Evaluation of Aircrew Noise Exposure Levels on a Canadian CH-147F Chinook Helicopter

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ABSTRACT

The cabin and cockpit noise levels of a Royal Canadian Air Force CH-147F Chinook medium to heavy lift utility helicopter were evaluated in this study. The sound pressure levels were measured at nine aircrew locations through 43 unique and representative flight and ground conditions in accordance with the ISO 5129:2001 standard. Additionally, the performance of a combination of currently in service helmets and headsets were evaluated in accordance with the ANSI Standard S12.42. The hearing protection performance results were used in combination with the measured sound pressure levels to evaluate the performance of the hearing protection in the context of the CH-147F noise environment. Results showed that the David Clark headsets equipped with active noise reduction provided the most superior hearing protection. The maximum exposure limit duration was calculated for each microphone location, hearing protector performance and flight condition combination. It was found that the David Clark headsets provided sufficient protection for an unlimited duration of exposure for an individual with a properly fitted headset. It was also found that improperly fitted hearing protection could result in an increased risk of hearing damage after merely 18 seconds.

INTRODUCTION

The Royal Canadian Air Force (RCAF) CH-147F Chinook medium to heavy lift utility rotorcraft provides the Canadian Forces with the unique capability of vertical take-off, landing, hovering and sling loading. The primary duties of the CH-147F include tactical transport of equipment and personnel during domestic or deployed operations; the CH-147F serves a vital role in search and rescue and other emergency roles.

During typical operations of the CH-147F, aircrew are exposed to high Sound Pressure Levels (SPL), which may lead to communication degradation, discomfort and hearing damage, especially in the case of prolonged exposure durations as discussed in multiple studies such as those completed by Fitzpatrick (Ref 1) and Marshall (Ref 2).

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The low frequency SPL of the CH-147F are primarily dominated by tones excited by the structural and aerodynamic acoustic noise occurring at the N/rev harmonics of the two 3-bladed rotors. In addition, high frequency noise produced by the engines, transmission, hydraulics and other systems is also present.

This article presents the combined results of two independent sets of measurements that determine the noise exposure levels of the aircrew. First, the laboratory evaluation of the hearing protection performance of various helmets and headsets currently in use with the RCAF are presented. Secondly, an overview of the experimental set-up, measurement and analysis of the noise assessment of the CH-147F performed on December 9th, 2014. The assessment of the CH-147F was performed at Petawawa, Ontario with the support of the 450 THS squadron. SPL were simultaneously measured at nine cabin and cockpit locations throughout 43 representative flight and ground conditions. These two sets of measurements are then used in combination to evaluate the performance of the hearing protectors specifically in the context of the CH-147F noise environment.

CHARACTERIZATION OF HEARING PROTECTORS

The Aeroacoustics and Structural Dynamics group of the National Research Council Canada (NRCC) Flight Research Laboratory has evaluated the Hearing Protector (HP) performance of a selection of headsets and helmets currently in use with RCAF.

Measurement Method

It has been shown that the selection of an appropriate HP is in part, dependent on the noise spectrum of the aircraft; it becomes necessary to evaluate the Insertion Loss (IL) of the HP across a range of frequencies in contrast to a single number noise rating.

The Hearing Protection Evaluation Facility at NRCC includes a reverberant chamber and a G.R.A.S. 45 CB acoustic fixture that meets the requirements outlined in ANSI Standard S12.42, titled "Methods for the Measurement of Insertion Loss of Hearing Protection Devices in Continuous or Impulsive Noise Using Microphone-in-Real-Ear or Acoustic Test Fixture Procedures" (Ref 3). The small reverberant acoustic chamber at NRCC has a volume of $65m^3$ and was used to generate homogeneous white noise at 118 dB for the hearing protector characterization. In-house developed software controls the SPL in third octave bands. As per ANSI S12.42, the 100 Hz to 10 kHz inclusive 3^{rd} octave bands are controlled within a tolerance of ±3 dB while all other frequencies are heavily attenuated.

The G.R.A.S 45 CB acoustic fixture is shown in Figure 1 fitted with a Gentex HGU-56P-CF helmet. This fixture contains appropriately sized, flesh simulated ear canals; an internal temperature of 37 ± 2°C; and flexible auricles and circumaural bases of sufficient diameter to support in-ear, over-ear and circumaural HP.

Figure 1: G.R.A.S. 45 CB Acoustic Fixture

Results

The IL of 3 flight helmets and 6 headsets, namely, the Gentex HGU-56P-CF, MK10R and SPH 5-CF helmets and the David Clark 40600G-15, 40600G-20, 40699G-01, 40752G-01 and 40411G-19 headsets, are displayed in Figure 2 through Figure 4. Note that four of the five David Clark headsets were equipped with Active Noise Reduction (ANR) capability. These four headsets were evaluated without the ANR to determine their "passive" hearing protection performance as well as being evaluated with the ANR activated to determine their "active" hearing protection performance. Each data point represents the measured averaged insertion loss in each 3^{rd} octave band of interest.

As seen in Figure 2, the general trend for these helmets is a higher IL (superior hearing protection) at the high frequency bands. The lower frequency bands exhibited significantly reduced IL. Specifically the HGU-56P-CF, currently in use onboard the Canadian CH-147F Chinook helicopters, exhibited a minimum insertion loss of 9.3 dB within the 250 Hz 3^{rd} octave band and a maximum insertion loss of 50.7 dB within the 5 kHz 3^{rd} octave band.

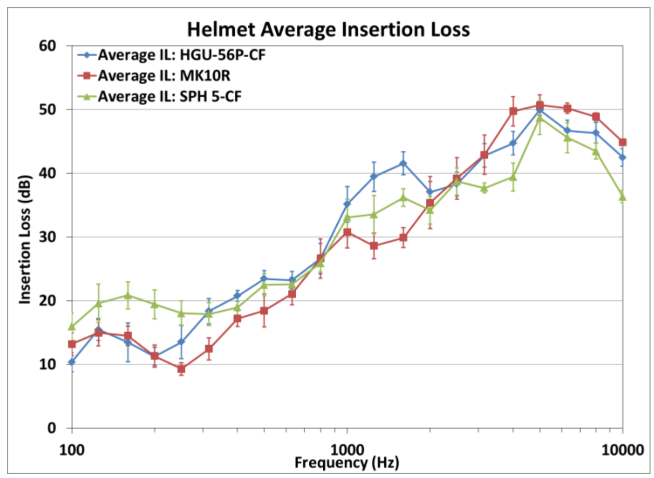

Figure 2: Gentex Helmet Average Insertion Loss

Figure 3 presents the HP performance of five passive models of David Clark headsets currently in use by the RCAF. Similar to the helmets, the headsets exhibit greater IL at higher frequencies.

