Experimental Investigation - Effects of an Acoustically Absorptive Ceiling on the Aircraft Noise Reduction of An Open and Semi-Enclosed Outdoor Structure

Michael Caley (1) and John Savery (2)

(1) Senior Consultant, Savery & Associates Pty Ltd, Brisbane, Australia
(2) Director, Savery & Associates Pty Ltd, Brisbane, Australia

ABSTRACT

Research was conducted into the aircraft noise reduction achieved by an outdoor recreation structure compared to a free-field control measurement location. The outdoor test structure was modified to simulate a building facade with an external overhead verandah or balcony. The test structure was located under the flight-path of the main runway at Brisbane Airport. The structure was configured with three alternative roof-ceiling constructions, including a bare metal option, a transmission loss option and a transmission loss/absorptive ceiling option. Four partial wall configurations/orientations, including the fully-open situation (i.e. no walls) were investigated. For each test configuration, the $L_{Amax,slow}$ flyover was sampled for nominally 10 jet aircraft flyover events and then averaged. The noise level of each flyover event was measured under the centre of the shelter, and at a free-field position 10 m from the edge of the structure. The averaged measured level under the shelter for the various test scenarios ranged from a 1 dB(A) increase compared with the free-field position to a 6.5 dB(A) decrease.

INTRODUCTION

Where the a site of a new residential development that is impacted by aircraft noise is determined to be 'acceptable' for a residential building as per Australian Standard 2021(2000) then the outdoor recreation area exposure is also assumed to be acceptable.

However if the site acceptability is determined to be 'Conditional', with a requirement for upgrading of building noise insulation in accordance with AS2021, then additional examination of the acceptability of outdoor noise exposure is normally not requested. This is because AS2021 does not make recommendations for acceptable levels of aircraft noise exposure in outdoor areas.

Design compliance with AS2021 for the habitable spaces of buildings (by building upgrades for conditionally acceptable sites) therefore does not mean that outdoor aircraft noise levels for outdoor recreation spaces at ground level, or on balconies of residential apartment buildings will be acceptable

Research was conducted into the aircraft noise reduction of an outdoor structure to explore how compliance with a possible future $L_{Amax(slow)}$ criterion for aircraft noise at a formal ground level or balcony outdoor recreation space could be improved.

A possible design goal for aircraft noise in formal outdoor space

A goal for the management of maximum flyover levels from large aircraft to within approximately 75 dB(A) $L_{Amax,slow,}$ at residential areas around airports was derived from the Airservices Australia *Environmental Principles*(2002) document where ideal minimum residential over-flight altitudes are discussed.

So if the predicted flyover noise levels at a given site were expected to reach say 78 dB(A) on a regular basis, 3 dB(A) of additional attenuation would be necessary from a free-standing outdoor structure or balcony to achieve a hypothetical 75 dB(A) $L_{Amax,slow}$ design goal for a formal outdoor recreation space.

METHODOLOGY

Experimental Site

The test structure that was utilised for experimental investigations was the flat section of the Brisbane City Council 'Solar Barbeque' shelter at the Comslie Beach Reserve, shown unmodified in Figure 1. This structure is located approximately 5300m from the nearest end and within 150 m of the centreline of the main runway at Brisbane Airport, with over-flight altitudes typically in the range of 3000-4000 ft (takeoffs) and 1000-1200 ft (landings).

The dimensions of the (almost) flat section of the test structure are 3.6m x 4.6m x 2.2m height. The shelter is constructed on a concrete pad in an open mown grass area with no nearby reflecting surfaces.

Some perspective of the height of over-flights can be gauged

Source: (Author 2005)
Figure 1 Unmodified Test Structure

from the photograph of an aircraft disappearing over the trees to the north of the test site in Figure 2.

Source: (Author 2005)
Figure 2 Test Site Over-flight Perspective

Test Configurations

The outdoor shelter was configured with three alternative roof-ceiling constructions as follows:-

1. Colorbond metal roof only (existing structure)
2. Colorbond metal roof, plus Tontine TSB5 polyester in 190mm airspace, 19mm plywood ceiling (overall approx. Rw 40)
3. As above, plus 32 kg/m^3 Tontine Soundsorb2 (NRC 0.95) with perforated foil facing fixed to 85% of underside of ceiling (average NRC 0.81)

The structure was tested with a number of wall configurations as follows:-

1. Open sided (no walls)
2. 19mm plywood wall on 4.6m side perpendicular to flight-path
3. 19mm plywood wall on 3.6m side parallel to flight-path
4. 19mm plywood walls on adjacent 4.6m and 3.6m sides

