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Development of an Aircraft Intercom Replication System for Assessment of In-flight Intercom Acoustic Sound Pressure Levels

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ABSTRACT

Flight measurements were conducted on the National Research Council's (NRC) Dassault Falcon 20 jet to assess cabin and cockpit environment sound pressure levels (SPL) for determining the aircrew noise exposure. Furthermore, the NRC has developed a methodology to quantify the contribution of aircrew speech to personnel noise exposure. Preliminary onboard investigation suggested that aircraft intercom communications potentially increased aircrew at-ear noise exposure by 5-10 dB(A). The objective of this paper is to present the NRC's development of an in-laboratory intercom replication system for investigating the significance of aircraft intercom acoustic SPLs relative to the overall aircrew at-ear SPLs. The aircraft intercom system output to headset system voltage was measured and recorded onboard the NRC Falcon aircraft, and subsequently replicated through a headset fitted on an acoustic test fixture (ATF) in the NRC Flight Research Laboratory Hearing Protection Evaluation facility. Laboratory replicated SPLs exhibited a deviation of less than 3dB from operational Falcon 20 measurements between the 200 and 2500Hz 1/3rd octave frequency bands. Further investigation is underway to reduce the replicated intercom SPL discrepancies found in frequency ranges below 200Hz and above 3000Hz and to replicate combined intercom and cabin SPLs in laboratory.

1. INTRODUCTION

The evaluation of aircrew exposure noise levels in the cabin and cockpit environment is essential for mitigating long-term health effects and enhancing personnel safety[1]. The aircraft cabin noise, perceived as background noise by aircrew, masks aircraft intercom communications. Aircrew tend to set the volume level of their aircraft intercom system to maximum, which could potentially lead to high levels of aircrew at-ear noise exposure and harmful health effects such as fatigue and hearing loss. On the other hand, the deteriorated speech intelligibility caused by the cabin noise masking may represent a major safety issue as aircrew may not be able to correctly understand commands and other vital communications. In accordance to ISO 5129:2001[2], the

NRC Flight Research Laboratory (FRL) has conducted flight measurements on several Royal Canadian Air Force (RCAF) and NRC aircraft to evaluate aircrew cabin noise exposure. However, the contribution of aircraft intercom acoustic SPLs to the overall aircrew at-ear SPLs is not considered in ISO 5129:2001[2], nor was it part of NRC's initial flight test investigations. This paper presents the development of an in-laboratory aircraft intercom replication system to assess the significance of aircraft intercom acoustic SPLs relative to the overall aircrew noise exposure.

2. BACKGROUND

A preliminary intercom SPL measurement was conducted inside the FRL hangar onboard the NRC Dassault Falcon 20 jet. Instrumentation included an acoustic test fixture manikin, G.R.A.S. 45 CB; a data acquisition system (DAS), LMS SCADAS XS; and two speakers with a stereo amplifier. The complete test setup is depicted in Figure 1 below. Cabin noise recordings of a previous Falcon 20 flight test were played back inside the aircraft cabin via the speakers. Two David Clark H10-46 headsets were connected into the aircraft intercom system. A human test operator spoke continuously into one headset for 60 seconds as speech inputs to the aircraft intercom system, whilst the other headset was fitted onto the ATF manikin and the combined cabin and intercom SPLs were measured at the ATF manikin eardrum location.

Figure 1. NRC Dassault Falcon 20 jet intercom and cabin SPL investigation setup

A total of 16 measurements were recorded. Results indicated that with cabin background noise representative of standard steady level flight cabin noise, the aircraft intercom system added 5-10dB(A) to the overall SPL perceived inside the ATF manikin ear canal[3]. Previous research by Kuronen also concluded that aircraft in-flight intercom increased pilot at-ear SPLs by 4-10dB[4]. Thus it is suggested that intercom SPL is a potentially significant source of the aircrew's overall SPL exposure, and should be investigated further to assess potential aircrew auditory risks.

