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General Aviation Interior Noise: Part II – In-Flight Source / Verification

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May 2002

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1. PROGRAM OBJECTIVES

The objectives of the project are to verify the noise source/path identification technology previously developed for single engine propeller driven aircraft that can be used to identify interior noise sources originating from:

- Structure-borne engine/propeller vibration
- Airborne propeller transmission
- Airborne engine exhaust noise
- Engine case radiation

and demonstrate a significant level of noise reduction in the aircraft cabin through application of state-of-the-art passive or active noise control measures.

2. PROGRAM APPROACH

The technical approach made use of the Cessna Model 182E aircraft used in the previous effort as a test bed for noise control application. The present phase of the project reports on flight test results during application of various passive noise treatments in an attempt to verify the noise sources and paths for the aircraft. The data presented establishes the level of interior noise control that can be expected for various passive noise control applications within the aircraft cabin. Subsequent testing will address specific testing to demonstrate the technology available to meet a specified level of noise control by application of passive and/or active noise control technology.

3. TEST PROCEDURE

3.1 Aircraft Operating Conditions

The aircraft was operated in the 75% Power Cruise condition at a fixed engine speed of 2,400 rpm for all test configurations. The limited ground testing was also at 2,400 rpm and approximately 75% power, to the limit that the aircraft wheel brakes would maintain the aircraft's stationary condition. All testing was performed at Cessna Aircraft Company, Single-Engine Product Engineering, 7751 E. Pawnee, Wichita, KS 67207 during the week of May 8, 2000.

3.2 Test Configurations

Specific test configurations, in the order they were conducted, are listed in Table 3.1. The baseline run with no treatment was flown as the last flight test due to initially poor weather, which grounded the aircraft for the first several days, during which the under cowling treatment was applied and remained during most of the testing. A list of the instrumentation used during the tests is given in Table 3.2. Figures 5.1 through 5.3 show the position of a majority of the instrumentation installed in the aircraft. In general, the sensor nomenclature in Table 3.2 is consistent with the previous flight tests conducted on the test aircraft and the sensors were located at identical locations. The areas of the test aircraft, where application of noise absorption or noise blocking materials were used to identify paths of noise propagation, are listed in Table 3.3, along with the material used, the configuration nomenclature, approximate area of coverage, and approximate weight of the material. The initial material application was intended to provide a measurable level of control, if indeed the path is active, with the second application providing additional confirmation. Table 3.4 gives the make-up of the passive control materials. Figure 5.4 shows the firewall treatment, which covered approximately 60% of the firewall. Further coverage could not be achieved due to space limitations. The under cowling muffler treatment is shown in Figure 5.5. The muffler is a double wall element, which is used as a heat exchanger for cabin heat. Figures 5.6 and 5.7 show the coverage of noise absorption material on the cowling surfaces, which was approximately 80%. The interior window treatments and instrumentation shield (not allowed to be attached) are shown in Figure 5.8. Two levels of treatment were used on the windshield and side windows. A tail pipe extension, shown in Figure 5.9, was developed by Cessna and was used only during ground tests.

Table 3.1 Test Configurations.

Event	Configuration	Designation	Comments
1	Under Cowling Treatment (UCT) – C2+MW+C3	Ground #1	EC14 – Cowling Mic Cable Melted
2	Under Cowling Treatment (UCT)– C2+MW+C3	Flight #1	
3	UCT + Cessna Tail Pipe Extension	Ground #2	
4	UCT + Instrument Panel Shield (IPS)	Flight #2	Wemac blowing air near AC22
5	UCT + Windshield Level #1 (WS1)	Flight #2	AC7 accelerometer came loose due to windshield heat.
6	UCT + Windshield Level #2 (WS2)	Flight #2	AC7 accelerometer came loose due to windshield heat.
7	UCT + Front Side Windows Level #1 (FW1)	Flight #2	
8	UCT +FW1 + Rear Side Windows Level #1 (RW1)	Flight #2	
9	UCT + Front Side Windows Level #2 (FW2) + RW1	Flight #2	
10	UCT + FW2 + Rear Side Windows Level #2 (RW2)	Flight #2	
11	UCT + FW2	Flight #2	
12	UCT	Flight #2	Repeat of Event #2
13	UCT + WS2 + FW2 + RW2	Ground #3	AC7 accelerometer came loose due to windshield heat.
14	UCT – Muffler Wrap	Flight #3	
15	Baseline – No Treatment	Flight #4	

Table 3.2 Instrumentation Layout and Channel Assignment.

Channel	Type – Nomenclature	Description
1	Accelerometer – EC2	Engine lateral vibration
2	Accelerometer – EC12	Firewall normal acceleration – mid center
3	Microphone – EC14	Firewall sound pressure level – upper center
4	Microphone – AC1	Mic above pilot's control column
5	Microphone – AC2	Mic above copilot's control column
6	Microphone – AC3	Mic near right rear seat passenger's head
7	Microphone – AC4	Mic near left rear seat passenger's head
8	Microphone – AC20	Mic between pilot and co-pilot ear height
9	Microphone – AC21	Mic behind pilot's head
10	Microphone – AC22	Mic behind co-pilot's head
11	Accelerometer – CB1	On center of aft cabin bulkhead
12	Accelerometer – AC5	Instrument panel right side
13	Accelerometer – AC7	Windshield right side
14	Accelerometer – AC9	Pilot's side window center
15	Accelerometer – AC11	Right rear passenger's window center
16	Microphone – TC1	Mic in A/C tail cone

Table 3.3 Schedule of Treatment Locations and Applicable Materials.

Location to be Treated	Config.	Area (ft^2)	Weight (lbs)	Applicable Materials	Usage
Under Cowling: UCT					
Firewall	C2	4.6	4.6	WB10-PSA	Add Transmission Loss & Absorption
Muffler Wrap	MW	3.0	3.25	WB10 + Fiberfax	Add Transmission Loss
Cowling Surface	C3	**		E-100SM-PSA	Add Absorption
In Cabin:					
Front Side Windows (2)	FW1	2.8R 2.8L	2.91R 2.80L	1) WB10-PSA	Add Transmission Loss
	FW2	2.8R 2.8L	2.97R 2.70L	2) R104-10CM-25PSA	Increase Transmission Loss
Rear Side Windows (2)	RW1	1.75R 1.75L	1.80R 1.86L	1) WB10-PSA	Add Transmission Loss
	RW2	1.75R 1.75L	1.70R 1.88L	2) R104-10CM-25PSA	Increase Transmission Loss
Instrument Panel	IPS	4.5	4.5	WB10- PSA	Add Transmission Loss
Windshield	WS1	11.5	11.65	1) WB10-PSA	Add Transmission Loss
	WS2	11.5	11.38	2) R104-10CM-25PSA	Increase Transmission Loss

** 80% Coverage of both Top and Bottom of Cowling With 1” Absorption Material – estimate from photographs.

Table 3.4 Description of Materials.

Material	Weight/Area (lbs/ft^2)	Description
WB10	1.0	Loaded vinyl w/ and w/o PSA
E-100SM-PSA	0.17	1” absorbing foam with 1 mil aluminized polyester surface + PSA
R104-10CM-25PSA	1.04	1.0 lb/ft^2 loaded vinyl with 0.25” decoupling foam + PSA

PSA – Pressure Sensitive Adhesive

4. TEST RESULTS

A composite spectrum of the seven interior microphones recorded during the flight test of the baseline configuration is given in Figure 4.1. The spectra are dominated by harmonics of the fundamental of the engine rotational frequency at 40 Hz (engine speed of 2,400 rpm). The major tones are at the blade passage frequency of 80 Hz and firing frequency of 120 Hz and their harmonics. The un-weighted and A-weighted spectra levels in the displayed frequency range are given in Table 4.1.

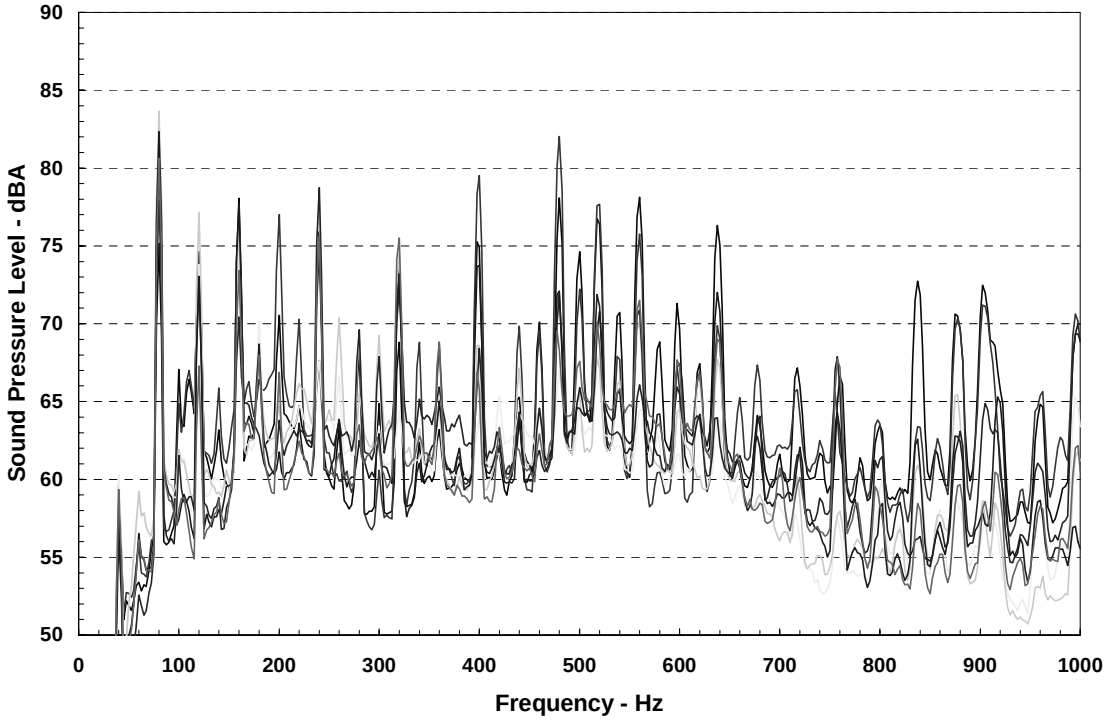


Figure 4.1 Interior Microphone Spectra: Baseline Aircraft @ 2,400 rpm 75% Power Cruise.

Table 4.1 Interior Microphone Levels: Baseline Aircraft @ 2,400 rpm 75 % Power Cruise.

Microphone	Un-Weighted	A-Weighted
AC1	107.2	93.0
AC2	105.4	92.6
AC3	108.4	89.3
AC4	109.7	91.0
AC20	107.4	90.1
AC21	107.8	90.5
AC22	107.1	89.7

The spectral levels at each of the tones were extracted for the seven interior microphones, the microphone under the cowling, EC14, and the tail cone microphone, TC1. These data are presented in tabular form in Appendix A for each of the 15 test configurations listed in Table 3.1. For the purposes of comparing the effectiveness of the various noise control treatments on cabin noise reduction, the maximum, minimum, and energy average of the seven cabin microphones were computed at each of the tones and are presented in tabular form in Appendix B. Of particular interest are the higher level tones at 80 Hz (fundamental blade passage, 1P), 120 Hz (fundamental firing, 1F), 160 Hz (second blade passage, 2P), 240 Hz (2F-3P), 400 Hz (5P), and 480 Hz (4F-6P). Repeat data runs were made with the under cowling treatment to establish flight-to-flight repeatability in the measurements. The data presented in Figure 4.2 gives a measure of the repeatability of the higher tone levels. The data bars are drawn from the minimum tone level to the maximum tone level with the data point representing the energy average level for the seven interior microphones. It appears that repeatability to within 1.5 dB is achieved for all but the fundamental firing tone at 120 Hz, which exhibits a 4-dB variation between flights.

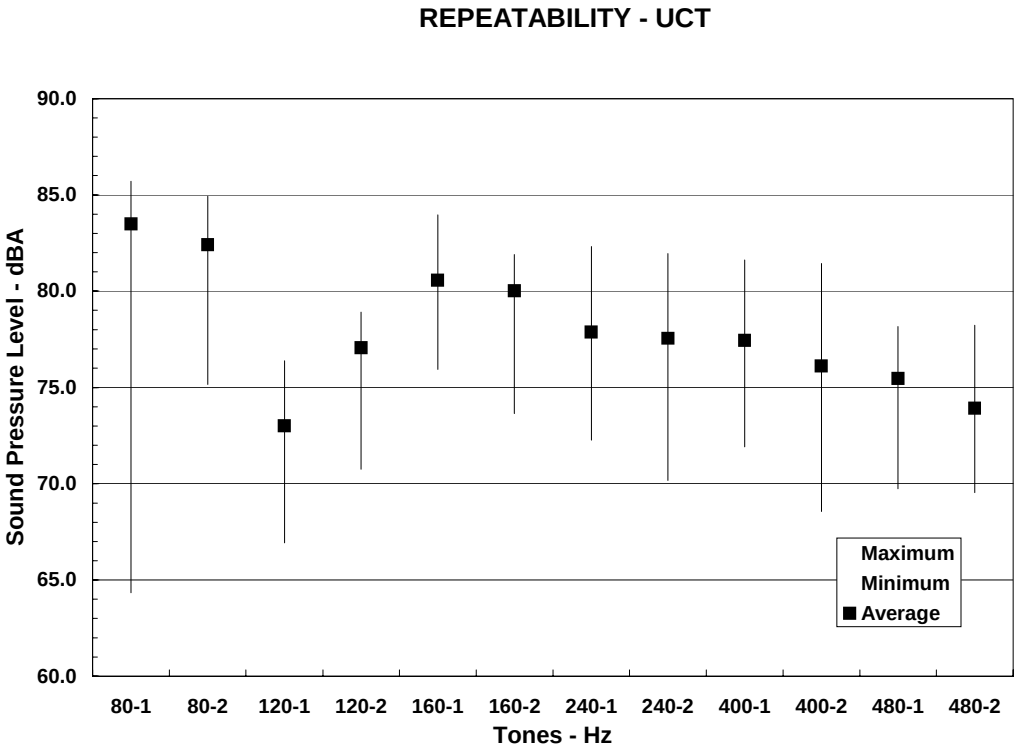


Figure 4.2 Repeatability of Cabin Tone Levels.

The effects of the various treatments on the higher level tones are given in Appendix C in the form of plots of the minimum, maximum, and average sound pressure levels within the cabin. Complete coverage of the windshield and side windows of the cabin could not be done due to safety issues associated with flying the aircraft totally blind. This configuration was ground tested along with the exhaust pipe extension, which was not designed to be airworthy. Review of the data in Appendix C shows little promise that application of passive control treatments will result in lower cabin noise levels for the lower frequency tones. However, there appears to be

some promise that treatment of the windshield will lower the average cabin levels for the 400 Hz tone, as shown in Figure C-5. Likewise, the tone at 480 Hz appears to be sensitive to nearly all the passive treatments, as shown in Figure C-6. As one should expect, passive treatment appears to be more effective for higher frequency control.

Plots of the sound level distributions within the cabin at the various microphone locations for the baseline and several treatment configurations are given in Appendix D. The baseline configuration distributions are given in Figures D-1 through D-6. As seen in Figure D-1, the noise levels for the fundamental propeller tone at 80 Hz are considerably higher in the rear of the aircraft than in the pilot and copilot's locations. This trend was also observed during our previous flight tests with the rear seats removed from the aircraft and before it was fitted with a new engine. The opposite trend of higher noise levels in the forward cabin is seen in the 400 Hz and 480 Hz tones.

The effect of window treatments on the distribution of the 80 Hz tone levels is given in Figure D-7, where levels are given for the baseline (B), windshield treatment (W), and side windows (S). Here, we see that the windshield treatment has little effect on the levels at the pilot and copilot's locations; however, the side window treatment showed reductions on the order of 3 dB at both locations. These results verify the limited results found using acoustic holography during the previous flight test evaluation on source/path identification. It is also of interest that the windshield treatment lowered the aft cabin levels while the side window treatment increased the aft cabin levels at the 80 Hz tone. The trends observed in the noise levels for the window treatments during ground tests showed opposite trends to those during flight for the 80 Hz tone, see Figure D-8. Figures D-9 and D-10 show the windshield treatments to be effective for noise control in the forward cabin for the higher frequency tones. The under cowling treatment was also effective in lowering the noise levels in the forward cabin for the 480 Hz tone, as shown by the data in Figure D-11.

