



Society of Automotive Engineers, Inc.
TWO PENNSYLVANIA PLAZA, NEW YORK, N. Y. 10001

AEROSPACE INFORMATION REPORT

AIR 1216

Issued April 1972
Revised

COMPARISON OF GROUND-RUNUP AND FLYOVER NOISE LEVELS

FOREWORD

In 1967, during discussions of the engines to be selected for the forthcoming advanced-technology commercial jet transports (747, DC-10, and L-1011), questions arose concerning the various methods used to predict flyover noise levels from ground-runup noise measurements. Significant and inconsistent differences had been noted between predicted and measured spectra of the flyover noise from transports powered by turbo-jet-and low-bypass-ratio turbo-fan engines. The differences were considered to be due partly to variations in the noise-prediction methods and partly to the variety of noise-measurement techniques. Another issue was the scatter that had been observed in reported measurements of the ground-runup noise produced by JT3D-powered jet transports. Variations in the acoustical characteristics of the ground surface between the engine and the microphones as well as differences in microphone locations were suspected of being principal causes of the differences that had been noted in the ground-runup noise measurements.

Because these questions were of concern to the members of SAE Committee A-21, a special test was arranged in February 1968 under the auspices of the Committee. This report has been prepared to document some of the results of this special test. It was not the intention of the test program to develop generalized results suitable for all possible airplane/engine configurations, ground conditions, microphone placements, or data-reduction and data-analysis techniques. The results of the test, however, did provide valuable information concerning procedures for predicting flyover noise levels as well as measuring both ground-runup and flyover noise. The tests also provided a unique opportunity for the participating organizations to make independent simultaneous field measurements of the noise produced by two quite different noise sources, the JT3D-3B engine on a 707-320C and the JT8D-1 engine on a 727-100.



TABLE OF CONTENTS

	Page
1. SUMMARY	1
2. INTRODUCTION	1
3. SCOPE	1
4. ANALYSES	2
5. COMPARISON OF FLYOVER AND GROUND-RUNUP SPL'S	3
6. COMPARISON OF GROUND-RUNUP SPL'S OVER CONCRETE AND OVER GRASS	4
7. CONCLUDING REMARKS	5
8. RECOMMENDATIONS	5
9. REFERENCES	5

LIST OF TABLES

I. AVERAGE DIFFERENCES BETWEEN LEVEL-FLIGHT FLYOVER AND GROUND-RUNUP SPL'S FOR A 707-320C	6
II. AVERAGE DIFFERENCES BETWEEN LEVEL-FLIGHT FLYOVER AND GROUND-RUNUP SPL'S FOR A 727-100	7
III. AVERAGE DIFFERENCES BETWEEN GROUND-RUNUP SPL'S MEA- SURED OVER CONCRETE AND OVER GRASSY SURFACES FOR A 707-320C	8
IV. AVERAGE DIFFERENCES BETWEEN GROUND-RUNUP SPL'S MEA- SURED OVER CONCRETE AND OVER GRASSY SURFACES FOR A 727-100	9

LIST OF ILLUSTRATIONS

	Page
1. Microphone array used for flyover noise tests, Brown Field, February 1968	10
2. Difference between flyover SPL's and ground-runup SPL's for 707-320C; all SPL's measured over concrete surfaces	11
3. Difference between flyover SPL's and ground-runup SPL's for 727-100; all SPL's measured over concrete surfaces	14
4. Average difference between flyover and ground-runup SPL's. Differences averaged over three engine power settings for 707 and 727 airplanes. All SPL's measured over concrete surfaces	17
5. Difference between ground-runup SPL's measured over concrete and over grassy surfaces for 707-320C	18
6. Difference between ground-runup SPL's measured over concrete and over grassy surfaces for 727-100	21
7. Portion of array of microphones used for ground-runup SPL measurements over concrete surface, Brown Field, February 1968	24
8. Average difference between ground-runup SPL's measured over concrete and SPL's measured over grassy surfaces. Differences averaged over three engine power settings for each airplane	25

