

**HYBRID DIESEL-ELECTRIC BUS / TROLLEY BUS  
DEMONSTRATION PROJECT:  
TECHNICAL COMPARISON OF IN-USE PERFORMANCE**

**APPENDIX B  
NOISE TESTING REPORT**



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Dec 31, 2007



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# Edmonton New Technology Buses Evaluation Project

## Noise Measurement Test Results: (Hybrids, Diesels & Trolleys) December 31, 2007

### 1. ABSTRACT

This noise measurement test report is one element in a series of reports detailing the test procedures and results in a year-long evaluation comparing various new technology and current technology transit buses. The overall evaluation involves performance, costs and environmental effects of several transit bus technologies including: 2006 diesel, 2007 clean diesel, parallel hybrid electric, series hybrid electric, advanced electric trolley and existing electric trolley.

This report specifically summarizes the results of sound level testing conducted on six diesel-fuelled buses and two electric trolleys. The diesel-fuelled buses were tested at Namao Armed Forces Base on September 18<sup>th</sup> and 19<sup>th</sup>, 2007. That test included a conventional diesel 2006 bus (4498), a conventional diesel 2007 bus with DPF (4554) and the three different hybrid electric bus technologies, (6001, 6003, 6005 and 6006). Both Orion hybrids (6005 and 6006) were tested to provide a measure of test and bus model repeatability. The two trolley buses were tested on 80<sup>th</sup> Street adjacent to the Cromdale garage on October 20<sup>th</sup>, 2007. The New Flyer-Allison parallel hybrid (6001) was re-tested at the same time to provide a link between the idealized airport test setting and the less idealized situation testing along a street with a trolley line.

The test background, methodology and procedure are described in detail in a May 9 report titled "Sound Level Measurements - Test Plan [1]. To summarize, noise levels for each bus were measured in 8 specified driving conditions, including idle, acceleration, stopping, cruising and high speed run. Each condition was repeated 3 or 4 times and the maximum A-weighted decibel reading was noted at two points inside the bus (front and rear) and at one point outside and 15 m to the side of the bus lane as it passed by. For the high speed run, no pass-by measurement was taken ... only on-board readings. Due to the limitations of the on-street test site for the trolleys, no high speed runs were taken.

These sound level measurements provided some expected results. For operating buses, the highest noise levels were at the back of the bus, it was quieter at the front of the bus near the driver and the quietest position was outside the bus fifty feet away. Noise levels were below the threshold for concern about hearing damage but were high enough to be irritating in some buses. The new trolley was the quietest bus overall. The range of hybrid buses provided both the highest and lowest noise levels with the straight diesel buses falling between. Considering the noise at the rear of the bus, the highest one-condition noise level was found in the New Flyer ISE series hybrid (ie 6003) during a high speed run. The highest average noise level for all test conditions was in the New Flyer Allison Parallel hybrid (ie 6001). The non-hybrid buses were a little quieter than these two New Flyer hybrid types and the Orion parallel hybrids (ie 6005/6006) had significantly lower noise levels at their worst location, (ie back of the bus).

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## 2. Sound Level Measurements

### 2.1 Test Buses and Test Dates

The complete set of new bus technologies under study is:

<b>Baseline:</b>	<b>Model Year</b>	<b>Bus Number</b>
2 New Flyer - Diesel buses (D40LFR)	2006	<b>4498</b> ,4500
2 New Flyer - Clean diesel buses (D40LFR)	2007	<b>4453</b> ,4454
<b>Hybrid Electric:</b>		
2 New Flyer - Allison Parallel hybrid buses (DE40LFR)	2006	<b>6001</b> ,6002
2 New Flyer - ISE Series hybrid buses (DE40LFR)	2006	<b>6003</b> ,6004
2 Orion - BAE SERIES hybrid buses (ORION VII)	2006	<b>6005</b> , <b>6006</b>
<b>Trolleys:</b>		
2 BBC Trolley Buses (existing)	1982	<b>121</b> ,150
1 New Flyer Kiepe Trolley Bus (E40LFR)	2007	<b>6000</b>

Six of the buses capable of independent operation, (ie not trolleys), were noise tested at CFB Namao on September 18 and 19, 2007:

- 6001 New Flyer - Allison Parallel hybrid bus
- 6003 New Flyer - ISE Series hybrid bus
- 6005 Orion - BAE series hybrid bus
- 6006 Orion - BAE series hybrid bus
- 4498 New Flyer 2006 diesel bus
- 4553 New Flyer 2007 diesel bus.

The Namao site provided an idealized location for standard noise test measurements. It was completely flat and open with no competing traffic noise and no noise-reflective buildings or signs. It also provided room for testing bus acceleration up to approximately 80 km/hr and acceleration performance was tested for each bus type. Only one problem occurred during the Namao tests. While testing bus 6001, the sound level meter at the front, inside location failed so those measurements were missed.

On October 20, 2007, two trolleys and one diesel hybrid bus were noise tested using the North-bound lane of 80<sup>th</sup> Street adjacent to the parking lot North of Cromdale garage:

- Tested buses were:
- 121 BBC Trolley
  - 6000 New Flyer Kiepe Trolley bus
  - 6001 New Flyer - Allison Parallel hybrid bus.

Trolley lines tend to run in congested areas so it is difficult to find a noise test location with trolley lines and without excessive traffic and noise-reflective buildings over a sufficient length for noise testing. The 80<sup>th</sup> Street site just North of the Cromdale garage met minimum requirements for sufficient clearance from buildings across the street and was marginal for acceleration /braking distances for the noise tests. Some test runs were repeated due to interference from traffic noise. To provide a comparison with the more idealized runway tests and to replace the measurements missed earlier, hybrid bus 6001 was re-tested alongside the trolleys. This re-testing confirmed that the second set of tests

was equivalent to the first for those tests that were directly comparable ... ie excluding the higher speed runs at Namao.

## **2.2 Test Equipment:**

- 3 sound level meters (for 2 locations inside the bus and 1 exterior) meeting Type 1 or S1A requirements of ANSI Specification for Sound Level Meters
- 1 sound level calibrator accurate within 0.5 dB
- 1 anemometer accurate within 10% at 19 km/h (12 mph).
- Cones, Marking tape, Tape measure (3m and 30m)
- 4 Tripods 1.20 m (4 ft) height
- Two-way radios for coordinating test runs

## **2.3 Test Personnel:**

- Bus driver, (varied with bus)
- 3 meter reading personnel:
  - Sandra Wolf Lange / Paitoon Kongsereeparp (bus interior)
  - Dan Handford (bus interior)
  - David Checkel (exterior)