5. PHOTOGRAPHS

Instrumentation and Treatments

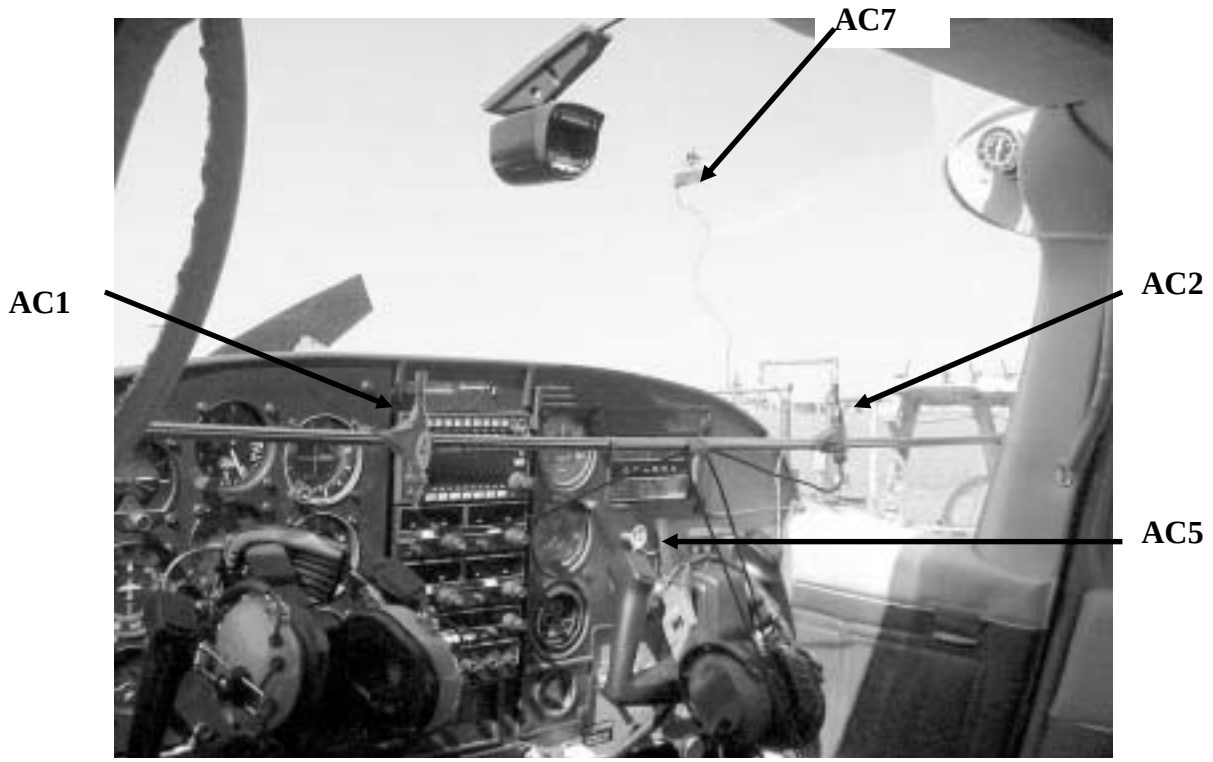


Figure 5.1 Forward Cabin Instrumentation.

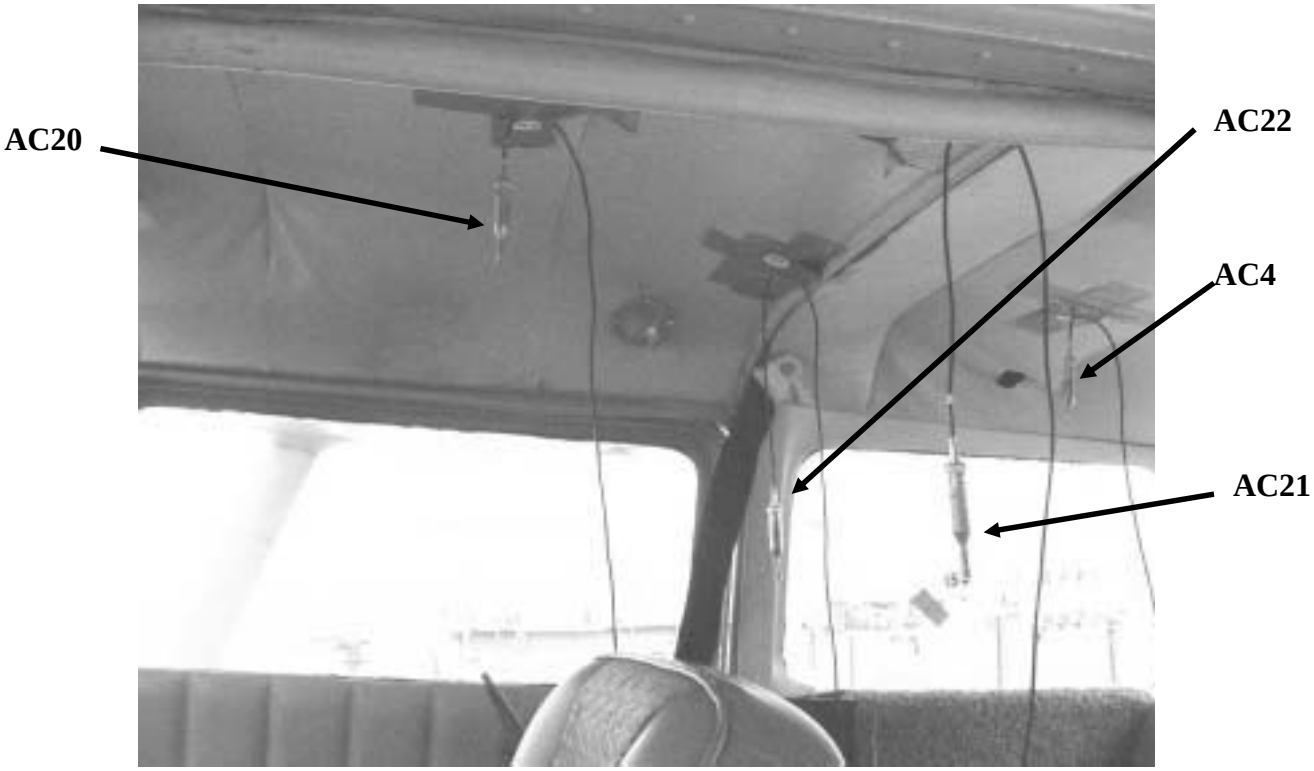


Figure 5.2 Mid Cabin Microphones.

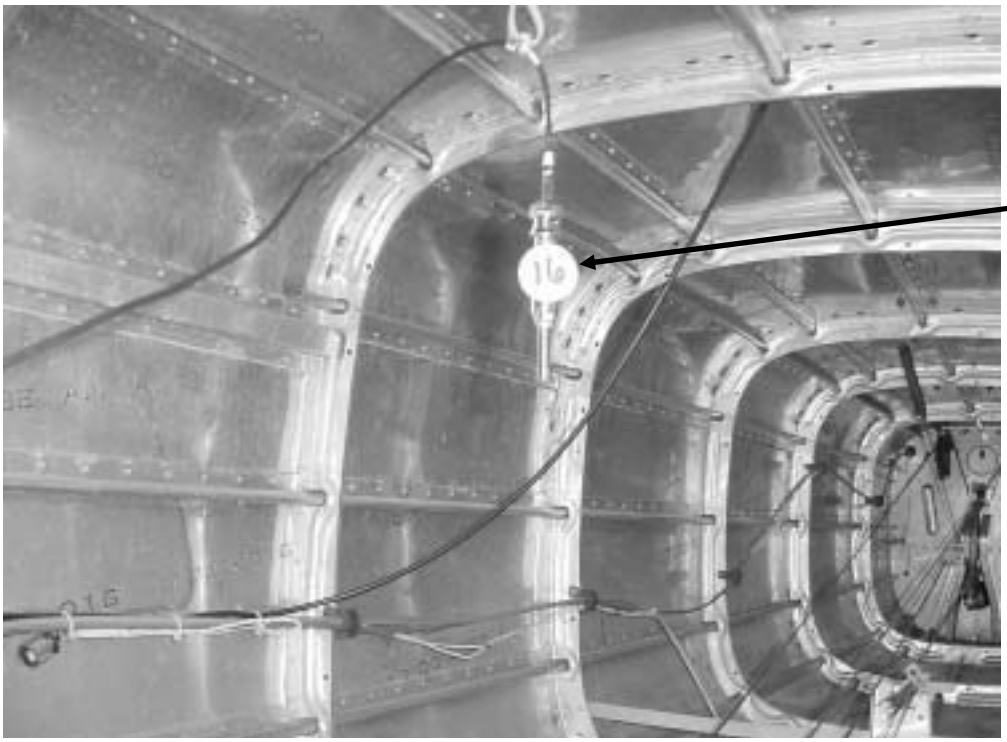


Figure 5.3 Tail Cone Microphone.

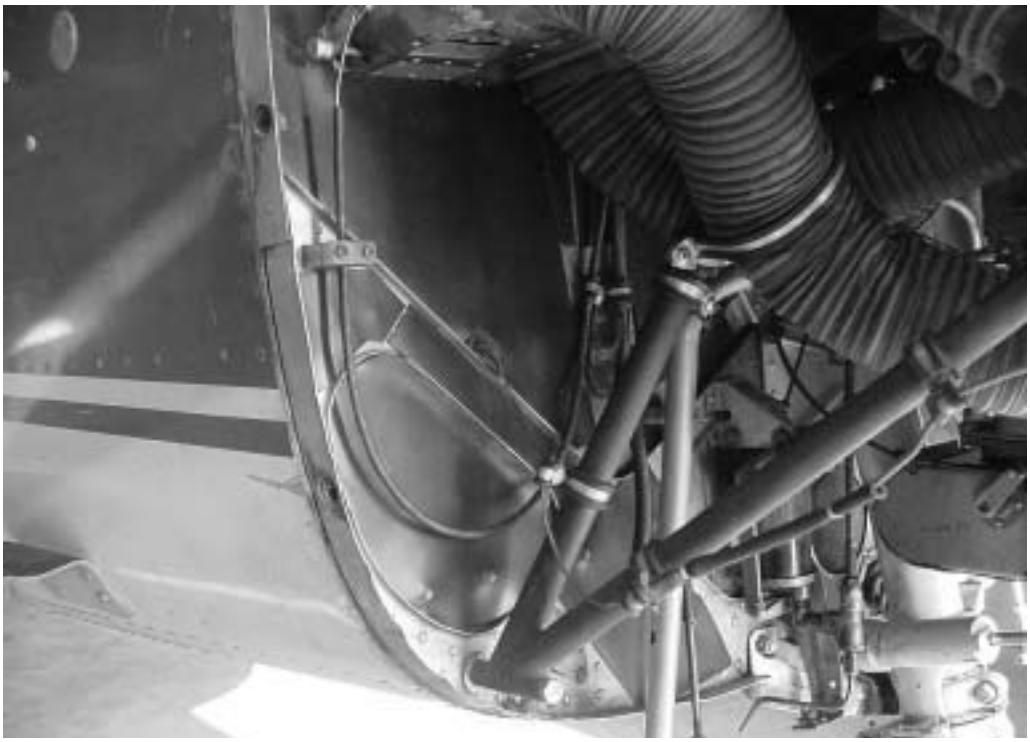


Figure 5.4 Typical Under Cowling Firewall Treatment.

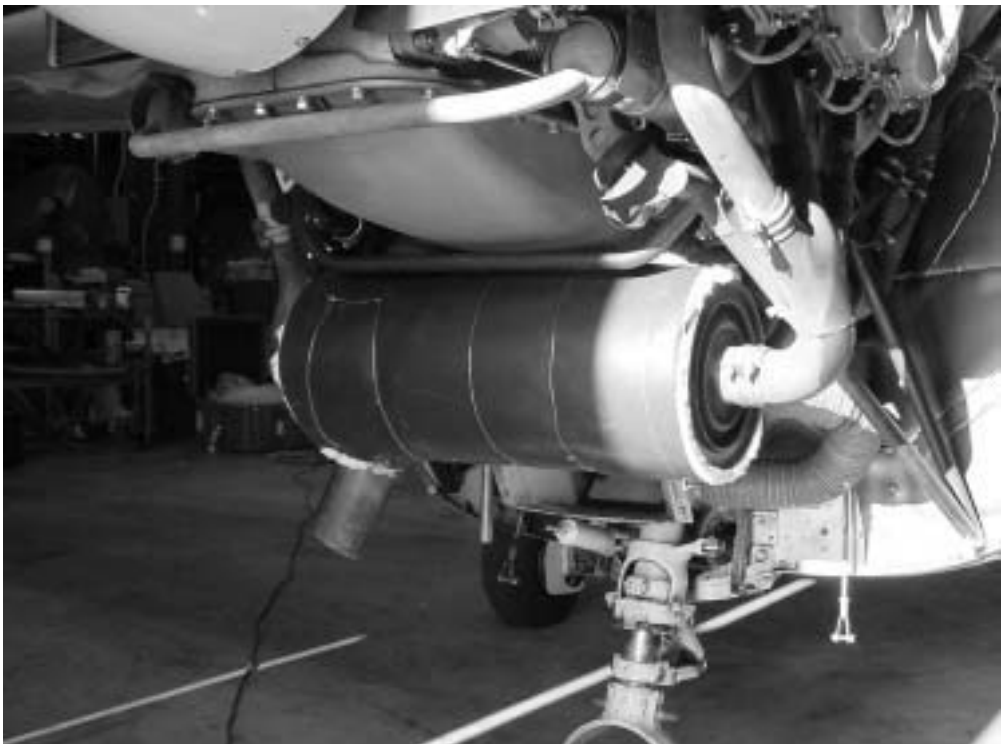


Figure 5.5 Under Cowling Muffler Wrap Treatment.

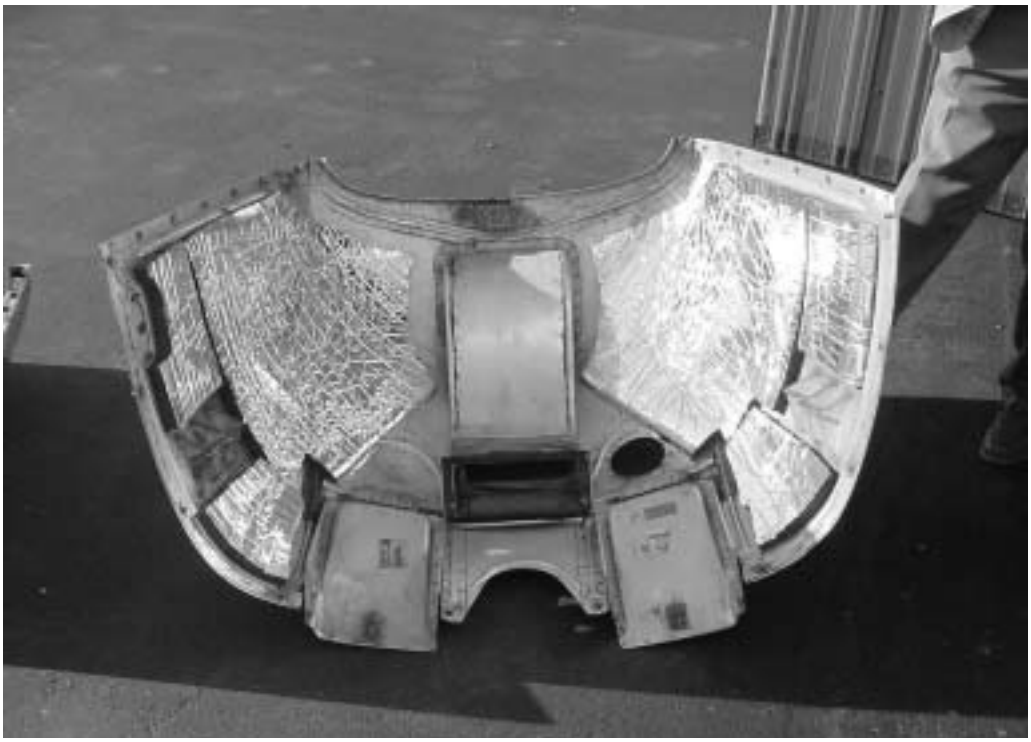


Figure 5.6 Lower Cowling Treatment.