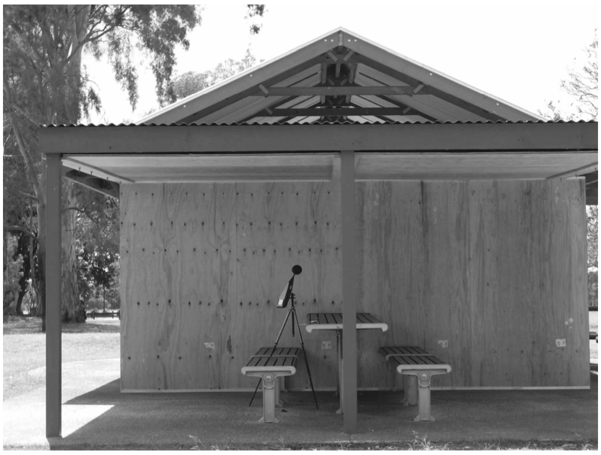
The plywood wall sheets where joined end-to-end by ‘tongue-and-groove’ strips and held together at the edges by aluminium channels. The plywood sheets for the wall(s) and ceiling were clamped to the structure in a manner that did not mark the structure, and which also allowed complete removal of building materials from the site each day before peak afternoon picnicking by the public.

Polyester sound absorption products were utilised to avoid fibre residues in a public eating area.

An illustration of an example configuration with roof/ceiling configuration No.3 and wall configuration No.4 is shown in Figure 3.

Source: (Author 2005)
Figure 3 Two-sided Enclosure with Absorptive Ceiling

A view of the structure with a reflective ceiling and one wall is illustrated in Figure 4.



Source: (Author 2005)
Figure 4 One-sided Enclosure with Reflective Ceiling

Measurements

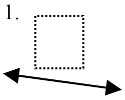
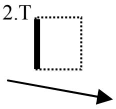
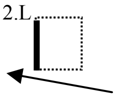
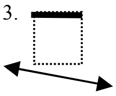
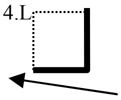
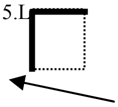
For each test configuration, the $L_{Amax,slow}$ flyover was sampled for nominally 10 jet aircraft flyover events. The noise level of each flyover event was measured under the centre of the shelter, and at a position 10m from the edge of the structure. Data was sampled with Type 1 instrumentation. The aircraft identification for each flyover event was obtained from Airservices Australia.

The aircraft flight direction was determined by the prevailing meteorological conditions that existed on each day of testing.

RESULTS

A summary of the test results is presented in Table 1. The plan of the test scenarios in relation to the flight path of aircraft is shown diagrammatically in the first column of Table 1. The arrow shows the flight direction. Arrows to the right of the page indicate takeoff movements (T) and arrows to the left indicate landing movements (L). The double-ended arrows indicate a 50-50 mix of takeoff and landing movements. Solid lines represent the plywood walls present for each test scenario. The East compass direction is towards the top of the page on Table 1.

Table 2 Summary Test Noise Reductions from Outdoor Structure

Test Scenario Diagram	Average Reduction Relative to Free-field Reference Position (number of samples in brackets) 1. Metal Roof Only	2. +Cavity absorption & Ceiling	3.+absorption under ceiling
1. 	-1.6 (13)	-2.6 (12)	-5.1 (13)
2.T 	N/A	-1.6 (5)	_[1]
2.L 	N/A	-0.5 (10)	-3.7 (14)
3. 	N/A	-2.3 (10)	-3.6 (11)
4.L 	N/A	-3.5 (11)	-6.5 (10)
5.L 	N/A	+1.0 (11)	-2.4 (13)

The aircraft composition for each test scenario, and attenuations for each flyover event are detailed in Table 2.

A summary of the measured free-field noise levels by aircraft type and movement type is detailed in Table 3.