## 2.4 Test Sites:

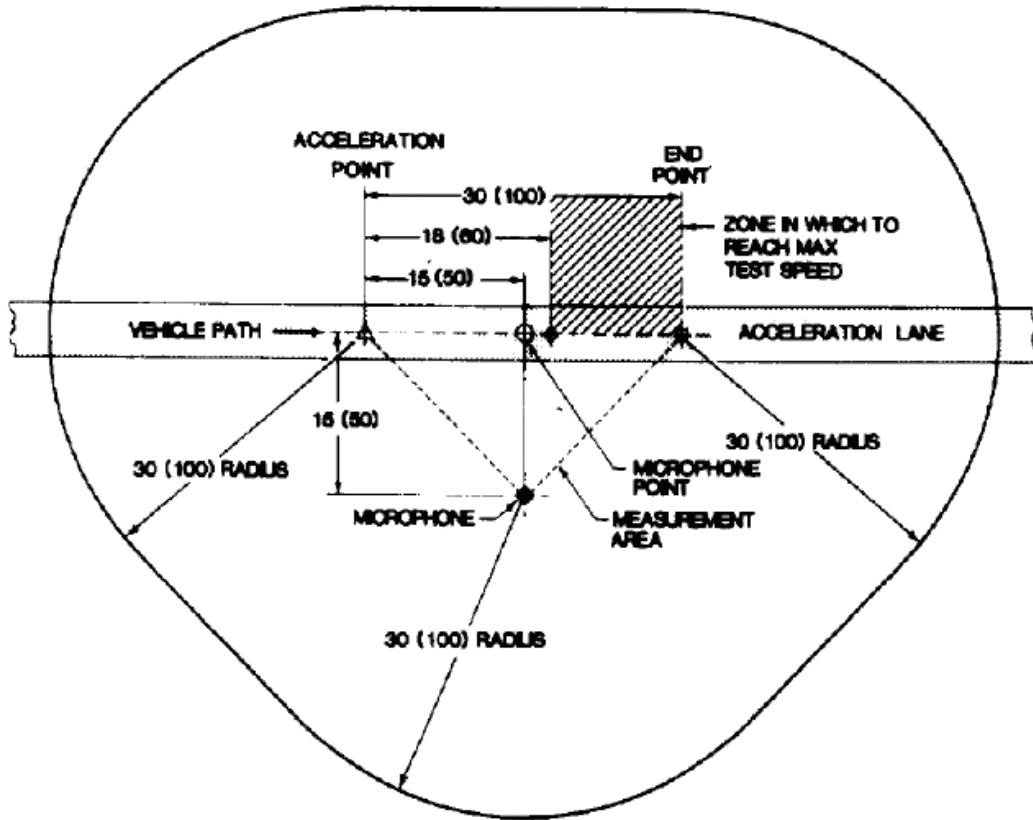
### a. CFB Namao

The desired test surface for all SAE noise test procedures is a highly reflective uniform asphalt plane surrounded by an extensive open space to prevent echoes and sound distortion. The first set of tests was performed at CFB Namao, on the north-east taxi way off the main runway, (see Figure 1 below). This site provided a suitably flat, open surface surrounded by open fields. Background exterior noise levels were typically 30 to 40 dBA which is considerably below the noise levels recorded with a bus present.



Figure 1. Satellite view of CFB Namao showing NE taxi way used for noise testing.  
Note that NE taxi way is approximately 600 m long and surrounded by flat agricultural fields.

The ideal noise test lane has a 30 m clearance from any noise-reflective walls or surfaces and allows for a microphone position 15 m to one side of the lane, which is also 30 m from any reflective surfaces, (as shown diagrammatically in Figure 2)



NOTE: DIMENSIONS ARE m(FT)

Figure 2. Test lane specified for SAE vehicle noise testing, (eg [1] to [6]), is a straight lane 30 m long with an external microphone 15 m to one side and 1.2 m (4 ft) above the asphalt.

At Namao, a test lane was set up near the middle of the taxi-way length and close to the South-East edge of the taxi-way, as shown diagrammatically in Figure 3. This test lane was marked by cones to position the bus at repeatable locations relative to the external microphone for idle, acceleration, deceleration and cruise-by noise level testing. Wind speed and air temperature were also monitored at the external microphone site. A high speed acceleration run used the full length of the taxi-way (approximately 600 m) for acceleration runs to speeds around 80 km/hr and subsequent deceleration.



Figure 3. Hybrid Bus 6005 located at centre of test lane, 15 m from external observer station with sound level meter, anemometer and thermometer.



**b. 80 Street North of Cromdale Garage**

Finding a noise test site for trolleys involved searching for a suitable length of street equipped with trolley wires, which could be shut down for testing and which had suitable clearance from noise-reflective surfaces. The chosen site was on 80<sup>th</sup> Street immediately North of Cromdale bus garage. The required clearances were obtained, (marginally) due to a break in the houses on the West side of the street and a parking lot on the East side of the street. The exterior test location was located in the parking lot 50 feet (15 m) from the curb location and traffic was blocked off the block between 116<sup>th</sup> and 117<sup>th</sup> Avenues for a short period. At this location, background noise levels were generally below 50 dB but there were periodic disturbances from other traffic and some test runs needed to be repeated due to background noise



Figure 4. Cromdale noise test site.

## 2.5 Test Protocol:

### Operating Conditions

The test protocol is defined in detail in “Sound Level Measurements – Test Plan”, S.W. Lange & M.D. Checkel, May 9, 2007 [1]. Basically noise levels were measured with the bus turned off and at eight operating conditions. The test conditions were:

- M1. Bus off. Background noise level.
- M2. Bus idling. Air Conditioning and accessories OFF.
- M3. Bus idling. Air Conditioning and accessories ON.
- M4. Bus accelerating from a stop. (Start with door at start of acceleration test lane).
- M5. Bus accelerating from 30 km/h cruise, (as bus reaches start of acceleration lane).
- M6. Bus cruising through test lane at 30 km/hr steady speed.
- M7. Bus cruising through test lane at 60 km/hr steady speed.
- M8. Bus stopping from 50 km/hr. (Stop with door at end of acceleration test lane).
- M9. Bus accelerating from a stop to maximum safe speed, as limited by conditions of test site. The 600 m taxi way length permitted speeds reaching around 80 km/h.

For the Namao test site, the in-lane test conditions (M2 to M8) were typically repeated four times, with the bus going opposite directions through the test lane so that the exterior measurement was effectively made from each side, twice. The high speed test condition (M9) was repeated two or three times.

For the 80<sup>th</sup> Street test site, the in-lane test conditions were typically repeated four times with the bus backing up to take subsequent runs. All runs at this site were run in a Northward direction and all exterior measurements were made from the East (Right) side of the bus. This would have been a limitation with diesel buses (because the exhaust tip is on the Left side of the bus) but was deemed acceptable for the trolley buses. Because of the limited test lane length, the peak speeds were lower and the high-speed acceleration test (M9) was not run at this site. Again, this is not considered a serious limitation for the trolleys which typically operate on streets with 50 km/hr speed limits and are probably speed limited to 70 km/hr or less.

## Measurements

Sound level measurements were made at three different test points. For the in-lane test conditions (M2 to M8), noise measurements were made both interior and exterior to the bus. For the high-speed acceleration test (M9), only interior measurements were made.

