

Unmanned Aircraft Systems (UAS)
Broad Agency Announcement (BAA)

Call# 005

Final Report

Project Title:

*Unmanned Aircraft Systems' Use of Command and Control
(C2) Link Relay of Voice Communications for Traffic Awareness
and Coordination in the Terminal Environment*

Company Name:

AURA Network Systems, Inc.

Contract Period of Performance:

September 23, 2024, to September 22, 2025

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Executive Summary

This report presents the results of testing a Command and Control (C2) voice link to an Uncrewed Aircraft System (UAS) using AURA Network Systems' (AURA) licensed UHF link. Voice transmissions from a Remote Pilot Surrogate were sent to AURA's Ground Radio System (GRS), carried on its licensed UHF C2 link to an Inspired Flight IF1200A drone, and then relayed via a legacy VHF link to an Air Traffic Control (ATC) Surrogate station. The objective was to evaluate end-to-end latency against the DO-377B requirements and voice quality across the hybrid communication chain under different test scenarios. Testing demonstrated that the voice quality was clear and intelligible across all test case scenarios, and the measured latency met and exceeded the guidelines established in DO-377B. Measuring the latency of legacy VHF communication was out of scope for this project as defined by the UAS Integration Office Project Statement of Work (SOW) and was addressed in an earlier report from the William J. Hughes Technical Center (AVCT-UAS-DR-FR-001). As stated above, this project compared the measured latency of AURA's 450 MHz digital communication link against the requirements established in DO-377B. These results support the viability of having a remote pilot connect to an Uncrewed Aircraft (UA) over AURA's network and providing voice communication to ATC over legacy VHF radio links. Future testing could include testing AURA's link using a Cessna or other small airplane to ATC at an active airport.

Acronyms

A2G: Air-to-Ground

ATC: Air Traffic Control

AVCM: Air Voice Communication Module

BLDC: Brushless DC Motors

BVLOS: Beyond Visual Line Of Sight

C2: Command and Control

C2CSP: Command-and-Control Communications Service Provider

CI: Confidence Interval

CS: Control Station

CTAF: Common Traffic Advisory Frequency

EMI: Electromagnetic Interference

G2A: Ground-to-Air

GRS: Ground Radio System

GVCM: Ground Voice Communication Module

GVT: Ground Voice Terminal

MCT: Message Completion Test

MRM: Modem and RF Module (AURA Airborne Radio)

MRT: Modified Rhyme Test

NAS: National Airspace System

NPUASTS: Northern Planes UAS Test Site

POLQA: Perceptual Objective Listening Quality Analysis

RPIC: Remote Pilot in Command

SD: Standard Deviation

UAS: Uncrewed Aircraft System

UA: Uncrewed Aircraft

UHF: Ultra High Frequency

UND: University of North Dakota

UNICOM: Universal Communications

UTA: Universal Telephony Adapter

VHF: Very High Frequency

Introduction

Voice communications on Very High Frequency (VHF) channels are used in the National Airspace System (NAS) to coordinate approaching aircraft entering the airport traffic pattern, landing, taxi, and departures. Large Uncrewed Aircraft Systems (UAS) departing and arriving aerodromes will be sharing airspace with manned aircraft and will need to participate in the airport Universal Communications (UNICOM) or Common Traffic Advisory Frequency (CTAF) conversations (where available), or air traffic control (ATC) communications where ATC service is provided. In this project, AURA and AURA's partner, Northern Plains UAS Test Site (NPUASTS), demonstrated technologies that support this use case.

This project has demonstrated that an instantiation of a terrestrial Command and Control (C2) link system using FCC-licensed, dedicated spectrum, and purpose-built ground infrastructure can provide the remote operator of a UAS with voice communications relay services suitable for ATC communications. "Suitable" means that the C2 link system meets DO-377B integrity and latency performance requirements. "Integrity" as used here, relates to authentication and establishment of a two-way voice connection between a UAS and a Control Station (CS). As a Command-and-Control Communications Service Provider (C2CSP), AURA provides not only the over-the-air link but also the connections on the ground between multiple ground radio sites, network aggregation locations, and remote pilot operations centers.

Methodology

Radio Links

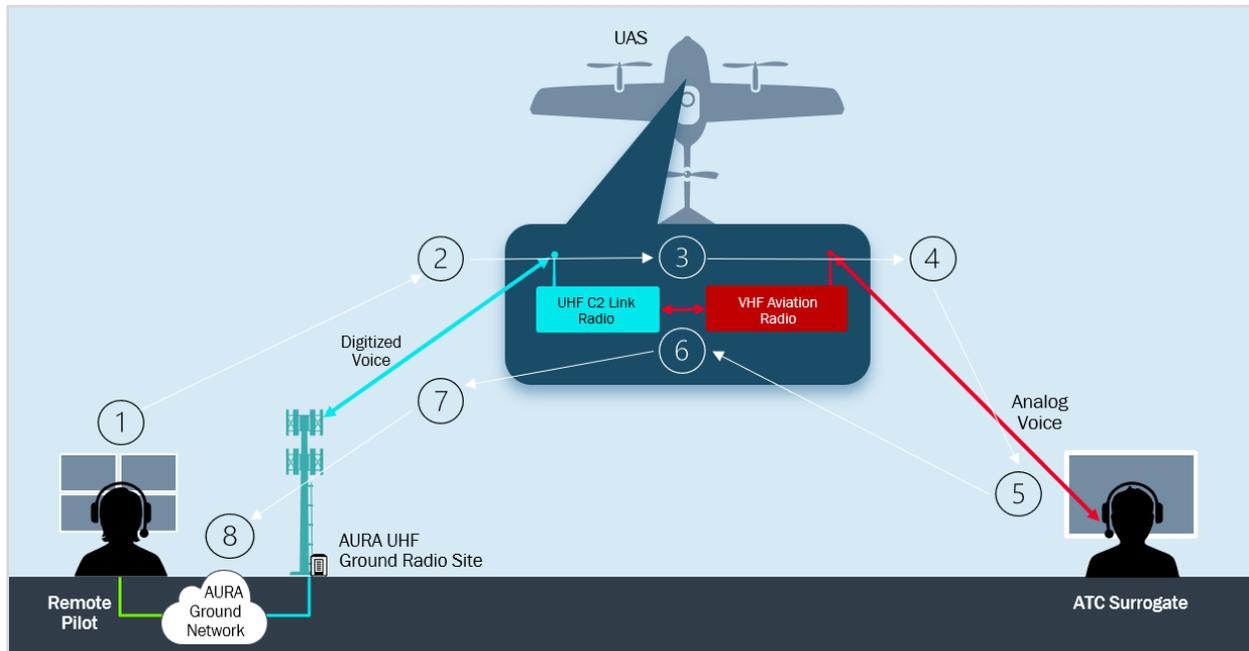


Figure 1: Overview of RF Links Connecting Air Traffic Controller to Remote Pilot

During the voice and latency testing in North Dakota the following steps were employed:

1. A Remote Surrogate Pilot spoke into a headset, and the voice was digitized and passed over a ground network to a ground radio site.
2. The ground radio site included a radio operating on AURA’s licensed spectrum (454/459 MHz) and transmitted the voice packets to a drone.
3. The drone included a radio operating on AURA’s licensed spectrum that received the voice packets and converted the signal to analog voice. The analog voice signal was passed to a VHF radio on the drone.
4. The analog voice signal was transmitted from the VHF radio on the drone to the “Air Traffic Controller” on the ground, who received the signal with a second VHF radio.

5. When the “Air Traffic Controller” spoke, the analog voice signal was transmitted from the second VHF radio to the drone.
6. The VHF radio on the drone received the signal, and the analog voice was passed to the AURA radio on the drone.
7. The analog voice was digitized, and the AURA radio transmitted the voice packets over AURA’s licensed spectrum to the AURA ground radio site.
8. The voice packets were sent over the ground network to the Remote Pilot Station, where the voice packets were converted to analog voice and sent to the Remote Pilot headset.

This voice and latency testing demonstrated two-way communication between a remote drone pilot and an Air Traffic Controller using a hybrid link that combines AURA’s licensed UHF band for beyond visual line of sight (BVLOS) connectivity with the VHF band allocated for use by ATC.

Figure 2 below depicts the physical location of the various parts of the voice and latency testing. The Remote Surrogate Pilot station was located in the Mayville Airport Pilot’s Lounge. Voice from the Remote Surrogate Pilot (referred to as Remote Pilot in the rest of this document) was digitized and sent over an internet link (green connection to AURA’s ground network) to AURA’s Buxton, ND ground station site. The Buxton, ND site included a radio tower and AURA’s ground radio system (GRS). The voice packet was transmitted over AURA’s UHF to the UAS (the drone). The drone was operated at a farm located approximately five miles outside Mayville, ND. The drone was controlled by the Remote Pilot in Command (RPIC). The RPIC was not involved in any of the audio tests other than flying the drone.

The voice packets received at the drone on the AURA UHF transmission were converted to analog audio and passed to a VHF radio on the drone. The VHF radio transmitted the audio on a frequency

of 123.375 MHz (25 KHz channel) to a ground-based VHF radio situated in a trailer at the same farm where the drone was operating.

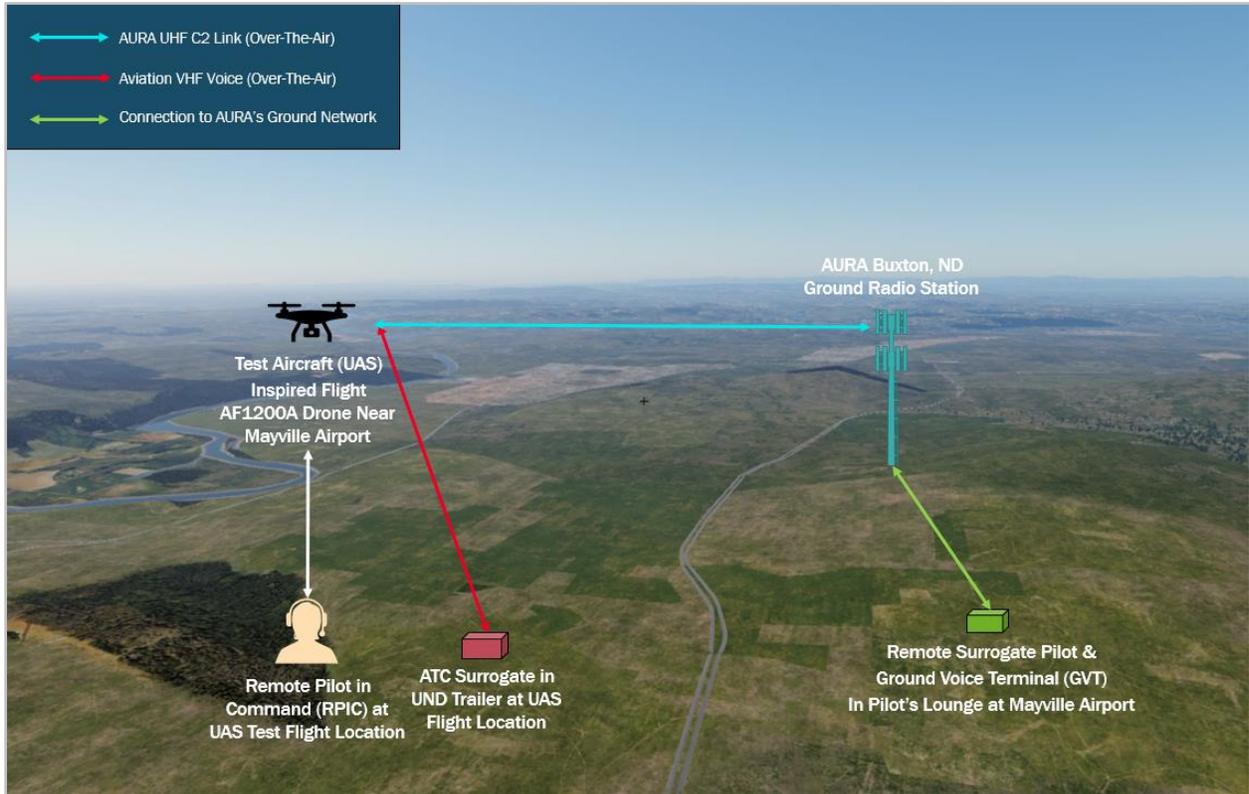


Figure 2: Illustrative Overview of the Site Locations

Data Collected

Data was collected to quantify the latency of the AURA UHF transmission link and to measure the intelligibility of the different links in the test system. The intelligibility testing leveraged test methods discussed in the FAA technical note “Voice Over Internet Protocol: Speech Intelligibility Assessment”¹, which outlines Message Completion Tests (MCT) and Modified Rhyme Tests (MRT). MCT and MRT tests were performed on each of the RF links, UHF, VHF, and the combined link UHF plus VHF.

Data collected included:

¹ https://hf.tc.faa.gov/publications/2009-voice-over-internet-protocol/full_text.pdf

- **Latency**

- The length of time for a voice signal to traverse the link was measured.
- Latency measurements were facilitated by test equipment acquired from GL.COM.
- A first Dual Universal Telephony Adapter (UTA)² from GL.COM located at the pilot station, was one endpoint of the link to be measured for latency. A second Dual UTA located on the drone was the second endpoint of the link to be measured. Latency was measured in both directions from the pilot station to the drone, and from the drone to the pilot station.
- Both Dual UTAs had a GPS receiver and were synchronized to GPS time.
- A WAV file was sent from the first Dual UTA over the radio link and collected by the second Dual UTA.
- GL.COM software was used to measure the latency of the voice signal over the link.

