

# Acoustical Acceptance Testing of Portland International Airport Ground Run-up Enclosure

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**Abstract:** The Port of Portland (The Port) constructed an aircraft ground run-up enclosure (GRE) at Portland International Airport (PDX) to allow unrestricted daytime and nighttime aircraft maintenance run-ups, while complying with Oregon Department of Environmental Quality (DEQ) community noise level standards. To ensure compliance with the DEQ standards, a rigorous acoustical acceptance-testing specification was developed and carried out. The PDX specification included “before” and “after” measurements of three representative aircraft run-ups conducted at the GRE site and at a nearby equivalent site. At each test site, measurements were required at six microphone locations at a reference distance of 400 feet (120 meters) from the test aircraft, where variability in measured sound levels due to meteorological conditions would be limited. Although not part of the official acceptance test, simultaneous measurements were conducted in representative community locations as the start of ongoing community monitoring to be conducted by the Port. In April 2001, the GRE met the acoustical acceptance testing specifications and demonstrated compliance with the DEQ community requirements. The multiple-microphone arrays displayed the significant effect of noise shielding provided by aircraft fuselages and suggested that modifications may be appropriate for future applications of the test procedure.

## PROJECT BACKGROUND

Aircraft maintenance run-ups are a necessary part of routine aircraft engine maintenance during which an engine typically is brought up to and maintained at a certain power setting, ranging from idle power to take-off power, depending upon the particular maintenance check being performed. The power setting may be maintained for anywhere from a few seconds to several minutes and the procedure may be repeated several times, potentially including several engine-run cycles and lasting for 30 to 60 minutes. Because of the extended nature and uncertain duration of maintenance run-ups, and because they often are performed at night, when aircraft are not needed for regularly-scheduled service, run-up noise has the potential to be a source of annoyance in nearby residential areas.

The Oregon DEQ’s *Noise Control Regulations for Industry and Commerce (1)* set standards for noise levels in residential areas caused by industrial noise sources and apply as well to aircraft maintenance run-ups. In 1996, the Port reached an interim agreement with the Oregon DEQ that prohibited non-emergency maintenance run-ups between 11 PM and 7 AM and restricted the locations and headings of aircraft conducting run-ups. The agreement also authorized run-ups “if conducted within a Port of Portland approved facility which can attenuate the source engine noise to comply with the requirements of regulatory statutes.”(2) As a result of the interim agreement, the Port engaged in a study to provide a facility for performing aircraft maintenance run-ups while complying with DEQ community noise level standards in residential areas near PDX. Subsequently, a GRE was recommended and constructed. Successful acoustical acceptance testing of the GRE was completed in April 2001.

## Project Area

PDX is located along the southern side of the Columbia River. The closest homes to the GRE site are located south of the airport at distances of approximately 4,000 to 5,000 feet (1,200 to 1,500 meters). Clusters of homes also are located to the west of the airport at distances of about 8,000 to 9,000 feet (2,400 to 2,700 meters) from the GRE. The closest homes to the north of PDX are located north of the Columbia River in the State of Washington, at distances of about 9,000 to 10,000 feet (2,700 to 3,000 meters) from the GRE site. Although the Oregon DEQ regulations do not apply to residents of Washington, the Port’s goal was to comply with the same criteria in these areas. Figure 1 shows the location of the GRE and the general vicinity around PDX.

## GRE Configuration

As shown in Figure 2, the PDX GRE is a three-sided, open-roofed enclosure of roughly rectangular shape, with an interior width of 207 feet (63 meters) at the open end and an interior depth of 278 feet (85 meters). The enclosure is large enough to accommodate an MD-11 size aircraft, and at its highest point, is approximately 55 feet (16 meters) in height. The walls, which are constructed of noise-absorptive panels supported by an external frame, slope downward towards the front of the GRE and are perforated by several louvered vents on each side for aerodynamic

purposes. A blast deflector is located at the rear of the facility to deflect jet exhaust upwards. The location and orientation of the GRE were based upon many factors including using the limited available space on the airfield, maximizing acoustical benefit, maximizing functionality of the facility based upon prevailing winds, and considering additional factors such as sight lines from the air traffic control tower and potential electro-magnetic interference with navigational aids. The budgeted cost of the facility, including civil engineering work such as utility relocations, pavement, and a taxiway tie-in, was \$7.8 million; the final project cost was \$7.5 million.