### Interior:

Interior/Front. The sound level was measured at the front-most passenger seat position on the Right side of the bus and the approximate height of the passenger's ear. This is effectively just behind the right front wheel cover.

Interior/Rear. The sound level was measured using a tripod-mounted microphone placed just in front of the rear row of seats and at the approximate height of the passenger's ear.

### Exterior

Exterior. The measurement point was 15 m (50 ft) to the side of the test lane and 1.2 m (4 ft) above the asphalt surface.

In each case, the measurement personnel observed sound level meter (set to read dBA on the Fast setting) and recorded the highest reading observed during the specified maneuver, (eg from start time to clearing the accel lane for M4). Measurements were recorded on paper during the test and averaged (linearly) using a spreadsheet later.

### 3. Noise Measurement Results

#### 3.1 Sound Level Reading Results For Bus 6001 New Flyer Allison Parallel Hybrid

Measurement Location	M 1			M 2			M 3			M 4			M 5			M 6			M 7			M 8			M 9							
	SL	AF		SL	AF		SL	AF		SL	AF		SL	AF		SL	AF		SL	AF		SL	AF		SL	AF						
Interior Front	22	33		57	1		72	2		54	5		51	12		48	16		54	21		55	27		58	31						
	23	34					73	3		51	6		51	13		48	17		55	22		58	28		60	32						
										52	7		52	14		47	18		54	23		52	29									
										52	8		52	15		47	19		57	24		54	30									
Average	23			57			72.5			52	9		51.5		48			55	25		55			59								
	SL			SL			SL			SL			SL		SL			SL			SL			SL			SL					
Interior Rear	36			64			75			75			85		77			81			84			86			88					
	35			64			76			79			87		74			81			82			85			85					
	35			64			75			78			84		75			81			86											
	36			64			75			81			87		76			83			79											
				64			76						87					81														
Average	36			64			75.5			79			85		76			81.4			83						86					
	SL	WS	BD	T	SL	WS	BD	T	SL	WS	BD	T	SL	WS	BD	T	SL	WS	BD	T	SL	WS	BD	T	SL	WS	BD	T				
Exterior					58	3.2	10		58	4.5	10		67	1.45	S	9	70	5	N	9	67	4	N	8	70	3.25	S	8	65	1.7	N	9
					58	1.5			59	2.5			66	2.15	N		69	3.1	S		63	3.1	S		70	3.15	N		65	4	N	
					58	4.2			58	4.7			69	3.2	N		70	3.8	N		64	2.4	N		70	2.35	S		64	3.5	S	
													65	4.3	S		69	1	S		63	1.9	S		72	2	N		66	4	S	
Average					58				58.3				67				69.5				64				70.5			65				
Loudest per bus side													69				70				67				72			66				
Lowest per bus side													65				69				63				70			64				

Table 1: Record of sound level results for bus 6001 in dBA.

The 9 measurement test conditions (M1 through M9) provide 9 columns.

The measurement positions (interior front, interior rear and exterior) are arranged in rows.

Exterior measurements are accompanied by wind speed (m/s), bus direction (North=Left side to microphone / South=Right side to microphone) and air temperature (°C).

Lowest dBA values are highlighted in green and highest dBA values in yellow.

Bus 6001 (New Flyer Allison parallel hybrid) was typical in having the highest sound levels at the interior rear seating position, (directly over the drivetrain), and the lowest sound levels at the interior front seating position, (close to the driver). External noise levels generally fell between these two extremes and showed a marginally higher value on the Left (exhaust tailpipe) side of the bus than the Right.

For bus 6001, the noisiest operating condition was Mode 5 (accelerating from 30 km/hr) with an average noise level of 86 dBA at the rear. The high speed acceleration run from 0 to 80+ km/hr came close at 85.5 dBA.

When this bus was re-tested later on 80<sup>th</sup> Street, the highest noise level modes were avoided since speeds were limited by the limited space available.

Using a simple linear average of the measured noise levels for all modes gave the results:

- Front Interior: 56.2 dBA
- Rear Interior: 78.7 dBA
- Exterior: 64.7 dBA

### 3.2 Sound Level Reading Results For Bus 6003 New Flyer SE Series Hybrid

Measurement Location:	M 1		M 2		M 3		M 4		M 5		M 6		M 7		M 8		M 9												
	SL	AF	SL	AF	SL	AF	SL	AF	SL	AF	SL	AF	SL	AF	SL	AF	SL	AF											
Interior Front	35.1	63	55.1	35	70.5	37	70.3	39	84.2	44	81.4	48	70.5	53	71.8	57	74	61											
	36.3	64	56.6	36	70.7	38	67.4	40	67	45	62.6	49	72.3	54	66.1	58	75	62											
							69.3	41	68.2	46	62.5	51	70.1	55	67.9	59													
							67.8	42	68.4	47	62.9	52	73.7	56	67.3	60													
Average	35.7		55.9		70.6		68.7		67		62.4		71.7		68.2		75												
SL																													
Interior Rear	24		65		75		79		77		69		78		78		80												
	25		64		76		80		78		69		77		81		89												
	27		65		75		79		78		68		76		80														
	24		65		76		80		79		70		77		83														
Average	25		64.8		75.5		79.5		78		69		77		80.5		90												
SL	WS	BD	T	SL	WS	BD	T	SL	WS	BD	T	SL	WS	BD	T	SL	WS	BD	T										
Exterior	27	1.78	6	55	2	7	56	1	7	68	1.2	S	7	73	2	S	7	59	1.57	S	7	77	1.68	N	7	69		N	7
	35	1.75		55			56			73	2.5	N		71	1.46	N		61	1	N		70	1.75	S		67	1.46	S	
							68			68	0.92	S		59	2.1	S		68	1	N		70			70		N		
							73	3	N	72	1.03	N		60		N		68	1.05	S		68	1.17	S					
Average	31			55			56			70.5			71				59.8				70.8				68.5				
Loudest per bus side										73			73				61				77			70					
Lowest per bus side										68			68				59				68			67					

Table 2: Record of sound level results for bus 6003 in dBA.

The 9 measurement test conditions (M1 through M9) provide 9 columns.

The measurement positions (interior front, interior rear and exterior) are arranged in rows.

Exterior measurements are accompanied by wind speed (m/s), bus direction (North=Left side to microphone / South=Right side to microphone) and air temperature (°C).

Lowest dBA values are highlighted in green and highest dBA values in yellow.

Bus 6003 (New Flyer SE series hybrid) also showed its highest noise levels at the interior rear seating position. For this bus, the exterior noise levels were marginally lower than those at the front interior seating position. The highest overall noise level was 89.5 dB, recorded during the high speed acceleration run. This was the highest single-mode reading for any of the bus technologies tested.