3. PROPOSED APPROACH

The development and commissioning of the NRC laboratory aircraft intercom replication system is summarized in the following 3 steps:

A. Characterization of the aircraft intercom system;
B. Laboratory replication of the aircraft intercom system;
C. Measurement of the in-flight aircraft intercom system output voltage.

A. Characterization of the aircraft intercom system

In order to verify the accuracy of the laboratory intercom replication system, the ATF manikin at-ear SPLs and the aircraft intercom output voltages were first measured onboard the NRC Falcon 20 jet. Testing was conducted inside the FRL hangar, with only the aircraft's intercom system powered on. A G.R.A.S. 45 CB ATF manikin, an LMS SCADAS XS DAS, a TASCAM DR-05 audio player, a Philips portable speaker SBA3011ORG, and two David Clark H10-46 headsets were setup as shown in Figure 2a.

The intercom audio input signals included an 80-10,000 Hz linear sine sweep (-1V to 1V range), a male and a female voice recording. The 3 audio files were played into the portable speaker as input signals for the aircraft intercom system. The input headset's microphone was held 1-inch on top of the portable speaker as the intercom input, shown in Figure 2b). The output headset was fitted onto the ATF manikin. The intercom output voltage and the ATF manikin at-ear SPLs were measured simultaneously.

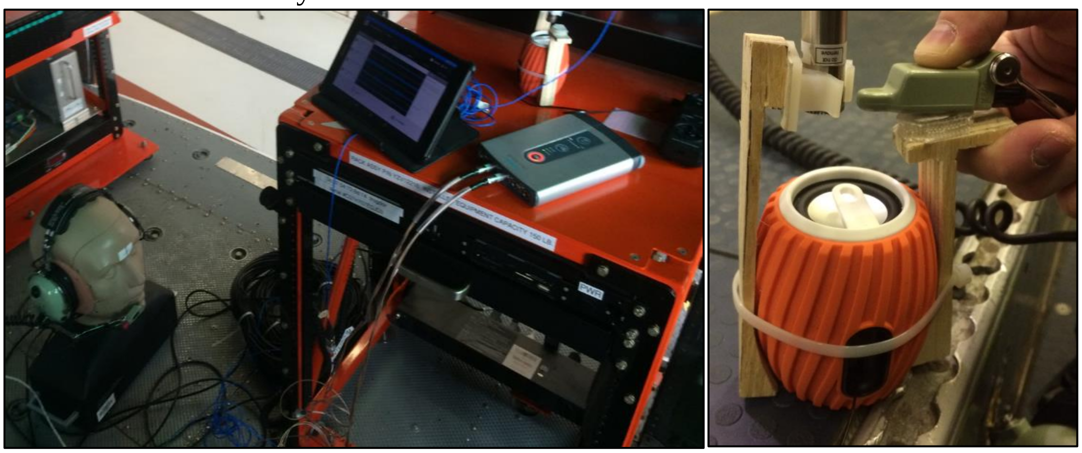

Figure 2 a) Onboard Validation Measurement Setup b) Speaker-Headset Setup

B. Laboratory replication of the aircraft intercom system

To replicate the ATF manikin at-ear SPLs measured during the onboard characterization, the Falcon 20 recorded intercom output voltage was replayed in the laboratory through an acquired intercom audio controller following a procedure summarized in Figure 3. The output voltage was first converted into waveform audio format and transferred into a TASCAM DR-05 linear PCM audio player. Outputs from the audio player were amplified by a Brüel & Kjær 2706 power amplifier to compensate for waveform audio format amplitude compression. An Andrea Systems Model A301-6 intercom audio controller connected the amplifier to a David Clark H10-46 headset fitted onto a G.R.A.S. 45 CB ATF manikin. The replicated intercom acoustic SPLs were measured at the ATF manikin eardrum location.