### **APPLICABLE COMMUNITY STANDARDS AND ACCEPTANCE SPECIFICATIONS**

The purpose of the GRE project was to reduce noise levels in nearby residential areas and to allow unrestricted daytime and nighttime aircraft maintenance run-ups, while complying with DEQ community noise level standards. To ensure compliance with the DEQ standards, comprehensive acoustical acceptance-testing specifications were developed.

#### **DEQ Standards**

The Oregon DEQ Noise Control Regulations for Industry and Commerce limit overall sound levels by defining A-weighted statistical noise levels generated by a particular noise source (shown in Table 1), which are not to be exceeded at the property line of any noise-sensitive property. The limits vary depending upon how long a noise source is active during any one-hour period and include separate standards for daytime (7 AM to 10 PM) and nighttime (10 PM to 7 AM) activities. For example, during nighttime, sound levels of up to 60 dBA (the  $L_1$  limit) are permissible for up to six minutes per hour. Noise events with total durations longer than six minutes during a one-hour period would be restricted by the nighttime  $L_{10}$  limit of 55 dBA. Similarly, once the total duration of a noise event exceeded 30 minutes during one hour, the  $L_{50}$  limit of 50 dBA would restrict the acceptable noise level.

Based upon the assumption that run-ups would exceed six minutes but be limited to a cumulative total of fewer than 30 minutes in any one-hour period, the DEQ  $L_{10}$  limits were selected as the design criteria for the GRE analysis. (Run-ups of 30 minutes, or greater, cumulative duration during any one-hour period would be governed by the more restrictive  $L_{50}$  limits.) Accordingly, run-ups generating steady sound levels, measured at noise-sensitive locations, of 60 dBA or less during the day and 55 dBA or less during the night were considered, for the purposes of the analysis, to be in compliance with the DEQ regulations.

In practice, it would be difficult to apply the DEQ regulations to a particular noise source in communities where other noise sources (such as local street traffic, aircraft flight operations, trains, etc.) regularly generate noise levels exceeding the DEQ limits. Most maintenance run-ups at PDX occur at night, however, when background sound levels in the community are lowest and scheduled flight operations are minimal. During these nighttime periods, measured background ( $L_{90}$ ) sound levels in residential areas near PDX ranged from about 40 to 45 dBA.

#### **Acoustical Specifications**

Because the GRE project was driven by the Port's desire to reduce noise levels in residential areas caused by run-ups at PDX as well as to comply with the demanding DEQ standards, conservative noise reduction goals were developed for run-ups as heard in residential areas. Based upon these community goals, aggressive requirements were then developed for the acceptance-test specifications.

The testing methods for the acoustical specifications were based on American National Standards Institute S12.8-1998, "Methods for Determining the Insertion Loss of Outdoor Noise Barriers" (3) (ANSI S12.8-1998). The intent of the specifications was to demonstrate the GRE's performance through measurements made at a relatively modest distance over which the effects of atmospheric on sound propagation would be reduced. Therefore, the specifications set requirements for measured reduction in sound level (insertion loss) at a distance of 400 feet (120 meters) from the test aircraft. Although high-power aircraft run-ups often include significant components of low-frequency noise, the GRE specifications required only A-weighted measurements because A-weighted metrics were the basis of the controlling portion of the DEQ standard.

At the request of the Port, the specifications required testing of the three representative aircraft types that had been used throughout the analysis. These included the F28, a Stage 2 (older-generation, generally noisier) air-carrier aircraft that is exempt from the Stage 2 phase-out due to its size, the B737-300/400, a common Stage 3 (newer-generation, generally quieter) air-carrier aircraft operating at PDX, and the DHC8, the most common turboprop aircraft at PDX at the time of the study. Measurements were required at a total of six locations, with three on each

side of the aircraft. The reported insertion loss for each aircraft was the arithmetic average of the mean insertion loss measured at each location. The specifications are summarized below:

*The vendor shall demonstrate, through acoustical measurements as described below, that the GRE provides, at a minimum, the specified insertion losses (reduction in A-weighted sound level) for the following three aircraft types:*

<i>Aircraft Type</i>	<i>Required Insertion Loss</i>
<i>1. F28 (any series)</i>	<i>17 dB</i>
<i>2. B737-300/400</i>	<i>18 dB</i>
<i>3. DHC8 (any series)</i>	<i>15 dB</i>