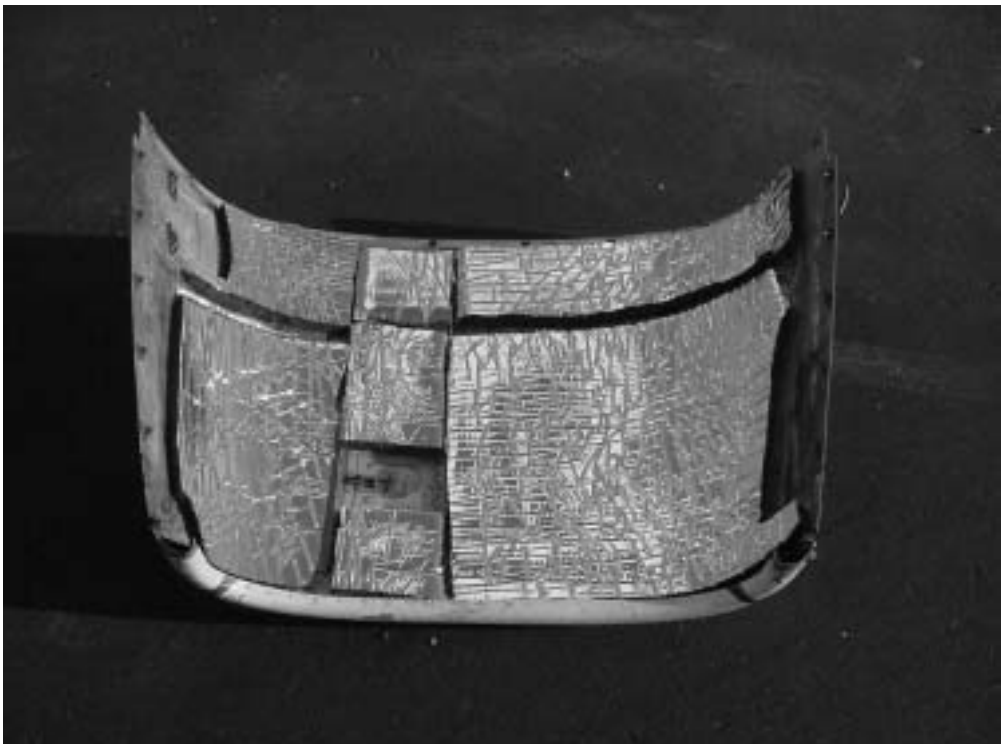


Figure 5.7 Upper Cowling Treatment.

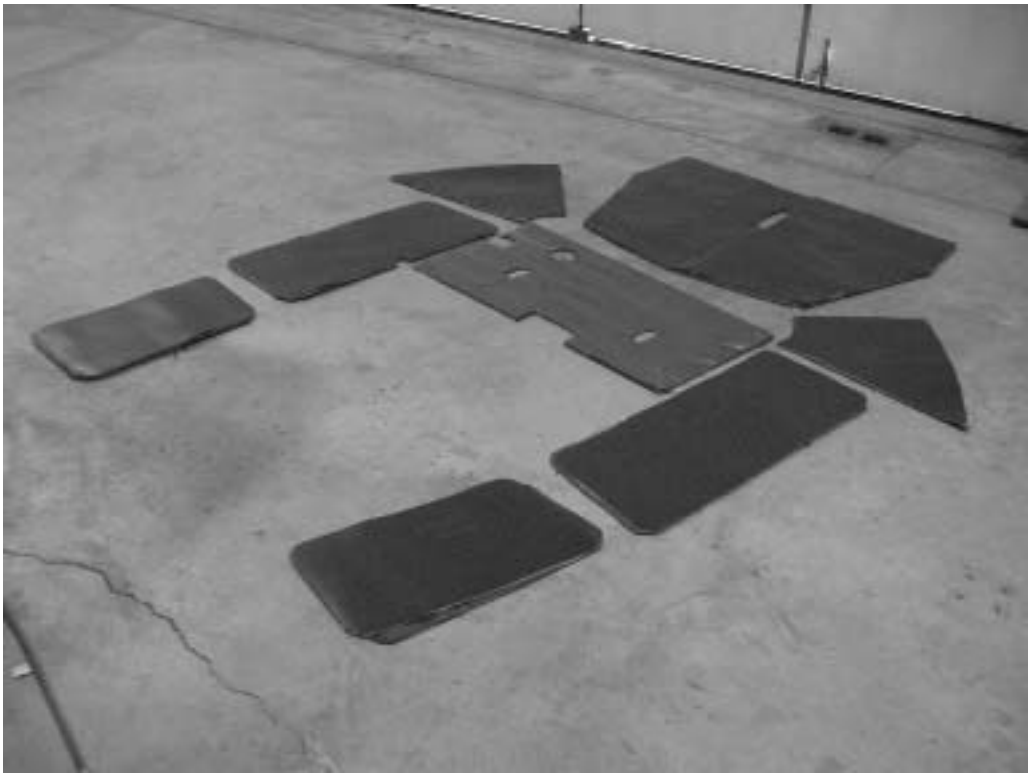


Figure 5.8 Interior Treatment.

Figure 5.9 Tail Pipe Extension.

Appendix A

Microphone Responses at Engine Harmonics

Table A-1. Microphone Response at Engine Harmonics: Ground Test #1 – UCT.

Frequency (Hz)	EC14 SPL dBA	AC1 SPL dBA	AC2 SPL dBA	AC3 SPL dBA	AC4 SPL dBA	AC20 SPL dBA	AC21 SPL dBA	AC22 SPL dBA	TC1 SPL dBA
40	Lost	72.1	71.5	71.1	70.5	70.5	69.5	70.6	73.5
80	Data	76.7	76.2	81.4	85.7	79.7	85.1	80.4	81.9
120		83.6	81.4	83.5	85.6	80.1	79.9	74.8	84.4
160		93.9	86.6	92.5	90.5	76.6	89.2	92.6	87.2
200		76.7	74.3	70.9	72.1	73.1	72.9	68.1	76.3
240		84.1	78.2	80.5	84.9	83.4	79.2	78.4	86.3
280		70.2	67.4	71.6	70.5	73.9	70.2	70.0	73.4
320		71.9	72.9	77.2	72.1	75.8	71.0	79.3	77.3
360		67.4	67.6	68.1	68.0	69.8	67.9	67.3	78.0
400		72.4	71.8	70.3	69.4	73.6	67.5	73.2	84.3
440		65.6	68.0	66.2	67.4	65.4	65.6	66.7	78.1
480		74.2	71.1	68.4	68.6	67.5	70.8	70.1	83.0
520		70.8	72.0	64.1	67.6	70.2	68.9	67.3	86.2
560		70.8	69.2	66.2	66.7	67.8	66.7	66.2	82.4
600		71.5	72.0	62.9	62.6	65.6	64.0	67.3	74.4
640		64.7	67.2	63.8	63.8	65.2	64.8	66.2	81.7
680		65.6	66.2	59.3	59.9	60.1	60.5	61.1	81.1
720		69.7	67.4	58.7	59.4	62.9	63.1	62.3	81.1
760		63.4	62.5	56.6	56.8	61.0	59.1	60.5	76.4
800		66.5	65.3	60.0	59.6	63.2	60.6	58.7	80.1
840		63.4	62.4	57.2	57.7	57.5	58.0	55.7	76.5
880		63.6	63.0	59.0	59.2	60.3	58.6	57.3	79.7
920		61.3	60.4	55.2	55.6	61.5	55.2	56.7	71.6
960		62.9	63.3	57.2	57.4	61.4	57.7	58.6	76.8

Table A-2. Microphone Response at Engine Harmonics: Flight Test #1 – UCT.

Frequency (Hz)	EC14 SPL dBA	AC1 SPL dBA	AC2 SPL dBA	AC3 SPL dBA	AC4 SPL dBA	AC20 SPL dBA	AC21 SPL dBA	AC22 SPL dBA	TC1 SPL dBA
40	76.3	60.3	61.9	62.9	60.7	60.4	58.6	61.8	58.7
80	95.1	72.4	64.3	84.8	85.7	84.7	85.2	83.7	85.4
120	93.4	71.6	72.8	72.8	76.4	71.5	73.9	66.9	76.6
160	98.9	80.2	77.1	80.0	82.4	79.0	84.0	75.9	78.2
200	88.0	75.8	70.4	70.4	69.4	66.7	67.3	67.2	71.8
240	90.3	72.3	72.5	72.7	82.3	79.6	79.2	74.8	77.0
280	90.7	68.9	65.1	70.5	68.4	67.7	71.2	66.4	69.2
320	91.8	74.3	73.0	70.1	76.8	76.1	70.9	74.6	74.5
360	95.5	69.6	66.1	67.3	67.7	69.3	67.2	70.5	75.4
400	96.6	81.6	80.0	71.9	74.6	74.3	76.9	73.6	77.4
440	89.1	70.9	71.0	68.9	70.2	66.8	69.5	68.2	74.7
480	96.3	78.2	75.9	76.5	69.7	71.5	76.0	75.2	78.0
520	99.5	75.5	78.0	72.5	70.0	78.5	72.1	74.8	84.7
560	90.2	81.2	78.4	70.7	73.7	72.2	71.7	77.8	78.5
600	89.4	74.9	76.2	67.5	73.6	70.6	71.6	74.4	71.9
640	87.4	76.2	73.5	66.3	69.8	66.6	70.6	71.2	76.5
680	92.8	70.9	69.0	64.4	64.1	67.6	64.7	65.2	77.4
720	96.4	78.8	77.6	63.8	67.0	70.1	68.9	67.1	76.5
760	89.9	67.6	72.9	62.9	61.8	72.4	65.2	68.9	72.5
800	91.3	70.7	69.5	62.2	62.6	66.0	60.9	60.3	74.7
840	89.7	71.0	76.1	63.2	71.5	63.8	72.4	64.7	73.9
880	91.2	70.6	72.8	64.7	66.6	69.8	66.0	60.2	73.1
920	88.5	66.9	71.0	59.4	59.7	68.2	63.6	62.9	71.8
960	90.2	69.5	67.2	63.0	59.1	64.9	66.4	61.0	73.8

Table A-3. Microphone Response at Engine Harmonics: Ground Test #2 – UCT + Tail Pipe Extension.

Frequency (Hz)	EC14 SPL dBA	AC1 SPL dBA	AC2 SPL dBA	AC3 SPL dBA	AC4 SPL dBA	AC20 SPL dBA	AC21 SPL dBA	AC22 SPL dBA	TC1 SPL dBA
40	73.7	69.7	68.9	68.6	68.6	68.4	68.0	68.0	65.1
80	99.4	77.5	75.9	81.7	85.8	81.9	86.0	81.4	76.4
120	85.4	81.9	79.6	79.2	80.0	77.2	80.3	79.4	78.5
160	107.0	92.1	85.6	92.3	88.9	79.3	88.0	92.6	78.5
200	86.6	78.2	75.5	70.1	72.4	74.6	73.8	69.1	69.6
240	87.5	84.3	79.3	78.3	87.3	80.6	80.5	79.6	84.8
280	90.9	69.7	67.8	70.4	72.0	74.8	71.9	69.2	67.9
320	93.0	73.6	72.5	76.2	73.4	77.3	74.4	78.2	70.4
360	91.9	67.7	67.4	66.6	67.9	70.6	68.9	68.4	72.0
400	95.9	74.0	71.7	70.0	69.1	74.0	67.7	70.4	75.5
440	84.9	67.9	65.9	66.1	66.3	66.4	66.2	65.3	72.2
480	93.8	71.8	69.8	68.6	70.1	67.5	69.7	68.9	81.3
520	86.4	72.8	74.0	64.4	66.1	70.0	66.0	66.6	82.0
560	87.2	66.4	68.1	65.2	65.4	65.9	62.5	67.0	77.0
600	83.9	64.6	66.1	62.4	63.9	63.7	63.8	63.9	70.9
640	85.8	63.7	65.5	62.1	63.7	65.5	64.4	65.1	75.3
680	85.9	61.0	63.8	62.0	58.3	59.5	59.6	61.9	74.6
720	89.8	64.0	64.9	59.4	59.3	62.2	61.9	62.6	74.5
760	83.5	60.4	61.6	58.3	56.0	58.7	58.5	58.9	73.3
800	85.3	64.8	62.1	60.0	60.3	60.0	59.3	58.0	77.3
840	82.0	60.1	59.6	56.8	56.9	55.7	55.3	54.7	73.1
880	83.8	62.7	62.1	58.4	59.1	59.6	57.5	56.5	77.2
920	80.9	57.8	57.6	53.9	54.6	57.6	54.3	53.7	68.3
960	82.1	61.1	61.3	57.1	54.7	58.5	56.1	57.4	76.1

Table A-4. Microphone Response at Engine Harmonics: Flight Test #2 – UCT + IPS.

Frequency (Hz)	EC14 SPL dBA	AC1 SPL dBA	AC2 SPL dBA	AC3 SPL dBA	AC4 SPL dBA	AC20 SPL dBA	AC21 SPL dBA	AC22 SPL dBA	TC1 SPL dBA
40	72.7	60.5	62.3	63.8	61.5	60.7	58.9	66.0	Lost
80	97.6	78.0	74.2	84.1	84.9	82.8	83.7	82.2	Data
120	92.6	79.1	78.1	75.7	78.9	74.5	74.9	71.9	
160	101.2	82.3	75.2	80.9	77.3	73.2	78.3	79.8	
200	89.5	77.7	73.2	68.9	70.0	67.7	67.5	71.3	
240	92.3	73.6	68.4	75.6	79.2	80.9	79.0	75.8	
280	85.2	70.4	68.8	73.5	72.6	70.7	70.1	71.8	
320	90.6	72.2	75.9	73.0	77.7	78.3	73.3	76.6	
360	92.7	66.3	68.7	68.6	69.3	71.1	68.1	72.7	
400	93.6	82.2	74.3	73.8	73.4	73.7	76.6	73.7	
440	85.2	72.1	70.2	67.9	69.6	67.7	69.0	69.2	
480	96.6	83.7	80.1	72.1	75.2	74.3	78.0	75.2	
520	98.8	69.3	74.2	70.8	68.1	72.7	72.8	74.3	
560	89.7	79.0	78.5	71.4	70.4	72.6	70.7	74.5	
600	90.7	73.8	73.4	66.8	70.2	70.4	71.9	71.5	
640	89.0	67.9	77.4	68.7	69.2	65.7	69.1	69.7	
680	89.1	68.2	70.2	64.6	63.6	65.3	65.1	66.2	
720	96.6	75.6	71.4	63.1	62.7	67.5	66.7	66.2	
760	91.0	66.5	70.0	60.5	63.7	67.4	63.9	66.6	
800	88.6	70.4	72.7	64.4	61.5	68.8	65.8	64.9	
840	89.2	69.4	70.2	61.5	68.7	67.2	70.2	67.9	
880	89.2	72.8	72.8	60.4	66.0	64.2	65.0	64.8	
920	90.1	73.4	69.2	60.4	66.0	69.4	68.5	64.9	
960	87.0	69.4	73.4	61.3	60.1	69.2	63.7	64.3	

Table A-5. Microphone Response at Engine Harmonics: Flight Test #2 – UCT + WS1.