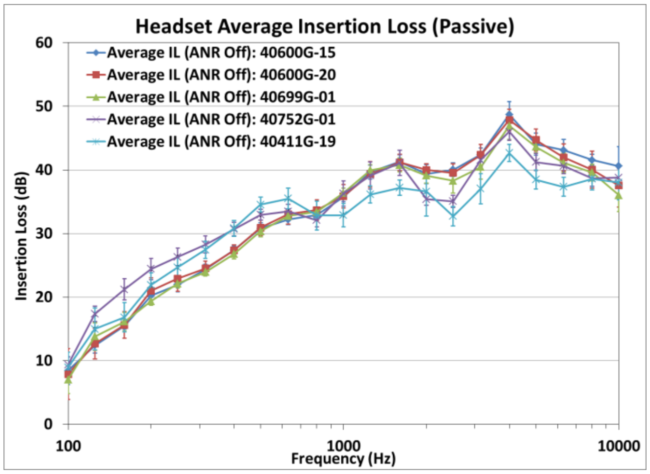

Figure 3: David Clark Headset Average Insertion Loss (without Active Noise Control)

Figure 4 presents the HP performance of the four models of David Clark headsets that were integrated with ANR functionality, currently in use by the RCAF. The active noise control features provide significant improvement in noise reduction for the noise energy below the 500 Hz 3rd octave bands. This is a significant frequency range as it covers the critical low frequency bands characteristic of rotorcraft noise, as is shown in the following section.

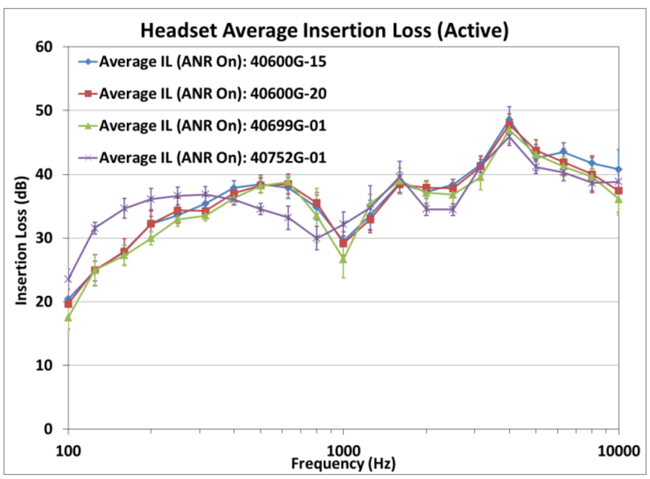

Figure 4: David Clark Headset Average Insertion Loss (with Active Noise Control)

CH-147F FLIGHT TEST

Measurement Method

On December 9th, 2014, with the support of the RCAF 450 THS squadron at Petawawa Ontario, a CH-147F Chinook helicopter was outfitted with an acoustic measurement system. This system consisted of nine PCB 378B02 microphones, a Teletronics MSSR data acquisition system and a custom built power and equipment integration unit.

The aircrew noise exposure evaluation measurements were performed in accordance with ISO 5129:2001 (Ref 4) and MIL-STD-1294A (Ref 5). The two standards require measurements in representative configurations such as doors and windows open / closed and acoustic treatments in place / removed. The standards MIL-1294 and ISO 5129 include steady level flight, hover and ground settings as the primary measurement conditions. However, the CH-147F noise environment is sensitive to alterations in the aircraft orientation, proximity to the ground, engine power settings, aircraft velocity etc. Therefore, the measurement method used included a thorough list of flight conditions including maneuvers and different engine settings to adequately represent the standard operation of the RCAF CH-147F. The list of measured flight conditions has been included in Table 1 and Table 2.

The aircraft operation conditions can be categorized into three groups:

1. **Ground Interaction** flight conditions included take-off, landing and hover;
2. **Closed Door** flight conditions included steady level flight, maneuvers, hover and static sling conditions;
3. **Open Door** flight conditions included steady level flight, maneuvers, hover and static sling conditions.

Table 1: Flight Conditions: Doors Open

Run	Flight Condition	Task Description	Duration (s)
1	Stationary Ground	EPUSHA ON	60
2		Ground Power, Avionics ON	60
4		APU ON, Avionics Running	60
6		APU ON, Engine Levers Idle	60
8b		APU ON, Engine Levers Flight	60
10		APU OFF, Engine Levers Flight	60
11	Hover	Hover 10 ft., doors open, hatch open	60
12		Hover 40 ft., doors open, hatch open	60
13	Sling	Sling 40 ft., doors open, hatch open	60
14		Sling 80 ft., doors open, hatch open	60
35	Level	30 kts	60
36		80 kts	60
37		120 kts	60
38		140 kts	60
39		150 kts	60
40	Maneuver	80 kts, 30 Deg bank	60
41		80 kts, 45 Deg bank	60
42		100 kts, 30 Deg bank	60
43		100 kts, 45 Deg bank	60
44		120 kts, Rate 1 turn	60
45		140 kts, Rate 1 turn,	60
46		70 kts, Descend turn, 60 Deg	60
47		70 kts, Descend turn, 60 Deg, reverse	60

Table 2: Flight Conditions: Doors Closed

Run	Flight Condition	Task Description	Duration (s)
15	Hover	Hover 10 ft., door closed	60
16		Hover 40 ft., door closed	60
17	Sling	Sling 40 ft., door closed, hatch closed	60
18		Sling 80 ft., doors closed, hatch closed	60
19	Level	30 kts	60
20		80 kts	60
21		120 kts	60
22		140 kts	60
23		150 kts (optional)	60
24	Maneuver	80 kts, 30 Deg bank	60
25		80 kts, 45 Deg bank	60
26		100 kts, 30 Deg bank	60
27		100 kts, 45 Deg bank	60
28		120 kts, Rate 1 turn	60
29		140 kts, Rate 1 turn,	60
30		70 kts, Descend turn, 60 Deg	60
31		70 kts, Descend turn, 60 Deg, reverse	60
32	Approach	Normal Approach to Hover	60
33		Normal Approach to Landing (no Hover)	60
34		Roll on Landing	60

Based on the feedback from RCAF CH-147F operators, these conditions were chosen to be representative of standard CH-147F operations during search and rescue, transportation, field resupply and other typical mission operations.

