system. The three sets of spectra were based on the analysis of takeoff centerline, takeoff sideline, and approach flyovers of an aircraft similar to that from which the test tape recordings were made. These sets of data exhibited the same characteristics of the test tape recordings in terms of rate of rise and decay, and high-frequency tone and low-frequency broadband spectra content.

Test Instructions

Each participating organization was furnished a detailed set of instructions describing how the tape was to be processed and what data were to be reported. The intent of the instructions was to minimize data analysis variations among the organizations from sources other than those due to the spectrum analysis. Each of the three flyover noise recordings contained on the analog test tape was to be processed four times using a system that conformed to the proposed ARP to determine the variation within an organization. Specific method for processing the calibration signals also were specified.

In order to minimize variations in the calculation of EPNL and the reporting of the results, no corrections for the presence of background noise were to be included. Because most of the participating organizations had existing software using the EPNL claculation procedure defined in FAR Part 36, this procedure was specified for the test.

Specific data processing information and summary output data were requested from each organization. Requested information relating to the calibration signals included in the type of spectrum analyzer used, playback results of the 1-V reference signal, start times for the reference level, and frequency response corrections derived from the analysis of the pink noise. Also requested were the data processing start times used for each flyover noise recording and the averaging technques that were used. Finally, a summary data sheet was provided for tabulating the maximum OASPL, PNLM, PNLTM, and EPNL for each of the four replications for each of the three flyovers. In addition, complete one-third-octave-band sound pressure level histories were required, but these data are not discussed in this paper. Instructions also were distributed for the processing of the tabulated reference spectral histories provided to each participant. The instructions were to cycle the spectra for the three flyovers through the same EPNL computation program that was used to process the test tape signals. In this way any difference among the organizations in the procedure for calculating PNL or EPNL could be identified.

Analysis System Variations

Although the various spectrum analysis systems used by the participating organizations were to meet the requirements of the proposed ARP, they were different in some respects. Two types of spectrum analyzers were used by the various organizations as the bases of their analysis systems: Hewlett-Packard (HP) model 8054A real-time spectrum analyzer and General Radio (GR) model 1921 real-time analyzer. Both analyzers contain a set of parallel analog one-third-octave filters having center frequencies covering the audio frequency range up to 10,000 Hz. The HP 8054A contains a bank of quasi-rms detectors employing analog resistor-capacitor (RC) averaging, whereas the GR 1921 employs a single digital detector using true integration techniques with selectable integration times ranging from ⅛ to 32 sec. Thus, the averaging techniques used by the two analyzers are quite different. A standard HP 8054A is equipped with two dynamic response modes, RMS FAST and RMS SLOW. The RMS SLOW mode has a nominal RC time constant of 1 sec. This mode meets the dynamic response requirements of proposed ARP 1264 for a signal that is increasing in level. However, the effective response for a decaying signal is slower and tracking of a rapidly decaying signal, as might occur in a low-altitude flyover, may not be possible in this mode.

For a system that uses the GR 1921, the procedure used to obtain the required dynamic response, together with the required sample rate, is somewhat more involved and requires additional averaging of the analyzer's output. Since the proposed standard requires a sampling interval of 0.5 sec, the integration time of the GR 1921 must be set at 0.5 sec or less. However, when this is done, the dynamic response requirements of ARP 1264 will not be met without additional smoothing. The required data smoothing usually takes place in a follow-on computer program as some sort of a moving-average routine. For example, an averaging time of 1.5 sec can be obtained by averaging linearly (with respect to energy) three successive 0.5-sec integration time samples in a routine that deletes the earliest of the three samples as it accepts a new sample. Generally speaking, both 1.0- and 1.5-sec averaging times, as defined in the preceding, will meet the dynamic response requirements of the proposed standard. A more detailed discussion of these two types of averaging techniques and potential differences in the flyover noise levels they may cause is discussed in Ref. 4.

The more significant variations in data processing techniques are summarized in Table 6. These variations include differences in the analyzer used, integration time, and averaging times used to process the data.