*The insertion-loss measurements shall be performed using the “Indirect Measured Method” including “before” measurements with the test aircraft in an equivalent alternate location without the GRE and “after” measurements performed with the test aircraft in the GRE. A-weighted sound levels shall be measured at each of six measurement locations during both the “before” and the “after” measurements. The reported insertion loss for each aircraft type shall be the arithmetic average (i.e., the average across the six measurement locations) of the mean insertion loss measured at each location.*

*For each of the three aircraft types, the identical aircraft, engine, and power setting shall be used during the “before” and the “after” measurements. In each case, the run-up shall be conducted with a single engine at takeoff power. Measurements shall be conducted at six locations, each 400 feet ( $\pm 10\%$ ) from the geometric center of the aircraft and located at the following radials on both sides of the aircraft: 60 degrees, 90 degrees, and 135 degrees ( $\pm$  five degrees, with zero degrees defined as the front of the aircraft). (4)*

## **MEASUREMENT METHODOLOGY**

The acceptance test followed the “Indirect Measured Method” described in ANSI S12.8-1998 including “before” measurements with the test aircraft in an equivalent alternate location outside of the GRE and “after” measurements with the aircraft in the GRE. This method is intended for use when an outdoor noise barrier has been installed prior to any direct “before” measurements and cannot be readily removed to permit such measurements. Figure 1 shows the locations of both the “before” (“out-of-GRE”) and the “after” (“GRE”) run-up sites. To ensure the validity of the test, certain conditions for the equivalence of the sound sources and the acoustical environment must be met. In addition to the six microphone locations described in the specification, a reference microphone, as specified in ANSI S12.8-1998, was used to monitor the sound source for equivalence during the “before” and the “after” measurements.

Measurements were conducted for the following three aircraft types: F28 Mk. 4000, B737-300, and DHC8 Mk. 200. For each of the three types, the identical aircraft, engine, and power setting was used during the “before” and the “after” measurements. In each case, the run-up was conducted with a single engine at takeoff power. All acoustical measurements were conducted using microphones and amplifiers in conformance with the specifications of ANSI Standard S1.4 for precision (Type 1) (5) sound level meters. Calibrations, traceable to the U.S. National Institute of Standards and Technology (NIST) were carried out in the field using acoustical calibrators.

Meteorological measurements were conducted at a location in the vicinity of the test site with data collected both 50 feet (15 meters) and six feet (two meters) above ground level. The meteorological measurements were used to compare equivalent wind and cloud cover classes, as defined by ANSI S12.8-1998, for the “before” and “after” measurements. During the data analysis, acoustical test data obtained during measurement periods not meeting the requirements for atmospheric equivalence were disallowed. No acoustical measurements were conducted when the average wind speed exceeded 5 m/s (11 mph), regardless of wind direction.

As required by ANSI S12.8-1998, the test report provided the following acoustical data:

- date and time of day for each set of measurements;

- unadjusted background and source acoustical levels at each receiver and reference position for each set of measurements;
- adjustments to measured levels;
- insertion loss for each receiver for each measurement;
- mean insertion loss for each receiver; and
- total experimental uncertainty for each mean insertion loss.

## ACCEPTANCE TEST RESULTS

Table 2 summarizes the results of the acceptance test measurements. The GRE exceeded the required reduction in A-weighted sound level with at least 95% certainty for the B737-300 and the DHC8. For the F28, the required insertion loss was within the range of the 95% confidence interval of the measured insertion loss. It should be noted, however, that the reported mean insertion loss was an average of insertion losses from the six measurement positions. Due to shielding provided by the F28's fuselage, the measured insertion losses for the F28 at each of the individual microphone locations ranged from about 11 dB to 16 dB on the side of the aircraft opposite the engine conducting the test (the shielded side) and from about 18 to 21 dB on the same side of the aircraft as the test engine (the unshielded side). This result indicates that the insertion loss requirements were met for all test locations on the louder (unshielded side) of the aircraft. The effect of fuselage shielding is described below.

