Noise Measurement Report: Unconventional Aircraft – Joint Base Cape Cod; September 2021

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Measurement and Initial Noise Data Report – March 2022

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This report discusses the processes and results of an acoustic measurement program conducted at Joint Base Cape Cod in Bourne, Massachusetts from September 26th to October 1st, 2021. The test was conducted in support of the FAA's research into the acoustic characteristics of unconventional aircraft, and the inclusion of unconventional aircraft in the National Airspace System. Five small Unmanned Aerial Vehicles were measured – the DJI M600, DJI M200, DJI Phantom 4 Pro, the ArgenTech FireEye Series 2, and the ALTI Transition. This report contains a summary of the noise metric results collected from acoustic instrumentation used during the test. Analyses of these data sets, and of digital audio recordings from the measurement microphones will be presented in one or more follow-up reports.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
oz	ounces	28.35	grams	g
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
mL	milliliters	0.034	fluid ounces	fl oz
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
g	grams	0.035	ounces	oz
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	Kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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List of Abbreviations

Abbreviation	Term
AGL	Above Ground Level
AgTS	ArgenTech Solutions
ANSI	American National Standards Institute
AWRF	Acoustic Weather Research Facility
B&K	Brüel & Kjær (acoustic equipment manufacturer)
CARS	CompactRIO Acoustic Recording System
CFR	Code of Federal Regulations
CORS	Continually Operating Reference Station
COTS	Commercial/Consumer Off-the-Shelf
CPA	Closest Point of Approach
DJI	Dà-Jiāng Innovations (UA manufacturer)
FAA	Federal Aviation Administration
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
IPP	Integrated Pilot Program
JBCC	Joint Base Cape Cod
L_{AE}	Sound Exposure Level (SEL)
L_{ASmx}	Maximum A-weighted Level, slow response (LAMax)
L_{Aeq}	Equivalent Continuous Sound Level (LEQ)
LD	Larson Davis (acoustic equipment manufacturer)
MASSDOT	Massachusetts Department of Transportation
NAS	National Airspace System
NI	National Instruments (acoustic equipment manufacturer)
PTH	Pressure time-history
SD	Sound Designs (acoustic equipment manufacturer)
SLM	Sound Level Meter
START	Survey and Tracking Apparatus for Research in Transportation
UA	Unconventional Aircraft
USDOT	United States Department of Transportation
VTOL	Vertical Takeoff and Landing

1. Introduction

The Volpe Unconventional Aircraft (UA) Noise Research Team, in support of the Federal Aviation Administration's (FAA) Office of Environment and Energy noise division AEE-100, has been conducting and facilitating UA noise measurements for approximately 7 years. The purpose of these noise measurements has been to gather data to characterize the acoustic signatures of various types of UA, which can then be used to inform noise policy and regulations, encourage the development of specific aircraft designs, and highlight operations that may be acoustically relevant to the communities around proposed flight paths.

The primary purpose of this measurement campaign at Joint Base Cape Cod (JBCC) was to capture robust acoustics, tracking, and weather data to be used by FAA AEE-100 to inform and assist in the development of environmental assessments for proposed UA operations in and around communities in the United States. An additional goal was to share the collected data (after appropriate anonymization) with fellow government, industry researchers, and academic research teams to facilitate knowledge transfer and collaboration amongst all stakeholders.

This report can be viewed as a continuation of the work done by the Volpe UA Noise Research Team in July 2019 as part of the UAS Integration Pilot Program at the Choctaw Nation test site near Daisy, Oklahoma[1]. There are many similarities between the Choctaw measurement campaign and this effort at JBCC, such as aircraft types, operations, and core data types. There have also been many improvements and changes made to the measurement hardware, software, and operations to fit the requirements provided by FAA AEE-100, driven by the present-day UA noise landscape.

The acoustic measurements took place at the Aviation Weather Research Facility (AWRF) grounds at JBCC in Falmouth, Massachusetts from September 27th through October 1st, 2021. Data were captured for five UA platforms. Over the course of five measurement days, the Volpe UA Noise Research Team collected high-quality acoustics, tracking, and weather data for over 300 individual flight events, distributed over the four aircraft with loaded and unloaded weights ranging from 1.4kg to 31.7kg, including various multi-rotor platforms, as well as a large fixed-wing / VTOL hybrid platform.

The initial results of the acoustic measurement are included in this report. Additional reports may include more detailed analyses of the recorded data as more data are collected in future measurements campaigns.

2. Measurement Description

2.1 Measurement Team Members and Partners

2.1.1 Volpe UA Noise Research Team

The Volpe UA Noise Research team comprises approximately a dozen people, mostly staff members of the Environmental Measurement & Modeling Division at the U.S. DOT's Volpe National Transportation Systems Center (Volpe Center). The team is currently led by Dave Read and Chris Cutler-Wood, and is focused on gathering data and presenting information to assist in the development and understanding of UA noise, community impacts of UA operations, and potential regulatory frameworks. The Volpe UA Noise Research Team previously collected the noise, tracking and meteorological data at the Choctaw Nation of Oklahoma IPP site in July 2019. The team meets bi-weekly to discuss ongoing data analysis and planning for future measurement campaigns as directed by the primary sponsor, FAA/AEE.

2.1.2 Consortiq

Consortiq, based in Annapolis, Maryland and London, U.K. is a global, unmanned data aerial vehicle consulting, training and data collection service provider, specializing in more unusual and complex use cases within hazardous environments. Consortiq provided the vehicles and operators for the JBCC measurements.

2.1.3 ArgenTech Solutions

ArgenTech Solutions, Inc. (AgTS) is a New Hampshire (NH) based, veteran-owned, small business. AgTS has extensive experience and competence in managing complex technical services 24/7, world-wide, in support of Unmanned Aircraft Systems (UAS), services for the US Department of Defense (DOD). In partnership with Consortiq, AgTS provide additional vehicles and operators for the JBCC measurements.

2.2 Measurement Site

2.2.1 AWRF Site History and Background

The Aviation Weather Research Facility (AWRF) is a 155-acre parcel of land located on JBCC. The site is managed by the Volpe Center's Aviation Weather & PNT Applications Division (V-345) with funding from the Federal Aviation Administration. The AWRF site has been a valuable Volpe asset for over 30 years, most notably for the validation and verification of a wide variety of complex atmospheric and meteorological sensors that measure visibility, rainfall, wind, and cloud ceiling. The AWRF site has also supported unconventional aircraft operational activities, most recently hosting the UA GPS Backup Demonstration, which involved flights of multiple UA platforms and GNSS tracking systems for the purpose of testing the relative precision and accuracy of the tracking systems. The AWRF site includes a dedicated building with electricity, heat, running water, and internet, and can be accessed by team members at any time of day or night. The building served as a primary UA vehicle staging and secure storage area for the measurement campaign.

2.2.2 Historical Meteorological Analysis

As part of the initial measurement site scoping process, a meteorological analysis was undertaken for the AWRF site to demonstrate the probability of acceptable weather conditions, specifically wind speed and wind direction, during the targeted measurement timeframe of May through October. Historical meteorological data from a permanent, continuously-operational Vaisala WXT-520 weather sensor at the AWRF site was analyzed to produce bi-hourly averages for selected weather metrics for each month within the measurement timeframe. These meteorological data were cross-referenced and compared with publically available METAR reports from the local KFMH (Cape Cod Coast Guard Air Station) at JBCC to ensure nominal accuracy. A sample of the analysis is shown below in Figure 1 and Figure 2.

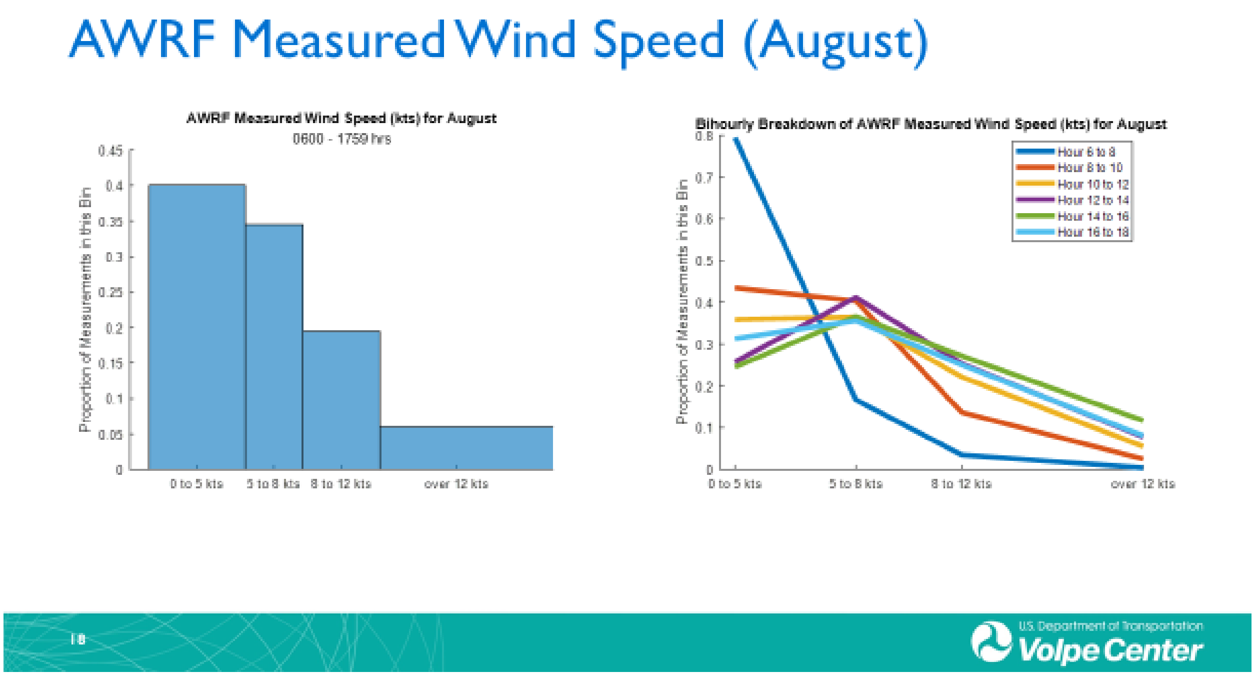


Figure 1 - AWRF Wind Speed Analysis, August

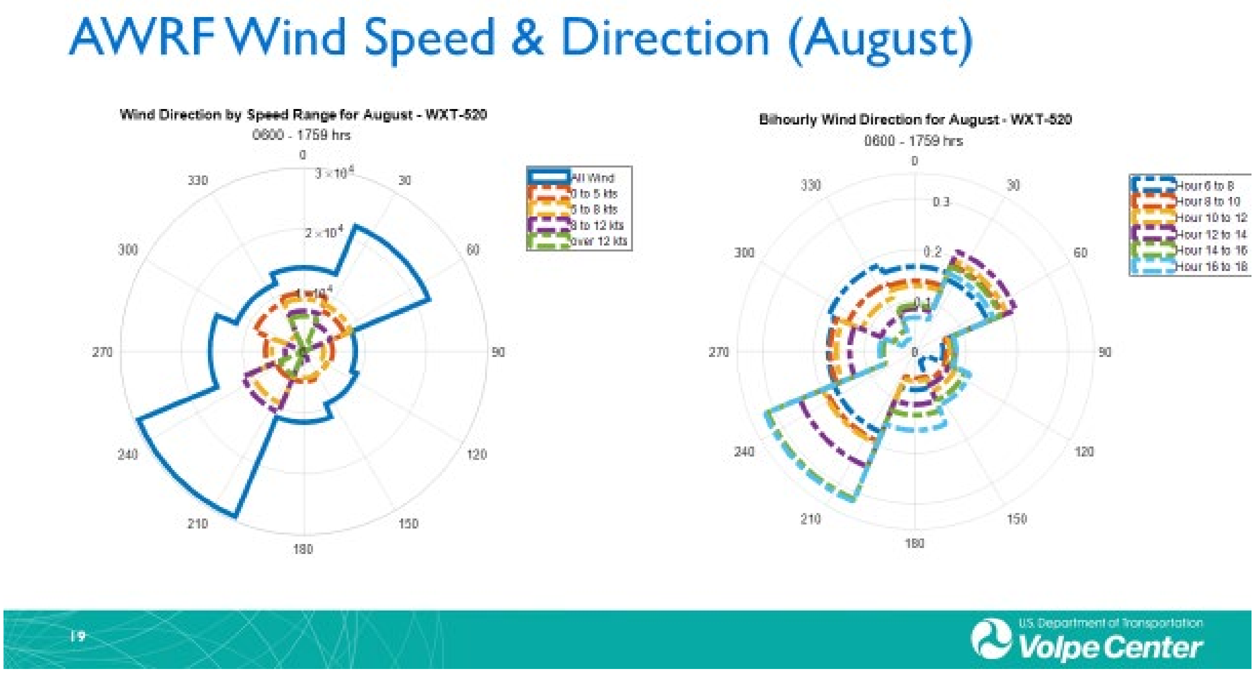


Figure 2 - AWRF Wind Direction Analysis, August

Upon review of the meteorological data, it was concluded that the AWRF site had an acceptable probability of suitable weather conditions for the proposed UA noise measurements in the May through October timeframe. It was also observed that, on average, weather conditions tend to be more favorable in the early morning through the early afternoon (0600 – 1000 local). The full meteorological analysis can be found in Appendix F.

2.2.3 Preliminary Site Scoping (APR2021, AUG2021)

Due to the proposed measurement site's relative proximity to the Volpe Center (an approximate 1 hour and 30-minute drive from Cambridge, MA), Volpe UA Noise Research Team members were able to visit the AWRF grounds for two separate site scoping trips.

The first trip occurred on Monday April 12, 2021, and was supported by Volpe employees from both V-324 and V-345. During the first site scoping, the team assessed the overall feasibility of the site with respect to ambient noise sources, available flight area, building amenities, and potential options for erecting an elevated microphone array. Although the weather conditions during this site visit were sub-optimal, the site was determined to be an acceptable option for the UA noise measurement campaign. Requests were submitted to the AWRF site managers to coordinate the expansion of on-site mowed areas in order to support installation of acoustic arrays and supporting equipment.

The second site scoping trip took place on Wednesday and Thursday August 18-19, 2021, after the site had officially been chosen to host the UA noise measurement campaign. The second site scoping trip allowed Volpe team members to survey all relevant measurement locations, including microphone array locations, nominal flight path end points, as well as the acoustics station and crane positions. The surveying process included both the physical measurement of distances from the measurement array origin and the collection of stable, raw satellite data at each measured position using a laptop, u-blox software, and uBlox NEO-M8T High Gain GPS receiver. The surveyed positions were physically marked with stakes and flagging tape. These surveyed positions served as permanent locations for the upcoming noise measurement campaign, as well as any potential, subsequent measurements at the AWRF. By means of leaving permanent markers, the site scoping survey saved approximately 5-6 hours of field time per future measurement. In addition to the survey activities, the second site scoping allowed the Volpe personnel to confirm the availability of particular on-site hardware, tools, and other materials to inform the final pack list for the September 2021 measurement campaign. Figure 3 shows a satellite image of the surveyed AWRF site (outlined in yellow), the nominal flight path (red line), and proposed center of the microphone array (blue cross).

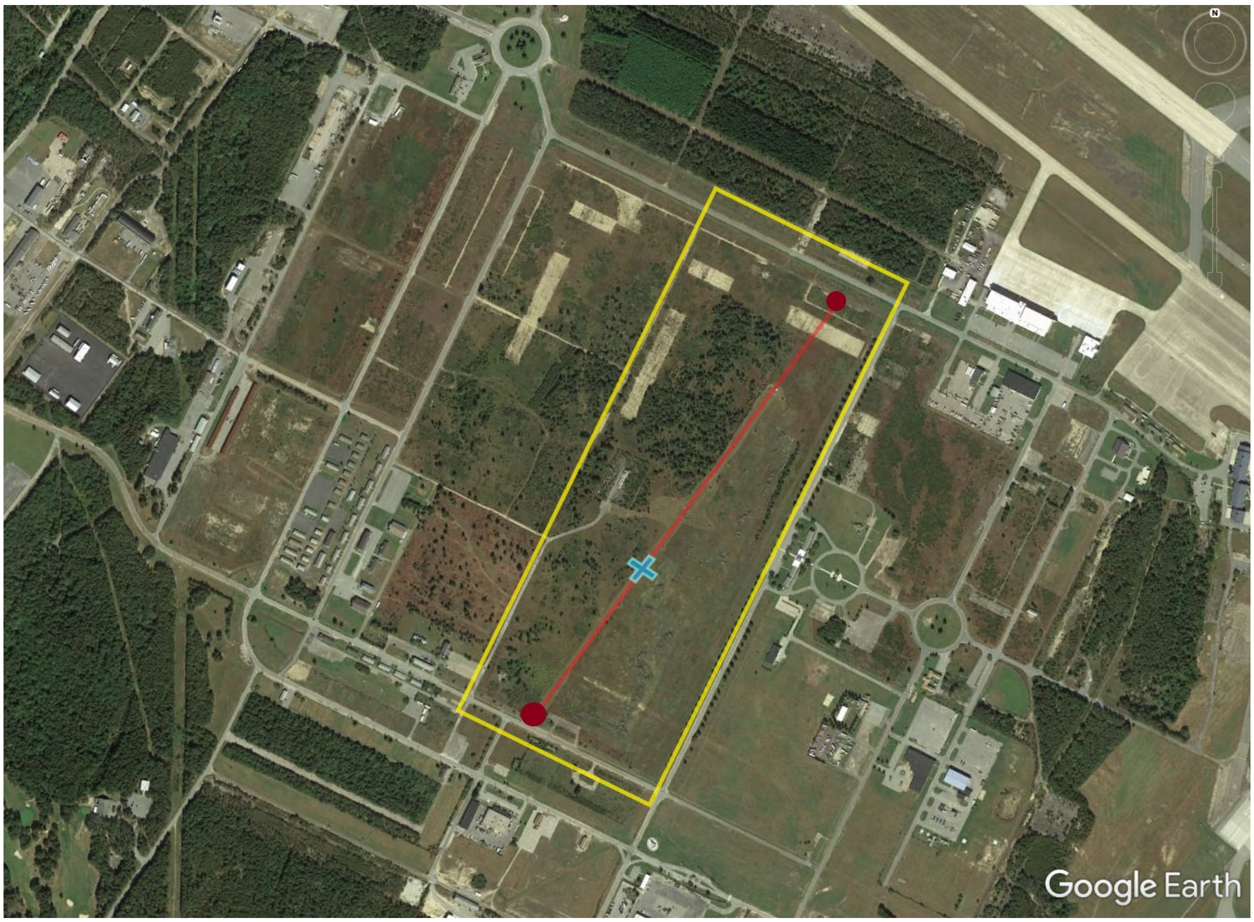


Figure 3 - Preliminary AWRF measurement site layout

2.3 Measurement Layout and Design

The development and implementation of the microphone arrays was influenced by existing guidance for military jet and commercial helicopter source noise measurement campaigns. The primary goal of the array design was to capture acoustic data that could be used to create noise "spheres", or three-dimensional representations of the aircraft source noise for different flight conditions. These noise spheres can be used in acoustic modeling programs to simulate the various potential noise impacts in communities based on particular operational parameters. In order to gather the necessary acoustic data for noise sphere generation, it was important to position the microphones in such a way as to capture the noise from the aircraft at many different emission angles. The acoustic emission angle is the angle created by the straight line from the center of the aircraft to the microphone position relative to the horizon at a given point in time. Due to the anticipated low signal-to-noise ratio of these aircraft, it was recommended that the team use a microphone array consisting of both a ground-plane microphone array and a vertical, elevated microphone array, to capture additional emission angles without increasing the slant range, or acoustic path length from the aircraft to the microphone position.

Figure 4 presents a plan view including the ground microphone array, the nominal UA vehicle flight track for flyover operations, the nominal hover location for hover operations, as well as the location of the elevated array. Figure 5 shows an aerial view of the fully deployed microphone arrays during the JBCC measurement campaign (taken from the DJI M210 onboard camera system), with ground microphone positions circled in black, and elevated mic positions identified with yellow arrows. The combined deployed microphone arrays comprised a total of 21 microphone positions: 14 ground-plane, 5 elevated, and 2 ancillary positions, described in the following sections. Due to input channel constraints, data was actively collected at a total of eighteen microphones positions at any point during the measurements.

