AEROSPACE – AEROACOUSTICS AND STRUCTURAL DYNAMICS

NATIONAL RESEARCH COUNCIL CANADA

EVALUATION OF AIRCREW NOISE EXPOSURE DUE TO THE USE OF INTERCOM DEVICES IN RCAF CH-149 HELICOPTER FLIGHT OPERATIONS

Volume 1 of 1

Report Number: LTR-FRL-2018-0025

Date: March 2018

Authors: YONG CHEN, ANDREW PRICE, SILIN YANG, SEBASTIAN GHINET, ANANT GREWAL, VIRESH WICKRAMASINGHE

National Research Council Canada Conseil national de recherches Canada

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EXECUTIVE SUMMARY

The National Research Council (NRC) Flight Research Laboratory (FRL) was tasked to evaluate the cabin, cockpit and exterior surrounding sound pressure levels for the Royal Canadian Air Force (RCAF) CH-149 Cormorant aircraft. A ground and flight measurement mission was completed on the vehicle CH149908 at RCAF Comox CFB in January, 2017. In addition, the intercom voltage of voice communication signal was also recorded at a cabin aircrew station. To support DND flight operational needs, NRC-FRL performed extensive data analysis of the recorded voice signal to investigate the squelch issue in aircrew voice communications, and also to determine aircrew noise exposure levels due to the use of the CH-149 helicopter cabin intercom devices.

This report focuses on the presentation of technical methods and derived aircrew noise exposure levels due to the use of cabin intercom devices in this mission. Related technical information such as the performance of RCAF hearing protection equipment, data acquisition procedures, measured flight conditions, the Overall Sound Pressure Levels (OSPL) of the cabin in representative flight conditions have been presented separately in NRC technical report LTR-FRL-2017-0016.

It was observed that the recorded CH-149 intercom voice signal had a severe saturation issue. The saturated intercom voice signal may have contributed to the strong background noise in the aircrew intercom voice communications. The existence of significant squelch was also confirmed in the intercom voice communication signal. Spectral analysis of the CH-149 intercom voice signal indicated that the squelch issue was related to strong tonal noises at multiple discrete frequencies. Further analysis indicated that the high squelch levels and multiple tonal frequency peaks mainly existed in the start-up operation and taxi sections of the mission, which adversely affected the quality of the intercom voice communication signal. In comparison, the tonal noise peaks were less severe in the flight section. However, strong background noise still existed in the intercom voice signals, which may be related to the intercom voice signal saturation issue.

Besides the intercom voice signal saturation issue, analysis of the intercom voice signals showed that the CH-149 intercom device introduced considerable level of noise exposure to the aircrew in the mission. The CH-149 intercom device introduced an averaged non-weighted OSPL of 81.9 dB at the aircrew ear entrance location during the entire flight mission. It is also important to note that the dominant noise energy of the CH-149 intercom communication occurred in the audible frequency range between 1 kHz and 4 kHz. Combining the helicopter cabin background noise and intercom communication noise, the aircrew may be effectively exposed to higher noise levels. The actual noise exposure of the aircrew will need to be

determined depending on the hearing protection equipment used, aircrew stations and noise exposure time in representative missions.

Based on this investigation, it was concluded that the CH-149 helicopter intercom voice communication can introduce significant noise levels to the aircrew in flight missions, but additional investigation combining cabin noise is required to quantify the significance. The aircrew effective noise dose needs to be determined based on both intercom noise and cabin background noise exposures. Proper selection of hearing protection devices, adequate configuration and use of the helicopter intercom devices are important factors to alleviate the risk of hearing damage to the aircrew in CH-149 flight operations.

It was also important to note that the squelch issue and severe saturation of the intercom voice signals observed in this mission may adversely affect the quality of the aircrew voice communication. Therefore, further investigation of the voice signal saturation issue is recommended in order to identify the root causes to improve the quality of aircrew voice communication.

Concurrently with this work, NRC has worked on the development of an intercom replication system to enable further investigative capabilities on the ground avoiding expensive flight testing. Further details are presented in the Appendix.

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Table 1: Table of Acronyms

Acronym	Description
AETE	Aerospace Engineering Test Establishment
ASD	AeroAcoustics and Structural Dynamics group
CEP	Communication Ear Plug
CFB	Canadian Forces Base
DAS	Data Acquisition System
DND	Department of National Defence
DTAES	Directorate Technical Airworthiness and Engineering Support
EMI	ElectroMagnetic Interference
FRF	Frequency Response Function
FRL	Flight Research Laboratory
HP	Hearing Protector
ICS	Intercom Communication System
IL	Insertion Loss
KIAS	Knots, Indicated Air Speed
NRC	National Research Council
OSPL	Overall Sound Pressure Level
RCAF	Royal Canadian Air Force
SAR	Search and Rescue
SLF	Steady Level Flight
SPL	Sound Pressure Levels

1.0 INTRODUCTION

The CH-149 Cormorant helicopter is a versatile aerial platform used by the RCAF for Search and Rescue (SAR) missions. However, its cabin and proximity environment are generally unpleasant due to the high noise levels associated with the main rotor aerodynamic tonal noise, engine gear meshing tones, high-frequency hydraulics, engine exhaust noise and other broadband noises. The demanding acoustic environment requires the use of specialised Hearing Protectors (HPs) to attenuate noise exposure for the aircrew and ground support personnel.

The evaluation of noise spectra and levels associated with the cabin, cockpit and exterior noise is essential for the selection of appropriate HPs to provide the required level of personnel safety and mitigation of potential aircrew hearing loss. In the Royal Canadian Air Force (RCAF) CH-149 Cormorant helicopter fleet, the aircrew are required to use flight helmets for hearing, impact and thermal protection, as well as voice communication in flight missions; the use of Communication Ear Plugs (CEPs) is not mandatory. It is important to ensure that adequate hearing protection is provided to maintain aircrew noise exposure levels within the operational limits in accordance with the Canadian Aviation Occupational Health and Safety Regulations [**1**].

The National Research Council (NRC) Aerospace Research Center has been tasked to assess the performance of several in-service HPs, and has also completed a noise evaluation flight mission on a RCAF CH-149 Cormorant Helicopter. The flight measurement was performed on the RCAF CH-149 Cormorant SAR helicopter CH-149908 on Wednesday, January 11th, 2017, with the support of Squadron 442, 19 Wing at Comox Canadian Forces Base (CFB), and the aircraft is shown in Figure 1. In this mission, Sound Pressure Levels (SPLs) were measured at 11 cabin and cockpit locations as well as 10 exterior locations in the aircraft's vicinity. The results have been analysed to determine the occupational noise exposure of the aircrew and ground crew working with the aircraft throughout 48 representative flight and ground operational conditions. The results were used in conjunction with HP Insertion Loss (IL) data measured previously using the NRC Hearing Protection Performance Evaluation Facility. The combination of in-flight measurement data and HP IL data enabled the estimation of the maximum cumulative noise exposure dose for individuals with properly fitted hearing protection at specific locations. Technical methods, detailed assessment results and recommendations have been presented in the National Research Council Technical Report LTR-FRL-2017-0016 [**2**], and submitted to DND authorities for reference.

Figure 1: CH-149 Cormorant Helicopter, 442 Squadron, 19 Wing Comox, CFB

In addition to the noise measurement for the CH-149 helicopter cabin and exterior locations, voltage of the intercom voice communication signal in this mission was also recorded. The objective of this additional task was twofold: first, to determine the combined aircrew noise exposure due to aircraft cabin noise level in combination with the intercom sound level and second to identify a squelch issue reported by the aircrew on the CH-149 intercom voice communication devices. The NRC Flight Research Laboratory (FRL) performed extensive post data analysis of the recorded voice signal in order to investigate the squelch issue in the aircrew voice communications, and also to determine aircrew noise exposure levels due to the use of the CH-149 helicopter cabin intercom devices.

2.0 MEASUREMENT OF CH-149 INTERCOM SIGNALS

The measurement of the RCAF CH-149 helicopter Intercom Communication System (ICS) voice signal was performed by the NRC-FRL Aeroacoustics and Structural Dynamics (ASD) group. The ground calibration procedure took place on Tuesday, January 10th, 2017 and the flight measurement took place on Wednesday, January 11th, 2017. This measurement took place in conjunction with the tasks of hearing protection and the noise assessment of the CH-149 Cormorant cabin noise environment as reported in LTR-FRL-2017-0016 [**2**].

The CH-149 ICS measurement procedure consisted of two phases. The Phase I was to characterize the intercom system on the ground with voltage measurements and SPL measurements, using laboratory equipment. In Phase II the laboratory calibration equipment was removed for flight and the voltage of aircrew voice communication signal only was measured. The SPLs of the aircrew voice communication during the flight was determined through data post-processing based of two sets of data: the characterization of the CH-149 ICS and the recorded voltage of inflight ICS signals.

2.1 GROUND CALIBRATION PROCEDURE

The ground calibration was completed first to characterize the CH-149 ICS. The location of the equipment has been indicated in Figure 2.

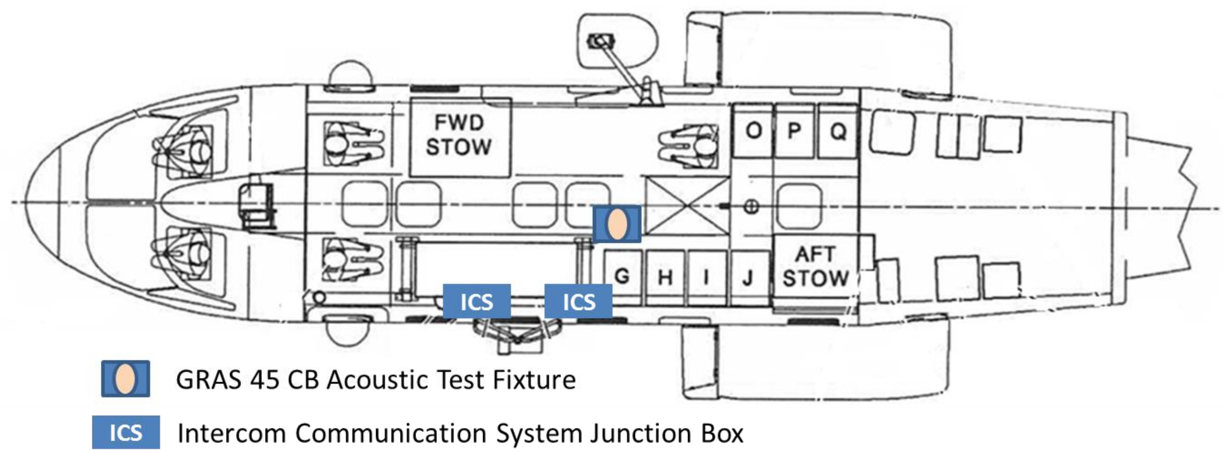


Figure 2: CH-149 Cormorant Intercom Ground Calibration Location Schematic

It is worth noting that the CH-149 Cormorant helicopter has 12 intercom system stations: namely the pilot, co-pilot, jump seat, FE hoist, SARTech 1, SARTech 2, Stretcher 1, Stretcher 2, Passenger 1, Passenger 2, Ground Crew 1 and Ground Grew 2. The NRC ground measurement calibration was completed at the Stretcher 1 and Stretcher 2 stations.

The equipment utilized for the CH-149 ICS noise measurement and characterization is listed in Table 2. A schematic diagram indicating the equipment configuration for the intercom characterization is shown in Figure 3. Please note that for the ground calibration procedure, audio signals were prepared by NRC.

Table 2: Ground Calibration Equipment

#	Equipment	Description
1	GRAS 45 CB	Acoustic test fixture for recording helmet sound pressure levels
2	SPH5-CF Helmet 1	Utilized as intercom OUTPUT (ICS voltage receiver)
3	SPH5-CF Helmet 2	Utilized as intercom INPUT (mouth microphone)
4	Portable Speaker	Philips SBA3011ORG/37
5	Microphone	PCB Model 378B02, Laboratory Grade
6	Audio Device	TASCAM Linear PCM Recorder, utilized for audio playback
7	DAS	Siemens LMS SCADAS XS Data Acquisition System (DAS)

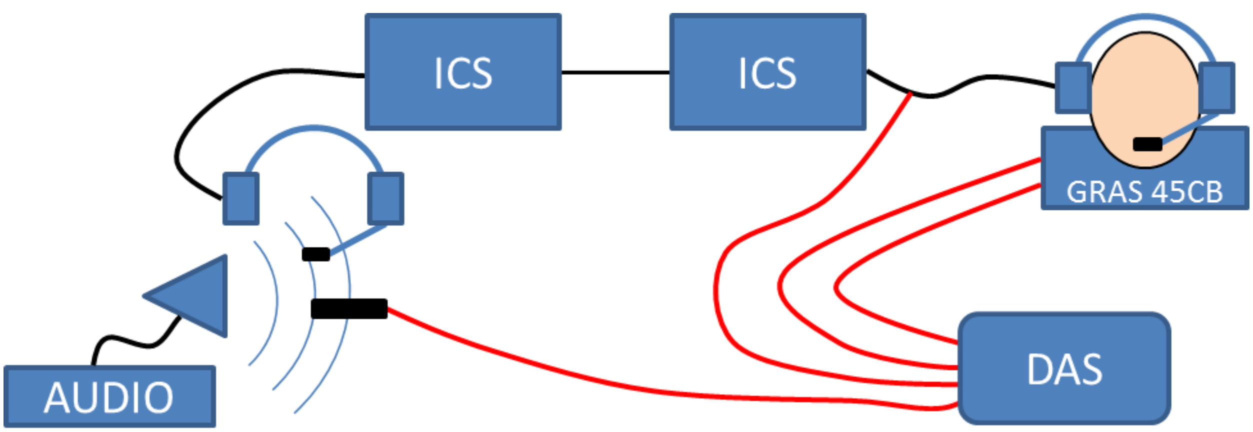


Figure 3: CH-149 Cormorant Intercom Ground Calibration Equipment Schematic

In the characterization of the intercom system, several instruments including an audio device, the CH-149 ICS, an independent laboratory grade microphone and a Data Acquisition System (DAS) were used. The DAS was configured to record the voltage signals from the ICS system to the receiver helmet, and the left and right sound pressure levels at the ear canal locations of the GRAS 45CB acoustic test fixture. This configuration enabled tracking of the SPLs and signals at three separate points to determine the dynamics of the signal transfer path from the microphone (on the input flight helmet) to the speakers (on the output flight helmet). The recorded signals along the voice transfer path of the intercom system included:

- Microphone input SPL of the 1st helmet (input helmet)
- Input voltage of the 2nd helmet (output helmet)

- Speaker output SPL of the 2nd helmet (output helmet)

Two separate and pre-recorded calibration files, one male and one female voice, were played back through the audio device. Three different ICS volume settings were used to characterize the dynamics of the ICS; the volume settings are shown in Figure 4. A total of 6 calibration measurements and one repeat condition were recorded in the characterization process. The helmet speaker volume setting was set to the maximum in all test conditions.