Despite having the highest single-mode noise reading, the noise levels in other operating modes were relatively lower so the average noise level for all test modes was lower than that for the 6001 (New Flyer Allison parallel hybrid). Using a simple linear average of the measured noise levels for all modes gave the results:

- Front Interior: 67.4 dBA
- Rear Interior: 76.7 dBA
- Exterior: 64.5 dBA

### 3.3 Sound Level Reading Results For Bus 6005 Orion BAE Parallel hybrid

	M 1				M 2				M 3				M 4				M 5				M 6				M 7				M 8				M 9			
Measurement Location:	SL	AF			SL	AF			SL	AF			SL	AF			SL	AF			SL	AF			SL	AF			SL	AF			SL	AF		
Interior Front	39.6	34			63.7	1			68.4	5			79.1	9			75.4	13			68.1	18			67.7	22			68.2	26			73	30		
	40.3	35			64.7	2			68.3	6			70.1	10			73.2	14			69.7	19			74.4	23			72.4	27			73	31		
					64.2	3			67.5	7			74.1	11			73.2	15			68.7	20			70.5	24			72.5	28			74	32		
					64.1	4			67.3	8			71.5	12			75.5	16			68.5	21			68.2	25			78.1	29			74	33		
Average	40				64.2				67.9				73.7				74.3				68.8				70.2				72.8				74			
SL																																				
Interior Rear	30				62				66				73				73				69.5				70.5				72.5				76			
	31.5				62.5				67				72				73.5				70.5				71.5				73.5				76			
					62				66.5				72				72.5				68.5				71.5				74.5				76			
					62				66				72.5				73.5				69.5				70.5				71.5				76			
Average	30.8				62.1				66.4				72.4				73.1				69.6				71				73				76			
SL																																				
Exterior		WS	BD	T	SL	WS	BD	T	SL	WS	BD	T	SL	WS	BD	T	SL	WS	BD	T	SL	WS	BD	T	SL	WS	BD	T	SL	WS	BD	T	SL	WS	BD	T
					58	2.45	10		60	58	10	71	2.4	N	10	69	0.6	N	10	63.5	1.1	N	10	66	2.9	N	10	65	3	N	10					
					58				61	0.6		69	1	S		70	2	S		64	2.1	S		65.5	2.9	S		64	1.3	S						
					58.5	0.27			58.5	3.5		71		N		70		N		63	3.25	N		67		N		64	2.63	N						
					58	0.78			58			69.5	0.82	S		70	0.54	S		64		S		66	1.04	S		65	38							
Average					58.1				59.4			70.1				69.8				63.6				66.1				64.5								
Loudest per bus side												71				70				64				67				65								
Lowest per bus side												69				69				63				65.5				64								

Table 3: Record of sound level results for bus 6005 in dBA.  
 The 9 measurement test conditions (M1 through M9) provide 9 columns.  
 The measurement positions (interior front, interior rear and exterior) are arranged in rows.  
 Exterior measurements are accompanied by wind speed (m/s), bus direction (North=Left side to microphone / South=Right side to microphone) and air temperature (°C).  
 Lowest dBA values are highlighted in green and highest dBA values in yellow.

Bus 6005 (Orion BAE parallel hybrid) was typical in showing its highest noise levels at the interior rear seating position during high power acceleration and its lowest noise levels at the exterior measurement point during idling. However, the highest overall noise level was only 76 dB which is considerably lower than the values for other hybrid technologies. In fact, the interior rear noise levels were so low that the interior front levels exceeded them in several operating modes.

Using a simple linear average of the measured noise levels for all modes gave the results:

- Front Interior: 70.1 dBA
- Rear Interior: 70.4 dBA
- Exterior: 64.5 dBA

### 3.4 Sound Level Reading Results For Bus 6006 Orion BAE parallel hybrid

Measurement Location:	M 1				M 2				M 3				M 4				M 5				M 6				M 7				M 8				M 9			
	SL	AF			SL	AF			SL	AF			SL	AF			SL	AF			SL	AF			SL	AF			SL	AF			SL	AF		
Interior Front	34	68			51.4	36			74.3	40			72.5	44			70.3	48			64.9	52			67.3	56			74.2	60			73	65		
	36	69			61	37			72.9	41			74.6	45			72.2	49			66.5	53			71.2	57			68.3	61			73	66		
					61.1	38			72.8	42			72.7	46			68.3	50			66.3	54			73.5	58			70.2	62			74	67		
					61.2	39			71.7	43			71.1	47			71.2	51			67.7	55			71.8	59			70.6	64						
Average	35				61.2				72.9				72.7				70.5				66.4				71				70.6				73			
	SL				SL				SL				SL				SL				SL				SL				SL				SL			
Interior Rear	25				55				73				70.5				68				64				69				67.8				75			
	27				55				73				68.5				69				65				68.5				67.8				75			
					55				72.5				69.5				69				67				71.5				68				73			
					55.5				73				70				67				63				67.5				71.5							
Average	26				55.1				72.9				69.6				68.3				64.8				69.1				68.6				74			
	SL	WS	BD	T	SL	WS	BD	T	SL	WS	BD	T	SL	WS	BD	T	SL	WS	BD	T	SL	WS	BD	T	SL	WS	BD	T	SL	WS	BD	T	SL	WS	BD	T
Exterior					58	2.1	10		56	3	10		69	2.5	S	10	70	6	S	10	64	2.9	S	10	69	2.9	S	10	66	1.73	S	10				
					58	3.5			59	3.4			71	3.15	N		70	3.1	N		65		N		71		N		66	2.6	N					
					59	2.55			60	3.8			69.5	2.85	S		69.5	1.8	S		65	3.5			71	3	S		65.5	1.25	S					
						0.76			60.5	3.3			72		N		72	3.5			63	2.1	N		72	3.05	N		70	3.4	N					
Average					58.3				58.9				70.4				70.4				64.3				70.8				66.9							
Loudest per bus side													72				72				65				72				70							
Lowest per bus side													69				69.5				63				69				65.5							

Table 4: Record of sound level results for bus 6006.

The 9 measurement test conditions (M1 through M9) provide 9 columns.

The measurement positions (interior front, interior rear and exterior) are arranged in rows.

Exterior measurements are accompanied by wind speed (m/s), bus direction (North=Left side to microphone / South=Right side to microphone) and air temperature (°C).

Lowest dBA values are highlighted in green and highest dBA values in yellow.

Bus 6006 is a same-model repeat of bus 6005 and the overall noise levels were very similar. The one difference was a lower idling noise level (55 dBA) at the interior front seating position, making that measurement location and operating condition the quietest point. As with other cases, the interior rear was the loudest measuring point / condition combination with an average noise level of 74.3 dBA.