- **POLQA (Perceptual Objective Listening Quality Analysis)**

- A standard phrase with a male voice was sent over the link. The recorded phrase was compared to the original phrase to provide a POLQA score that was determined using GL.COM test equipment and software.
- A standard phrase with a female voice was sent over the link and recorded. The recorded phrase was compared to the original phrase to provide a POLQA score that was determined using GL.COM test equipment and software.

- **Two-way Communication Test**

- Two-way Communications testing included a live volunteer on a headset acting as an ATC Surrogate (located in the trailer at the farm where the drone was flown) and

² <https://www.gl.com/next-gen-dual-uta-hd-voice-testing.html>

a second volunteer on a headset as the Remote Pilot (located in the Mayville Airport Pilot's Lounge). The volunteers held a conversation with a script provided and proctored by the University of North Dakota (UND). The volunteers filled out and submitted a survey after completing the scripted conversation.

- **Modified Rhyme Test (MRT)**

- WAV file played over a link and recorded. The University of North Dakota used the file to measure the intelligibility and acceptability of the voice recording. The voice recording used male and female voices, which were recorded at different starting locations of the communication link, such as ATC Surrogate, Remote Pilot, and the drone aircraft. UND recruited human subjects who held a private pilot certificate and tested the intelligibility and acceptability of the recordings from a human factors' perspective.

- **Message Completion Test (MCT)**

- WAV file played over a link and recorded. The University of North Dakota used the file to measure the intelligibility and acceptability of the voice recording. The voice recording used male and female voices, which were recorded at different starting locations of the communications link, such as ATC Surrogate, Remote Pilot, and the drone aircraft. UND recruited human subjects who held a private pilot certificate and tested the intelligibility and acceptability of the recordings from a human factors' perspective.

- **Intelligibility and Accessibility Survey Data Collected in Test Scenarios 1 – 7**

(Scenarios defined below)

- At each test location, participants were asked to rate the intelligibility and acceptability of the audio calls using a seven-item Likert Scale listed below, which reflects the definition and rating scale used.
- Intelligibility referred to how well the test subject was able to understand what was said in each condition. The rating scale was as follows:
 1. I could understand **nothing** that was said.
 2. I could understand **nearly nothing** that was said.
 3. I could understand **a little** of what was said.
 4. I could understand **about half** of what was said.
 5. I could understand **most** of what was said.
 6. I could understand **nearly everything** that was said.
 7. I could understand **everything** that was said.
- Acceptability referred to the perceived suitability of the audio experienced by the test subject under each condition, taking into account the requirement to listen for multiple hours daily as part of their professional responsibilities. The rating scale was as follows:
 1. In **all** foreseeable situations, the audio would be **unsatisfactory**.
 2. In **nearly all** foreseeable situations, the audio would be **unsatisfactory**.
 3. In **most** foreseeable situations, the audio would be **unsatisfactory**.
 4. In **about half** of the foreseeable situations, the audio would be **satisfactory**.
 5. In **most** foreseeable situations, the audio would be **satisfactory**.
 6. In **nearly all** foreseeable situations, the audio would be **satisfactory**.
 7. In **all** foreseeable situations, the audio would be **satisfactory**.

- MRT and MCT pre-recorded WAV files were played over the link and recorded at the Remote Pilot Station.
- **Test Scenario 5:** Drone to ATC Surrogate over the VHF radio link.
 - MRT and MCT pre-recorded WAV files were played over the link and recorded at the ATC surrogate station.
- **Test Scenario 6:** Remote Pilot Station to ATC over the UHF and VHF radio links.
 - MRT and MCT pre-recorded WAV files were played over the link and recorded at the ATC surrogate station.
- **Test Scenario 7:** Live conversation between volunteers at the Remote Pilot Station and the ATC Surrogate Station over the UHF and VHF radio links.
 - Scenario 7 testing was proctored by UND.
 - Volunteers were recruited by UND and utilized headsets at the ATC Surrogate and Remote Pilot Station locations. The volunteers, all holding at least an FAA private pilot certificate, read the dialogue scripted by experienced air traffic controllers. The human factors subjects communicated using normal radio calls back and forth to each other.
 - Each volunteer completed a survey created by UND related to their experience of the intelligibility and acceptability of voice communication between the ATC Surrogate and the Remote Pilot.
- **Test Scenario 8:** Remote Pilot Station to the drone over the UHF radio link, and drone to the Remote Pilot Station over the UHF radio link.
 - Latency was measured from the Remote Pilot Station to the drone
 - Latency was measured from the drone to the Remote Pilot Station.

- POLQA was measured for male and female voice files from the Remote Pilot Station to the drone.
- POLQA was measured for male and female voice files from the drone to the Remote Pilot Station.

Test Equipment

Remote Pilot Station	
<p>Remote Pilot Station: Located at the Mayville Airport Pilot’s Lounge</p>	
<p>Remote Pilot Station GL.COM Dual UTA: Includes a GPS antenna and a computer to control the UTA</p>	
<p>Remote Pilot Station Ground Voice Communication Module (GVCM): AURA proprietary equipment that digitizes voice from the headset microphone or Dual UTA and outputs voice packets. Received voice packets are converted back to audio and output to the headset speakers or the Dual UTA.</p>	

Remote Pilot Station Headset



Remote Pilot Station Keysight Power Supply:
Provides power for the GVCN.



Remote Pilot Station Router:
Sends and receives voice packets over the Internet.



Ground Station Site

Buxton, ND Ground Station Site:
Tower with outdoor antenna.



Buxton, ND Ground Station Site:
Included an AURA UHF ground radio system (GRS) and a router connected to the internet.



ATC Surrogate Station

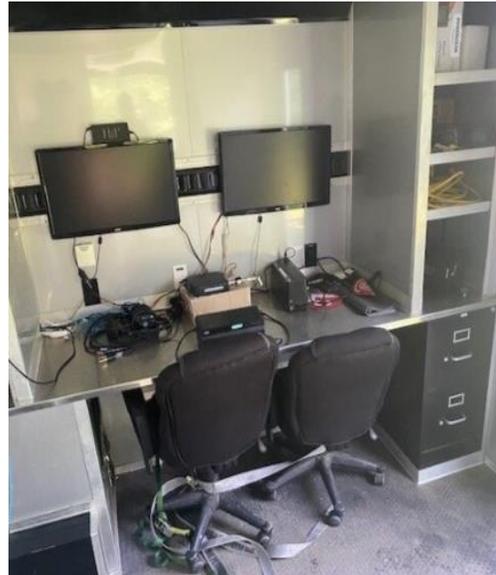
Air Traffic Control (ATC) Surrogate Station:

The trailer provided by UND was located at a farm approximately five miles from the Mayville Airport that also served as the drone launch site.



Air Traffic Control (ATC) Surrogate Station:

Inside the trailer provided by UND located at the farm drone launch site.



Air Traffic Control (ATC) Surrogate Station:
ICOM VHF radio connected to a VHF antenna mounted on the trailer.

Radio was set to 25 KHz channel at 123.375 MHz (UND received FCC authorization to use this channel).



Air Traffic Control (ATC) Surrogate Station:
H1N Recorder³



Air Traffic Control (ATC) Station:
Headset



Drone

³ https://digitalzakka.com/product/zoom-h1n-digital-audio-recorder-perfect-for-interviews-and-dslr-recording/?gad_source=1&gad_campaignid=22689262531&gbraid=0AAAAADxJpJRT5U-6fpU1ddNxNqiQm_qd9&gclid=CjwKCAjwpMTCBhA-EiwA_-MsmZ7vUTDxhb_cCo0qE4HE2A1OZ51RPI0bl2Ym0ZQzOH-34Z6wBPhlkxoC0TsQAvD_BwE

Drone (Inspired Flight IF1200A):

Components were carefully configured on the drone with cables dressed to clear the propellers.

Inserted Ferrite chokes on most of the non-RF lines to reduce EMI.

VHF and UHF Antennas were mounted under the payload plate.



Drone (Inspired Flight IF1200A):

Trig Aviation VHF radio was mounted on top of the batteries on the drone to provide separation of the VHF radio from the other circuits.

The Trig has a stuck microphone feature. If the microphone is keyed for more than 35 seconds, the radio assumes a fault and shuts off the transmitter. Care must be taken to break up transmissions to less than 30-second increments.

Radio was set to 25 KHz channel on 123.375 MHz (UND received FCC authorization to use this channel).



Drone (Inspired Flight IF1200A):

AURA Airborne Voice Communication Module (AVCM).

Converts voice packets received by the UHF radio to analog voice.

Converts analog voice from the VHF radio to voice packets.



<p>Drone (Inspired Flight IF1200A): AURA UHF Airborne Radio.</p> <p>Includes a GPS antenna for acquiring a time base.</p>	
<p>Drone (Inspired Flight IF1200A): GL.COM Dual UTA</p> <p>Includes a GPS antenna and a computer to control the UTA.</p>	
<p>Drone (Inspired Flight IF1200A): DROK Power Supply⁴</p> <p>Converts power from the drone to the voltage required by the radio.</p>	
<p>Drone (Inspired Flight IF1200A): TASCAM Mixer⁵</p> <p>Provides Audio Switching and playback for different test scenarios.</p> <p>The mixer is battery-powered. Batteries were changed regularly.</p>	

⁴ https://www.amazon.com/Converter-Regulator-Adjustable-Regulated-Laboratory/dp/B0978T3JKH/ref=pd_lpo_d_sccl_1/142-9942396-4821805?pd_rd_w=2iGuG&content-id=amzn1.sym.4c8c52db-06f8-4e42-8e56-912796f2ea6c&pf_rd_p=4c8c52db-06f8-4e42-8e56-912796f2ea6c&pf_rd_r=J9VXWVPP5SAR4VZH013T&pd_rd_wg=LXy7y&pd_rd_r=4f424adc-89a8-4f8a-8a95-a773166e9889&pd_rd_i=B0978T3JKH&psc=1

⁵ https://www.amazon.com/Tascam-DR-60DMKII-4-Channel-Portable-Recorder/dp/B00MIXFBL0/ref=sr_1_15?crd=1ZBA5W2A5VWME&dib=eyJ2IjoiMSJ9.ongr2vg0MfiHJqcKI1-kfgmxoKSOh_nDwgKzJX9LLr4sFJxSq4jI5s25OrJbDq6gZbRqz5KGY6o9cWqFHZU64UYgDJLmXs3fTnLQbMmGrozi9Dgy-THQ9EeLVsiNOD0PhMejYKtzRzYuyw9Sy_abBUKOUvkw3jWI5ajW16I1_HVKK95Z_m8sv5_EnsJMvK19y4Ioyn07TWuBJVS-s5dTzTyZrKdjVQ9zxaKq3UoW7SxkhAP4v7PveAAwlsRWoJpQFkmW-N0TSe4BIwX_16pw3CUGXSb5-_hmXgHJUeotNag.6oA5_K66eGXq1HB3IKU_8my-GiyYjsQYpq4eJXhEWB8&dib_tag=se&keywords=tascam%2Bdigital%2Bvoice%2Brecorder&qid=1750191216&s_prefix=tascam%2Bdigital%2Bvoice%2Brecorde%2Caps%2C211&sr=8-15&th=1

Test Procedure

Scenario 1

This test used the ground network and the AURA UHF link. The VHF radio was not part of this test. Intelligibility and acceptability were measured from the Pilot Station to the Drone.

