Cabin noise exposure assessment of the Royal Canadian Air Force CH-147F helicopter through flight testing

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ABSTRACT
Military helicopter aircrews are often required to spend extended periods of time at their station in the cockpit or the cabin to perform various duties. For example, Canadian aircrews are routinely known to spend over six hours per day in order to perform operations that include pre-flight, flight, and post-flight tasks while wearing helmets for hearing protection. The objective of this particular project was to measure the cabin noise levels of the CH-147F helicopter at selected aircrew stations through representative flight operations to determine the aircrew noise level exposures inside the aircraft during flight missions. This paper focuses on the performance evaluation of existing hearing protection solutions used by the Royal Canadian Air Force (RCAF) personnel at selected aircrew workstations, based on noise level measurements on a RCAF CH-147F Chinook helicopter during representative flight conditions. The study allowed the selection of an optimal hearing protection solution for CH-147F helicopter aircrew. Additionally, the present study provided a clear insight on the difference between open and closed door noise environments as well as specific behavior related to various flight conditions. A number of recommendations were provided to the RCAF to mitigate hearing damage risk in diverse mission situations.

Keywords: Hearing Protection, Helicopter Cabin Noise, Exposure Durations

1. INTRODUCTION
The paper presents the compiled results of a testing campaign aimed at evaluating the noise exposure of RCAF personnel at workstations inside the cabin and cockpit of the CH147F helicopter. The Sound Pressure Levels at nine cabin crew stations were measured during the flight test campaign for a total number of 43 representative flight manoeuvres in accordance with ISO 5129:2001 [1] and MIL-STD-1294A [2]. A-weighted Sound Pressure Levels at each workstation during each flight sequence were investigated in 1/3rd octave frequency bands and the overall sound pressure levels (OSPL) were calculated. The OSPL values were used to determine the maximum exposure durations per employee per 24 hour period based on the measured noise levels at various workstations in the helicopter cockpit and cabin for hearing-unprotected aircrew during each flight sequence. In particular, OSPL results were calculated for hearing-unprotected situations and this data is useful to assess new hearing protection devices under consideration in the future.

It was observed that at low frequencies, tonal harmonics of the rotor rotating speed were prevalent in all flight conditions while the high frequencies SPL was mainly dictated by the rotor transmission gear meshing tonal noise.

The Insertion Loss frequency spectra of three pilot helmets and five headsets were used to determine the noise levels at which the aircrew is exposed when protected with a specific hearing protection device. The Insertion Losses of all hearing protection devices were measured at NRC-Aerospace Hearing Protection Evaluation Facility in agreement with ANSI/ASA S12.42-2010 [3] Standard test procedure using an Acoustic Test Fixture (ATF) method in a reverberant field for

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OSPL higher than 120dB. The OSPL values were calculated to determine the maximum duration limits of exposure per employee per 24 hour period based on the measured noise levels at various workstations in the helicopter cockpit and cabin for hearing protected aircrew during each flight condition.

The OSPL data for aircrew wearing hearing protection at each cabin and cockpit workstation during each flight condition presented in this article is applicable only when aircrew wear perfectly fitted hearing protection. This data is important because it can be used to calculate the noise exposure of any individual on the aircraft based on various flight sequences composing an entire mission and their respective duration in agreement with ISO 9612:2009 [4] and CSA Z94.2-14 [5].

It is important to note that noise exposure during missions involving open doors flight operations were characterized by very high noise levels at most cabin positions. Therefore, a very detailed evaluation of noise exposure levels for all aircrew is required when performing missions that involve open door operations.

Flight test data analysis results demonstrated that Gentex SPH5-CF helmet provides the best hearing protection performance at all aircrew stations inside the cockpit and the cabin for CH-147F aircrew based on the current study.

Headsets with Active Noise Reduction (ANR), such as the David Clark 40600G-15 and 40600G-20, were shown to provide the best hearing protection which exceeds more than 24 hours maximum limit durations. Considering that all helmets were only capable of passive hearing protection, it is important to emphasize the importance of implementing ANR solutions in helmets. Integrating ANR technology to helmets would further improve noise protection for CH147F aircrew.

2. FLIGHT TEST PROCEDURE

Flight measurements were conducted on the RCAF CH-147F helicopter in Petawawa, Ontario to record aircraft cockpit and cabin noise environment. The noise was measured at station locations of the pilots, flight engineer, load master and passengers within the CH147F helicopter.

A detailed presentation of the flight test procedure including sensors and aircrew locations, flight segments details, microphone mounting, airworthiness considerations and instrumentation were provided in Ref. [7]. In order to improve clarity and ease of reading of this paper, flight sequence measurement runs for both open and closed doors configurations are shown in Table 1. Additionally, the test aircraft layout and instrumentation suite are shown in Figure 1.