1. SUMMARY

Ground-runup and flyover noise levels were measured on 707-320C and 727-100 airplanes. The ground-runup data for both airplanes included measurements made over a concrete surface and over a grassy surface. Comparisons are presented of the differences between maximum one-third-octave-band sound pressure levels measured during the aircraft flyovers and the corresponding maximum one-third-octave-band sound pressure levels obtained by projecting the ground-runup measurements to a 400 ft sideline distance comparable to the aircraft height above the ground for the level-flight flyover noise measurements. Comparisons are also presented of the differences between maximum one-third-octave-band sound pressure levels measured during the ground-runups over the concrete surface and over the grassy surface and projected to a 400 ft sideline distance. All projections of ground-runup noise measurements to the 400 ft distance included corrections for inverse-square loss and atmospheric absorption. No corrections for ground absorption, shielding, or ground reflections were included.

The scatter in the separate results obtained by the participating organizations indicates that additional studies are warranted to determine the reasons for the scatter. In addition, further efforts are required to develop standard data-acquisition and data-reduction procedures in order to obtain more consistent measurements of ground-runup and flyover noise levels. These efforts, in turn, may lead to a need for additional work to develop consistent methods to account for the acoustical differences between various types of engines and engine installations.

2. INTRODUCTION

- 2.1 In February 1968, measurements were made of the flyover and ground-runup noise levels produced by a 707-320C four-engine jet transport and a 727-100 three-engine jet transport. These airplanes were equipped with low-bypass-ratio turbofan engines. The 707-320C was powered by JT3D-3B engines with a bypass ratio of about 1.4; the 727-100 was powered by JT8D-1 engines with a bypass ratio of about 1.0.
- 2.2 Eight different organizations made measurements during the tests. The eight organizations were (1) McDonnell Douglas Corporation (MDC), (2) General Electric Company (GE), (3) Pratt & Whitney Aircraft Division (P&WA), (4) Rolls-Royce Limited (RR), (5) The Boeing Company (TBC), (6) Lockheed-California Company (LCC), (7) Rohr Corporation (ROHR), and (8) Bolt Beranek and Newman, Incorporated (BBN). For various reasons, only the first five of these eight organizations were able to provide sufficient data for use in the analyses.
- 2.3 The tests were conducted at Brown Field, located near San Diego, California, as a part of a program initiated by the Society of Automotive Engineers' Committee A-21. The participating organizations made concurrent measurements but were responsible for their own microphone placement and calibrations, data recording, data reduction, and the projection of their measured ground-runup noise levels to equivalent level-flight flyover noise levels.
- 2.4 The principal purpose of this report is to present and discuss, for each aircraft, the differences between flyover sound pressure levels (SPL's) and SPL's projected to comparable flyover conditions from the ground-runup measurements. A second purpose of this report is to present the differences between ground-runup SPL's, measured at comparable distances from the engine, over concrete and over grassy surfaces. Analyses are presented for three different engine power settings for both types of comparisons for both airplanes.

3. SCOPE

- 3.1 Because of the special circumstances under which these tests were conducted, it is necessary to carefully define the limitations on the validity of the results. The measurements and the comparisons reported here apply only to the specific locations of the noise sources and microphones and only for the specific weather and ground-surface conditions existing at the time of the tests. It cannot be assumed that these conditions are representative of most field measurements of aircraft exterior noise.
- 3.2 Furthermore, although the recommendations of Reference 1 for microphone height and orientation were generally followed for the flyover noise measurements, there were rather wide variations in microphone height and orientation during the ground-runup noise measurements, where standard procedures had not been established at the time of the tests. Therefore, some of the scatter that was observed in the comparisons between flyover SPL's and projected ground-runup SPL's, as well as the comparisons between

the ground-runup SPL's over the two types of ground surfaces, may be due to differences in the microphone arrangements used by the participating organizations.