A total of nine ICP PCB 378B02 microphones were used to measure the acoustic environment at nine representative aircrew locations inside the CH-147F cabin. The microphone locations have been graphically depicted in Figure 5. The microphones were mounted with a combination of standing position tripods, seated position mounts and GoPro® gooseneck mounts.

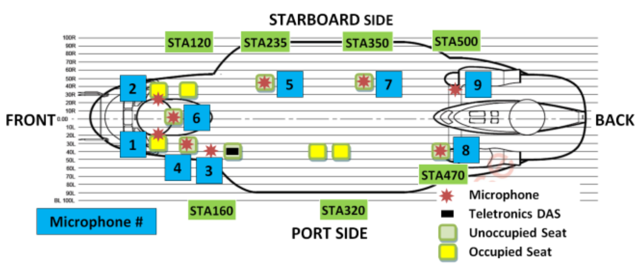

Figure 5: CH-147F Microphone Configuration

As per the ISO 5129 and MIL-1294 standards, the two occupied and seated position microphones (Mics 1 and 2) were located within 0.1 m of the typical ear position. The Mic1 position is shown in Figure 6. This position was within 0.1m of the pilot's helmet on the right side.

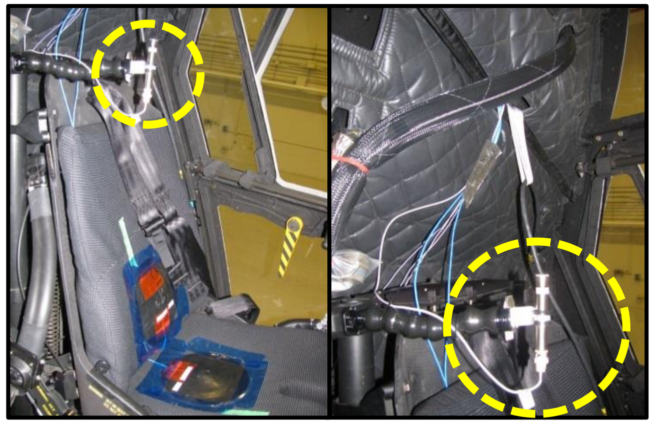

Figure 6: Mic1 Configuration

The two unoccupied and standing position microphones (Mics 3 and 9) were located 1.65 m above the floor with the primary axis of the microphone oriented vertically with the diaphragm facing upwards. The Mic3 position is shown in Figure 7. It should be noted that although the microphone is oriented horizontally in the photo, the microphone was oriented vertically for the measurement. Additionally all the microphones located in the cabin (Mics 3-9) were outfitted with windscreens as the open door flight conditions may introduce air currents throughout the cabin.

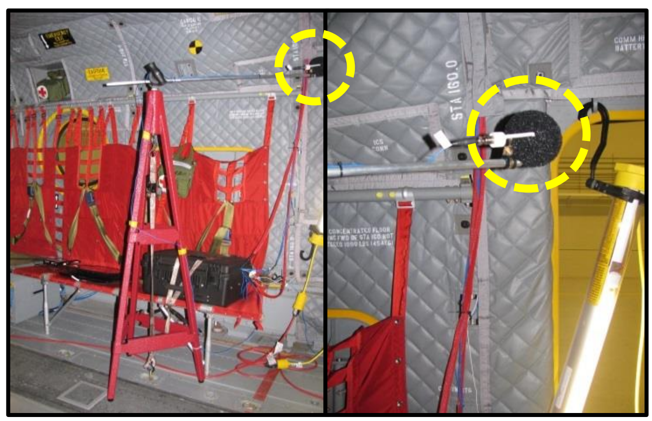

Figure 7: Mic3 Location

The five unoccupied and seated position microphones (Mics 4-8) were located 0.15 m in front of the headrest and 0.8 m above the seat cushion with the primary axis of the microphone oriented vertically with the diaphragm facing upwards. Microphone 4 was placed in a Flight Engineer or Loadmaster seat which features a cushioned seat bottom. Microphones 5, 7 and 8 were placed in cabin "passenger" seats. The passenger seat refers to a rag and tube design with canvas stretched across a metal structure. Microphone 6 was placed on the deployable jump seat of the cockpit. This position was chosen due to its proximity to the auxiliary power unit and cabin cooling fans which produce a significant level of noise.

Figure 8: Mic4 (Left) and Mic5 (Right) Positions

The SPL at the nine cabin crew stations were measured throughout the duration of the 43 representative airborne and ground based measurements. Different methods of analysis were employed to the data in accordance with ISO 5129 (Ref 4) and the Canadian Aviation Occupational Health and Safety Regulations (Ref 6) Additional investigation methods were exploited to analyse and interpret the data.

The averaged Power Spectral Density (PSD) curves were first analyzed to extract narrow band frequency information for each microphone position at each flight condition. The un-weighted and A-weighted 3rd octave band SPL for each microphone position and flight condition were considered in accordance with ISO 5129. The Overall Sound Pressure Levels (OSPL) were calculated and then used to calculate the maximum exposure duration limit per aircrew per 24 hour period based on the environmental noise levels in accordance with the Canadian Aviation Occupational Health and Safety Regulations. A sample of the regulation exposure limits are presented in Table 3.

Table 3: Condensed Canadian Aviation Occupational Health and Safety Regulations Exposure Limits (Ref 6)

A-weighted SPL [dB(A)]	84	90	96	102	108	114
Max Exposure Duration [hours]	16	4	1	0.25	0.064	0.016

The measured insertion loss frequency spectra of the hearing protectors were considered in combination with the A-Weighted 3rd octave band SPLs to calculate the OSPL for hearing protected cases. These calculated OSPL values were used to determine the maximum duration limit of exposure per aircrew per 24 hour period based on the hearing protected environmental noise levels in accordance with the Canadian Occupational Health and Safety Regulations for each aircrew location during each flight segment conditions.