Figure 4: CH-149 Cormorant Cabin Intercom Audio Settings

2.2 FLIGHT MEASUREMENT CONFIGURATION

The GRAS 45CB acoustic test fixture, the audio device and the NRC speaker were introduced to characterize the CH-149 ICS on the ground only, and were not used for flight measurement. During the flight mission, the ICS measurements were made with the DAS only to record the voltage signal between the CH-149 ICS and a single passenger flight helmet worn by one of the NRC researchers. The configuration is schematically shown in Figure 5.

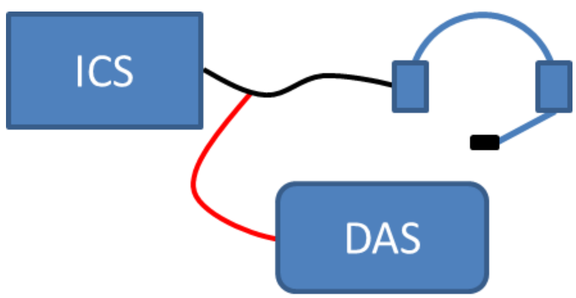


Figure 5: CH-149 Cormorant Intercom Flight Configuration Equipment Schematic

The flown flight measurement conditions were selected based on discussions with CH-149 operational aircrew, Aerospace Engineering Test Establishment (AETE) test pilots, NRC test pilots and previous experience acquired during the CH-147F flight measurement to encompass the majority of CH-149 helicopter standard manoeuvres and operations. The 48 measured flight conditions are listed in Table 3. These conditions were selected in support of the CH-149 Cormorant hearing protection and cabin noise assessment project, and the voltages of the ICS were recorded concurrently.

Table 3: Flight Sequence Measurement Runs

ID	Flight Condition	Category
3	Ground, APU ON, Avionics Running	Ground
4	Ground, APU ON, Engine Levers Idle	
5	Ground, APU ON, Engine Levers Flight	
5B	Ground, APU ON, Engine Levers Flight (Repeat Condition)	
6	Ground, APU OFF, Engine Levers Flight	
7	Doors Closed, 10 ft Hover over land	Hover/Hoist
11	Doors Closed, 40 ft Hover over land	
12	Doors Closed, 10 kts SLF	Steady Level Flight
13	Doors Closed, 30 kts SLF	
14	Doors Closed, 80 kts SLF	
15	Doors Closed, 120 kts SLF	
15A	Doors Closed, 130 kts SLF	
16	Doors Closed, 140 kts SLF	
17	Doors Closed, 148 kts SLF (Vne)	
18	Doors Closed, 80 kts, 30 Deg Bank	Manoeuvres
19	Doors Closed, 80 kts, 45 Deg Bank	
20	Doors Closed, 100 kts, 30 Deg Bank	
21	Doors Closed, 100 kts, 45 Deg Bank	
22	Doors Closed, 120 kts, Rate 1 Turn	
23	Doors Closed, 140 kts, Rate 1 Turn	
24	Door Closed, 70 kts, Descending Turn	
25	Door Closed, 70 kts, Reverse Descending Turn	
30	Doors Open, 10 ft Hover over land	Hover/Hoist
32	Doors Open, 40 ft Hover over land	
33	Doors Open, 40 ft Hoist	
34	Doors Open, 100 ft Hoist	
36	Doors Open, 10 kts, SLF	Steady Level Flight
37	Doors Open, 30 kts, SLF	
38	Doors Open, 80 kts SLF	
39	Doors Open, 120 kts, SLF	
40	Ramp Open, Hoist Door Closed, 130 kts, SLF	
44	Doors Open, 30 kts, 30 Deg Bank	Manoeuvres
46	Doors Open, 60 kts, 30 Deg Bank	
47	Doors Open, 60 kts, 45 Deg Bank	
48	Doors Open, 80 kts, 30 Deg Bank	
49	Doors Open, 80 kts, 45 Deg Bank	
50	Doors Open, 100 kts, 30 Deg Bank	
51	Doors Open, 100 kts, 45 Deg Bank	
52	Doors Open, 120 kts, Rate 1 Turn	
53	Doors Open, 70 kts, Descending Turn	
54	Doors Open, 70 kts, Reverse Descending Turn	
55	Doors Closed, Normal Approach to Hover	Landing
56	Doors Open, Normal Approach to Hover	
57	Doors Closed, Normal Approach to No Hover Landing	
58	Doors Closed, Roll on Landing	
59A	Doors Open, Low Speed Crawl	Crawl
59B	Doors Open, Low Speed Crawl (Repeat Condition)	
60	Doors Open, Moderate Speed Crawl	

*The Doors Open condition refers to the hoist door and ramp open unless otherwise specified.

The majority of flight conditions were nominally flown at 1000 ft pressure altitude. The maximum flight speed was 144 KIAS, and occurred during the measurement condition ID 17. All flight measurement conditions were maintained for a minimum of 60 seconds to generate stationary datasets. Outside air temperature was 2 °C; wind speed was 4 kts. No restrictions were placed upon aircrew communications with the intention to record a standard working environment that contained periods of quiet radio and active voice communications.

Two seats “G” and “H”, as observable in Figure 2, were occupied by the NRC research personnel during the flight. Specifically, the researcher seated at “G” utilized the SPH5-CF pilot helmet wherein the ICS voltage levels were recorded by the NRC DAS; the voltage signal was tapped and recorded from the nearest ICS junction box.

In terms of the electronics airworthiness requirements, the LMS SCADAS XS DAS is a miniature DAS similar in size and electrical capacity to a tablet personal computer, and its wireless communication setting was disabled in the mission. System checks were completed in addition to the standard aircraft start up procedure to assess the potential Electromagnetic Interference (EMI) interaction of the DAS equipment with the aircraft instruments. With such considerations, the equipment was flown as non-essential, self-powered, stand-alone “cargo” equipment. The LMS SCADAS XS unit was installed on the stretcher together with another airworthy NRC DAS for cabin noise and vibration recording, as shown in Figure 6. For details of the additional equipment, please refer to LTR-FRL-2017-0016 [**2**] as submitted to DND DTAES in March, 2017 [**2**].

Figure 6: Data Acquisition System Mounting Location

3.0 ASSESSMENT OF AIRCREW NOISE EXPOSURE DUE TO THE USE OF INTERCOM DEVICES

3.1 CHARACTERIZATION OF CH-149 INTERCOM DEVICES

Transfer functions were derived based on the ground calibration datasets to characterize the CH-149 ICS, with the objective of determining aircrew noise exposure due to intercom voice communications in the flight missions.

3.1.1 Procedures

The following procedure was used to identify the transfer function of the SPH5-CF flight helmets; and instrumentation configuration was shown previously in Figure 3.

1. Pre-recorded voice signals were played back through an external audio device to simulate aircrew speech communications in the cabin;
2. The voice signal was picked up by the microphone of the 1st helmet (input helmet) and then transmitted through the ICS;
3. The output voltage of the intercom communication system was measured and used as the **input signal** of the transfer function;
4. The output voltage was simultaneously used to drive the speakers of the 2nd helmet (output helmet) that was installed on the GRAS 45CB acoustic fixture;
5. The SPLs at the left and right ear canal locations of the GRAS 45CB acoustic fixture were measured and used as the **output signals** to derive the transfer functions.

3.1.2 Dynamic Characterization of Aircrew Voice Signal Transfer Path

In the characterization procedure, the dynamics of the intercom communication box was assumed to be linear. Therefore, the pre-recorded voice signals were mainly utilized to provide the broadband voice excitation within the audible frequency range; it is reasonable to assume the content of speech would not affect the results of the characterization.

A calibration test dataset was used to derive the transfer functions of the voice signal transfer paths; the gain of the intercom box was set at the maximum. The gain setting of the intercom box was not expected to affect the results of the helmet transfer function characterization. The identified transfer function of the SPH5-CF helmet is shown in Figure 7.

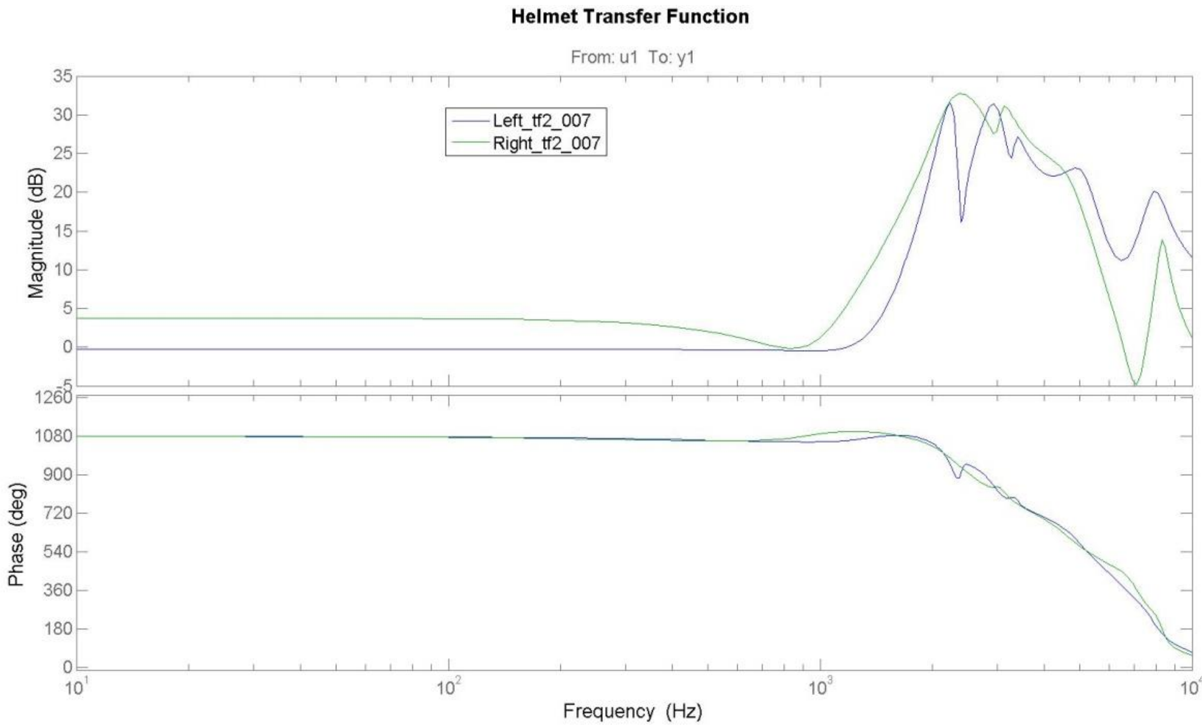


Figure 7: Transfer Function of the SPH5-CF Flight Helmet

The characterization results showed that the dynamic performances of the left and right ear voice paths were generally consistent in terms of both magnitude and phase features. It was important to note that the SPH5-CF flight helmet demonstrated effective amplification to the speech signals only above the frequency range of 1k Hz, while the frequency range below 1kHz was not enhanced at the same magnitude.

Despite the fact that these dynamics might be helpful to attenuate helicopter cabin noise related to the rotor aerodynamics, the fundamental frequency components of human speech (typically a few hundred Hertz) are also attenuated, which may have resulted in degraded quality of voice communication over the SPH5-CF flight helmet. However, since the higher harmonic frequency components of the aircrew voice signals above 1 kHz were effectively transmitted, the intelligibility of the aircrew voice speech was not expected to be reduced significantly.

3.1.3 Validation of the Dynamics of the Voice Transfer Path

To verify the accuracy of the identified dynamics of the voice signal transfer paths, other calibration datasets were used for validation. As an example, the derived transfer functions of the right ear transfer path in two separate calibration datasets are shown in Figure 8.

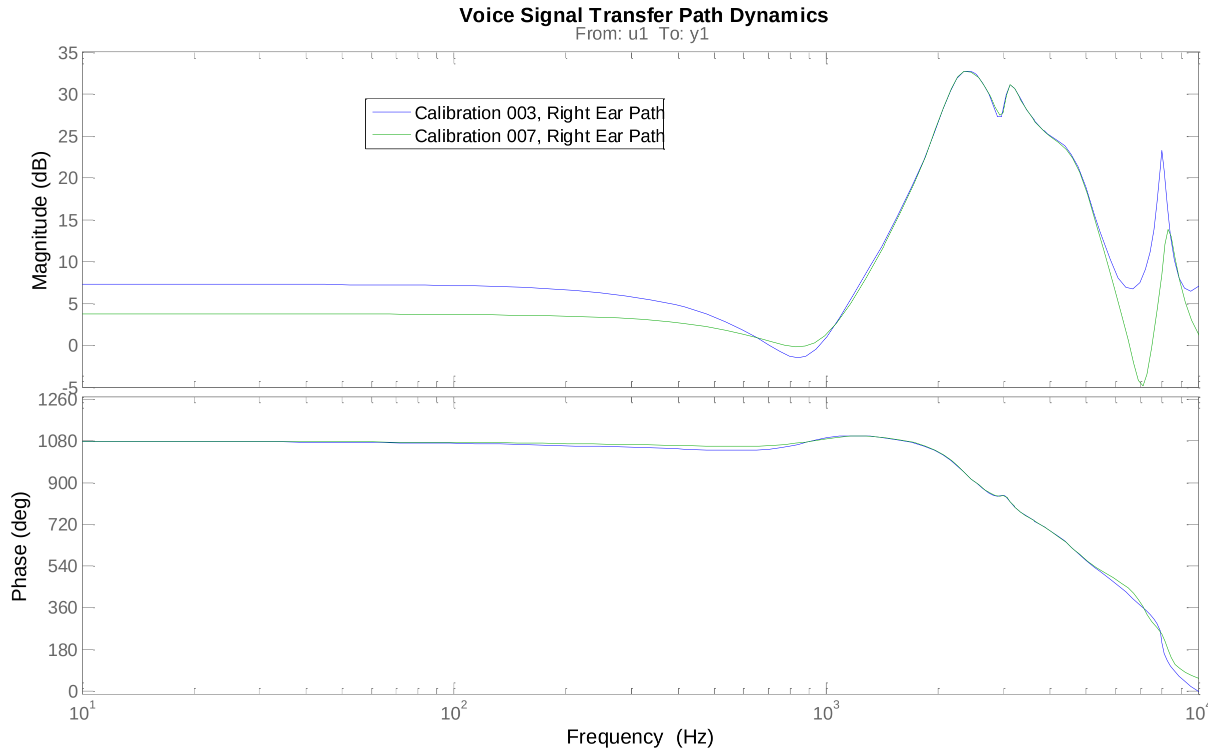


Figure 8: Derived Transfer Functions for the Voice Signal Path, Right Ear

As expected, it is shown that the gain setting of the intercom communication box and the male and female voice used as the simulated voice speech did not affect the results of the characterization. The identified transfer functions in two separate calibration conditions showed consistent characterization.