- 3.3 The differences in microphone arrangements coupled with the different heights of the engines above the ground for the 707-320C and the 727-100 airplanes probably introduced systematic distortions in the spectra of the measured SPL's due to ground-reflection effects that produced varying phase shifts and acoustic path-lengths. The comparisons presented in this report contain, therefore, not only the intrinsic differences between actual flyover noise measurements and projections from ground-runup noise measurements, but also the differences resulting from differing microphone arrangements, recording, calibration, and data processing techniques.
- 3.4 Finally, it is noted that the choice of composite spectra (maximum SPL in each 1/3-octave band regardless of time of occurrence during a flyover) for the comparisons makes it impossible to separate the intrinsic differences from the other differences due to variations in test geometry and measuring techniques.
- 3.5 Nevertheless, in spite of the limitations noted above, the test did provide valuable information related to the refinement of techniques for predicting flyover noise levels from ground-runup noise measurements. The tests also provided a unique opportunity for the participating organizations to make independent simultaneous field measurements of the noise produced by two quite different noise sources, the JT3D-3B engine on a 707-320C and the JT8D-1 engine on a 727-100. The tests also demonstrated the need for development of additional standardized procedures for measuring flyover and ground-runup noise in order to reduce the scatter in the resulting data.

4. ANALYSES

- 4.1 The flyover noise tests included SPL measurements made beneath actual takeoff and landing flight paths as well as beneath level-flight passes at nominal heights of 400 and 1000 ft made along the centerline of the runway. During the level-flight flyovers, the microphones used by the various organizations were grouped along the asphalt surface at the edge of the concrete runway, as shown in Figure 1. Only the SPL's from the level-flight flyovers were used in the analyses presented in this report because, for this condition, more data were available than for the takeoffs or landings and because the surface beneath the microphones was uniform and acoustically comparable to the concrete surface over which the more complete sets of ground-runup data were obtained.
- 4.2 The magnetic tape recordings of the level-flight flyover SPL's were reduced to obtain the maximum one-third-octave-band SPL's occurring during each flyover. The ground-runup data consisted of one-third-octave-band SPL's recorded at various angles along a circular arc in the far-field, at a distance of 150 ft from the engine, during stabilized engine operation at various power settings. The flyover noise tests were made with all engines operating, i.e., either four or three engines. The ground-runup tests were conducted with only one engine operating, i.e., one of the outboard engines on the 707-320C and one of the fuselage-mounted engines on the 727-100. The differences between flyover and ground-runup SPL's were adjusted to a common basis by subtracting $10 \log N$ (where N was the number of engines, i.e., either 6 or 4, 8 dB) from the flyover noise levels. No corrections for different numbers of engines were needed, of course, when comparing the ground-runup SPL's measured over the two types of terrain because only single-engine data were available.
- 4.3 The comparisons presented in this report are at comparable values of engine referred rotor speed, i.e., at values of actual rotor speed divided by $\sqrt{\theta_{t_2}}$ where $\theta_{t_2} = T_{t_2}/T_{std}$ and T_{t_2} is the total temperature at the engine inlet in degrees Rankine and T_{std} is 518.7°R. This parameter was chosen because the turbo-machinery noise from the fan stages, which controls the perceived noise levels from the JT3D and JT8D engines, is directly related to the fan-rotor tip Mach number and hence to referred rotor speed. Measurements of T_{t_2} were obtained from the standard total temperature gages located in the cockpit of the airplanes.