Using a simple linear average of the measured noise levels for all modes gave the results:

Front Interior: 69.8 dBA

Rear Interior: 67.8 dBA

Exterior: 65.7 dBA

### 3.5 Sound Level Reading Results For Bus 4498 New Flyer 2006 Diesel

	M 1			M 2			M 3			M 4			M 5			M 6			M 7			M 8			M 9							
Measurement Location:	SL			SL			SL			SL			SL			SL			SL			SL			SL							
Interior Front	32.3			54.9			71.8			70.7			89.3			87.8			71.8			87.7						75				
	34.1			54.9			73.2			71.5			89.5			87.1			88.5			85.6						76				
										71.1			72.1			87.2			87.9			87.4										
										71.2			89.5			86.4			70.1			87.9										
Average	33.2			54.9			72.4			71.1			70.1			87.1			89.5			87.2						75				
	SL			SL			SL			SL			SL			SL			SL			SL						SL				
Interior Rear	22			76			76			76.5			78			72.5			77			76						85				
	23			62			75.5			77			81			75.5			76			76						84				
	26			62			76			76.5			79			75			75			83										
	24			62			76			78.5			77			75			75			83										
Average	23.8			62			75.9			77.1			78.8			74.5			75.8			79.5						84				
	SL	WS	BD	T	SL	WS	BD	T	SL	WS	BD	T	SL	WS	BD	T	SL	WS	BD	T	SL	WS	BD	T	SL	WS	BD	T	SL	WS	BD	T
Exterior					59	0.56	N	7	58.5	1.6	N	7	79	1.23	S	7	78	1.22	N	8	69	1.51	N	8	70	1.8	N	8	72	1.85	N	8
					60	0.84			60				77	1.07	N		77	2.45	S		68	1.48	S		68		S		72			
					60				80	1.84	S		79	2	N		69	1.7	N		70	1.45	N		72							
					59				78	1.81	N		77	1.28	S		67		S		70		S		72							
Average					59.1				59.2				78.5			77.8			68.3			69.5						72				
Loudest per bus side													80			79						70						72				
Lowest per bus side													77			77			67			68						72				

Table 5: Record of sound level results for bus 4498 in dBA.

The 9 measurement test conditions (M1 through M9) provide 9 columns.

The measurement positions (interior front, interior rear and exterior) are arranged in rows.

Exterior measurements are accompanied by wind speed (m/s), bus direction (North=Left side to microphone / South=Right side to microphone) and air temperature (°C).

Lowest dBA values are highlighted in green and highest dBA values in yellow.

As a conventional diesel-powered bus, 4498 had generally higher noise levels at the rear of the bus and its noisiest operating condition was during the high speed acceleration with a reading of 84.3 dBA.

It is interesting to note that the consistent 72 dBA measured from the exterior location during stopping (mode 8) was associated with the air release noise after the end of braking.

Using a simple linear average of the measured noise levels for all modes gave the results:

- Front Interior: 68.4 dBA
- Rear Interior: 76.0 dBA
- Exterior: 69.2 dBA



### 3.6 Sound Level Reading Results For Bus 4553 New Flyer 2007 Diesel

	M 1				M 2				M 3				M 4				M 5				M 6				M 7				M 8				M 9			
Measurement Location:	SL	AF			SL	AF			SL	AF			SL	AF			SL	AF			SL	AF			SL	AF			SL	AF			SL	AF		
Interior Front	33	99			54.8	70			71.7	74			83.3	76			70.2	80			85.2	84			72.1	88			82.7	92			75	96		
	34	100			56.2	71			71.8	75			82.4	77			72	81			83.4	85			72.1	89			82.8	93			78	97		
					56.1	72			70.4	78			71.7	82			65	86			73.9	90			63.4	94			75	98						
Average					55.7	73			71.3	79			72.3	83			64.4	87			67.9	91			67.1	95										
	33.5				55.7				71.8				66.9				71.6				64.5				71.5				64				76			
	SL				SL				SL				SL				SL				SL				SL				SL				SL			
Interior Rear	23				59				75				75				79				70				75.5				81							
	24				59				75				78.5				80.5				69				77				80.5							
	21								76				76				79				71				75				83							
	22								80.5				81				70.5				70.5				73.5				81.5							
Average					59				75				77.8				79.9				70.1				75.5				81.5							
	SL	WS	BD	T	SL	WS	BD	T	SL	WS	BD	T	SL	WS	BD	T	SL	WS	BD	T	SL	WS	BD	T	SL	WS	BD	T	SL	WS	BD	T	SL	WS	BD	T
Exterior					55	2.05	N	10	56	2.8	N	10	71	2.8	S	10	70.5	3.95	S	10	64	2.65	S	9	72	3	S	9	68	3	S	9				
					55.5				55.5	2.7			71	1	N		71		N		63	2.1	N		72	2.7	N		65	1.9	N					
					55				55	2.7			71	2.95	S		70	4.9	S		67	2.8	S		71.5	2.5	S		65	1.8	S					
					55.8	3.15			56	2.5			70.5	2.15	N		71		N		64	2.85	N		69		N		65	2.45	N					
Average					55.3				55.6				70.9				70.6				64.5				70.9				65.8							
Loudest per bus side													71				71				67				72				68							
Lowest per bus side													70.5				70				63				68				65							

Table 6: Record of sound level results for bus 4553 in dBA.

The 9 measurement test conditions (M1 through M9) provide 9 columns.

The measurement positions (interior front, interior rear and exterior) are arranged in rows.

Exterior measurements are accompanied by wind speed (m/s), bus direction (North=Left side to microphone / South=Right side to microphone) and air temperature (°C).

Lowest dBA values are highlighted in green and highest dBA values in yellow.

As a diesel-powered bus with a particulate trap, 2007 and later buses like 4553 might be expected to be marginally quieter than prior diesels. Like most of the other buses, the loudest noises are at the interior rear seating position during the high speed acceleration. However, the peak noise level is somewhat lower at 81.7 dBA (compared with 84.3 dBA for the 2006 diesel bus).

Using a simple linear average of the measured noise levels for all modes gave the results:

Front Interior: 67.8 dBA

Rear Interior: 75.1 dBA

Exterior: 64.8 dBA

### 3.7 Sound Level Reading Results For Bus 0121 1982 BBC Trolley

0121: 2007-10-20																												
Measurement Location:	M 1			M 2			M 3			M 4			M 5			M 6			M 7			M 8			M 9			
Interior Front	SL			SL			SL			SL			SL			SL			SL			SL			SL			
	35			52			69			60			65			57			70			68			68			
	35			52			69			62			66			59			67			69			69			
	35			52			69			61			64			61			69			68			68			
Average	35.0			52.0			69.0			60.8			65.1			59.3			69.0			69.3			###			
	SL			SL			SL			SL			SL			SL			SL			SL			SL			
Interior Rear	35			62			66			68			74			66			77			76			76			
	36			62.5			66			74			74.5			66			78			77			77			
	37			63			65			72			75			65			77			78			78			
	36			62			67			70			75			65			77			79			79			
Average	36			62.4			66			71			74.6			65.5			77.3			76			###			
	SL	WS	WD	T	SL	WS	WD	T	SL	WS	WD	T	SL	WS	WD	T	SL	WS	WD	T	SL	WS	WD	T	SL	WS	WD	T
Exterior	47.3				49.2				48.6				60.1			65.6			57.1			68.7			69.7			
	47				48.8				48.8				61.3			65.4			59.0			69.4			68.1			
	48.5				48.6				48.7				61.5			66.2			59.0			69.5			68.1			
	47.6				48.4				48.5				62.1			65.9			58.0			68.5			68.3			
Average	46.9				48.8				48.7				60.9			65.8			58.3			69.2			68.6			
	47.46				48.8				48.7				61			65.8			58.3			69.2			68.6			

Table 7: Record of sound level results for bus 0121 in dBA.  
 Only 8 measurement test conditions were used (M1 through M8).  
 The final high-speed test condition was not available and irrelevant anyways.  
 The 8 measurement test conditions (M1 through M8) provide 8 columns.  
 The measurement positions (interior front, interior rear and exterior) are arranged in rows.  
 Lowest dBA values are highlighted in blue and highest dBA values in yellow.