In addition to the direct comparison of the identified functions, the recorded sound pressure signal waveforms were also used to verify the accuracy of the identified transfer functions of the voice signal transfer paths, and the results are listed in Table 4. The percentage value was calculated by summing up the error at each discrete frequency and calculating the Root Mean Square Error. It is shown that the identified transfer functions of the voice signal transfer path can be used to accurately predict the SPLs in the left and right ear canal locations of the GRAS 45CB acoustic fixture. Therefore, it is logical to estimate the SPLs that the aircrew may be exposed to during flight by measuring the output voltage of the ICS despite the gain settings of the ICS. Naturally, the gain settings of the SPH5-CF flight helmet should be set consistently for ground and in-flight measurements. In this assessment, the SPH5-CF flight helmet was set at the maximum gain in both ground calibration and the flight measurement mission for consistency.It has to be mentioned that this maximum gain set-up is used often by aircrew.

Table 4: Verification of Identified Transfer Functions in Calibration Dataset

Dataset for verification	Transfer Functions in dataset 007		Transfer Functions in dataset 003	
	Left Ear	Right Ear	Left Ear	Right Ear
002	85.1%	81.6%	85.9%	82.0%
003	82.1%	81.4%	82.5%	81.7%
006	95.4%	89.5%	94.9%	90.1%
007	94.0%	88.5%	93.2%	88.4%

3.2 ESTIMATE AIRCREW NOISE EXPOSURE DUE TO INTERCOM COMMUNICATIONS

Due to the difficulties in direct measurement of the aircrew noise exposure solely due to the use of the ICS, the SPLs that the aircrew was exposed to during the flight mission were estimated indirectly.

It was assumed that the transfer function derived from the ground calibration procedure without engines running were also representative of inflight. With the identified transfer functions of the voice signal transfer path between the output voltage of ICS and the left and right ear locations, the SPLs inside the ear canal at eardrum locations of the GRAS 45CB acoustic fixture can be estimated based on the voltages measured at the output of the CH-149 ICS. Therefore, by further considering the acoustic features of the ear canals of the GRAS 45CB acoustic fixture, the SPLs at the aircrew ear entrance locations can be indirectly estimated so that the effect due to the use of helicopter intercom system can be evaluated.

3.2.1 Overview of Voice Signals Recorded from the Intercom System

The recorded voltage of the voice communication signal is shown in Figure 9. The entire duration of the mission was roughly 3 hours, which included three separate operational sections: a start-up section for 2800 seconds, a flight operation section for 7435 seconds and a ground taxi operation section for 765 seconds.

Compared with the typical records of ground calibration signals, as shown in Figure 10, the intercom voice signal recorded on the CH-149 helicopter ICS during the mission showed severe saturation at a relatively low voltage range of +/- 0.2 V. In comparison, the recorded voltage of the voice communication signal exceeded +/- 1 V in the ground calibration procedure, and there was no saturation observed. It is important to note that the severely saturated voice signal may have introduced strong background noise to negatively affect the quality of aircrew voice communication.

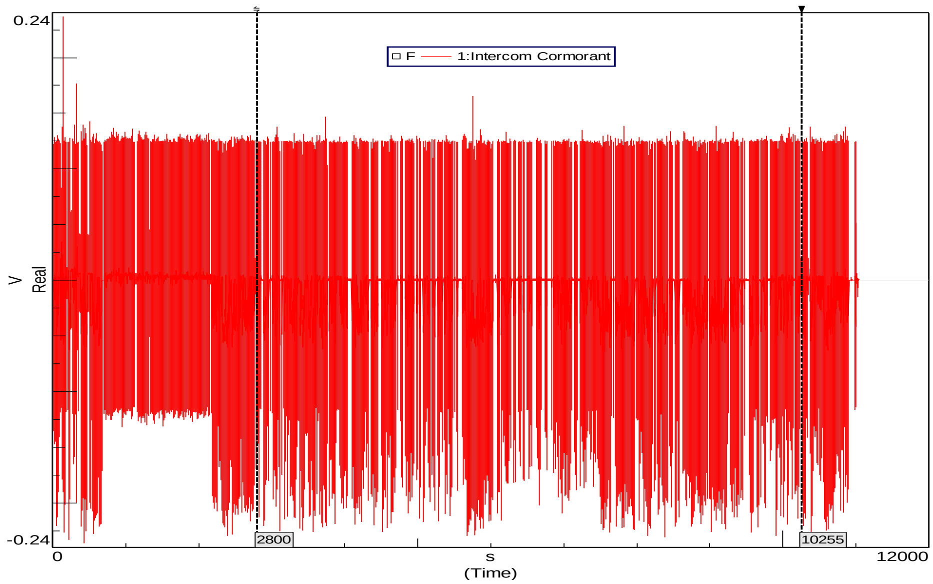


Figure 9: Voltage Signal of Voice Communications, During Flight

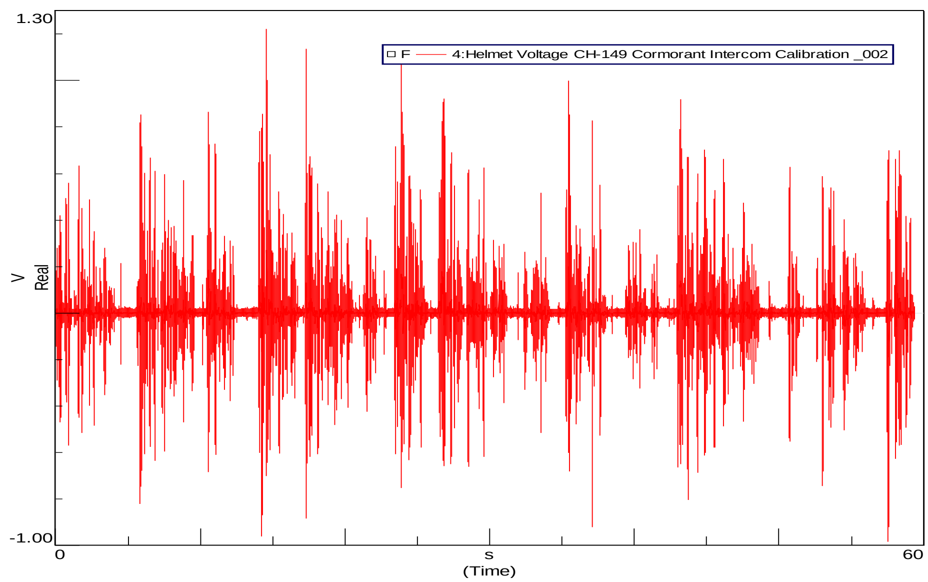


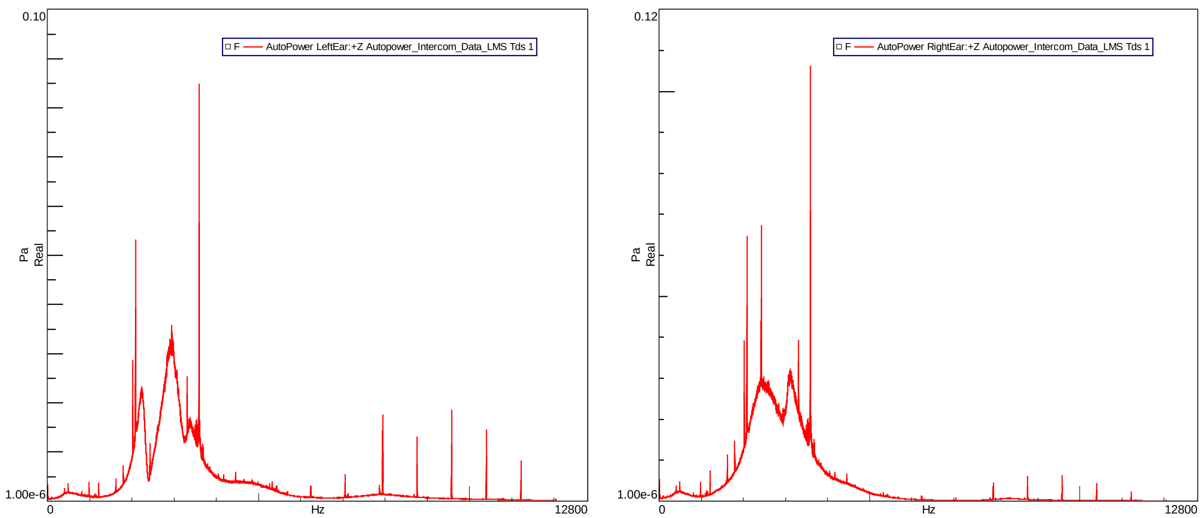
Figure 10: Voltage Signal of Voice Communications, During Ground Calibration

3.2.2 Spectral Analysis of the CH-149 Cormorant Voice Signals

Averaged spectral analysis of the recorded voltages revealed that multiple significantly high peaks of tonal noises existed in the inflight voice signal of the CH-149 ICS, while the tonal noise issue was less obvious in the recorded signal during ground calibration procedure, as shown in Figure 11, Left Ear Sound Pressure Spectrum b. Right Ear Sound Pressure Spectrum

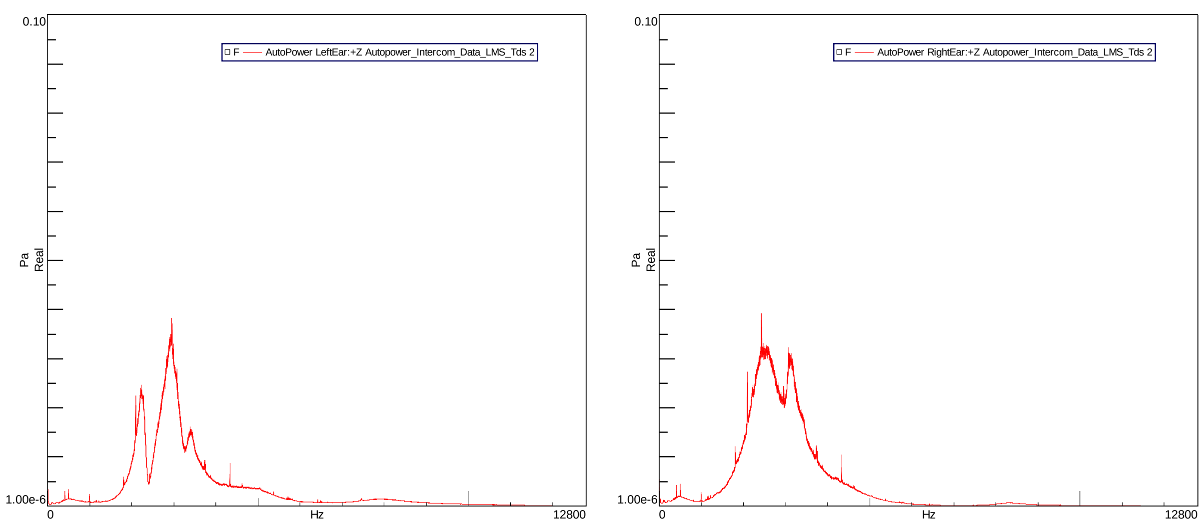
Figure 12, Left Ear Sound Pressure Spectrum b. Right Ear Sound Pressure Spectrum

Figure 13 and Figure 14. High amplitudes of the multiple tonal peaks may be related to the squelch issue, and the saturated voice signal may be related to the strong cabin noise of the CH-149 ICS. The data recorded during the cabin noise measurement mission have only provided enough information to observe a number of issues. However, the root causes for the severely saturated voltages are hard to identify without additional data recording and analysis.



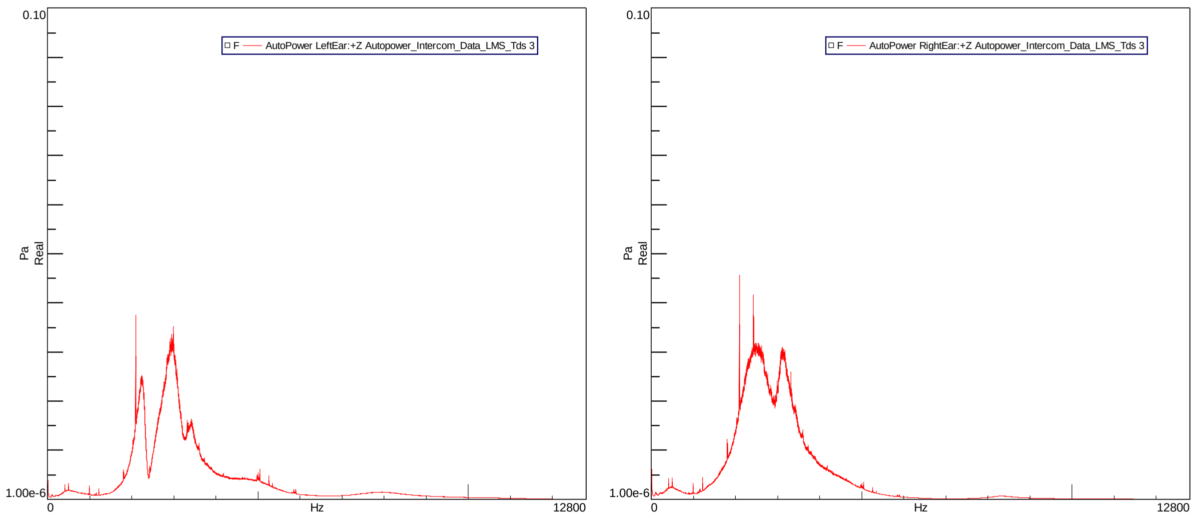
a. Left Ear Sound Pressure Spectrum b. Right Ear Sound Pressure Spectrum