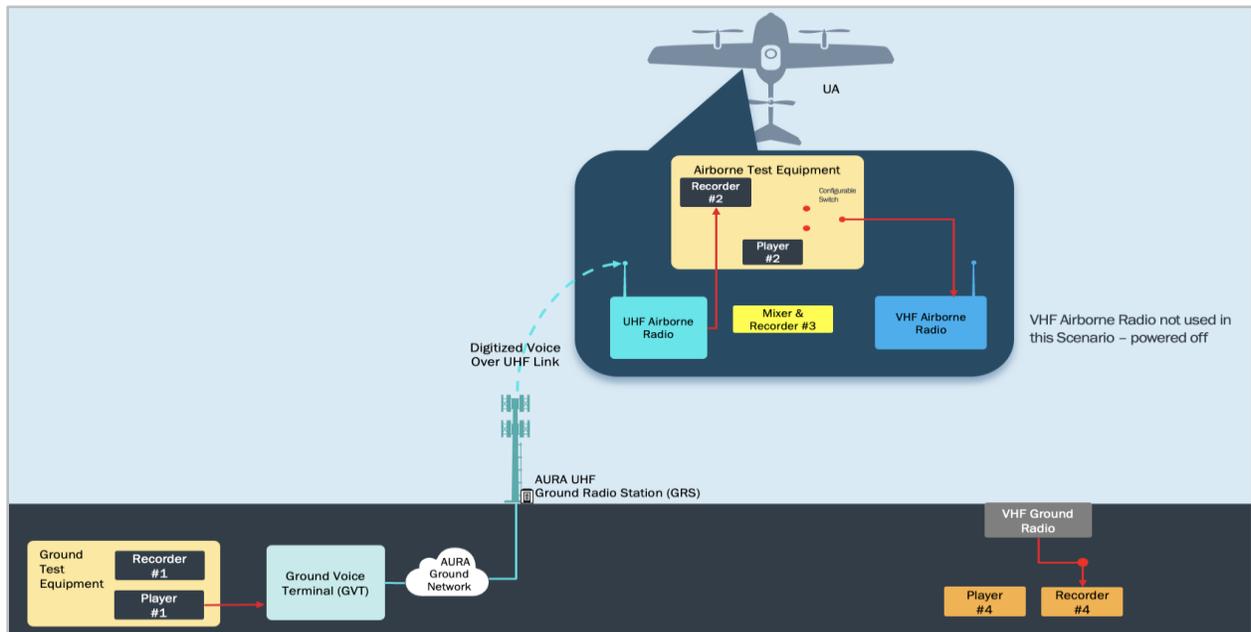


Figure 4: Graphic for Test Case Scenario 1

Scenario 1: GVT (Pilot) to UHF Airborne Radio (Drone)

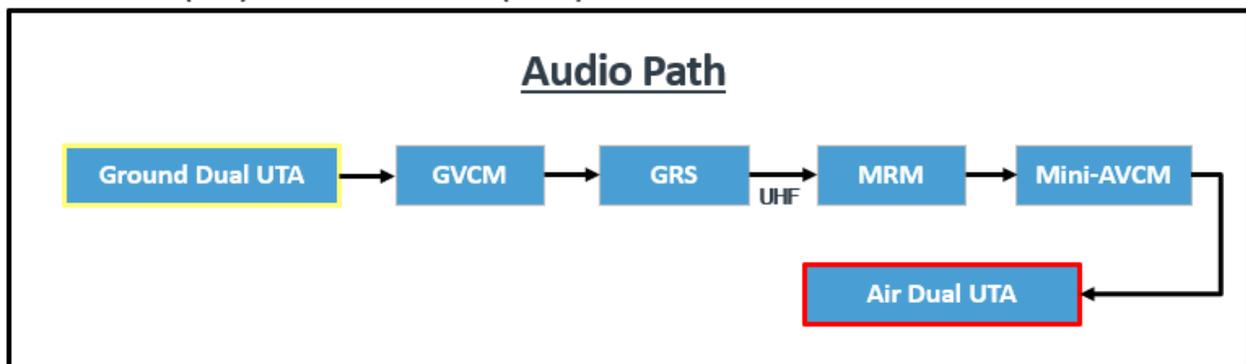


Figure 5: Audio Path for Test Case Scenario 1

TEST PROCEDURE:

1. Ensured prerequisites were met (e.g., batteries swapped as necessary).

2. Established RF connection between the radios.
3. Flew the drone to the operating altitude.
4. Captured audio files.
5. Returned the drone to the ground.
6. Archived the data.

Scenario 2

This test used the ground network and the AURA UHF link. The VHF radio was not part of this test. Intelligibility and acceptability were measured from the drone to the Remote Pilot Station.

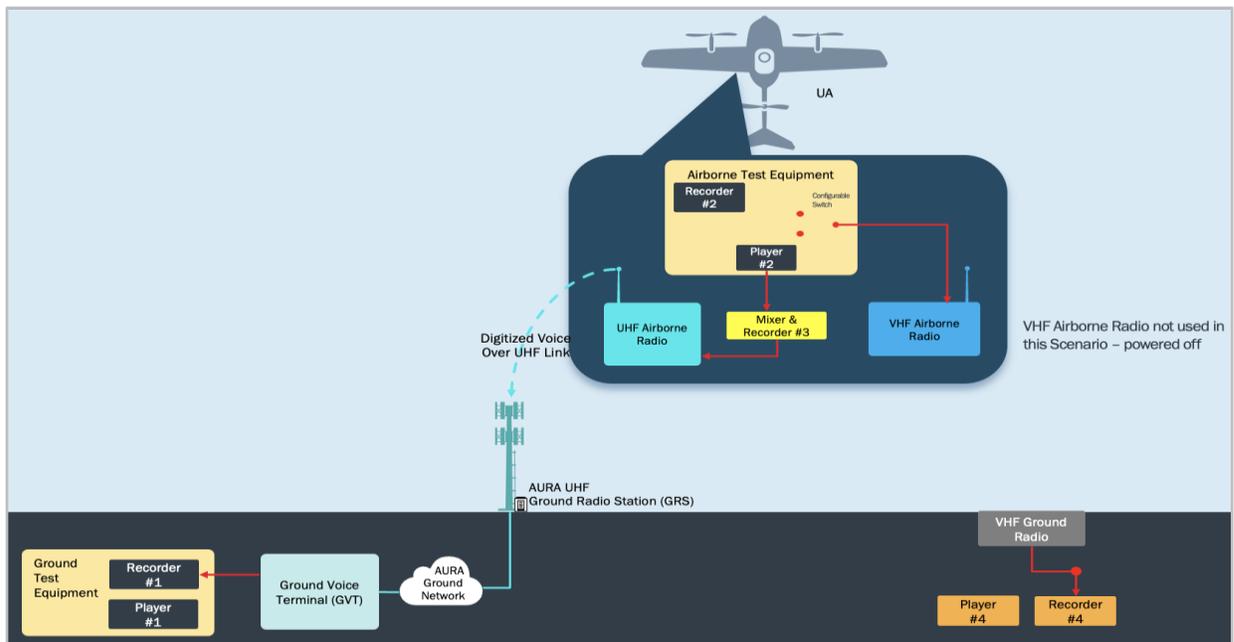


Figure 6: Graphic for Test Case Scenario 2

Scenario 2: UHF Airborne Radio (Drone) to GVT (Pilot)

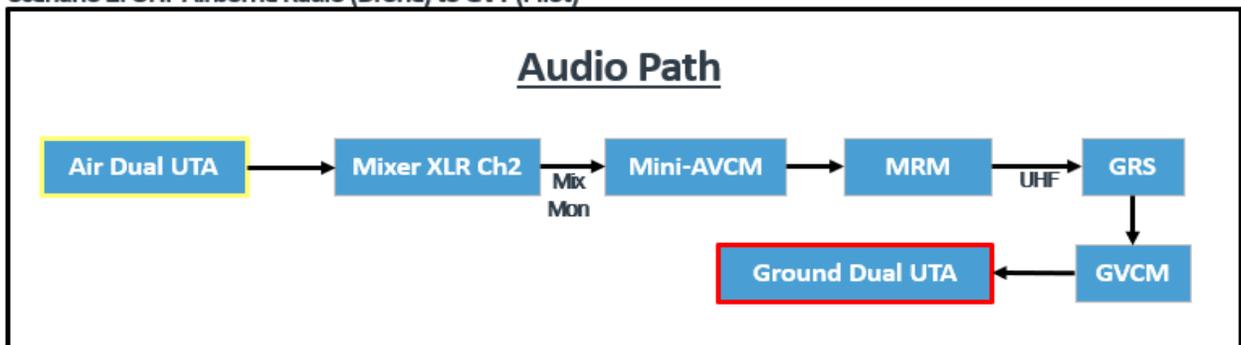


Figure 7: Audio Path for Test Case Scenario 2

TEST PROCEDURE:

1. Ensured prerequisites were met (e.g., batteries swapped as necessary).
2. Established RF connections between the radios.
3. Flew the drone to the operating altitude.
4. Captured audio files.
5. Returned the drone to the ground.
6. Archived the data.

Scenario 3

This test used the VHF link⁶. The ground network and AURA UHF link are not part of this test.

Intelligibility and acceptability were measured from the ATC Surrogate station to the drone.

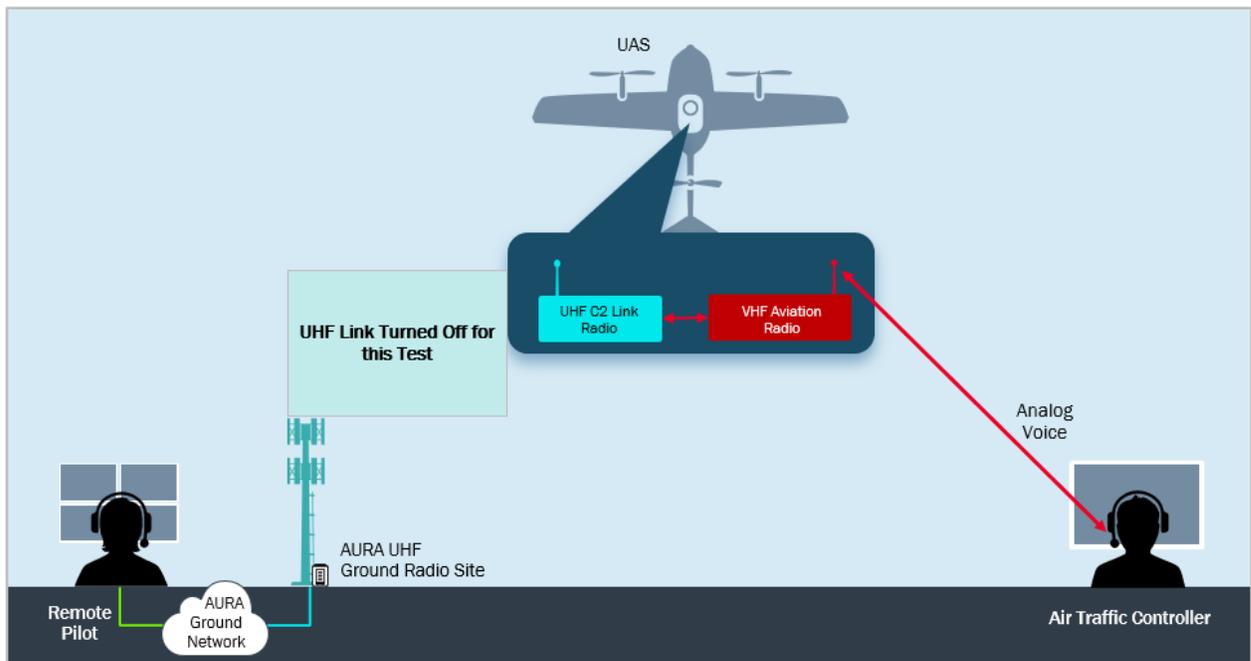


Figure 8: Graphic for Test Case Scenario 3

⁶ Note: The VHF channel used was licensed for the duration of the test by UND. During testing involving the VHF link a handheld VHF radio was periodically used to monitor the channel for other users. While it is possible others may have been on the channel, AURA did not observe any other users stepping on the transmission.

Scenario 3: VHF Radio (ATC) to VHF Airborne Radio (Drone)

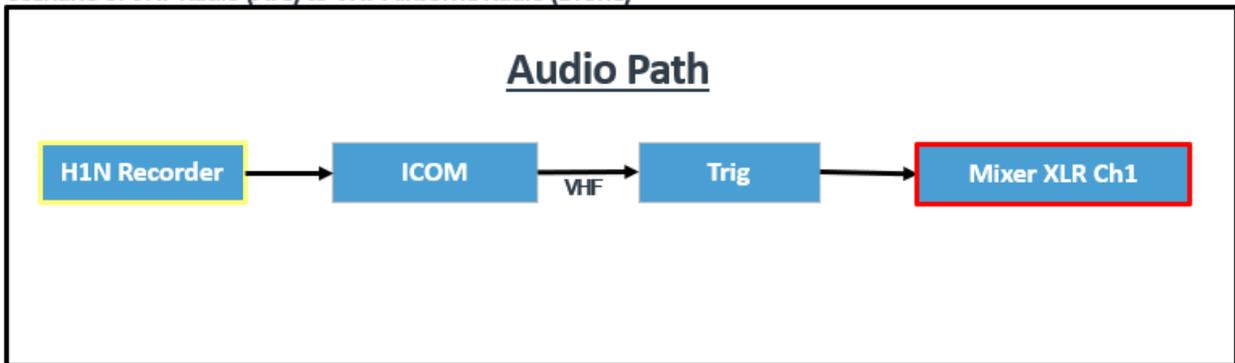


Figure 9: Audio Path for Test Case Scenario 3

TEST PROCEDURE:

1. Ensured prerequisites were met (e.g., batteries swapped as necessary).
2. Established RF connections between the radios.
3. Ensured ATC Surrogate (ICOM) was powered on and cabled correctly.
 - a. Ensured the VHF radio was set to 123.375 MHz
4. Flew the drone to the operating altitude (for this test, the drone was on the ground).
5. Captured the audio files.
6. Archived the data from the TASCAM Mixer.

Scenario 4

This test used the ground network, the AURA UHF link, and the VHF link. Intelligibility and acceptability were measured from the ATC Surrogate Station to the Remote Pilot Station.