Frequency (Hz)	EC14 SPL dBA	AC1 SPL dBA	AC2 SPL dBA	AC3 SPL dBA	AC4 SPL dBA	AC20 SPL dBA	AC21 SPL dBA	AC22 SPL dBA	TC1 SPL dBA
40	73.2	59.5	60.9	62.3	60.1	59.5	57.6	61.0	Lost
80	94.7	76.9	71.3	83.9	84.1	83.4	83.7	82.3	Data
120	93.3	77.5	77.6	75.5	77.5	72.4	73.7	67.6	
160	100.2	80.7	75.3	80.1	80.0	74.4	79.2	79.2	
200	88.8	75.7	73.1	69.4	70.2	67.6	67.2	66.3	
240	92.5	74.8	74.6	77.0	78.1	80.1	76.0	71.5	
280	84.1	66.3	71.0	73.0	75.6	70.4	67.0	70.7	
320	90.5	75.0	73.5	73.5	75.4	77.7	74.6	76.3	
360	94.2	67.6	62.8	68.1	68.1	70.9	69.7	67.1	
400	92.3	77.8	76.1	72.1	71.5	74.5	74.7	69.2	
440	85.8	69.0	69.7	67.5	69.5	69.9	70.2	66.4	
480	95.6	76.3	75.6	70.6	74.3	72.0	74.3	73.9	
520	100.4	73.3	72.9	71.7	72.6	75.1	76.5	73.0	
560	88.2	75.6	78.7	71.2	71.6	72.1	71.7	72.0	
600	90.6	72.4	75.9	67.3	69.1	69.7	70.6	70.6	
640	88.4	73.6	71.9	68.2	69.8	68.5	70.7	69.6	
680	91.0	68.8	70.7	63.8	64.6	66.7	64.4	63.9	
720	96.9	74.2	76.5	65.2	66.0	68.0	67.4	68.0	
760	91.1	73.4	65.8	61.4	64.5	69.5	64.7	65.6	
800	87.8	70.7	64.0	63.0	66.4	69.1	69.4	65.4	
840	88.5	71.0	66.7	69.0	64.0	67.4	67.9	64.3	
880	87.0	75.0	67.8	63.9	61.7	66.0	62.7	65.5	
920	92.1	75.1	69.6	66.0	67.6	65.2	70.6	65.9	
960	88.0	71.0	67.9	61.9	60.8	69.5	64.7	60.6	

Table A-6. Microphone Response at Engine Harmonics: Flight Test #2 – UCT + WS2.

Frequency (Hz)	EC14 SPL dBA	AC1 SPL dBA	AC2 SPL dBA	AC3 SPL dBA	AC4 SPL dBA	AC20 SPL dBA	AC21 SPL dBA	AC22 SPL dBA	TC1 SPL dBA
40	71.6	59.1	60.7	62.0	59.8	59.1	57.4	60.7	Lost
80	97.2	80.1	77.2	83.0	83.8	81.4	82.1	80.3	Data
120	94.0	79.3	78.7	77.7	79.8	75.7	75.5	71.5	
160	98.3	77.9	79.1	79.4	79.8	76.3	81.2	77.5	
200	88.5	77.2	73.8	69.6	69.4	69.4	66.3	65.2	
240	93.3	74.8	73.3	73.5	80.8	80.5	76.4	75.2	
280	83.8	68.1	70.3	71.8	72.3	69.8	67.8	67.4	
320	87.9	74.4	78.5	74.6	72.6	75.3	71.0	76.3	
360	93.4	67.3	65.0	67.6	66.9	69.8	67.7	68.6	
400	92.6	73.1	75.2	70.0	72.0	70.3	72.2	71.6	
440	84.8	66.7	71.1	66.7	67.2	68.8	65.3	65.3	
480	96.1	74.2	75.8	72.0	70.1	71.0	74.3	71.3	
520	100.0	71.7	71.4	69.6	70.7	70.3	72.9	72.0	
560	90.9	71.7	78.7	72.3	71.6	73.7	71.3	73.8	
600	90.9	69.1	81.1	67.3	70.0	71.2	70.4	70.4	
640	87.8	66.1	76.6	65.4	69.4	68.7	72.0	70.3	
680	90.9	64.0	66.4	63.9	62.7	65.6	64.3	63.3	
720	96.7	72.3	73.4	62.3	64.4	65.3	61.6	64.1	
760	91.5	72.2	68.7	60.3	61.4	64.3	60.9	62.1	
800	89.4	69.2	64.0	62.1	61.9	64.8	63.2	62.1	
840	89.9	71.2	64.9	65.6	64.2	63.4	67.5	62.3	
880	89.7	70.3	63.5	59.9	62.0	67.6	62.4	60.0	
920	88.5	73.6	68.4	58.6	63.0	69.3	62.9	64.2	
960	88.7	67.4	68.2	59.7	57.0	63.5	60.3	60.6	

Table A-7. Microphone Response at Engine Harmonics: Flight Test #2 – UCT + FW1.

Frequency (Hz)	EC14 SPL dBA	AC1 SPL dBA	AC2 SPL dBA	AC3 SPL dBA	AC4 SPL dBA	AC20 SPL dBA	AC21 SPL dBA	AC22 SPL dBA	TC1 SPL dBA
40	72.2	54.9	55.8	60.0	58.3	56.7	56.3	58.7	Lost
80	97.1	77.3	74.2	84.1	85.0	83.1	83.5	82.7	Data
120	93.9	79.8	79.5	77.3	80.0	75.9	75.0	71.9	
160	98.0	78.7	79.4	79.4	78.6	74.7	80.8	78.0	
200	88.6	77.3	73.4	69.2	68.3	68.2	67.5	66.7	
240	93.4	76.1	70.9	70.3	81.2	81.0	79.3	76.1	
280	83.3	68.4	67.6	73.9	70.6	72.4	69.8	69.1	
320	88.8	71.3	69.2	72.1	74.2	76.1	74.0	77.1	
360	93.4	67.2	67.4	69.7	68.1	71.0	67.3	68.6	
400	91.9	81.0	74.1	76.6	72.5	73.3	76.5	71.6	
440	84.5	69.3	67.6	69.5	68.4	69.0	66.5	65.7	
480	96.6	80.6	76.1	72.4	73.2	74.3	72.8	74.4	
520	99.1	78.7	75.5	74.1	69.6	76.3	71.9	73.8	
560	92.8	77.2	78.1	70.1	69.6	73.4	72.2	71.9	
600	91.4	74.8	76.8	65.6	69.7	68.6	71.9	71.7	
640	88.3	71.8	72.1	72.6	72.2	67.0	70.7	71.9	
680	91.1	68.9	69.2	67.2	64.5	66.8	65.8	63.3	
720	97.5	77.1	77.6	65.7	63.0	69.0	66.8	66.1	
760	92.5	74.7	66.6	65.5	62.5	71.6	69.1	65.3	
800	90.3	71.8	69.2	64.2	64.3	65.7	64.6	62.7	
840	89.8	70.6	76.0	69.1	70.0	65.6	72.8	71.4	
880	90.3	69.5	74.1	62.2	68.6	70.5	67.5	62.3	
920	87.8	71.7	71.6	61.2	66.7	68.3	65.6	61.6	
960	89.1	66.4	70.9	61.3	58.9	66.2	61.5	62.5	

Table A-8. Microphone Response at Engine Harmonics: Flight Test #2 – UCT + FW1 + RW1.

Frequency (Hz)	EC14 SPL dBA	AC1 SPL dBA	AC2 SPL dBA	AC3 SPL dBA	AC4 SPL dBA	AC20 SPL dBA	AC21 SPL dBA	AC22 SPL dBA	TC1 SPL dBA
40	72.9	55.6	56.6	60.4	58.6	57.2	56.4	59.1	Lost
80	96.5	77.5	74.7	84.5	84.8	82.7	83.2	82.9	Data
120	94.2	78.2	78.3	75.6	78.2	76.1	74.6	71.0	
160	97.6	78.5	79.5	79.9	80.0	75.1	81.6	78.9	
200	88.4	76.1	72.9	69.5	69.5	69.2	67.3	67.0	
240	93.0	74.6	71.7	71.5	81.7	80.7	78.9	74.7	
280	83.3	67.8	66.0	73.2	68.6	70.5	69.2	70.5	
320	88.4	72.6	68.3	75.5	71.2	76.8	73.8	75.6	
360	93.5	68.9	67.2	70.1	66.9	69.7	68.9	67.4	
400	91.7	80.1	75.4	70.8	75.2	72.6	76.2	70.4	
440	85.1	69.7	68.9	68.8	67.6	68.5	66.3	65.7	
480	96.2	80.6	77.4	71.0	73.0	73.8	70.6	71.9	
520	98.9	78.7	77.8	72.4	73.6	75.3	72.8	74.6	
560	92.2	76.5	77.6	70.7	70.0	71.7	72.2	71.7	
600	90.7	74.2	77.1	68.1	68.9	69.9	69.6	69.7	
640	87.3	71.9	72.2	69.2	69.8	67.5	69.7	71.8	
680	90.6	68.6	68.8	64.6	63.5	65.4	65.5	63.8	
720	96.6	75.4	75.7	64.3	61.8	70.3	65.5	67.3	
760	92.2	73.6	70.8	64.8	64.6	71.8	65.7	63.1	
800	90.6	73.0	67.4	64.2	62.7	66.8	63.9	61.2	
840	90.2	74.1	74.7	66.5	65.1	66.3	66.5	66.9	
880	89.9	67.9	72.8	62.2	69.9	66.2	68.1	63.4	
920	88.1	69.2	69.9	61.5	64.6	68.7	66.5	62.9	
960	89.7	68.5	70.4	61.4	59.9	66.6	66.2	62.8	

Table A-9. Microphone Response at Engine Harmonics: Flight Test #2 – UCT + FW2 +RW1.

Frequency (Hz)	EC14 SPL dBA	AC1 SPL dBA	AC2 SPL dBA	AC3 SPL dBA	AC4 SPL dBA	AC20 SPL dBA	AC21 SPL dBA	AC22 SPL dBA	TC1 SPL dBA
40	72.4	52.1	52.2	56.2	53.8	52.2	51.5	54.7	Lost
80	96.9	76.8	74.9	84.0	84.3	82.5	82.5	82.3	Data
120	94.5	78.6	78.7	76.4	78.9	76.5	75.2	72.0	
160	97.9	79.6	79.7	80.7	80.7	72.5	82.3	80.2	
200	88.3	77.1	73.6	68.7	69.2	68.8	67.0	66.5	
240	93.2	74.7	69.7	72.2	82.2	80.1	79.2	76.0	
280	83.8	68.5	67.9	73.3	68.0	70.6	69.2	70.8	
320	89.0	72.4	67.6	75.1	70.9	77.5	73.0	76.3	
360	93.4	67.0	68.1	68.9	67.4	70.1	68.1	66.5	
400	92.9	81.5	74.2	72.4	75.5	73.4	76.6	71.1	
440	84.5	67.6	68.6	69.5	67.7	69.6	66.1	64.4	
480	97.0	81.2	76.7	72.5	72.3	73.2	71.5	73.6	
520	99.9	78.7	76.2	73.6	75.4	77.1	72.0	75.4	
560	91.4	77.0	79.9	71.0	69.0	71.1	72.3	70.0	
600	90.5	75.7	80.0	66.4	66.8	69.0	72.4	67.4	
640	89.1	72.2	70.4	69.9	67.8	67.4	71.7	70.8	
680	91.1	69.8	68.0	64.3	62.5	64.3	64.7	62.7	
720	97.6	77.7	76.8	63.4	62.8	67.4	64.7	65.6	
760	92.8	76.2	71.0	68.7	63.8	74.3	70.8	65.1	
800	90.9	71.7	69.2	63.1	63.0	68.7	62.7	64.2	
840	91.0	73.0	76.1	69.8	69.3	69.8	67.8	71.8	
880	90.3	68.6	73.1	61.7	66.5	69.2	68.4	63.8	
920	88.7	72.4	72.8	64.5	66.4	70.5	66.3	62.6	
960	90.3	69.4	70.7	60.6	58.8	66.6	67.3	60.2	

Table A-10. Microphone Response at Engine Harmonics: Flight Test #2 – UCT + FW2 +RW2.

Frequency (Hz)	EC14 SPL dBA	AC1 SPL dBA	AC2 SPL dBA	AC3 SPL dBA	AC4 SPL dBA	AC20 SPL dBA	AC21 SPL dBA	AC22 SPL dBA	TC1 SPL dBA
40	72.8	52.7	53.0	57.1	54.7	53.3	52.5	55.6	Lost
80	96.2	76.8	73.9	84.8	85.0	83.1	83.5	83.3	Data
120	94.5	79.1	79.2	76.2	78.8	76.5	75.2	71.6	
160	98.0	80.0	79.0	80.8	80.0	73.3	81.3	79.5	
200	88.9	77.5	73.2	69.9	68.6	68.4	67.4	66.8	
240	94.0	74.7	71.8	73.7	82.1	80.2	79.6	74.7	
280	82.9	67.3	67.9	73.4	69.7	70.7	68.9	71.2	
320	87.9	71.5	65.9	74.2	71.1	78.7	72.6	75.9	
360	93.4	68.6	67.0	69.5	66.7	70.3	68.0	66.4	
400	92.1	81.9	75.0	73.4	77.2	75.0	77.3	71.1	
440	84.7	67.2	66.9	68.4	67.6	68.7	65.6	65.3	
480	96.5	81.4	78.4	69.1	72.6	73.4	72.3	71.9	
520	99.2	79.7	78.5	70.3	73.8	76.0	73.8	72.4	
560	91.4	78.1	78.6	70.6	68.7	71.0	71.5	70.7	
600	90.3	75.1	75.4	65.6	66.6	69.2	69.0	69.3	
640	87.3	70.1	70.5	68.7	68.2	66.3	72.1	70.3	
680	91.4	69.2	67.1	64.6	63.8	64.9	65.5	62.5	
720	96.2	75.1	76.1	65.2	62.6	69.2	64.3	65.6	
760	91.9	75.6	69.1	64.0	62.3	69.6	66.7	65.3	
800	89.8	72.7	68.0	63.9	61.8	66.7	61.8	62.5	
840	90.3	72.2	73.5	66.2	64.3	68.6	65.8	67.1	
880	89.4	65.3	73.1	61.3	65.5	63.4	65.9	61.4	
920	90.2	69.2	69.0	61.9	63.8	68.6	64.3	63.4	
960	89.1	67.7	68.9	60.1	58.0	67.2	66.2	60.9	

Table A-11. Microphone Response at Engine Harmonics: Flight Test #2 – UCT + FW2.

Frequency (Hz)	EC14 SPL dBA	AC1 SPL dBA	AC2 SPL dBA	AC3 SPL dBA	AC4 SPL dBA	AC20 SPL dBA	AC21 SPL dBA	AC22 SPL dBA	TC1 SPL dBA
40	72.0	52.6	51.7	56.3	54.1	51.3	51.3	54.4	Lost
80	97.7	77.1	75.7	81.9	82.2	80.5	80.5	80.3	Data
120	94.1	77.3	77.1	76.9	78.9	74.7	73.8	70.3	
160	97.2	83.0	82.1	83.6	84.2	71.6	84.5	83.6	
200	87.4	75.2	72.7	69.1	67.8	68.6	66.2	65.4	
240	91.9	74.6	74.4	74.1	80.1	78.8	75.4	77.7	
280	85.4	67.5	66.4	71.5	71.0	69.5	71.1	71.3	
320	87.9	74.2	74.2	76.6	72.6	77.2	73.0	76.1	
360	91.8	67.2	68.6	70.4	66.9	71.4	68.4	65.8	
400	92.9	79.6	77.3	68.5	76.2	72.5	74.7	69.2	
440	85.5	66.1	68.7	66.7	65.5	67.4	65.9	65.0	
480	94.3	77.4	77.7	70.1	73.3	72.6	69.9	71.9	
520	98.0	79.1	79.0	70.1	72.7	74.3	74.3	71.9	
560	89.8	76.6	78.2	69.2	67.1	71.6	69.2	69.6	
600	89.6	75.6	78.7	65.7	67.0	70.3	71.2	70.3	
640	88.4	69.7	71.4	68.0	66.4	67.0	67.8	66.3	
680	89.3	67.6	67.3	63.4	61.7	63.8	63.8	62.5	
720	95.8	71.3	72.6	62.6	62.4	67.0	64.2	64.0	
760	90.2	73.0	69.4	63.4	62.5	69.8	67.3	64.6	
800	88.8	71.1	67.3	63.0	60.2	68.5	63.1	62.7	
840	89.0	71.8	71.5	63.9	65.8	64.9	66.3	66.4	
880	99.8	75.0	71.2	62.6	66.5	65.2	65.4	67.1	
920	87.5	68.5	70.2	59.7	60.6	66.8	65.0	61.8	
960	90.1	69.0	70.0	59.5	57.4	67.5	63.1	60.1	

Table A-12. Microphone Response at Engine Harmonics: Flight Test #2 – UCT.