Figure 11: Spectral Plots of Voice Communication Signals in the Start-up Operation Section



a. Left Ear Sound Pressure Spectrum b. Right Ear Sound Pressure Spectrum

Figure 12: Spectral Plots of Voice Communication Signals in the Flight Section



a. Left Ear Sound Pressure Spectrum   b. Right Ear Sound Pressure Spectrum

Figure 13: Spectral Plots of Voice Communication Signals in the Taxi Section

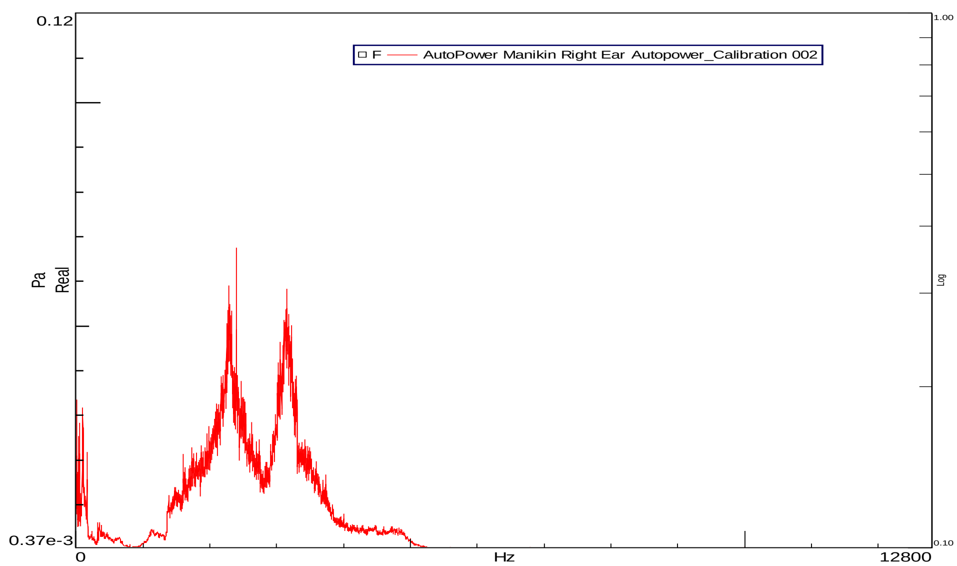
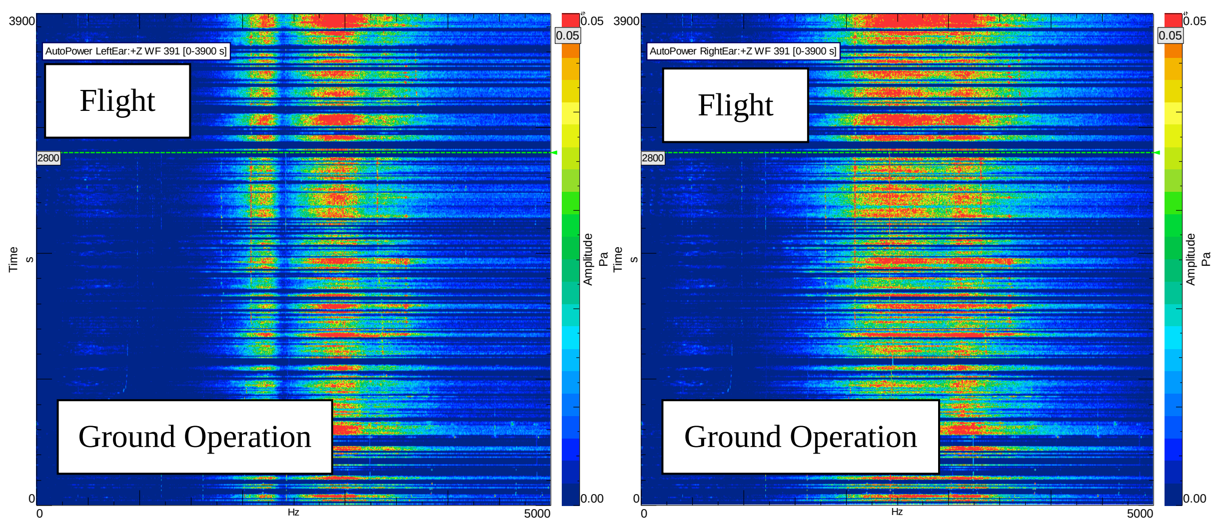


Figure 14: Spectral Plots of Voice Communication Signals from Ground Calibration

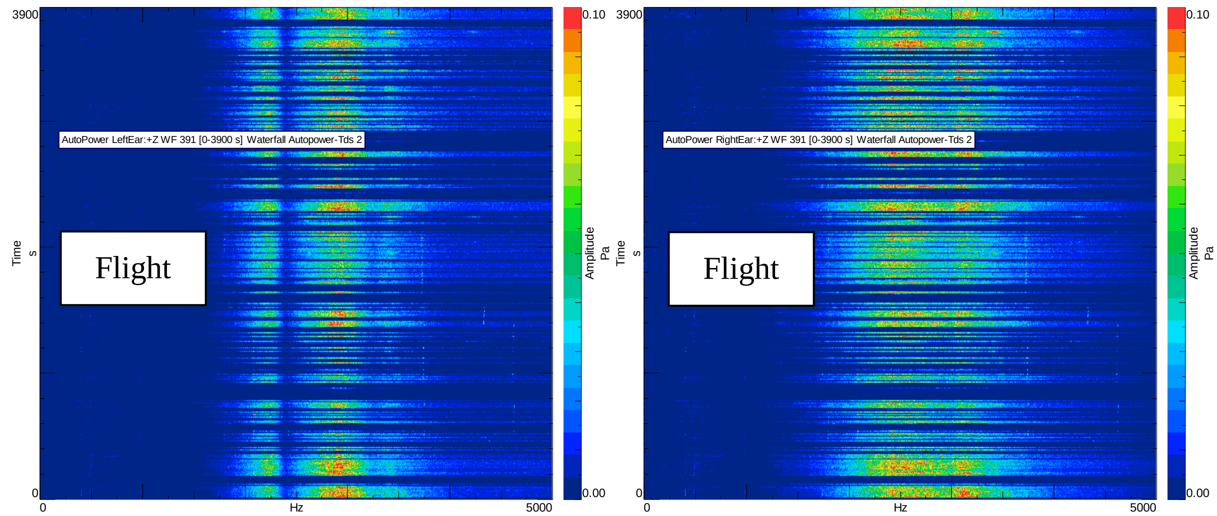
Waterfall analysis were generated to identify the flight segments associated with the tonal peaks during the flight mission; the results for start-up, flight and taxi sections are shown in Figure 15, Figure 16 and Figure 17, respectively. It was shown that multiple tonal noise peaks existed in the ICS signals in both ground calibration and flight operations. However, compared to the signals in ground calibration procedure, significantly higher peak amplitudes and more tonal frequencies were identified for the CH-149 helicopter during the start-up and taxi sections, while the tonal noise issue was less severe during the flight section. Specifically, it was observed that:

- Dominant energy of the ICS existed between 1.5 and 4 kHz. Fundamental frequencies of voice speech below 1 kHz seemed to be suppressed. This was consistent with the observations in the ground calibration procedure. Despite the degraded quality of the voice signal due to this frequency dependent signal suppression, the speech intelligibility may not be significantly affected.
- A few tonal noise frequencies were identified in both the ground calibration procedures and the CH-149 flight mission, such as at the 1.6 kHz, 2.4 kHz and 3.7 kHz.
- In addition to the existing tonal frequencies, a few unique noise tones existed only in the start-up and taxi sections, such as at the 1.8 kHz, 2.1 kHz and 3.3 kHz etc.
- In comparison, the tonal noise issue was not significant during the flight section, suggesting that the tonal noises could be related to landing operation equipment, ground operation or other electric interferences.
- The strong tonal noises may be related to the squelch issue.
- Considering the negative impact, the root causes for the severe saturation of the voice signal should be investigated to verify if this is unique to one station, one vehicle, the measurement method or rather a common issue within the RCAF CH-149 Cormorant helicopter fleet.



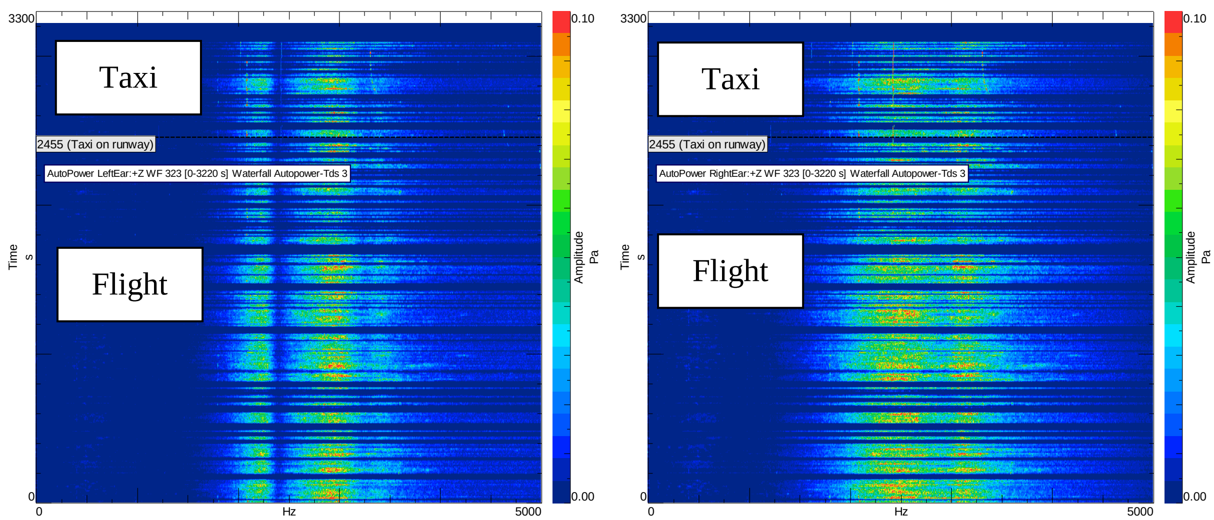
a. Left Ear SPL Calculation　　　b. Right Ear SPL Calculation

Figure 15: Waterfall Plots of ICS SPLs in the Stat-up Section



a. Left Ear SPL Calculation b. Right Ear SPL Calculation

Figure 16: Waterfall Plots of ICS SPLs in the Flight Section



a. Left Ear SPL Calculation b. Right Ear SPL Calculation

Figure 17: Waterfall Plots of ICS SPLs in the Taxi Section

3.2.3 Assessment of Aircrew Noise Exposure

1. Aircrew Noise Exposure at the Ear Canal Location

Based on the recorded voice communication signal and the derived transfer functions for the left and right ear channels of the intercom devices including the SPH5-CF flight helmet, the noise levels at the aircrew eardrum location can be evaluated; the results are listed in Table 5.

Table 5: Averaged Noise levels due to the Intercom signal

OAPSL	GRAS 45CB Ear Drum Location (dB)			Ear Entrance Location (dB)		
	Left	Right	**Averaged**	Left	Right	**Averaged**
First (0-3900s)	93.1	95.3	**94.3**	80.5	83.0	**81.9**
Second (3901-7800s)	93.2	93.2	**93.2**	80.4	82.9	**81.9**
Third (7801-11020s)	93.1	95.3	**94.4**	80.5	83.1	**82.0**
Averaged (11020s)	93.2	94.7	**94.0**	80.5	83.0	**81.9**

Since the recorded voice signal data duration lasted for nearly three hours, the entire data section was cut into three separate sections, as indicated as First, Second and Third in Table 5, respectively. Each section was approximately one hour in duration. It is important to note that 2800 seconds of the First section was related to the ground start-up operations, while the last 765 second of the Third section was related to the taxi run of the CH-149 vehicle on the run way.

The evaluation results indicated that usage of the CH-149 ICS introduced significant noise levels to the aircrew at the recorded station. On average, the OSPL at the aircrew ear canal location were estimated as 94.0 dB. 1/3 Octave plots for the Third section are shown as an example in Figure 18. It is shown that the dominant noise energy occurred between 1.25 kHz and 4 kHz frequency range, and the OSPL reached 94.4 dB at the aircrew eardrum location.

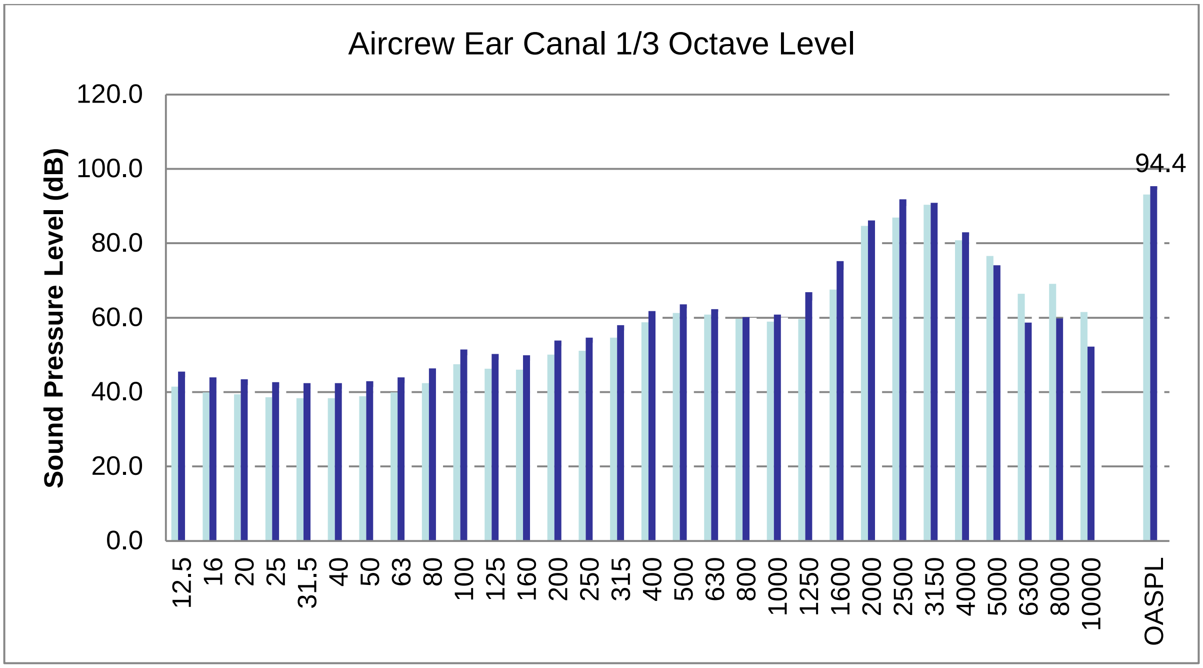


Figure 18: Example 1/3 Octave Spectrum of the ICS SPL Calculations

There was a slight difference in the noise levels of the left and right ear canal locations. The SPL was 93.2 dB at the left ear canal and 94.7 dB at the right ear canal. This difference was possibly related to the imperfect fit of the SPH5-CF flight helmet on the GRAS 45CB acoustic fixture. This led to a mismatch in the identified model for the left and right speaker channels in the ground calibration procedure. It is common for helmet fittings to impact SPL measurement results.