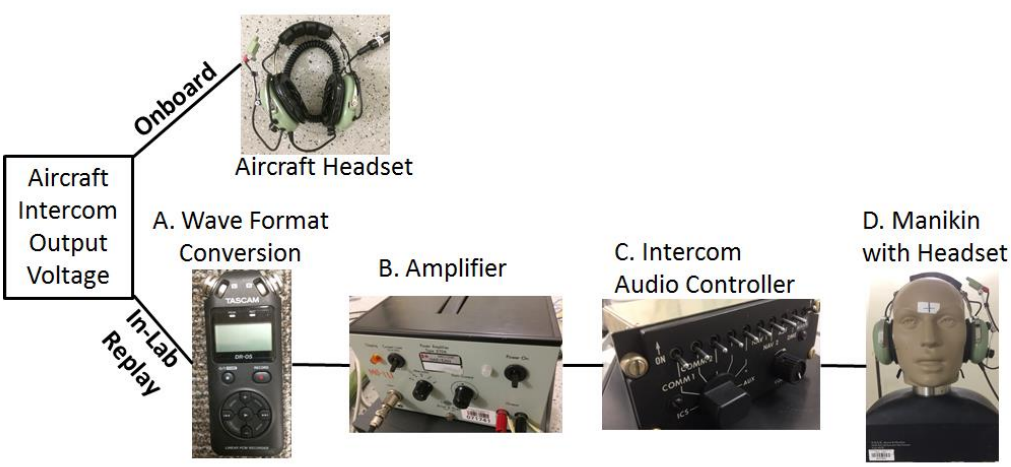

Figure 3. Aircraft intercom output voltage replication on ground

As presented in Figure 3, the intercom replication process was designed to match the in-laboratory ATF manikin at-ear SPLs with the onboard headset SPLs. To achieve this, the effects of different hardware—namely, A. the audio player, B. power amplifier, and C. intercom audio controller, and D. the ATF manikin—on the aircraft intercom voltage signal were accounted for. A: First, the amplitude of the onboard intercom voltage recordings was modified by a linear scaling factor (amplitude gain) during the conversion process from voltage to waveform audio file. B: The power amplifier compensated for this conversion factor by applying an inverse scaling factor to the audio player output signal, before replaying it into the headset. C: The intercom audio controller and D: the David Clark H10-46 headset settings were selected to be consistent with the Falcon 20 onboard characterization measurements. The ATF manikin ear also exhibits a transfer function similar to that of the human ear[5] to ensure the replication consistency with aircrew noise exposure. Comparison between the onboard and replicated ATF manikin at–ear SPLs were summarized in the RESULTS AND DISCUSSION section.

C. Measurement of the in-flight aircraft intercom system output voltage

Once the laboratory intercom replication system is validated, it can be applied to in-flight intercom voltage data to replicate in-flight aircrew at-ear SPLs. Thus, Falcon 20 in-flight intercom system output voltage was recorded following the cable connection scheme shown in Figure 4. The following test setup was implemented: an LMS SCADAS XS DAS was tied into the intercom–to-headset connection to measure the aircraft intercom system output voltage, in the same manner as a voltmeter. The model of headset is variable and often contingent upon the type of aircraft; this measurement utilized a David Clark H10-46 headset. In-flight Falcon 20 intercom output voltage was recorded by the DAS, and would later be analyzed after validating the laboratory intercom replication system.