Frequency (Hz)	EC14 SPL dBA	AC1 SPL dBA	AC2 SPL dBA	AC3 SPL dBA	AC4 SPL dBA	AC20 SPL dBA	AC21 SPL dBA	AC22 SPL dBA	TC1 SPL dBA
40	73.2	59.7	61.2	62.6	60.5	59.8	58.0	61.4	Lost
80	96.7	77.6	75.1	84.1	84.9	82.4	83.4	82.1	Data
120	94.5	78.8	78.5	76.3	78.9	76.3	75.4	70.7	
160	97.6	80.5	79.0	80.7	80.7	73.6	81.9	79.9	
200	87.5	76.4	73.1	69.7	68.9	69.0	67.6	67.2	
240	93.3	74.7	70.2	73.8	82.0	78.7	77.1	77.2	
280	83.5	68.5	68.2	71.1	69.6	70.9	69.9	71.6	
320	88.6	74.2	70.0	75.9	71.2	77.6	72.6	75.7	
360	93.0	67.5	66.9	68.0	67.3	70.3	68.6	67.4	
400	91.4	81.4	76.3	68.6	74.8	73.2	75.8	68.6	
440	85.1	67.5	67.5	66.6	66.3	68.5	66.4	65.8	
480	94.9	78.2	76.1	69.7	71.4	72.0	69.5	72.3	
520	98.0	76.1	76.2	73.1	74.3	74.1	72.3	75.6	
560	91.0	74.8	75.7	71.2	68.3	73.2	69.8	73.3	
600	89.4	72.6	78.7	66.1	68.0	71.6	72.7	69.7	
640	87.9	69.4	70.5	67.3	67.4	64.6	69.0	69.0	
680	89.5	67.6	67.0	63.9	62.4	65.4	64.9	62.8	
720	95.5	73.5	72.3	62.8	62.9	66.5	65.9	65.0	
760	91.1	72.2	70.8	63.3	62.4	69.5	65.3	63.0	
800	89.1	72.2	66.9	64.2	63.3	67.1	64.1	61.7	
840	89.6	69.1	74.5	62.3	66.5	66.5	64.4	63.1	
880	90.4	68.0	72.2	60.7	67.1	64.7	63.6	61.8	
920	88.5	69.2	69.3	58.8	61.9	65.7	63.5	59.8	
960	88.9	68.7	70.4	60.8	60.6	66.2	62.9	61.3	

Table A-13. Microphone Response at Engine Harmonics: Ground Test #3 – UCT + WS2 + FW2 + RW2.

Frequency (Hz)	EC14 SPL dBA	AC1 SPL dBA	AC2 SPL dBA	AC3 SPL dBA	AC4 SPL dBA	AC20 SPL dBA	AC21 SPL dBA	AC22 SPL dBA	TC1 SPL dBA
40	73.8	65.0	64.5	64.4	63.3	63.9	62.9	63.1	59.0
80	97.7	77.3	73.2	78.9	77.8	77.3	79.1	78.3	76.0
120	92.0	83.9	81.9	85.8	87.3	82.7	82.3	79.1	79.8
160	107.1	89.8	84.2	90.4	85.8	83.6	83.6	92.5	83.6
200	86.2	78.8	75.1	70.4	72.5	75.8	74.9	69.4	67.2
240	88.6	78.9	71.4	78.9	83.9	78.3	75.1	72.3	82.0
280	85.5	70.5	71.9	69.7	72.7	78.0	74.1	69.2	64.8
320	91.9	72.6	71.8	73.7	75.6	78.0	75.8	76.5	70.3
360	85.7	70.1	64.9	66.6	69.8	73.3	71.5	70.9	68.9
400	92.1	73.2	68.4	70.8	70.5	74.6	70.6	69.8	76.4
440	84.4	67.7	66.1	66.5	65.2	70.2	66.1	65.8	68.2
480	90.4	72.4	71.1	70.3	69.0	69.6	69.1	71.9	72.9
520	85.9	70.8	67.7	64.5	64.5	68.3	66.3	66.3	71.8
560	88.1	67.7	66.5	65.4	65.9	68.1	65.0	65.7	70.8
600	84.8	66.3	67.0	63.0	61.6	67.2	65.5	66.1	69.6
640	86.5	63.7	65.6	61.9	62.6	66.5	66.7	66.2	71.2
680	85.5	62.6	60.3	59.8	59.3	63.5	63.1	62.9	65.8
720	92.3	64.0	64.0	59.8	57.6	65.9	62.2	63.7	73.3
760	85.4	62.3	61.9	55.8	58.1	61.6	60.9	62.2	70.8
800	84.9	64.8	64.1	60.4	62.0	65.4	64.3	64.3	67.9
840	85.5	61.7	60.3	59.1	62.3	60.9	60.1	58.8	64.3
880	88.2	65.7	64.0	57.8	61.7	60.4	60.0	60.1	74.8
920	83.4	61.0	60.1	56.9	56.2	61.1	56.2	58.0	61.3
960	85.4	64.0	62.7	59.1	58.1	63.4	61.3	60.4	75.4

Table A-14. Microphone Response at Engine Harmonics: Flight Test #3 – UCT Minus Muffler Wrap.

Frequency (Hz)	EC14 SPL dBA	AC1 SPL dBA	AC2 SPL dBA	AC3 SPL dBA	AC4 SPL dBA	AC20 SPL dBA	AC21 SPL dBA	AC22 SPL dBA	TC1 SPL dBA
40	74.4	60.9	62.0	61.9	59.9	60.0	58.1	61.0	58.0
80	94.5	73.3	70.4	83.7	85.7	83.8	85.1	82.8	86.6
120	94.0	77.5	77.0	74.1	77.6	72.7	73.6	67.2	75.4
160	100.9	79.3	74.2	78.1	79.0	75.5	77.6	79.2	82.2
200	83.0	77.1	74.3	70.3	69.8	67.7	66.1	67.5	72.6
240	92.0	72.4	72.4	73.9	78.6	77.7	78.1	70.4	76.6
280	85.4	70.2	71.1	74.1	75.3	72.8	69.5	70.7	68.8
320	88.8	75.1	69.0	69.4	77.9	76.0	75.7	77.3	71.4
360	93.9	69.0	69.9	68.2	67.9	70.3	71.6	69.1	74.8
400	95.0	80.6	79.0	70.0	73.8	71.8	76.8	69.3	78.1
440	87.1	71.5	71.5	68.8	70.6	67.5	68.3	68.3	74.8
480	95.1	80.2	80.0	72.4	74.5	75.8	75.2	72.0	77.4
520	100.9	74.7	78.5	68.8	69.7	74.7	77.1	71.5	82.9
560	93.8	78.5	76.2	74.7	73.6	74.7	71.6	76.7	76.4
600	91.3	73.2	74.3	65.7	68.9	75.0	73.3	69.5	74.4
640	91.8	71.9	78.3	69.4	72.5	69.2	72.3	74.6	79.3
680	90.8	69.4	70.2	64.7	64.5	68.7	65.3	64.5	76.2
720	96.0	71.4	71.7	61.6	62.9	65.4	65.5	64.0	75.0
760	93.9	66.9	70.2	60.7	62.5	71.7	65.6	69.3	74.4
800	90.4	71.0	68.8	64.0	61.2	70.0	62.9	64.2	75.7
840	92.8	68.8	73.4	61.4	65.9	60.7	65.1	62.4	71.7
880	88.7	73.3	74.5	63.5	69.3	68.5	64.4	64.7	76.5
920	93.3	68.2	70.8	61.5	62.5	69.3	72.1	63.3	69.2
960	87.0	69.5	66.3	62.1	59.1	65.3	63.6	65.5	76.4

Table A-15. Microphone Response at Engine Harmonics: Flight Test #4 – Baseline.

Frequency (Hz)	EC14 SPL dBA	AC1 SPL dBA	AC2 SPL dBA	AC3 SPL dBA	AC4 SPL dBA	AC20 SPL dBA	AC21 SPL dBA	AC22 SPL dBA	TC1 SPL dBA
40	74.6	60.6	61.6	62.3	60.4	60.3	58.6	61.3	58.7
80	95.1	79.8	77.1	84.1	85.5	82.2	84.2	82.5	85.4
120	93.1	76.8	76.8	75.8	79.1	74.9	75.0	69.5	75.4
160	97.3	79.0	80.2	77.0	78.7	73.3	79.8	75.8	80.1
200	88.6	79.5	73.5	69.7	68.6	67.5	65.8	69.5	73.3
240	89.0	71.1	78.4	71.3	80.2	81.1	77.3	78.1	77.2
280	86.1	71.7	71.1	72.5	69.3	72.6	66.6	67.5	68.6
320	87.7	76.2	71.8	68.4	77.4	75.4	76.1	78.5	71.8
360	94.5	71.9	67.2	68.3	68.7	70.1	68.8	72.0	75.2
400	88.5	82.7	78.6	68.0	72.3	71.7	77.3	70.0	77.3
440	86.6	73.1	69.4	68.8	70.7	68.0	67.5	66.4	74.6
480	97.9	85.2	81.2	70.8	75.6	75.1	75.8	72.9	77.1
520	99.5	81.4	80.3	71.8	71.4	75.3	74.4	73.3	84.0
560	90.8	79.2	81.7	68.9	74.0	70.3	74.8	75.4	76.0
600	91.6	70.3	74.2	66.0	68.8	70.0	71.8	71.5	73.3
640	93.6	73.3	79.4	68.1	71.6	67.4	75.2	72.9	78.5
680	94.5	70.8	68.1	64.7	63.6	68.0	66.6	63.1	75.4
720	98.9	69.1	70.7	61.0	63.5	65.8	66.2	64.4	74.9
760	96.2	67.2	70.7	61.5	62.4	70.6	67.8	71.4	73.5
800	93.6	68.0	68.0	63.9	60.0	65.9	62.6	63.2	74.5
840	89.8	67.7	76.2	60.8	65.0	60.8	65.6	62.5	72.0
880	92.3	74.1	74.2	62.7	68.5	67.3	66.9	64.0	76.2
920	93.5	66.1	70.7	60.0	61.5	66.1	69.3	63.8	68.6
960	89.8	70.0	69.3	62.5	58.1	65.6	63.1	62.8	75.0

Appendix B

Variation of Cabin Tone Levels

Table B-1. Variation of Cabin Tone Levels: Ground Test.

	GTUCT			GTUTC+EPE			GTUTC+WS+F&R		
Frequency (Hz)	SPL dBA Maximum	SPL dBA Minimum	SPL dBA Average	SPL dBA Maximum	SPL dBA Minimum	SPL dBA Average	SPL dBA Maximum	SPL dBA Minimum	SPL dBA Average
40	72.1	69.5	70.9	69.7	68.0	68.6	65.0	62.9	63.9
80	85.7	76.2	82.1	86.0	75.9	82.7	79.1	73.2	77.7
120	85.6	74.8	82.3	81.9	77.2	79.9	87.3	79.1	84.0
160	93.9	76.6	90.9	92.6	79.3	90.0	92.5	83.6	88.5
200	76.7	68.1	73.3	78.2	69.1	74.4	78.8	69.4	74.9
240	84.9	78.2	82.0	87.3	78.3	82.6	83.9	71.4	78.8
280	73.9	67.4	70.9	74.8	67.8	71.4	78.0	69.2	73.3
320	79.3	71.0	75.3	78.2	72.5	75.6	78.0	71.8	75.3
360	69.8	67.3	68.1	70.6	66.6	68.4	73.3	64.9	70.3
400	73.6	67.5	71.6	74.0	67.7	71.6	74.6	68.4	71.6
440	68.0	65.4	66.5	67.9	65.3	66.4	70.2	65.2	67.1
480	74.2	67.5	70.6	71.8	67.5	69.7	72.4	69.0	70.7
520	72.0	64.1	69.3	74.0	64.4	70.0	70.8	64.5	67.4
560	70.8	66.2	68.0	68.1	62.5	66.1	68.1	65.0	66.5
600	72.0	62.6	68.1	66.1	62.4	64.2	67.2	61.6	65.6
640	67.2	63.8	65.2	65.5	62.1	64.4	66.7	61.9	65.1
680	66.2	59.3	62.7	63.8	58.3	61.2	63.5	59.3	61.9
720	69.7	58.7	65.0	64.9	59.3	62.4	65.9	57.6	63.1
760	63.4	56.6	60.6	61.6	56.0	59.2	62.3	55.8	60.9
800	66.5	58.7	62.9	64.8	58.0	61.2	65.4	60.4	63.9
840	63.4	55.7	59.7	60.1	54.7	57.5	62.3	58.8	60.6
880	63.6	57.3	60.7	62.7	56.5	59.9	65.7	57.8	62.1
920	61.5	55.2	58.9	57.8	53.7	56.0	61.1	56.2	59.0
960	63.3	57.2	60.5	61.3	54.7	58.6	64.0	58.1	61.8
OVERALL	95.1	88.0	92.7	93.7	87.8	92.1	93.2	87.6	91.0

Table B-2. In-Flight Repeatability: Under Cowling Treatment.

	UCT1			UTC2		
Frequency (Hz)	SPL dBA Maximum	SPL dBA Minimum	SPL dBA Average	SPL dBA Maximum	SPL dBA Minimum	SPL dBA Average
40	62.9	58.6	61.1	62.6	58.0	60.7
80	85.7	64.3	83.5	84.9	75.1	82.4
120	76.4	66.9	73.0	78.9	70.7	77.1
160	84.0	75.9	80.6	81.9	73.6	80.0
200	75.8	66.7	70.8	76.4	67.2	71.5
240	82.3	72.3	77.9	82.0	70.2	77.5
280	71.2	65.1	68.7	71.6	68.2	70.1
320	76.8	70.1	74.3	77.6	70.0	74.6
360	70.5	66.1	68.5	70.3	66.9	68.2
400	81.6	71.9	77.4	81.4	68.6	76.1
440	71.0	66.8	69.6	68.5	65.8	67.0
480	78.2	69.7	75.5	78.2	69.5	73.9
520	78.5	70.0	75.4	76.2	72.3	74.7
560	81.2	70.7	76.7	75.7	68.3	73.0
600	76.2	67.5	73.4	78.7	66.1	73.2
640	76.2	66.3	71.8	70.5	64.6	68.5
680	70.9	64.1	67.3	67.6	62.4	65.2
720	78.8	63.8	73.7	73.5	62.8	68.9
760	72.9	61.8	69.1	72.2	62.4	68.2
800	70.7	60.3	66.4	72.2	61.7	67.1
840	76.1	63.2	71.2	74.5	62.3	68.7
880	72.8	60.2	68.8	72.2	60.7	67.1
920	71.0	59.4	66.3	69.3	58.8	65.7
960	69.5	59.1	65.6	70.4	60.6	66.1
OVERALL	89.9	87.6	88.8	89.1	87.0	88.0

Table B-3. Effect of Treatments on In-Flight Cabin Microphone Levels.