Based on this approach, the maximum duration limits of exposure without a HP could be directly compared against the maximum duration limits of exposure with a HP.

Results

This project's analysis included 43 different flight conditions in combination with 12 various HP solutions for each of the nine measured aircrew locations. However, this article presents the analysis from a single **closed door** flight condition and its corresponding **open door** flight condition. The insertion loss of the various HP solutions will then be applied to the two flight conditions to evaluate their contextual performance.

To provide an overview of the results, Figure 9 presents the OSPL of the nine different aircrew microphone locations for each of the 43 different flight conditions. The abscissa outlines the flight condition Run ID whose corresponding description is found in Table 1 and Table 2. The calculated maximum exposure duration limits for an aircrew without hearing protection are superimposed as horizontal black lines in Figure 9. Of note, the Mic9 located near the rear ramp, in closest proximity to the aircraft engines, consistently recorded the highest noise levels. Some of the flight conditions exhibiting the highest OSPL include Runs 14 and 18, sling conditions; Runs 23 and 39, 150 knots level flight conditions; and Run 45, 140 knots with a rate 1 turn maneuver condition.

The Run ID 29 and Run ID 45 flight conditions represent a rate 1 turn at 140 knots with high noise levels. It is worthwhile evaluating the performance of the various HPs at these conditions as aerodynamic load generated noise and mechanical aircraft noise will be present.

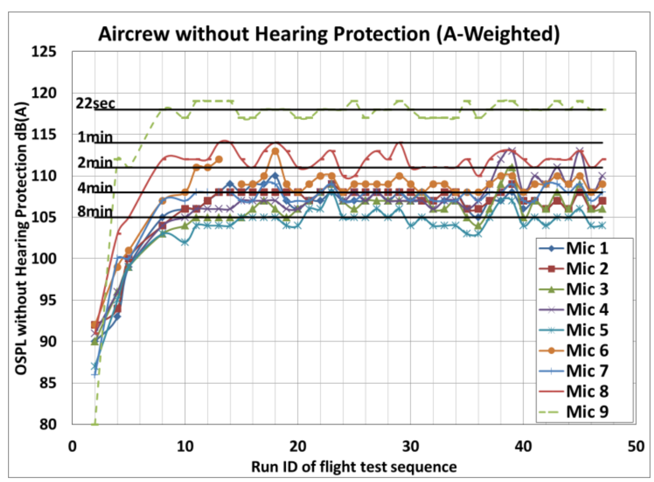

Figure 9: A-Weighted Overall Sound Pressure Level without Hearing Protection

The PSD plot of the **closed door**, 140 knots during a rate 1 turn maneuver flight condition is presented in Figure 10.

This flight condition highlights highly tonal behaviour with the low frequency noise energy dominated by the N/rev harmonics of the tandem rotors. The nominal rotation speed of the rotors is 215 RPM or 3.75 Hz and each rotor has three blades; the combination of the RPM and number of blades leads to a dominant harmonic at 11.25 Hz.

Higher frequency tones above 500 Hz are most likely attributable to the CH-147F hydraulic systems and the aircraft engine transmission. Depending on the cabin or cockpit location, electrical panel, auxiliary power unit and avionics noise may also be present at levels strong enough to influence the OSPL within the cabin.

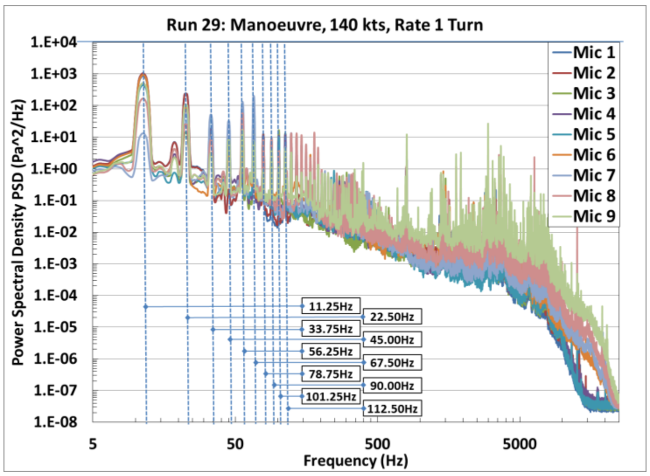

Figure 10: Power Spectral Density Plot of Run 29

The un-weighted 3rd octave band SPL for the **closed door**, 140 knots during a rate 1 turn maneuver were calculated as shown in Figure 11. The OSPLs for all the microphone positions are similar with a spread of 122 to 126 dB. All microphones measured the highest noise energy in the 12.5 Hz 3rd octave band with the exception of Mic7, which was located midway through the cabin near an electrical panel.

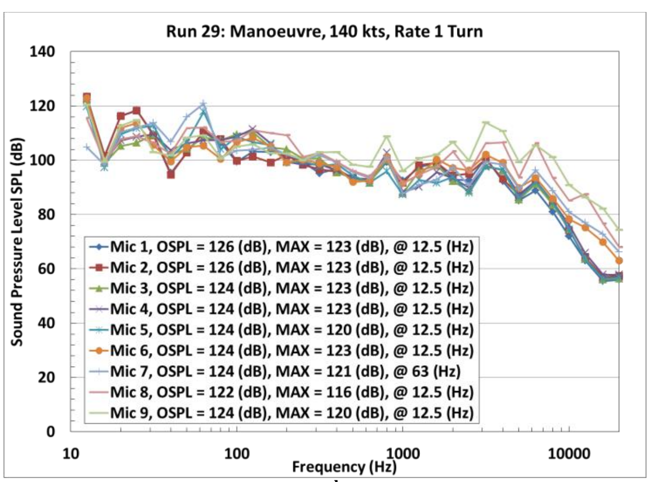

Figure 11: Un-Weighted 3rd Octave Data for Run 29

The A-weighted 3rd octave band SPL for the **closed door**, 140 knots during a rate 1 turn maneuver were calculated as shown in Figure 12. With the applied A-weighting filter, the low frequency noise has been attenuated significantly. Additionally, the spread of the OSPL is larger; the lowest OSPL being 107 dB(A) and the highest being 119 dB(A). Although the A-weighting is equally applied to each microphone position, the degree to which the attenuation affects the OSPL is different. This distinction emphasizes the limitation of evaluating HPs with one-number approaches such as OSPL and Noise Reduction Ratings.