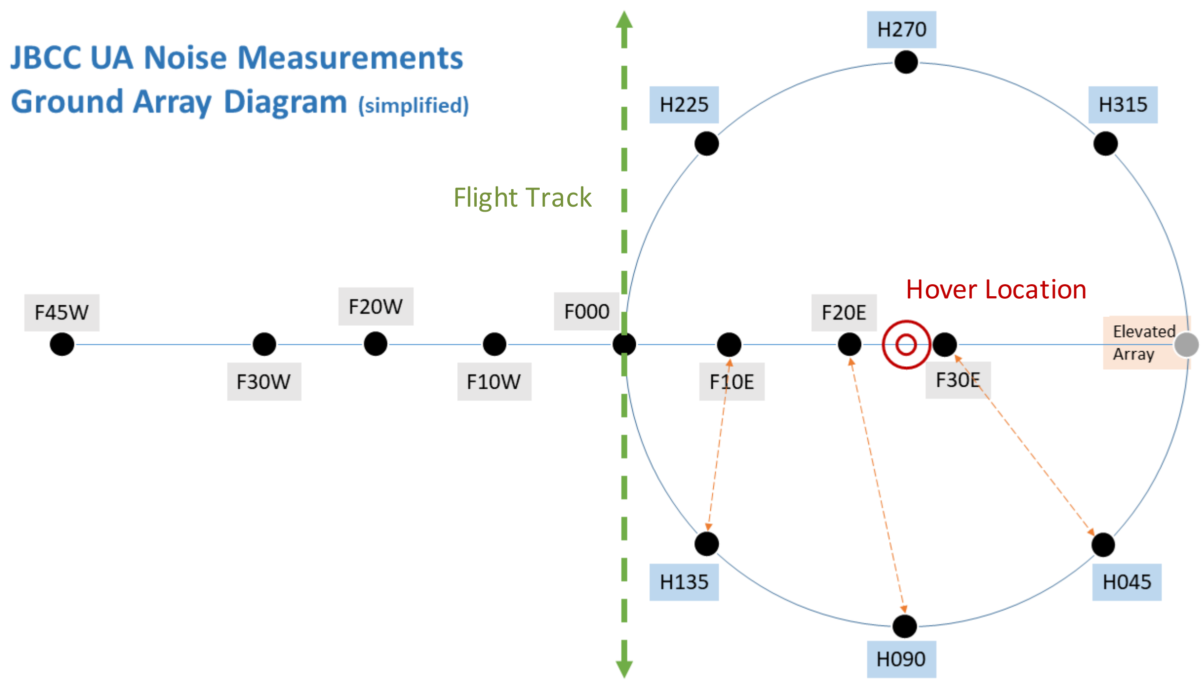


Figure 4 - Simplified Microphone Position Diagram

Figure 5 - Deployed JBCC microphone arrays, aerial view

2.3.1 Ground-Plane Microphone Array

The ground-plane microphone array comprised 14 total microphones, arranged in a linear pattern (primarily for flyover operation data collection) and a circular pattern (primarily for hover operation data collection). All ground positions were surveyed in the site scoping visits prior to the measurement campaign. A ground plate was installed at each position by clearing a shallow patch of soil, placing the ground plate at the center, and filling in the soil around the plate to create a smooth ground-to-plate transition and minimize any acoustical artifacts caused by acoustical impedance differences and/or edge diffraction. A sample of a completed ground plate installation can be seen in Figure 6.

Figure 6 - Ground plate installation with microphone

2.3.2 Vertical, Elevated Microphone Array

To facilitate the elevated array, the team designed a 110 ft. mounting apparatus comprising three connected caving ladders and custom-built mounting arms for the microphones and associated cabling. Microphones were installed and calibrated while on the ground, and the completed rig was then gently hoisted into the air and hung vertically by a construction crane on site. A sample of a deployed elevated microphone installation can be seen in Figure 7.

Figure 7 - Elevated microphone array with DJI M600 in background

2.3.3 Ancillary Microphone Positions

At the request of FAA AEE, the Volpe UA Noise Research Team deployed microphones at two additional measurement locations, separate from the main measurement array. Each position employed a B&K 4189 microphone, PRM831 preamplifier, a Roland RD-05 digital audio recorder to record audio data, and an LD831 class 1 sound level meter to capture live noise level metrics. Microphones were mounted on 4 ft. tripods at both of these positions and oriented for grazing incidence, as opposed to the inverted, ground plate installation for the main ground array.

One of the ancillary positions was a far “sideline” position, approximately 450 feet from the F000 microphone position on the East microphone axis. This position was intended to capture acoustical data for the purpose of investigating the lateral attenuation of the UA noise signatures.

The other ancillary microphone was co-located with the existing F45W position for the purpose of enabling direct comparison between the acoustical data captured with the ground plate installation versus the 4 ft. tripod installation.

2.4 Unconventional Aircraft

The Consortiq and ArgenTech teams supplied a total of 10 unconventional aircraft for the noise measurement campaign. The aircraft represented a wide variety of configurations, sizes, flight mechanics, and power sources, ranging from small commercial-off-the-shelf vehicles to large, custom-built hybrid aircraft capable of hours-long operations well above 5,000 ft. AGL. The aircraft are listed and described in this section, along with relevant specifications and photos. Of the ten total aircraft made available for this measurement campaign, acoustics and tracking data were captured during operations of five aircraft, which are described in the following sub-sections. The relevant specifications for each of the five measured aircraft can be found in Tables 1 and 2.

2.4.1 ArgenTech FireEye Series 2

The ArgenTech FireEye Series 2 is a hybrid powered, vertical takeoff and landing (VTOL) and fixed-wing aircraft. The aircraft has a MTOW of 31.7kg, a maximum airspeed of 54 knots, and a maximum operational time of approximately 3 hours. During takeoffs and landings, the aircraft is controlled by eight electrically powered rotors. The aircraft transitions to forward flight using a gasoline powered pusher propeller to gain forward airspeed and utilizes standard flight surfaces for control. The aircraft was flown on Friday October 1, 2021.

Figure 8 - ArgenTech FireEye Series 2 on Landing Pad

2.4.2 ALTI UAS Transition

The ALTI UAS Transition is a hybrid powered, vertical takeoff and landing (VTOL) and fixed-wing aircraft. The aircraft has a MTOW of 18kg, a maximum airspeed of 51 knots, and a maximum operational time of approximately 3 hours. During takeoffs and landings, the aircraft is controlled by four electrically powered rotors. The aircraft transitions to forward flight using a gasoline powered pusher propeller to gain forward airspeed and utilizes standard flight surfaces for control. The aircraft was flown on Tuesday September 28, 2021, and Wednesday 29SEP2021.

Figure 9 - ALTI Transition on Landing Pad

2.4.3 DJI Matrice 600

The DJI Matrice 600 (M600) is an electrically powered six-rotor aircraft. The aircraft has a MTOW of 15.1kg, a maximum airspeed of 18 meters per second, and a maximum operational time of approximately 35 minutes. For this measurement campaign, the aircraft was flown with the landing legs continuously deployed (unfolded). The M600 was flown on the four measurement days between Monday September 27, 2021 and Thursday September 30, 2021.

Figure 10 - DJI M600 Prepared for Takeoff at JBCC

2.4.4 DJI M210 V2 RTK

The DJI Matrice 210 (M210) is an electrically powered four-rotor aircraft. The aircraft has a MTOW of 6.14kg, a maximum airspeed of 49.5 miles per hour, and a maximum operational time of approximately 35 minutes. For this measurement campaign, the aircraft was flown with the landing legs continuously deployed (unfolded). The M210 was flown on the three measurement days between Wednesday September 29, 2021 and Friday October 1, 2021.

Figure 11 - DJI M210 V2 RTK during Takeoff

2.4.5 DJI Phantom 4 Pro

The DJI Phantom 4 Pro (P4P) is an electrically powered four-rotor aircraft. The aircraft has a MTOW of 1.6kg, a maximum airspeed of 45 miles per hour, and a maximum operational time of approximately 30 minutes. This aircraft has fixed landing legs. The M210 was flown on the two measurement days, Thursday September 30, 2021 and Friday October 1, 2021.

Figure 12 -DJI Phantom 4 Pro with START System Installed

2.4.6 Vehicle Specifications

Specifications for each vehicle were collected from the vehicle operators prior to the measurement campaign and reduced into a simplified table for quick reference and use in the flight card development process. The Vehicle specifications tables are shown below in Tables 1 and 2. Please note that, due to differences in manufacturer reports, the units for speed and weight parameters may vary between aircraft.

Table 1 - Specifications for the AgT FIreEye & ALTI Transition

Vehicle Information		ArgenTech FireEye Series 2		ALTI UAS Transition	
Parameter	***Definition***	**Value**	**Units**	**Value**	**Units**
Weight	*Empty Weight*	26.6	kg	11.8	kg
	Max Weight	31.7	kg	18	kg
	Max Payload	3.5	kg	1.5	kg

Velocity	*Vmax*	54	kts	51	kts
	Vcruise	45	kts	43	kts
	Vmin	40	kts	31	kts
	Voperational	45	kts	43	kts
Altitude	*Flyover Low*	500	ft	150	ft
	Flyover High	750	ft	300	ft
	Hover Low	10	ft	10	ft
	Hover High	75	ft	75	ft
	Operational	1000	ft	600	ft

Table 2 - Specifications for DJI Aircraft (M600, M210, and P4P)

Vehicle Information		DJI M600		DJI M210 V2 RTK		DJI Phantom 4 Pro	
Parameter	***Definition***	**Value**	**Units**	**Value**	**Units**	**Value**	**Units**
Weight	*Empty Weight*	9.1	kg	4.8	kg	1375	g
	Max Weight	15.1	kg	6.14	kg	1600	g
	Max Payload	6	kg	1.2	kg	225	g
Velocity	*Vmax*	18	m/s	45.9	mph	45	mph
	Vcruise	10	m/s	12.5	mph	12.5	mph
	Vmin	5	m/s	7.5	mph	7.5	mph
	Voperational	18	m/s	12.5	mph	12.5	mph
Altitude	*Flyover Low*	50	ft	50	ft	50	ft
	Flyover High	100	ft	100	ft	100	ft
	Hover Low	2	ft	2	ft	2	ft
	Hover High	50	ft	50	ft	50	ft
	Operational	400	ft	400	ft	400	ft

2.5 Flight Test Procedures

The flight test procedures for this measurement campaign were influenced by the procedures of previous flight tests such as those conducted at the Choctaw Nation IPP site in July 2019, and those conducted in Liberty, NC in July 2021. In all cases, the flight test procedures were meant to represent both steady-state flight conditions (for the purposes of evaluating relationships between the flight parameters and the acoustic signature), and operational flight conditions (to accurately characterize the aircraft noise as it may be experienced in real-world operation). To accommodate this, the flight test procedures included takeoff, landing, hover, and level flyover events at varying speeds, altitudes, and aircraft takeoff weights. The specific values for these flight parameter variables were determined on an individual aircraft basis, depending on the specific operational and physical constraints of each platform (found in Tables 1 and 2).

2.5.1 Flight Card Development

To organize the flight test procedures for all aircraft, it was necessary to create flight cards for each platform with standardized naming convention ("Test ID") for all possible flight events. A summary table of flight events can be seen in Table 3. These Test IDs were used throughout the measurement to communicate upcoming and completed flight events between the acoustics and flight teams. A physical flight card was printed for each aircraft, specific to its operational capabilities, and was used to confirm the appropriate number of successful events were captured. It was decided that 6 acceptable events (3 in each flight direction) per Test ID would be sufficient for data analysis.

Table 3 - Flight Card Summary

TEST ID	Condition	Weight	Speed	Altitude
F01	Level Flyover	Max Weight	Vmax	Flyover Low
F02	Level Flyover	Max Weight	Vmax	Flyover High
F03	Level Flyover	Empty Weight	Vmax	Flyover Low
F04	Level Flyover	Empty Weight	Vmax	Flyover High
F05	Level Flyover	Max Weight	Vcruise	Flyover Low
F06	Level Flyover	Max Weight	Vcruise	Flyover High
F07	Level Flyover	Empty Weight	Vcruise	Flyover Low
F08	Level Flyover	Empty Weight	Vcruise	Flyover High
F09	Level Flyover	Max Weight	Vmin	Flyover Low
F10	Level Flyover	Max Weight	Vmin	Flyover High
F11	Level Flyover	Empty Weight	Vmin	Flyover Low
F12	Level Flyover	Empty Weight	Vmin	Flyover High
H01	Hover	Max Weight	-	Hover High
H02	Hover	Empty Weight	-	Hover High
H03	Hover	Max Weight	-	Hover Low
H04	Hover	Empty Weight	-	Hover Low
V01	Idle	-	Ground Idle	Ground
V02	Takeoff	Max Weight	Vcruise	Ground to Flyover Low
V03	Takeoff	Empty Weight	Vcruise	Ground to Flyover Low

V04	Landing	Max Weight	Vcruise	Flyover Low to Ground
V05	Landing	Empty Weight	Vcruise	Flyover Low to Ground
V06	Level Flyover	Max Weight	Voperational	Operational
V07	Level Flyover	Empty Weight	Voperational	Operational

3. Measurement Instrumentation and Data Acquisition Procedures

3.1 Acoustic Data Collection System

3.1.1 Acoustic Data Collection Hardware

The primary acoustic data collection system used for this measurement campaign was the CompactRIO Acoustic Recording System (CARS). This system comprised two data acquisition nodes, based on NI model cRIO-9037 controllers. Each node was powered by a pair of 18-20 amp-hour, 12-volt sealed lead-acid batteries and accepted 8 microphone inputs that were fed through two gain amplifiers (B&K Nexus 2693, 4 channels each). The amplifiers provided DeltaTron a current supply to power the DeltaTron preamplifiers as well as provide selectable gain to the incoming signal. Each gain amplifier was powered by a sealed lead-acid battery. Each input channel of the gain amplifiers was connected to a microphone/preamplifier pair: a pre-polarized, pressure-response microphone (GRAS 40AO) connected to a B&K 2671 DeltaTron microphone pre-amplifier. Each recording node used an NI-9467 model GPS time synchronization module connected to a GPS antenna to set and synchronize recording node system times to UTC. In addition, each recording node had a channel dedicated to recording the amplitude modulated IRIG-B signal from Master Clock GPS200A time code generators. Analog-to-digital conversion was done using either NI-9250 or NI-9232 modules, at a rate of 102,400 samples per second and 24-bit precision. Microphone and IRIG-B signals were written to files on a 500 GB solid state drive local to each recording node. Each node was connected to a network switch which was connected to a field laptop to control the recording node via LabVIEW. A diagram of the complete signal chain for each node is shown in Figure 27. Figure 13 shows the connected field setup of both data acquisition nodes of CARS.

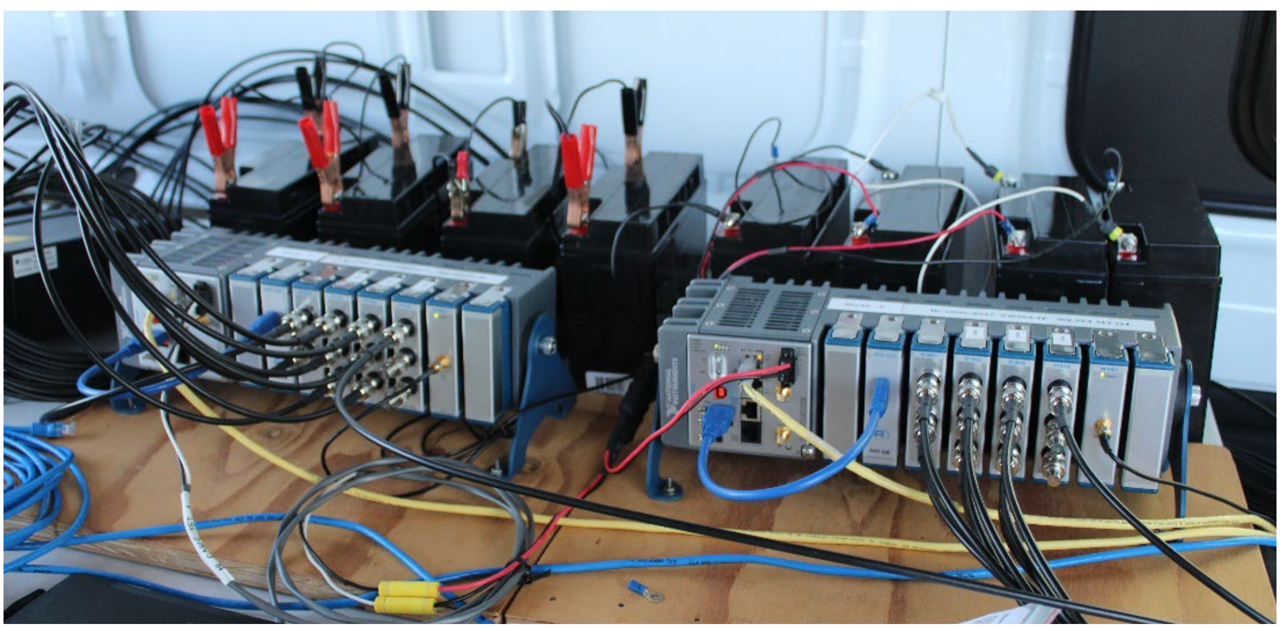


Figure 13 - CARS Nodes

Cables were run from all microphone positions to the end of the van used to house the acoustics equipment. The full CARS setup in Figure 14 shows the sealed lead-acid batteries behind the two data acquisition nodes, as well as the four gain amplifiers and field laptop.

Figure 14 - Full CARS Setup with Acoustics Lead

3.1.2 Acoustics Data Measurement Software

Control of the acoustic data acquisition system was accomplished using in-house software developed in the NI LabVIEW environment, version 2017. The software was designed to provide flexibility in measurement configuration and monitoring, and also as a platform for electronic logging and tasks such as calibration. As part of software setup, the user is required to input information on nominal or stated microphone sensitivity, signal gain applied by Nexus amplifiers, and linear operating range of the full system for the specified configuration. To aid in field setup, those input settings are supplied via ASCII input files which were pre-generated for these measurements. Furthermore, the user has an option to start the software using the last set of measured microphone sensitivities. During operation, the software provides a display of ½-second levels for each channel, a time history plot of those levels, and a 1/3rd octave band spectrum display generated using the ANSI-compliant NI Sound and Vibration toolkit. Examples are shown in Figures 15 and 16. The user has the option of applying different time averaging and frequency weighting, though it is important to note that those options apply to displayed levels only; primary recorded data are microphone signals with no averaging or frequency weighting applied. In addition to level displays, the CARS software also provides a live signal display – a modulated IRIG-B signal is shown in Figure 17.

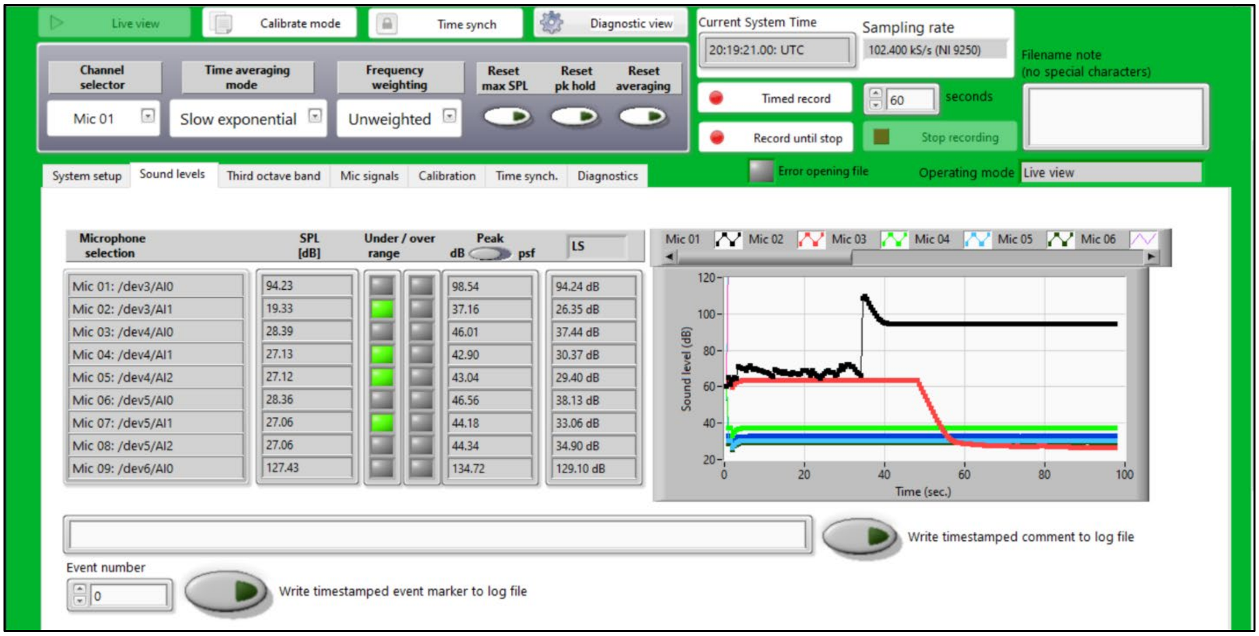


Figure 15 - An example of the live display of the CARS software

Figure 16 - 1/3rd octave band display in CARS software

Figure 17 - CARS software signal display (IRIG-B signal shown)

Following software startup, the general procedure was to use the time synchronization modules to set CARS system times to UTC. System times were used to timestamp the starting point of raw recorded files, and starting times of the processed acoustic data files came from post-processed IRIG-B recordings made simultaneously with each event. Pretest microphone calibration routines were also software-based. In addition to setting microphone sensitivity, 10-second duration recordings of calibration signals were made for each channel. Post-test calibration checks were completed in a similar manner.

As part of typical test sequences, the acoustic measurement system operator initiated data recording on both nodes, either following a signal from the test director ("data on"), or in anticipation of such a signal. In the case of early recording initiation, data were trimmed to the actual "data on" time. Data recording was stopped following a signal from the test director ("data off"). Following this sequence, the acoustic measurement system operator signaled the acoustics support field technician that data files were closed and the downloading of files from the recording nodes to the second laptop could be initiated as part of post-event data quality checks. In addition to real-time monitoring and start/stop of data recording, the measurement system software was also used to electronically log timestamped operator comments to an ASCII file.

Acoustic data quality checks were performed alongside recording events to ensure the quality and completeness of the acquired data. Following recording of each event, a program was run on a second laptop to automatically download the last set of recorded files from each node. The acoustics support field technician then ran a Matlab script to generate unweighted (Z-weighted) and A-weighted spectrogram plots for each microphone signal. An example of one such plot is shown in Figure 18. The technician also listened to recordings from each microphone. These checks were intended to catch problems specific to each microphone channel such as insect noise or hardware malfunction, and ensured data quality somewhat in real-time throughout the measurement day.