On average the SPLs in the three separate sections were relatively consistent in terms of magnitude. However, it was noted that the SPL in the Second section, which was entirely related to the flight conditions, was about 1.1 dB lower than the First and Third section. This was possibly due to the effect of significant tonal noise peaks as observed in the ground start-up operations and taxi run sections.

2. Aircrew Noise Exposure at the Ear Entrance Location

The current standards apply noise limits at the human ear entrance location only. The ground calibration procedure enabled the identification of SPLs at the eardrum locations. Therefore, the transfer function of the GRAS 45CB acoustic fixture (eardrum SPL vs entry of the ear SPL, under an earmuff) for a 3M headset was taken into account in order to estimate the aircrew noise exposure at the ear-entrance. The acoustic transfer function of the ear canal on the GRAS 45CB acoustic fixture with a 3M earmuff has been characterized previously, as shown in Figure 19. The characterization results were used in this assessment.

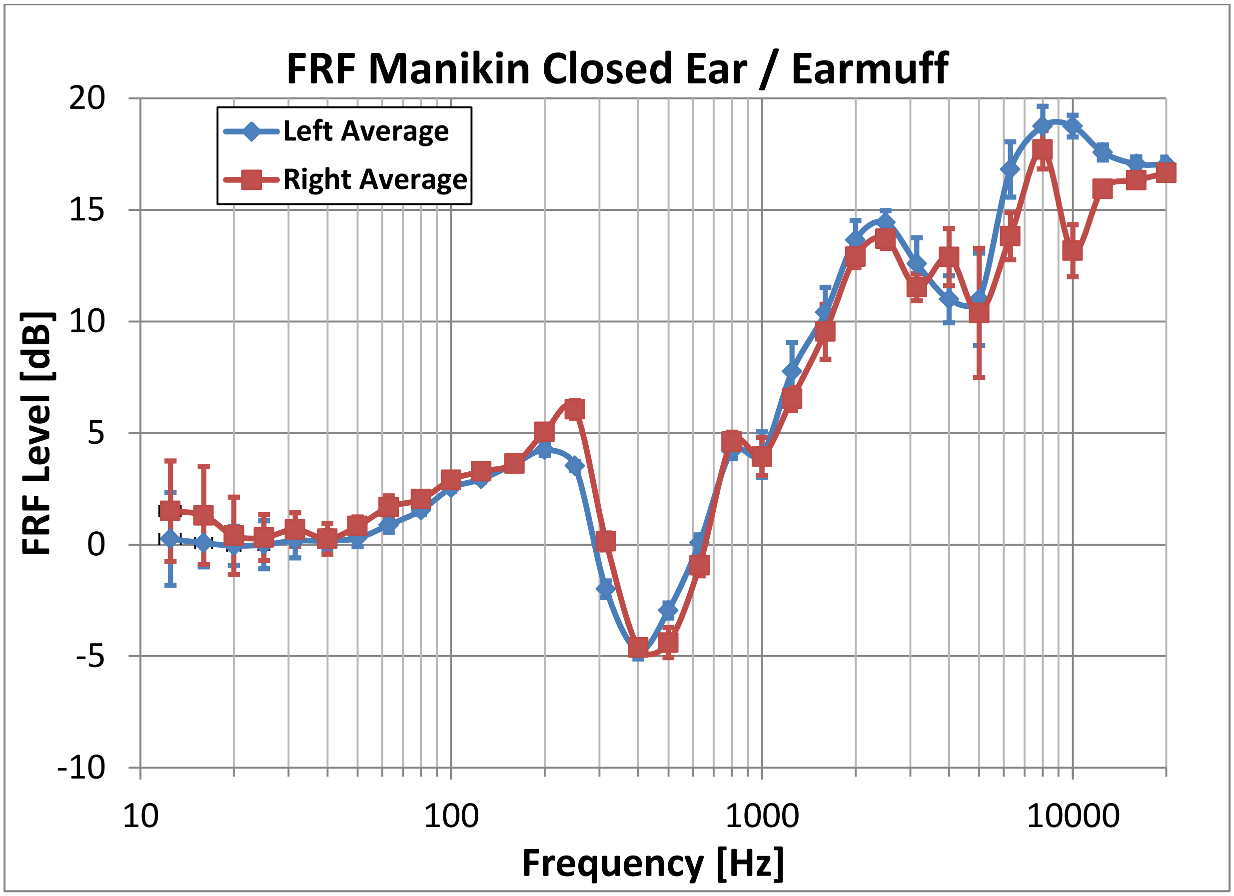


Figure 19: GRAS 45 CB Acoustic Fixture Closed-Ear Canal Transfer Function

Considering the ear canal transfer function of the GRAS 45CB, the SPLs at the ear-entrance locations were estimated; the results are shown in Table 5. On average, the OSPL due to the use of the CH-149 ICS was 81.9 dB in the mission. The SPLs at the left and right ear entrances showed a difference of 2.5 dB, indicating an improper proper fit of the flight helmet may affect the aircrew noise exposure levels during flight missions.

Please note that in Table 5 the estimated SPLs only account for the CH-149 intercom usage, and the noise dose due to cabin noise was not accounted for. The effective aircrew noise dose will need to be determined based on the exposures to the cabin noise as well as the use of the ICS.

3.2.4 Assessment of Intercom Communication Intermittency

Assessment results indicated the aircrew were exposed to OSPL in the vicinity of 81.9 dB due to the use of the aircraft ICS. The above assessment provided a temporally averaged OSPL in the three separate operational sections for reference.

Considering the fact that the ICS is used intermittently, it is understood that the SPLs will change with time throughout the flight. The values presented in Table 5 correspond to OSPLs temporally averaged throughout the entire mission. Specifically, the OSPL will be higher when aircrew are communicating and lower when there is no ICS communication.

It is clearly shown that SPL during the aircrew talk over the CH-149 intercom devices was relatively significant. For a selected audio section with voice communications, the SPL reached 87.3 dB (entrance to the ear). In comparison, the averaged noise level was only 81.9dB over the entire flight. Proper tuning and use of the CH-149 ICS including the flight helmet is important to provide effective hearing protection to the helicopter aircrew in SAR missions.

These calculations did not account for aircraft cabin noise. Aircrew actual noise exposure will be a combination of aircraft cabin noise, the protection afforded by the hearing protector and ICS SPLs. Unweighted, unprotected OSPL cabin noise could reach as high as 121 dB in the CH149 Cormorant in-flight. When protected with the SPH5-CF pilot helmet, A-Weighted, protected CH-148 cabin noise in the absence of ICS OSPLs did not exceed 84 dB(A) [**2**].

It is observed that cabin noise provides the most significant source of noise exposure for aircrew. However, for aircrew properly fitted with a hearing protector listening to the aircraft ICS set to maximum volume, it is possible that the ICS system will increase the overall noise exposure dose. To quantify the increase in noise exposure due to the ICS system, further investigation will be required: Replication of the ICS signals in a cabin noise environment using the NRC ICS replication system can be performd as discussed in Section 6.0: Appendix. Otherwise, integration in the inflight cabin noise measurement test procedure of the GRAS 45CB acoustic test fixture will provide the direct objective results.

4.0 CONCLUSIONS AND SUGGESTIONS

This report presented the technical methods and assessment results of aircrew noise exposure level calculations due to the use of CH-149 Cormorant helicopter ICS in a typical SAR mission.

4.1 CONCLUSIONS

The recorded CH-149 ICS voice signal exhibited a severe signal saturation issue, with the maximum voltage less than 0.24 V. The saturated ICS signals may have contributed to the strong background noise in the aircrew intercom voice communication. The squelch issue was confirmed in the ICS signal, and was at times observed to be severe; audio playback of the recorded voice signal also confirmed this issue. Spectral analysis of the CH-149 ICS signals indicated that the squelch issue was related to strong tonal noises at multiple discrete frequencies. Further spectral analysis indicated that higher squelch levels and multiple tonal frequency peaks mainly existed in the ground start-up and taxi sections of the mission, which may have adversely affected the quality of aircrew ICS communications. In comparison, the tonal noise peak issue was less severe in the flight section. However, strong background noise still existed in the ICS signals, which may be related to the ICS saturation issue.

Despite the ICS signal saturation issue, analysis of the recorded ICS signal showed that the CH-149 intercom device delivered relatively high levels of noise to the aircrew during a flight mission. The CH-149 ICS introduced an averaged non-weighted OSPL of 81.9 dB at the aircrew ear entrance location during the measured ground operation and flight mission. Specifically, the non-weighted OSPL reached 87.3 dB during ICS communications. However, these calculations did not account for aircraft cabin noise; inclusion of aircraft cabin noise is required to assess the significance of the ICS system to the full aircrew noise exposure dose.

It is important to note that the dominant noise energy of the CH-149 ICS occurred in the audible frequency range between 1 kHz and 4 kHz. Combining the helicopter cabin background noise and intercom communication noise, the aircrew may be effectively exposed to higher noise levels. The actual noise exposure of the aircrew will need to be determined depending on the hearing protection equipment used, aircrew stations and noise exposure time in representative missions.

Based on this investigation, it was concluded that the CH-149 helicopter ICS may introduce noise sufficiently to increase the aircrew noise exposure dose in flight missions. The aircrew effective noise dose needs to be determined based on both the intercom noise and cabin background noise exposures. Proper selection of hearing protection devices, adequate configuration and use of the helicopter intercom devices are important factors to alleviate the risk of hearing damage to the aircrew in CH-149 flight operations.

4.2 SUGGESTIONS

Assessment results indicated that the voice saturation and squelch issues may negatively affect the quality of aircrew voice communications. However, all the analysis and evaluation presented in this report was performed based on the voice signal recorded at one specific aircrew station in a representative mission of a selected CH-149 Cormorant helicopter. Therefore, it is important to continue the investigation:

1. To identify the root causes for the voice voltage saturation issue that may lead to strong background noise in the aircrew voice communications;
2. To identify the root causes for the multiple tonal peaks in the voice voltage signal that may be related to the squelch issue in the CH-149 helicopter aircrew voice communications;
3. To investigate the effect of the combination of ICS noise and aircraft cabin noise on the noise exposure for the aircrew.
4. To investigate if similar intercom signal saturation, squelch noise issues also exist in other RCAF aircraft.

Access to CH-149 intercom data would be invaluable to continue this investigation. It will be difficult to assess the squelch and signal saturation without independent data sets from different aircraft and aircrew stations. In addition, the estimation of aircrew noise exposure dose due to the combination of ICS communications and cabin noise will be greatly simplified with the flight of the GRAS 45CB acoustic test fixture. Alternatively, measurement of inflight voice communication voltage again will provide an opportunity to assess the signal quality and enable utilization of the NRC intercom replication facility as discussed in Section 6.0: Appendix.

5.0 REFERENCES

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6.0 APPENDIX: LABORATORY INTERCOM REPLICATION SYSTEM DEVELOPMENT

This appendix discusses the development of a ground-based Laboratory Intercom Communication (ICS) system and Sound Pressure Level (SPL) assessment system at NRC.

6.1 INTRODUCTION

The quantitative assessment of aircrew noise exposure is a well-defined field of study. Many standards have been developed on the subject of in-flight cabin noise measurement and hearing protection performance evaluation, such as the Canadian Z94.2-14 [**3**], International ISO 4869-1 [**4**] American ANSI S12.42-2010 on hearing protection [**5**] and International ISO 5129 on inflight noise measurements [**6**]. These standards provided technical methods to measure the cabin noise environment in flight and assess the Insertion Loss (IL) performance of Hearing Protectors (HPs). The combination of the HP IL performance and cabin noise enables the objective and consistent estimation of aircrew noise dosage in alignment with the Canadian Aviation Occupational Health and Safety Regulations [**1**].

However, the subject of the contribution of aircraft intercom communications to aircrew overall noise dosage and its impact on aircrew hearing loss is less defined. Specifically, the acoustic energy related to intercom communications is currently neglected by the standard noise exposure assessment and estimation of aircrew noise dosage. As discussed in the main report (LTR-FRL-2018-0025), there exist feasible technical approaches to quantify these noise effects due to the use of aircraft intercom communication devices. As part of NRC's effort to assess the contribution of aircraft intercom communications, a ground-based laboratory intercom replication system was developed. This system enables an objective and consistent assessment of intercom noise dosage on the aircrew in conjunction with the use of different HP systems without the need to assess each HP through expensive and complex flight. Instead, an intercom ground calibration procedure will be completed for each aircraft to match the intercom settings.

6.2 PRELIMINARY NRC FALCON 20 MEASUREMENT

A preliminary investigation to assess the contribution of aircrew intercom communications to the overall noise dosage was performed in the NRC Dassault Falcon 20's cabin. The test procedure utilized the following equipment:

- Two speakers for noise reproduction
- G.R.A.S. 45 CB acoustic test fixture for acoustic measurement
- Two David Clark H10-26 David Clark headsets for intercom system input/output

- The intercom communication system on the NRC Dassault Falcon 20 aircraft

The test layout is shown in Figure 20. The procedure involved 4 distinct test conditions:

1. Ambient (background) noise
2. Ambient noise with intercom communications
3. Steady level flight (SLF) replication noise (replicated from the speakers)
4. SLF replication noise with intercom communications

Additional test conditions involved permutations of alternative human "intercom sound sources" and alternative cabin noise audio playback files.

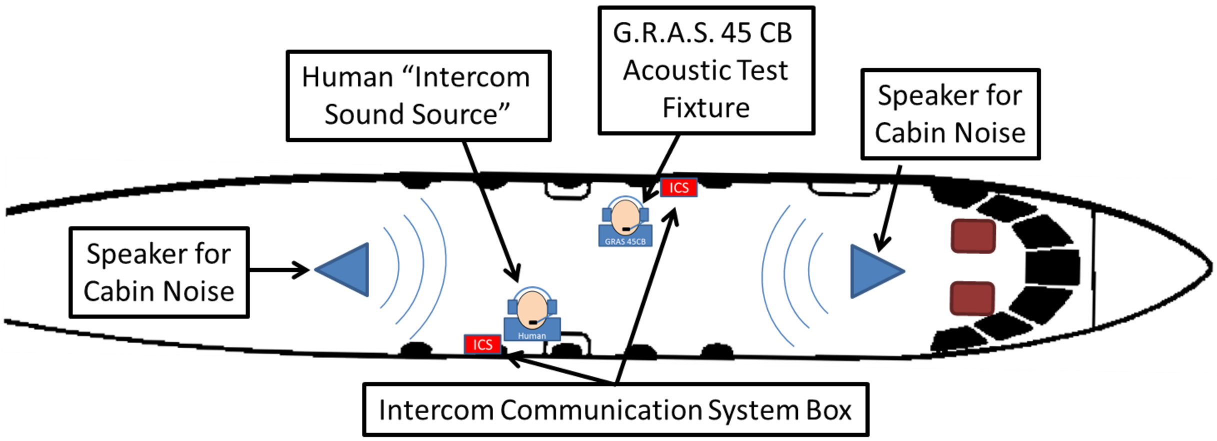

Figure 20: Preliminary Intercom Investigation Test Setup on NRC Dassault Falcon 20

Example results are shown in Figure 21. The green and blue 3rd octave band bars correspond to the left and right ear measurements of the GRAS 45 CB acoustic test fixture with a fitted headset and cabin noise replicated with speakers. The pink and light blue curves correspond to the left and right ear measurements of the GRAS 45 CB acoustic test fixture with a fitted headset, replicated cabin noise and intercom communications.