Table 6 Variations in data processing techniques

SPECTRUM ANALYZER	MODE OF OPERATION	NO. OF ORGANIZATIONS
GR1921	0.5 SEC INTEGRATION TIME/ 1.5-SEC AVERAGING TIME	7
GR1921	0.5-SEC INTEGRATION TIME/ 1.0 SEC AVERAGING TIME (a)	1
GR1921	0.45-SEC INTEGRATION AND AVERAGING TIMES (b)	1
GR1921	NOT DEFINED	1
HP8054A	0.035-SEC TIME CONSTANT/ 1.3-SEC AVERAGING TIME	1
HP8054A	0.35-SEC TIME CONSTANT/ 0.5-SEC SAMPLE RATE (b)	1

NOTE (a) 0.5-SEC AVERAGING TIME USED FOR DECAY PORTION OF THE APPROACH FLYOVER
(b) MAY NOT MEET ARP 1264 DYNAMIC RESPONSE REQUIREMENTS

Test Results

Conventional statistical analysis-of-variance techniques were applied to the data received from participating organizations to provide an evaluation of proposed ARP 1264. The specific objectives of the analysis were: 1) to determine if all of the data, regardless of the analysis system or techniques used (assuming conformance with ARP 1264), could be included in the same population set; 2) to determine the variance in the data both within organizations, as determined by repeat analyses, and from organization to organization; and 3) to identify probable sources of variance.

The data analysis was limited to the maximum OASPL, PNLM, PNLTM, and EPNL values obtained by each organization by 1) analyzing the test tape and 2) calculating values from the sets of reference one-third-octave-band spectral histories. The statistical analyses of each of these data sets are discussed in the following paragraphs.

Test Tape Data

Of the four noise units for which data were reported, the maximum OASPL provides the best indication of analysis system uniformity, since it can be measured directly. Each of the four units (PNLM, PNLTM, and EPNL) must be calculated from one-third-octave-band sound pressure level data and, thus, are subject to variations resulting from differences between organizations in their calculation procedures. Although all organizations were requested to use specific calculation procedures (as defined in FAR Part 36) and indicated compliance with this request, there is evidence that calculation differences did exist among organizations. These differences will be discussed later.

Maximum OASPL

Of the 12 organizations reporting data, 10 performed their test tape analyses using a system based on the GR 1921 analyzer; two used systems based on the HP 8054A analyzer. Although all organizations using the same model analyzer did not use the analyzer in the same manner, a statistical analysis (t-test for comparing two means) revealed a bias between the two sets of analysis systems. It was determined that a significant difference at a 99% confidence level occurred in the analysis of two of the three flyover recordings. As shown in Table 7, the mean HP 8054A data were higher than the GR 1921 data from the takeoff and approach centerline flyovers by 1.1 and 1.6 dB, respectively. The two sets of analysis systems differed by less than 0.1 dB for the takeoff sideline case, a difference not significant at a 99% confidence level. Of the two organizations using an HP 8054A based system, one used the analyzer with a short time constant (0.35 sec), which does not appear to comply with proposed ARP 1264 in that adequate smoothing may not be provided resulting in excessively high output. Based on this fact, plus the small sample size of the HP 8054A data set (one cannot be confident that these two samples are representative of the total population of HP 8054A based analysis systems), it was

Table 7 Comparison of maximum overall sound pressure level [a]

FLYOVER	ANALYZER	NO. OF ORGANIZATIONS	RANGE OF ORGANIZATION MEANS	OVERALL MEANS	SIGNIFICANT DIFFERENCE AT 99-PERCENT CONFIDENCE
TAKEOFF CENTERLINE	HP 8054A	2	101.3 TO 101.7	101.5	
	GR 1921	9	99.7 TO 100.7	100.4	
				$\Delta = 1.1$	YES
TAKEOFF SIDELINE	HP 8054A	2	100.8 TO 100.9	100.8	
	GR 1921	9	100.3 TO 101.0	100.8	
				$\Delta = 0.0$	NO
APPROACH CENTERLINE	HP 8054A	2	102.7 TO 103.6	103.2	
	GR 1921	9	100.6 TO 102.4	101.6	
				$\Delta = 1.6$	YES

[a] Four repeats per mean.

decided to perform the remaining statistical analysis using only GR 1921 based data.