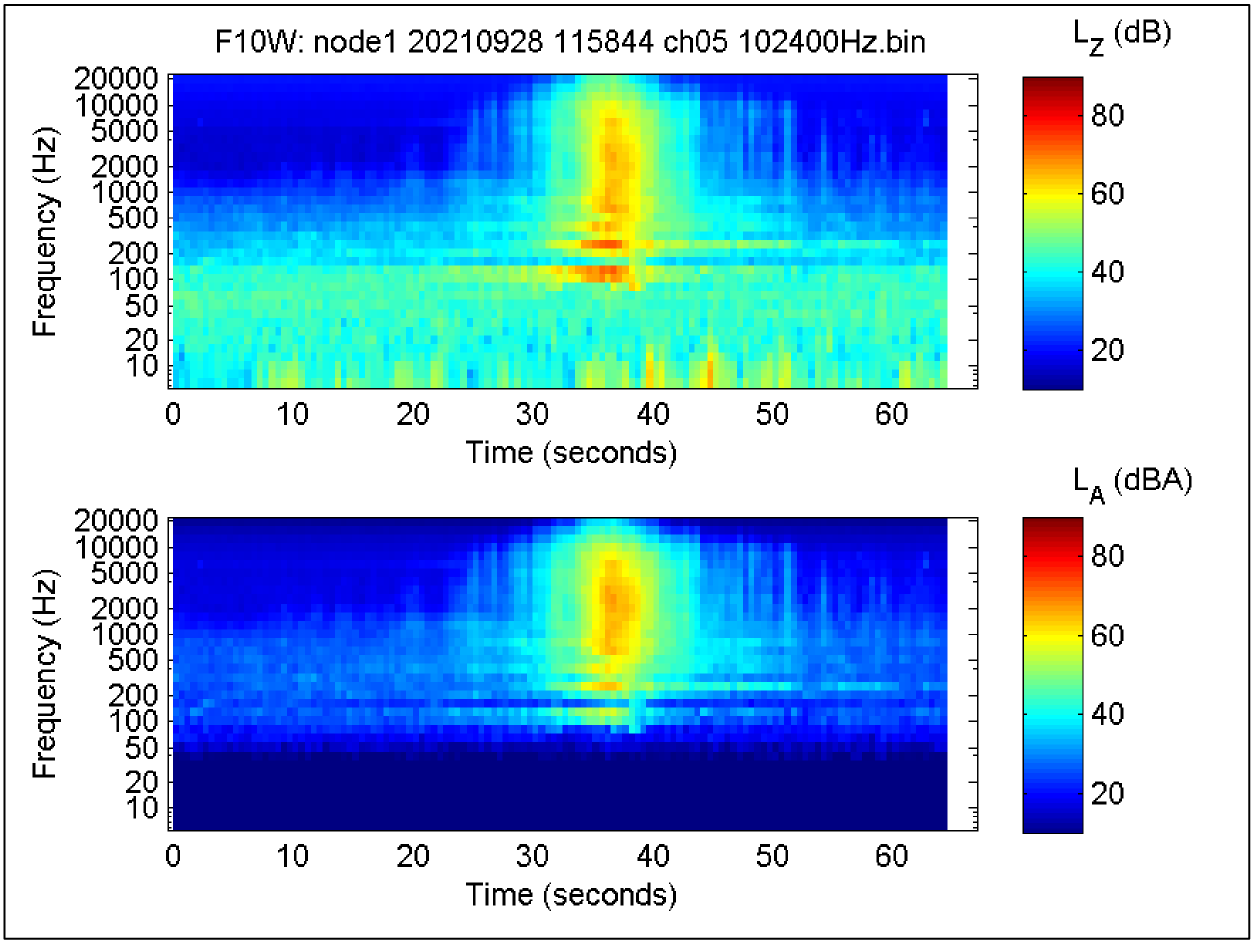


Figure 18 - Example of data quality check plot

3.2 "START" Tracking System

Time-space-position-information (TSPI) for each aircraft tested at JBCC was provided by the Survey and Tracking Apparatus for Research in Transportation (START) system. START is a GNSS-based vehicle tracking and surveying platform developed by Volpe for the purpose of deriving precise positioning information from UAS and other automated vehicles. The development and implementation of this system was to ensure high quality, accessible TSPI data for all aircraft, independent of exterior configuration and internal GPS hardware and software limitations. Often times, the internal GPS systems for UA platforms do not collect position data at a great enough precision or resolution for the purposes of noise measurement analysis. Even if the internal systems collect data of adequate quality, the data they collect is often only accessible through proprietary software tools that vary between manufacturers and operator platforms (if accessible at all). The Volpe START system eliminates much of the uncertainty related these disparate and inaccessible systems and provides consistent, high-quality tracking data.

START comprises primarily consumer off-the-shelf (COTS) products that have been configured for the purpose of collecting and storing satellite observations suitable for applying carrier-phase based corrections via post process kinematic (PPK) methods. To accomplish this, START is mounted to each aircraft prior to testing. At JBCC, up to four START systems were simultaneously deployed on different test aircraft in order to minimize transition times between aircraft and optimize field measurement personnel time. During flight tests, satellite data were collected simultaneously, at both the Rover (UAS/aircraft-under-test) and a Reference Position on the ground. For the purpose of these measurements, data from a Continually Operating Reference Station (CORS) at Falmouth, MA (MAFA) were used. MAFA is the nearest CORS to JBCC and is operated by the Massachusetts Department of Transportation (MASSDOT).

START hardware consists of a u-blox NEO-M8T receiver which is integrated with a grounding plate and active, dual-feed, ceramic patch antenna. The system is controlled and configured using a miniature computer which runs u-blox u-center software. Data are stored at the computer on removable SDHC media. Power is provided by 5V, 2A, USB "power banks" of various capacities. The core components of the START Rover are presented, along with weights and dimensions, in Table 4. Figure 19 displays the START integrated receiver/antenna mounted on top of a DJI M600 test aircraft at JBCC.

Table 4 - START System Components

Function	Component	Weight (g)	Length (mm)			Comments
			X	Y	Z	
Receiver	uBlox NEO-M8T High Gain: X-Series	80	100	100	25	with integrated antenna + ground plate
***Rover Control Computer**	Intel Compute Stick	60	113	38	12	
Rover Battery	4400 mAH Power Bank	115	95	46	22	Option 1
Rover Battery	5000 mAH Power Bank	124	98	47	22	Option 2
Rover Battery	6000 mAH Power Bank	148	99	47	22	Option 3
**USB interconnect cables not included*						

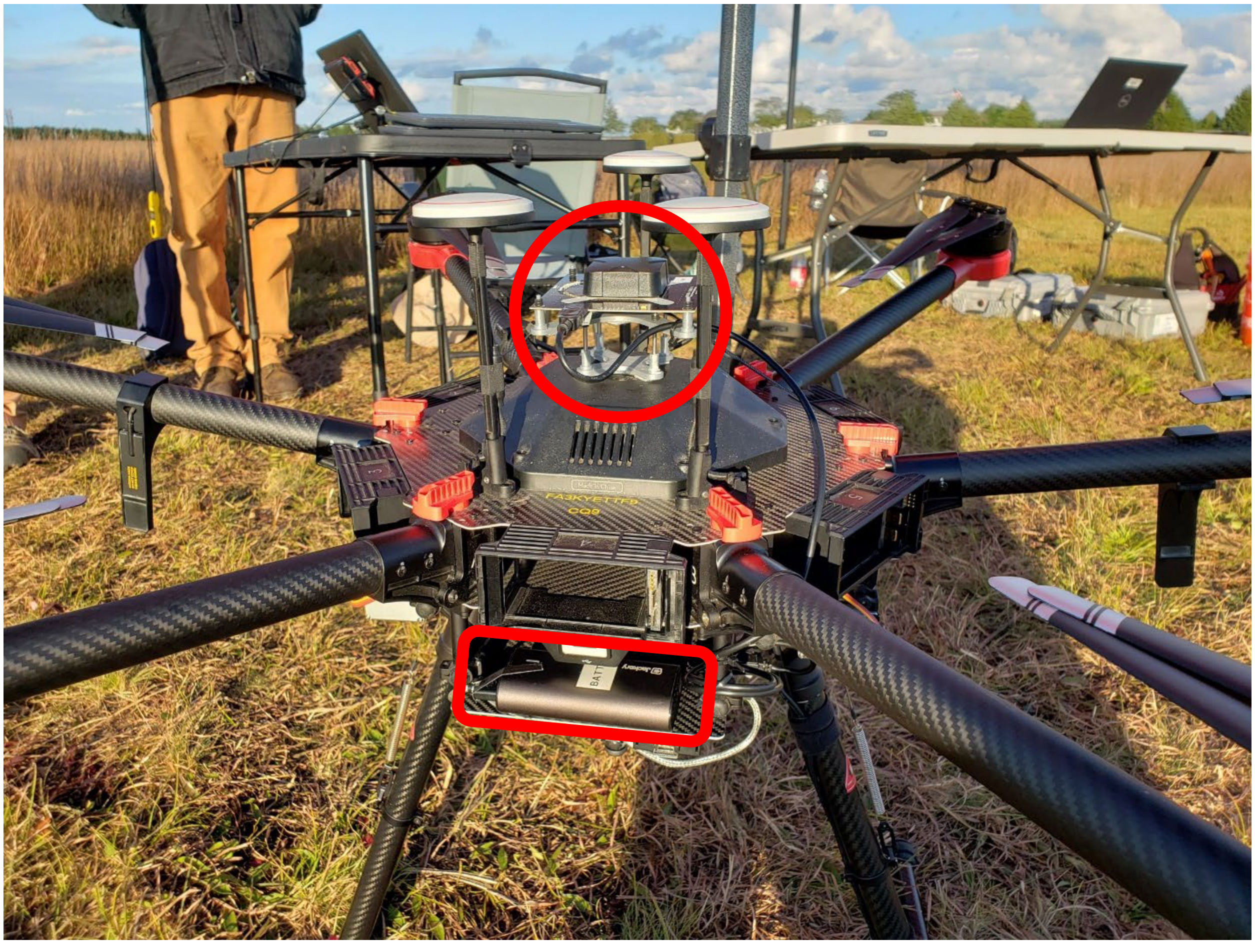


Figure 19 - START System Mounted on DJI M600

3.3 Meteorological Data Collection Systems

Each flight test day, the Volpe team set up a Vaisala WXT520 weather station to collect localized wind speed, temperature, and relative humidity data at a 2Hz resolution (twice per second) to contextualize the acoustics data. The weather sensor was elevated 14.5 feet above the ground, southeast of the microphone array center point, between the acoustics van and the flight path. A westerly view of the system setup is pictured in Figure 20.

Figure 20 – Volpe Temporary Weather Station Setup at JBCC (Westerly View)

A pre-existing permanent Vaisala WXT520 weather station was simultaneously collecting 1Hz meteorological data in the vicinity of the flight test area. This sensor was elevated 15 feet above the ground, approximately 750 feet north of the microphone array.

3.4 Meteorological Data Supplementary Comparison

The 2Hz meteorological data captured with the temporary Volpe set up were averaged to 1Hz for direct assessment with the meteorological data captured at the pre-existing permanent weather station. A supplementary comparison between data measured at each location was conducted post-measurement to evaluate whether the data from the permanent weather station (distanced farther from the microphone array) are representative of the meteorological conditions at the flight test area. Agreement between data from both locations would allow future measurement teams to leverage the existing system for future flight test deployments at JBCC, rather than setting up and tearing down the temporary system closer to the microphone array each day.

Data measured at both locations were synchronized and compared prior to analysis. Only one-second timestamps for which both systems collected reliable data for each meteorological metric were compared. Meteorological data were collected with the temporary weather station at different times of day and for different durations, depending on the flight test schedule. Data collected each day were separated into 3-hour bins for analysis in order to account for diurnal meteorological trends. The “morning” bin represents data collected between 9:30:00-12:30:00 UTC. The “afternoon” bin represents data collected between 12:30:01-15:30:00 UTC. The “evening” bin represents data collected between 15:30:01-18:30:00 UTC. The “night” bin represents data collected from 18:30:01 to the end of the flight test day (no later than 23:00:00 UTC). The following tables split up by day, display the average percent delta[1] for each of the three meteorological metrics.[2]

Table 5 – September 28th Met Station Comparison

Temporal Bin	Wind Speed Delta (kts)	Temperature % Delta	Relative Humidity % Delta
Morning	0.30	-0.09	-4.95
Afternoon	0.63	-0.44	-4.87

Table 6 - September 29th Met Station Comparison

Temporal Bin	Wind Speed Delta (kts)	Temperature % Delta	Relative Humidity % Delta
Afternoon	2.64	-0.95	-8.65
Evening	2.05	0.15	-9.33
Night	0.97	1.37	-8.06

Table 7 - September 30th Met Station Comparison

Temporal Bin	Wind Speed Delta (kts)	Temperature % Delta	Relative Humidity % Delta
Morning	-0.04	-0.39	-4.26
Afternoon	0.21	0.10	-6.41
Evening	0.90	0.56	-9.47
Night	1.18	0.78	-10.10

Table 8 – October 1st Met Station Comparison

[1] Average Percent Delta = average of each one-second {[(Temporary - Permanent)/Permanent]*100} measurement within the temporal bin

[2] Wind speed data captured with the temporary weather station in units of meters per second were converted to knots to facilitate direct comparison with the permanent wind speed measurements. A 20-second rolling average of wind speed measurements from each system was then computed to minimize the effects of instantaneous wind gusts. Wind speed percent delta computations for each temporal bin were based on the 20-second rolling averages.

Temporal Bin	Wind Speed Delta (kts)	Temperature % Delta	Relative Humidity % Delta
Morning	-0.11	0.32	-5.00
Afternoon	0.52	-0.97	-7.35

The above tables show that the average relative humidity percent delta is always negative, regardless of time of day or day of flight testing. Figure 21 illustrates that both locations closely track the same trends throughout the day, but the flight test area weather sensor recorded a lower relative humidity. This difference could potentially be explained by the landscaped flight test area, which would otherwise be covered in tall brush that can retain more moisture. The permanent system is set up outside of the landscaped zone, above the tall brush. The difference between the mowed flight test area and the tall brush is shown in Figure 20. It is also apparent that there are discrepancies between the wind speed data collected at both locations. This difference is likely due to the openness of the cleared flight test area; the temporary weather sensor is farther away from trees and other larger obstructions than the permanent weather system. Figure 22 depicts measured wind speed data for September 29th at both locations, in which the average wind speed deltas and percent deltas are the largest out of all the test days.

It is reasonable to conclude that the data collected at the permanent weather station is not entirely representative of the meteorological conditions at the flight test area due to its distance from the measurement area. The team recommends that a temporary weather station continue to be set up within the flight test area for future flight test deployments at the AERF site until a more complete comparison validation can be completed.

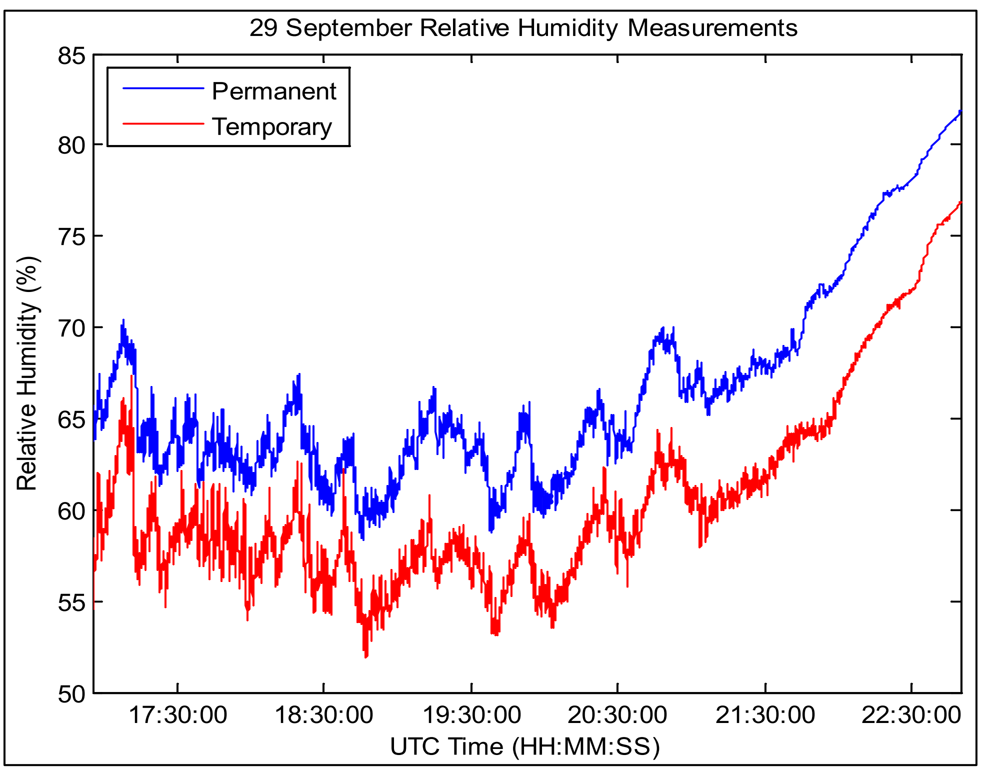


Figure 21 – September 29th Relative Humidity Measurements

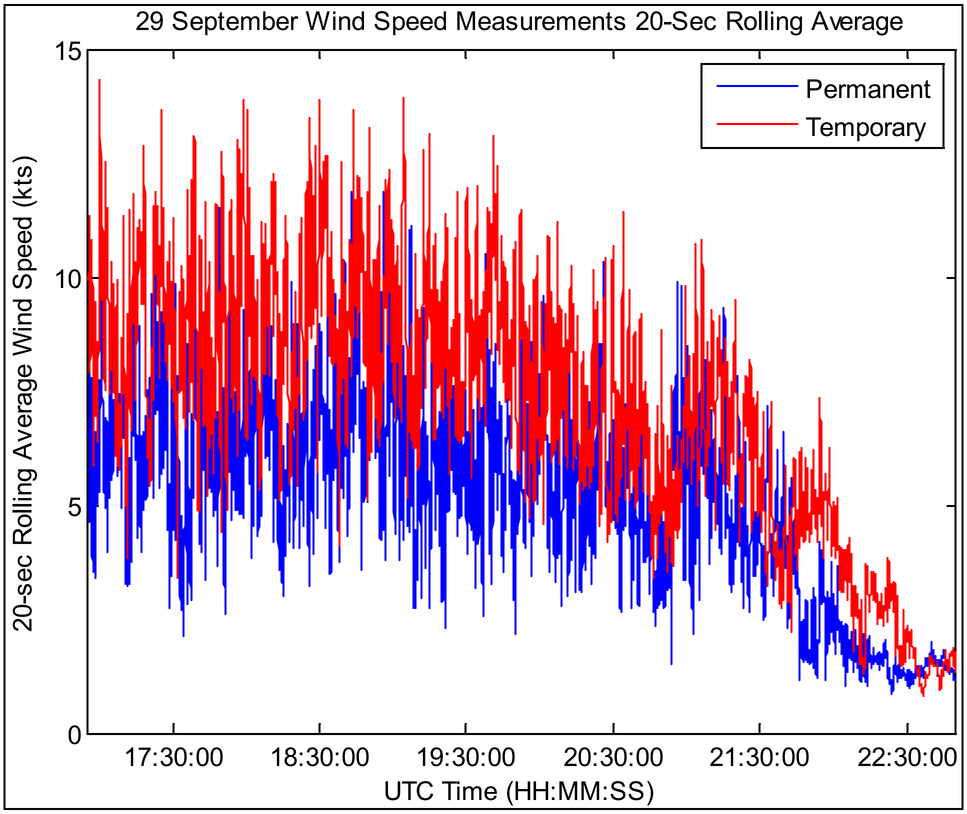


Figure 22 – September 29th Wind Speed Measurements (20-Sec Rolling Average)

4. Data Description

4.1 Pressure Time-History Acoustic Data

The pressure time-history acoustic data were formatted into digital files following the ANSI/ASA S12.75 standard. Data files comprise an ASCII header (lines 1-52) and binary pressure time-history acoustic data. The acoustic data file naming convention and header description are given in Sections 4.1.1 and 4.1.2, respectively. One-third octave band spectral time histories were generated from the acoustic pressure time history data files and are described in Section 4.2. For both types of data file, individual files correspond to a specific event and microphone location.

4.1.1 Acoustic Data File Naming Convention

An acoustic data file was created for each event/microphone combination. File names follow the convention:

RUN[nnnn]_JBCC_[vehicle]_[test ID]_[mic ID]_102400HZ_CH[nnn].bin

Where terms correspond to:

- RUN[nnnn] ⍰ four-digit run number (e.g. 0081)

- JBCC ⍰ test location, Joint Base Cape Cod
- [vehicle] ⍰ short name of vehicle model or noise source (e.g. M600)
- [test ID] ⍰ test-point identifier (e.g. F05)
- [mic ID] ⍰ microphone position identifier (e.g. F45W)
- 102400HZ ⍰ sampling rate
- CH[nnn] ⍰ data acquisition system channel number (e.g. ch008)

An example acoustic data file name is RUN0081_JBCC_M600_F05_F45W_102400HZ_CH008.bin. Noise source abbreviations are as follows:

- AMBI ⍰ ambient measurement
- HORN ⍰ horn test
- M600 ⍰ DJI Matrice 600
- TRNS ⍰ ALTI UAS Transition
- M210 ⍰ DJI M210 V2 RTK
- FIRI ⍰ ArgenTech FireEye SERIES 2
- PHM4 ⍰ DJI Phantom 4 Pro

4.1.2 Acoustic Data File Header Description

The test conditions and contents of each acoustic file are described in the header lines which follow the ANSI/ASA S12.75 standard header format. This header includes metadata: measurement event details, acoustic recording channel information, microphone information and location. Header fields are described in Table 9; Figure 23 shows an acoustic file header with example entries for these measurements.