As an electric trolley bus, # 121 was very quiet in operation. The highest exterior noise level was only 69 dB and occurred with the bus cruising by at speed.  
 The highest interior noise level was at the back of the bus during a hard stop and reached 78 dB. and interior noise levels were during a hard stop. At the front of the bus, the loudest noise level was only 69 dB.

Using a simple linear average of the measured noise levels for all modes gave the results:

- Front Interior: 59.9 dBA
- Rear Interior: 66.3 dBA
- Exterior: 58.5 dBA

### 3.8 Sound Level Reading Results For Bus 6000 New Flyer 2006 Kieppe Trolley

6000: 2007-10-20	M 1	M 2	M 3	M 4	M 5	M 6	M 7	M 8	M 9											
Measurement Location:	SL	SL	SL	SL	SL	SL	SL	SL	SL											
Interior Front	32	54	71	68	67	66	68	69												
	32	66	67	66	64	76	70													
		68	69	67	73	70														
Average	32.0	47.0	71.0	67.3	67.5	65.5	72.0	69.3												
	SL	SL	SL	SL	SL	SL	SL	SL	SL											
Interior Rear	38	52	70	75	74	72	74	76												
	35	46	69	76	74	71	75	75												
	36	52	71	74	73	68	78	75												
	34	46	70	75	74	71	74	76												
Average	35.75	49	70	75	73.8	70.5	75.3	76												
	SL	WS	WD	T	SL	WS	WD	T	SL	WS	WD	T	SL	WS	WD	T	SL	WS	WD	T
Exterior	46.9	51.1	53.1	60.8	63.3	61.3	65.0	66.1												
	47.0	50.9	52.4	61.1	64.0	59.6	67.9	68.4												
	47.0	50.4	51.2	61.5	64.1	59.3	67.5	68.2												
			50.9	61.4	64.5	60.7	65.0	68.9												
Average	47.0	50.8	51.9	62.0	64.0	60.2	66.4	67.9												

Table 8: Record of sound level results for bus 6000 in dBA.  
 The 8 measurement test conditions (M1 through M8) provide 8 columns.  
 The measurement positions (interior front, interior rear and exterior) are arranged in rows.  
 All exterior measurements are from the Right side of the bus.  
 Lowest dBA values are highlighted in green and highest dBA values in yellow.

As a new trolley, the 6000 was particularly quiet. The interior was very quiet while idling with fans and accessories off (M2) and noise levels were significantly higher with fans and accessories on, but still on (M3) but still only 70 or 71 decibels. The highest noise levels were reached during stops with 76 dBA at the rear seating area.

Using a simple linear average of the measured noise levels for all modes gave the results:

- Front Interior: 61.4 dBA
- Rear Interior: 65.6 dBA
- Exterior: 58.8 dBA

## 4. Sound Level Results Comparison

		M1	M2	M3	M4	M5	M6	M7	M8	M9	Loudest Noise Level dB	Loudest as % of Max %	Average Noise Level dB	Average Noise %
		Background Noise	Idle Noise	Idle+Acc Noise	Accel 0+ Noise	Accel 30+ Noise	Cruise 30 Noise	Cruise 60 Noise	Stop Noise	Accel 80 Noise				
		Level dB	Level dB	Level dB	Level dB	Level dB	Level dB	Level dB	Level dB	Level dB				
6001	Front	22.5	57.0	72.5	52.3	51.5	47.5	55.0	54.8		72.5	90%	55.8	72%
	Rear	35.5	64.0	75.5	79.3	86.0	75.5	81.4	82.8		86.0	107%	77.8	100%
	Outside		58.0	58.3	67.0	69.5	64.3	70.5	65.0		70.5	88%	64.7	83%
	Avg per mode	29.0	59.7	68.8	66.2	69.0	62.4	69.0	67.5		76.3	95%	66.1	85%
	Loudest p mode	35.5	64.0	75.5	79.3	86.0	75.5	81.4	82.8		86.0	107%	77.8	100%
6003	Front	35.7	55.9	70.6	68.7	67.0	62.4	71.7	68.2		71.7	89%	66.3	85%
	Rear	25.0	64.8	75.5	79.5	78.0	69.0	77.0	80.5		80.5	100%	74.9	96%
	Outside	31.0	55.0	56.0	70.5	71.0	59.8	70.8	68.5		71.0	88%	64.5	83%
	Avg per mode	30.6	58.5	67.4	72.9	72.0	63.7	73.1	72.4		74.4	92%	68.6	88%
	Loudest p mode	35.7	64.8	75.5	79.5	78.0	69.0	77.0	80.5		80.5	100%	74.9	96%
6005	Front	40.0	64.2	67.9	73.7	74.3	68.8	70.2	72.8		74.3	92%	70.3	90%
	Rear	30.8	62.1	66.4	72.4	73.1	69.5	71.0	73.0		73.1	91%	69.6	90%
	Outside		58.1	59.4	70.1	69.8	63.6	66.1	64.5		70.1	87%	64.5	83%
	Avg per mode	35.4	61.5	64.5	72.1	72.4	67.3	69.1	70.1		72.5	90%	68.1	88%
	Loudest p mode	40.0	64.2	67.9	73.7	74.3	69.5	71.0	73.0		74.3	92%	70.5	91%
6006	Front	35.0	61.2	72.9	72.7	70.5	66.4	71.0	70.8		72.9	91%	69.4	89%
	Rear	26.0	55.1	72.9	69.6	68.3	64.8	69.1	68.6		72.9	91%	66.9	86%
	Outside		58.3	58.9	70.4	70.4	64.3	70.8	66.9		70.8	88%	65.7	84%
	Avg per mode	30.5	58.2	68.2	70.9	69.7	65.1	70.3	68.8		72.2	90%	67.3	87%
	Loudest p mode	35.0	61.2	72.9	72.7	70.5	66.4	71.0	70.8		72.9	91%	69.4	89%
4498	Front	33.2	54.9	72.4	71.1	70.1	67.1	69.5	67.2		72.4	90%	67.5	87%
	Rear	23.8	62.0	75.9	77.1	78.8	74.5	75.8	79.5		79.5	99%	74.8	96%
	Outside		59.1	59.2	78.5	77.8	68.3	69.5	72.0		78.5	98%	69.2	89%
	Avg per mode	28.5	58.7	69.1	75.6	75.5	69.9	71.6	72.9		76.8	95%	70.5	91%
	Loudest p mode	33.2	62.0	75.9	78.5	78.8	74.5	75.8	79.5		79.5	99%	75.0	96%
4553	Front	33.5	55.7	71.8	66.9	71.6	64.5	71.5	64.0		71.8	89%	66.6	86%
	Rear	22.5	59.0	75.0	77.8	79.9	70.1	75.5	81.5		81.5	101%	74.1	95%
	Outside		55.3	55.6	70.9	70.6	64.5	70.9	65.8		70.9	88%	64.8	83%
	Avg per mode	28.0	56.7	67.5	71.8	74.0	66.4	72.6	70.4		74.7	93%	68.5	88%
	Loudest p mode	33.5	59.0	75.0	77.8	79.9	70.1	75.5	81.5		81.5	101%	74.1	95%
6001 (2)	Front	29.0	53.0	53.0	69.3	70.5	67.5	71.3	74.8		74.8	93%	65.6	84%
	Rear	32.8	60.9	60.9	76.0	79.5	74.3	79.1	77.3		79.5	99%	72.6	93%
	Outside	50.1	55.1	54.0	68.6	70.5	63.3	70.3	61.5		70.5	88%	63.3	81%
	Avg per mode	37.3	56.3	56.0	71.3	73.5	68.3	73.6	71.2		74.9	93%	67.2	86%
	Loudest p mode	50.1	60.9	60.9	76.0	79.5	74.3	79.1	77.3		79.5	99%	72.6	93%
0121	Front	35.0	52.0	69.0	60.8	65.1	59.3	69.0	69.3		69.3	86%	63.5	82%
	Rear	36.0	62.4	66.0	71.0	74.6	65.5	77.3	77.5		77.5	96%	70.6	91%
	Outside	47.5	48.8	48.7	61.2	65.8	58.3	69.2	68.6		69.2	86%	60.1	77%
	Avg per mode	35.5	54.4	61.2	64.3	68.5	61.0	71.8	71.8		72.0	89%	64.7	83%
	Loudest p mode	36.0	62.4	69.0	71.0	74.6	65.5	77.3	77.5		77.5	96%	71.0	91%
6000	Front	32.0	47.0	71.0	67.3	67.5	65.5	72.0	69.3		72.0	89%	65.6	84%
	Rear	35.8	49.0	70.0	75.0	73.8	70.5	75.3	75.5		75.5	94%	69.9	90%
	Outside	47.0	50.8	51.9	62.0	64.0	60.2	66.4	67.9		67.9	84%	60.4	78%
	Avg per mode	33.9	48.9	64.3	68.1	68.4	65.4	71.2	70.9		71.8	89%	65.3	84%
	Loudest p mode	35.8	50.8	71.0	75.0	73.8	70.5	75.3	75.5		75.5	94%	70.3	90%
Loudest, all buses											0.0	0%	78.7	100%
Quietest, all buses											70.1	78%	56.2	71%