## ACOUSTICAL SHIELDING PROVIDED BY AIRCRAFT FUSELAGES

Due to the expectation that the aircraft itself would provide some amount of noise shielding, the acceptance test required measurements at three locations on each side of the aircraft. The effects of shielding, however, were expected to be minimal due to several factors including the position of the rear-mounted engines on the F28, the extent of the propeller blade arc of the DHC8 both above and below the fuselage, and the low-mounted engines on the B737-300 combined with the potential for ground reflections from the pavement in the immediate vicinity of the aircraft. Based on these factors, shielding was expected to reduce "before" sound levels on the shielded side of the aircraft by only about three decibels, with an overall effect on the insertion loss averaged across the six measurements locations of one to two decibels.

The results of the acceptance test demonstrated that the potential significance of shielding provided by the aircraft itself was somewhat greater than had been expected. Comparisons of the data from corresponding pairs of microphone locations on either side of each test aircraft indicated significant acoustical shielding provided by the fuselage (and possibly other components) of each of the three test aircraft. The shielding was particularly evident during the "before" measurements where the data microphones were otherwise unshielded. Because of the small relative differences in distance to each paired microphone and the relatively calm wind conditions, it is likely that shielding provided by the aircraft was the primary cause of the measured differences in sound levels<sup>1</sup>.

The effect of fuselage shielding for the F28 is demonstrated by Figure 3, which shows the measured "before" (i.e. no-GRE) and "after" (i.e. with-GRE) sound levels at each of the six test locations, along with the reported insertion loss ("I.L."). At test locations 1, 2, and 3 on the right side of the aircraft (the "unshielded" side with the right engine operating), the measured "before" sound levels averaged approximately 103 dBA. At the three mirror-image locations (locations 4, 5, and 6) on the left side of the aircraft (the "shielded" side because the fuselage intervened between the test engine and the microphones), the measured "before" sound levels averaged about 96 dBA. The primary reason for the difference in sound levels was the shielding provided by the aircraft's fuselage. In the "after" case, because the GRE provided much more significant shielding than the aircraft itself, the sound levels were only minimally influenced by fuselage shielding. Therefore, although the "after" measurements were similar on both sides of the aircraft (averaging about 84 dBA on the unshielded side and about 83 dBA on the shielded side), the average measured insertion loss on the shielded side of the aircraft was approximately 13 dB, compared to an average of approximately 19 dB on the louder, unshielded side.

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<sup>1</sup>Because the microphone arrays were aligned with the geometric center of the aircraft rather than the test engine, the arrays were not precisely symmetrical around the engine. In all cases, however, the offset between the engine and the center of the microphone array was less than 20 feet (six meters), or approximately five percent of the distance to the microphones.

Table 3 provides a summary of the “before” measurements showing the presumed effects of fuselage shielding for all three of the test aircraft. The table shows that the measured effects of the shielding ranged from about four to nine decibels, depending upon the aircraft and microphone location, and averaged about six decibels. For this test, it is estimated that, on average, shielding provided by the aircraft reduced measured values of overall insertion loss (i.e., averaged over all six microphone locations) by about three decibels.

Although fuselage shielding was not unexpected, the magnitude of the effect exceeded expectations, on average, decreasing the measured insertion losses for all aircraft types by about three decibels. It is important to note, however, that the shielding had no effect whatsoever on the insertion loss on the unshielded side of the aircraft (i.e., the same side as the engine conducting the run-up), where the loudest “no-GRE” sound levels would occur, nor did the effects of fuselage shielding cause any increase whatsoever in measured run-up sound levels in residential areas. These results suggest that future applications of similar test procedures be modified to take the effects of fuselage shielding into account. Potential approaches include limiting microphone locations to the unshielded side of the aircraft, including an appropriate shielding adjustment in the development of the specification, or weighting the computed insertion loss towards the unshielded side of the aircraft by using an energy average of “before” and “after” measurements at all microphone locations.

### COMMUNITY MEASUREMENTS

Although the acoustical acceptance testing of the GRE was based solely on its performance at the 400-foot (120-meter) measurement distances described above, the Port made a commitment to the community to conduct ongoing community measurements to ensure compliance with the DEQ requirements. As a result, the Port requested that community measurements be conducted at the five closest sensitive receptor groups located around the airport simultaneously with the GRE’s acoustical acceptance test. The community measurements were intended to be the first set of measurements in an ongoing program to be conducted by the Port, and were not associated with the actual acceptance testing of the GRE. Figure 1 shows the locations of the five measurement sites relative to the GRE site.