- 4.4 The measured values for the level-flight flyover noise levels were adjusted to a common height above the runway of 400 feet. In order to obtain data comparable to the level-flight flyover noise measurements, the ground-runup SPL's were projected to a 400 ft sideline distance from the measurements made along the circular arc over the concrete surface. The adjustments made to the level-flight flyover SPL's and to the 400 ft sideline projections both included inverse-square distance corrections and atmospheric absorption corrections. Atmospheric absorption corrections were applied to all measurements to correct the data for the differences between the atmospheric conditions existing at the time of the tests and the atmospheric absorption occurring at an ambient temperature of 59 F and a relative humidity of 70 percent. The atmospheric absorption corrections were based on the data presented in Reference 2 and the ambient temperatures and relative humidities measured near the surface of the ground. No corrections were included for ground absorption, ground reflection, or shielding effects.
- 4.5 In order to obtain single-valued comparisons for the differences between the ground-runup SPL's measured over the concrete surface and the SPL's measured over the grassy surface, the ground-runup SPL's for both cases were also projected to a 400 ft sideline distance, accounting again for inverse-square distance corrections and atmospheric absorption corrections. No ground-absorption, shielding, or ground-reflection corrections were applied. Composite spectra of the one-third-octave-band SPL's were then generated for each engine power setting by selecting the maximum one-third-octave-band SPL's along the 400 ft sideline distance. The differences in the composite spectra were used to represent the differences due to propagation over concrete and over grass.
- 4.6 Although ground reflection effects were certainly present in the measurements, no corrections for ground reflections were included because there was no standard correction procedure available at the time of the tests. Corrections for ground absorption and shielding effects were not included because the flyover noise measurements were made directly under the aircraft flight path while the ground-runup measurements were made around a single outboard engine at a distance of 150 feet. Moreover, the projections from the ground-runup measurements were made to an equivalent overhead distance and not to locations to the side of the flight path.

5. COMPARISON OF FLYOVER AND GROUND-RUNUP SPL'S

- 5.1 One-third-octave-band spectra of the differences between composite SPL's for the 400 ft level-flight flyovers and the 400 ft ground-runup projections are given in Fig. 2(a), 2(b), and 2(c) for the 707-320C airplane and in Fig. 3(a), 3(b), and 3(c) for the 727-100 airplane. All SPL's were taken from the data measured over a concrete surface.
- 5.2 The results presented in Fig. 2(a), 2(b), and 2(c) are for nominal referred low-pressure rotor speeds per engine of 4900, 5950, and 6750 rpm, respectively. These engine power settings correspond approximately to nominal referred net thrust per engine of 5000, 10,000 and 14,500 pounds. The results presented in Fig. 3(a), 3(b) and 3(c) are for nominal referred low-pressure rotor speeds per engine of 6200, 7500, and 8100 rpm, respectively, corresponding approximately to nominal referred net thrusts per engine of 5000, 8000 and 12,000 pounds. The referred net thrust is the net thrust produced during flight but referred to a sea level ambient pressure by dividing the value of the calculated net thrust by the pressure ratio δ_{am} , i. e., by the ratio of the ambient pressure at the height of the aircraft, in inches of mercury, to the standard sea level pressure of 29.92 in. of mercury.
- 5.3 The data presented in Fig. 2 and 3 illustrate the variation in the results obtained by the separate organizations. The data for the 707-320C aircraft show a reasonable degree of agreement, having a spread of ± 1 to ± 5 dB depending on frequency and engine power setting. The data for the 727-100 aircraft have a larger spread with values ranging from ± 1 to ± 7 dB depending on frequency and engine power setting.
- 5.4 The results shown for the 707-320C contain data from five organizations. The results shown for the 727-100, however, are based on data supplied by only four organizations because data from Rolls-Royce were not available for the 727-100. A generalized value for the difference between flyover and ground-runup SPL's was calculated by averaging the SPL difference at each one-third-octave-band center frequency. The heavy solid lines in Fig. 2 and 3 represent the average differences for each case.