	Baseline			UCT			UCT-MW		
Frequency (Hz)	SPL dBA Maximum	SPL dBA Minimum	SPL dBA Average	SPL dBA Maximum	SPL dBA Minimum	SPL dBA Average	SPL dBA Maximum	SPL dBA Minimum	SPL dBA Average
40	62.3	58.6	60.8	62.9	58.6	61.1	62.0	58.1	60.7
80	85.5	77.1	82.9	85.7	64.3	83.5	85.7	70.4	83.0
120	79.1	69.5	76.1	76.4	66.9	73.0	77.6	67.2	75.3
160	80.2	73.3	78.2	84.0	75.9	80.6	79.3	74.2	77.9
200	79.5	65.8	73.2	75.8	66.7	70.8	77.1	66.1	72.1
240	81.1	71.1	78.0	82.3	72.3	77.9	78.6	70.4	75.8
280	72.6	66.6	70.7	71.2	65.1	68.7	75.3	69.5	72.4
320	78.5	68.4	75.8	76.8	70.1	74.3	77.9	69.0	75.4
360	72.0	67.2	69.9	70.5	66.1	68.5	71.6	67.9	69.6
400	82.7	68.0	77.1	81.6	71.9	77.4	80.6	69.3	76.3
440	73.1	66.4	69.6	71.0	66.8	69.6	71.5	67.5	69.8
480	85.2	70.8	79.3	78.2	69.7	75.5	80.2	72.0	76.8
520	81.4	71.4	77.1	78.5	70.0	75.4	78.5	68.8	74.8
560	81.7	68.9	76.8	81.2	70.7	76.7	78.5	71.6	75.6
600	74.2	66.0	71.0	76.2	67.5	73.4	75.0	65.7	72.4
640	79.4	67.4	74.3	76.2	66.3	71.8	78.3	69.2	73.7
680	70.8	63.1	67.2	70.9	64.1	67.3	70.2	64.5	67.4
720	70.7	61.0	66.9	78.8	63.8	73.7	71.7	61.6	67.7
760	71.4	61.5	68.7	72.9	61.8	69.1	71.7	60.7	68.1
800	68.0	60.0	65.3	70.7	60.3	66.4	71.0	61.2	67.4
840	76.2	60.8	69.2	76.1	63.2	71.2	73.4	60.7	67.7
880	74.2	62.7	70.2	72.8	60.2	68.8	74.5	63.5	70.2
920	70.7	60.0	66.8	71.0	59.4	66.3	72.1	61.5	68.4
960	70.0	58.1	66.1	69.5	59.1	65.6	69.5	59.1	65.5
OVERALL	91.0	86.8	88.9	89.9	87.6	88.8	89.2	87.0	88.3

Table B-3. (continued) Effect of Treatments on In-Flight Cabin Microphone Levels.

		UCT+IPS			UCT+WS1			UCT+WS2	
Frequency (Hz)	SPL dBA Maximum	SPL dBA Minimum	SPL dBA Average	SPL dBA Maximum	SPL dBA Minimum	SPL dBA Average	SPL dBA Maximum	SPL dBA Minimum	SPL dBA Average
40	63.8	58.9	60.9	62.3	57.6	60.3	62.0	57.4	60.0
80	84.9	74.2	81.9	84.1	71.3	82.3	83.8	77.2	81.6
120	79.1	74.5	76.6	77.6	67.6	75.6	79.8	71.5	77.6
160	82.3	73.2	78.3	80.7	74.4	78.9	81.2	76.3	79.0
200	77.7	67.5	71.9	75.7	66.3	71.2	77.2	65.2	72.0
240	80.9	68.4	77.0	80.1	71.5	76.7	80.8	73.3	77.4
280	73.5	68.8	70.6	75.6	66.3	71.6	72.3	67.4	70.0
320	78.3	72.2	75.1	77.7	73.5	75.4	78.5	71.0	75.3
360	71.1	66.3	68.2	70.9	62.8	68.3	69.8	65.0	67.8
400	82.2	73.4	76.4	77.8	69.2	74.5	75.2	70.0	72.4
440	72.1	67.7	69.0	70.2	66.4	69.1	71.1	65.3	67.8
480	83.7	72.1	78.3	76.3	70.6	74.2	75.8	70.1	73.1
520	74.2	68.1	71.2	76.5	71.7	73.9	72.9	69.6	71.3
560	79.0	70.4	74.7	78.7	71.2	74.2	78.7	71.3	74.1
600	73.8	66.8	71.0	75.9	67.3	71.6	81.1	67.3	74.2
640	77.4	65.7	71.0	73.6	68.2	70.7	76.6	65.4	71.3
680	70.2	63.6	66.2	70.7	63.8	66.9	66.4	62.7	64.5
720	75.6	62.7	69.6	76.5	65.2	71.4	73.4	61.6	68.6
760	70.0	60.5	65.7	73.4	61.4	68.1	72.2	60.3	66.6
800	72.7	61.5	68.1	70.7	63.0	67.7	69.2	61.9	64.7
840	70.2	61.5	68.0	71.0	64.0	67.8	71.2	62.3	66.6
880	72.8	60.4	68.5	75.0	61.7	68.7	70.3	59.9	65.3
920	73.4	60.4	68.6	75.1	65.2	70.0	73.6	58.6	68.1
960	73.4	60.1	67.9	71.0	60.6	66.9	68.2	57.0	64.1
OVERALL	90.4	87.9	88.5	88.4	86.6	87.8	88.7	85.8	87.5

Table B-3. (continued) Effect of Treatments on In-Flight Cabin Microphone Levels.

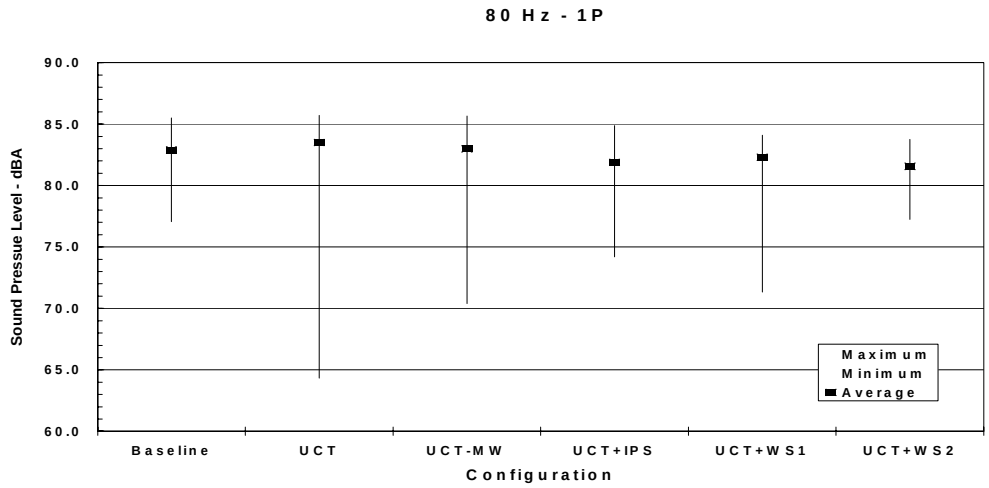
	UTC+FW1			UTC+FW1+RW1			UTC+FW2+RW1		
Frequency (Hz)	**SPL dBA Maximum**	**SPL dBA Minimum**	**SPL dBA Average**	**SPL dBA Maximum**	**SPL dBA Minimum**	**SPL dBA Average**	**SPL dBA Maximum**	**SPL dBA Minimum**	**SPL dBA Average**
40	60.0	54.9	57.6	60.4	55.6	58.0	56.2	51.5	53.6
80	85.0	74.2	82.6	84.8	74.7	82.6	84.3	74.9	82.1
120	80.0	71.9	77.8	78.3	71.0	76.6	78.9	72.0	77.1
160	80.8	74.7	78.8	81.6	75.1	79.4	82.3	72.5	80.1
200	77.3	66.7	71.9	76.1	67.0	71.4	77.1	66.5	71.8
240	81.2	70.3	78.1	81.7	71.5	77.9	82.2	69.7	78.0
280	73.9	67.6	70.8	73.2	66.0	69.9	73.3	67.9	70.1
320	77.1	69.2	74.1	76.8	68.3	74.1	77.5	67.6	74.3
360	71.0	67.2	68.7	70.1	66.9	68.6	70.1	66.5	68.2
400	81.0	71.6	76.3	80.1	70.4	75.6	81.5	71.1	76.3
440	69.5	65.7	68.2	69.7	65.7	68.1	69.6	64.4	68.0
480	80.6	72.4	75.8	80.6	70.6	75.6	81.2	71.5	75.9
520	78.7	69.6	75.1	78.7	72.4	75.6	78.7	72.0	76.0
560	78.1	69.6	74.3	77.6	70.0	73.8	79.9	69.0	74.7
600	76.8	65.6	72.6	77.1	68.1	72.3	80.0	66.4	74.1
640	72.6	67.0	71.5	72.2	67.5	70.6	72.2	67.4	70.3
680	69.2	63.3	67.0	68.8	63.5	66.2	69.8	62.5	66.0
720	77.6	63.0	72.8	75.7	61.8	71.4	77.7	62.8	72.4
760	74.7	62.5	69.7	73.6	63.1	69.5	76.2	63.8	71.8
800	71.8	62.7	67.3	73.0	61.2	67.4	71.7	62.7	67.4
840	76.0	65.6	71.8	74.7	65.1	70.4	76.1	67.8	72.0
880	74.1	62.2	69.5	72.8	62.2	68.5	73.1	61.7	68.6
920	71.7	61.2	68.3	69.9	61.5	67.2	72.8	62.6	69.4
960	70.9	58.9	65.7	70.4	59.9	66.5	70.7	58.8	66.8
OVERALL	**89.6**	**87.2**	**88.4**	**89.1**	**86.9**	**88.2**	**89.8**	**87.2**	**88.5**

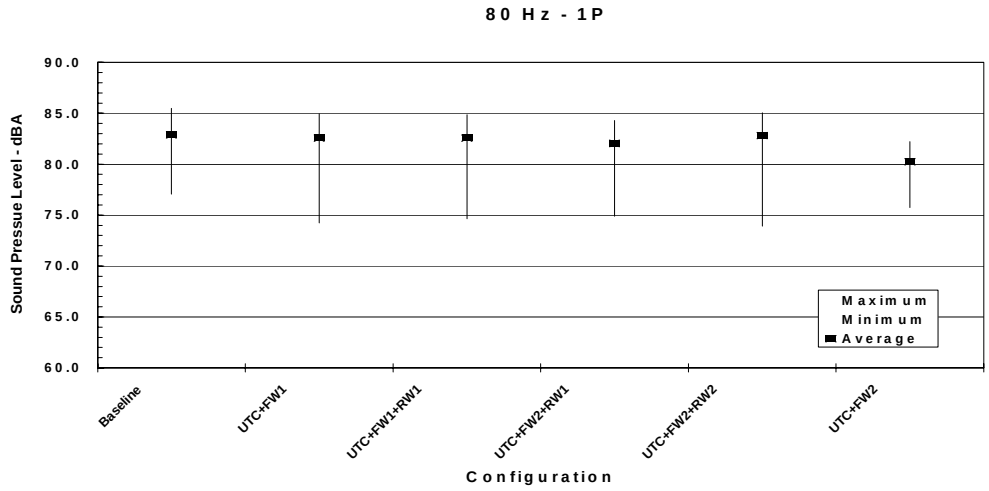
Table B-3. (continued) Effect of Treatments on In-Flight Cabin Microphone Levels.

	Baseline			UTC+FW2+RW2			UCT+FW2		
Frequency (Hz)	SPL dBA Maximum	SPL dBA Minimum	SPL dBA Average	SPL dBA Maximum	SPL dBA Minimum	SPL dBA Average	SPL dBA Maximum	SPL dBA Minimum	SPL dBA Average
40	62.3	58.6	60.8	57.1	52.5	54.5	56.3	51.3	53.5
80	85.5	77.1	82.9	85.0	73.9	82.8	82.2	75.7	80.2
120	79.1	69.5	76.1	79.2	71.6	77.3	78.9	70.3	76.2
160	80.2	73.3	78.2	81.3	73.3	79.6	84.5	71.6	82.9
200	79.5	65.8	73.2	77.5	66.8	72.0	75.2	65.4	70.6
240	81.1	71.1	78.0	82.1	71.8	78.1	80.1	74.1	77.0
280	72.6	66.6	70.7	73.4	67.3	70.3	71.5	66.4	70.1
320	78.5	68.4	75.8	78.7	65.9	74.3	77.2	72.6	75.2
360	72.0	67.2	69.9	70.3	66.4	68.3	71.4	65.8	68.8
400	82.7	68.0	77.1	81.9	71.1	77.1	79.6	68.5	75.5
440	73.1	66.4	69.6	68.7	65.3	67.3	68.7	65.0	66.6
480	85.2	70.8	79.3	81.4	69.1	76.2	77.7	69.9	74.3
520	81.4	71.4	77.1	79.7	70.3	76.0	79.1	70.1	75.7
560	81.7	68.9	76.8	78.6	68.7	74.4	78.2	67.1	73.5
600	74.2	66.0	71.0	75.4	65.6	71.6	78.7	65.7	73.4
640	79.4	67.4	74.3	72.1	66.3	69.8	71.4	66.3	68.5
680	70.8	63.1	67.2	69.2	62.5	65.9	67.6	61.7	64.9
720	70.7	61.0	66.9	76.1	62.6	71.2	72.6	62.4	68.1
760	71.4	61.5	68.7	75.6	62.3	69.7	73.0	62.5	68.6
800	68.0	60.0	65.3	72.7	61.8	67.2	71.1	60.2	66.6
840	76.2	60.8	69.2	73.5	64.3	69.5	71.8	63.9	68.3
880	74.2	62.7	70.2	73.1	61.3	67.1	75.0	62.6	69.6
920	70.7	60.0	66.8	69.2	61.9	66.7	70.2	59.7	66.2
960	70.0	58.1	66.1	68.9	58.0	65.7	70.0	57.4	66.1
OVERALL	91.0	86.8	88.9	89.9	87.1	88.5	89.3	86.6	88.2

Appendix C

Selected Cabin Tone Level Variations with Treatment Configuration





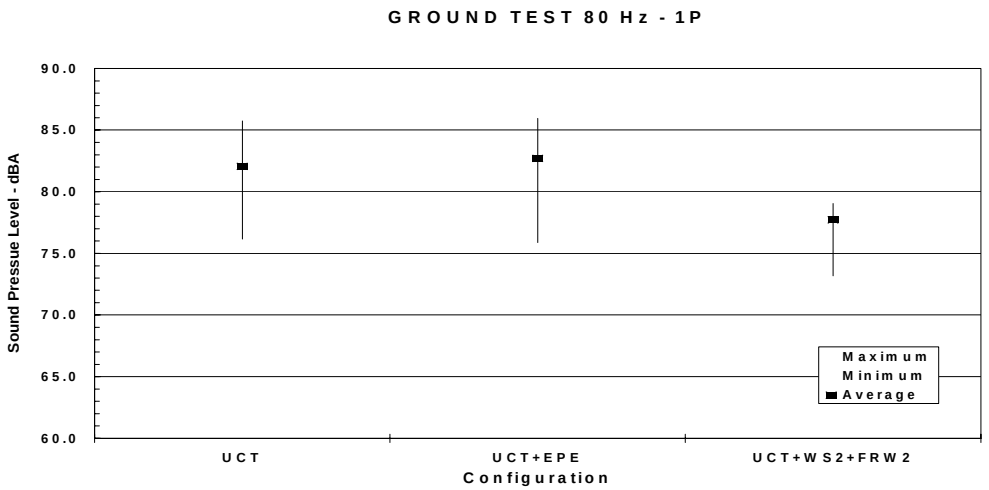


Figure C-1. Effect of Treatment Configuration on Cabin 80 Hz – 1P Tone Level.