#### Methodology

Community noise measurements were conducted at five locations representing the closest sensitive residential receptors around the airport using microphones and amplifiers in conformance with the specifications of ANSI Standard S1.4 for precision (Type 1) sound level meters (5). Calibrations, traceable to the U.S. National Institute of Standards and Technology (NIST) were carried out in the field before and after the measurements using acoustical calibrators. At each site, a portable noise monitor was set to sample and record the sound level every second during the entire measurement period (the continuous time history). At four of the five community locations, weather-monitoring equipment was installed to measure the wind speed and direction five feet above ground level. A fifth weather station, located in the vicinity of the GRE, included instruments at 50 feet (15 meters) and five feet (1.5 meters) above ground level. In addition, a member of the airport staff was stationed at each community noise-monitoring site, logging the dominant noise sources during the measurement period on a palmtop computer. All of the noise monitors and the palmtop computers used to log the noise sources were synchronized to the second with the noise measurement equipment on the airport. Using the site logs, local events could be identified and excluded from the analysis of the run-up noise from the aircraft in the community. After excluding these events, the approximate average sound level during the run-ups was determined.

Figure 4 provides a sample of the continuous time-history data collected at one of the five community measurement sites during the F28 tests. This site was located in a residential area approximately 7,700 feet (2,300 meters) from the GRE. The sample includes two 10-minute run-ups conducted inside the GRE (from approximately 12:20 AM until 12:30 AM and again from approximately 12:35 AM until 12:45 AM), and two 10-minute run-ups conducted outside of the GRE at the equivalent “before” location (from approximately 1:15 AM until 1:25 AM and again from approximately 1:45 AM until 1:55 AM). During the first inside-the-GRE sample, two unrelated aircraft departures occurred. On average, the measured community sound levels were about 15 to 20 decibels lower with the aircraft in the GRE than with the aircraft at the equivalent “before” location, although some of the difference in sound levels may have been due to differences in distance to the two test sites, relative orientation of the test aircraft to the measurement site, and shielding provided by intervening buildings or terrain. Figure 4 also demonstrates the variability in long-distance sound propagation due to atmospheric effects, even over a relatively short time period. During the two out-of-GRE run-ups, the measured community sound levels varied by approximately 10 decibels

even though the measured sound level at the reference microphone varied by less than one decibel during the same period.

## Results

Table 4 shows the approximate average-measured sound levels at the community sites during the in-the-GRE portion of the acceptance test for each of the three test aircraft and also indicates the average wind conditions that were present during each measurement (downwind, calm, or upwind). Overall, the measured community sound levels were in close agreement with the expected (computed) sound levels and met the project's design goal of 55 dBA under all intended conditions. While some of the measured sound levels at Sites 1 and 2 were above 55 dBA, these exceedences occurred during downwind conditions, and were anticipated. Even under the downwind conditions present during the measurements, however, measured sound levels exceeded the 55-dBA benchmark by no more than about three decibels (differences in sound levels of less than three decibels generally are difficult to perceive). At Sites 3, 4, and 5 (where all measurements occurred under either calm or upwind conditions), the measured sound levels were well below the 55-dBA benchmark. At some sites, the run-up sound levels were low enough compared to background noise levels that it was possible to determine only an upper limit to the run-up level. In all of these cases, however, the measured sound levels were below 55 dBA.

As noted above, the Port had made a commitment to the community to conduct ongoing monitoring to ensure the GRE's effectiveness. The results of the first complete year of operation appear to validate both the effectiveness of the GRE and the DEQ standards, with over 1,700 run-ups conducted inside the GRE and no related noise complaints received from the community.

## CONCLUSIONS

At the time of its implementation, the PDX acoustical specification was the most rigorous specification of its type for a GRE in the United States and provided the assurance required by the Port that the facility would allow unrestricted run-ups in compliance with DEQ standards. An unintended result of the comprehensive test procedure was the demonstration of the potential significance of noise shielding provided by the aircraft itself. Although this effect was not unexpected, its magnitude exceeded expectations, on average, decreasing the measured insertion losses for all tested aircraft types by about three decibels. Because this shielding has no effect on the insertion loss on the unshielded side of the aircraft where the loudest sound levels occur, nor does it increase actual run-up sound levels in residential areas, the results suggest that future GRE specifications be modified to take the significant effects of fuselage shielding into account.