Table 9 - Metadata Table Fields

Data Field Name	Description
Header Size	Number of ASCII header lines before binary data
Test Description	VOLPE JBCC UAS MEASUREMENTS
Test Location	Description of geographic location where measurements were made
Run Number	Numerical identifier for a specific measured event
Date	Measurement date in DD MMM YYYY format
Start Time (UTC SPM)	Time at beginning of file in seconds past midnight, universal coordinated time format
Vehicle Make Model	Make and model of the unmanned aerial vehicle
Test ID	Test point identifier from test cards
Direction of Travel (Nominal)	Nominal direction of aircraft travel
Weight	Aircraft test-point weight, and nominal weight
Speed	Aircraft test-point speed, and nominal weight
Condition	Flight condition
Altitude	Aircraft test-point altitude, and nominal altitude
Sample Rate (Hz)	Acoustic data sampling rate in Hertz
Samples Total	Total number of data points in the binary portion of file
Data Format	Format of numerical data in binary portion of file

Machine Format	Sequence of bytes in the digital data
Units	Units of the numerical data in binary portion of file
Temperature (deg F)	Event-average air temperature in degrees Fahrenheit
Humidity (Percent)	Event-average relative humidity percentage
Wind AVG SPD (Knots)	Event-average wind speed in knots
Wind MAX SPD (Knots)	Maximum wind speed measured during event in knots
Wind SPD STD (Knots)	Standard deviation of wind speed during event in knots
Wind DIR (Deg)	Event-average wind direction in degrees
Ambient Noise Notes	Notes from acoustic log and observer log about ambient noise
Run Notes	Notes from acoustic log about the run
Channel Number	Acoustic data recording node channel number
Channel Description	Description of physical location of microphone
Channel ID	Alphanumeric microphone location identifier
Mic Latitude (deg)	Latitude of microphone location in decimal degrees
Mic Longitude (deg)	Longitude of microphone location in decimal degrees
Mic X (M, Local)	x-location of microphone in local coordinate system
Mic Y (M, Local)	y-location of microphone in local coordinate system
Mic Z (M, Local)	z-location of microphone in local coordinate system
Ground Elevation (M)	Elevation of local ground above datum
Datum	Geodetic datum system
Transducer Make Model	Transducer (microphone) make and model
Transducer SN	Transducer (microphone) manufacturer serial number
Transducer Sound Field	Type of pressure field microphone was designed to measure
Meas Sensitivity (mV/Pa)	Test-day measured microphone sensitivity in mV/Pa
Preamp Make Model	Microphone preamplifier make and model
Preamp SN	Microphone preamplifier manufacturer serial number
Amplifier Make Model	Signal conditioning amplifier make and model
Amplifier SN	Signal conditioning amplifier manufacturer serial number
Transducer Supply	Power supply type for the transducer (microphone)
Orientation	Microphone orientation
Windscreen Make Model	Windscreen type, make, and model
DAQ Make Model	Acoustic data acquisition device make and model
DAQ SN	Acoustic data acquisition device manufacturer serial number
DAQ Device Number	Acoustic data acquisition device input path description
DAQ Coupling	Acoustic data acquisition system input coupling
Channel Notes	Notes specific to acoustic measurement channel

RUN0081_JBCC_M600_F05_F45W_102400HZ_CH008.bin

```
;HEADER SIZE................: 52
;TEST DESCRIPTION...........: VOLPE JBCC UAS MEASUREMENTS
;TEST LOCATION..............: JOINT BASE CAPE COD, MA, USA
;RUN NUMBER.................: 0081
;DATE.......................: 28 SEP 2021
;START TIME (UTC SPM).......: 43048.138132
;VEHICLE MAKE MODEL.........: DJI MATRICE 600
;TEST ID....................: F05
;DIRECTION OF TRAVEL (NOM)..: NORTH
;WEIGHT.....................: MAX WEIGHT, 15.1 KILOGRAMS
;SPEED......................: VCRUISE, 10 M/S NOMINAL
;CONDITION..................: LEVEL FLYOVER
;ALTITUDE...................: FLYOVER LOW, 50 FT NOMINAL
;SAMPLE RATE (HZ)...........: 102400
;SAMPLES TOTAL..............: 5427215
;DATA FORMAT................: REAL*4
;MACHINE FORMAT.............: LITTLE ENDIAN
;UNITS......................: PASCALS
;TEMPERATURE (DEG F)........: 69.6
;HUMIDITY (PERCENT).........: 79.7
;WIND AVG SPD (KNOTS).......: 7.4
;WIND MAX SPD (KNOTS).......: 10.5
;WIND SPD STD (KNOTS).......: 1.8
;WIND DIR (DEG).............: 238
;AMBIENT NOISE NOTES........: BIRDS, INSECTS
;RUN NOTES..................: NONE
;CHANNEL NUMBER.............: 008
;CHANNEL DESCRIPTION........: FLYOVER GROUND MICROPHONE
;CHANNEL ID.................: F45W
;MIC LATITUDE (DEG).........: 41.654543625
;MIC LONGITUDE (DEG)........: -70.545220673
;MIC X (M, LOCAL)...........: -30.4087
;MIC Y (M, LOCAL)...........: 0.3247
;MIC Z (M, LOCAL)...........: -0.1145
;GROUND ELEVATION (M).......: 5.6807
;DATUM......................: WGS84
;TRANSDUCER MAKE MODEL......: GRAS 40AO
;TRANSDUCER SN..............: 450231
;TRANSDUCER SOUND FIELD.....: PRESSURE
;MEAS SENSITIVITY (mV/Pa)...: 9.712
;PREAMP MAKE MODEL..........: BK 2671
;PREAMP SN..................: 2048208
;AMPLIFIER..................: BK NEXUS 2693
;AMPLIFIER SN...............: 3009994
;TRANSDUCER SUPPLY..........: DELTATRON, 4 MILLIAMPS
;ORIENTATION................: INVERTED
;WINDSCREEN MAKE MODEL......: MODIFIED BK UA-0237, 90 MM HEMISPHERE
;DAQ MAKE MODEL.............: NI-9232
;DAQ SN.....................: 1BFA316
;DAQ DEVICE NUMBER..........: NODE1/DEV5/AI2
;DAQ COUPLING...............: DC
;CHANNEL NOTES..............: NONE
```

Figure 23 - Example acoustic data file header block

4.2 1/3 Octave-Band, Half-Second Time-History Data

Pressure time-history acoustic data were processed in one-third octave band spectra time histories at 0.5 second increments. To do so, ANSI-compliant methods from the NI Sound and Vibration toolkit were used as part of an in-house tool. One-third octave band files were created in the SuperFAR format (Read et al., 2017). File format is comma-separated ASCII text with one file per microphone per event. File naming convention follows that of the acoustic data files described in Section 4.1.1. The spectra represent slow exponentially time averaged levels with flat frequency weighting. Note that each timestamp corresponds to the instant 0.75 seconds prior to the output of the most recent sample within the average, as described in ICAO Annex 16. An example file with header is shown in Figure 23. Note that levels are given in decibels re: 20 µPa for one-third octave bands with center frequencies from 6.3 Hz to 20 kHz.

```
FileType**,Spectral Time-History,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
FileName**,RUN0004_JBCC_M600_F03_F000_102400HZ_CH004.RAW.STH.csv,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
FileDateTime**,12/17/2021, 07:58 pm,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
ProjectName**,JBCC with placeholder met data,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
MicrophoneID**,na,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
AveragingMethod**,SLOW,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
TimeStampType**,ICAOSLO,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
AdjustmentCode**,No adjustments,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
StartTime**,11,42,30.000,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
ReferenceTime**,11,42,30.000,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
ReferenceTimeType**,START,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
GeneratedBy**,.bin file,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
NumberOfGenerationFiles**,1,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
GenFileName1**,RUN0004_JBCC_M600_F03_F000_102400HZ_CH004.bin,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
GenFileDateTime1**,12/16/2021, 09:45 pm,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
OtherRecords**,0,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
NumberOfCommentLines**,2,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
UserLevelOffset,0.000000 dB,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
Bandwidth,1/3 octave,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
Rec#,TODHH,TODMM,TODSS,RelTime,B8/6.3Hz,B9/8Hz,B10/10Hz,B11/12.5Hz,B12/16Hz,B13/20Hz,B14/25Hz,B15/31.5Hz,B16/40Hz,
1,11,42,29.75,0.25,19.8,21.8,25.0,38.1,30.7,36.4,41.7,38.8,40.2,42.0,42.4,44.3,37.7,38.5,30.9,33.0,31.5,28.9,25.8,
2,11,42,30.25,0.75,31.7,37.5,36.2,43.3,37.2,40.4,42.1,41.5,42.2,42.9,44.3,46.4,41.2,39.8,33.2,34.4,33.5,31.3,29.8,
3,11,42,30.75,1.25,35.1,39.8,39.3,43.1,39.2,39.9,43.3,43.2,42.7,42.3,44.7,46.5,41.8,41.3,34.5,35.4,35.5,32.8,31.7,
4,11,42,31.25,1.75,33.3,40.1,40.5,44.0,41.9,40.8,45.6,45.0,43.8,43.6,45.5,47.2,43.0,41.9,34.7,36.0,37.4,33.3,32.1,
```

Figure 24 - Example one-third octave band time history file

4.3 Tracking System Data Summary

GNSS signals, as received on Earth, have inherent errors, such as satellite clock drift and atmospheric delays, which adversely affect positional accuracy and precision. However, when GNSS observables are collected simultaneously at a reference position and a point, or points of interest (Rover), then the data from the Reference Position may be used to enhance the precision of the Rover data using post-process kinematic (PPK) corrections. This is accomplished by comparing carrier phase measurement differences between the "known" location of the reference antenna and the Rover position, e.g., a microphone location or aircraft trajectory. In this manner, the accuracy of the Rover position may be improved to centimeter-level, relative to the Reference Position and other points that have been surveyed, such as the microphone positions.

For the JBCC flight tests, START hardware was configured to collect GNSS observables at 10 Hz. These raw data were saved to a proprietary u-blox format (.ubx). For post-processing, however, data must first be converted to the Receiver Independent Exchange Format (RINEX). RINEX is a standard which defines GNSS data formats so that they may be compatible with processing tools. Once converted to RINEX, RTKLIB software was used to apply PPK corrections. RTKLIB is an open source suite of software tools that is widely used in academia, industry and government. RTKLIB Demo5, used to process the JBCC data set, is a branch of RTKLIB optimized for practical applications and use with lower cost receivers, such as those produced by u-blox.

The RTKPOST software tool produces the PPK output in the form of ASCII text files (.pos) which contain the timing, positioning and velocity data of interest. Specifically, the .pos files include the data time stamp, latitude/longitude (ITRF2014), height (WGS84 ellipsoid), quality flags (indicating solution type), # of satellites used in solution, velocities (N, E, U), and several other parameters that may be used to asses solution quality. An example the PPK output file is shown below in Figure 25.

The PPK output files were processed further using a code written in R, originally developed by the Volpe team to process tracking data from previous measurement campaigns where the START system was deployed. This additional post-process uses the PPK output file data, along with surveyed reference position data to calculate position in a local coordinate system (where [0, 0, 0] is the centerline microphone position), and the nominal flight track is oriented parallel to the Y-axis. The R program also calculates additional aircraft kinematic metrics such as ground speed, emission angle, and slant range for each position record. The PPK data converted to the local coordinate system along with aircraft ground speed is used as input data for the noise hemisphere creation process.

% (lat/lon	Q=1:fix	2:float	3:sbas	4:dgps	5:single	6:ppp	ns=# of satellites)															
% UTC	latitude(deg)	longitude(deg)	height(m)	Q	ns	sdn(m)	sde(m)	sdu(m)	sdne(m)	sdeu(m)	sdun(m)	age(s)	ratio	vn(m/s)	ve(m/s)	vu(m/s)	sdvn	sdve	sdvu	sdvne	sdveu	sdvun
2021/09/27 13:51:59.10	41.654291763	-70.544798875	6.2640	1	9	0.0082	0.0055	0.0100	-0.0033	-0.0021	-0.0028	0.10	11.3	-0.02859	0.03476	0.01389	0.11888	0.09388	0.08691	-0.04029	-0.01806	-0.02266
2021/09/27 13:51:59.20	41.654291730	-70.544798833	6.2685	1	9	0.0082	0.0055	0.0100	-0.0033	-0.0021	-0.0028	0.20	11.3	0.01210	-0.00818	-0.02403	0.11878	0.09376	0.08688	-0.04028	-0.01808	-0.02266
2021/09/27 13:51:59.30	41.654291741	-70.544798843	6.2656	1	9	0.0081	0.0055	0.0099	-0.0033	-0.0021	-0.0028	0.30	11.3	0.00722	0.00263	-0.00943	0.11870	0.09367	0.08703	-0.04028	-0.01814	-0.02271
2021/09/27 13:51:59.40	41.654291748	-70.544798843	6.2629	1	9	0.0081	0.0055	0.0099	-0.0033	-0.0021	-0.0028	0.40	11.3	0.00122	0.00139	0.01034	0.11866	0.09362	0.08726	-0.04028	-0.01821	-0.02279
2021/09/27 13:51:59.50	41.654291748	-70.544798836	6.2653	1	9	0.0081	0.0055	0.0099	-0.0033	-0.0021	-0.0028	0.50	11.3	-0.00102	-0.02580	-0.00994	0.11863	0.09361	0.08722	-0.04025	-0.01820	-0.02279
2021/09/27 13:51:59.60	41.654291746	-70.544798860	6.2643	1	9	0.0081	0.0055	0.0100	-0.0033	-0.0021	-0.0028	0.60	11.3	0.00224	-0.00651	-0.00671	0.11888	0.09370	0.08698	-0.04042	-0.01813	-0.02270
2021/09/27 13:51:59.70	41.654291754	-70.544798873	6.2643	1	9	0.0082	0.0055	0.0101	-0.0033	-0.0021	-0.0028	0.70	11.3	-0.00993	0.01998	-0.01241	0.11950	0.09402	0.08812	-0.04073	-0.01839	-0.02304
2021/09/27 13:51:59.80	41.654291746	-70.544798854	6.2643	1	9	0.0082	0.0055	0.0104	-0.0033	-0.0022	-0.0029	0.80	11.3	0.00341	0.00590	-0.01984	0.11937	0.09442	0.09467	-0.04024	-0.01985	-0.02515
2021/09/27 13:51:59.90	41.654291740	-70.544798846	6.2651	1	9	0.0083	0.0056	0.0106	-0.0034	-0.0022	-0.0030	0.90	11.3	0.02701	-0.01291	-0.03865	0.12145	0.09457	0.11107	-0.04179	-0.02343	-0.03023
2021/09/27 13:52:00.00	41.654291766	-70.544798854	6.2602	1	9	0.0084	0.0057	0.0102	-0.0034	-0.0022	-0.0029	-0.00	11.3	0.00137	-0.01728	0.00891	0.14308	0.10481	0.13173	-0.05355	-0.02803	-0.03593
2021/09/27 13:52:00.10	41.654291766	-70.544798872	6.2609	1	9	0.0083	0.0058	0.0098	-0.0033	-0.0020	-0.0028	0.10	11.3	0.01251	0.01450	0.01684	0.20163	0.15666	0.11409	-0.07038	-0.02265	-0.02728
2021/09/27 13:52:00.20	41.654291775	-70.544798860	6.2621	1	9	0.0090	0.0060	0.0122	-0.0036	-0.0025	-0.0034	0.20	11.3	0.00173	0.00241	0.01713	0.09167	0.07425	0.06330	-0.02970	-0.01300	-0.01628
2021/09/27 13:52:01.40	41.654291758	-70.544798852	6.2637	1	9	0.0081	0.0055	0.0099	-0.0033	-0.0021	-0.0028	0.40	11.2	-0.00779	-0.00253	-0.02937	0.11863	0.09361	0.08670	-0.04023	-0.01807	-0.02265
2021/09/27 13:52:01.50	41.654291746	-70.544798857	6.2607	1	9	0.0081	0.0055	0.0099	-0.0033	-0.0021	-0.0028	0.50	11.2	0.01201	0.01180	-0.01559	0.11861	0.09359	0.08666	-0.04022	-0.01807	-0.02264
2021/09/27 13:52:01.60	41.654291760	-70.544798839	6.2584	1	9	0.0081	0.0055	0.0099	-0.0033	-0.0021	-0.0028	0.60	11.2	-0.01049	-0.01660	-0.00104	0.11869	0.09367	0.08671	-0.04023	-0.01806	-0.02265
2021/09/27 13:52:01.70	41.654291748	-70.544798857	6.2584	1	9	0.0081	0.0055	0.0099	-0.0033	-0.0021	-0.0028	0.70	11.2	0.00270	0.00767	0.00011	0.11876	0.09378	0.08675	-0.04022	-0.01805	-0.02266
2021/09/27 13:52:01.80	41.654291758	-70.544798851	6.2569	1	9	0.0082	0.0055	0.0100	-0.0033	-0.0021	-0.0028	0.80	11.2	-0.02066	0.01050	0.01546	0.11875	0.09377	0.08685	-0.04021	-0.01807	-0.02270
2021/09/27 13:52:01.90	41.654291739	-70.544798835	6.2579	1	9	0.0082	0.0055	0.0100	-0.0033	-0.0021	-0.0028	0.90	11.2	0.00176	-0.01137	0.01199	0.11886	0.09382	0.08697	-0.04028	-0.01806	-0.02273
2021/09/27 13:52:02.00	41.654291738	-70.544798845	6.2603	1	9	0.0081	0.0055	0.0099	-0.0033	-0.0021	-0.0028	-0.00	11.1	0.00746	-0.00062	-0.00836	0.11855	0.09357	0.08650	-0.04018	-0.01805	-0.02261
2021/09/27 13:52:02.10	41.654291746	-70.544798853	6.2594	1	9	0.0082	0.0056	0.0100	-0.0033	-0.0021	-0.0028	0.10	11.1	0.00392	0.02507	-0.00809	0.11887	0.09388	0.08690	-0.04023	-0.01805	-0.02271
2021/09/27 13:52:02.20	41.654291743	-70.544798821	6.2606	1	9	0.0082	0.0055	0.0100	-0.0033	-0.0021	-0.0028	0.20	11.1	0.01093	-0.01684	-0.02768	0.11876	0.09376	0.08680	-0.04022	-0.01805	-0.02269
2021/09/27 13:52:02.30	41.654291756	-70.544798839	6.2586	1	9	0.0081	0.0055	0.0099	-0.0033	-0.0021	-0.0028	0.30	11.1	-0.00870	0.00059	-0.02172	0.11867	0.09367	0.08673	-0.04021	-0.01806	-0.02268
2021/09/27 13:52:02.40	41.654291754	-70.544798837	6.2548	1	9	0.0081	0.0055	0.0099	-0.0033	-0.0021	-0.0028	0.40	11.1	-0.00793	0.00632	0.00605	0.11862	0.09361	0.08670	-0.04021	-0.01806	-0.02267

Figure 25 - Example of PPK Output File Format

4.3.1 VerifyRINEX

VerifyRINEX is a console application developed by Volpe and intended to quickly assess the completeness and integrity of RINEX files derived from START data. Due to their compact nature and often high levels of radio frequency interference (RFI) from internal transmitters, small UA can be a challenging environment for low level GNSS signals. To monitor and mitigate missing or incomplete START Rover data, data contents were checked for completeness, both during and after each vehicle flight test. A log of all missing data points, per day, per aircraft/file can be found in Appendix C. Only files with at least one data dropout are listed. Note that gaps are listed for any data dropout, whether occurring during flight events or inactive periods.

4.4 Log Sheets and Metadata Tables

Daily acoustic log sheets were maintained to track all flight event times. Anomalous ambient noise contamination and trajectories that deviated significantly from the nominal flight path based on visual inspection were also documented in the logs. Table 10 describes all data recorded on the field logs.

Table 10 - Acoustic log sheet data fields

Data Field Name	Description
Date	mm/dd/yyyy
Acoustics System	CARS 1 & 2 or ancillary LD 831 sound level meters
Site Name	JBCC
Aircraft	Model name
Site ID	Linear or Hover array
Personnel	Last name of team member filling out field log (Kaye)
Test Director	Initials of Test Director (CCW)
Acoustics Lead	Initials of Acoustics Lead (RD)
Tracking Lead	Initials of Tracking Lead (RS)
Facilities Director	Initials of Facilities Director (CS)
Event ID	From flight card (e.g., F01, V02, H04)
Event Description	Aircraft condition (e.g., level flyover, hover, takeoff, landing)
Direction of Flight	Initial of cardinal direction with vertical indicator, if applicable (e.g., N, S, up S, N down)
Data On Time	hh:mm:ss (UTC) of signal to initiate acoustic recording before event
Time @ OH	hh:mm:ss (UTC) of when aircraft flew over array center point
Data off Time	hh:mm:ss (UTC) of signal to end acoustic recording after event
Comments	Notes on ambient noise contaminations during event or anomalous trajectories, if applicable (e.g., distant roadway noise at end, windy throughout, very southerly hover)

Daily site diagrams were also drawn depicting the microphone array configurations and flight paths implemented that day, along with key locations of personnel and other landmarks.

Supporting information for the JBCC measurement is summarized in the metadata file named *2021_JBCC_UA_Measurement-Volpe_METADATA.xlsx*. The excel spreadsheet includes the four sheets described below. Note that much of the metadata information was also included in header lines in the acoustic data files.