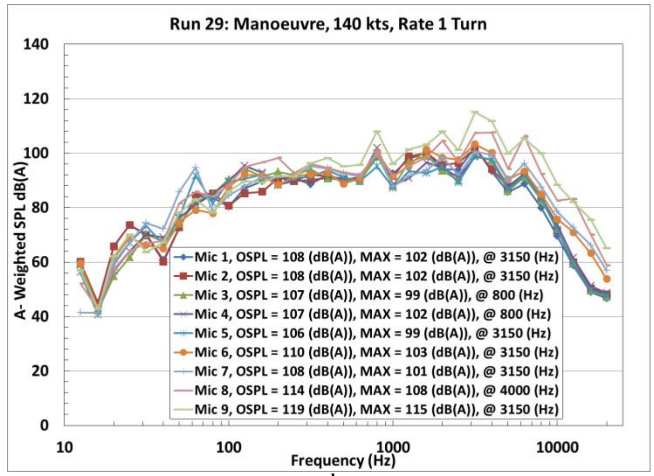

Figure 12: A-Weighted 3rd Octave Data for Run 29

Through a similar process, the A-weighted 3rd octave band SPLs for the **open door** at 140 knots during a rate 1 turn maneuver were calculated as displayed in Figure 13. The spread of OSPL for the nine microphones is 106 to 119 dB(A). It is noteworthy that the Mic9 position exhibited the loudest OSPL for both the **closed door** and **open door** conditions but remained consistent at 119 dB(A). This emphasizes the prevalence of the high frequency engine and mechanical noise that would likely remain consistent between the **open** and **closed door** conditions.

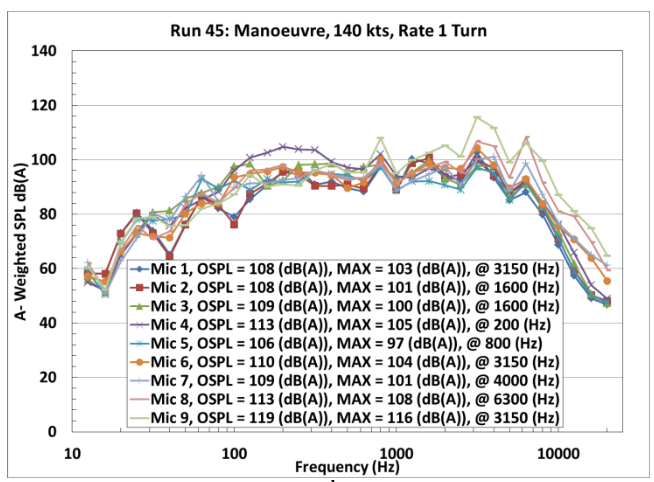

Figure 13: A-Weighted 3rd Octave Data for Run 45

As per the Canadian Aviation Occupational Health and Safety Regulations' exposure limits, an excerpt of which is shown in Table 3, the maximum exposure limit duration for an aircrew without a HP at each Mic location was calculated for each flight condition. The hearing unprotected maximum exposure limits for the nine microphone locations for the **open door** and **closed door**, 140 knots during a rate 1 turn maneuver flight conditions, are displayed in Table 4. It can be seen that the most significant difference between the two runs occurred at the Mic4 location. This microphone was stationed in close proximity to a hatch that was opened for the **open door** flight condition. Additionally, Mic4 was not in the vicinity of the engines, avionics or other mechanical noise sources which likely produced consistent noise levels between the **open door** and **closed door** flight conditions.

The Mic9 location exhibited the shortest exposure limit duration of 18 seconds for aircrew personnel who are not equipped with a HP. In accordance with the Canadian Aviation Occupational Health and Safety Regulations, when an individual meets or exceeds their exposure limit duration, it is recommended for that individual to exit the loud noise environment and to spend the remainder of 24 hours in a quiet environment, below 84 dB(A). Further exposure to the loud noise environment will run the increased risk of hearing damage or other adverse health effects for the individual without hearing protection.

As 18 seconds (Mic9 location) up to 6 minutes (Mic5 location) does not provide a feasible window in which to operate, it is evident that properly fitted hearing protection must be worn at all times. Removing the helmet for adjustment could result in exceeding the exposure limit duration and the subsequently increase the risk of adverse health effects.

Table 4: Exposure Limit Durations for Run 29 and Run 45 for Aircrew without Hearing Protection

Microphone Number	*Run 29 Exposure Limit [H:M:S]*	*Run 45 Exposure Limit [H:M:S]*
1	0:03:50	0:03:50
2	0:03:50	0:03:50
3	0:04:48	0:03:00
4	0:04:48	0:01:12
5	0:06:00	0:06:00
6	0:02:24	0:02:24
7	0:03:50	0:03:00
8	0:00:58	0:01:12
9	0:00:18	0:00:18

HEARING PROTECTION PERFORMANCE WITHIN THE CH-147F CABIN NOISE ENVIRONMENT

Considering the measured hearing protection performance based on IL data and the measured SPL in 3rd octave band format, the exposure limits for aircrew with a properly fitted HP were calculated.

The RCAF predominantly uses the Gentex HGU-56P-CF helmet for all aircrew onboard the CH-147F Chinook helicopter. Figure 14 and Figure 15 present the SPL in 3rd octave bands for aircrew protected with the HGU-56P-CF helmet at each microphone location for the **closed door** and **open door** at 140 knots during a rate 1 turn maneuver flight conditions. These results were obtained by combining the HGU-56P-CF helmet IL data with the SPL data presented in Figure 12 and Figure 13.

As the HGU-56P-CF helmet demonstrates superior performance at attenuating higher frequency noise, the curve of the plots has taken on a low frequency dominated shape. The spread of the OSPL levels range from 84 - 90 dB(A) for the **closed door** at 140 knots during a rate 1 turn maneuver flight condition and 87 - 97 dB(A) for the corresponding **open door** flight condition. The SPL dominant 3rd octave bands are 100, 125, 160 and 200 Hz which primarily contain noise energy located at the N/rev rotor harmonics. The Mic9 location is an exception as it demonstrates the 800 Hz 3rd octave band as containing the highest SPL. This 800 Hz 3rd octave band is not dominated by rotor harmonics but more likely dominated by the CH-147F transmission or hydraulic system noise.