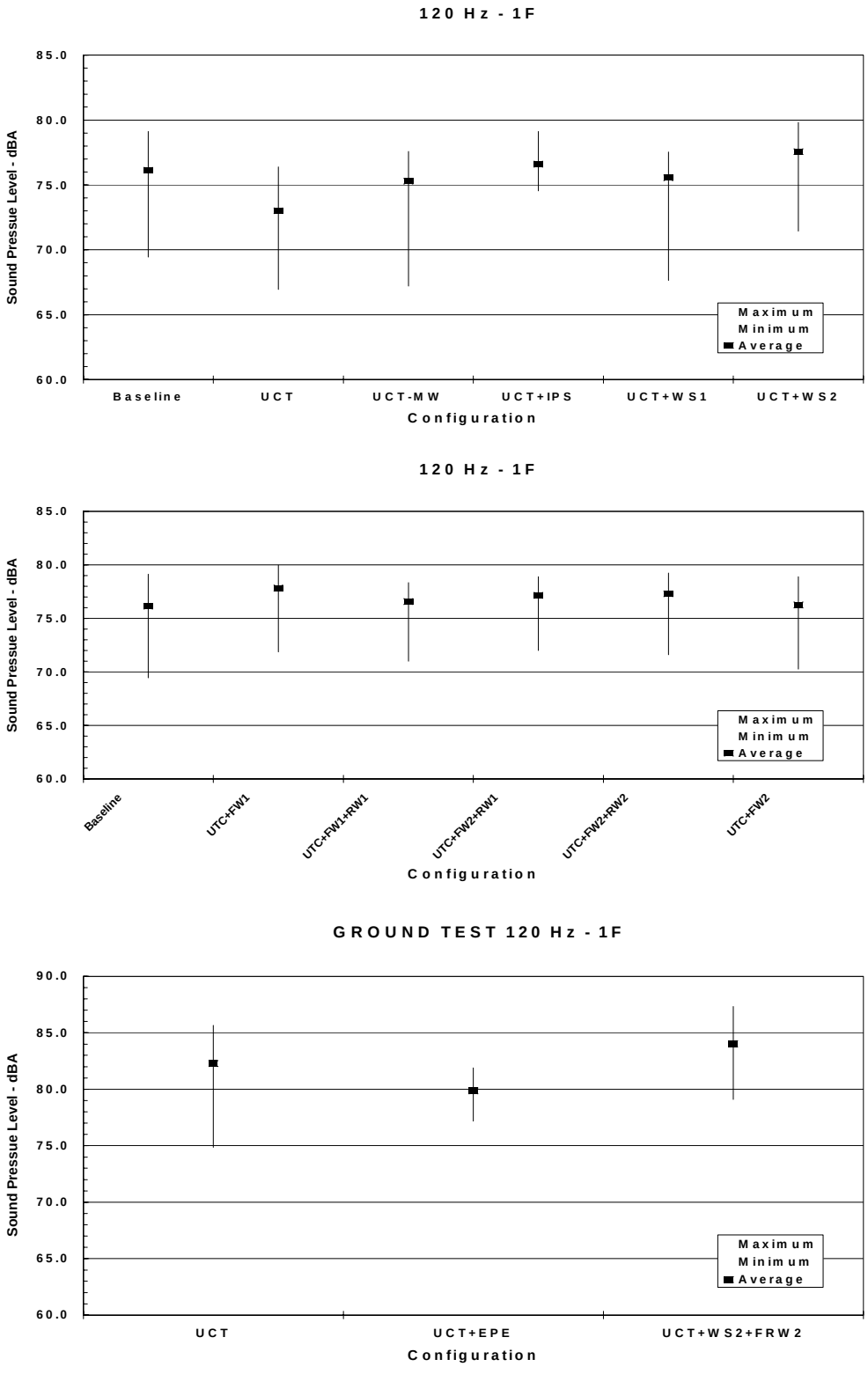


Figure C-2. Effect of Treatment Configuration on Cabin 120 Hz – 1F Tone Level.

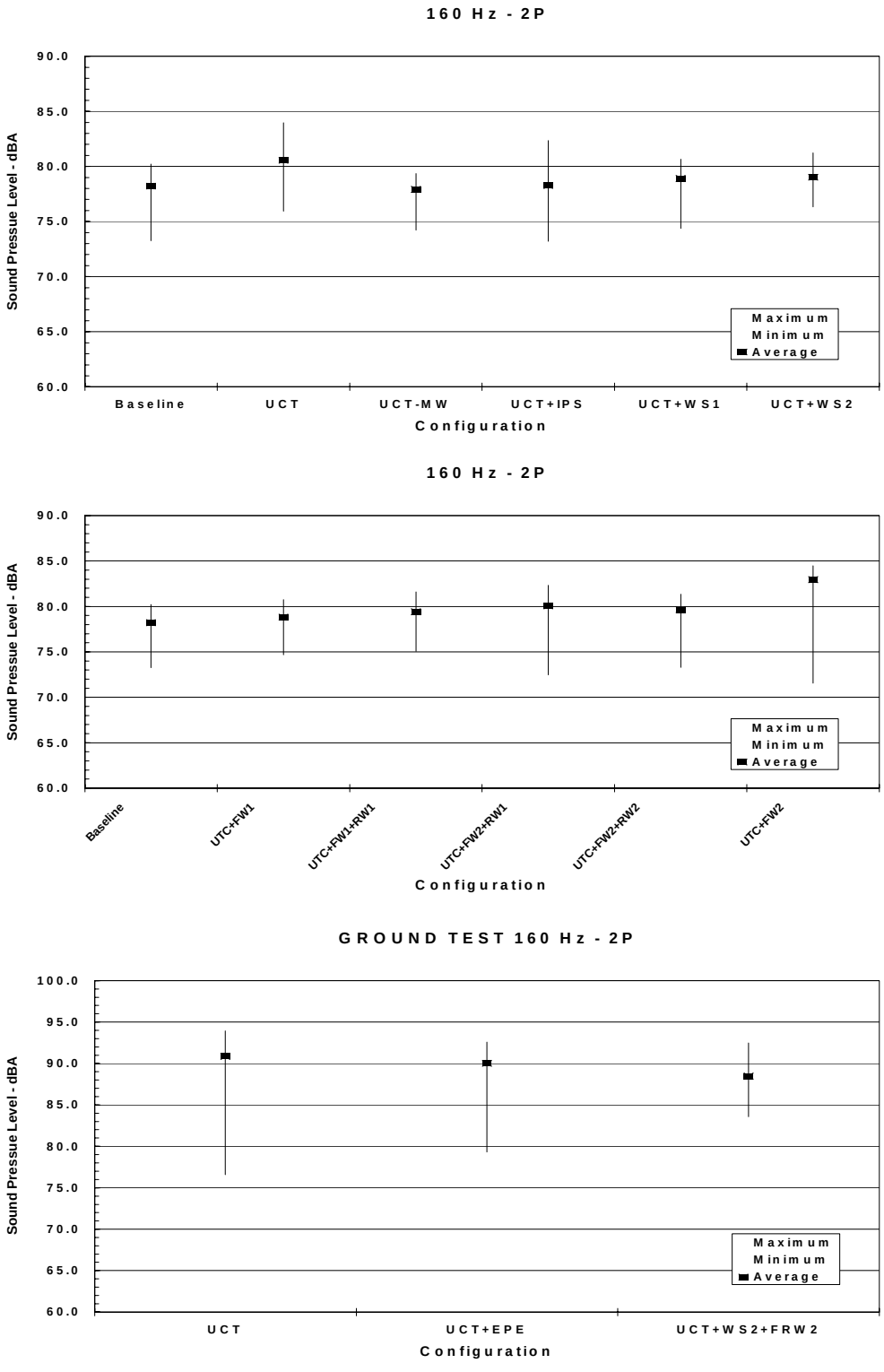
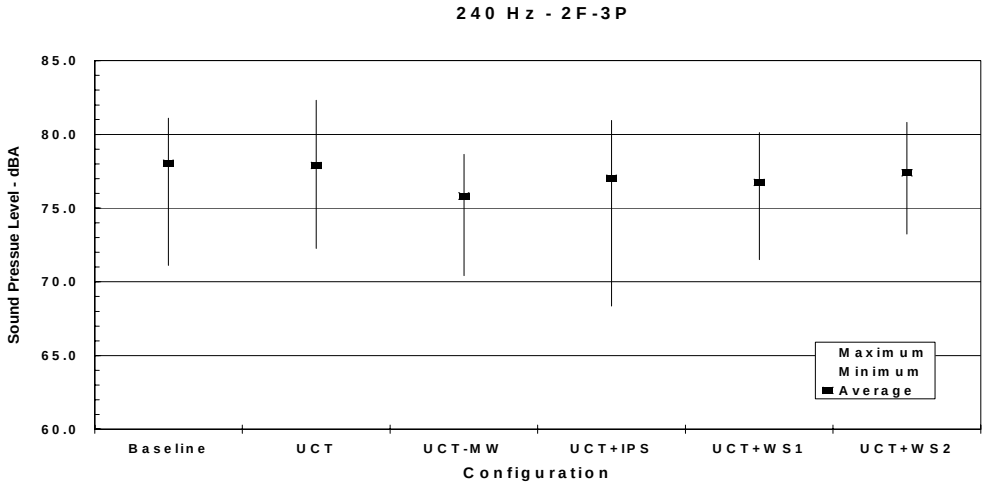
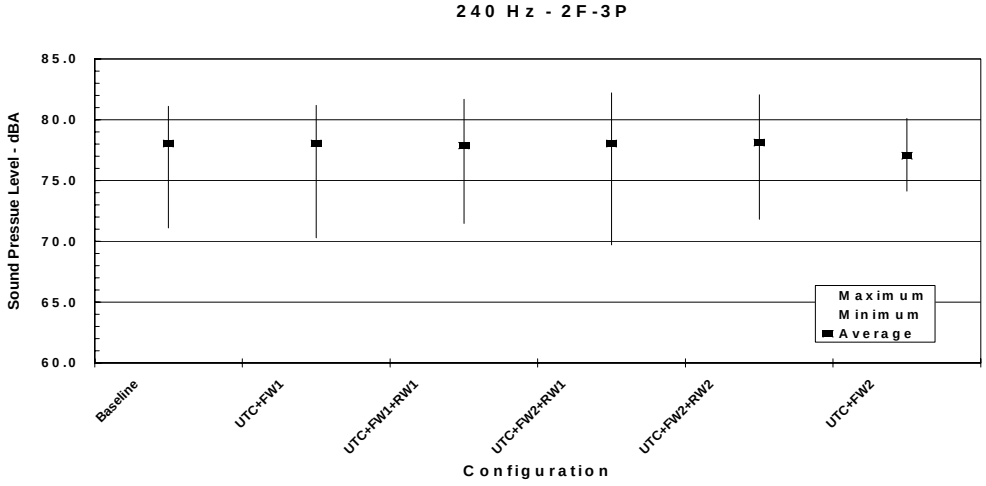


Figure C-3. Effect of Treatment Configuration on Cabin 160 Hz – 2P Tone Level.





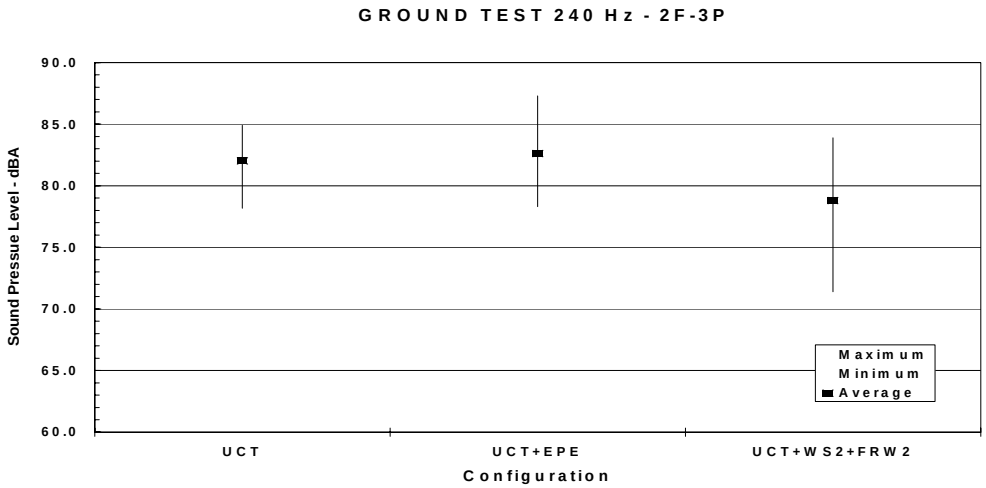


Figure C-4. Effect of Treatment Configuration on Cabin 240 Hz – 2F-3P Tone Level.

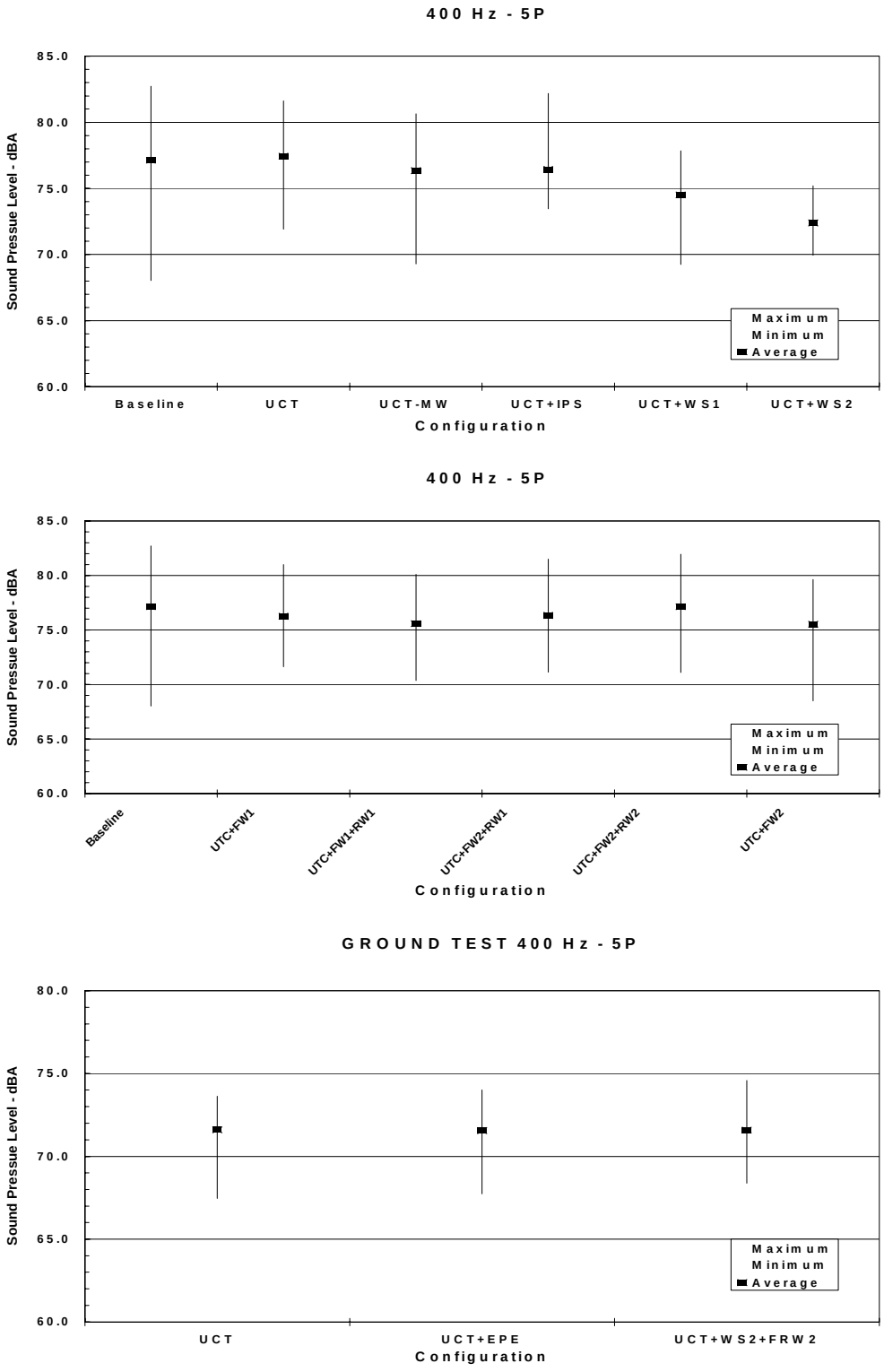


Figure C-5. Effect of Treatment Configuration on Cabin 400 Hz – 5P Tone Level.