Table 7: Comparative table of all sound level measurement results

The 8 measurement test conditions (M1 through M8) provide 8 columns, (Mode 9 is excluded).

Four more columns are added at the end of the table. The first two give the dBA value of the loudest test mode and a percentage comparison to the loudest test mode noise level of any bus. The last two columns give the average dBA level of all test modes for the given measurement position as well as a percentage comparison to the loudest average.

The measurement positions (interior front, interior rear and exterior) are arranged in rows for each bus. Lowest dBA values are highlighted in blue and highest dBA values in yellow.

This measurement procedure produces a lot of information! Considering 9 buses, 8 or 9 test operating conditions and either 2 or 3 measurement locations gives 216 individual measurements, each with some significant information about how a bus will be perceived, either by its drivers, its passengers, or the surrounding public.

**4.1 Loudest Noise in any Mode (excluding M9 high-speed acceleration run)**

Humans are particularly sensitive to the loudest noises they hear so the first way to rate and rank buses is by considering the loudest noise they produce in any mode. For example, the peak noise levels measured during testing were generally measured from the rear interior of the bus.

Interior Rear, Max	
	Loudest Result dBA
6001	86.0
4553	81.6
6003	80.5
4498	79.5
6001(2)	79.5
121	77.5
6000	75.5
6005	73.1
6006	72.9

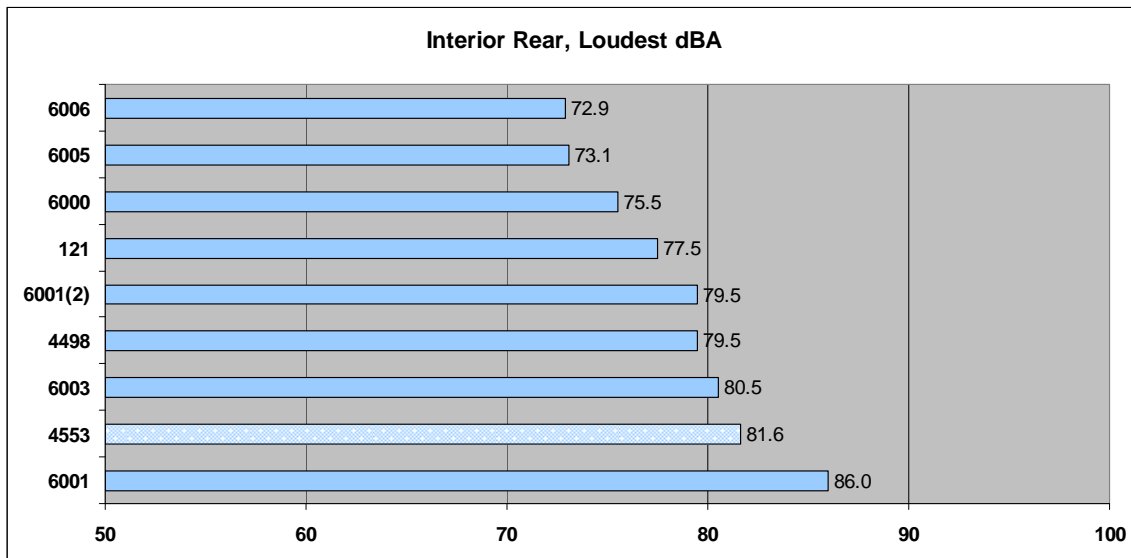


Figure 4.1a Comparison of loudest test mode noise levels at the interior rear position.

The two Orion BAE buses (6005 and 6006) were the quietest buses. The New Flyer / Allison hybrid (6001) was the noisiest when it was tested in an area with higher speed. The other diesels and hybrids fell fairly close together at 79.5 to 81.6 dBA. The trolleys fell between with 75.5 dBA (for 6000) at the rear seats. Since a difference of 3 dBA is generally considered quite significant, the wide range of noise levels (ie. 13 dBA or a range from 73 dBA to 86 dBA) is a very significant difference in peak noise level at the rear passenger seats.