1. RUN METADATA summarizes test conditions for each event;
2. CH METADATA summarizes acoustic measurement channel attributes;
3. CH MEASURED SENSITIVITY provides a table of the daily measured sensitivities for each channel; and
4. ELECTROSTATIC ACTUATOR RESPONSE provides a table of electrostatic actuator response data for each microphone used in the JBCC measurements

Start time and end time in the run metadata table correspond to earliest microphone file starting time and the latest microphone file end time. For many runs, the file start and end times are the same for all microphones. For other runs, it was not always possible to trim files to common start/end times without removing useful data and as such the start/end times for channels 1–8 may be slightly different from channels 9–16, as indicated by header fields START TIME and SAMPLES TOTAL in each file.

Log sheets for the tracking system (START) were also populated during the flight tests. START logs are used to identify system components deployed on each aircraft and to correlate tracking file names with takeoff and landing event times to aid in post-processing corrections to tracking data.

4.5 Database Design and Implementation

Data collected at JBCC were curated to be stored in a relational database. The primary function of the database is to facilitate access to data by creating an index of events that correlates data recorded in separate systems by date, time, and location of measurement site. The database was designed with a generic format that is intended to be suitable for housing data collected in future unconventional aircraft measurement campaigns. The database contains time-history of sound level data at several frequency weightings and across the 1/3 octave band, as well as meteorological data, session logs, flight logs, meteorological data, tracking data, and some instrument settings. The database does not contain raw pressure time-history data but does contain a reference and link to the location of raw audio files associated with each event.

The database is composed of data sourced from the Acoustic Data Collection System, the “START” Tracking System, and the Meteorological Data Collection System. A Python script is used to convert the source data that have been output from each system into an indexed file structure that can be readily imported into a relational database by way of Structured Query Language (SQL). During the format conversion, the user is prompted to provide the list of aircraft for which data were collected, as well as the name of the acoustic measurement device and date of measurement associated with each event file extracted from the sound level meter. These inputs are used to create an index for each event in the relational database. The SQL script used to create the database requires the user to provide 2 inputs:

1. A path to the data files that have been pre-processed, in Python, into an indexed file structure.
2. A list of the files containing tracking data, separated and named by aircraft and date

A list of the database tables is detailed in Table 11. Table data are sourced from output files from the acoustic measurement device, START system output files, digitized log files, or are derived from one or more of those systems. A complete data dictionary, detailing fields from each table, can be found in Appendix D.

Table 11 - Database Tables & Descriptions

Table Name	Description	Source
Master_List	List of Unique Events - [Index] field is Primary Key	SLM
Aircraft	List of Aircraft - [Aircraft_ID] field is Primary Key	Derived
Calibration_History	1/3 Octave Band Time History of Calibration Records - [Index] is Foreign Key	SLM

Overall_Settings	Sound Level Meter Settings - [Index] is Foreign Key	SLM
Log_Sheet	Digitized log sheets	Log
Session_Log	Session logs from Sound Level Meter - [Index] is Foreign Key	SLM
Time_History	Time History of Sound Level Records at LASeq, LASmax, LZSeq, and 1/3 Octave Band Frequencies - [Index] is Foreign Key	SLM
Time_History_Key	Time History Record of Keys indicating status change of Sound Level Meter During Events - [Index] is Foreign Key	Derived
Weather	Meteorological Data - [Index] is Foreign Key	SLM
Weather_Expanded	Expanded Meteorological Data - [Index] is Foreign Key	SLM
Tracking	dGPS data from the START Tracking System - [Aircraft_ID] is Foreign Key	START

The entity relationship diagram in Figure 26 depicts the eleven database tables and any primary or foreign key relationships between tables. The key icon indicates a primary key relationship and points to the parent table, which holds the primary key field. The Master List table serves as a primary key and central point of reference when querying or manipulating event data sourced from the Acoustic Data Collection System. Data from logs and START tracking system can be correlated to each event by date, time, and aircraft.

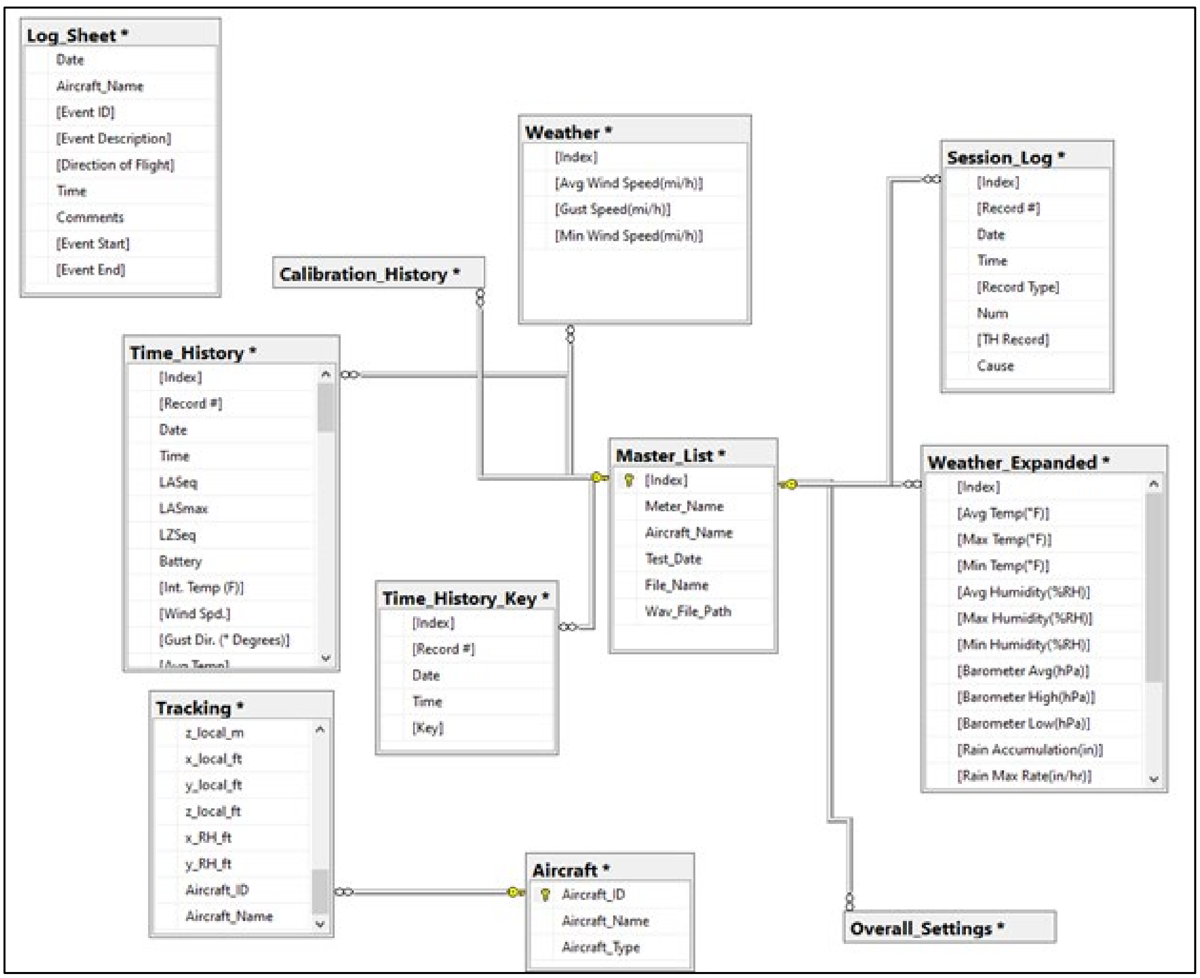


Figure 26 - Database Entity Relationship Diagram

5. Preliminary Noise Level Summary

The maximum overall slow time-averaged, A-weighted sound levels (LAS_{max}) were identified and extracted at three specific microphone locations (F000, F45W, and F90E) for all "F01" (max weight, max speed, low flyover altitude) flight events flown over the course of the measurement campaign by four UA platforms. Time synchronized slant range (straight line distance from the aircraft to the microphone of interest) values at the time of LAS_{max} were calculated and extracted for each event and microphone position. The LAS_{max} values were then normalized to a slant range of 400 ft. to facilitate basic comparison between aircraft noise levels. Tables 12 through 15 present arithmetic averages of Slant Range, LAS_{max}, and normalized LAS_{max} for all F01 flight events, broken down by aircraft and microphone position. The total number of F01 flight events for each aircraft is listed in each table. Note that the process used for normalization of LAS_{max} level to a reference slant range of 400 ft. only includes a distance-dependent adjustment for spherical spreading, using Equation 1. This preliminary data summary suggests potential directivity differences between the three microphone positions, as the averaged, normalized, LAS_{max} values do not converge as one might expect with an omnidirectional acoustic source. It is also possible that the LAS_{max} occurred at slightly different times at each microphone position, thereby affecting the slant range and subsequent normalization. Further investigation is needed to confirm the factors contributing to this discrepancy.

$$LAS_{max}(400\ ft.normalized) = 20 * \log(\frac{SR\ @\ LAS_{max}}{400})$$

Equation 1 - LASmax Normalization to 400 ft. (Spherical Spreading Adjustment)

Table 12 - LASmax Summary table for DJI M600

DJI M600			
Total Number of "F01" Flight Events			12
Mic Location	Slant Range @ LAS_{max} (ft)	LAS_{max} (dBA)	LAS_{max} normalized to 400 ft. (dBA)
F000	56.69	73.8	56.8
F45W	111.25	63.9	52.8
F90E	127.86	59.2	49.3

Table 13 - LASmax Summary table for DJI M210

DJI M210			
Total Number of "F01" Flight Events			6
Mic Location	Slant Range @ LAS_{max} (ft)	LAS_{max} (dBA)	LAS_{max} normalized to 400 ft. (dBA)
F000	85.15	67.7	54.2
F45W	76.23	67.5	53.1
F90E	169.05	54.5	47.0

Table 14 - LASmax Summary table for ArgenTech FireEye Series 2

ArgenTech FireEye Series 2			
Total Number of "F01" Flight Events			**12**
Mic Location	**Slant Range @ LAS_{max} (ft)**	**LAS_{max} (dBA)**	**LAS_{max} normalized to 400 ft. (dBA)**
F000	432.11	69.6	70.3
F45W	449.71	69.4	70.4
F90E	354.88	66.0	64.9

Table 15 - LASmax Summary table for DJI Phantom 4 Pro

DJI Phantom 4 Pro			
Total Number of "F01" Flight Events			**6**
Mic Location	**Slant Range @ LAS_{max} (ft)**	**LAS_{max} (dBA)**	**LAS_{max} normalized to 400 ft. (dBA)**
F000	42.52	70.0	50.5
F45W	103.98	56.8	45.1
F90E	124.08	54.4	44.2

6. Conclusions and Next Steps

6.1 General Observations

Overall, many of the efficiencies anticipated by using the AWRF site at Joint Base Cape Cod were realized during the course of the measurement campaign. Of particular importance to the uninterrupted operation of the aircraft was access to electrical power out in the field, which eliminated the need for pilots and aircraft to return to the AWRF building for battery swaps and charging. This was a huge time saving mechanism and allowed the team to pivot from one aircraft to another with minimal interruption. Coordination with other JBCC base operations was also key to a successful campaign, especially when there were other nearby military and coast guard operations (both aircraft and ground vehicles).

As expected (and as is the case for any measurement campaign) the weather proved to be the largest source of day-to-day uncertainty. It was necessary to keep a close eye on available weather and wind forecasts each day, and for the Test Director to make a “go / no-go” decision each evening prior to the next measurement day. The AWRF site may present marginally higher risks of wind speeds above acceptable flight and measurement limits, but not enough so to avoid the site altogether for future campaigns, particularly in light of the significant efficiency and cost savings associated with the site..

Despite rigorous pre-planning and coordination with the UA pilots and fleet managers, it became apparent that the specifics of the required flight operations had not been communicated clearly enough, and time was spent fine tuning flight programs in the field. Although the team is asking for relatively “simple” flight operations (straight-line, one altitude), some operators may not have experience “stacking” these flights for repeatable test events. The Volpe team recommends that any prospective UA operators be required to fly test flight events (based on the measurement flight cards) prior to the measurement campaign to ensure there are no major issues or questions once the aircraft are onsite. This will also aid the team by discovering any differences between the manufacturers quoted flight specifications and the real-world performance of the aircraft. It will also highlight any particular safety concerns that might be able to be worked through prior to the measurement deployment.

During the measurement campaign, the START system experienced loss of satellite signal for varying lengths of time between a few seconds and a few minutes. These dropouts occurred on one particular aircraft, regardless of time of day, flight event, or system components. The Volpe team suspected this aircraft emits a substantial amount of RF energy from the internal aircraft system, motors, and batteries, which had a significant impact on START system performance. This suspicion was confirmed with the use of an RF “sniffer” that indicated high levels of potentially contaminating energy emanating from large sections of the aircraft. Unfortunately, there were few other mounting options for the START system, particularly for the receiver module, and so the dropouts were difficult to avoid during flight tests for this aircraft. In the future, the RF sniffer will be used to determine ideal and/or suboptimal mounting positions for the START system components. The Volpe team may also fabricate or procure shielding components to protect the START system components from RF interference when mounted on aircraft.

Anecdotally, the most interesting flight condition for all of the aircraft measured (in terms of loudness and acoustic "harshness") seemed to be the transition states between hover and forward flight. This was especially apparent for the fixed-wing, hybrid aircraft, which matches the anecdotal experience from previous measurement campaigns. Additionally, there seems to be noticeable directivity in the noise from all of the aircraft, both on the ground and at/above the rotor plane.

In comparison to traditional aircraft, the noise generated by the aircraft measured in this campaign was often extremely variable and often heavily influenced by the aircrafts' use of rotor speed to maintain a constant ground speed against small changes in wind. These fluctuations will likely not be captured by acoustic metrics that average energy over a large time period.

6.2 Next Steps and Recommendations

Further analysis of the acoustics and tracking will be needed to make substantial conclusions about the anecdotal points raised in Section 6.1 such as transition state noise, directivity, and short time varying characteristics. The Volpe team continues to work with FAA to perform such analyses and use the conclusions to inform future policy and measurement recommendations.

Of particular interest will be the noise hemisphere creation process using the data gathered by the larger microphone array, which will be applied to environmental analyses of particular UA operations in the community, as well as highlight any particular directivity inherent to these aircraft.

7. References

[1]Read, D.R., Senzig, D., Cutler, C., Elmore, E., Hua, H. (2020). *Noise Measurement Report: Unconventional Aircraft - Choctaw Nation of Oklahoma: July 2019*. Report Number DOT-VNTSC-FAA-2020-03. https://rosap.ntl.bts.gov/view/dot/49647

[2]Acoustical Society of America, American National Standards Institute. (2012). *S12.75 - Methods for the Measurement of Noise Emissions from High Performance Military Jet Aircraft*. Melville, NY.

[3]ICAO, Annex 16 to the Convention on International Civil Aviation. (2017). "*Environmental Protection*, Volume I, Aircraft Noise". Eighth Ed.

[4]Read, D.R., Cutler, C., O'Neil, E. (2017). *Volpe SuperFar V6.0 Software and Support Documentation*. Letter Report V324-FB48B3-LR3. https://rosap.ntl.bts.gov/view/dot/34598

8. Appendix A: Acoustic Instrumentation

8.1 Signal Path Table and Diagram

Table 16 - Volpe CARS Signal Path Details

Signal path number	Mic Array Position(s)	Cable length (ft)	Gain amp number	Gain amp channel	NI node number	NI channel	B&K 2671 s/n	G.R.A.S. 40AO s/n	Mic sensitivity (mV/Pa)	B&K 2693 s/n	cRIO 9037 s/n	AI module model	AI module s/n	Master Clock GPS 200A s/n
1	F30E/H045	150	1	1	1	/dev3/ai0	2048356	450121	10.71	3009990	01B0DE4F	NI-9250	1E4AF4B	n/a
2	F20E/H090	200	1	2	1	/dev3/ai1	2263944	427509	9.82	3009990	01B0DE4F	NI-9250	1E4AF4B	n/a
3	F10E/H135	200	1	3	1	/dev4/ai0	2048357	427457	9.26	3009990	01B0DE4F	NI-9232	1BC67DC	n/a
4	F000	200	1	4	1	/dev4/ai1	2048207	427455	12.14	3009990	01B0DE4F	NI-9232	1BC67DC	n/a
5	F10W	250	2	1	1	/dev4/ai2	2048159	407580	9.67	3009994	01B0DE4F	NI-9232	1BC67DC	n/a
6	F20W	250	2	2	1	/dev5/ai0	2263947	450114	12.97	3009994	01B0DE4F	NI-9232	1BFA316	n/a
7	F30W	300	2	3	1	/dev5/ai1	2263949	407565	10.13	3009994	01B0DE4F	NI-9232	1BFA316	n/a
8	F45W	350	2	4	1	/dev5/ai2	2048208	450231	10.17	3009994	01B0DE4F	NI-9232	1BFA316	n/a
9	F50E	150	3	1	2	/dev3/ai0	2263953	427458	11.19	3009989	01B0DE4E	NI-9250	1E4AF4F	n/a
10	F60E	200	3	2	2	/dev3/ai1	2048206	450150	11.66	3009989	01B0DE4E	NI-9250	1E4AF4F	n/a
11	F70E	200	3	3	2	/dev4/ai0	2048158	315753	13.01	3009989	01B0DE4E	NI-9232	1BDA52C	n/a
12	F80E	250	3	4	2	/dev4/ai1	2048157	315754	12.71	3009989	01B0DE4E	NI-9232	1BDA52C	n/a
13	F90E	250	4	1	2	/dev4/ai2	2048032	315766	12.11	3009988	01B0DE4E	NI-9232	1BDA52C	n/a
14	H225	250	4	2	2	/dev5/ai0	2125164	315801	11.22	3009988	01B0DE4E	NI-9232	1BC67DD	n/a
15	H270	200	4	3	2	/dev5/ai1	2263946	264031	11.35	3009988	01B0DE4E	NI-9232	1BC67DD	n/a
16	H315	200	4	4	2	/dev5/ai2	2125166	282648	9.76	3009988	01B0DE4E	NI-9232	1BC67DD	n/a
17	Time code		n/a	n/a	1	/dev6/ai0	n/a	n/a	n/a	n/a	01B0DE4F	NI-9232	1BC67D8	8337010
18	Time code		n/a	n/a	2	/dev6/ai0	n/a	n/a	n/a	n/a	01B0DE4E	NI-9232	1BC67E0	8273096

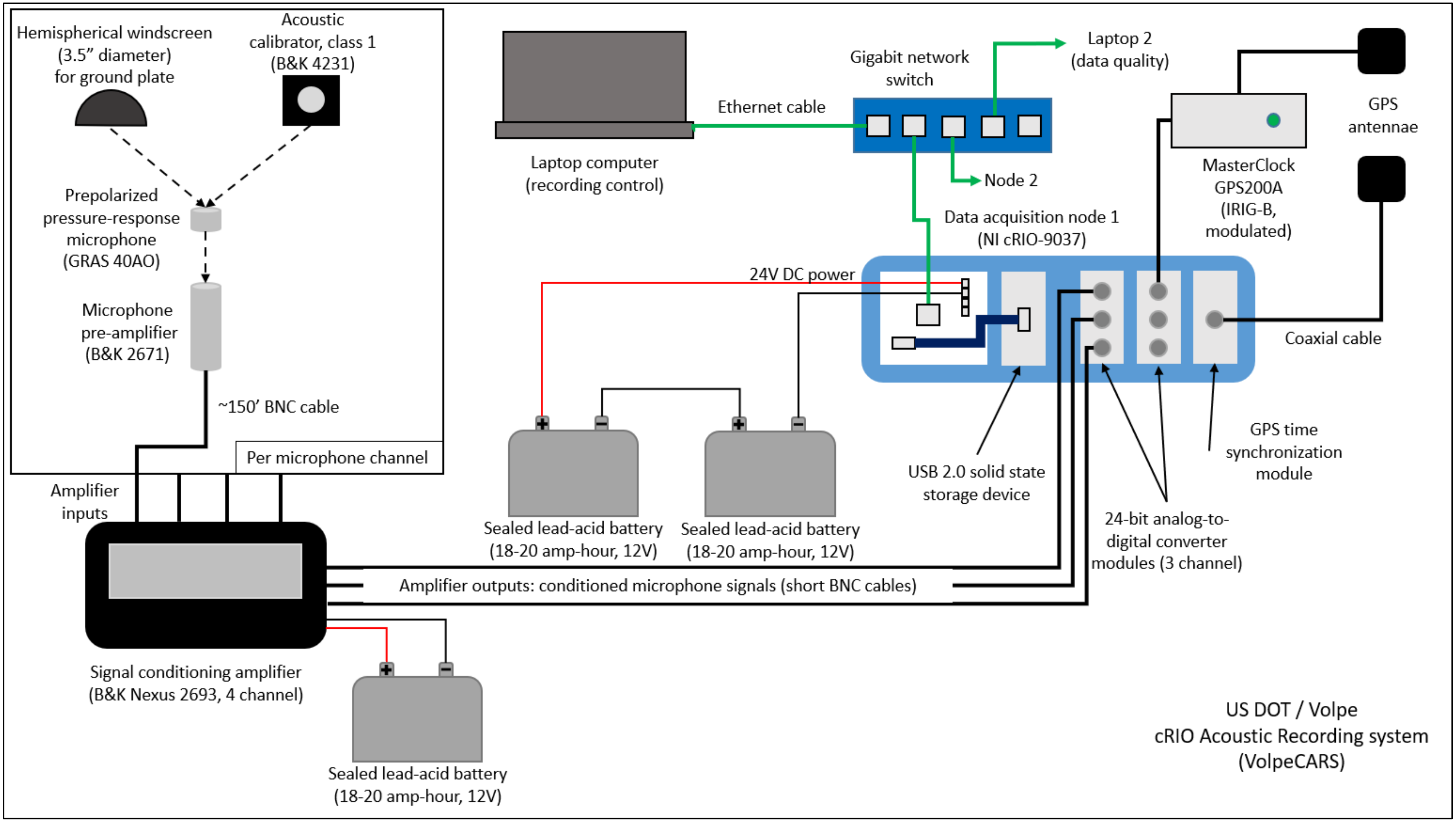


Figure 27 - Volpe CARS Diagram

8.2 Acoustics System Setup Documentation and Field User Guide

1. **General equipment setup**
   a. **Ground plate setup**
      i. Place and center ground plate on relatively flat, level terrain at predetermined, surveyed, location.
      ii. Use local soil or potting soil to provide flat, level mounting surface for ground plate: remove excess vegetation, rocks, etc. from plate location, place soil in area and temporarily install and remove the plate to identify and fill-in any voids; compress the soil under the plate to form stable solid surface; nestle the ground plate into the soil, making sure that all air pockets are eliminated and the edges of the plate are flush with the ground. If necessary, trim local grass, etc. within several inches of the edge of the plate. The goal is to integrate the plate into the local surface as smoothly as possible, and to minimize abrupt transition between acoustical surfaces.

   b. **Ground plane microphone setup**
      i. Screw (3) spider legs into mic preamplifier collar assembly.
      ii. Attach microphone to preamplifier – back preamplifier through spider collar before connecting cable.
      iii. Attach 150' – 350' BNC microphone cable to preamplifier, and suspend cable above plate using cable support inserted into ground adjacent to plate.
      iv. Route BNC mic cable to instrument table and connect to B&K Nexus signal conditioning amplifier input.