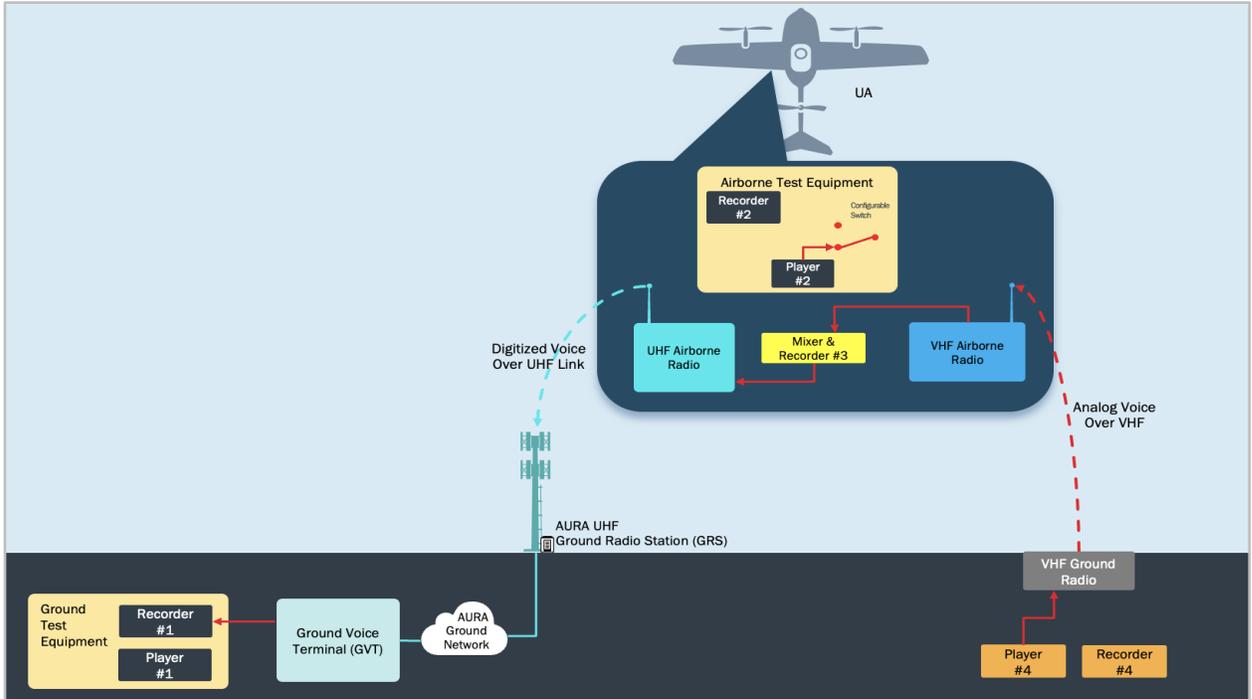


Figure 10: Graphic for Test Case Scenario 4

Scenario 4: VHF Radio (ATC) to GVT (Pilot)

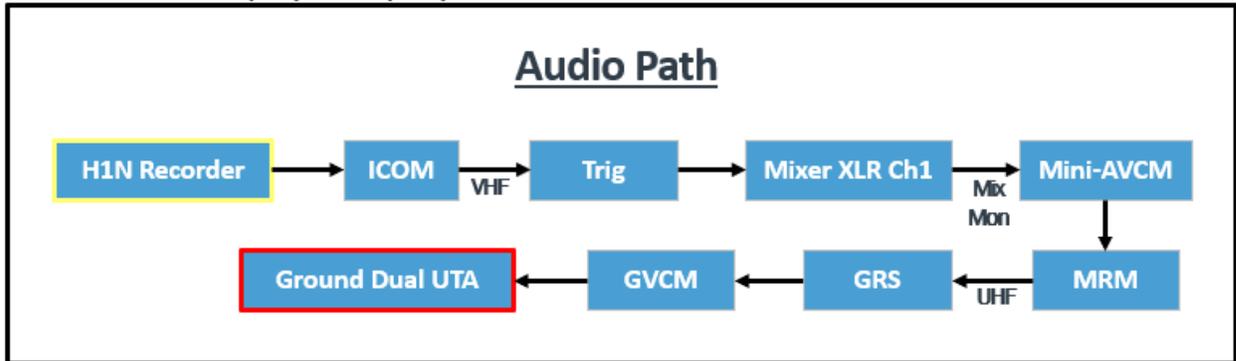


Figure 11: Audio Path for Test Case Scenario 4

TEST PROCEDURE:

1. Ensured prerequisites were met (e.g., batteries swapped as necessary).
2. Established RF connections between the radios.
3. Ensured ATC Surrogate was powered on and cabled correctly.
4. Flew the drone to the operating altitude (for this test, the drone was on the ground).
5. Captured audio files.

6. Archived the data.

Scenario 5

This test used the VHF link. The ground network and the AURA UHF link were not used for this test. Intelligibility and acceptability were measured from the drone to the ATC Surrogate Station.

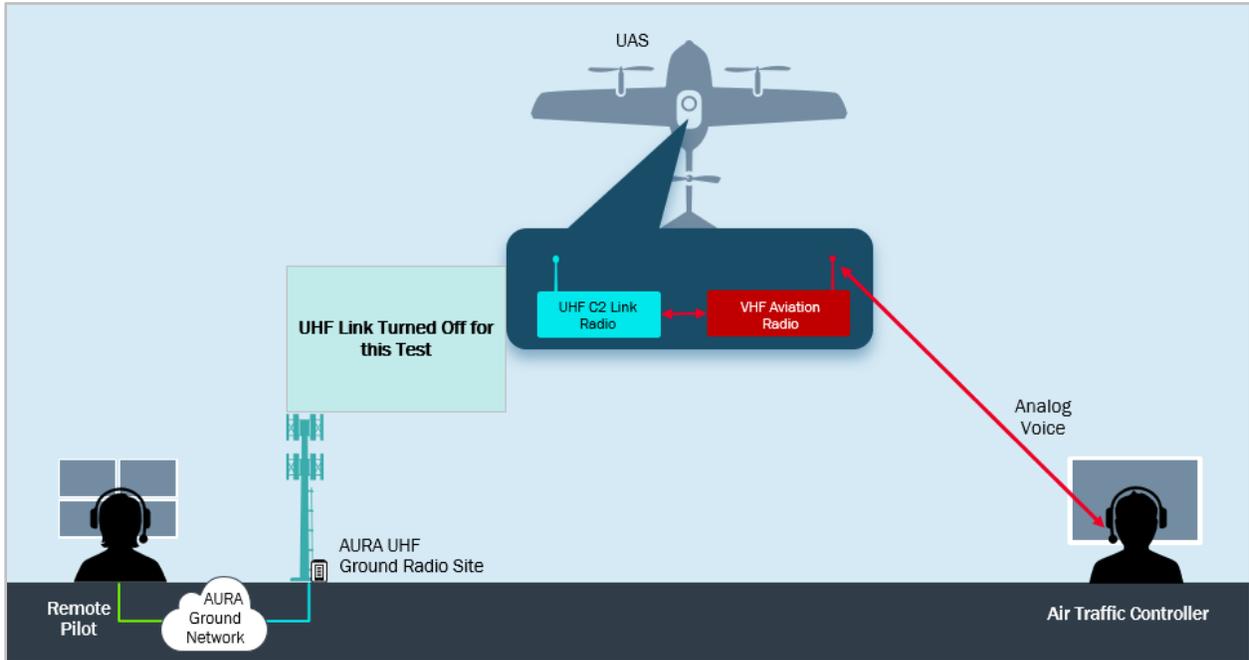


Figure 12: Graphic for Test Case Scenario 5

Scenario 5: VHF Airborne Radio (Drone) to VHF Radio (ATC)

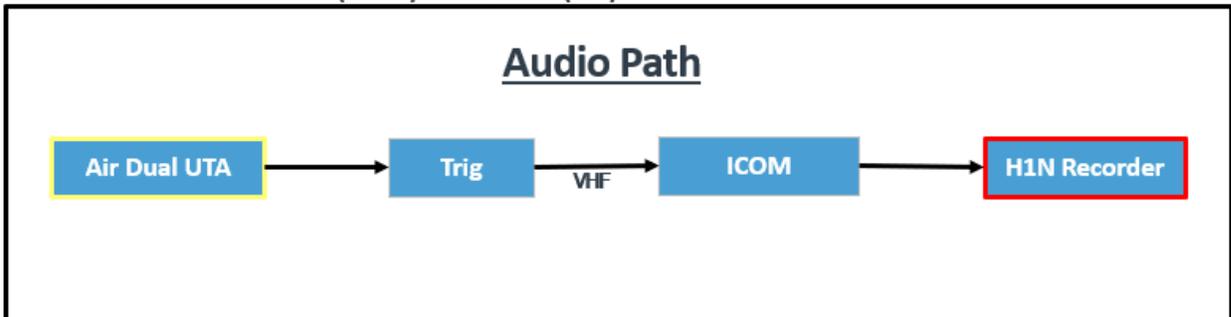


Figure 13: Audio Path for Test Case Scenario 5

TEST PROCEDURE:

1. Ensured prerequisites were met (e.g., batteries swapped as necessary).
2. Established RF connections between the radios.
3. Flew the drone to the operating altitude (for this test, the drone was on the ground).

4. Captured the audio files.
5. Archived the H1N Recording.

Scenario 6

This test used the ground network, the AURA UHF link, and the VHF link. Intelligibility and acceptability were measured from the Remote Pilot Station to the ATC Surrogate Station.

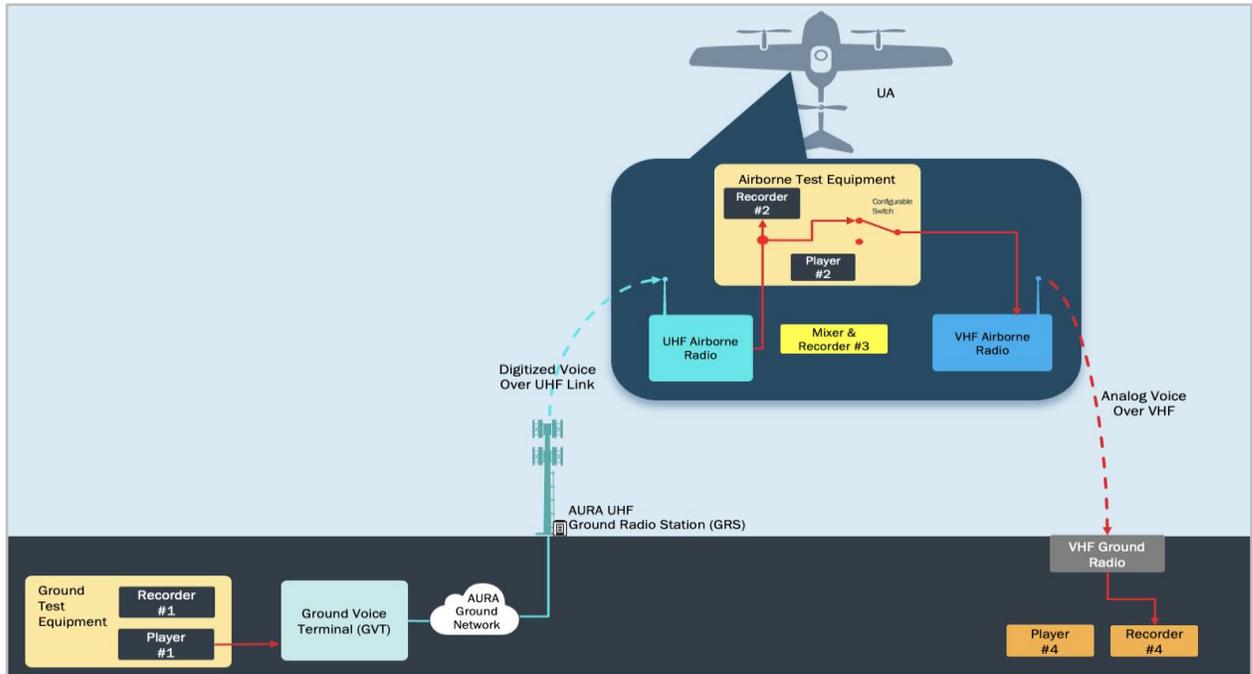


Figure 14: Graphic for Test Case Scenario 6

Scenario 6: GVT (Pilot) to VHF Ground Radio (ATC)

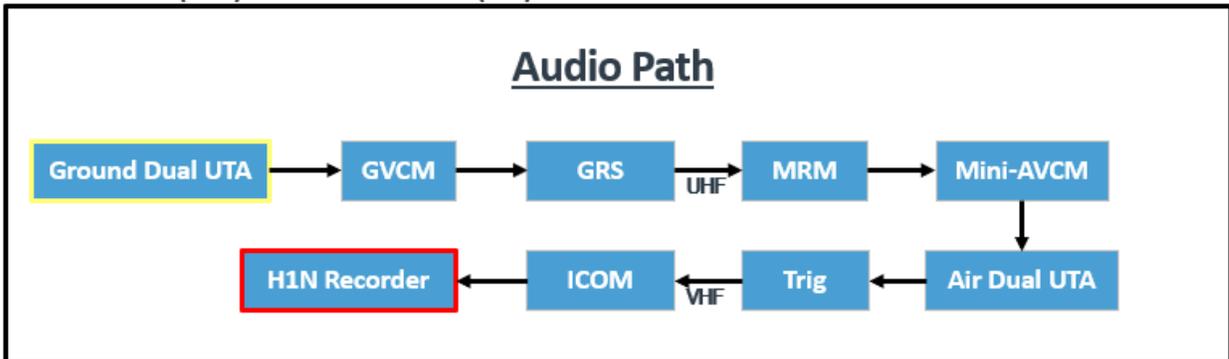


Figure 15: Audio Path for Test Case Scenario 6

TEST PROCEDURE:

1. Ensured prerequisites were met (e.g., batteries swapped as necessary).

2. Established RF connections between the radios.
3. Flew the drone to the operating altitude (for this test, the drone was on the ground).
4. Captured the audio files.
5. Archived the data.

Scenario 7

This test utilized live volunteers on headsets located at the Remote Pilot Station and the ATC Surrogate Station. The objective was to test voice communication from the ATC Surrogate Station to the Remote Pilot Station and from the Remote Pilot Station to the ATC Surrogate Station. UND-provided volunteers conversed as a Remote Pilot and as an ATC Surrogate. The volunteers executed scripted dialogue that was provided by experienced air traffic controllers at UND. Each volunteer recorded their observations in a survey after completing their live conversation. This test used the ground network, the AURA UHF link, and the VHF link.