- 5.5 Comparison of these average SPL differences indicated that there were only small variations among the average SPL differences for the three engine power settings on the two aircraft. Therefore, the corresponding grand averages of the average SPL differences were calculated by averaging the three sets of average differences for each airplane. The resulting spectra of the average SPL differences are shown in Figure 4. Tabulated values of the average SPL differences for each engine power setting and the corresponding grand averages are shown in Tables I and II for the 707-320C and the 727-100 airplanes, respectively.
- 5.6 As indicated by the spectra in Fig. 4, the average SPL differences were distinctly different for the two airplanes. For the 707-320C, the average difference between flyover and projected ground-runup maximum SPL's varied from -8 dB at 80 Hz to +4.5 dB at 2500 Hz. For the 727-100, however, in the frequency range from 125 to 8000 Hz, the average difference was approximately constant at a value of -2.5 dB.
- 5.7 In examining the results shown in Figs. 2, 3, and 4, it is noted that, had there been sufficient time available, it would have been instructive to have tested the hypothesis that engine power setting was not the primary parameter affecting the magnitude of the spectrum of the average difference between measured and predicted flyover noise levels. One way to have done this would have been to have compared the grand averages of the differences shown in Fig. 4 to the grand averages obtained by first averaging the differences in the SPL's for the three thrust levels for each organization and then average the differences between the various organizations. This procedure might have indicated how much of the scatter in the results was due to differences in data-acquisition and data-reduction techniques, since, for each organization, these techniques were the same for all three power settings on each airplane.

6. COMPARISON OF GROUND-RUNUP SPL'S OVER CONCRETE AND OVER GRASS

- 6.1 Comparisons are shown in Figs. 5 and 6 of the differences in the composite SPL's projected to a 400 ft sideline distance from the SPL measurements made over concrete and the SPL measurements made over grass. The referred rotor speeds in Figs. 5 and 6 correspond to those of the SPL differences shown for the comparable conditions in Figs. 2 and 3. The separate data points and the average differences have the same significance as discussed above for the differences between flyover and ground-runup SPL's. Figure 6(a) contains data from three organizations in contrast to Figs. 6(b) and 6(c) which are based on data from four organizations. Comparable data from the General Electric Company were not available for the 6200-rpm power setting.
- 6.2 The data from the McDonnell Douglas Corporation in Figs. 5 and 6 were obtained in full octaves at center frequencies of 63, 125, 250, and 500 Hz and in one-third-octave-bands above 800 Hz. The full octave data were converted to one-third-octave-band data by subtracting 4.8 dB from the octave levels and plotted as equivalent one-third-octave-band data at the appropriate center frequencies. This procedure was not used for the flyover noise measurements where one-third-octave-band SPL data were obtained for each of the 24 bands with center frequencies between 50 and 10,000 Hz.
- 6.3 The reasonably good agreement that was evident in the results presented in Fig. 2 is repeated in the results for the 707-320C shown in Fig. 5. In contrast, the results for the 727-100 in Fig. 6 show scatter that is greater than the scatter in Figs. 2, 3, or 5. Although the reasons for the greater scatter are unknown, it is suspected that differences in the heights of the engines and the microphones above the ground surface may have been the principal reason for most of the scatter. On the 707-320C, the centerline of the outboard engine was approximately 6 ft above the surface. On the 727-100, the centerline of the fuselage-mounted engine was approximately 13 ft above the surface. During the tests, the choice of microphone height above the ground and of microphone orientation with respect to the engine was made by personnel from the various participating organizations. A sample of the divergence of opinion as to the correct choice for these two variables is shown by the photograph in Fig. 7 taken during the ground-runup tests of the 707-320C. The variation in microphone height was even greater during the tests of the 727-100.
- 6.4 At the time of these tests, there was no accepted standard procedure applicable to ground-runup noise measurements. If more consistent test results are to be obtained in the future, it would seem to be desirable to develop standard procedures to be used for microphone location and orientation during ground-runup tests.