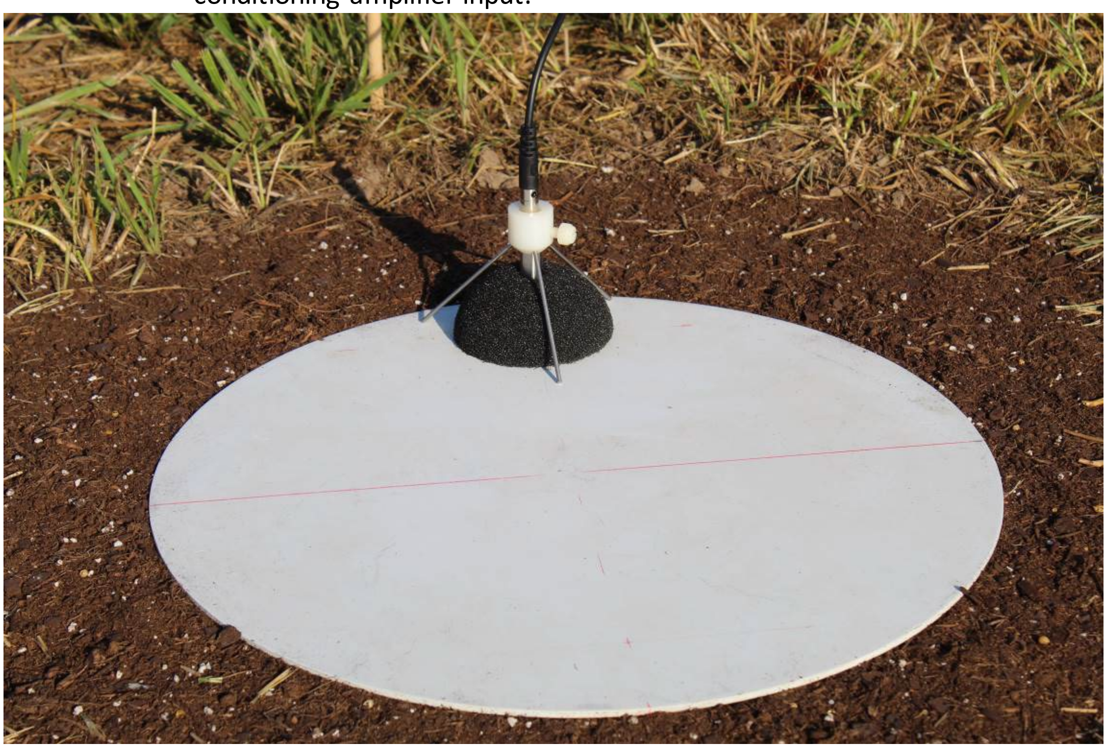


Figure 28 - Ground plate & Mic Setup

2. Instrument table setup

a. Timecode generator

i. Connect GPS antenna to antenna input at rear of MasterClock GPS-200A.
ii. Position the antenna to allow for best possible exposure to the sky, away from other instrumentation.
iii. Connect ring lugs of DC power cable to 12V battery.
iv. Connect the RS232-to-BNC adapter to the RS-232 output (rear) of the GPS-200A; connect a BNC cable to recording node on channel 9 (module 6, analog input 0).
v. Turn on GPS-200A time code generator by inserting DC power cable to DC input jack at rear of GPS-200A. A solid green light indicates power.

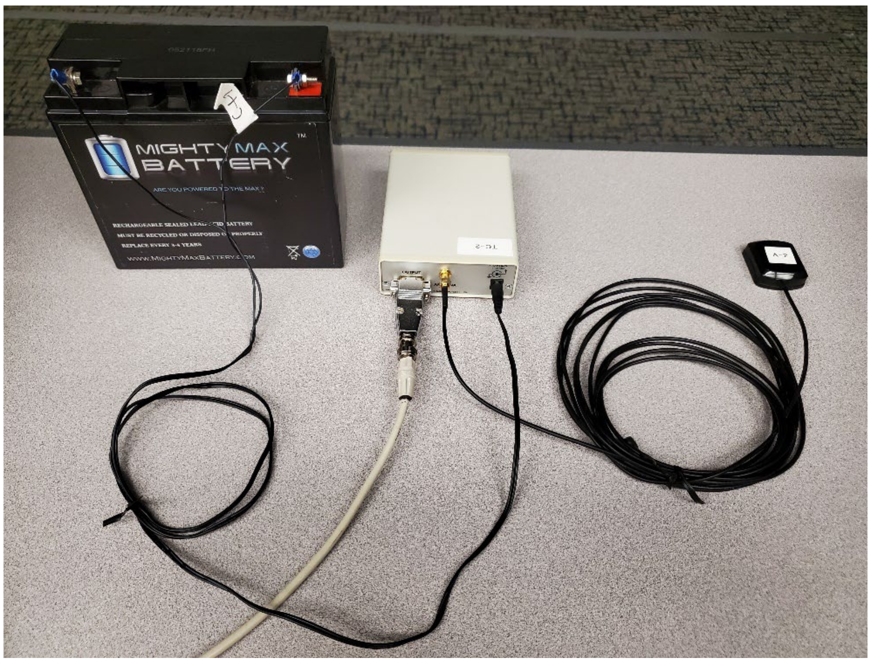


Figure 29 - MasterClock setup steps i-v

b. B&K Nexus signal conditioning amplifiers

i. Connect B&K DC power cables to 12V batteries via cigarette-lighter-style connectors.
ii. Power on amplifiers <u>before</u> connecting microphones. Note: if microphones are connected to amplifier when it is powered on, the amplifier will read the TEDS from the preamplifier and will apply the transducer sensitivity in the amplifier. Sensitivity will be applied in software by the recording node instead.
iii. Connect microphone preamplifiers to signal conditioning amplifier <u>inputs</u> using BNC cables.

Figure 30 - Nexus signal conditioning amplifier setup – steps i-ii

3. cRIO recording node hardware setup

a. Connect GPS antenna to antenna input on 9467 module (module 7).
b. Use USB cable to connect solid state drive (module slot 2) to upper USB input on left side of recording node front panel.
c. Use BNC cables to connect signal conditioning amplifier <u>outputs</u> for microphones 1-8 to input modules 3-6 as follows. Note that analog input numbers are printed on each module near the upper left quadrant of BNC terminals.
    i. Channel 1 → module 3, input 0
    ii. Channel 2 → module 3, input 1
    iii. Channel 3 → module 4, input 0
    iv. Channel 4 → module 4, input 1
    v. Channel 5 → module 4, input 2
    vi. Channel 6 → module 5, input 0
    vii. Channel 7 → module 5, input 1
    viii. Channel 8 → module 5, input 2
d. Use BNC cable to connect signal from GPS-200A to module 6, input 0.
e. Connect ethernet cable to ethernet port 1 on recording node (labeled "10/100/1000") and connect other end to network hub port 2 or 3.
f. Use quick-disconnect power cable to connect recording node power to a pair of sealed lead-acid batteries wired in series for 24V power. If quick-disconnect power cable is not already connected to recording node, connect bare wires to black screw terminal (V1→positive terminal of power source, C→negative terminal of power source).
g. Note: cRIO will boot automatically when power is connected. During the boot-up sequence, the 4-LED panel in the upper left corner of cRIO chassis will show a green LED and a yellow LED in positions 1 and 2 respectively. When cRIO operating system is running, the second LED will turn off.

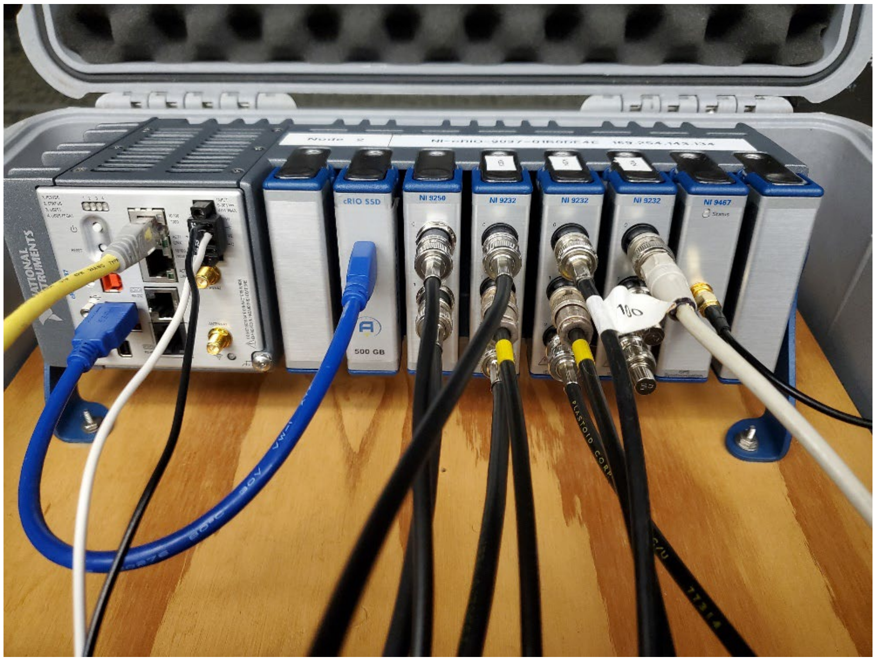


Figure 31 - cRIO recording node setup – steps a-f

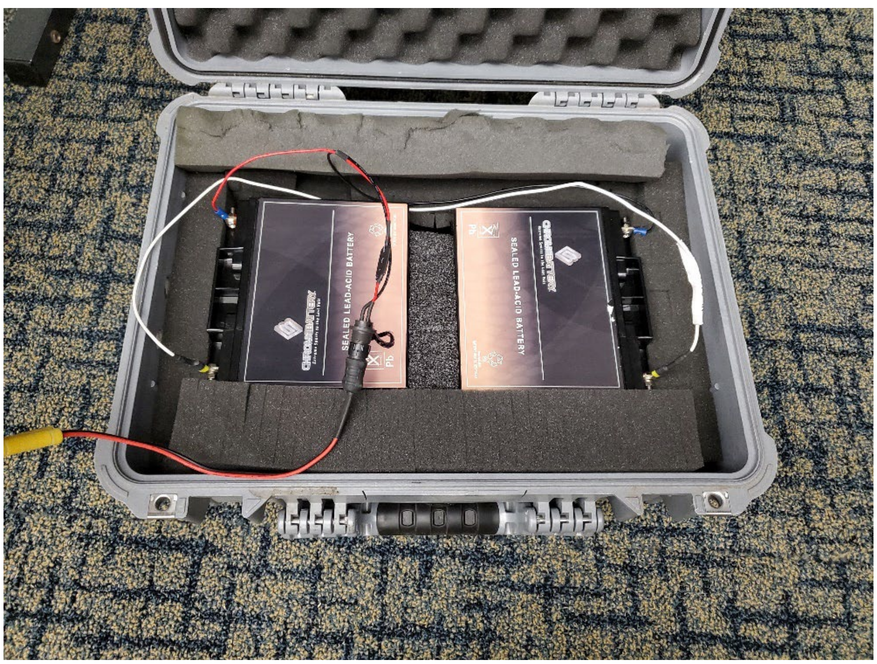


Figure 32 - cRIO recording node batteries and quick disconnect power cable

h. Network hub:
   i. The two cRIO recording nodes and field laptop will be connected over a local network through a hub. Connect a power inverter to terminals of a 12V battery.
   ii. Connect the AC-DC power converter to the power outlet on the inverter and connect the DC power to the network hub.
   iii. Use an ethernet cable to connect the ethernet port on the back of the field laptop to port 1 on the hub.

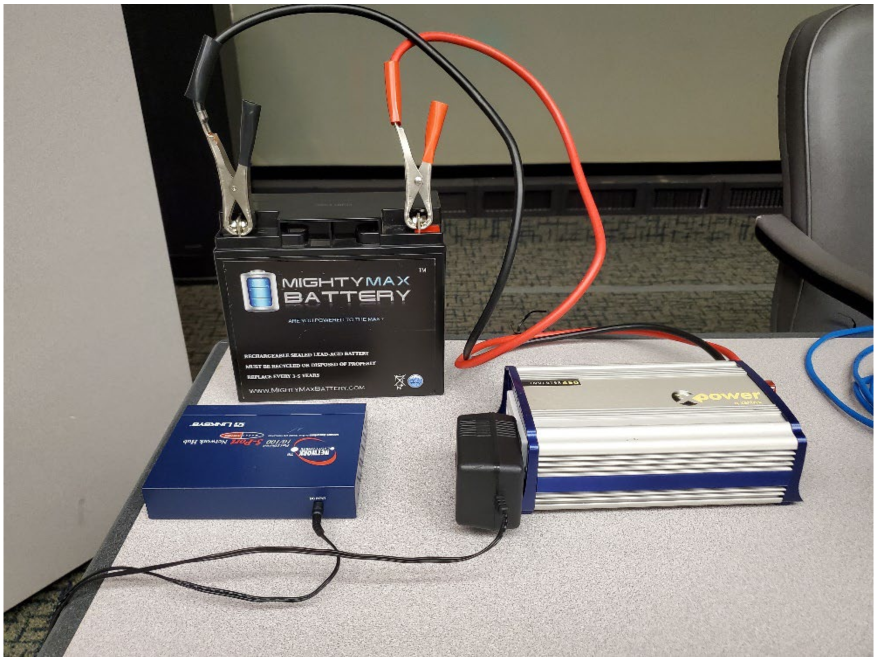


Figure 33 - Network hub powered through inverter setup – steps i-ii

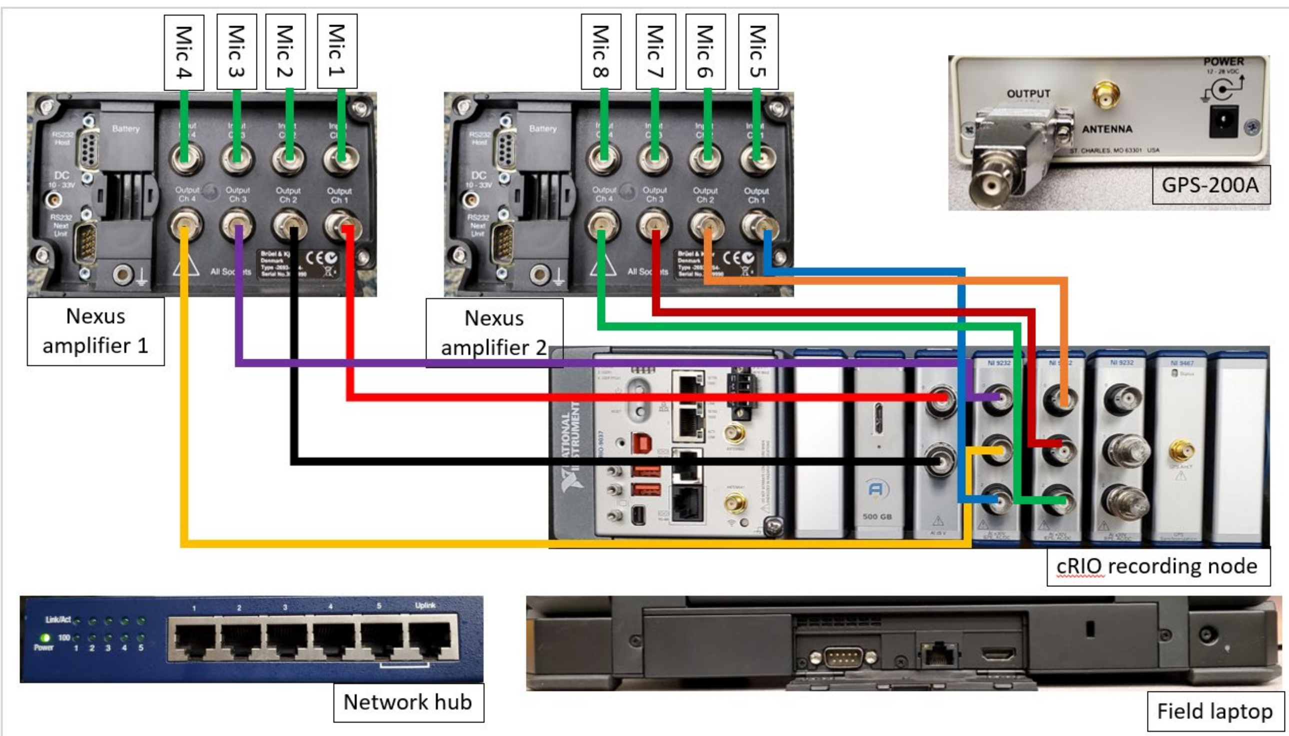


Figure 34 - Cabling diagram for acoustic signals

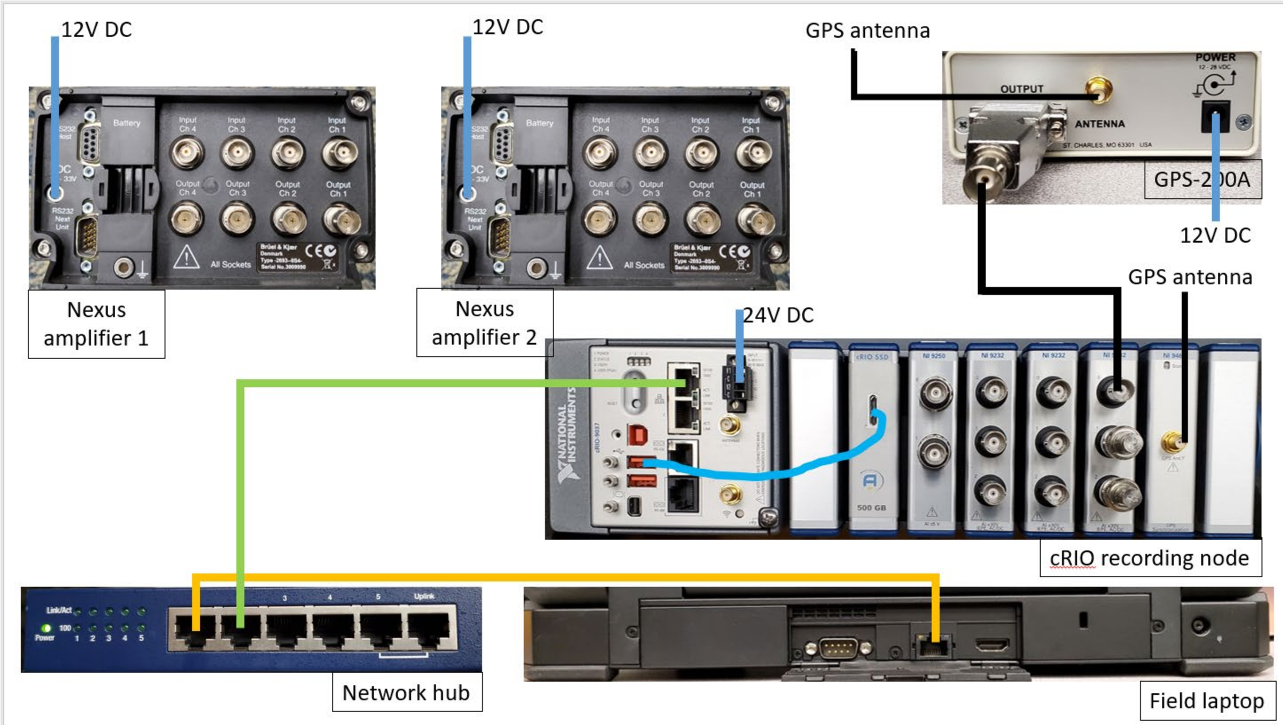


Figure 35 - Cabling diagram for power and non-acoustic signals

4. Instrument setup

a. B&K Nexus signal conditioning amplifiers

i. Amplifier Setup screen: set filtering to 0.1 Hz to 100 kHz, and set sensitivity according to desired gain:

Amplifier sensitivity	Total gain in amplifier
100 mV/Pa	−20 dB
316 mV/Pa	−10 dB
1.00 V/Pa	0 dB
3.16 V/Pa	10 dB
10.0 V/Pa	20 dB
31.6 V/Pa	30 dB
100 V/Pa	40 dB
316 V/Pa	50 dB
1.00 kV/Pa	60 dB
3.16 kV/Pa	70 dB
10.0 kV/Pa	80 dB

Specific gains are subject to change based on measured aircraft noise; initial gain settings for JBCC configuration will be 30 dB on NI-9250 channels and 40 dB on NI-9232 channels. If gain level(s) are to be changed in amplifiers, corresponding change must be made in recording node setup.