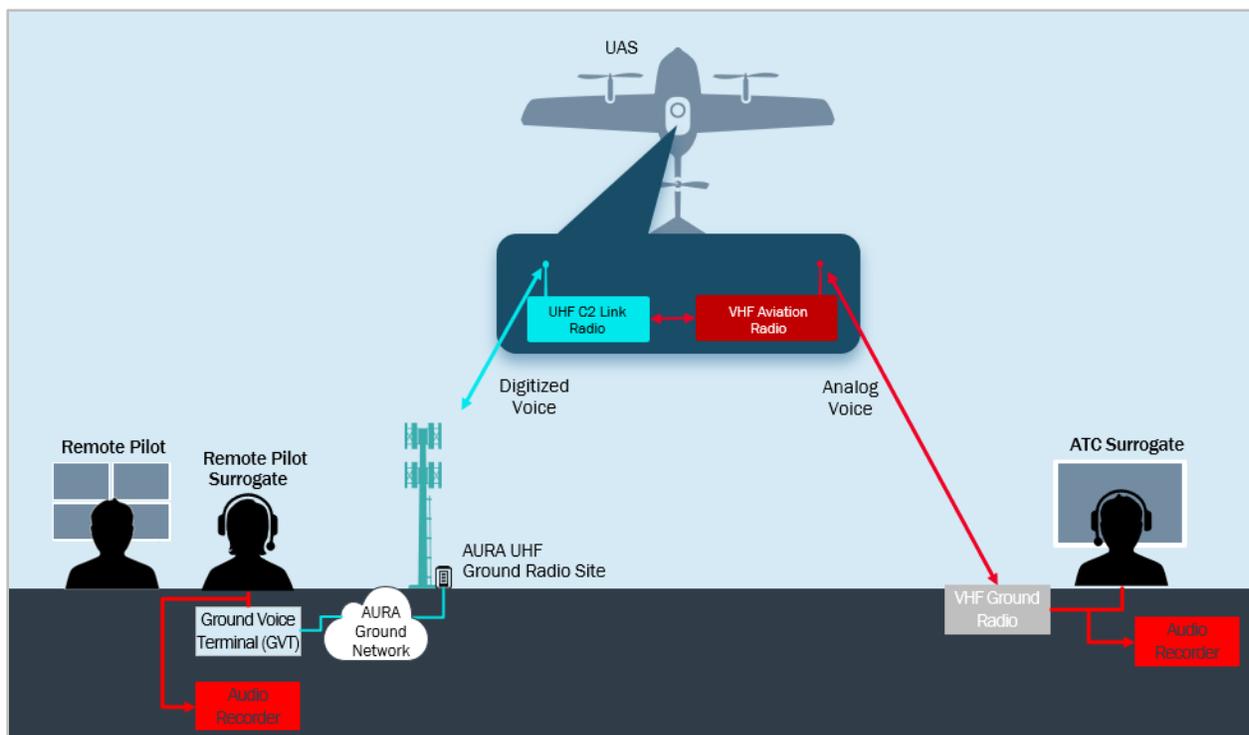


Figure 16: Graphic for Test Case Scenario 7

Scenario 7: ATC to Pilot (Freeform)

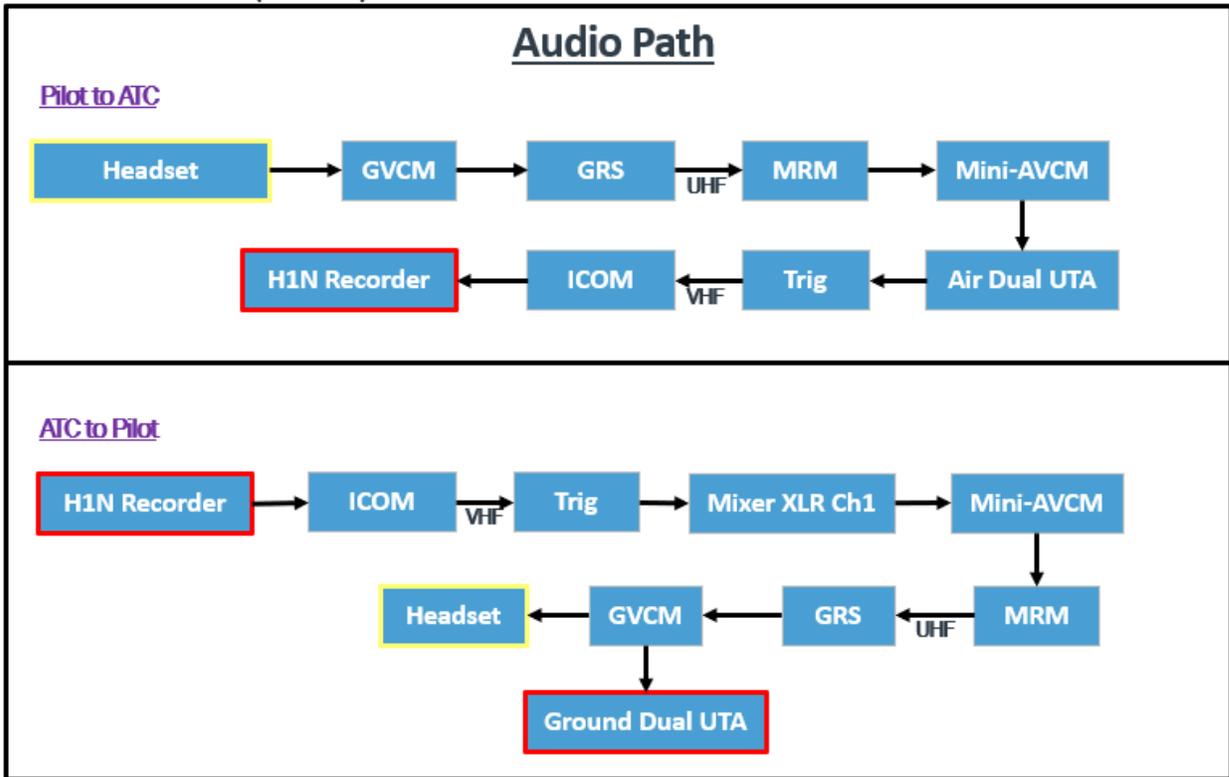


Figure 17: Audio Path for Test Case Scenario 7

TEST PROCEDURE:

1. Ensured prerequisites were met (e.g., batteries swapped as necessary).
2. Established RF connections between the radios.
3. Flew the drone to the operating altitude (for this test, the drone was on the ground).
4. Captured the audio files.
5. Archived the data.

Scenario 8

This test measured POLQA and Latency on the link from the Remote Pilot Station to the drone and from the drone to the Remote Pilot Station over the ground network and AURA's UHF. The VHF link is not used on this test. Both A2G and G2A were measured in this test.

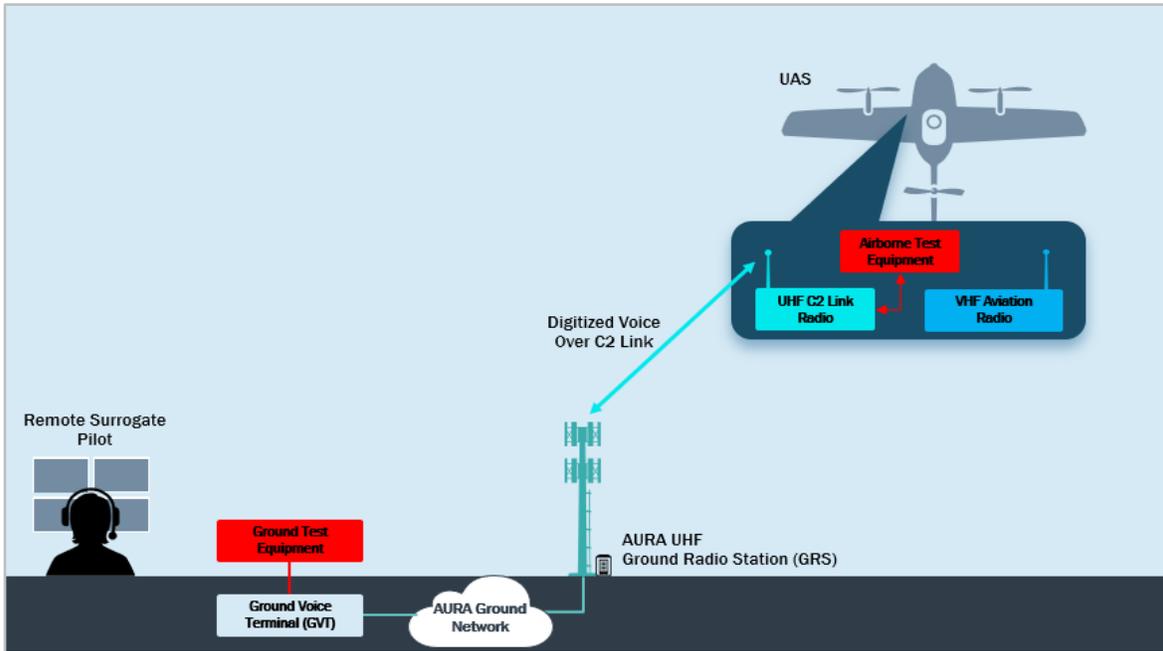


Figure 18: Graphic for Test Case Scenario 8

Scenario 8: A2G/G2A POLQA and Latency

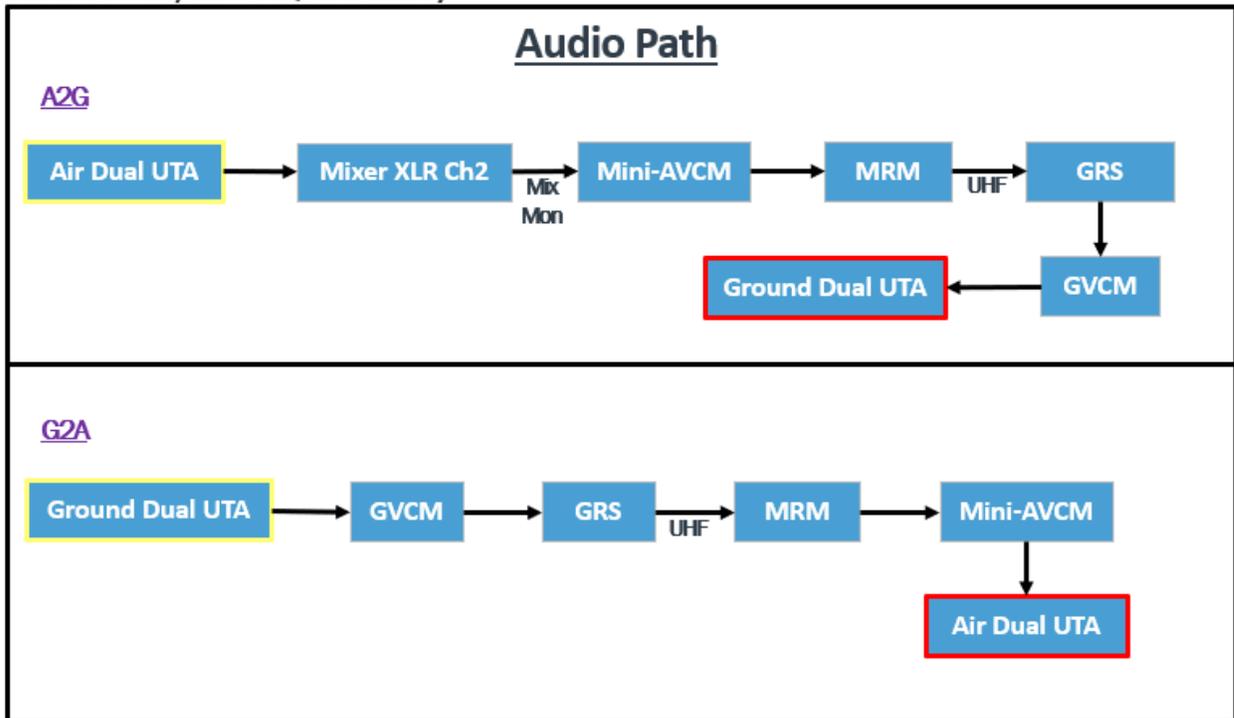


Figure 19: Audio Path for Test Case Scenario 8

TEST PROCEDURE:

1. Ensured prerequisites were met (e.g., batteries swapped as necessary).

2. Established RF connections between the radios.
3. Flew the drone to the operating altitude.
4. Captured audio files.
5. Returned the drone to the ground.
6. Archived the data.

Intelligibility Procedure

Test Case Scenarios 1 – 6

Prior to any study procedures taking place, each participant reviewed the study protocol with a member of the study team and then provided their informed consent. Participants were then asked to self-report demographic information, including their gender, age, academic progress, flight experience, and pilot/medical certifications. Participants were then asked to complete six scenarios, each with different versions of the Modified Rhyme Test (MRT) and the Message Completion Test (MCT).

The MRT is an intelligibility test that consists of six lists of 50 items (American National Standards Institute [ANSI], 1996). The purpose of this task was to evaluate whether participants could identify a spoken word and distinguish it from a set of phonemically similar words. Each item contained six rhyming monosyllabic words that differed only in their initial or final phoneme (e.g., pus, pub, pun, puff, puck, and pup; or hold, cold, told, fold, sold, and gold). Participants listened to an audio recording and were tasked to choose the word that was played from a given list. All participants received five training trials to familiarize themselves with the procedure before moving on to the testing items. After completing the MRT, participants were asked to rate the intelligibility and acceptability of the communications heard in the test (see Figure 20). Each MRT item was presented to the participants in the format shown in the Figure below.

