FACTORS AFFECTING MEASURED AIRCRAFT SOUND LEVELS IN THE VICINITY OF START-OF-TAKEOFF ROLL

Horonjeff, Richard D.[1], Fleming, Gregg G.[2], Rickley, Edward J.[2],
Connor, Thomas L[3].

1) Harris Miller Miller & Hanson Inc., 429 Marrett Road, Lexington, MA 02173.
2) Volpe National Transportation Systems Center, Kendall Square, Cambridge, MA 02142.
3) Federal Aviation Administration, Office of Environment & Energy, 800 Independence Avenue SW, Washington, DC 20591.

INTRODUCTION

This paper presents the findings of a recently conducted measurement and analysis program of jet transport aircraft sound levels in the vicinity of the start-of-takeoff roll. The purpose of the program was two-fold: (1) to evaluate the computational accuracy of the Federal Aviation Administration's Integrated Noise Model (INM) in the vicinity of start-of-takeoff roll with a recently updated database (INM 3.10), and (2) to provide guidance for future model improvements. Focusing on the second of these two goals, this paper examines several factors affecting Sound Exposure Levels (SELs) in the hemicircular area behind the aircraft brake release point at the start-of-takeoff roll. In addition to the aircraft type itself, these factors included (1) the geometric relationship of the measurement site to the runway, the wind velocity (speed and direction), aircraft gross weight, and start-of-roll mode (static or rolling start).

APPROACH

Data acquisition consisted of the simultaneous acquisition of data at five, far-field acoustic measurement sites, one wind measurement site, and one aircraft observation site. The measurements were conducted at Baltimore-Washington International Airport, approximately 15 miles south of Baltimore, Maryland.

Acoustic Measurement Sites. Figure 1 shows the locations of the five measurement sites. Jet transport departures took place on runway 28 which is shown with the large arrows indicating direction of movement. Sites 1, 3, and 5 were located to cover a range of azimuth angles about the aircraft brake release point. Sites 2, 3, and 4 were placed to cover a range of distances along a common azimuth. Site 1 was located adjacent to a general aviation parking apron with complete unobstructed line-of-sight to the aircraft. The remaining sites were rear yards of single family residences and were at least 150 feet from the nearest structure which could have considered a source of acoustic shielding between source and receiver. Distances from the brake release point to the measurement site as well as azimuth angles (relative to the aircraft nose) are shown in Table 1.

Acoustic Measurement Hardware and Procedures. Unattended measurements were conducted at each site using a Bruel & Kjaer Model 4155 1/2-inch electret microphone, a Larson-Davis Model 827-0V or 900B microphone preamplifier, and

TABLE 1. RANGE AND AZIMUTH TO MEASUREMENT SITES

Site	Range (meters)	Azimuth (degrees)
1	1255	080
2	865	118
3	1128	110
4	1420	118
5	913	166