- 6.5 In spite of the scatter in the separate results, it was noted for these ground-runup comparisons, as for the comparisons of the flyover SPL's to the projected ground-runup SPL's, that the average SPL differences were approximately constant for the three engine power settings for each airplane. The corresponding grand averages of the average SPL differences are shown in Fig. 8. As in Fig. 4, the average SPL differences for the two airplanes were distinctly different. Almost all of the differences were positive, indicating that the SPL's over the concrete surface were higher than the SPL's measured over the grassy surface. This trend was expected because of the absorption provided by the earth and grass, compared to the absorptivity of concrete, i.e., because of the difference in the acoustic impedance of the two surfaces. The difference in SPL's for the 707-320C had a broad peak at approximately +13 dB in the one-third-octave bands centered at 250 and 315 Hz. For the 727-100, the peak occurred at a lower frequency in the one-third-octave-band centered at 160 Hz and with a value of approximately +9 dB. The SPL difference in the frequency range from 2500 to 10,000 Hz was approximately the same for both airplanes, with a value of approximately +3 dB. Tabulated values of the separate average SPL differences and the grand averages of the SPL differences for the two airplanes are given in Tables III and IV.

7. CONCLUDING REMARKS

Sound pressure level measurements obtained on a 707-320C airplane and on a 727-100 airplane were analyzed to determine the one-third-octave-band spectra of the average differences between the composite SPL's measured during level-flight flyovers and the composite SPL's projected to equivalent aircraft heights from measurements made during static engine ground-runups. Analyses were also made to determine the average differences between composite one-third-octave-band spectra projected from ground-runup SPL's measured over a concrete surface and ground-runup SPL's measured over a grassy surface. Distinctive differences were noted in the results obtained from the two aircraft.

8. RECOMMENDATIONS

The scatter in the separate results obtained by the participating organizations indicates that additional studies are warranted to determine the reasons for the scatter that was noted. In addition, further efforts are required to develop standard data-acquisition and data-reduction procedures in order to obtain more consistent measurements of ground-runup and flyover noise levels.

These efforts, in turn, may lead to a need for additional work to develop consistent methods to account for the acoustical differences between various types of engines and engine installations.

9. REFERENCES

1. SAE Committee A-21, "Measurements of Aircraft Exterior Noise in the Field", SAE Aerospace Recommended Practice ARP 796, June 15, 1965.
2. SAE Committee A-21, "Standard Values of Atmospheric Absorption as a Function of Temperature and Humidity for Use in Evaluating Aircraft Flyover Noise," SAE Aerospace Recommended Practice ARP 866, proposed revision April 1970.

TABLE I
AVERAGE DIFFERENCES BETWEEN LEVEL-FLIGHT FLYOVER
AND GROUND-RUNUP SPL'S FOR A 707-320C

One-third-octave-band center frequency, Hz	Average sound-pressure-level ^a differences, dB			
	Referred low-pressure rotor speed, rpm			Average for the three rotor speeds
	4900	5950	6750	
50	-5.0	-6.3	-4.7	-5.3
63	-6.0	-6.4	-5.6	-6.0
80	-7.5	-8.8	-7.9	-8.1
100	-5.5	-8.6	-9.1	-7.7
125	-4.8	-8.1	-7.1	-6.7
160	-4.8	-7.8	-6.1	-6.2
200	-3.5	-6.6	-5.5	-5.2
250	-2.8	-4.3	-4.6	-3.9
315	-2.3	-4.8	-5.0	-4.0
400	-1.6	-4.3	-4.0	-3.3
500	-1.0	-3.4	-3.9	-2.8
630	-0.6	-2.8	-2.7	-2.0
800	-1.4	-1.5	-1.4	-1.4
1000	1.7	0.2	0.2	0.7
1250	2.6	2.0	1.8	2.1
1600	1.6	6.3	3.3	3.7
2000	1.6	2.6	4.8	3.0
2500	5.7	6.3	1.3	4.4
3150	2.4	-0.3	2.7	1.6
4000	5.5	3.6	-3.6	1.8
5000	1.7	-0.4	-2.4	-0.4
6300	-0.7	-2.2	-2.4	-1.3
8000	-0.3	-0.5	-6.0	-2.3
10000	0.8	-0.4	-2.1	-0.6

^aAll SPL's measured over concrete surfaces.