Clip can be played only once.



pin

sin

tin

fin

din

win

Figure 20: Stimulus Presentation for the MRT

Participants were then asked to complete the MCT, which examined the intelligibility and acceptability of standard ATC words and phraseology. For this task, participants were instructed to listen to five ATC phrases and fill in the missing details (e.g., altitudes, headings, call signs) as shown in the Figure below. The purpose of this task was to examine whether controllers could accurately perceive and recite the missing details after listening to a recording of the phrase. Similar to the MRT, all participants received five training trials of the MCT to familiarize themselves with the procedure before moving on to the testing items. Upon completion of the MCT, participants were asked to rate the intelligibility and acceptability of the communications heard throughout the test (see Figure 21).

Okay, [redacted], we'll call [redacted] approach, thanks

Clip can be played only once.



Figure 21: Mission Completion Task Administration

Scenario 7

Prior to any study procedures taking place, each participant reviewed the study protocol with a member of the study team and then provided their informed consent. Participants were then asked to self-report demographic information, including their gender, age, academic progress, flight experience, and pilot/medical certifications. Participants were then driven from the University of North Dakota campus to the Mayville Airport (Remote Pilot Surrogate) and to a farm approximately five miles from the Mayville Airport (ATC Surrogate). Each participant played the role of both the air traffic controller and pilot for each test scenario. As the ATC Surrogate, the participant was tasked to read a series of radio calls; the Remote Pilot Surrogate was then tasked to respond to the calls as appropriate and rate the intelligibility and acceptability of the communication they received. Half of the radio calls were administered using a VHF line and half used a UHF line. Participants were compensated with a \$25 gift card per hour of their participation.

Test Results, Data Analysis, and Discussion

Test Results: Test Scenario 8 (Latency and POLQA)

Latency Test Results for AURA UHF Link versus DO-377B Requirements

Latency AURA UHF	Measured Ground-to-Air	Measured Air-to-Ground	DO-377B Requirement
Mean	152+/-2.1 (ms)	170+/-2.2 (ms)	198 (ms)
99%	175 (ms)	193 (ms)	238 (ms)

POLQA Scores for AURA UHF Link

POLQA AURA UHF		Measured Ground-to-Air	Measured Air-to-Ground
	Male	3	3.76
	Female	2.52	3.32

Latency

Latency was measured from the Remote Pilot Station to the drone over the AURA UHF radio link and from the drone to the Remote Pilot Station (raw data is included in Appendix A).

The table below shows the latency in comparison with DO-377B requirements. Mean latency was calculated as the arithmetic average and was displayed with the 95% confidence interval range.

The 99th percentile threshold was calculated using the calculated mean and standard deviation as

$$99th\ Percentile = mean + 2.326 * (standard\ deviation)$$

where 2.326 is the approximate z-score at the 99th percentile for the normal distribution.

Results were:

	Sample Size	Mean Latency (ms) ± 95% CI	99% Percentile
DO-377B Requirement	N/A	198ms (no CI requirement)	238ms
Measured Ground-to-Air (G2A)	71	152ms±2.1 ms	175ms
Measured Air-to-Ground (A2G)	68	170ms ±2.2 ms	193ms

Discussion:

Calculated latency means (and associated 95% CI values) and predicted 99th percentile values were well below the requirements specified in DO-377B.

Note that both the 95% confidence interval and predicted 99th percentile values were calculated assuming a Gaussian distribution of the latency data. Given that the observed results were well

within the required tolerances, a more comprehensive functional fit for the distributions was not necessary to demonstrate compliance.

Additionally, the test passed voice packets over the local internet from the Remote Pilot Station location at the Mayville Airport Pilot’s Lounge to the ground radio located at AURA’s Buxton, ND ground station site. While the results indicated strong performance under the defined test conditions, it is worth noting that a commercial deployment would benefit from dedicated links, which could further reduce variability in the latency of the ground network.

POLQA

POLQA scores were collected for the AURA UHF link air-to-ground and ground-to-air for male and female voices. Results measured were:

	Female POLQA	Male POLQA
Air-to-Ground (A2G)	3.32	3.76
Ground-to-Air (G2A)	2.52	3.00

Discussion:

POLQA scores are extremely sensitive to audio levels in each stage of the audio chain. During testing, a single setting for the audio levels was used for both male and female voice files. While the female scores could potentially be improved by increasing the playback volume (as the female voices tended to sound softer than the male voices and are typically higher in pitch), doing so often resulted in clipping of the male voice samples. Therefore, the volume levels were carefully selected to provide an optimal balance, minimizing distortion, and ensuring acceptable scores for both male and female files using a single consistent setting.

The ground-to-air POLQA scores were lower than the air-to-ground scores. This is due to power supply-induced hum in the GVCM, which digitizes the voice samples in the Remote Pilot Station. A lab-grade Keysight power supply was used to power the GVCM to mitigate this noise. This mitigation effort reduced the noise but did not completely eliminate it. A production-grade GVCM implementation would include enhanced power supply filtering, which could significantly reduce the power supply noise and further improve the audio quality.

Test Results: Test Case Scenarios 1 – 7 (Intelligibility)

Below is the summary of MRT (Modified Rhyme Testing) and MCT (Message Completion Test) test results. The table shows percent correct for the MRT and MCT for the different scenarios (over the VHF only, over AURA UHF only, and over both the VHF and AURA UHF radio links). The table also indicates the intelligibility and acceptability scores for each scenario.

		ATC to Drone	Drone to ATC	
Legacy VHF Only	MRT	72.87%	93.49%	
	Intelligibility	4.67	6	
	Acceptability	4.03	6.03	
	MCT	91.51%	93.05%	
	Intelligibility	6.05	6.34	
	Acceptability	5.61	6.26	
AURA UHF Only			Pilot to Drone	Drone to Pilot
	MRT	92.11%	93.89%	
	Intelligibility	6	6.08	
	Acceptability	5.82	6.13	
	MCT	88.84%	94.61%	
	Intelligibility	6.29	6.39	
	Acceptability	6.21	6.39	
VHF and UHF			Pilot to ATC	ATC to Pilot
	MRT	81.7%	67.6%	
	Intelligibility	5.2	3.97	
	Acceptability	4.46	3.57	
	MCT	91.74%	82.83%	
	Intelligibility	5.83	5.26	
	Acceptability	5.43	4.89	

How to Interpret Intelligibility and Acceptability Scores:

Score	Intelligibility
1	I could understand nothing that was said.
2	I could understand nearly nothing that was said.
3	I could understand a little of what was said.
4	I could understand about half of what was said.
5	I could understand most of what was said.
6	I could understand nearly everything that was said.
7	I could understand everything that was said.
Score	Acceptability
1	In all foreseeable situations, the audio would be unsatisfactory.
2	In nearly all foreseeable situations, the audio would be unsatisfactory.
3	In most foreseeable situations, the audio would be unsatisfactory.
4	In about half of the foreseeable situations, the audio would be satisfactory.
5	In most foreseeable situations, the audio would be satisfactory.
6	In nearly all foreseeable situations, the audio would be satisfactory.
7	In all foreseeable situations, the audio would be satisfactory.

The following are Intelligibility and Acceptability results for end-to-end communication.

ATC Surrogate Location Overall Intelligibility & Acceptability – Pilot to ATC Communication

	n	Cumulative %
Intelligibility		
I could understand nothing that was said.	0	0
I could understand nearly nothing that was said.	0	0
I could understand a little of what was said.	0	0
I could understand about half of what was said.	0	0
I could understand most of what was said.	0	0
I could understand nearly everything that was said.	2	6.3
I could understand everything that was said.	30	93.8
Acceptability		
In all foreseeable situations, the audio would be unsatisfactory.	0	0
In nearly all foreseeable situations, the audio would be unsatisfactory.	0	0
In most foreseeable situations, the audio would be unsatisfactory.	0	0
In about half of the foreseeable situations, the audio would be satisfactory.	0	0

In most foreseeable situations, the audio would be satisfactory.	3	9.4
In nearly all foreseeable situations, the audio would be satisfactory.	11	34.4
In all foreseeable situations, the audio would be satisfactory.	18	56.3

Remote Pilot Location Overall Intelligibility & Acceptability – Pilot to ATC Communication

	n	Cumulative %
Intelligibility		
I could understand nothing that was said.	0	0
I could understand nearly nothing that was said.	0	0
I could understand a little of what was said.	0	0
I could understand about half of what was said.	0	0
I could understand most of what was said.	3	9.1
I could understand nearly everything that was said.	12	36.4
I could understand everything that was said.	18	54.5
Acceptability		
In all foreseeable situations, the audio would be unsatisfactory.	0	0
In nearly all foreseeable situations, the audio would be unsatisfactory.	0	0
In most foreseeable situations, the audio would be unsatisfactory.	0	0
In about half of the foreseeable situations, the audio would be satisfactory.	0	0
In most foreseeable situations, the audio would be satisfactory.	9	28.1
In nearly all foreseeable situations, the audio would be satisfactory.	10	31.3
In all foreseeable situations, the audio would be satisfactory.	13	40.6

Data Analysis: Test Scenarios 1 – 6 (Intelligibility)

Background Questionnaire:

A total of 40 individuals ($N_{\text{Male}} = 32$, $N_{\text{Female}} = 8$) participated in the study. The average age of participants was 22.640 ($SD = 3.48$). All the participants held a private pilot certificate, and the majority ($N = 39$) held a current FAA medical certificate. The participants in this sample had an average of 270.785 ($SD = 184.477$) flight hours. Additional information related to this sample's education level and degree progress were included in the table below. The demographic

information shows that most participants were nearing the end of their degree program, which is indicative of more flight hours and increased familiarity with ATC radio transmissions.

Education Level	N	%
<i>Freshman</i>	4	10.3
<i>Sophomore</i>	3	7.7
<i>Junior</i>	11	28.3
<i>Senior</i>	15	38.5
<i>Graduate Student / Professional</i>	6	15.4

Degree Progress	M	SD
<i>Course Credit Hours</i>	116.000	45.463

Overview:

The percentage of words correctly produced for the MRT test, and the percentage of words correctly reproduced for the MCT test were computed separately for each test scenario 1 - 6. Additionally, intelligibility and acceptability ratings were also evaluated for each of the 6 scenarios. Three sets of analysis were conducted to compare the performance of signals produced from various pathways.

Comparison One: Test Scenario #1 and #2

The first set of analyses compared the performance of Test Scenario #1 – GVT (Remote Pilot) to UHF Airborne Radio and Test Scenario #2 - UHF Airborne Radio to GVT (Remote Pilot). A series of correlated sample “t-tests” and “Cohen’s d” effect sizes are presented below for tables 1 - 6. The *t-tests* (*t*) assess whether there are statistically significant differences between the means of these paired samples. A significant difference means there is a small likelihood the differences are due to chance and a large likelihood that the differences are due to the independent variable. *Cohen’s D* quantifies the magnitude of these differences. An effect size of 0.2 is considered small, an effect size of 0.5 is considered medium, and an effect size of 0.8 is considered large.

The results indicated minimal differences on the MRT test when the UHF signal originated from the airborne vehicle or when it originated from the ground. Although the MRT test was higher when originating from the airborne vehicle (93.89%) than the ground (92.11%) the advantage was minimal (1.9% difference). Ratings of intelligibility and accessibility were not significantly different.

The results also indicated minimal differences on the MCT test when the UHF signal originated from the airborne vehicle or when it originated from the ground. Although the MCT test was higher when originating from the airborne vehicle (94.61%) than the ground (88.84%) the advantage was minimal (6% difference). Ratings of intelligibility and accessibility were not significantly different.

Table 1

	Scenario 1 (S1)	Scenario 2 (S2)		
	MRT S1	MRT S2	t	Cohen's D
Mean (SD)	92.11 (4.41)	93.89(4.05)	-2.296*	0.34

Table 2

	Scenario 1 (S1)	Scenario 2 (S2)		
	MRT Intelligibility S1	MRT Intelligibility S2	t	Cohen's D
Mean (SD)	6.00 (.465)	6.08 (.539)	0.723	0.12

Note: A score of 6 indicated the person responded, "I could understand **nearly everything** that was said."

Table 3

	Scenario 1 (S1)	Scenario 2 (S2)		
	MRT Acceptability S1	MRT Acceptability S2	t	Cohen's D
Mean (SD)	5.82 (.766)	6.13 (.844)	-2.63*	0.43

Note: A score of 5 indicated the person responded, "In **most** foreseeable situations, the audio would be **satisfactory**."

Note: A score of 6 indicated the person responded, "In **nearly all** foreseeable situations, the audio would be **satisfactory**."

Table 4

	Scenario 1 (S1)	Scenario 2 (S2)		
	MCT S1	MCT S2	t	Cohen's D
Mean (SD)	88.84 (18.06)	94.61(5.41)	-2.052*	0.33

Table 5

	Scenario 1 (S1)	Scenario 2 (S2)		
	MCT Intelligibility S1	MCT Intelligibility S2	t	Cohen's D
Mean (SD)	6.29 (.80)	6.39 (.75)	-.61	0.099

Note: A score of 6 indicated the person responded. "I could understand **nearly everything** that was said."