A summary of the analysis of variance of the OASPL data analyzed by the GR 1921 based systems appears in Table 8. Results, as expected, show that 1) the variation is larger from organization to organization than it is within an organization performing repeat tests, and 2) most variation appears in the approach centerline flyover data, the signal with the most rapid transient; and least variation appears in the takeoff sideline data, the flyover that has the least rapid transient.

PNLM, PNLTM, and EPNL

The output of the data analysis system (the sound pressure level data) is used to calculate PNL, the basic measure of annoyance. The same sound pressure level data also are the basis for determining the presence of a tone and determining the tone correction that is added to PNL to produce PNLT. A duration correction, based on the value of PNLT during the period of time that the PNLT of the flyover signal is within 10 PNdB of PNLTM, then is applied to produce EPNL. In addition to the analysis system, each step in the calculation procedure leading to an EPNL value is a potential source of variance. In order to give an indication of the magnitude of probable sources, the statistical analysis procedure described in the following paragraphs was used. The results of this analysis are summarized in Table 9-11 for takeoff centerline, takeoff sideline, and approach centerline, respectively. Values from Table 9 are used as examples in the following discussion and are shown in parentheses.

First, the relationship between maximum OASPL and PNLM was determined from the data, as shown in Fig. 1. As discussed in the previous paragraph, the analysis of variance of the maximum OASPL data established the variation in the data attributable to the analysis system. Multiplying the slope of the regression line drawn through the OASPL vs PNLM data of Fig. 1 times the variance associated with the OASPL data (Table 8) provides an indication of the component of variance in PNL attributable to the analysis system (0.2 PNdB within organization and 0.6 PNdB organization-to-organization). The scatter about the regression line represents the component of variance most likely attributable to nonuniformities in the procedure to calculate PNL (0.3 PNdB). The relationship between OASPL and PNL also demonstrates the difference between the GR 1921 and HP 8054A based analysis systems for the takeoff and approach centerline cases.

The relationship between PNLM and PNLTM was determined in a similar manner, and is shown in Fig. 2. Multiplying the slope of the regression line drawn through the data times the components of variance established for PNL (the values shown in the PNLM column) provides the components of variance in PNLT attributable to the analysis system (0.2 PNdB within organization and 0.8 PNdB organization-to-organization) and the PNL calculation procedure (0.4 PNdB). In this case, the scatter about the regression line represents the component of variance in PNLT most likely attributable to nonuniformities in the tone correction calculation procedure (0.3 PNdB). It can be noted from this relationship that unique data points exist in the takeoff centerline and takeoff sideline cases. The significantly different tone calculations implied by these data points may be the result of idiosyncrasies of the calculation procedure discussed earlier. These unique values were not included in the analysis to determine the variance attributable to the tone correction calculation procedure.

The correlation between PNLTM and EPNL, shown in Fig. 3, is not as strong as the relationships between maximum OASPL vs PNL and PNLM vs PNLTM. This is not surprising, since the maximum OASPL, PNLM, and PNLTM values are similar in that all are based on one-third-octave-band spectra from one 0.5-sec time period, whereas the EPNL value is an integration of all of the PNLT values over each of the 0.5-sec periods in which PNLT is within 10 PNdB of PNLTM. As described for the other relationships, the regression line drawn through the PNLTM vs EPNL relationship provided the means of indicating the likely sources of variance in the EPNL data, the analysis system (0.1

Table 8 Maximum overall sound pressure level summary of analysis of variance[a]

FLYOVER	SOURCE OF VARIATION (2σ) REPEAT ANALYSES WITHIN ORGANIZATIONS (dB)	ORGANIZATION TO ORGANIZATION (dB)	TOTAL VARIATION (2σ) (dB)
TAKEOFF CENTERLINE	0.2	0.6	0.7
TAKEOFF SIDELINE	0.1	0.4	0.4
APPROACH CENTERLINE	0.3	1.1	1.2

[a] Based on GR analyzer; 9 participating organizations.