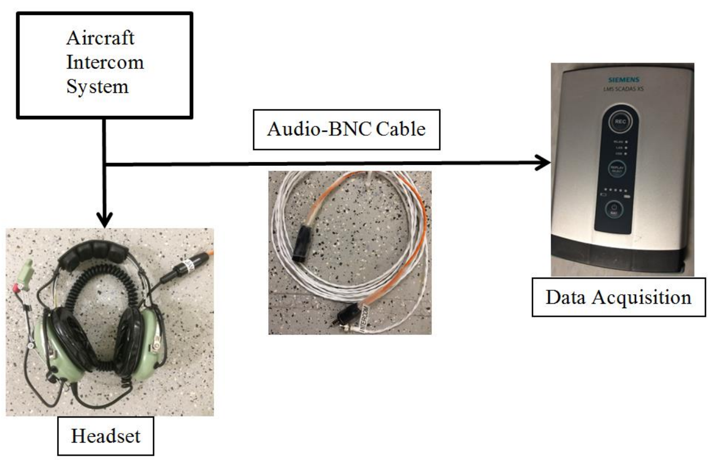

Figure 4. Aircraft intercom system output voltage measurement

Although in-flight aircrew at-ear SPLs can be directly measured with an onboard ATF manikin, the in-flight intercom voltage measurement was simpler to implement. The selected DAS did not require additional hardware such as power supply or current converter; this hardware selection significantly simplified testing and flight certification, enabling flight measurements onboard strictly regulated RCAF aircrafts. In addition, the DAS was compatible with NRC standard acoustical measurement facilities and post-processing software, ensuring high fidelity post-flight analysis in accordance with appropriate standards.

4. RESULTS AND DISCUSSION

A total of 6 onboard characterization measurements were completed, and the measured aircraft intercom output voltage was replicated in the laboratory. The complete test matrix is summarized in Table 1 below.

Table 1. Onboard characterization and in-laboratory replication test matrix

Intercom Volume Level	Testing Condition	Intercom Input Audio Files		
		80-10,000 Hz Linear Sine Sweep	Male Voice Recording	Female Voice Recording
Max	Onboard Characterization	Case #1a	Case #2a	Case #3a
	In-laboratory Replication	Case #1b	Case #2b	Case #3b
Medium	Onboard Characterization	Case #4a	Case #5a	Case #6a
	In-laboratory Replication	Case #4b	Case #5b	Case #6b

SPLs measured at the ATF manikin eardrum location during both the onboard characterization and in-laboratory replication measurements were presented in Figure 5 to Figure 7.