Table 6

	Scenario 1 (S1)	Scenario 2 (S2)		
	MCT Acceptability S1	MCT Acceptability S2	t	Cohen's D
Mean (SD)	6.21 (.74)	6.39 (.82)	-1.362	0.22

Note: A score of 6 indicated the person responded, "In **nearly all** foreseeable situations, the audio would be **satisfactory**."

Comparison Two: Test Scenario #3 and #5

The second set of analyses compared the performance of Test Scenario #3 - VHF Ground Radio to VHF Airborne Radio to Test Scenario #5 - VHF Airborne Radio down to VHF Ground Radio. A series of correlated sample “t-tests” (t) and “Cohen’s d” effect sizes are presented below are presented below for tables 7 - 12. The *t-tests* (t) assess whether there are statistically significant differences between the means of these paired samples. A significant difference means there is a small likelihood the differences are due to chance and a large likelihood that the differences are due to the independent variable. *Cohen’s D* quantifies the magnitude of these differences. An effect size of 0.2 is considered small, an effect size of 0.5 is considered medium, and an effect size of 0.8 is considered large.

The results indicated significant differences on the MRT test when the VHF signal originated from the ground. The MRT test was significantly higher when originating from the airborne vehicle (93.49%) than the ground (72.87%) the advantage was 21% higher. Ratings of intelligibility and accessibility were both significantly higher when the VHF signal originated from the airborne vehicle.

The results indicated no significant differences on the MCT test when the VHF signal originated from the airborne vehicle or when it originated from the ground. Ratings of intelligibility and accessibility were significantly higher when the VHF signal originated from the airborne vehicle.

Table 7

	Scenario 3 (S3)	Scenario 5 (S5)		
	MRT S3	MRT S5	t	Cohen’s D
Mean (SD)	72.87 (7.25)	93.49 (3.27)	-17.53*	2.81

Table 8

	Scenario 3 (S3)	Scenario 5 (S5)		
	MRT Intelligibility S3	MRT Intelligibility S5	t	Cohen's D
Mean (SD)	4.67 (.81)	6.00 (.61)	-9.27*	1.48

Note: A score of 4 indicates the person responded, "I could understand **about half** of what was said."

Note: A score of 6 indicates the person responded, "I could understand **nearly everything** that was said."

Table 9

	Scenario 3 (S3)	Scenario 5 (S5)		
	MRT Acceptability S3	MRT Acceptability S5	t	Cohen's D
Mean (SD)	4.03 (1.16)	6.03 (.844)	-10.29*	1.65

Note: A score of 4 indicates the person responded, "In **about half** of the foreseeable situations, the audio would be **satisfactory**."

Note: A score of 6 indicates the person responded, "In **nearly all** foreseeable situations, the audio would be **satisfactory**."

Table 10

	Scenario 3 (S3)	Scenario 5 (S5)		
	MCT S3	MCT S5	t	Cohen's D
Mean (SD)	91.51 (10.65)	93.05 (10.16)	-1.11	0.18

Table 11

	Scenario 3 (S3)	Scenario 5 (S5)		
	MCT Intelligibility S3	MCT Intelligibility S5	t	Cohen's D
Mean (SD)	6.05 (.887)	6.34 (.59)	-2.49*	0.39

Note: A score of 6 indicates the person responded, "I could understand **nearly everything** that was said."

Table 12

	Scenario 3 (S3)	Scenario 5 (S5)		
	MCT	MCT	t	Cohen's D
	Acceptability S3	Acceptability S5		
Mean (SD)	5.61 (1.09)	6.26 (.677)	-3.95*	0.64

Note: A score of 5 indicates the person responded, “In **most** foreseeable situations, the audio would be **satisfactory**.”

Note: A score of 6 indicates the person responded, “ In **nearly all** foreseeable situations, the audio would be **satisfactory**.”

Comparison Three: Test Scenario #4 and #6

A third set of analyses compared the performance of Scenario #4 - VHF Ground Radio to the Airborne Radio and back down through UHF to the GVT to Scenario #6 - GVT up through UHF to the Airborne Radio and back down to the VHF Ground Radio. A series of correlated sample “t-tests” (t) and “Cohens D” effect sizes are presented below for tables 13 - 18. The *t-tests* (t) assess whether there are statistically significant differences between the means of these paired samples. A significant difference means there is a small likelihood the differences are due to chance and a large likelihood that the differences are due to the independent variable. *Cohen's D* quantifies the magnitude of these differences. An effect size of 0.2 is considered small, an effect size of 0.5 is considered medium, and an effect size of 0.8 is considered large.

The results indicated significant differences on the MRT test when the VHF signal originated from the ground than the UHF signal originating from the ground (67.6% vs. 81.7%). Ratings of intelligibility and accessibility were both significantly higher when the UHF signal originated from the ground than the VHF signal originating from the ground

The results also indicated significant differences on the MCT test when the VHF signal originated from the ground than the UHF signal originating from the ground (82.8% vs. 91.74%). Ratings of

intelligibility and accessibility were significantly higher when the UHF signal originated from the ground than the VHF signal originating from the ground.

Table 13

	Scenario 4 (4S)	Scenario 6 (S6)		
	MRT S4	MRT S6	t	Cohen's D
Mean (SD)	67.6 (6.0)	81.7 (6.26)	-10.19*	1.72

Table 14

	Scenario 4 (4S)	Scenario 6 (S6)		
	MRT Intelligibility S4	MRT Intelligibility S6	t	Cohen's D
Mean (SD)	3.97 (.923)	5.2 (.719)	-8.62*	1.46

Note: A score of 3 indicates the person responded, "I could understand **a little** of what was said."

Note: A score of 5 indicates the person responded, "I could understand **most** of what was said."

Table 15

	Scenario 4 (4S)	Scenario 6 (S6)		
	MCT Acceptability S3	MCT Acceptability S6	t	Cohen's D
Mean (SD)	3.57 (1.24)	4.46 (1.22)	-4.74*	0.80

Note: A score of 3 indicates the person responded, "In **most** foreseeable situations, the audio would be **unsatisfactory**."

Note: A score of 4 indicates the person responded, "In **about half** of the foreseeable situations, the audio would be **satisfactory**."

Table 16

	Scenario 4 (4S)	Scenario 6 (S6)		
	MCT S4	MCT S6	t	Cohen's D
Mean (SD)	82.83 (12.65)	91.74 (11.25)	-8.91*	0.7

Table 17

	Scenario 4 (4S)	Scenario 6 (S6)		
	MCT Intelligibility S4	MCT Intelligibility S6	t	Cohen's D
Mean (SD)	5.26 (.91)	5.83 (1.09)	0.57	0.47

Note: A score of 5 indicates the person responded, "I could understand **most** of what was said."

Table 18

	Scenario 4 (4S)	Scenario 6 (S6)		
	MCT Acceptability S3	MCT Acceptability S5	t	Cohen's D
Mean (SD)	4.89 (1.28)	5.43 (1.33)	0.54	0.38

Note: A score of 4 indicates the person responded,, "In about half of the foreseeable situations, the audio would be satisfactory."

Note: A score of 5 indicates the person responded, "In most foreseeable situations, the audio would be satisfactory."

Data Analysis: Scenario 7 (Intelligibility)

Background Questionnaire:

38 individuals participated in the two-way communication event at the Mayville Airport (Remote Pilot Surrogate) and the farmer's location (ATC Surrogate). The participant sample consisted of 31 males (81.6%) and 7 females (18.4%) with an average age of 24.26 ($SD = 6.057$). The participants within the sample averaged 263.05 ($SD = 31.404$) flight hours. The demographic information shows that most participants were nearing the end of their degree program, which is indicative of more flight hours and increased familiarity with ATC radio transmissions.

Table 19

Education Level	N	%
<i>Freshman</i>	0	0
<i>Sophomore</i>	2	5.3
<i>Junior</i>	7	18.4
<i>Senior</i>	19	50
<i>Graduate Student / Professional</i>	10	26.3
Degree Progress	M	SD
<i>Course Credit Hours</i>	123.03	60.75
Medical Certificate	N	%
<i>1st Class</i>	26	68.4
<i>2nd Class</i>	5	13.2
<i>3rd Class</i>	4	10.5
<i>Other</i>	3	7.9
Pilot Certificates	N	%
Private Pilot License	11	
Private Pilot with Instrument Rating	6	
Commercial Pilot License	13	
Commercial Pilot with Instrument Rating	1	
Certified Flight Instructor	7	

The results for both intelligibility and acceptability are shown below – these results reflect only when the aircraft was on the ground.

Table 20*ATC Surrogate Location Overall Intelligibility & Acceptability*

	n	Cumulative %
Intelligibility		
I could understand nothing that was said.	0	0
I could understand nearly nothing that was said.	0	0
I could understand a little of what was said.	0	0
I could understand about half of what was said.	0	0
I could understand most of what was said.	0	0
I could understand nearly everything that was said.	2	6.3
I could understand everything that was said.	30	93.8
Acceptability		
In all foreseeable situations, the audio would be unsatisfactory.	0	0
In nearly all foreseeable situations, the audio would be unsatisfactory.	0	0
In most foreseeable situations, the audio would be unsatisfactory.	0	0
In about half of the foreseeable situations, the audio would be satisfactory.	0	0
In most foreseeable situations, the audio would be satisfactory.	3	9.4
In nearly all foreseeable situations, the audio would be satisfactory.	11	34.4
In all foreseeable situations, the audio would be satisfactory.	18	56.3

Table 21*Pilot Location Overall Intelligibility & Acceptability*

	n	Cumulative %
Intelligibility		
I could understand nothing that was said.	0	0
I could understand nearly nothing that was said.	0	0
I could understand a little of what was said.	0	0
I could understand about half of what was said.	0	0
I could understand most of what was said.	3	9.1
I could understand nearly everything that was said.	12	36.4
I could understand everything that was said.	18	54.5
Acceptability		
In all foreseeable situations, the audio would be unsatisfactory.	0	0
In nearly all foreseeable situations, the audio would be unsatisfactory.	0	0
In most foreseeable situations, the audio would be unsatisfactory.	0	0
In about half of the foreseeable situations, the audio would be satisfactory.	0	0
In most foreseeable situations, the audio would be satisfactory.	9	28.1
In nearly all foreseeable situations, the audio would be satisfactory.	10	31.3
In all foreseeable situations, the audio would be satisfactory.	13	40.6

The results of the intelligibility and acceptability study completed at Mayville Airport indicated that the majority of the participants at the ATC Surrogate location found communication to be satisfactory and intelligible. The latter implies that participants were able to understand, at a minimum, most of what was said, and the audio would be satisfactory in most foreseeable situations. Similarly, participants at the Remote Pilot location reported similarly favorable remarks, with most participants reporting that they could understand at minimum most of what was said, reporting that in most foreseeable situations the audio would be satisfactory.

Intelligibility Summary:

The results of the comparison between Test Scenario 1 and Test Scenario 2 indicated minimal differences on the MRT test when the UHF signal originated from the airborne vehicle or when it originated from the ground. Although the MRT test was higher when originating from the airborne vehicle (93.89%) than the ground (92.11%), the advantage was minimal (1.9% difference). Ratings of intelligibility and accessibility were not significantly different.

The results also indicated minimal differences on the MCT test when the VHF signal originated from the airborne vehicle or when it originated from the ground. Although the MCT test was higher when originating from the airborne vehicle (94.61%) than the ground (88.84%), the advantage was minimal (6% difference). Ratings of intelligibility and accessibility were not significantly different.

The comparison between Test Scenario 3 and Test Scenario 5 indicated significant differences on the MRT test when the VHF signal originated from the ground. The MRT test was significantly higher when originating from the airborne vehicle (93.49%) than the ground (72.87%) the

advantage was 21% higher. Ratings of intelligibility and accessibility were both significantly higher when the VHF signal originated from the airborne vehicle.

The results also indicated no significant differences on the MCT test when the VHF signal originated from the airborne vehicle or when it originated from the ground. Ratings of intelligibility and accessibility were significantly higher when the VHF signal originated from the airborne vehicle.

The comparison between Test Scenario 4 and Test Scenario 6 indicated significant differences on the MRT test when the VHF signal originated from the ground than the UHF signal originating from the ground (67.6% vs 81.7%). Ratings of intelligibility and accessibility were both significantly higher when the UHF signal originated from the ground than the VHF signal originating from the ground.

The results also indicated no significant differences on the MCT test when the VHF signal originated from the ground than the UHF signal originating from the ground. Ratings of intelligibility and accessibility were significantly higher when the UHF signal originated from the ground than the VHF signal originating from the ground.

Lessons Learned - Electromagnetic Interference (EMI)

During the flight test window of 6/9/25 – 6/13/25, valuable insights were gained regarding VHF audio performance during drone operations. While electromagnetic interference (EMI) affected VHF audio quality when the drone was airborne, successful link establishment and testing were achieved with the drone on the ground using remote mag mount antennas for both VHF and UHF ports. This setup enabled productive testing and data collection.