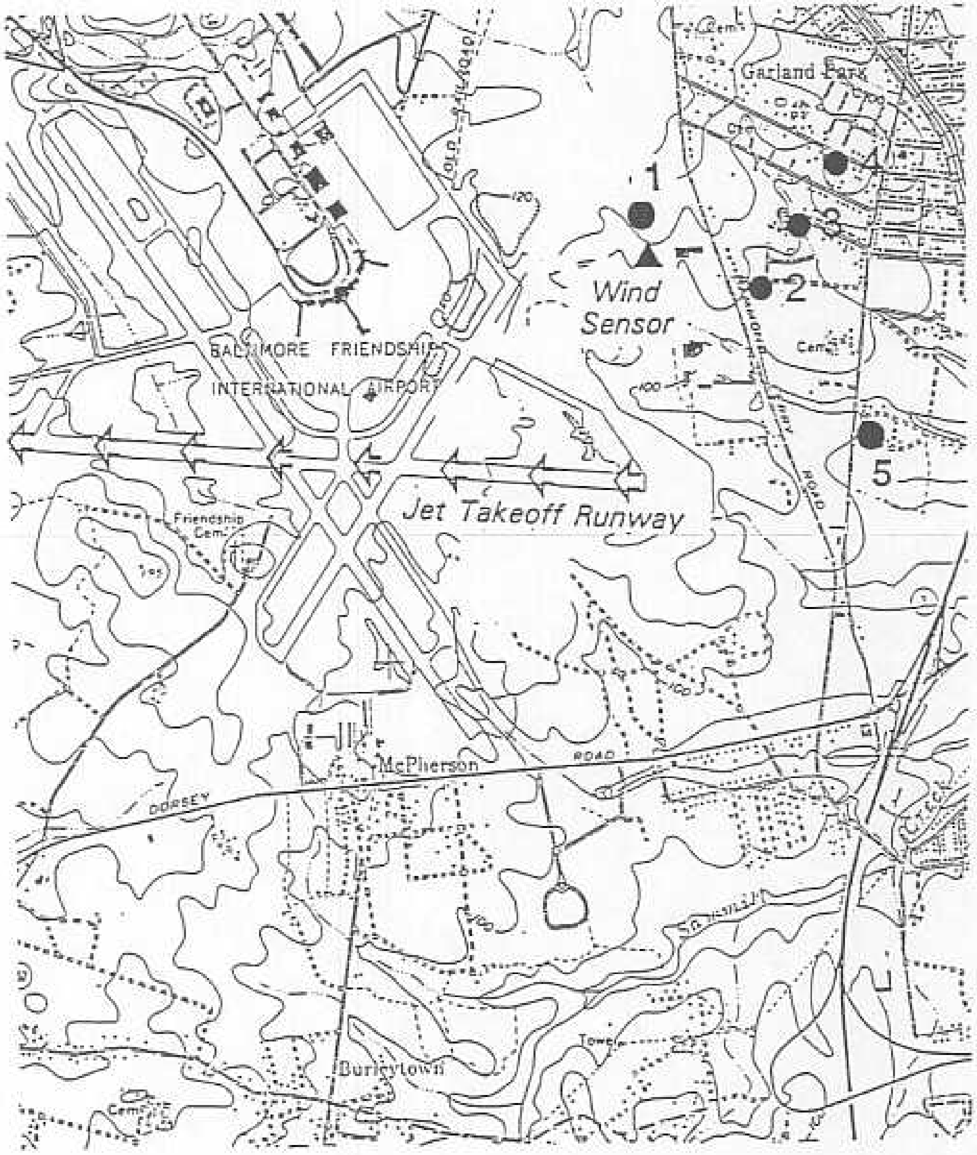

FIGURE 1. ACOUSTIC MEASUREMENT SITE LOCATIONS

a Larson-Davis Model 820 or 870 Precision Sound Level Meter. A 3-inch, open cellular foam windscreen was used during all measurements. All units were carefully time-synchronized to ensure inter-unit timing accuracies of better than 500 milliseconds.

Because of the large source-receiver distances, and attendant low sound levels at the measurement sites, acoustic data were collected and stored as a series of A-weighted sound levels at 1/2 second intervals (instead of the more traditional threshold-discriminated SELs). SELs were computed during post-processing by visual inspection of the data and manual selection of the temporal integration bounds for each noise event. This was particularly important for the quieter Stage 3 aircraft, such as the Boeing 737:300 and 400 models, since maximum signal-to-background noise ratios of 10 to 15 decibels were not uncommon for these aircraft. These low signal-to-noise ratios did not allow for integration over the top 20 decibels of sound level time-history that would have been desirable (or were otherwise possible for some of the higher sound level aircraft). For the sake of consistency, the results reported here use an SEL computed over the top 10 decibels of the time-history regardless of the dynamic range available for the event. For completeness, estimated background noise levels were also subtracted during the SEL computation process.

Conflicting Aircraft Noise Sources. Because of the unattended aspect of the sound level monitoring it was imperative to determine when other significant airport related activity might conflict with measurements of jet transport takeoffs. Logs were maintained of all jet transport landing activity as well as all general aviation and commuter aircraft activity.

Aircraft Identification. Positive aircraft type identification was obtained in a two-step process. First, an observer was stationed approximately 400 feet from the brake-release end of the runway where each departing aircraft could easily be seen. For each departure, the brake-release time was logged as was the type of aircraft, the aircraft registration number, and whether a static or rolling start was observed. At the conclusion of field data acquisition the registration numbers were checked against FAA records to ensure the proper aircraft type has been identified for each aircraft movement.