The fundamental frequency of the human voice typically varies, but studies show that the average is 239 Hz or less [**7**]. Notice that the aircraft intercom communication contribution was primarily limited to a range of 500 Hz to 6300 Hz; thus the aircraft ICS may filter out certain low frequency components of the human voice.

The A-weighted Overall Sound Pressure Level (OSPL) measured at the GRAS 45 CB acoustic test fixture eardrum was calculated and averaged for the various experimental conditions. It was observed that the intercom noise contribution to the OSPLs was sensitive to the different audio files used to replicate the aircraft cabin noise, as listed in Table 6. In the preliminary assessment using two voice files, the use of the aircraft ICS effectively increased the aircrew overall noise exposure level by 5.1 and 10.2 dB(A), respectively. Therefore, it was determined that aircraft intercom communications had the potential to contribute significantly to an aircrew's noise dosage.

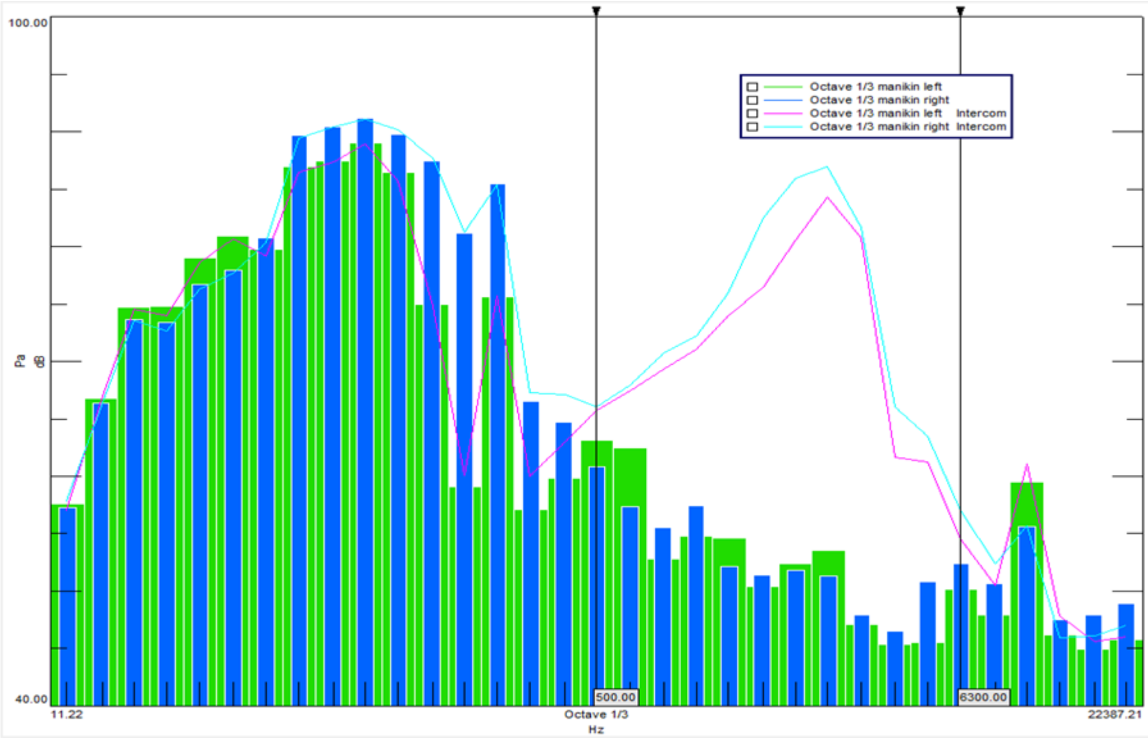

Figure 21: Preliminary Intercom Investigation: Cabin Noise with Speech, Linear Weighted 3rd Octave Band Logarithmic Sound Pressure Levels [dB]

Table 6: Preliminary Intercom Investigation Results Summary

Cabin Noise File	Average OSPL no intercom	Average OSPL with intercom	Difference
File A	82.68 dB(A)	87.74 dB(A)	5.1 dB(A)
File B	79.14 dB(A)	89.39 dB(A)	10.2 dB(A)

6.3 LABORATORY INTERCOM REPLICATION SYSTEM

The NRC ground-based laboratory intercom replication system was developed to reduce the cost in the investigation of intercom communication contributions to the aircrew noise exposure without requiring extensive flight testing on the aircraft.

The schematic flowcharts presented in Figure 22 show the technical steps of the aircraft intercom replication in the laboratory. Three primary steps are outlined.

1. **Ground Measurement**. The aircraft intercom system voltage output and headset SPLs are measured. In this way a transfer function is developed with voltage as the input and

SPLs as the output. The aircraft is not in flight, but additional equipment and cables are brought on board for the calibration.

2. **Inflight Measurement**. The voltage output of the aircraft ICS is recorded in flight. The only equipment required for flight is the data acquisition system and intercom cable. Thus regular flight activities can take place uninhibited.
3. **Calibration and Replication**. The ground measurement data and derived transfer function (from step 1) are used to calibrate the system. This is necessary to account for the transfer function differences in helmets, ICSs and utilizing the aircraft intercom voltage output as the ground based intercom voltage input. With the system calibrated, in-flight voltage data can be replicated and a variety of headsets and flight conditions can be analysed.

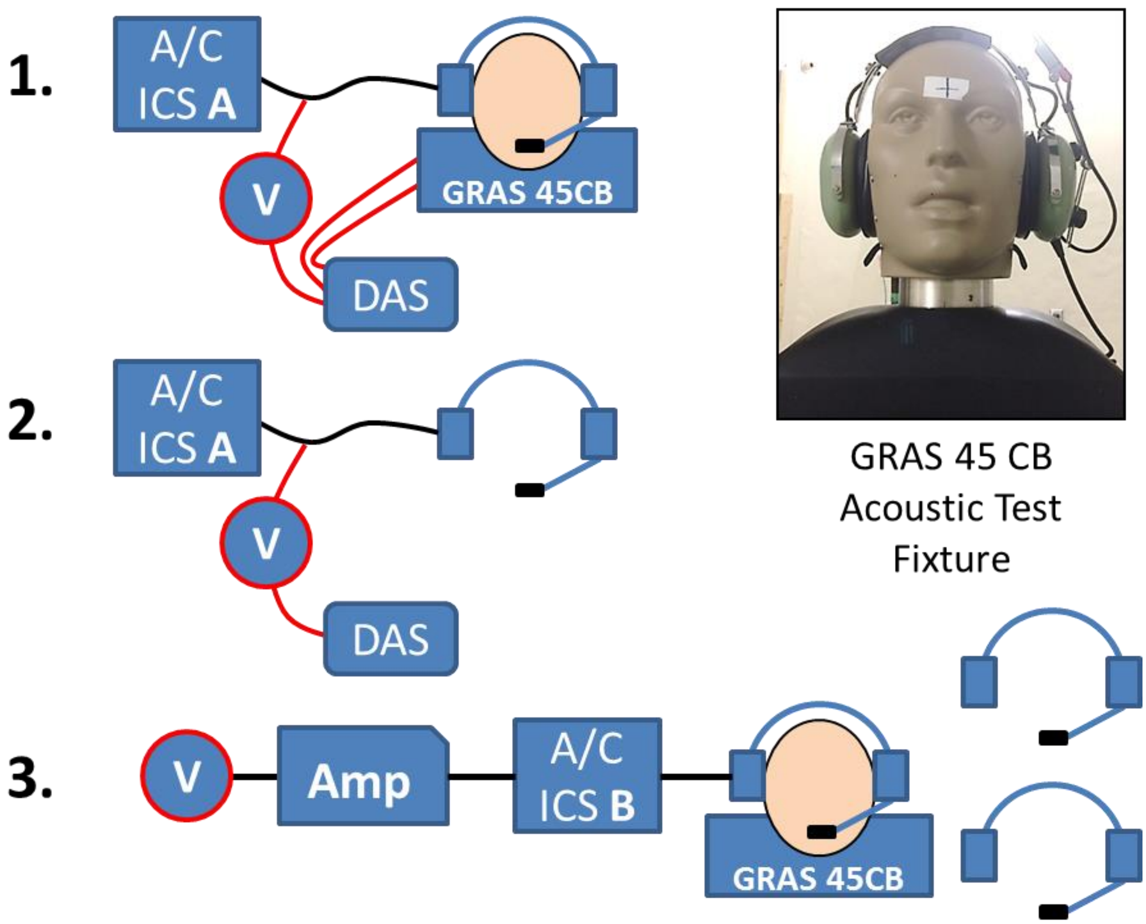

Figure 22: Intercom Ground Replication Process

Currently the NRC laboratory intercom replication system is capable of replicating intercommunication SPLs and voltages. Results will be shown in the following section. Further development effort is required for the calibration step and furthering comprehension of the variable parameters of an inflight aircraft ICS.

6.4 GROUND BASED INTERCOM REPLICATION SYSTEM RESULTS

This section reviews the cabin noise replication results of a number of NRC aircraft as part of the commissioning procedure. The replication process used steps 1 and 3 as indicated in Figure 22. Specifically, both voltage levels and SPLs were measured in the cabin of the tested aircraft. The voltage was post-processed and used as an input to the ICS, and the helmet settings and various gains were adjusted to match the measured SPLs in the aircraft cabin.

In addition to the CH-149 project discussed in the main report (LTR-FRL-2018-0025), three different NRC aircraft were used throughout the intercom replication system development, including the NRC: Bell 205 Helicopter, Convair 580 Turboprop Aircraft and Dassault Falcon 20 Jet.

Two ground investigations were completed for each aircraft: one used a pre-recorded voice signal and the other used a sine-sweep played through a speaker unit. The intention was to model the performance of the ICSs as they were intended (voice signals) and to model the full frequency range of the ICSs (sine-sweeps). The six permutations are incorporated in Figure 23 to Figure 28, in which the red curves correspond to the intercom voltage measured on-board the aircraft on the ground; the blue curves correspond to the SPLs measured by the GRAS 45 CB acoustic test fixture when wearing a helmet or headset. Please note that the GRAS 45 CB acoustic test fixture wore the same headset for both the aircraft measurement and laboratory replication; however, the laboratory application objective is to operate independent of specific hearing protectors in the future. The solid curve represents the measured value from the aircraft and the dotted curve represents the replicated value with the laboratory intercom replication system after calibration.

Figure 23 and Figure 24 exhibit the Bell 205 investigation. It can be observed that the voltage levels were replicated with high accuracy between 250 Hz and 4000 Hz inclusive; the SPLs were replicated accurately up to 4000 Hz, inclusive. It was interesting to note that despite a relatively poor replication in voltage below 250 Hz, the SPLs maintained strong consistency. This was logical for the voice input of the aircraft ICS as the dominant energy of the voice communication signal was attenuated. Above 4000 Hz, the replication voltage accuracy was reduced; this was primarily due to the differences in the transfer functions of the aircraft and laboratory ICSs as well as the lack of signal excitation at those frequencies. As depicted in Figure 22 step 3, a signal amplifier was utilized to account for gain differences in the ICSs voltages; this was applied as a linear gain across all frequencies. The amplifier did not apply a frequency dependent gain, thus did not account for different ICS Frequency Response Functions (FRFs).