## ACKNOWLEDGEMENTS

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**TABLE 1 Oregon DEQ Allowable Statistical Noise Levels in Any One Hour  
(for New or Existing Industrial and Commercial Noise Sources)**

<b>Statistical Descriptor</b>	<b>Daytime Limits (7 am to 10 pm)</b>	<b>Nighttime Limits (10 pm to 7 am)</b>
L <sub>50</sub>	55 dBA	50 dBA
L <sub>10</sub>	60 dBA	55 dBA
L <sub>1</sub>	75 dBA	60 dBA

**TABLE 2 Insertion Loss Requirements and Test Results**

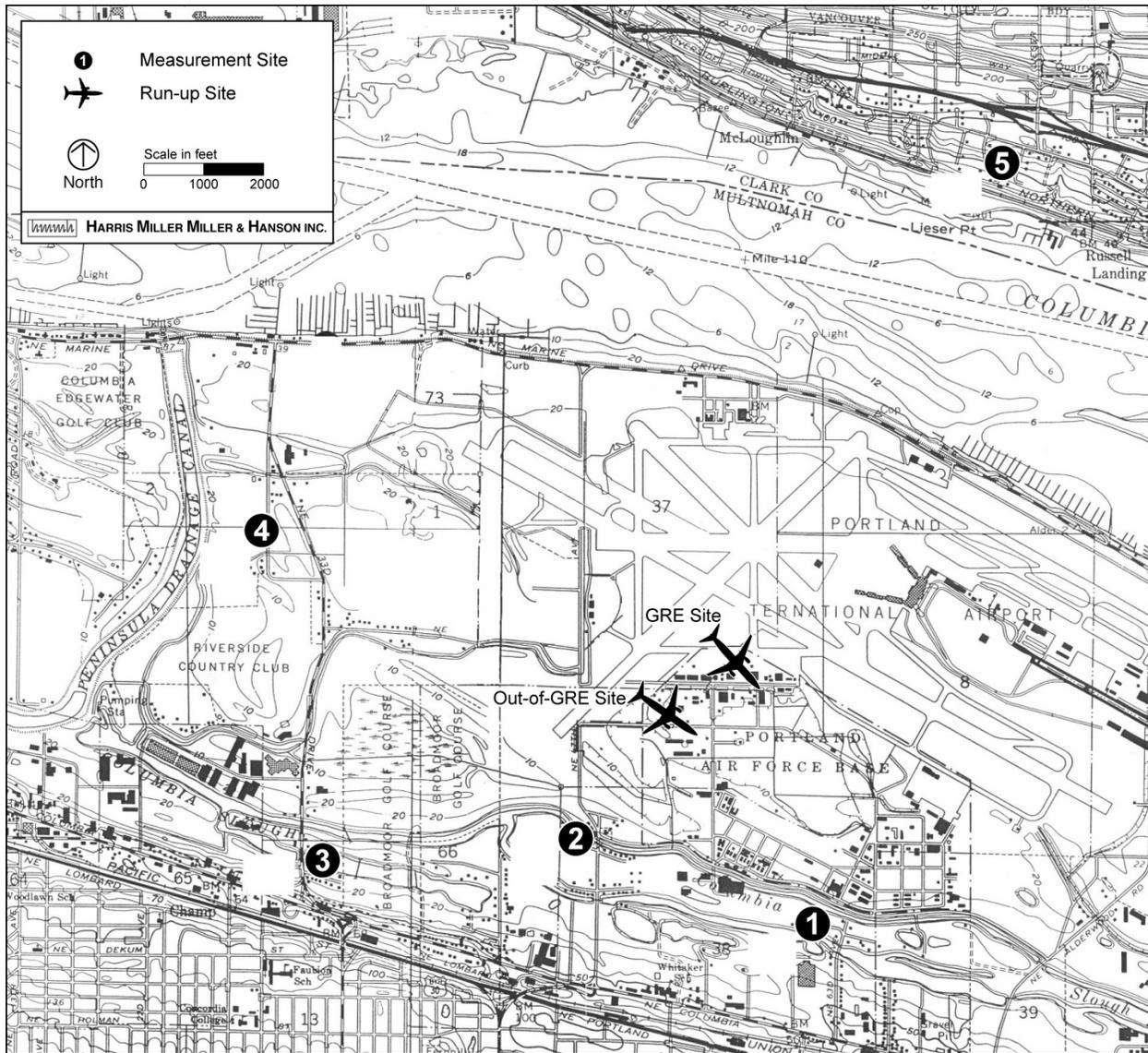
Aircraft Type	Insertion Loss (Reduction in A-weighted Sound Level, dB)			Comments
	Required	Measured Mean	95% Confidence Interval	
1. B737-300/400	18	20.2	18.2 to 22.2	Meets requirement with at least 95% certainty
2. DHC8 (any series)	15	17.3	15.4 to 19.3	Meets requirement with at least 95% certainty
3. F28 (any series)	17	16.3	15.5 to 17.1	Uncertain whether requirement is met at 95% level of certainty