Prior to June 2025 and during the Phase 3 Flight Test Preparation of the Integrated Master Schedule (10/28/24 – 5/16/25), AURA discovered that EMI from the 10W VHF radio interfered with the drone C2 link and prevented operation of the drone. At that time, the team implemented EMI mitigation strategies including the addition of ferrite chokes, careful cable routing, and antenna placements to reduce coupling effects. The mitigation efforts were successful for the drone C2 link and the operation of the drone. Shielding was also considered at that time but was not a viable option due to the strict weight restrictions on the drone payload. However, interference with the VHF audio link was observed when the drone was in flight during the June 2025 testing. Given the tightly coordinated schedule with the UND human factors volunteers, the team made a strategic decision to proceed with the testing scenarios involving the VHF link while the drone was grounded. This approach proved successful, enabling the completion of all planned testing scenarios, including those involving the UND human factors volunteers. Given AURA's previously successful efforts in mitigating the in-flight interference issue, AURA was confident that the observed interference could have been reduced to acceptable levels had time permitted during the test. The test vehicle was smaller than what was anticipated for aircraft requiring VHF Voice Relay capability. The flight test aircraft had stringent weight limits because of the Part 107 regulations. The voice relay requirement was intended to support BVLOS operations that would occur on larger aircraft that would not have the space limitations that led to the VHF interference.

It is important to note that in-flight testing of the UHF link met and exceeded latency requirements and yielded acceptable scores for those measured quantities without a stated requirement, specifically, intelligibility and voice quality (POLQA).

Additional testing was conducted by AURA at AURA's Frederick, MD lab after the June 2025 testing using an identical drone as the one used in North Dakota, in order to further investigate the

electromagnetic interference (EMI) issues observed during the ND tests. This testing is described in detail in Appendix B. This testing determined that when using small drones equipped with high-powered DC brushless motors, it is essential to implement EMI mitigation strategies to maintain voice relay quality over a VHF radio link. If standard aircraft installation practices and adequate spatial separation are followed, EMI concerns can be effectively addressed.

Audio Captures from Test Scenarios

Samples of the audio captured during testing:

WAV files were provided to the FAA as part of the Draft Final Report Submission via FAA’s KSN system.

PILOT to DRONE	Pilot Station to Drone_AURA_UHF.wav
DRONE to PILOT	Drone_to_Pilot_Station_AURA_UHF.wav
PILOT to DRONE to ATC Surrogate	Pilot to Drone to ATC Surrogate Station_AURA_UHF and VHF.wav
ATC Surrogate to DRONE	ATC Surrogate Station to Drone_VHF.wav
DRONE to ATC Surrogate	Drone to ATC Station_VHF.wav
ATC Surrogate to DRONE to PILOT	ATC Surrogate Station to drone to Pilot_VHF and AURA UHF.wav

Conclusion and Recommendations

This testing effort aimed to demonstrate and evaluate the latency and voice quality performance of AURA's UHF-based communication link between a Remote Pilot Station and a drone, with the objective of complying with DO-377B latency requirements and the audio quality of the transmitted voice samples.

Latency was measured in both directions; ground-to-air (G2A) and air-to-ground (A2G) over the AURA UHF link. The measured latencies were well below the thresholds specified in DO-377B, with mean latencies of 152ms and 170ms respectively, and 99% latencies of 175ms and 193ms. These values were well below the maximum DO-377B requirements, demonstrating robust timing performance under different test scenarios.

POLQA scores were found to be sensitive to voice file characteristics and system-level audio settings. A single gain setting was used in both male and female voice testing. Female samples, which tend to be softer and higher pitched, expectedly showed lower scores unless volume was increased, which then led to clipping in male voice samples. This highlighted the trade-off in optimizing scores across voice types using a shared gain profile.

Ground-to-air quality was affected by the power supply hum in the GVCM. This suggested that the GVCM's power filtering design is a limiting factor in enhancing the ground-to-air voice quality.

These results demonstrated that the AURA C2 link met its latency and voice quality requirements, while identifying key areas for engineering refinements. With the targeted improvements, AURA's C2 link and its solutions can be confidently advanced toward operational deployment.

In addition to quantitative latency testing, qualitative testing using human subjects for intelligibility and acceptability also showed favorable results for the use of UHF communications links. Results reflect that the UHF communication link was equivalent and at times better than the VHF communication link in terms of intelligibility and acceptability. This does not take into consideration outside technical variables, such as the placement of VHF ground antennas at the ATC Surrogate location or the physical location of the drone in relation to the ATC Surrogate ground antennas. Nonetheless, survey results showed consistent high ratings in relation to intelligibility and acceptability for all scenarios involving human test subjects. This remains consistent with test scenario 3 and 5, as well as scenario 4 and 6, which also involve comparison of UHF and VHF communication links. Furthermore, results in the two-way communication tests show both communication links originating at the VHF or UHF locations had high intelligibility and acceptability levels; further validating the use of UHF as a viable solution for a communication link between remote pilots, drones, and air traffic control.

Appendix A: Latency Data

Attached are the Ground-to-Air and Air-to-Ground latency data captured during test scenario 8.

Data was collected on 6/10/25 and 6/12/25. The data was combined into a single data set for analysis. The tables show the date and time of the test and the latency that was measured.

Ground-to-Air Latency Data

raw_time	Latency (ms)
6/10/25 11:08	156
6/10/25 11:08	156
6/10/25 11:09	156
6/10/25 11:09	156
6/10/25 11:10	155
6/10/25 11:25	144
6/10/25 11:26	154
6/10/25 11:27	146
6/10/25 11:28	146
6/10/25 11:28	146
6/10/25 11:28	149
6/10/25 11:30	150
6/10/25 11:30	150
6/10/25 11:30	141
6/10/25 11:31	154
6/10/25 11:32	148
6/10/25 11:32	145
6/10/25 11:33	149
6/10/25 11:33	152
6/10/25 11:34	146
6/10/25 11:35	150
6/10/25 11:35	147
6/10/25 11:35	147
6/10/25 11:37	147
6/10/25 11:37	145
6/10/25 11:37	168
6/10/25 11:38	171
6/10/25 11:39	169
6/10/25 11:39	173
6/10/25 11:40	169

6/10/25 11:40	169
6/10/25 11:41	165
6/10/25 11:42	167
6/10/25 11:42	171
6/10/25 11:42	172
6/10/25 11:44	166
6/10/25 13:31	159
6/10/25 13:31	159
6/10/25 13:32	155
6/10/25 13:32	152
6/10/25 13:33	151
6/10/25 13:34	153
6/10/25 13:34	153
6/10/25 13:34	134
6/10/25 13:36	138
6/10/25 13:36	138
6/10/25 13:36	137
6/10/25 13:37	156
6/10/25 13:38	159
6/12/25 13:20	146
6/12/25 13:20	148
6/12/25 13:21	146
6/12/25 13:21	145
6/12/25 13:22	148
6/12/25 13:23	148
6/12/25 13:23	148
6/12/25 13:23	148
6/12/25 13:23	150
6/12/25 13:25	150
6/12/25 13:25	145
6/12/25 13:25	148
6/12/25 13:26	145
6/12/25 13:27	150

6/12/25 13:27	144
6/12/25 13:28	145
6/12/25 13:28	150
6/12/25 13:29	155
6/12/25 13:30	152
6/12/25 13:30	157
6/12/25 13:30	150
6/12/25 13:32	145
6/12/25 13:32	155

6/10/25 11:40 AM	157
6/10/25 11:40 AM	161
6/10/25 11:41 AM	161
6/10/25 11:42 AM	162
6/10/25 11:42 AM	158
6/10/25 11:42 AM	155
6/10/25 11:44 AM	179
6/10/25 1:31 PM	172
6/10/25 1:31 PM	173
6/10/25 1:32 PM	173
6/10/25 1:32 PM	153
6/10/25 1:33 PM	170
6/10/25 1:34 PM	170
6/10/25 1:34 PM	170
6/10/25 1:34 PM	174
6/10/25 1:36 PM	171
6/10/25 1:36 PM	171
6/10/25 1:36 PM	171
6/10/25 1:37 PM	175
6/12/25 1:20 PM	182
6/12/25 1:20 PM	179
6/12/25 1:21 PM	179
6/12/25 1:21 PM	175
6/12/25 1:22 PM	199
6/12/25 1:23 PM	175
6/12/25 1:23 PM	175
6/12/25 1:23 PM	179
6/12/25 1:25 PM	176
6/12/25 1:25 PM	180
6/12/25 1:25 PM	180
6/12/25 1:26 PM	176
6/12/25 1:27 PM	174
6/12/25 1:27 PM	177
6/12/25 1:28 PM	177
6/12/25 1:28 PM	178
6/12/25 1:29 PM	175
6/12/25 1:30 PM	178
6/12/25 1:30 PM	178
6/12/25 1:30 PM	179
6/12/25 1:32 PM	182

Air-to-Ground Latency Data

raw_time	Latency (ms)
6/10/25 11:08 AM	169
6/10/25 11:08 AM	166
6/10/25 11:09 AM	170
6/10/25 11:09 AM	170
6/10/25 11:25 AM	163
6/10/25 11:25 AM	171
6/10/25 11:27 AM	182
6/10/25 11:28 AM	179
6/10/25 11:28 AM	162
6/10/25 11:28 AM	162
6/10/25 11:30 AM	183
6/10/25 11:30 AM	180
6/10/25 11:30 AM	160
6/10/25 11:31 AM	160
6/10/25 11:32 AM	160
6/10/25 11:32 AM	161
6/10/25 11:33 AM	161
6/10/25 11:33 AM	157
6/10/25 11:34 AM	158
6/10/25 11:35 AM	158
6/10/25 11:35 AM	162
6/10/25 11:35 AM	162
6/10/25 11:37 AM	162
6/10/25 11:37 AM	162
6/10/25 11:37 AM	160
6/10/25 11:38 AM	160
6/10/25 11:39 AM	160
6/10/25 11:39 AM	161

Appendix B: Electromagnetic Interference (EMI)

Brushless DC Motors

Brushless DC motors (BLDC motors) are known to generate electromagnetic interference (EMI), which can potentially affect nearby electronic devices, including those operating in the VHF (Very High Frequency) band.

Sources of EMI in BLDC Motors:

- **Electronic Commutation:** Unlike traditional brushed DC motors, which use brushes and a commutator for mechanical commutation, BLDC motors utilize electronic commutation through switching devices like transistors (MOSFETs or IGBTs). The rapid switching of currents and voltages in these devices can generate high-frequency noise and electromagnetic fields.
- **Motor Windings:** The motor windings themselves can act as antennas, radiating electromagnetic energy due to the rapid changes in current during operation.
- **Power Supply and Control Circuits:** The motor controller and power supply can also introduce noise and EMI into the system.
- **Cabling and Grounding:** Improperly routed or unshielded cables can act as antennas, radiating EMI. Also, grounding issues, like ground loops, can contribute to EMI.

Potential Effects on VHF Equipment:

- **Interference with Signals:** The EMI generated by BLDC motors can interfere with VHF signals, potentially causing disruptions, degradation of performance, or even malfunctions in VHF communication equipment, radios, or other devices.
- **Signal Swamping:** If the EMI is strong enough, it can overload the sensitive amplifiers in VHF receivers, potentially making it impossible to receive the intended signals.

Mitigation Strategies:

Several methods can be used to reduce EMI from BLDC motors and minimize interference with VHF equipment:

- **Shielding:** Enclosing the motor or sensitive electronic components in conductive materials (like metal enclosures or shielding cables) can block electromagnetic fields and prevent the radiation of EMI. This was not attempted due to weight restrictions on the drone payload.
- **Filtering:** Filters (e.g., low-pass filters, common-mode chokes) can be installed on power and signal lines to attenuate high-frequency noise. Ferrite was added to many of the lines.
- **Grounding and Bonding:** Proper grounding and bonding techniques, such as using shielded cables and connecting grounds to a single point (star grounding), can help reduce EMI and were utilized.
- **Optimized Commutation:** Using advanced control algorithms can minimize the switching noise generated by BLDC motors.
- **Cable Management:** Proper routing and shielding of cables were used to reduce their ability to act as antennas.
- **Distance:** Increasing the distance between the BLDC motor and sensitive VHF equipment can help reduce interference and was used to the extent possible given the small drone and payload size.
- **PCB Design:** Careful PCB layout design, including minimizing trace lengths, separating power and signal traces, and using ground planes, can help reduce EMI.

Additional EMI Testing Results – Frederick, MD Lab

Additional testing was conducted by AURA at AURA's Frederick, MD lab after the June 2025 testing using an identical drone as the one used in North Dakota (ND), in order to further investigate the electromagnetic interference (EMI) issues observed during the ND tests. A Remote Pilot Station was set up in the lab, and the ATC Surrogate Station was placed in a vehicle at a similar distance to replicate the original configuration. Two key modifications were made to isolate and resolve the VHF EMI interference which was suspected to be caused by the six large DC brushless motors on the Inspired Flight 1200A drone:

1. **Harness and Equipment Optimization:** AURA minimized potential EMI pathways by removing test equipment (GL.COM UTA) and minimizing the cabling between the UHF and VHF radios. Additionally, AURA replaced the original panel-mounted TRIG VHF radio (designed for aircraft avionics panels with shielding) with a handheld Sporty VHF radio that featured better case shielding and minimal exposed cabling.
2. **Spatial Separation of Antenna:** To further reduce EMI from the drone, AURA tethered the VHF antenna 20 feet below the drone during flight, increasing the distance between the drone and the antenna.

Results:

Audio was recorded from ATC Surrogate Station to Remote Pilot and from Remote Pilot to ATC Surrogate Station with the drone in the air. These modifications significantly mitigated the EMI noise generated by the drone, demonstrating that such interference can be addressed through design refinements.

Conclusion:

When using small drones equipped with high-powered DC brushless motors, it is essential to

implement EMI mitigation strategies to maintain voice relay quality over a VHF radio link. If standard aircraft installation practices and adequate spatial separation are followed, EMI concerns can be effectively addressed.