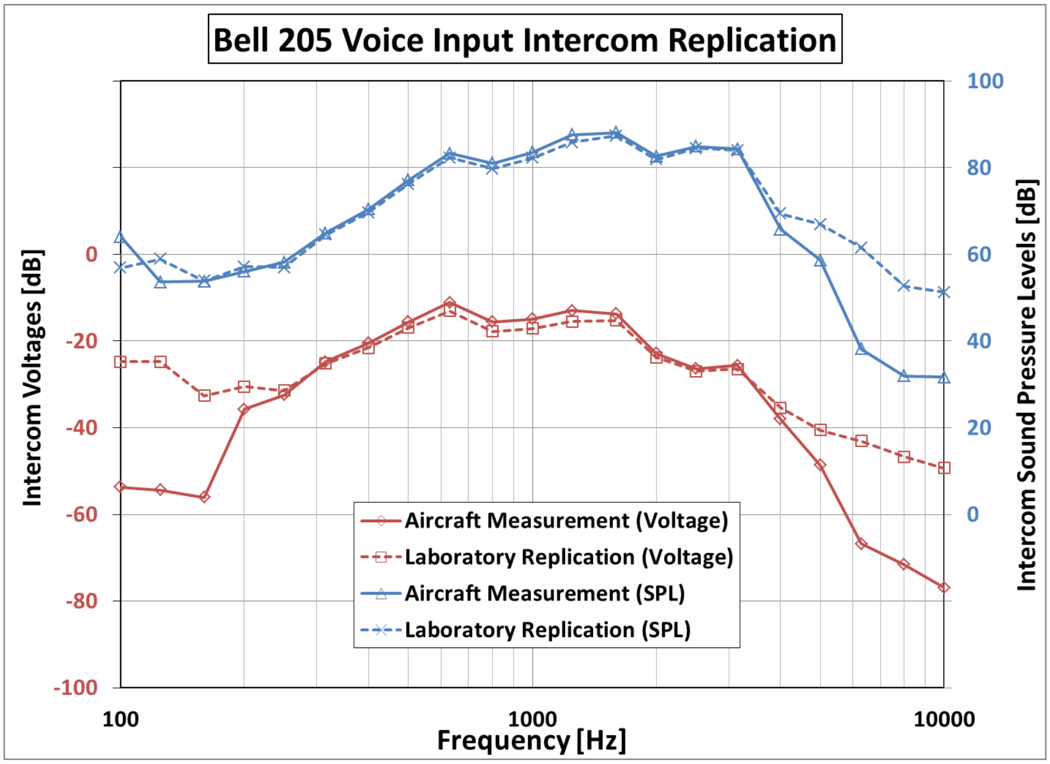

Figure 23: Bell 205 Intercom Replication with a Voice as Input

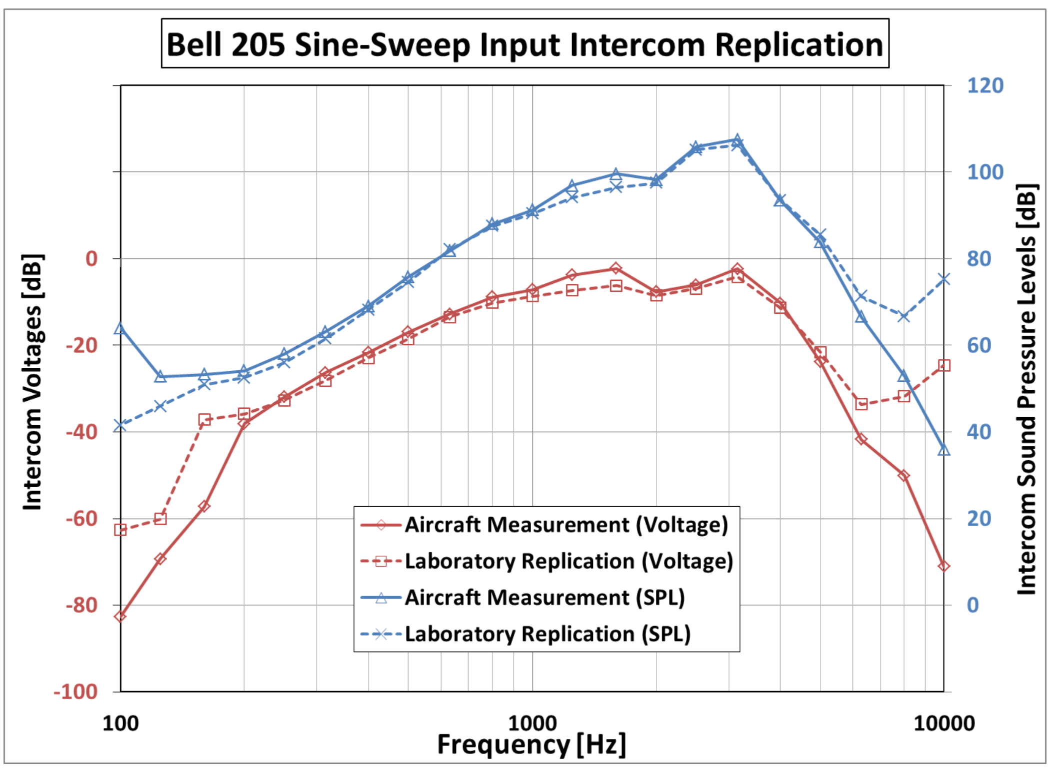

Figure 24: Bell 205 Intercom Replication with a Sine-Sweep as Input

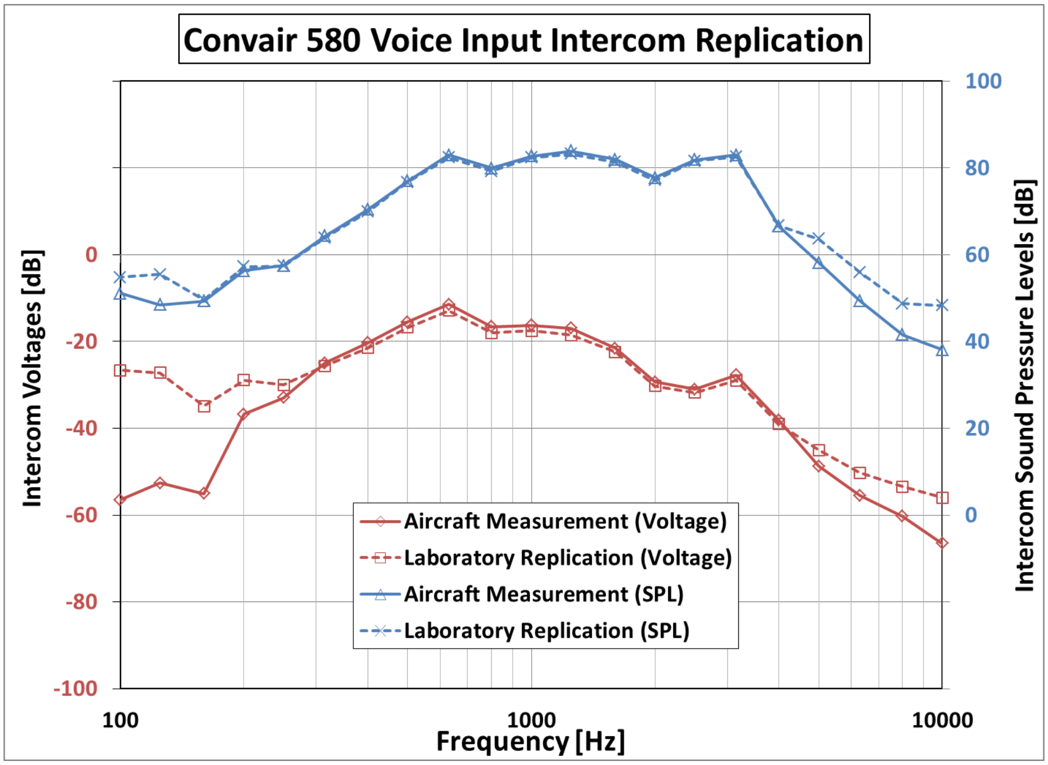

Figure 25: Convair 580 Intercom Replication with a Voice as Input

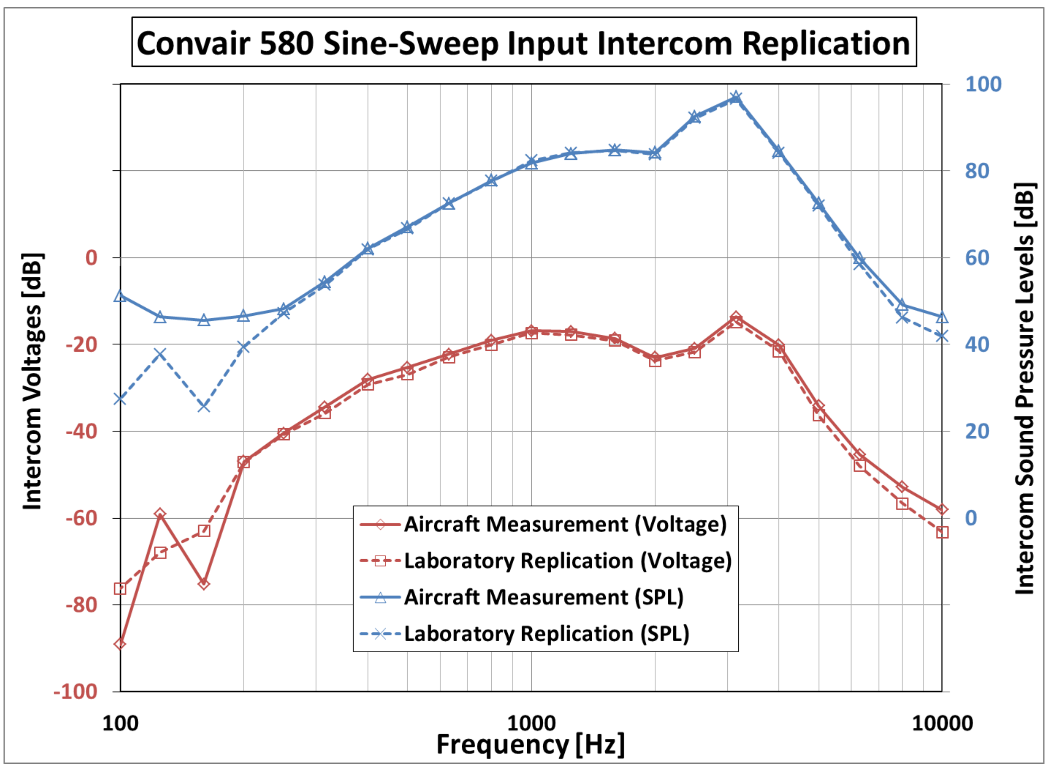

Figure 26: Convair 580 Intercom Replication with a Sine-Sweep as Input

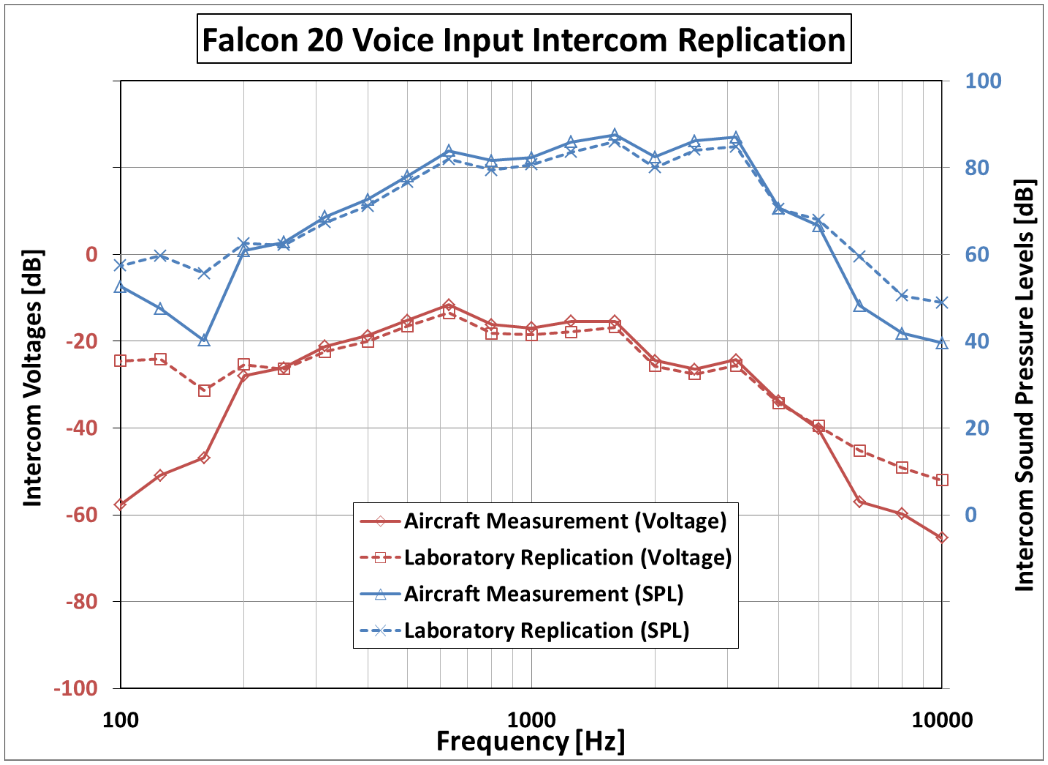

Figure 27: Falcon 20 Intercom Replication with a Voice as Input

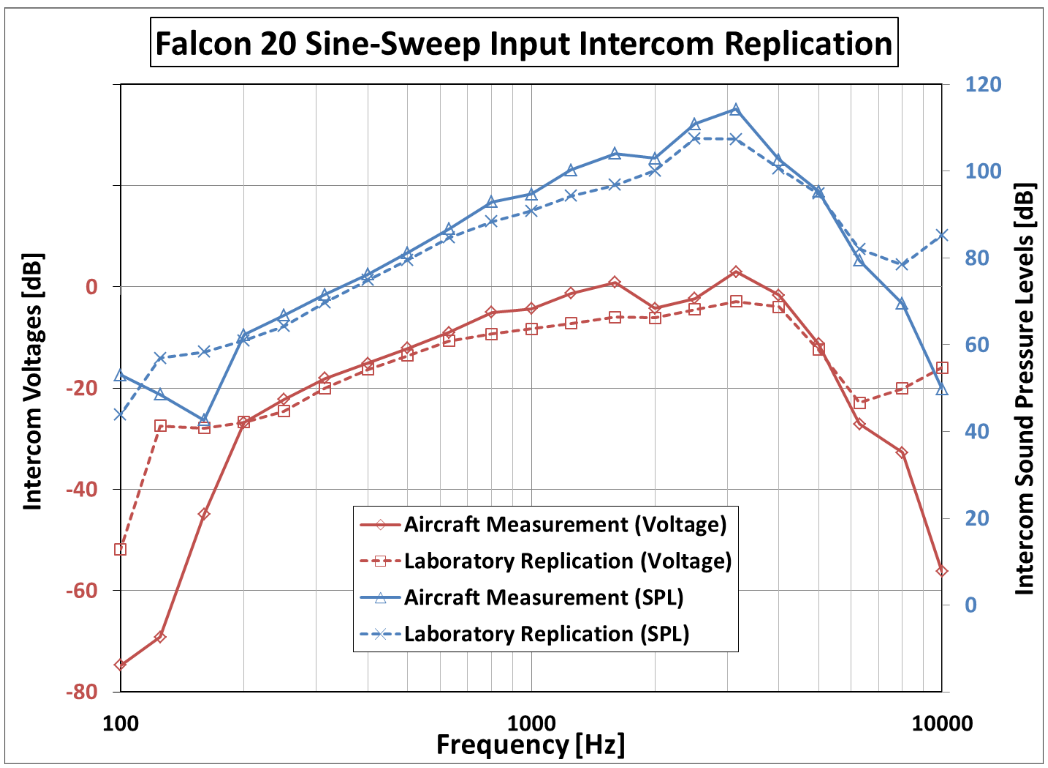

Figure 28: Falcon 20 Intercom Replication with a Sine-Sweep as Input

The investigation of Convair 580 aircraft intercom data exhibited superior performance results than the Bell 205 investigation. Good sound power replication performance was obtained between the frequency range of 200 Hz and 5000 Hz.

The investigation of the Falcon 20 aircraft noise replication exhibited similar performance as the Bell 205 investigation.

The investigation on the three NRC aircraft indicated that the FRFs were comparable between the laboratory ICS and the three aircraft ICS, with larger differences potentially occurring at the frequency extremities of analysis, namely near 100 Hz and 10 kHz. The measured FRF of the laboratory ICS is shown in Figure 29 as a reference. It can be observed that the system maintained a relatively flat gain of -5dB from approximately 200 Hz to 4000 Hz, and there was a slight attenuating curve approaching up to 10 kHz. More noticeable was a sharper attenuation below 200 Hz indicative of a system high-pass filter or dynamic behaviour of that nature. This behaviour was in line with the results obtained in the three aircraft investigations.