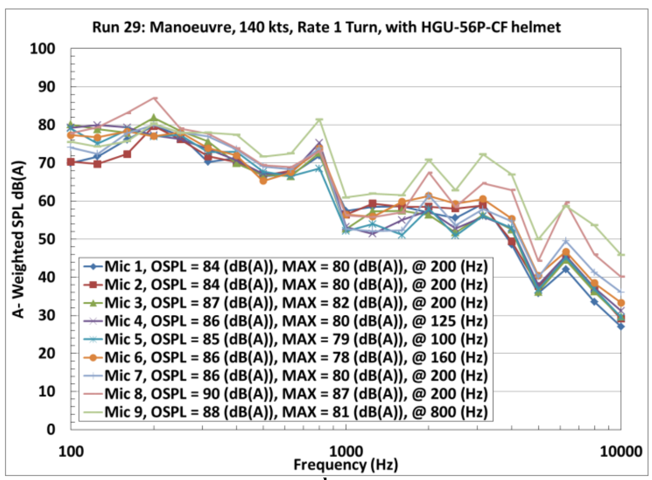

Figure 14: A-Weighted 3rd Octave Data for Aircrew Protected with the HGU-56P-CF Helmet for Run 29

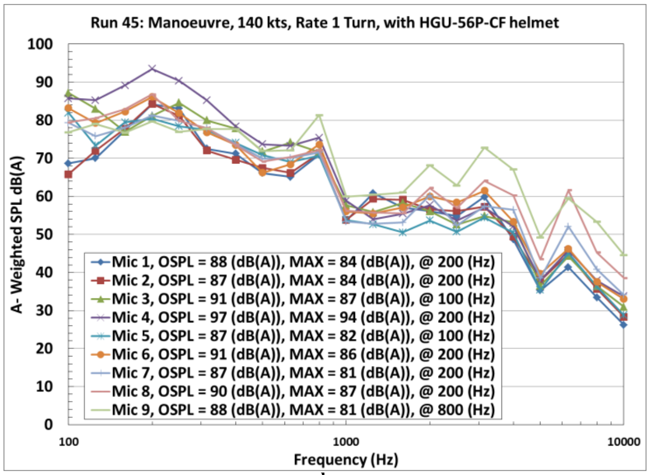

Figure 15: A-Weighted 3rd Octave Data for Aircrew Protected with the HGU-56P-CF Helmet for Run 45

The maximum exposure limit durations for aircrew protected with the HGU-56P-CF helmet for the **closed door** and **open door** at 140 knots during a rate 1 turn maneuver flight conditions at each of the nine microphone locations are presented in Table 5. The Mic4 location results in the shortest exposure limit duration of 48 minutes for the **open door** condition. However, comparing Table 4 and Table 5 demonstrates the importance of a properly fitted HP. The Mic9 position has a maximum exposure limit duration of 6 hours and 24 minutes for aircrew protected with the HGU-56P-CF helmet but a maximum exposure limit duration of 18 seconds for an aircrew without any HP. Therefore, if an individual located at the Mic9 position were to remove their helmet, it is highly unlikely that the individual would be able to complete their mission without exceeding the maximum exposure limit duration.

Table 5: Exposure Limit Durations for Run 29 and Run 45 for Aircrew with Hearing Protection

Microphone Number	*Run 29 Exposure Limit [H:M:S]*	*Run 45 Exposure Limit [H:M:S]*
1	16:00:00	06:24:00
2	16:00:00	08:00:00
3	8:00:00	03:12:00
4	10:00:00	00:48:00
5	13:00:00	08:00:00
6	10:00:00	03:12:00
7	10:00:00	08:00:00
8	4:00:00	04:00:00
9	6:24:00	06:24:00

It was observed that the **open door** and **closed door** flight conditions with the same airspeed, performing the same maneuver exhibit similar trends. Therefore, the remaining assessment of the HP performance will be focused on the effects on the Mic1, Occupied Portside Pilot Right Ear position; Mic4, Unoccupied Portside Flight Engineer Cabin Seat position; and Mic9, Aft Unoccupied Standing position Microphone for the open door at 140 knots during a rate 1 turn maneuver flight condition.

The influence of the different HP configurations is shown for the **open door** at 140 knots during a rate 1 turn maneuver flight condition for Mic1, Mic4 and Mic9 locations in Figure 16, Figure 17 and Figure 18, respectively. The dark bold curve represents the Mic location without any HP.

The OSPL at the Mic1 aircrew location, for an individual without a HP is 108 dB(A). The OSPL of 102.7 dB(A) measured at the Mic1 location was the highest within the 3150 Hz 3rd octave band. Additional 3rd octave bands with significant SPL include the 250 Hz, 800 Hz, 1250 Hz and 1600 Hz bands. This Mic1 location is primarily dominated by high frequency noise energy but also experiences significant low frequency noise energy. It would be ideal to select a HP with uniform performance across all the frequency bands to optimize exposure duration.

The eight curves beneath the dark bold line represent the perceived SPL as a function of frequency for eight different HP solutions. The HP solutions include three Gentex helmets, 4 David Clark headsets with Active Noise Reduction (ANR) and 1 David Clark headset without ANR. The eight HP solutions exhibit similar performance at 1000 Hz and above. The performance of the different HP solutions deviates significantly below 1000 Hz with the David Clark headsets providing on the order of 20 dB superior IL performance within the 250 Hz 3rd octave band depending on the helmet and ANR headset. A 20 dB improvement is a significant performance metric. Of final note, the David and Clark 40411G-19 headset without ANR provided an IL approximately midway between the helmets and ANR headsets.