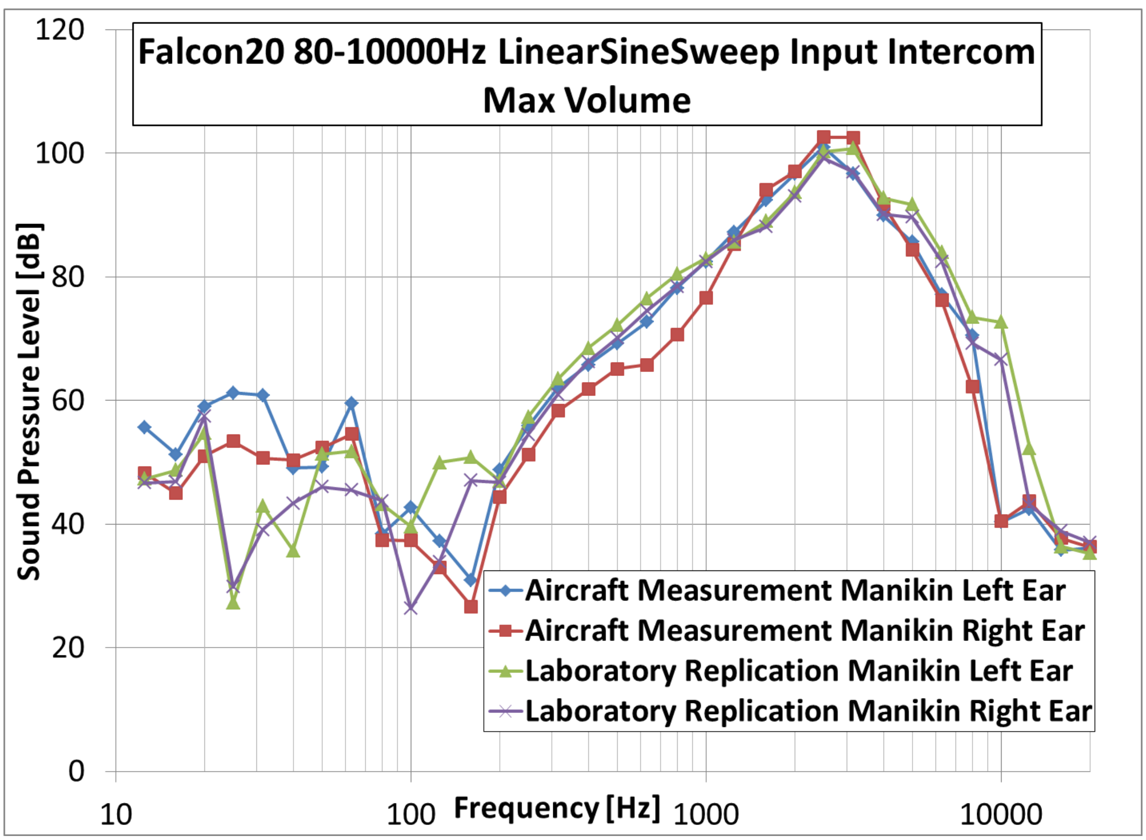

Figure 5. Case #1: Linear Sine Sweep Input Max Intercom Volume

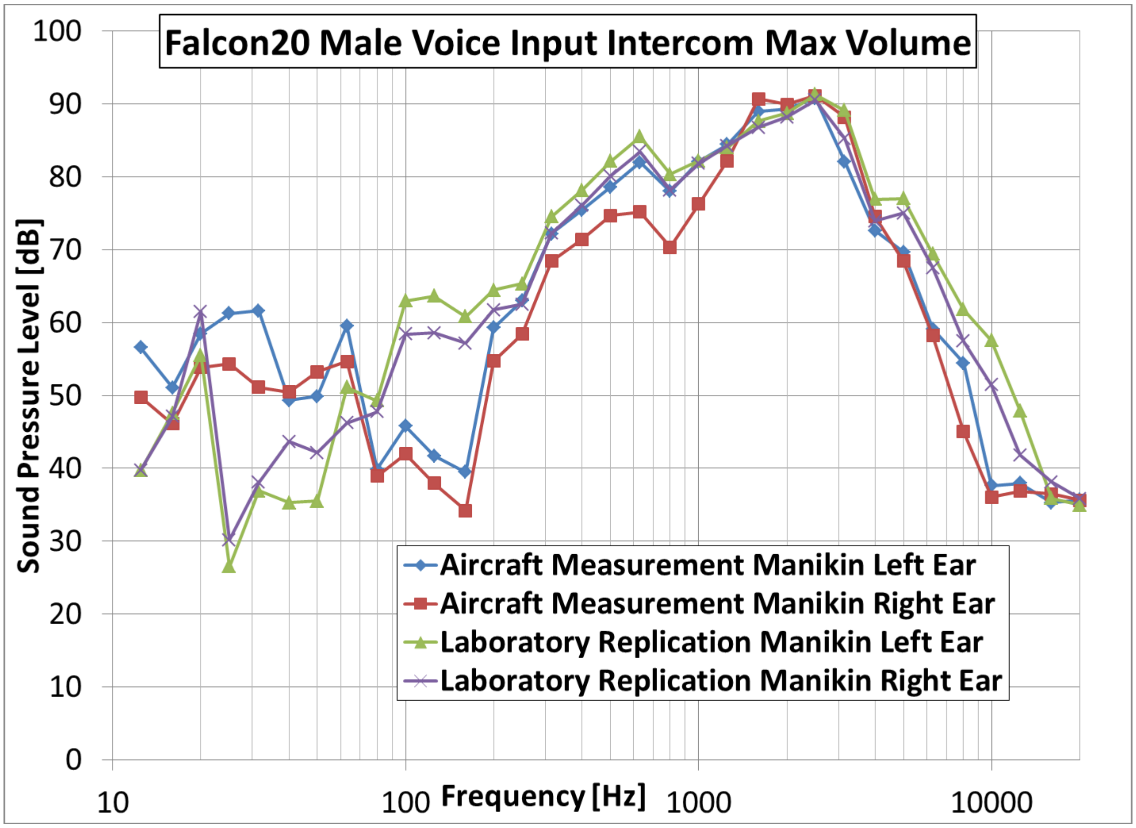

Figure 6. Case #2: Male Voice Input Max Intercom Volume

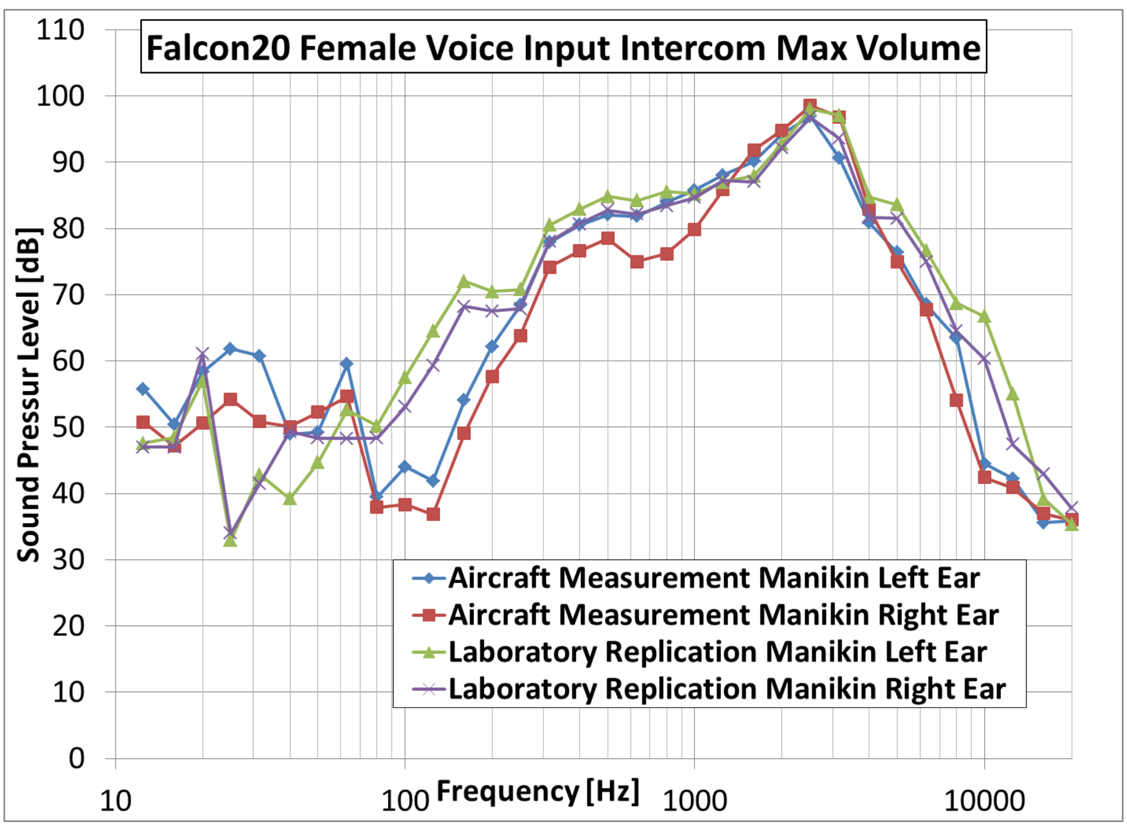

Figure 7. Case #3: Female Voice Input Max Intercom Volume

The overall ATF manikin at-ear SPLs for all 12 measurements were calculated utilizing the following 1/3rd octave to overall SPL summation equation[6]:

$$L[\text{dB}] = 10 \times \log_{10} \sum_{1}^{n} 10^{\frac{L_i[\text{dB}]}{10}}$$

where L[dB] is the overall SPL, and L_i[dB] is the SPL measured for each 1/3rd octave frequency band. Results were summarized in Table 2.