Table 2 Detailed Test Results by Test Scenario

Test Scenario	Aircraft	Shelter	Freefield	Change
No walls (1)	B737-700	69.9	72.2	-2.3
metal roof (1)	B737-700	69.7	72.1	-2.4
Takeoffs	B737-700	66.9	68.6	-1.7
	B737-300	70.5	76.3	-5.8
	B737-700	70.4	71.1	-0.7
	B737-800	72.9	72.4	0.5
	B747-300	82.4	83.5	-1.1
	B737-400	78.1	77.2	0.9
	B767-300	71.1	71.7	-0.6
	Dash 8B	61.4	63.4	-2
	A340-300	78.7	80.4	-1.7
	A330-200	75.9	76.6	-0.7
	B737-400	74.8	77.2	-2.4
	B767-300	69.4	71.5	-2.1
Average	**13**			**-1.6**
Std. deviation				1.6
No walls (1)	B737-800	70	71.9	-1.9
Timber ceil. (2)	B737-800	68.9	74.1	-5.2
Takeoffs	B737-700	67.5	69.8	-2.3
	B737-700	66.2	70.5	-4.3
	B737-400	72	74.6	-2.6
	B737-800	69.7	72.2	-2.5
	A330-300	76.7	76.9	-0.2
	B737-400	73.2	75.9	-2.7
	B737-300	72.8	76	-3.2
	B767-300	71.6	73.7	-2.1
	B717-200	69.6	71.6	-2
	Dash 8A	57.8	59.6	-1.8
Average	**12**			**-2.6**
Std. deviation				1.3
No walls (1)	F111	81.9	87.9	-6
Absorp. ceil. (3)	B717-200	68.7	72.9	-4.2
Landings	B767-300	74.4	78.5	-4.1
	A330-300	73.1	77.9	-4.8
	B737-800	72.3	77.8	-5.5
	B737-700	71.5	76.1	-4.6
	B737-400	71.6	77.9	-6.3
	B737-400	72.4	78.9	-6.5
	twin prop	63.5	70.3	-6.8
	B737-800	73.7	78.4	-4.7
	Beech 200 twin-prop	67.5	71	-3.5
	Metro 23 twin-prop	65.8	71.2	-5.4
	A320	69.3	73.4	-4.1
Average	**13**			**-5.1**
Std. deviation				1.0
North wall (2)	A330-300	75.1	78.6	-3.5
Timber ceil. (2)	B717-200	71.9	73.1	-1.2
Takeoffs	A320	67.3	69.8	-2.5
	B737-700	69.8	70.7	-0.9
	B767-300	75	75.1	-0.1
Average	**5**			**-1.6**
Std. deviation				1.4
North wall (2)	B767-300	78.8	79	-0.2
Timber ceil. (2)	B747-400	82	81.9	0.1
Landings	B717-200	72.5	72.6	-0.1
	B737-400	74.2	78.9	-4.7
	B737-800	76.7	77.6	-0.9
	B737-700	73.8	73.6	0.2
	Beech 1900 twinprop	76.1	77.1	-1
	B737-800	77.2	76.4	0.8
	B777-300	80.9	80.5	0.4
	Dash 8C	77.9	77.6	0.3
Average	**10**			**-0.5**
Std. deviation				1.6
North wall (2)	B737-700	77.2	78.8	-1.6
Absorp. ceil. (3)	twin prop	67.4	71	-3.6
Landings	B737-800	74.1	77.8	-3.7
	Dash 8C	70.1	73.2	-3.1
	B737-800	72.8	77.7	-4.9
	B737-400	75.2	79	-3.8
	B737-800	72.2	76.1	-3.9
	B737-700	74.7	77.4	-2.7
	B737-800	72.6	76.4	-3.8
	B737-800	71.1	76.7	-5.6
	twin prop	58.8	64.8	-6
	B737-400	71.6	77.2	-5.6
	B737-800	72.3	75.6	-3.3
	B737-400	70.9	77	-6.1
Average	**14**			**-3.7**
Std. deviation				1.3
East wall (3)	737-700	69.1	72	-2.9
Timber ceil. (2)	747-300	86.7	86.8	-0.1
Takeoffs	A310	73.5	75.1	-1.6
	A330-200	75.5	78	-2.5

[1] Meteorological conditions did not allow this test situation within the test programme.