**TABLE 3 Summary of “Before” Measurements Showing Presumed Shielding Provided by Aircraft Fuselages**

Aircraft Type	Engine Used for Run-up	Microphone Location (Distance and rotation from front of aircraft)	Measured Sound Level (L <sub>eq</sub> , dBA)		Measured Difference (dB)
			Left Side	Right Side	
1. B737-300	No. 1 (left)	360 ft., 65 deg.	97	91	6
		400 ft., 90 deg.	98	89	9
		360 ft., 130 deg.	--*	94	--
2. DHC8	No. 2 (right)	360 ft., 65 deg.	92	99	7
		400 ft., 90 deg.	89	95	6
		360 ft., 130 deg.	90	94	4
3. F28	No. 2 (right)	360 ft., 65 deg.	92	100	8
		400 ft., 90 deg.	94	100	6
		360 ft., 130 deg.	102	110	8
*Data disallowed at this position.					

**TABLE 4 Measured Community Sound Levels During GRE Acceptance Tests**

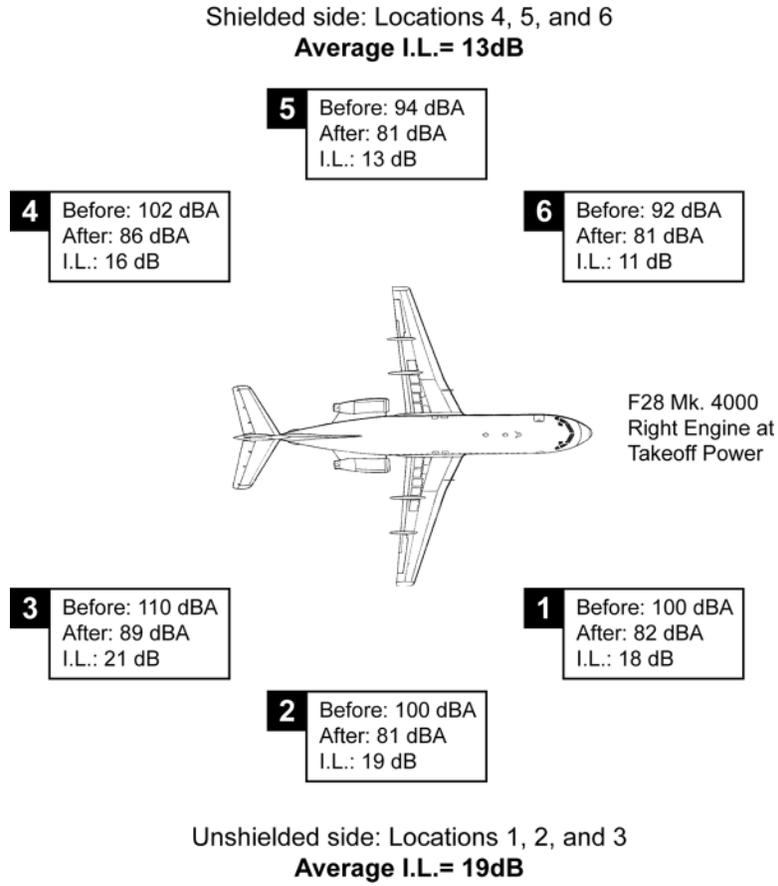
Measurement Site	Approximate Distance from GRE	Measured Average Sound Level (dBA)		
		F28	DHC8	B737-300
1. Bryant Street	4,700 ft. (1,400 m)	58 (D)*	57 (D)	57 (D)
2. Crystal Lane	4,000 ft. (1,200 m)	56 (D)	54 (C)	50 (D)
3. Holland Ct./33 <sup>rd</sup> Dr.	7,700 ft. (2,300 m)	47 (C)	<45 (C)	40 (C)
4. Sunderland Avenue	8,000 ft. (2,400 m)	<43 (U)	<44 (U)	<37 (U)
5. Russell Landing	9,400 ft. (2,900 m)	<44 (C)	<45 (C)	<35 (C)
*(D), (C), and (U) denote average downwind, calm, or upwind sound propagation conditions during measurements.				