Table 2. ATF manikin at-ear SPLs for onboard intercom characterization and in-laboratory replication

Testing Case #	Manikin Ear	At-Ear Intercom Overall SPL [dB]		Overall SPL Difference [dB]
		Onboard	In-Laboratory	
Case 1	Left	104.12	104.80	-0.68
	Right	106.61	102.75	3.86
Case 2	Left	95.84	96.77	-0.93
	Right	96.50	95.47	1.02
Case 3	Left	100.70	102.24	-1.54
	Right	102.45	100.47	1.98
Case 4	Left	97.72	97.66	0.05
	Right	100.17	95.63	4.54
Case 5	Left	88.10	89.26	-1.17
	Right	88.76	87.99	0.77
Case 6	Left	93.34	95.45	-2.11
	Right	95.17	93.72	1.45

As illustrated in Figure 5 to Figure 7, the laboratory replicated SPLs exhibited strong consistency with the onboard SPLs from 200 Hz to 2.5 kHz; the deviation within this range was less than 3 dB. At frequency bands below 200Hz and above 3000Hz, discrepancies greater than 10dB were exhibited.

These 10 dB discrepancies are potentially related to inconsistent background noise; the laboratory replication occurred in a controlled environment, whilst the aircraft intercom characterization testing was conducted onboard the Falcon 20 inside the operational FRL hangar. It is also worth noting that these discrepancies were reduced for the linear sine sweep intercom input, compared to the male and female voice inputs; this is likely due to the inadequacy of voice inputs for exciting the full frequency range. Another reason for the large discrepancies below 200Hz and above 3000Hz may be related to the transfer function of the intercom audio controller. Fundamentally, the aircraft intercom *output* voltage is measured and utilized as the in-laboratory intercom audio controller's *input* voltage; whilst an intercom system may be ideally designed to have a flat frequency response, the operational frequency response transfer function may require additional action to counteract. Additional work will focus on identifying the transfer function of the in-laboratory intercom audio controller and applying an inverse transfer function to the intercom input signals during laboratory replication to compensate. Poor headset fittings may explain the differences in the ATF manikin left and right ear SPLs from Table 2. Averaging of measurements from additional fittings will potentially exclude the inconsistencies in operational hangar noise and headset fittings.

Future in-laboratory replications will incorporate pre-recorded in-flight cabin background noise and in-flight intercom voltage recordings to measure the combined intercom and cabin background SPLs. This investigation will exhibit greater representation of operational conditions.

5. CONCLUSION

Aircraft cabin noise degrades the quality of aircrew communication and exposes aircrew to an increased risk of permanent hearing damage. The objective of the present investigation was to develop an in-laboratory aircraft intercom replication system to assess the contribution of aircraft intercom SPLs to the overall aircrew noise exposure. No in-flight measurements with the ATF manikin was feasible; however the ATF manikin at-ear SPLs in conjunction with the aircraft intercom system output voltage supplied to the headset were simultaneously measured onboard the NRC Dassault Falcon 20 jet inside the FRL hangar. The recorded intercom voltage was then replicated in laboratory into a headset through an intercom audio controller. Comparison between onboard and laboratory-replicated ATF manikin at-ear SPLs exhibited excellent correlation of less than 3dB difference within the range of 200-2500 Hz 1/3rd octave frequency bands. Disparities in frequency ranges below 200Hz and above 3000Hz were attributed to different background noise of the two testing locations, poor headset fittings and the transfer function of the intercom audio controller. Further investigation is underway to improve the aircraft intercom replication system and to replicate combined cabin and intercom SPLs in laboratory.

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