Table 9 Sources of variation – takeoff centerline flyover [a]

	PNLM (PNdB)	PNLTM (PNdB)	EPNL (EPNdB)
WITHIN ORGANIZATION DUE TO:			
MAXIMUM OASPL VARIATION	±0.2		
PNLM VARIATION		±0.2	
PNLTM VARIATION			±0.1
ORGANIZATION-TO-ORGANIZATION DUE TO:			
MAXIMUM OASPL VARIATION	±0.6		
PNLM VARIATION		±0.8	
PNLTM VARIATION			±0.4
MAXIMUM OASPL TO PNLM VARIATION	±0.3	±0.4	
PNLM TO PNLTM VARIATION		±0.3	±0.2
PNLTM TO EPNL VARIATION			±0.5
TOTAL VARIATION ($\sqrt{\Sigma\sigma^2}$)	±0.7	±1.0	±0.7

[a] GR analyzer; 10 participating organizations; in terms of 2 standard deviations.

Table 10 Sources of variation – takeoff sideline flyover[a]

	PNLM (PNdB)	PNLTM (PNdB)	EPNL (EPNdB)
WITHIN ORGANIZATION DUE TO:			
MAXIMUM OASPL VARIATION	±0.1		
PNLM VARIATION		±0.1	
PNLTM VARIATION			±0.1
ORGANIZATION-TO-ORGANIZATION DUE TO:			
MAXIMUM OASPL VARIATION	±0.4		
PNLM VARIATION		±0.4	
PNLTM VARIATION			±0.2
MAXIMUM OASPL TO PNLM VARIATION	±0.4	±0.4	
PNLM TO PNLTM VARIATION		±0.4	±0.2
PNLTM TO EPNL VARIATION			±0.5
TOTAL VARIATION ($\sqrt{\Sigma\sigma^2}$)	±0.6	±0.7	±0.6

[a] See footnote, Table 9.

Table 11 Sources of variation – approach centerline flyover[a]

	PNLM (PNdB)	PNLTM (PNdB)	EPNL (EPNdB)
WITHIN ORGANIZATION DUE TO:			
MAXIMUM OASPL VARIATION	±0.3		
PNLM VARIATION		±0.4	
PNLTM VARIATION			±0.1
ORGANIZATION-TO-ORGANIZATION DUE TO:			
MAXIMUM OASPL VARIATION	±1.0		
PNLM VARIATION		±1.2	
PNLTM VARIATION			±0.2
MAXIMUM OASPL TO PNLM VARIATION	±0.3	±0.4	
PNLM TO PNLTM VARIATION		±0.6	±0.1
PNLTM TO EPNL VARIATION			±1.4
TOTAL VARIATION ($\sqrt{\Sigma\sigma^2}$)	±1.0	±1.4	±1.4

[a] See footnote, Table 9.

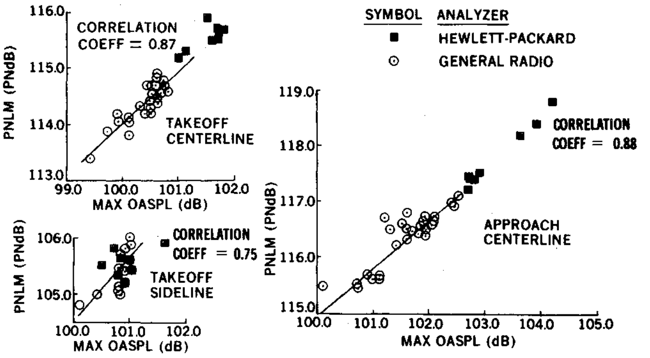

Fig. 1 Relationship between maximum OASPL and PNLM.