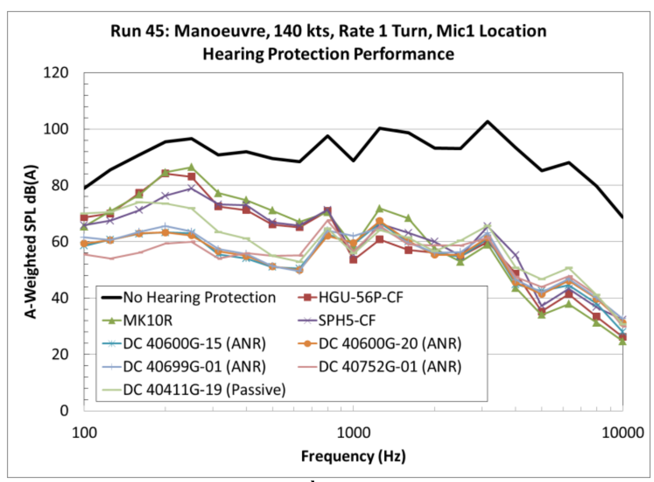

Figure 16: A-Weighted 3rd Octave Data for Aircrew at the Mic1 Location

The OSPL for the Mic4 location for an individual without a HP is 113 dB(A). The Mic1 location measured the highest SPL of 104.8 dB(A) within the 200 Hz 3rd octave band. Additional 3rd octave bands with significant SPL include the 160 Hz, 250 Hz, 315 Hz and 800 Hz bands. Compared to the Mic1 location, the dominant noise energy is contained within the lower frequency 3rd octave bands.

Similar to the Mic1 position, the eight various HP solutions were considered in combination with the CH-147F hearing unprotected SPL (dark bold curve) to calculate the hearing protected SPL frequency spectra at the Mic4 location. A HP with superior low frequency attenuation characteristics would be ideal for this measurement location.

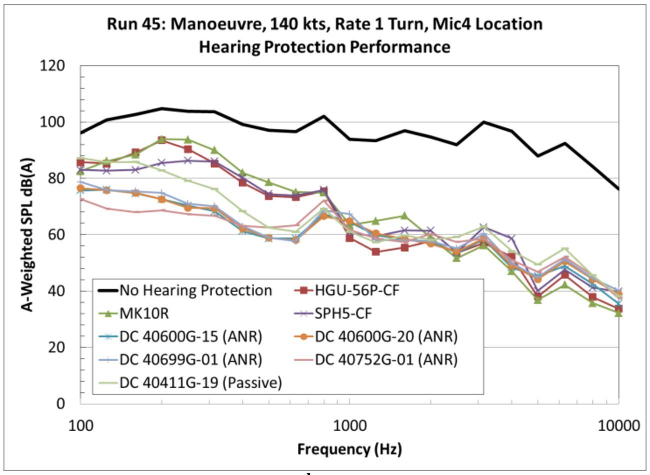

Figure 17: A-Weighted 3rd Octave Data for Aircrew at the Mic4 Location

The OSPL for the Mic9 location for an individual without a HP is 119 dB(A). This is the highest OSPL of all the microphone positions for the **open door**, 140 knots during a rate 1 turn maneuver flight condition. The highest SPL of 115.6 dB(A) was measured at the Mic9 location within the 3150 Hz 3rd octave band. Additional 3rd octave bands with significant SPL include the 800 Hz, 2 kHz, 4 kHz and 6.3 kHz bands. Compared to the Mic1 and Mic4 locations, the dominant noise energy is contained within the 3rd octave bands above 1 kHz.

Similar to the Mic1 and Mic4 positions, the eight various HP solutions were considered with the CH-147F hearing unprotected SPL (dark bold curve) to calculate the hearing protected SPL spectra at the Mic9 location. It is interesting to note that although the SPLs are highest at 800 Hz and above for the unprotected case, the SPLs are highest at 800 Hz and below for the Gentex helmet HP cases.

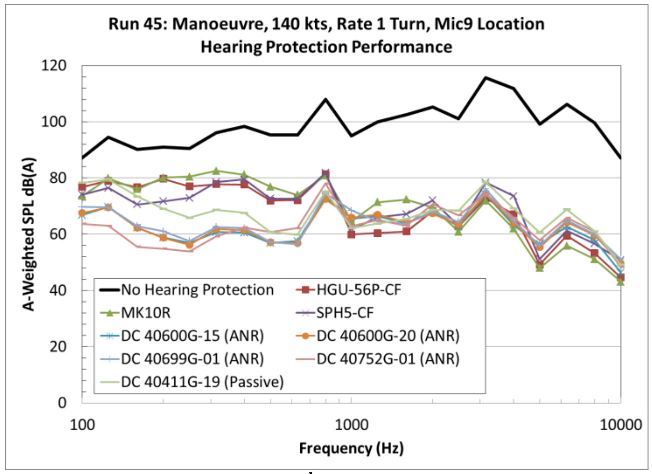

Figure 18: A-Weighted 3rd Octave Data for Aircrew at the Mic9 Location

The OSPL data for the various HPs analyzed for the Mic1, Mic4 and Mic9 locations during the **open door**, 140 knots during a rate 1 turn maneuver flight condition are displayed in Table 6. The conditions with the lowest calculated OSPL are identified with a box for each microphone location.

Out of the three helmets, the SPH5-CF provided the best IL at all aircrew stations inside the cockpit and cabin. The SPH5-CF exhibited the lowest OSPL at the Mic1, Mic4 and Mic9 locations. The MK10R exhibited inferior performance at each location. The HGU-56P-CF exhibited inferior performance with the exception of the Mic9 location. This exception is due to the fact that the Mic9 location included dominant SPL in the 3150 Hz 3rd octave band as shown in Figure 18. Recalling the HP performance data displayed in Figure 2, the HGU-56P-CF exhibited slightly superior IL performance in the higher frequency ranges specifically in the vicinity of the 3150 Hz 3rd octave band. A single number noise rating would not have been a sufficient indicator to identify these trends.

The four headsets with ANR exhibited superior performance than the three Gentex Helmets. The OSPL for each measurement position was at 83 dB(A) or less for all of the ANR headsets. In particular the David and Clark 40752G-01 exhibited improvements of 16 dB(A) at the Mic1 location, 18 dB(A) at the Mic4 location and 7 dB(A) at the Mic9 location in comparison to the currently in service HGU-56P-CF Gentex helmet. Although the particulars of the ANR algorithms' efficiency in reverberant room testing compared to the cabin noise environment is not being discussed in this article, the improvement in the HP performance is significant. Therefore, it is important to consider implementing additional ANR options with the Gentex helmets.