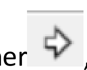
ii. Transducer setup screen: select DeltaTron power supply (triangle symbol) and sensitivity units V/Pa.

iii. Transducer supply screen: select 4 mA supply current and set cable length according to installed microphone cables (note: Nexus firmware assumes cable capacitance of 60 pF/m so an adjustment factor of 83.3/60 for RG-58 cable is included in cable length settings below):

1. 150 ft set cable length 64 m
2. 200 ft set cable length 84 m
3. 250 ft set cable length 104 m
4. 300 ft set cable length 128 m
5. 350 ft set cable length 148 m

b. cRIO recording node software: Virtual Sound Level Meter (VSLM)

i. In the VSLM front panel under system setup tab:

1. Enter input file location from previous step.
2. In the “Controller parameters” box on the right, ensure input configuration is set to “DC coupled” and “AC couple IRIG-B” is not selected.
3. Set “load sensitivities” switch to desired position; initial microphone sensitivities can be taken from input file or from memory (last calibrated values).
4. Run program by clicking the arrow in the upper left-hand corner , and check that “Input file status” reads “Input file found and loaded”.
5. Check that correct number of channels are shown under “selected channels” and that gain values are correct.

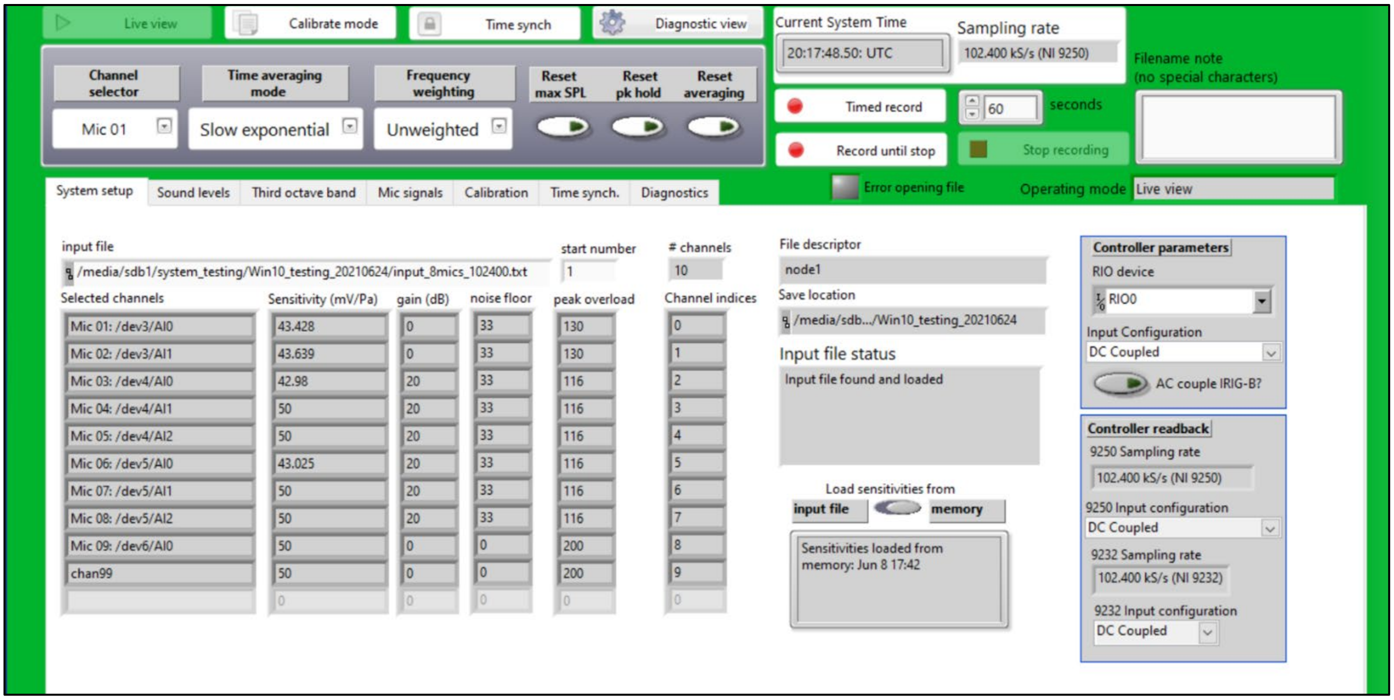


Figure 36 - VSLM system setup tab

ii. When the VSLM program is running, one can select different operating modes using the row of buttons along the top of the front panel and can view different data displays by selecting tabs such as "system setup". This is illustrated in Figure 37.

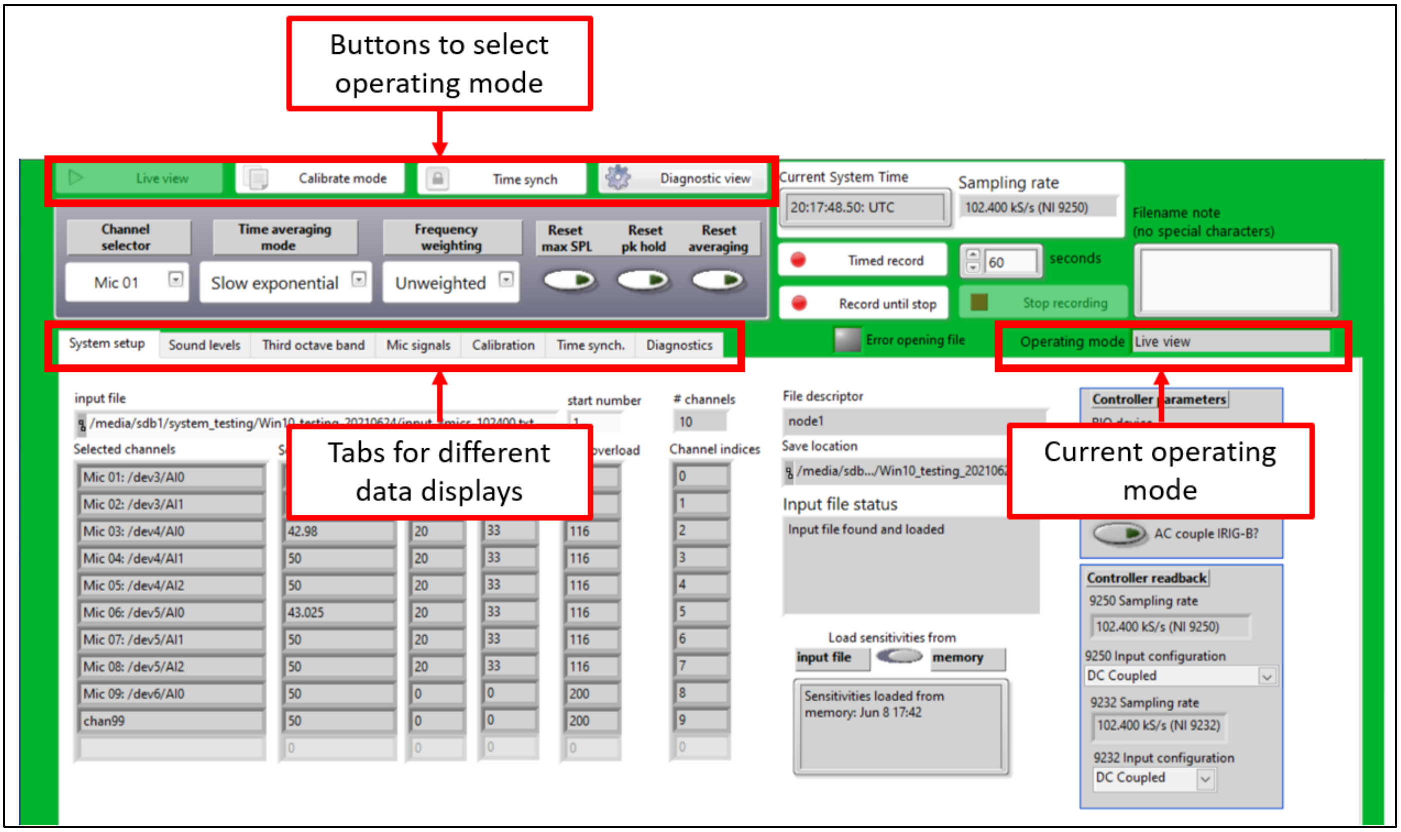


Figure 37 - VSLM basic controls

iii. In the VSLM front panel under sound levels tab (Figure 38) check that:

1. all channels are present and updating at 0.5-second intervals.

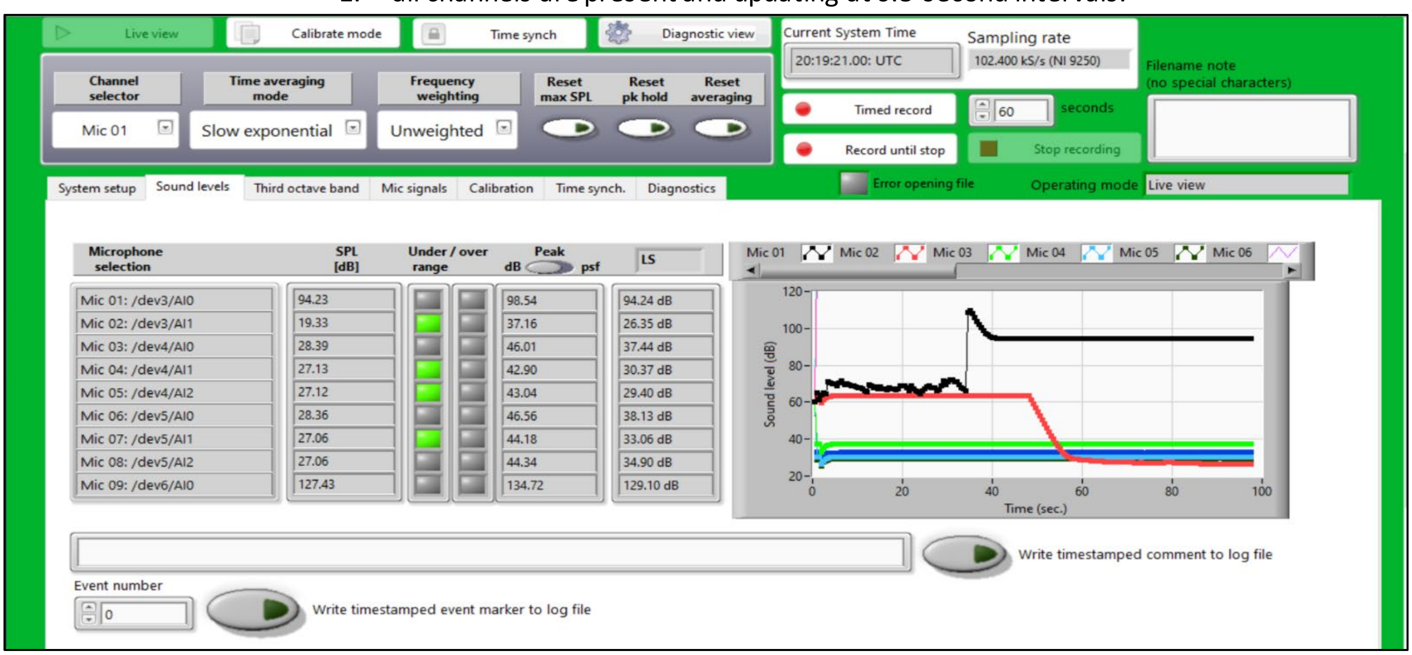


Figure 38 - VSLM Sound Levels tab

iv. Set recording time to 10 seconds, and press "Timed Record". Verify that:
   1. Operating mode indicator changes to "Time record" (Figure 39)

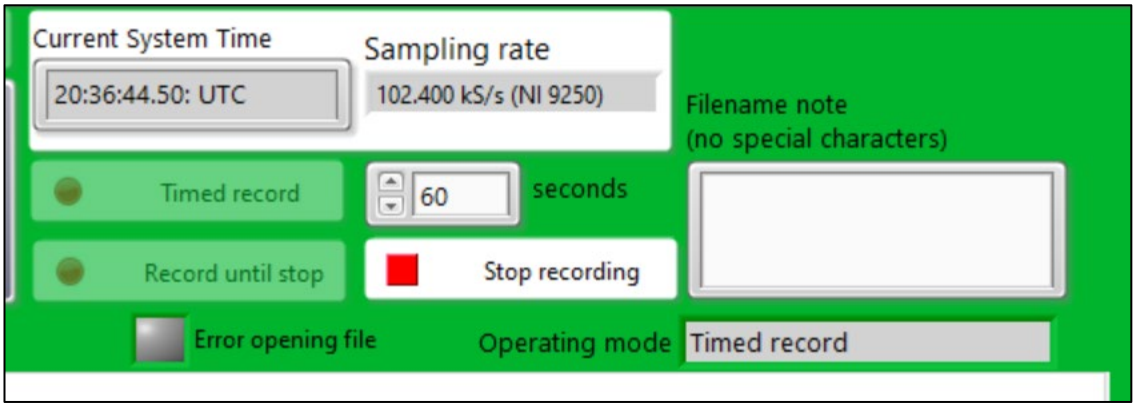


Figure 39 - VSLM in recording mode

   2. Files are recorded in the correct location (the location is shown on the Diagnostics tab)
   3. Files are of the correct number and size (7 binary files of around 4 MB each for 10 seconds at 102.4 kHz, 1 plain text file)

v. Select "Time synch" operating mode, and select "Time synch" tab. A GPS survey will take approximately 10-15 minutes, after which the UTC / GPS time displays will begin actively updating. Once that is true,
   1. Set selector switch to UTC.
   2. Press button to synchronize system time with selected source.
   3. Verify that time synch succeeded by reading the last entry in the time synch log on the right.
   4. Verify time with wristwatch pre-set to UTC (approximate match to check UTC vs GPS time).

vi. Press "Live View" mode and select sound levels tab.

vii. Before recording acoustic data for analysis, confirm that GPS-200A has received sufficient information from satellites. The GPS-200A front LED should be blinking once per second. Blinking twice per second indicates that GPS-200A lost satellite signals but is generating timecode signal in freewheeling mode.

viii. IRIG-B channels should report levels around 120 dB when a 50 mV/Pa sensitivity is applied[3]. A typical one-third octave band spectrum for an amplitude-modulated IRIG-B signal is shown in Figure 40; the 1 kHz carrier wave is evident.

[3] The concept of sensitivity as applied to an IRIG-B signal is not physically meaningful as the time code generator does not measure pressure. However, treating those signals in the same manner as acoustic data by calculating levels and spectra provides a convenient way to verify signal integrity.

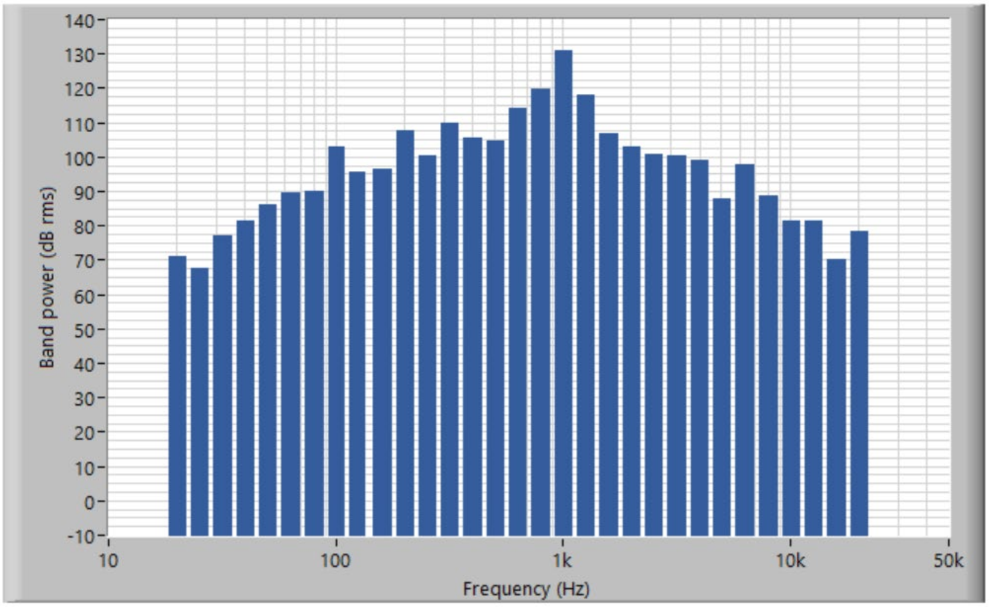


Figure 40 - IRIG-B one-third octave band spectrum

ix. The IRIG-B signal can also be visually inspected in the "Mic Signals" tab, after selecting diagnostic view operating mode and setting the channel selector to the IRIG-B channel. A typical IRIG-B signal is shown in Figure 41.

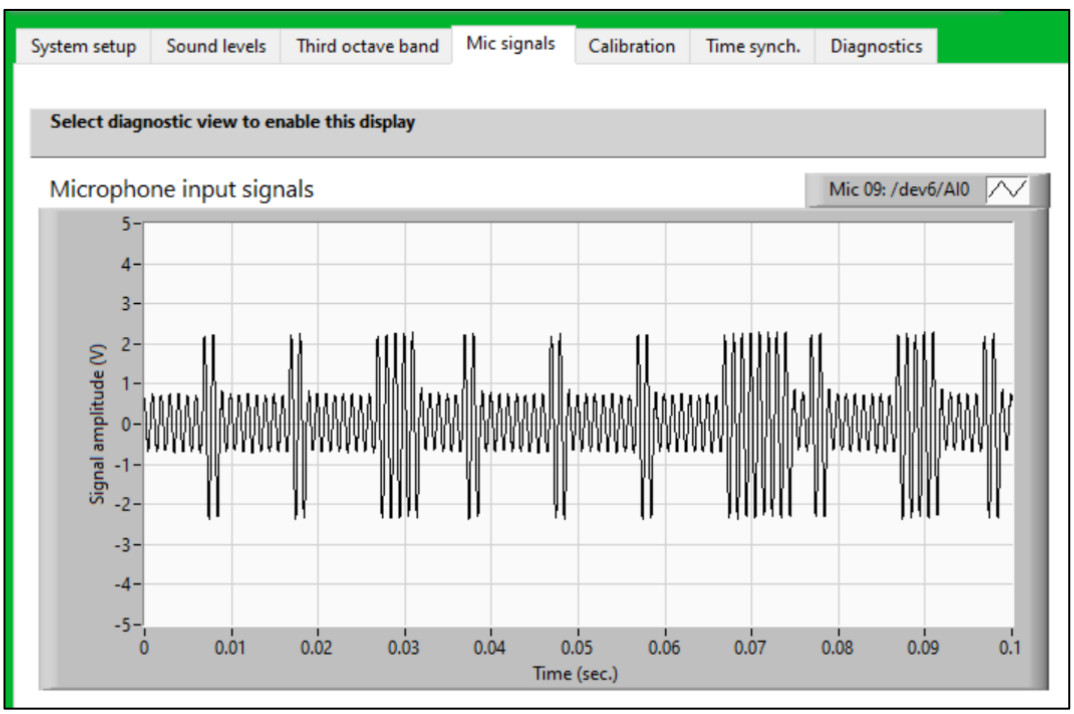


Figure 41 - IRIG-B signal

x. Repeat steps ii-xv for the second cRIO recording node.

5. Calibration

a. Virtual Sound Level Meter calibration(s)

i. Select “Calibrate mode”.

ii. Use “Channel Selector” to select mic to be calibrated and apply calibrator to microphone.

iii. Select the “Third octave band” tab (Figure 42) to verify that spectrum appears as expected with peak at correct frequency.

Figure 42 - VSLM one-third octave band tab

iv. Select the “Calibration” tab and enter calibration level from label (typically 94.1 dB or 114.1 dB) into LabVIEW calibration tab under “Nominal Calibration Signal (dB)”. When signal is steady as indicated by needle gauge / indicator light and “Measured sensitivity” value has stabilized, click “Replace value in memory” button to replace value in memory. After that, record the calibration signal by pressing the “Record Cal signal” button. Verify that the software goes into “Record 1ch” operating mode.

v. Repeat for additional microphones, making sure to change the microphone selected in the dropdown menu at the top left. Alternatively, conduct microphone simulator test using instructions from next section.

vi. When calibration is complete, click “write cal log to file” button to write calibration log, and then select live view operating mode.

b. Post-calibration

i. Verify that files were written and are of the appropriate size by checking the directory contents in the terminal window.

1. Calibration files will have names of the form:

[file descriptor]_[YYYYMMDD]_[HHMMSS]_cal_mic[NN]_102400Hz.bin

2. At 102.4 kHz, calibration files for each channel should be approximately 4 MB in size.

c. **Final ground mic setup**

   i. Slide narrow portion of spacer bar between ground plate and microphone until the microphone touches the top of the spacer bar. Tighten the plastic set screw to lock the mic/preamplifier into place.

   ii. Place microphone into top of hemispherical windscreen and position so that the diaphragm is ¾ distance from the center of the plate to the trailing edge of the plate.