![Figure 1. Sensor and aircrew locations in the CH-147F helicopter cabin.](image)

The CH-147F cabin sound pressure level measurements were performed for stationary flight conditions in accordance with ISO 5129:2001 [1], ISO 9612:2009 [4] and CSA Z107.56-06 [5]. The obtained sound pressure levels were analyzed according to applicable standards to access the noise environment inside the cockpit and the cabin of the CH-147F helicopter.

Stationary flight involved hovering in helicopter ground effect at two altitudes of 10 feet and 40 feet, respectively, as well as a sling configuration at two altitudes of 40 feet and 80 feet respectively. Steady airspeed maneuvers included climbing, level, and descending flight. The maximum flight speed attained during testing was 150 knots. Flight conditions for each maneuver were maintained for a minimum of 60 seconds to provide steady acoustic environments suitable for recording.
3. RESULTS

3.1 Flight measurements data analysis for aircrew without hearing protection

The OSPL data for aircrew without hearing protection at each cabin and cockpit workstation during each of the 43 flight sequences was regrouped in Figure 2. This data should not be interpreted as a case applicable only to the scenario when aircrew do not wear any hearing protection. The data presented in Figure 2 has the fundamental importance being considered as the worst case scenario. Some examples deemed as worst case scenario could be as follows:

- Improper hearing protection fitting for one or both ears;
- The hearing protection is taken off the head during flight for fitting adjustments. This situation is mainly triggered by perceived fitting discomfort or perceived high noise levels.
- Technical personnel may take off the hearing protection for short periods of time in order to listen to the sound from a pump, equipment etc. to verify the functionality from the noise signature.

The aforementioned cases are only a few examples of situations when aircrew can expose themselves to potentially harmful levels of noise with high risk of hearing loss.

It can be observed in Figure 2 that aircrew flying with an improperly fitted hearing protection could be at risk of serious hearing damage after only 18 seconds for aircrew located at rear cabin passenger position STA500 (Mic 9) to 8 minutes rear cabin passenger station STA235 (Mic 5) where the time limit depends on the workstation position in the cabin or cockpit. The high noise levels measured at Mic 8 and Mic 9 workstation locations have a very strong high frequency component mainly influenced by rotor transmission gear meshing and hydraulic systems tonal noise.

Aircrew standing at rear cabin passenger position STA500 (Mic 9) could be at serious risk of hearing damage after only 18 seconds of working in that area with an improperly fitted hearing protection or if the person decides to take off the hearing protection for any reason as discussed previously. Under the same circumstances, aircrew at seated cabin passenger position STA450 (Mic 8) could be at serious hearing damage risk after only 1-2 minutes.

It has to be mentioned that the pilot and the co-pilot could be at serious hearing damage risk after...
only 4 minutes of flying with an improperly fitted hearing protection.

Additionally, it is important to mention that the hearing-unprotected data in OSPL will also be useful in the future to assess new hearing protection devices, in conjunction with their insertion loss characteristics.

![Figure 2. OSPL for aircrew without hearing protection.](image)

### 3.2 Data analysis for aircrew wearing hearing protection

The OSPL data for aircrew wearing hearing protection at each cabin and cockpit workstation during each of the 43 flight sequences was regrouped in Figure 3 to Figure 5. This data is applicable only when aircrew wear perfectly fitted hearing protection.

The data presented in Figure 3 to Figure 10 has a fundamental importance in the sense that it can be used to calculate the noise exposure of any individual based on the flight sequences composing a mission and their respective duration.

Overall Noise Levels for aircrew wearing helmet HGU-56P-CF, MK10R and SPH-5CF are shown in Figure 3, Figure 4, and Figure 5 respectively. It can be observed by comparing Figure 3 to Figure 5 that the Gentex SPH-5CF helmet used by pilots provides the best hearing protection performance at all aircrew stations within the cockpit and the cabin among the three helmets considered.

Overall Noise Levels for aircrew wearing headsets David Clark 40411G-19, 40600G-15, 40600G-20, 40699G-01 and 40572G-01 are shown in Figure 6, Figure 7, Figure 8, Figure 9 and Figure 10 respectively. By comparing Figure 6 to Figure 10, it can be observed that headsets with Active Noise Reduction (ANR) provide an excellent hearing protection for all flight sequences for more than 24 hours maximum duration limits of exposure per employee per 24 hours. More precisely, it can be observed that the David Clark 40600G-15 and 40600G-20 headsets provide the best hearing protection performance at most aircrew stations inside the cockpit and the cabin over the entire list of the flight segments.