Interior Front, Max	
	Loudest Result dBA
6001(2)	74.8
6005	74.3
6006	72.9
4498	72.9
6001	72.5
4553	71.8
6000	72.0
6003	71.7
121	69.3

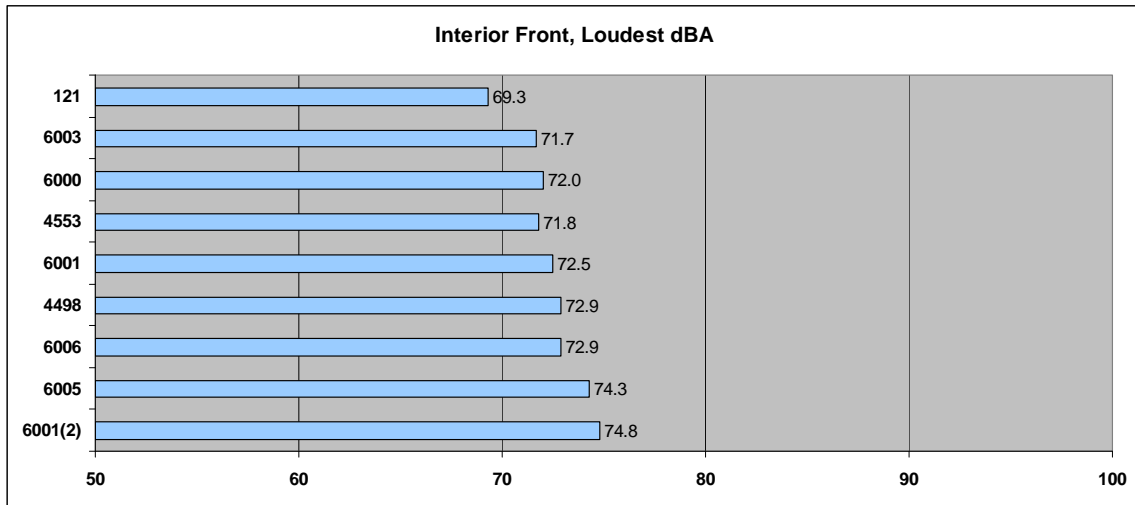


Figure 4.1b Comparison of loudest test mode noise levels at the interior front position.

Since drivers spend a lot of time in the bus, the loudest noise level at the front of the bus is also important. Figure 4.1b compares these results and shows that the difference between buses is much smaller at the front of the bus. Here, the primary noises are fans and the old trolley (121) has an advantage with less powerful / noise windshield fan. The other buses all fall very close to one another (within 3 dBA).

Exterior, Max	
	Loudest Result dBA
4498	78.5
6003	74.0
4553	70.9
6006	70.8
6001	70.5
6001(2)	70.5
6005	70.1
121	69.2
6000	67.9

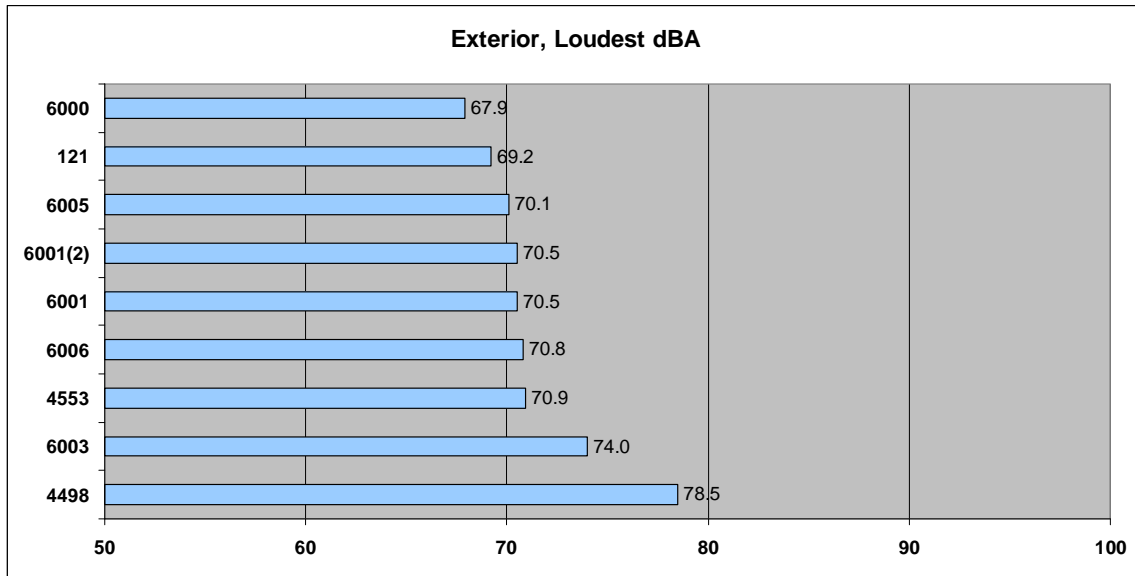


Figure 4.1c Comparison of loudest test mode noise levels measured from the exterior.

From the outside, most of the buses had virtually identical peak noise levels of 70-71 dBA. The exceptions were the 6003 (New Flyer ISE hybrid) at 74 dBA and the 4498, (New Flyer 2006 diesel bus). At 78.5 dBA, it was substantially noisier in accelerating away from stops than any of the other buses. This illustrates the benefits of diesel filters and assistive hybrid systems. However, the trolleys were the quietest with only 68dB for the new trolley.

At the front of the bus, the loudest test mode was set more by fan operation than by drivetrain and all buses clustered quite close together in the 70 to 75 dBA range.

As viewed from the street, the trolley was quietest at 68 dBA, most of the buses clustered at a respectable 70-71 dBA and the 2006 diesel was notably noisier at 78.5 dBA.

## 5. Conclusions

All values are below 90 dB, a value commonly taken as a threshold for hearing damage for continuous noise levels. Since the peak noise levels are both below that value and not continuous, hearing damage due to noise levels is not a concern.

In general, the noisiest location is the back of the bus close to the drivetrain. At this location, both the loudest peak noise levels (86 dBA from 6003) and the quietest peak noise levels (73 dBA from 6005 and 6006) are associated with hybrids. Hence, we cannot conclude that hybrid buses have any inherent advantage in terms of noise. Rather, it shows the importance of good noise control. At the back of the bus, the trolleys were slightly noisier than the Orion hybrids, most of the rest of the buses clustered around 80 dBA and the Allison hybrid either fell into that cluster or rose above it if testing allowed slightly higher speeds.



## 6. References:

- [1] "Sound Level Measurements – Test Plan", S.W. Lange & M.D. Checkel, prepared for City of Edmonton, Mobile Equipment Services, May 9, 2007, 48 pages.
- [2] SAE 336 – Sound Level for Truck Cabin Interior
- [3] 49CFR393.94 – Interior Noise Levels in Power Units. Applies to Trucks, Truck-Tractors, and Buses.
- [4] SAE 1470 – Measurement of Noise Emitted by Accelerating Highway Vehicles
- [5] SAE 366 – Exterior Sound Level for Heavy Trucks and Buses
- [6] SAE 1096 - Measurement of Exterior Sound Levels for Heavy Trucks Under Stationary Conditions