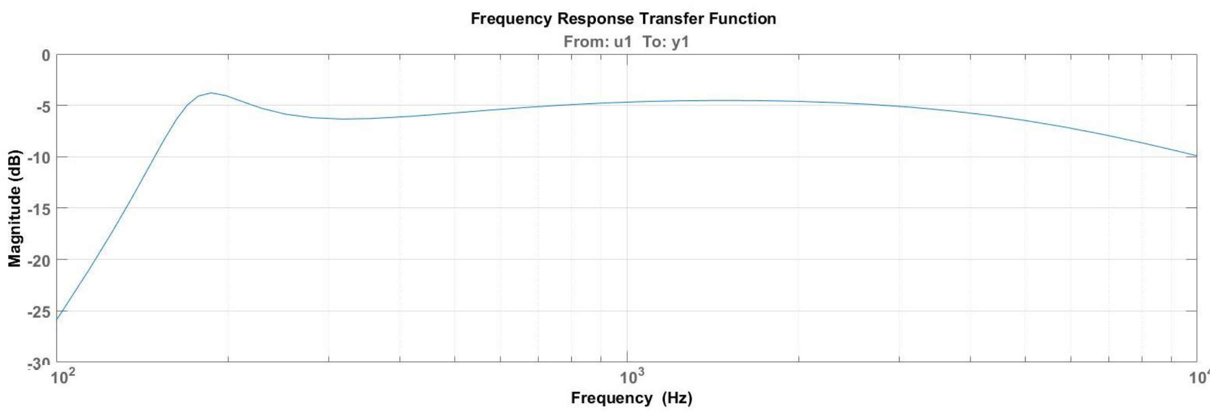

Figure 29: Frequency Response Function of the Laboratory Intercom System

At this stage, implementing an inverse transfer function to account for the FRF exhibited in Figure 29 is relatively simple. This implementation will improve the fidelity of the laboratory intercom replication system for future investigations. However, an amplifier provides a relatively simple correction method for the intercom FRFs; the gain of the amplifier is linear and frequency independent. A quick investigation into in-flight collected data was completed and discussed in the next section.

6.5 INFLIGHT INTERCOM REPLICATION RESULTS

As discussed in Figure 22, the intercom replication process included three steps: Ground Measurements, Inflight Measurements and Laboratory Replications.

Section 6.4 discussed ground measurements (step 1) completed on three NRC FRL aircraft and the subsequent calibration replication results (step 3). This section utilizes intercom data collected inflight (step 2) and the calibration settings (step 3) to replicate the aircraft intercom noise levels. Three plots are presented, one for each of the NRC aircraft investigations. The investigation was made based on the following assumptions:

- For simplicity and consistency, maximum intercom volume settings were chosen for all flights. Specifically, a number of potentiometers are utilized within the aircraft ICSs and aircrew hearing protectors, microphone sensitivities, intercom volume and headset volume settings. All settings were set to maximum; this is not necessarily representative of all operational conditions.
- To accommodate various airworthy requirements, a capacitor was installed in-line to the intercom voltage measurement; this was necessary for usage of an older DAS which was set to operate with constant current excitation sensors. Moving forward, the LMS SCADAS XS DAS will be solely utilized as it is a high impedance system with the ability to deactivate constant current excitation support. The capacitor was expected to behave as a very low frequency high-pass filter; this voltage measurement can be modelled as a simple resistive-capacitive circuit.
- The usage of different communication loops was not accounted for during the investigation: pilot–exterior, pilot-FE, full cabin etc.

Acknowledging these assumptions, the replicated ICS SPLs are representative of a worst case scenario wherein the aircrew have tuned their HP and ICS to maximum gain. While aircrew may utilize the maximum volume setting, the settings are variable at the discretion of the aircrew. Different configurations include lower ICS gain settings or the use of passive earplugs underneath the hearing protector. Therefore, these replicated values express the upper bound of noise energy aircrew will be exposed to when properly fitted with the appropriate hearing protector.

Figure 30, Figure 31 and Figure 32 contain inflight intercom replication demonstrations for the three aircraft investigations of Section 6.4. To perform the replication demonstration, the following steps were followed:

1. The GRAS 45 CB acoustic test fixture was set inside the NRC hearing protection evaluation facility;
2. A hearing protector with intercom capability was fitted to the acoustic test fixture;
3. Representative aircraft cabin noise was generated via speakers;
4. A SPL measurement was made with passive hearing protection and no intercom communications;
5. A SPL measurement was made with passive hearing protection and with intercom communications replicated from inflight collected intercom voltage data.

The overall sound pressure level (OSPL) was calculated and reported in the legend of each figure. The blue curves exhibited the measured SPLs while protected by a hearing protector. The red curves exhibited the measured SPLs while protected by a hearing protector and with intercom communications played through the speakers of the hearing protectors. Notably, the presented aircrew noise environment OSPLs are increased by the inclusion of the ICS signal (recall that this is a representative upper bound estimation).

The inclusion of intercom communications to the Bell 205 replication increased the aircrew OSPL by 5.5 dB(A). Please note that the Bell 205 exhibited high noise levels of 96.5 dB(A) in the cabin. Therefore, the added noise dose due to the aircraft ICS was less significant. In comparison, the cabins of the Convair and Falcon aircraft were much quieter at 77.3 and 80.3 dB(A), respectively. Typically, in a loud environment such as the Bell-205 cabin, a higher intercom volume setting may be used. In the quieter Convair and Falcon cabins, quieter intercom setting may be more representative. It is expected that the Convair and Falcon replication demonstrations are overestimated whereas the Bell 205 intercom replication demonstration is likely closer to operational conditions. Ideally for future measurements multiple ICS gain settings will be able to be assessed simultaneously and a survey of nominal gain settings used by aircrew could be completed.

Please note the frequency results below 200 Hz exhibited excellent consistency in the ICS replication results although the previous ground based replication results in Figure 23 to Figure 28 exhibited differences below 200 Hz. It is important to note that the energy contained within the voice excitation signal for the inflight measurements was low, below 200 Hz. As discussed, many aircraft ICSs exhibited attenuation of signals below 200 Hz. Once this attenuated voltage signal is recorded and utilized as an input to the inflight replication process, there exists little energy to excite below 200 Hz whether the ICS replication is active or inactive.

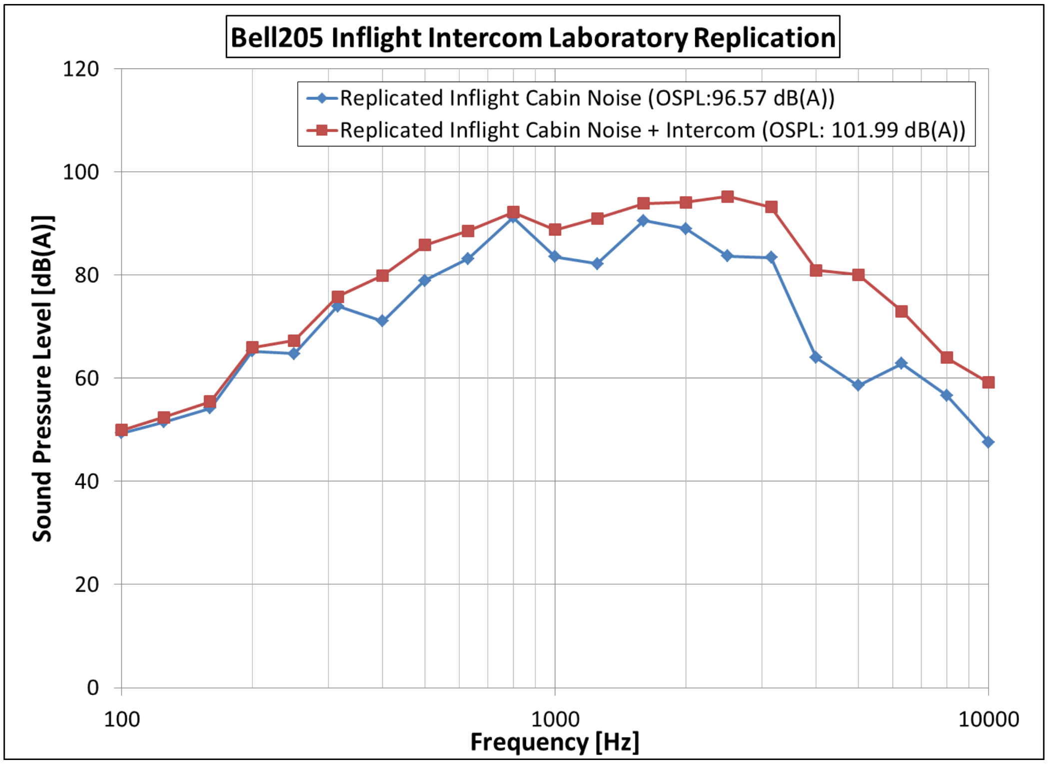

Figure 30: Bell 205 Inflight Intercom Replication Capability Demonstration

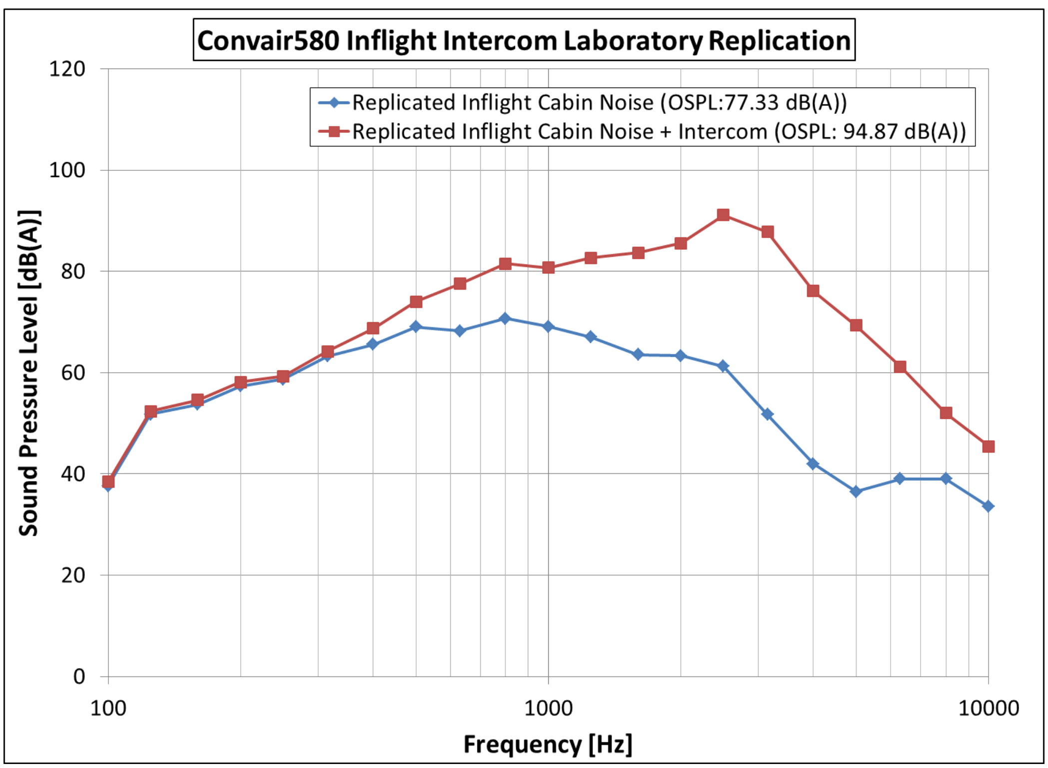

Figure 31: Convair 580 Inflight Intercom Replication Capability Demonstration

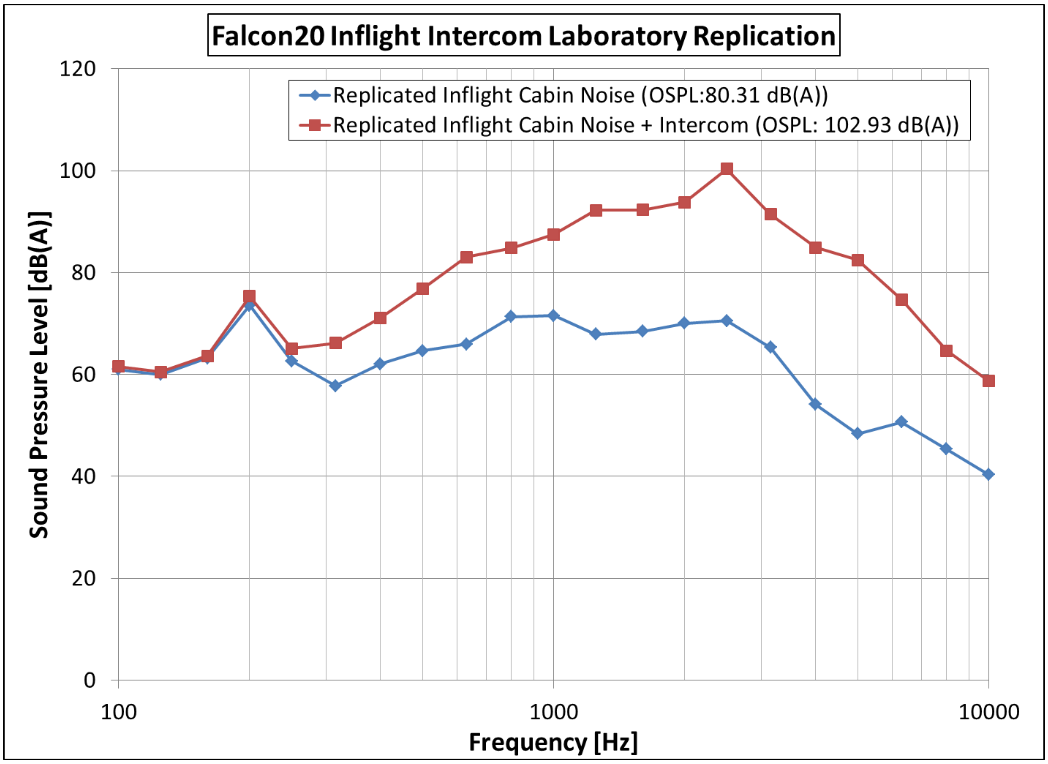

Figure 32: Falcon 20 Inflight Intercom Replication Capability Demonstration

6.6 CONCLUDING STATEMENTS

NRC has developed a laboratory based aircraft intercom replication system. It has the ability to assess the performance of hearing protectors in a simulated noise environment including cabin noise and the use of intercom communication devices. This provides a powerful tool with the potential to estimate the aircrew noise dosage in routine flight operations.

Despite the capability in replication of aircraft cabin and intercom communication noise, further enhancement may be performed to improve the methodology for aircraft inflight intercom voltage measurement. A consistent methodology needs to be developed to account for aircraft volume gain settings and airworthiness requirements.