It was observed in Figure 2 based on hearing-unprotected OSPL data, the standing cabin passenger position at STA500 (Mic 9) was the one exhibiting the highest noise levels. It has to be mentioned that the Mic 9 position is characterized by high frequency noise components that passive hearing protection solutions are successful in attenuating. It can be observed in Figure 3 to Figure 10 that when applying a frequency dependent sound attenuation through the hearing protector Insertion Loss, seated passenger position STA120 (Mic 4) and standing passenger position STA150 (Mic 3) become the main areas of concern for missions that include open door flight operations. The main explanation for this behaviour is that in the frequency range 200Hz to 400Hz, the noise waves related to main rotor (N/rev tonal peaks) are efficient and propagating from the open window and from the open ramp to combine their behaviour at workstation seated passenger position STA120 (Mic 4) – see for instance results...
related to runs 37 to 47 in Ref [7].

Figure 3. Noise Levels for aircrew wearing helmet HGU_56P-CF

Figure 4. Noise Levels for aircrew wearing MK10R helmet
Figure 5. Noise Levels for aircrew wearing SPH5-CF helmet.

Figure 6. Noise Levels for aircrew wearing headset David Clark 40411G-19.
Figure 7. Noise Levels for aircrew wearing headset David Clark 40600G-15

Figure 8. Noise Levels for aircrew wearing headset David Clark 40600G-20
Figure 9. Noise Levels for aircrew wearing headset David Clark 40699G-01

Figure 10. Noise Levels for aircrew wearing headset David Clark 40572G-01

Figure 11 provides a global assessment of the noise levels by highlighting the maximum OSPL for each hearing protection solution during each flight sequence.
It was observed that the most critical workstation was at Mic 4 location and further investigation will focus on this case to highlight the difference that could be measured between open and closed doors flight sequences. The OSPL results for the similar open-closed doors flight sequence runs for aircrew wearing one of the three Gentex helmets (HGU-56P-CF, MK10R, SPH5-CF) at Flight Engineer Seat STA120 portside (Mic 4) position were plotted in Figure 12, Figure 13 and Figure 14 respectively. Moreover, for each test run, the difference between the OSPL in open versus closed doors configurations was provided. It can be observed that the maximum difference can be as high as 13dBA for aircrew wearing the HGU-56P-CF helmet (see Figure 12), 13dBA for the MK10R helmet (see Figure 13), and 10dBA for the SPH5-CF helmet (see Figure 14).

The highest SPL level for any hearing protection considered in the study was recorded during the flight sequence Level 150 kts, Run 39. The A-weighted SPL was 98dBA for aircrew protected with the HGU-56P-CF helmet, 100dBA with the MK10R helmet and 94dBA with the SPH5-CF helmet. It can be concluded that the cumulated maximum duration limits of exposure per employee per 24 hours to the measured noise levels at the portside Flight Engineer Seat STA120 (Mic 4) workstation position for hearing protected aircrew should not exceed 38min cumulated over 24 hours when aircrew is protected with the HGU-56P-CF helmet, 24min with the MK10R helmet and 1h36min with the SPH5-CF helmet.
4. CONCLUSIONS

The paper presented results of a testing campaign that evaluated the noise exposure of RCAF personnel at workstations inside the cabin and cockpit of the CH147F helicopter. The data analysis was conducted in accordance with, ISO 5129:2001 [1], MIL-STD-1294A:1985 [2], ANSI/ASA S12.42-2010 [3], ISO 9612:2009 [4], and CSA Z107.56-06 [5] Standard test procedures and Canada Labor Code [7]. It was shown that the OSPL data for aircrew without hearing protection at each cabin and cockpit workstation during each of the 43 flight sequences has the fundamental importance of
It was shown that aircrew flying with an improperly fitted hearing protection could be at risk of serious hearing damage after only 18 seconds aircrew at rear cabin passenger position STA500 (Mic 9) to 8 minutes for rear cabin passenger station STA235 (Mic 5) depending on the workstation position in the cabin or cockpit. Similarly, the pilot (Mic 2) and the co-pilot (Mic 1) could be at serious risk of hearing damage after only 4 minutes of flying with an improperly fitted hearing protection.

Flight test data analysis results demonstrated that Gentex SPH5-CF helmet provides the best hearing protection performance at all aircrew stations inside the cockpit and the cabin based on the current study. The highest SPL level for any hearing protection considered was recorded during flight sequence Level 150 kts. The A-weighted SPL was 98dBA for aircrew protected with HGU-56P-CF helmet, 100dBA with MK10R helmet and 94dBA with SPH5-CF. The cumulated maximum duration limits of exposure per employee per 24 hours to the measured noise levels at portside Flight Engineer Seat STA120 workstation position for hearing protected aircrew should not exceed 38min cumulated over 24 hours when aircrew is protected with HGU-56P-CF helmet, 24min with MK10R helmet and 1h36min with SPH5-CF helmet.

Considering that all helmets were only capable of passive hearing protection, it is important to emphasize the importance of implementing ANR solutions in helmets to improve the level of hearing protection for helicopter aircrew.

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