Table 6: Run 45 Overall Sound Pressure Level Comparison for Various Hearing Protectors

Type of Hearing Protector	*Mic1 OSPL dB(A)*	*Mic4 OSPL dB(A)*	*Mic9 OSPL dB(A)*
No Hearing Protection	108	113	119
HGU-56P-CF	88	97	88
MK10R	90	99	90
SPH5-CF	83	93	88
DC 40600G-15 (ANR)	73	82	80
DC 40600G-20 (ANR)	73	82	80
DC 40699G-01 (ANR)	74	83	81
DC 40752G-01 (ANR)	72	79	81
DC 40411G-19 (Passive)	80	92	85

The maximum exposure limit durations for the various HPs evaluated at the Mic1, Mic4 and Mic9 locations for the **open door**, 140 knots during a rate 1 turn maneuver flight condition are displayed in Table 7. The conditions with the lowest calculated OSPL are identified with a box for each microphone location.

The David Clark 40600G and 40752G headsets exhibited the lowest calculated OSPL. All of the ANR equipped HPs exhibited sufficient performance for more than 24 hours maximum exposure duration limits for the **open door** at 140 knots during a rate 1 turn maneuver flight condition. Additionally, it can be shown that the David Clark headsets equipped with ANR provide sufficient protection for all of the 43 measured flight conditions at each of the nine microphone locations.

Table 7: Run 45 Maximum Exposure Limit Duration Comparison for Various Hearing Protectors

Type of Hearing Protector	*Mic1 Limit H:M:S*	*Mic4 Limit H:M:S*	*Mic9 Limit H:M:S*
No Hearing Protection	0:03:50	0:01:12	0:00:18
HGU-56P-CF	6:24:0	0:48:0	6:24:00
MK10R	4:00:00	0:30:0	4:00:00
SPH5-CF	>24:0:0	2:00:00	6:24:00
DC 40600G-15 (ANR)	>24:0:0	>24:0:0	>24:0:0
DC 40600G-20 (ANR)	>24:0:0	>24:0:0	>24:0:0
DC 40699G-01 (ANR)	>24:0:0	>24:0:0	>24:0:0
DC 40752G-01 (ANR)	>24:0:0	>24:0:0	>24:0:0
DC 40411G-19 (Passive)	>24:0:0	2:30:0	13:0:0

It is interesting to note that each HP that was not equipped with ANR had inferior performance at the Mic4 location than the Mic1 and Mic9 locations. In particular, for the **open door** flight condition, the SPH5-CF exhibited no exposure limit restriction for the Mic1 location, an exposure limit duration of 2 hours for the Mic4 location and exposure limit duration of 6 hours and 24 minutes at the Mic9 location. This trend is due to the fact that the measured SPL at the Mic4 location was dominated by low frequency components. This is in spite of the fact that the Mic9 unprotected OSPL was higher than the Mic4 unprotected OSPL. Recall that the HP without ANR exhibited inferior performance at lower frequencies.

CONCLUSION

This article presents an assessment of the cabin and cockpit noise of the RCAF CH-147F Chinook Helicopter during flight tests. The SPL at nine different cabin and cockpit aircrew stations including seated and standing positions were evaluated during a total of 43 representative flight conditions.

At low frequencies, harmonics associated with the N/rev of the 3 bladed rotors were prevalent. At high frequencies the SPLs were primarily dominated by the hydraulic and transmission system noise of the CH-147F Chinook helicopter.

The Mic9 position consistently exhibited the highest OSPL. During the **open door** at 140 knots during a rate 1 turn maneuver flight condition, the Mic9 OSPL was 119 dB(A) while the cockpit Mic1 exhibited 108 dB(A) and the cabin Mic4 exhibited 113 dB(A). The Mic9 location is in close proximity to the aircraft engines and experienced high frequency noise likely dominated by the CH-147F hydraulic and transmission systems.

It is evident that the noise spectrum is dependent on the cabin and cockpit location as shown by the different OSPL and frequency content. Therefore, it is necessary to select the most suitable HP that will provide sufficient protection for all cabin and cockpit locations.

Three different helmets and five different headsets currently in use with the RCAF were evaluated at all 43 distinct flight conditions. In particular, the performance of each HP at the Mic1, Mic4 and Mic9 locations during the **open door**, 140 knots during a rate 1 turn maneuver flight condition, were presented in this article. It was determined that a HP equipped with ANR exhibited superior performance. For the **open door**, 140 knots during a rate 1 turn maneuver flight condition, the maximum exposure limit was calculated to be unrestricted when an individual is properly fitted with a David and Clark headset equipped with ANR. It can be shown that the David and Clark headsets equipped with ANR provide sufficient hearing protection for all the measured flight conditions.

It is important to note that caution must be exercised even with a properly fitted and appropriately selected HP to avoid exceeding the daily exposure limits. At the Mic9 location, the maximum exposure limit duration without hearing protection is 18 seconds for the **open door** at 140 knots during a rate 1 turn maneuver flight condition. This means that if the hearing protection is removed in flight due to discomfort or an incorrect fit, the individual will exceed their maximum exposure limit duration and be exposed to an increased risk of adverse health effects or hearing damage. Therefore, it is important to properly fit a HP and to continue wearing the HP under noise exposure to avoid exceeding their maximum exposure limits.

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REFERENCES

[1]Fitzpatrick, D., "An Analysis of Noise-Induced Hearing Loss in Army Helicopter Pilots," *Journal of Aviation, Space and Environmental Medicine*, Vol. 59, 1988, pp. 937 – 941.

[2]Lapsley Miller, J. A., Marshall L., Heller, L and Hughes, L., "Low-level otoacoustic emissions may predict susceptibility to noise-induced hearing loss," *Journal of Acoustical Society of America*, Vol. 120, 2006, pp. 280 – 296.

[3]American National Standards Institute, "Methods for the Measurement of Insertion Loss of Hearing Protection Devices in Continuous or Impulsive Noise Using Microphone-In-Real-Ear or Acoustic Test Fixture Procedures". ANSI/ASA S12.42-2010

[4]International Organization for Standardization, "Acoustics-Measurement of Sound Pressure Levels in the Interior of Aircraft during Flight", ISO 5129:2001.

[5]United States Military Standard, "Acoustical Noise Limits in Helicopters", MIL-STD-1294A.

[6]Transport Canada, "Canadian Aviation Occupational Health and Safety Regulations, Part 2 – Levels of Sound," Department of Justice Canada.

The following references were also reviewed and utilized during this noise measurement, though not specifically referenced in this article:

[7]Canadian Standards Association, "Procedures for the measurement of occupational noise exposure," CSA Z107.56-06.

[8]International Organization for Standardization, "Acoustics – Determination of Occupational Noise Exposure – Engineering Method," ISO 9612:2009.