Test Scenario	Aircraft	Shelter	Freefield	Change
	B767-300	67.3	69.9	-2.6
	A320	72.1	74.4	-2.3
	B737-700	68.3	71.2	-2.9
	Bae 125/700/800	69.4	70.6	-1.2
	B767-300	72.9	74.9	-2
	B747-400	82.4	87	-4.6
Average	**10**			**-2.3**
Std. deviation				1.2
East wall (3)	A320	69	73.1	-4.1
Absorp. ceil. (3)	B737-800	75.7	77.9	-2.2
Landings	B737-400	72.5	77.7	-5.2
	B737-700	71.1	74.5	-3.4
	B737-800	72.1	77.6	-5.5
	B737-800	72.5	75.7	-3.2
	B737-800	77	77.1	-0.1
	B737-800	71.8	75.8	-4
	B737-700	73.4	77	-3.6
	B737-800	73.5	76.7	-3.2
	B737-700	71.6	76.9	-5.3
Average	**11**			**-3.6**
Std. deviation				1.6
West & South walls (4)	747-400	81.2	84.1	-2.9
Timber ceil. (2)	737-800	72.7	75.9	-3.2
Landings	737-800	71.7	75.4	-3.7
	Metro 23 Twin-prop	64.3	68.1	-3.8
	B737-700	70.2	74.3	-4.1
	B737-800	73.3	76.4	-3.1
	A330-200	74.6	76.5	-1.9
	B717-200	69.9	71.8	-1.9
	Dash 8A	69.6	75	-5.4
	B737-800	72	75.4	-3.4
	Cessna 441 Twin-prop	67.9	72.5	-4.6
Average	**11**			**-3.5**
Std. deviation				1.1
West & South walls (4)	B737-400	69.2	75.4	-6.2
Absorp. ceil. (3)	B737-800	69.6	76.6	-7
Landings	Dash 8C	65.2	73.9	-8.7
	B737-800	71.6	75.5	-3.9
	B737-400	72.1	77.6	-5.5
	B737-400	72.7	79.3	-6.6
	B737-800	68	74.2	-6.2
	Cessna 550 jet	62.8	68	-5.2
	B737-800	67.2	76.1	-8.9
	A320	67.1	74	-6.9
Average	**10**			**-6.5**
Std. deviation				1.5
North & East walls (5)	747-400	84	85.4	-1.4
Timber ceil. (2)	B737-800	78.7	76.9	1.8
Landings	A320	75.6	73.1	2.5
	B737-700	75.9	74.7	1.2
	B737-800	79.4	77.6	1.8
	A330-300	79.8	78.8	1
	twin prop	73.8	72.3	1.5
	A330-300	78.5	78.6	-0.1
	B767-300	78.4	77.3	1.1
	B737-800	77.4	75.8	1.6
	Dash 8A	74.2	73.8	0.4
Average	**11**			**1.0**
Std. deviation				1.1
North & East walls (5)	B747-400	80.6	82.9	-2.3
Absorp. ceil. (3)	B717-200	71.3	73.7	-2.4
Landings	B737-700	71.5	74.7	-3.2
	B737-800	75.2	77.7	-2.5

Test Scenario	Aircraft	Shelter	Freefield	Change
	B737-400	73	76.6	-3.6
	B777-300	78.1	81.2	-3.1
	B767-300	76.5	79	-2.5
	B737-800	74.3	77	-2.7
	A320	71.4	73.6	-2.2
	B737-700	72.1	74.4	-2.3
	Dash 8B	70.8	73.5	-2.7
	B737-700	76.7	77	-0.3
	B737-300	73.1	74.6	-1.5
Average	**13**			**-2.4**
Std. deviation				0.8

Table 3 Summary Free-field Levels by Aircraft Type – dB(A), slow

Aircraft	Movement	Count	Ave.	Std. dev.	max
A310	Takeoff	1	75.1	n/a	75.1
	Landing	Nil			
A320	Takeoff	2	72.1	n/a	74.4
	Landing	5	73.4	0.4	74.0
A330	Takeoff	3	77.4	1.1	78.6
	Landing	4	78.0	1.0	78.8
A340	Takeoff	1	80.4	n/a	80.4
	Landing	Nil			
B717-200	Takeoff	2	72.4	1.1	73.1
	Landing	4	72.7	1.0	73.7
B737-300	Takeoff	2	76.2	0.2	76.3
	Landing	1	74.6	n/a	74.6
B737-400	Takeoff	4	76.2	1.2	77.2
	Landing	11	77.8	1.2	79.3
B737-700	Takeoff	9	70.9	1.2	72.2
	Landing	12	75.8	1.6	78.8
B737-800	Takeoff	4	72.7	1.0	74.1
	Landing	27	76.6	1.0	77.9
B747-3/400	Takeoff	3	85.8	2.0	87.0
	Landing	4	83.6	1.5	85.4
B767-300	Takeoff	6	72.8	2.1	75.1
	Landing	4	78.5	0.8	79.0
B777-300	Takeoff	Nil			
	Landing	1	80.5	n/a	80.5
Bus. jets	Takeoff	1	70.6	n/a	70.6
	Landing	1	68.0	n/a	68.0
F111	Landing	1	87.9	n/a	87.9
Props.	Takeoff	2	61.5	2.7	63.4
	Landing	15	72.4	3.3	77.6

DISCUSSION

Implications for Design of Formal Outdoor Recreation Areas

The following general trends are interpreted from the test results:-

- The presence of reflective wall elements generally increased the measured level under the shelter
- an absorptive (vs reflective) ceiling decreased the measured level under the shelter.
- The direction of sound incidence relative to wall orientations, such as varied with takeoff or landing movement, determined whether the presence of walls provided attenuation through shielding (diffraction), or amplification through wall reflection effects.