Gross Weight Data. At the conclusion of each day's measurement session the completed aircraft observer logs were taken to each airline's airport station manager. The airlines provided the gate weights of each aircraft from the aircraft registration numbers and departure times.

Wind Speed and Direction. Wind speed and direction was obtained using an R.M. Young Model 5305 anemometer. The sensor was located atop a 10 meter high pole in an open area on airport property adjacent to acoustic measurement site 1. Speed and direction voltage outputs were connected to a Remote Measurement Systems, Inc. Model ADC-1 analog-to-digital converter which was connected via an RS-232 port to a Toshiba 1000 laptop computer. The computer read the instrument voltage every 2 seconds and stored the data on floppy disk for future data analysis. In the laboratory, 2-minute average wind vectors were computed for each aircraft departure.

RESULTS

For each aircraft type, SELs observed at a particular site typically spanned a range of 15 to 20 decibels. This section presents these results and provides insight into the reasons for this range.

SEL versus Wind Speed. Figure 2 shows measured SEL versus wind speed data points for Boeing 727-200 aircraft measured at each of the five measurement sites. Wind speed was derived by projecting the two-minute average wind vector (from brake release to two minutes thereafter) onto a propagation path connecting the brake release point and the measurement site. Positive values of wind speed indicate propagation path component was blowing from source to receiver (downwind propagation); negative values indicate a wind component blowing from receiver to source (upwind propagation).

The SELs shown are those computed over the top 10 decibels of the time history (for reasons cited earlier). In general, integration over the top 20 decibels produced levels 1 to 1.5 decibels greater. In many cases the A-weighted time histories showed a double peak, the first occurring during ground roll and a second after liftoff. Sound level integration always included both peaks.

In general, the variability in measured SELs covered a range of 15 decibels at sites 1 and 5, and a range of 20 decibels at sites 2, 3, and 4. Figure 2 suggests that about one-half of that range can be explained by wind, and this observation is consistent with theory as well as prior experimental findings[1 2]. Under downwind sound propagation conditions the underlying A-weighted time histories at all but site 1 showed the maximum level occurred within the first 5 to 10 seconds after brake release. Under upwind conditions of -5 miles per hour (-2.2 meters per second) or less the maximum level generally occurred after liftoff, suggesting a severe increase in overground sound attenuation which primarily affected the ground roll portion of the time history. This attenuation probably results from the combined effects of ground reflection, barrier attenuation from intervening structures, foliage, and wind shadow. This combination had the effect of reducing SELs by about 10 decibels over downwind conditions. Under downwind conditions (with positive wind gradient), direct sound rays are diffracted up and over barriers and cancelation effects of ground reflections are destroyed by the barriers.

At site 1 the effects of wind are not as pronounced, most likely due to the directional nature of noise source. Even under downwind propagation conditions the maximum sound level occurred at or after liftoff; thus, the ground roll portion of the time history contributes less to SEL at site 1 than it does at the other four sites. At site 5, very little data were acquired at negative wind velocities (aircraft tailwind conditions), but the beginnings of an upwind effect are just visible in the data.

A note of caution is important regarding the comparison of the SEL values shown in Figure 2 with the findings of others. First, they only contain energy over the top 10 decibels of the time history. Second, virtually all downwind data were obtained during moderately cold temperature conditions (-6 to + 4 degrees C) and relative humidities of about 35 percent. The upwind data were acquired in warmer temperatures near 21 degrees C and 60 percent relative humidity. The data were not adjusted for differences in atmospheric absorption during these measurement conditions.