**FIGURE 1** Portland International Airport General Vicinity, Run-up Locations, and Measurement Sites (Note: “Run-up Site” symbols [not to scale] indicate orientation of aircraft during run-ups. Aircraft at the GRE site were positioned with the aircraft nose towards the open end of the GRE, as shown in Figure 2.)



**FIGURE 2** Portland International Airport Ground Run-up Enclosure (photograph courtesy of Blast Deflectors, Inc.)



**FIGURE 3** Measured Effects of Fuselage Shielding During F28 Acceptance-Test Measurements (Not to Scale)

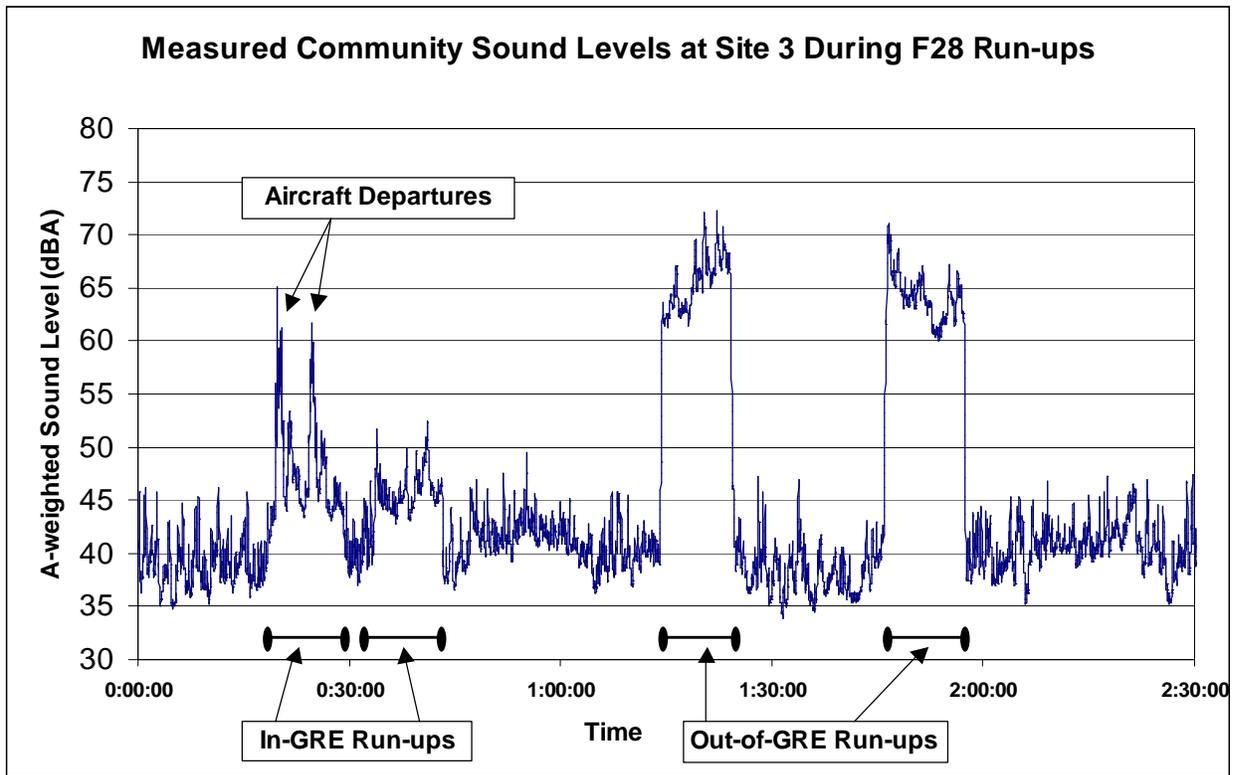


FIGURE 4 Community Measurement Site Time-History Data During F28 Acceptance Test