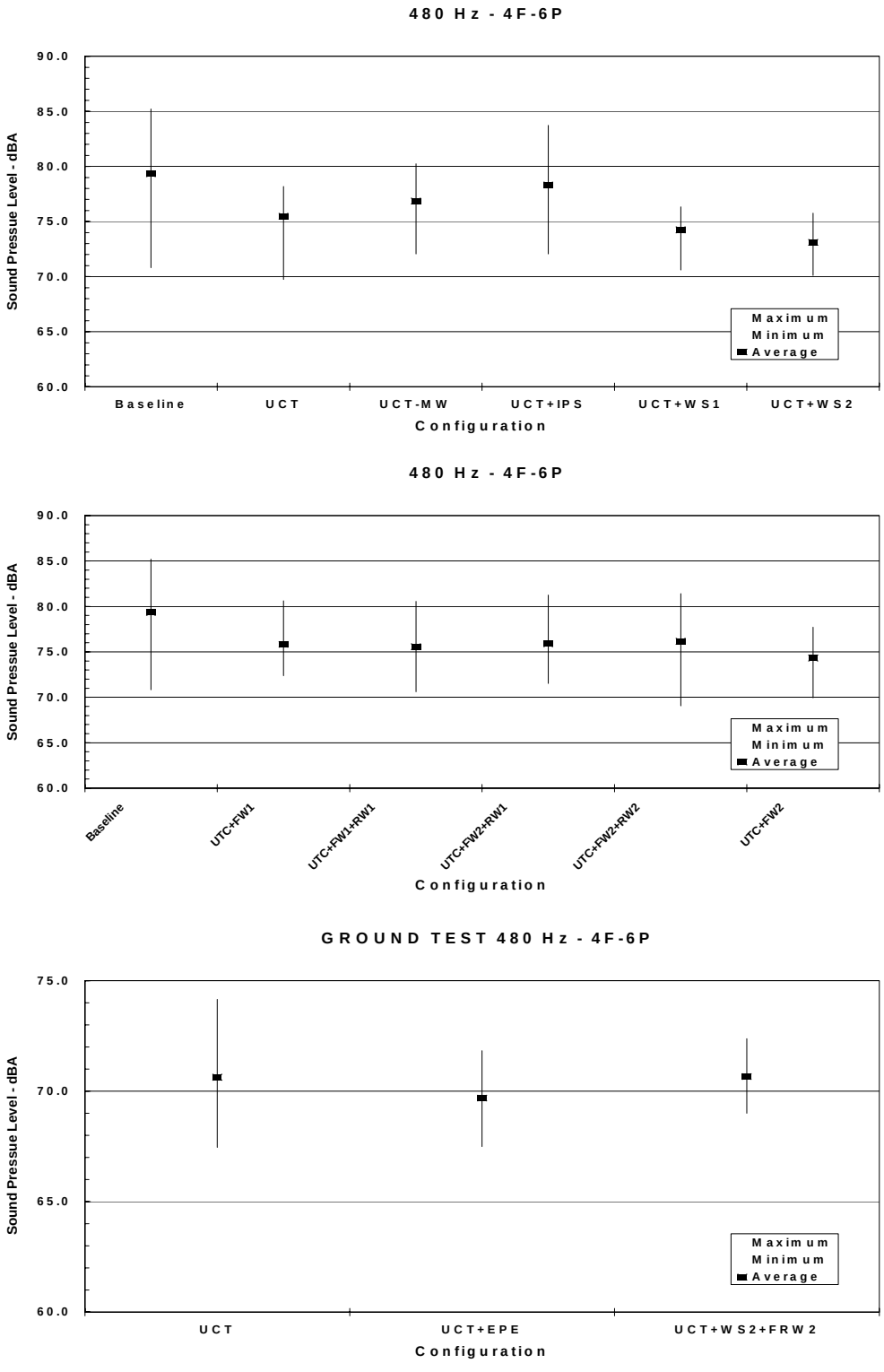


Figure C-6. Effect of Treatment Configuration on Cabin 480 Hz – 4F-6P Tone Level.

Appendix D

Distribution of Sound Pressure Levels Within the Cabin

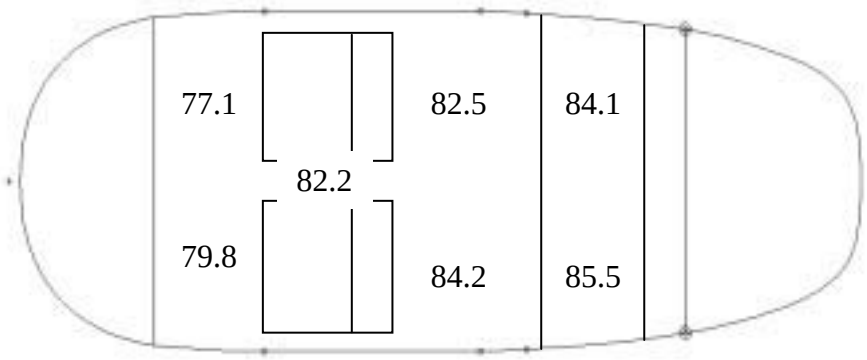


Figure D-1. Baseline: Distribution of SPLs at 80 Hz – 1P.

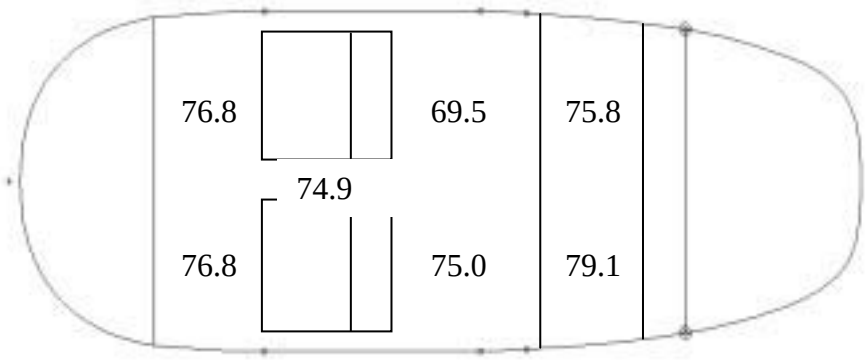


Figure D-2. Baseline: Distribution of SPLs at 120 Hz- 1F.

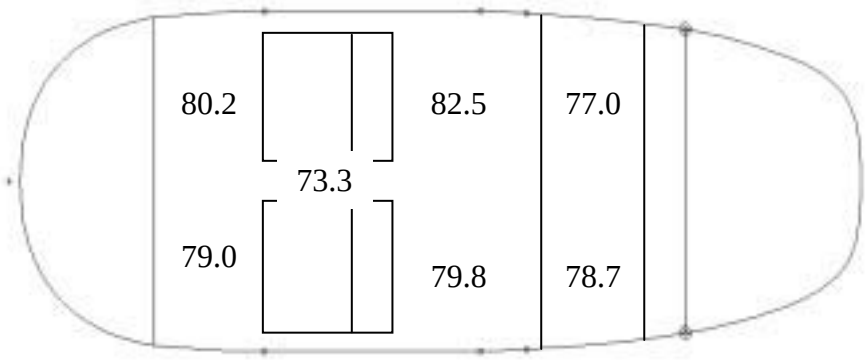


Figure D-3. Baseline: Distribution of SPLs at 160 Hz- 2P.

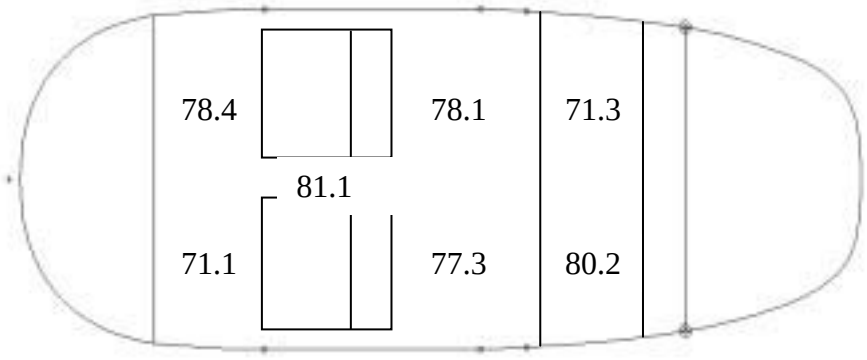


Figure D-4. Baseline: Distribution of SPLs at 240 Hz- 2F-3P.

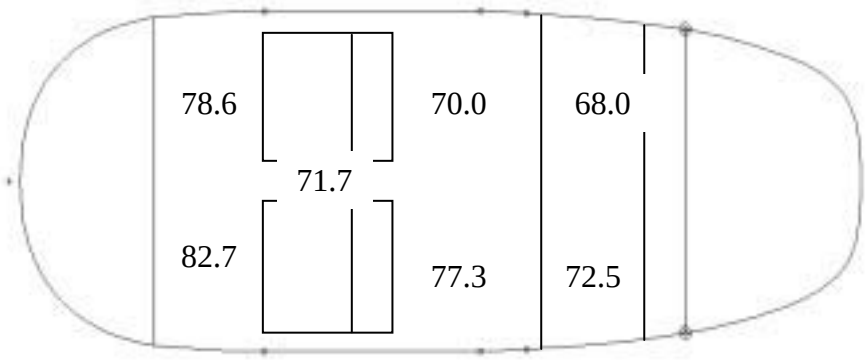


Figure D-5. Baseline: Distribution of SPLs at 400 Hz- 5P.

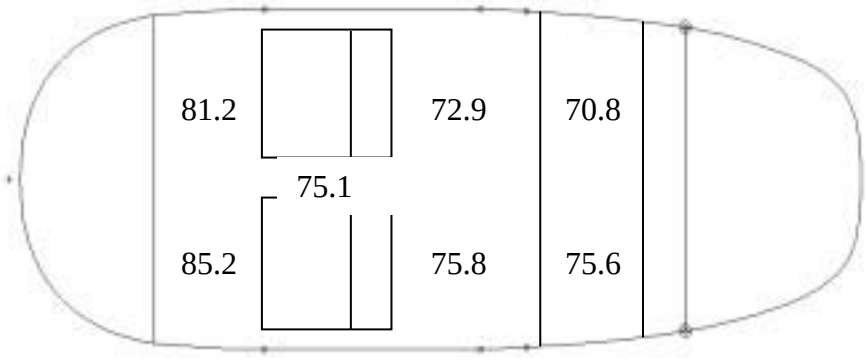


Figure D-6. Baseline: Distribution of SPLs at 480 Hz- 4F-6P.

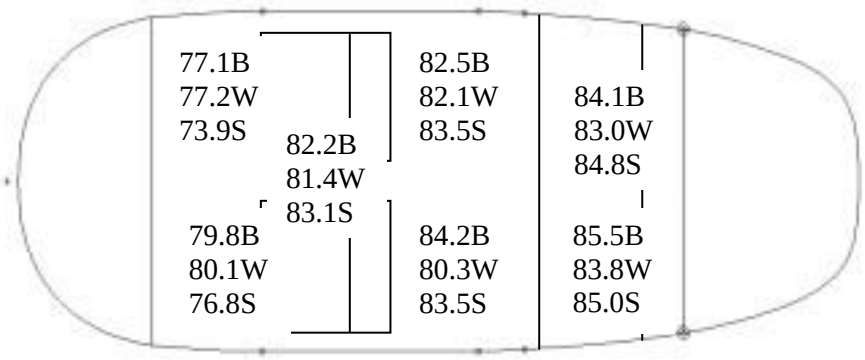


Figure D-7. Effect of Window Treatment on 80 Hz – 1P Tones: B-Baseline, W-Windshield, S-Side Windows.

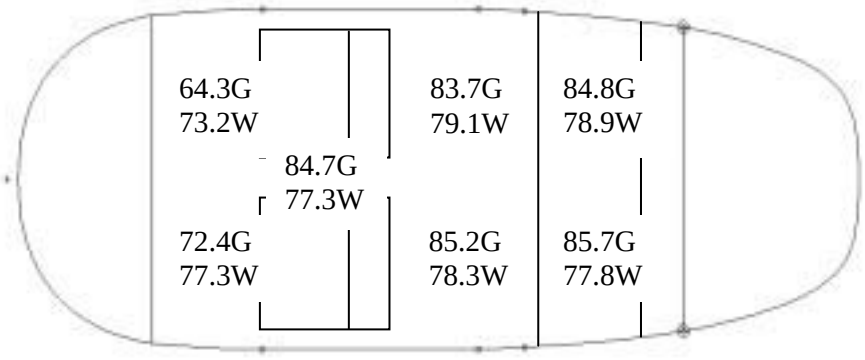


Figure D-8. Ground Test: Effect of Window Treatment on 80 Hz – 1P Tones: G-UCT Only, W-Windshield + Side Windows.

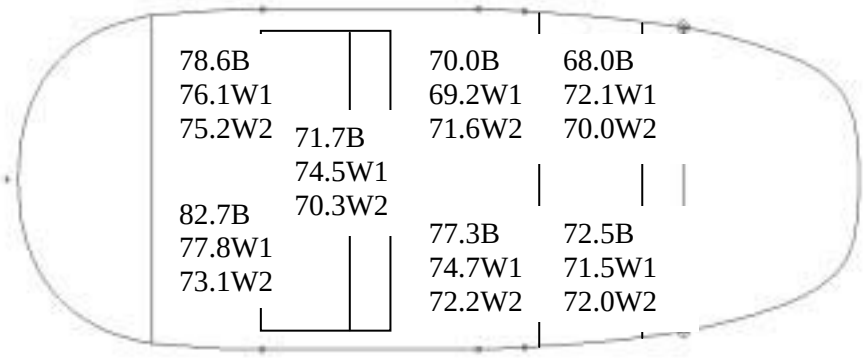


Figure D-9. Effect of Windshield Treatment on 400 Hz – 5P Tones: B-Baseline, W1-Level 1, W2-Level 2.

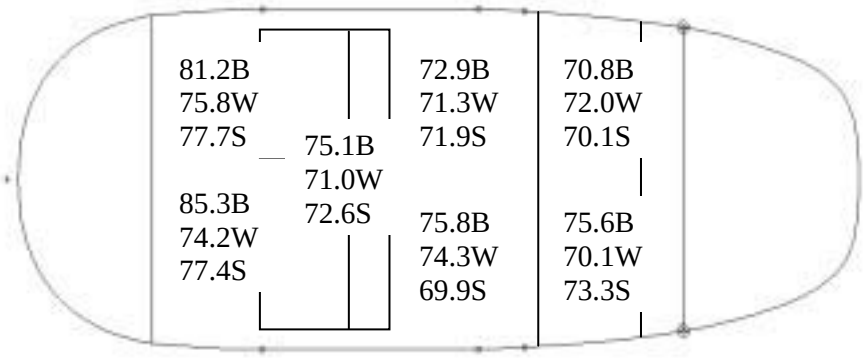


Figure D-10. Effect of Window Treatment on 480 Hz – 4F-6P Tones: B-Baseline, W-Windshield, S-Fwd Side Windows.

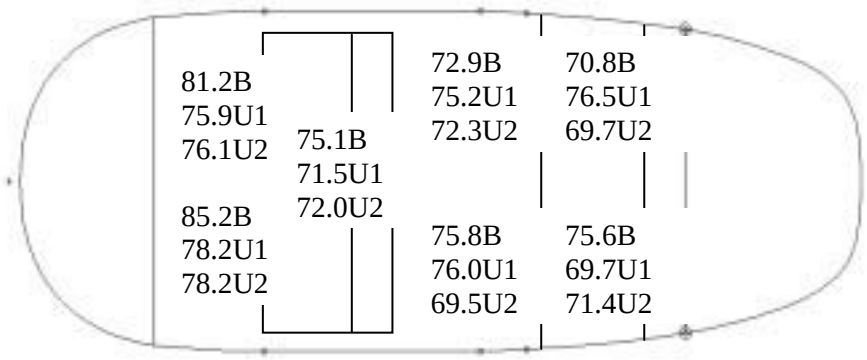


Figure D-11. Effect of Under Cowling Treatment on 480 Hz – 4F-6P Tones: B-Baseline, U1-Run#1, U2-Run#2.

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13. ABSTRACT *(Maximum 200 words)*

The technical approach made use of the Cessna Model 182E aircraft used in the previous effort as a test bed for noise control application. The present phase of the project reports on flight test results during application of various passive noise treatments in an attempt to verify the noise sources and paths for the aircraft. The data presented establishes the level of interior noise control that can be expected for various passive noise control applications within the aircraft cabin. Subsequent testing will address specific testing to demonstrate the technology available to meet a specified level of noise control by application of passive and/or active noise control technology.

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