The most reliable all-round attenuation performance is considered to be demonstrated for an open-sided structure with an absorptive ceiling. This is a feasible option for a free-standing formal outdoor recreation shelter structure. Attenuations relative to free-field of up to 5 dB(A) would appear to be readily achievable (Refer to Test Scenario 1 in Table 1).

The test results that could be related to a fully reflective balcony situation (Refer to Test Scenarios 2 to 6, represented by roof/ceiling configuration No.2 and wall configuration No.s 2 to No.6) show sensitivity to the direction of aircraft movement, producing either no change or a slight (1 dB) increase relative to the free-field reference position, up to a maximum of 3.5 dB(A) attenuation for the most favourable aircraft movement direction.

Considering all test configurations, an improvement of 2 dB(A) to 3 dB(A) can be achieved by adding absorption to the ceiling (i.e. balcony soffit).

While the test site was directly applicable to a specific residential development, a limitation of the test results more generally is that they are specific to nearly direct flyover events. Data was not obtained to enable analysis of attenuations for flight-paths further removed from the test site with lower angle of incidence during flyover.

The results of the study may also be regarded as specific (to some extent) to the geometrical configuration of the shelter tested and the specific measurement location utilised. Different results could be anticipated for shelter structures with higher eaves, wider or narrower coverage in plan, or for measurement locations closer to the edge of the structure.

Influence of Aircraft Type on Test Results

Rather than present the variability in noise reduction as a standard deviation only for a given test scenario, the complete data is presented to give the reader the opportunity to relate aircraft types to the resulting shelter performance. This is important since a constant composition of aircraft types was not achieved for each test situation.

It can be seen from Table 2 that for any particular scenario there is considerable variance between individual test results. This is believed to reflect the modal nature of the sound field under the shelter, particularly for aircraft overflights with proportionally more low-frequency energy. This observation would be accentuated by the L_{Amax} measurement parameter.

Considering modal effects, it might be expected that the variability in individual results would be reduced by the presence of ceiling absorption. This is observed for some test scenarios (e.g. wall configurations 1, 2 & 5) but not all. Varying sample composition may account for the departure from the prediction for wall configurations 3 & 4.

A trend towards higher noise reductions is also observable for smaller propeller aircraft with proportionally greater high frequency energy.

As the overall results presented in Table 1 are derived from an actual mix of aircraft types associated with Brisbane Airport the Table 1 results are considered to present a more reliable indication of shelter performance than individual test results for design purposes.

Implications for AS2021 Noise Intrusion Calculations

While this study did not set out to examine localised facade correction effects that may be applicable to AS2021 calculations of aircraft noise through building facades, significant conclusions can be drawn about the effect of balcony or verandah structures on the resulting noise exposure of facades beneath balcony or verandah structures. In particular, if the balcony or verandah ceiling is not absorptively treated there may be no significant exposure reduction compared to a free-field reference position. With an absorptive soffit under a balcony/verandah of similar dimensions/proportions to the experimental test structure it is considered that the reduction in noise exposure of the facade would be 2 dB(A) to 3 dB(A) relative to free-field levels.

CONCLUSIONS

It is concluded that a free-standing formal outdoor recreation shelter structure can be designed to significantly reduce the outdoor noise exposure ($L_{Amax,slow}$) for a formal outdoor recreation area. Attenuations relative to free-field of up to 5 dB(A) would appear to be readily achievable by utilising a shelter structure with an absorptive soffit and reasonable acoustic transmission loss.

For a standard (fully reflective) balcony situation the test results indicate sensitivity to the direction of aircraft noise incidence, producing either no change or a slight (1 dB) increase relative to the free-field reference position, up to a maximum of 3.5 dB(A) attenuation for the most favourable aircraft movement direction.

Considering all test configurations, an improvement of 2 dB(A) to 3 dB(A) relative to free-field is considered to be achievable by adding absorption to the ceiling or soffit of a balcony/verandah structure.

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