<u>Downwind SEL versus Gross Weight</u>. In general downwind sound propagation conditions are of greater interest for airport noise modelling purposes than are upwind conditions because safety considerations dictate aircraft head <u>into</u> the wind on departure. Focusing on just the downwind data (wind component greater than 1 mile per hour, or 0.4 meter per second) where ground roll influence is maximized, the effect of aircraft gross weight on acceleration (and subsequently SEL) was examined in a three step process. In step one the downwind SELs measured at site 2 were normalized by subtracting the group mean SEL for each aircraft type. Site 2 data was selected because it was the closest site to the start-of-roll where acceleration effects on SEL, if any, would be maximized. In step two the gross weights of each aircraft were normalized by subtracting the group mean gross weight for each aircraft type. In step 3 these normalized data were pooled to plot normalized SEL versus normalized gross weight, as shown in Figure 3. A regression line was also computed through the data points. The line has a slope of 0.83 dB per 10,000 pounds (4,535 kilograms) of weight, but with a standard error of plus or minus 0.25 decibels per 10,000 pounds.

<u>Downwind SEL versus Start Type</u>. Using only the normalized downwind SEL data developed for the gross weight analysis the effects of start type were also examined. The data were split into two groups (rolling and static start) which turned

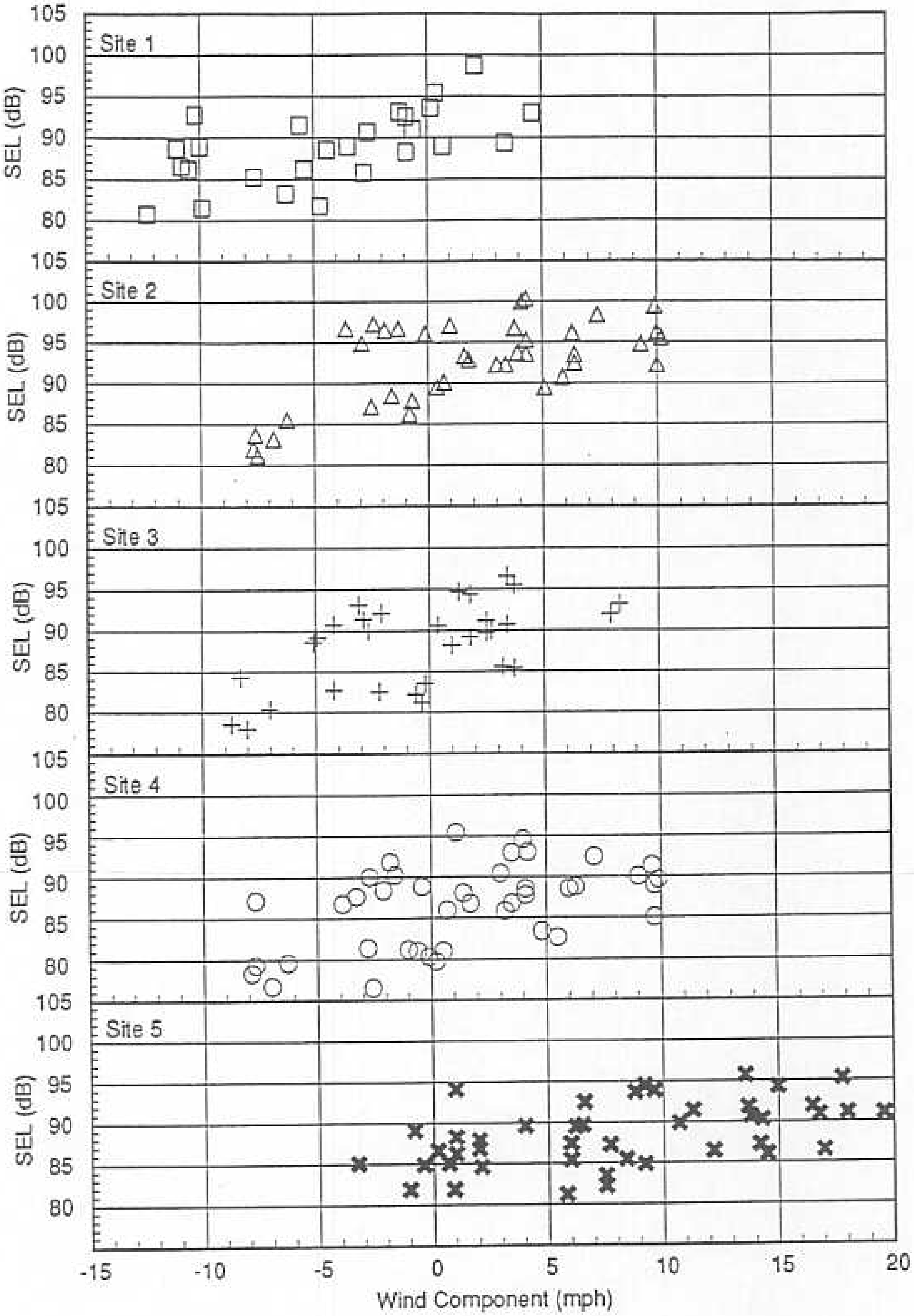

FIGURE 2. SEL VERSUS WINDSPEED FOR B-727 AIRCRAFT

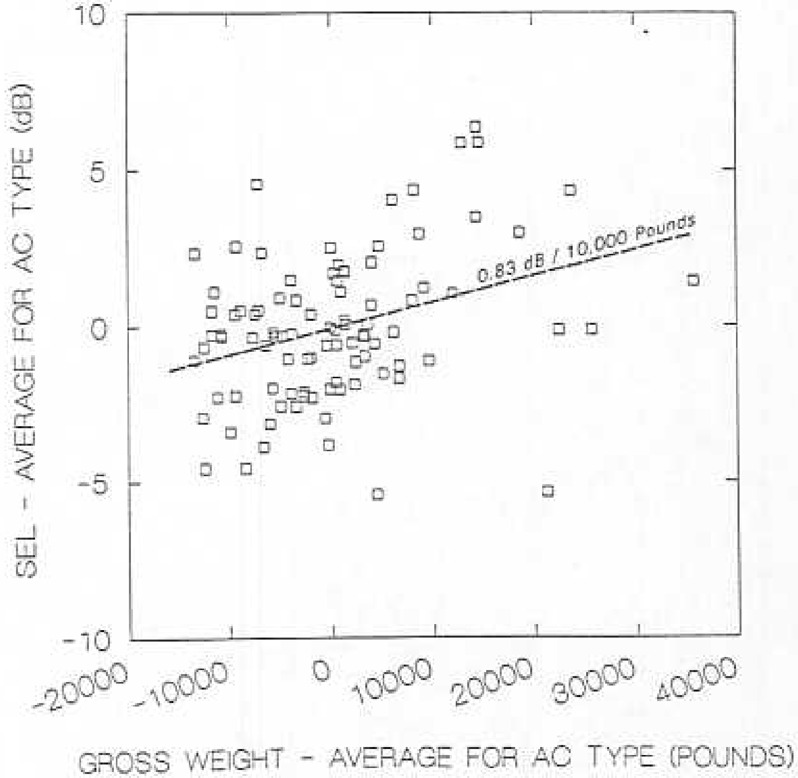

FIGURE 3. NORMALIZED SEL VERSUS NORMALIZED GROSS WEIGHT

out to be of nearly equal size (46 and 49, respectively). Mean values of normalized SEL were calculated for each group, and the difference in means was less than 0.1 decibel with a standard error of 0.4 decibel.

CONCLUSIONS

The results of this study support several important conclusions. The first is the importance of considering wind effects in any start of takeoff roll noise investigation. Second, once the propagation path wind speed reaches 0.5 to 1 meter per second or more, downwind propagation appears to stabilize at large measurement distances and the effects of increasing speed on SEL are minimal. Third, at large distances (1000 meters or more) the effect of wind diminishes at ground locations forward of the aircraft brake release point (site 1 in this study). Fourth aircraft gross weight has a small, but measurable effect. And fifth, a rolling versus static start does not appear to have any measurable impact on SEL at large distances (this may not be the case at smaller distances).

REFERENCES

1. Bishop, D.E. Overground Excess Sound Attenuation (ESA), Volume 2: Analysis of Data fof Flat Grassy Terrain Conditions, U.S. Air Force Report No. AFAMRL-TR-84-017, Vol. 2.
2. Bishop, D.E. Overground Excess Sound Attenuation (ESA), Volume 3: Application of ESA Data In NOISEFILE, U.S. Air Force Report No. AFAMRL-TR-84-017, Vol. 3.