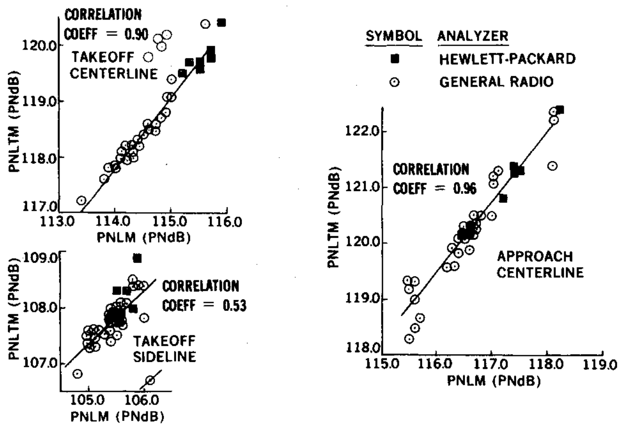

Fig. 2 Relationship between PNLM and PNLTM.

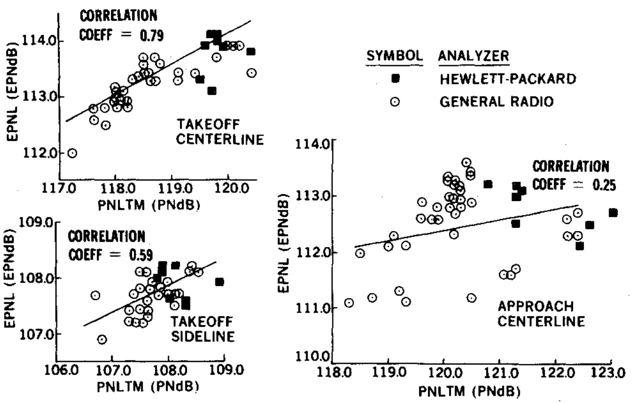

Fig. 3 Relationship between PNLTM and EPNL.

EPNdB within organization and 0.4 EPNdB organization-to-organization), and the calculation procedure.

In summary, the results of this statistical analysis, as shown in Tables 9-11, indicate that both the data analysis system and calculation procedures are sources of variations. As would be expected, the noise unit having the most complex calculation procedure, EPNL, has the largest indicated variance attributed to the calculation procedure. Conversely, PNL, which has the least complex calculation procedure, has the smallest variance attributable to the procedure.

Tabulated Spectral Data

A statistical analysis of variance was performed on the PNLM, PNLTM, and EPNL values calculated by participating organizations from the tabulated reference one-third-octave-band histories supplied. This analysis is summarized in Table 12. Although all organizations calculated the values in accordance with procedures defined in FAR Part 36, differences did occur in the calculated values. In all of the cases except one, the two standard deviations were approximately ±0.2 to ±0.4 dB. The one exception was the PNLTM calculated from the one-third-octave-band spectra provided for an approach flyover. In this case, the two standard deviations were ±0.9 PNdB. It is believed that the principal reason for variations in calculated values from the supplied spectra was that all organizations did not use identical programming techniques. The relatively large variation in the approach PNLT case resulted from tone corrections calculated by two organizations whose results differed from those of all other organizations. All organizations but these two calculated tone corrections of 3.0 or 3.1 dB, whereas the two exceptions calculated 2.5 and 4.1 dB for this case. The reason for this difference has not been determined.

Table 12 Analysis of variance – PNLM, PNLTM, and EPNL[a]

FLYOVER	PNLM (PNdB)	PNLTM (PNdB)	EPNL (EPNdB)
TAKEOFF CENTERLINE	±0.3	±0.4	±0.4
TAKEOFF SIDELINE	±0.2	±0.2	±0.3
APPROACH CENTER LINE	±0.4	±0.9	±0.4

[a]Calculated from tabulated reference ⅓-octave-band spectral histories; in terms of 2 standard deviations.

Summary of All Results

Major results of the data analysis discussed in this section can be summarized as follows:

1) All participating organizations used analysis systems based on one of two types of commercial one-third-octave-band, real-time analyzers manufactured by General Radio or Hewlett-Packard. For the takeoff and approach centerline cases, the data fell into separate population sets, depending on which analyzer was included in the system. For these two cases, the average differences between the two sets of data were 1.1 dB and 1.6 dB, respectively, with the HP 8054A data being higher than that of the GR 1921. However, it must be noted that the HP 8054A sample size was small (2 out of 12), and one of the two organizations used the analyzer in a manner that may not have conformed to proposed ARP 1264, and that could produce higher values.

2) From the GR 1921 analyzer data, variations from organization to organization were approximately 3.3 times the variations within organizations resulting from repeat analyses. The 2σ variations from organization to organization in terms of maximum OASPL were from ±0.4 dB to 1.2 dB, with the smallest variation occurring from the analysis of the takeoff sideline flyover and the largest from the approach centerline flyover. This result was expected, since these two flyover recordings provided the slowest and most rapid signal transients, respectively. The rapid signal transient presents a more difficult analysis problem.

3) Calculation procedures also were identified as sources of variance. For the calculated units, a 2σ variation of approximately 0.3 PNdB could be attributed to differences in PNL calculation procedures. An additional 2σ variation of from 0.3 to 0.6 PNdB could be attributed to differences in procedures to calculate tone corrections. These variations occurred, even though all organizations reported that they used the calculation procedure defined in FAR Part 36.

4) Variations of the same order of magnitude as those stated in Item 3, also resulted from the analysis of values calculated from the reference one-third-octave-band spectra histories. These data were provided to elminiate the analysis system as a source of variance and to determine if the calculation procedures were significant sources of variance. These results indicate that they were.

5) The total 2σ variation for the EPNL values calculated from the analysis of the test tape recordings were: takeoff

centerline – ±0.7 EPNdB; takeoff sideline – ±0.6 EPNdB; approach centerline – ±1.4 EPNdB.

Conclusions and Recommendations

The analyses of the analog test tape and reference spectral histories have proven to be a useful tool for evaluating flyover noise analysis system standards. The recent exercise conducted to evaluate the proposed SAE ARP 1264 standard resulted in several conclusions and recommendations. It can be concluded that the proposed ARP 1264 is a workable document, and addresses the important characteristics of a flyover noise analysis system. Moreover, it is concluded that the state-of-the-art in uniform analysis of aircraft flyover noise has been improved considerably by complying with the specifications of the proposed standard relative to those in effect at the time of the SAE-sponsored Brown Field tests in 1968.

Since a large part of the observed variations among the organizations was due to the procedures used for calculating the subjective measures of annoyance, such as PNL and PNLT, it is recommended that these calculation procedures be revised to reduce idiosyncrasies that can produce significant differences in the calculated value from negligible differences in the one-third-octave-band sound pressure level basic data. Because of the small sample size in this test of the HP 8054A processed data, it is recommended that other organizations employing this analyzer, as well as other types of analyzers, analyze the analog test tape.

Finally, based on the information obtained from this exercise, it is recommended that other proposed standards for the measurement and analysis of aircraft flyover noise be evaluated thoroughly in a similar manner before approval. The evaluation test should examine the feasibility and practicality of applying the standard and assure that it does, in fact, provide an improvement in the state-of-the-art.

Acknowledgment

A note of appreciation is extended to the Boeing Commercial Airplane Company for producing the master analog test tape, generating the 14 copies, and processing each of them on their noise analysis system to ensure the uniformity of their contents. Also, a note of thanks is extended to all the participating organizations, and particularly to Pratt & Whitney Aircraft for generating the reference spectral histories.

References

[1] "Comparison of Ground-Runup and Flyover Noise Levels," Society of Automotive Engineers, Committee A-21, AIR 1216, April 1972.

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[4] Stouder, D. J., "Use of Digital Averaging Techniques for the Analysis of Aircraft Flyover Noise," *Proceedings for the International Conference on Noise Control Engineering*, Institute of Noise Control Engineering, Washington, D. C., 1974.