6. Recording data and logging on cRIO nodes

a. Two recording modes are available: “Timed record” and “Record until stop”. These modes are initiated by pressing corresponding buttons in the upper right corner of the VSLM window. These recording modes are functionally equivalent except that “Timed Record” stops recording after a user-specified number of seconds.

b. To initiate recording, press “Record until stop” or enter the desired recording time and press “Timed record”. Verify that software goes into a recording operating mode and that “Error opening file” indicator did not change to red.

c. Recording from either mode can be stopped at any time by pressing the “Stop recording” button.

d. To electronically mark events, the user has two options:

   i. To write a text comment to the user log, type text in the box in the lower left part of the “Sound Levels” tab and press the “Write timestamped comment to log file” button (Figure 43).

   ii. To write an event number to the user log, press the “write timestamped event marker to log file” button in the lower left part of the “Sound Levels” tab. This also adds a marker to the diagnostics channel which can be correlated with acoustics channels during post processing.

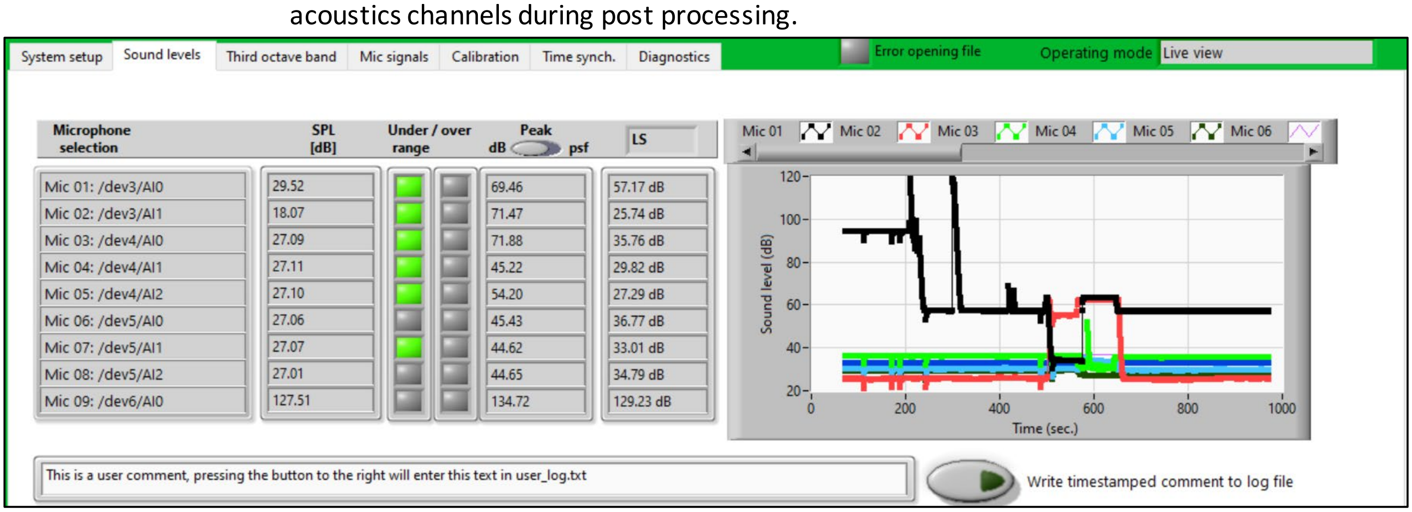


Figure 43 - Logging a comment in the VSLM Sound Levels tab

7. Audio sampling of data on cRIO nodes

a. The cRIO recording nodes do not output analog audio that can be listened to through headphones or speakers. To listen to recorded signals, a separate program is available called AudioSamplecRIO. That program can be started by clicking the  icon on the taskbar.

b. AudioSamplecRIO reads data from the last "Timed record" operation. To listen to channel audio, one must first record data using the "Timed record" mode.

c. After recording is complete and software is back in the "Live view" operating mode, specify in the AudioSamplecRIO window (Figure 44):
   i. channels to be converted to audio data,
   ii. desired output level of the audio file (select a value high enough that the signal is not clipped),
   iii. The sampling rate (102.4 kHz).

d. Run the AudioSamplecRIO program by clicking the arrow icon in the upper-left corner. The program may take a short amount of time to copy files from the recording node(s) to the laptop computer and convert files. It may be necessary to press the play button in the right side sub-window if sound does not begin playing through the field laptop following conversion.

e. Audio will play sequentially: if 10 seconds of data were recorded one will hear 10 seconds of audio from the first channel followed by 10 seconds of audio from the second channel, etc.

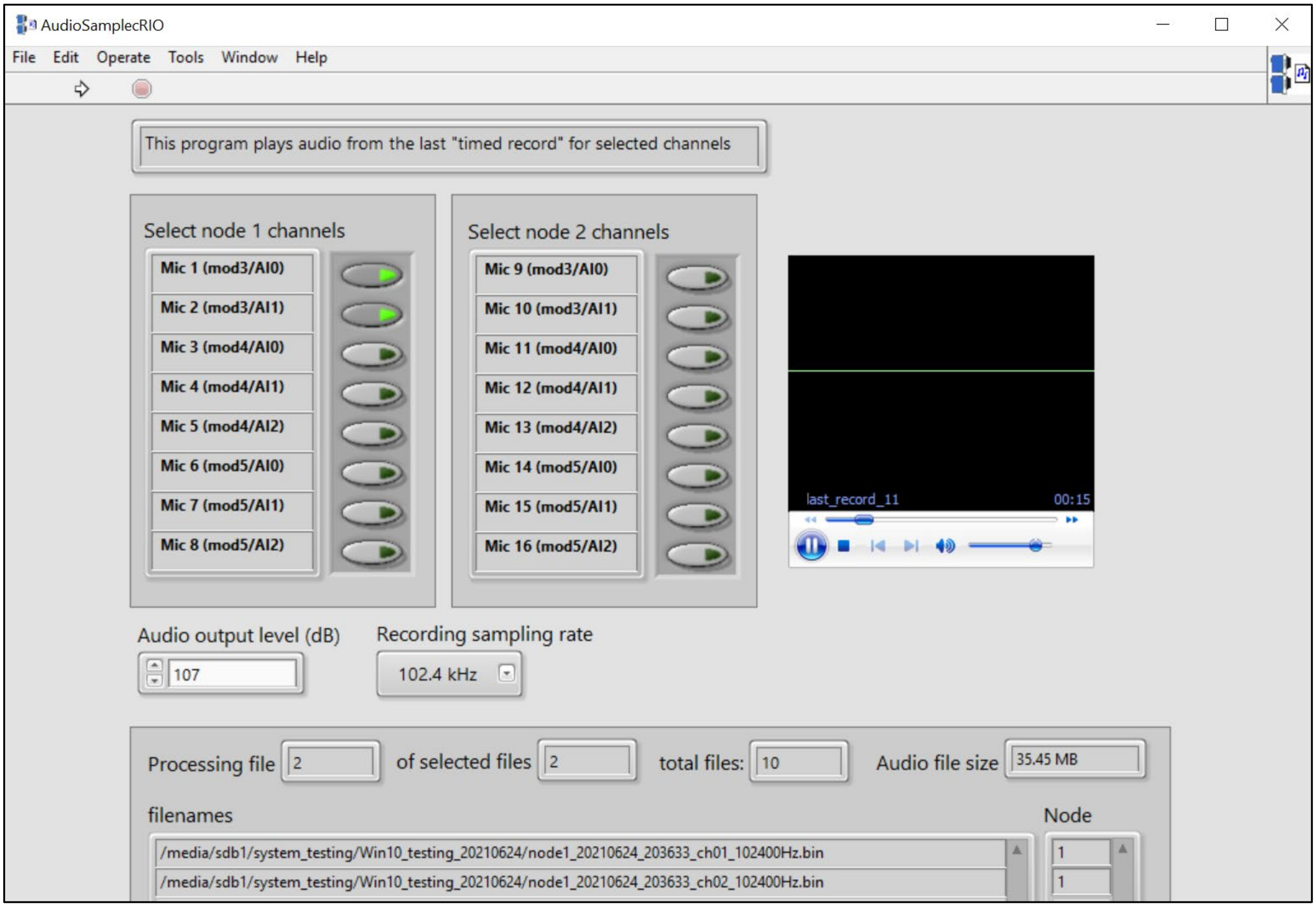


Figure 44 - AudioSamplecRIO window for listening to recorded acoustic data

8. Shutting down cRIO recording nodes

a. When one is finished using cRIO recording nodes they should be shut down. As a preliminary step, ensure that all programs have been stopped.
b. Power off the chassis by entering the following command in the terminal window(s) shutdown –h now
c. After a short time, the cRIO node LED in the upper left corner of the chassis will turn off. Note that if network hub is still powered on LEDs on the cRIO node ethernet port may stay illuminated, but LEDs on the storage drive and GPS module should also turn off.
d. When chassis is shut down, one can safely disconnect the power cable from the chassis.

Conversion of LabVIEW binary files to .wav format

e. Once files are copied to the field laptop (or any other Windows computer), the binary files created by LabVIEW can be converted to .wav file format using a program called bin2wav.exe.
f. Select the bin2wav icon  from the taskbar.
g. In the front panel, select a local .bin file to be converted to .wav format.

h. Use the dropdown menus to select desired wav file scale and nominal microphone sensitivity.

i. Run the program by pressing the button. If wav-file conversion settings are such that output was clipped, a red indicator will appear at the bottom of the window. This is not an indication that the signal was clipped during acquisition of data in the original binary file.

j. If .wav file signal was clipped, raise the output level and re-run the bin2wav program.

k. Notes:
    i. .wav files are not individually calibrated; selection of sensitivity and output level are a convenience to allow user to set the approximate level range
    ii. .wav files are not in broadcast wav file format; no starting time of day information is included in the .wav file metadata
    iii. VRTA.exe can read binary files from VSLM without conversion to .wav format.

Useful Information

Time synchronization indicator LEDs

- MasterClock GPS-200A
  - Solid green LED: power on, searching for satellites
  - Blinking green LED (once per second): satellites acquired, generating timecode signal
  - Blinking green LED (twice per second): satellite signals lost, generating timecode signal in freewheeling mode
- NI-9467 GPS module
  - Blinking amber LED: not enough or no satellites
  - Blinking green LED: searching for satellites and performing survey
  - Solid green LED: normal operation, timing information available
  - Solid yellow LED: antenna error

cRIO recording node:

- If unable to connect to cRIO recording node(s) in PuTTY, start NI-Max from start menu and expand "remote systems" in left pane. Check that node is connected and verify IP address. If IP address is different than expected, use address indicated in NI-Max.
- Some useful Linux commands:
  - df -h: Shows the amount of free disks space on cRIO node. This is useful for determining volume labels of storage drives
  - cd: change directory (examples: cd /media/sdb1, or cd .. to go up a directory)
  - mkdir: make a directory
  - ls –lh: list directory contents and file sizes
  - pwd: returns the working directory
  - tail –n 20 ./file.txt: shows the last twenty lines of "file.txt" (or however many lines you want to see). Useful if you want to look at the last few log entries without downloading the file
- To shut down cRIO, enter the following command in the terminal window shutdown –h now

VRTA:

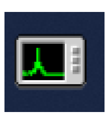
- The Volpe Real Time Analyzer (VRTA) program is installed on the field laptop. To start it, select the VRTA icon  on the taskbar.
- Basic instructions for VRTA can be found in the "about" tab.

Table 17 - Inventory of CARS System Components

Component	Model	Quantity
Recording node	NI cRIO-9037	2
2 analog input module	NI-9250	2
3 analog input module	NI-9232	6
SSD in c-series module housing	Arcale 500 GB	2
GPS time sync module	NI-9467	2
Time code generator	Master Clock GPS-200A	2
GPA antenna		4
Gain amplifier	B&K Nexus 2693	4
Microphone	GRAS 40 AO	16
Preamplifier	B&K 2671	16
Gigabit network switch	Ubiquiti	1
Field laptops	Dell Latitude 5424 Rugged	2
12V SLA battery	varies	10
Sound level calibrator	B&K 4231	2

9. Appendix B: Volpe START System

9.1 START User Guide

1. Overview

Survey and Tracking Apparatus for Research in Transportation (START) is a GNSS based vehicle tracking and surveying platform developed by Volpe. It is designed to support vehicle noise measurements by providing highly accurate positioning and timing information for the widest possible range of vehicles and use cases. In order to achieve this high level of adaptability, the platform is built around a core of small substitutable parts that may be optimized to accommodate the characteristics of the vehicle of interest.

The platform is comprised primarily of low cost consumer off-the-shelf (COTS) products that have been configured for the purpose of collecting and storing raw satellite observations suitable for post-processing. With a reference receiver at a "known" position on the ground (Base Station), and a second receiver, either at a position to be surveyed or mounted on a vehicle of interest (Rover), the two sets of satellite observations may be post-processed to produce highly accurate positioning and timing information. In most cases, the relative position accuracy of surveyed points and Rover data will be within a few centimeters. Such enhanced accuracy, beyond what is possible with a single point solution, is required for determining the time-space-position relationship between measurement microphones and the noise source.

The following guidance will identify the hardware components and provide step by step procedures for the setup and operation of all hardware and software. Additional information is provided in the appendices and includes: data integrity verification procedures, troubleshooting guidance, vehicle mounting solutions, receiver configuration settings, hardware dimensions/weights, and links to technical resources for more detailed information regarding system components.

2. Hardware

The following section provides system diagrams for the Rover and Base station setups (figures 1 and 2), followed by a complete list of parts which define the various configuration options that are available in the START platform. The numbered items represent the components required for a functional system configuration and the lettered items indicate the available options. Photos of select hardware components are also provided (Figure 45 and Figure 46).

2.1 Hardware diagrams

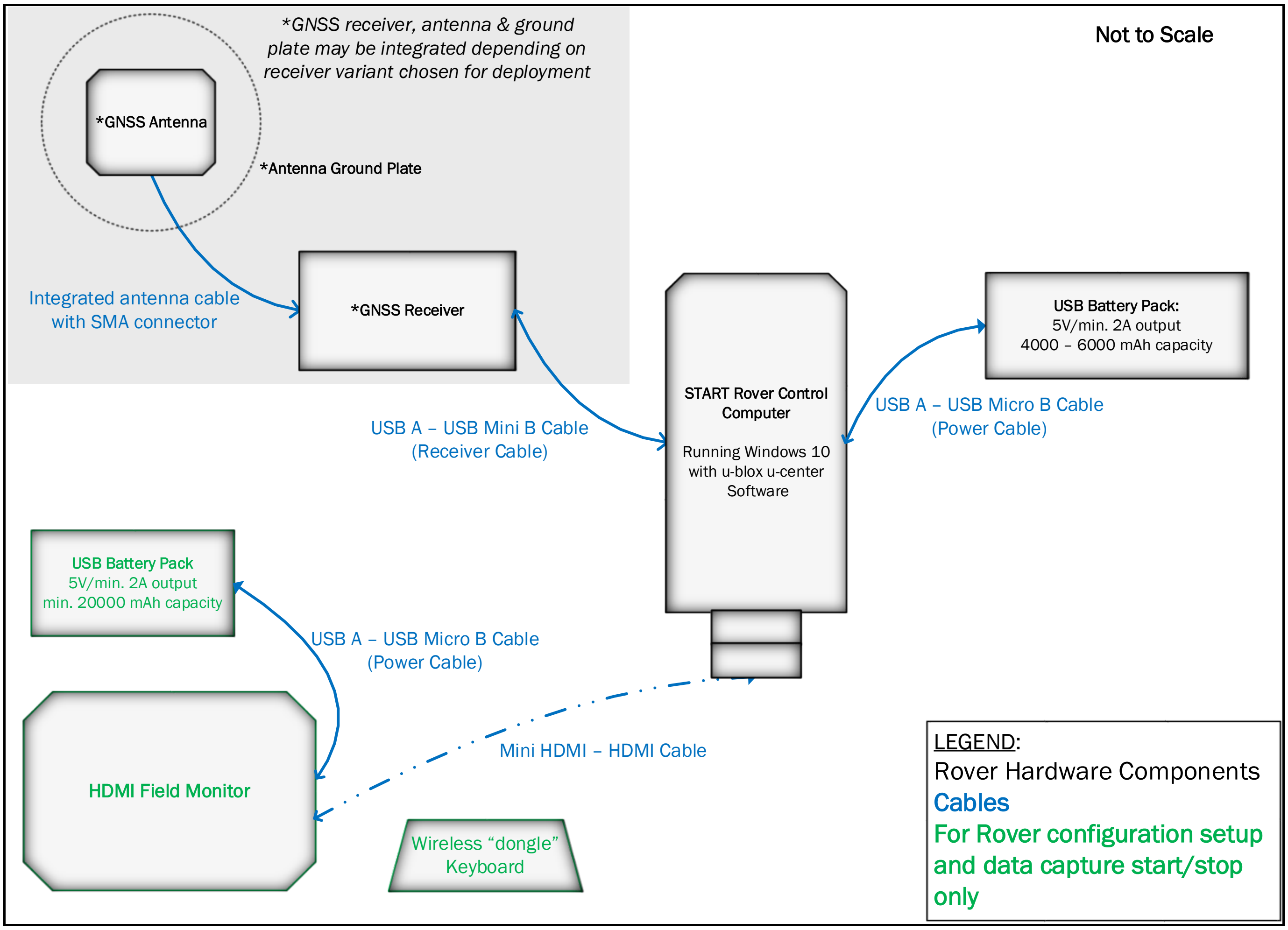


Figure 45 - START Rover setup

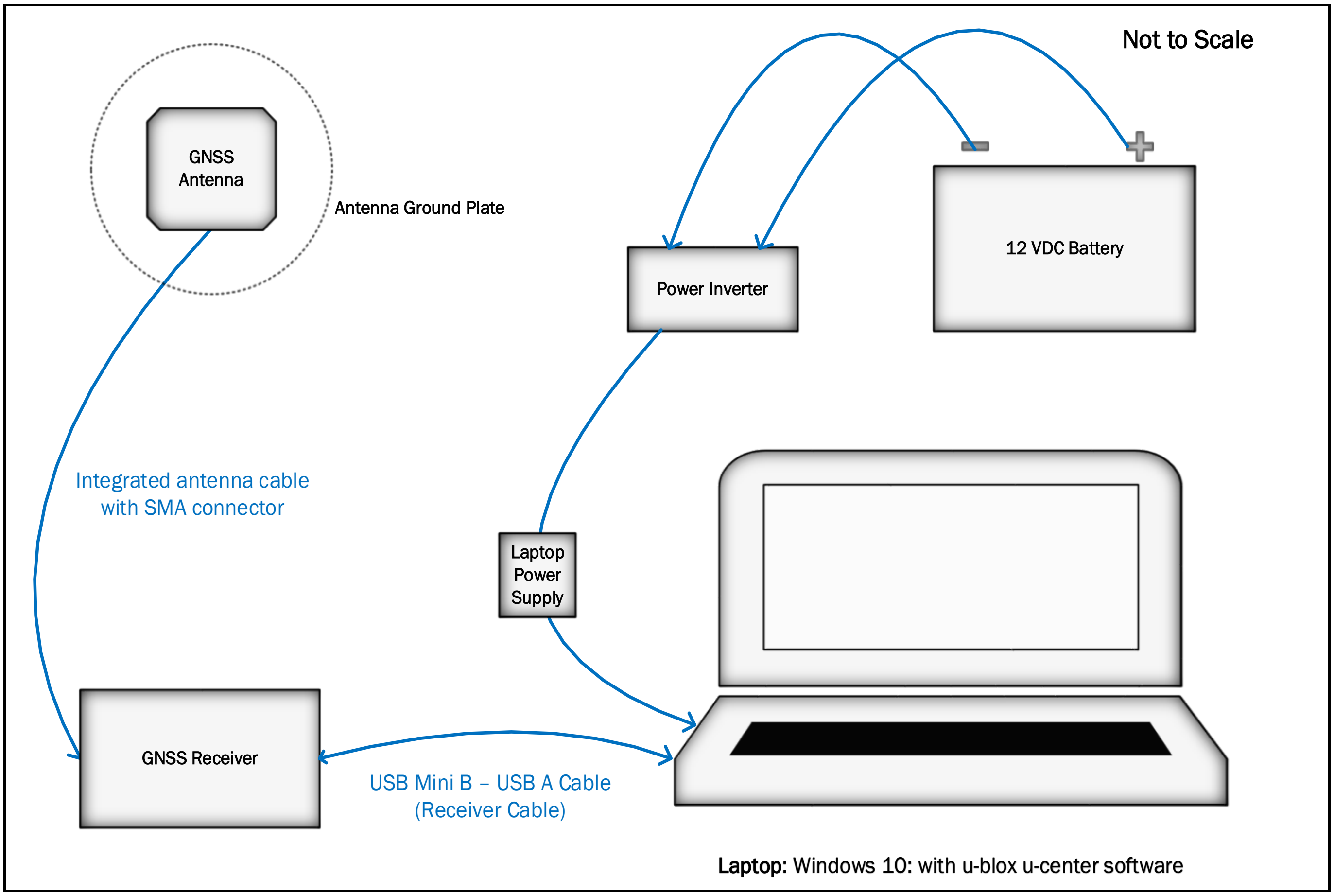


Figure 46 - START Base Station setup

2.2 START hardware with available options

The following list of components represents the hardware options that Volpe currently has available. It should be noted that multiples of each part are recommended based on anticipated needs for testing multiple vehicles within a day or having a sufficient number of spare components to substitute in the vent of equipment failures or damage occurring in-use.

2.2.1 ROVER

1. **START Rover Control Computer** - Windows 10 OS, running u-blox u-center v19.01 or later
   a. Intel Compute Stick - primary
   b. ACEPC W5 Pro mini - backup

2. **GNSS Receiver**
   a. u-blox NEO-M8T X-Series – recommended for most applications: integrates active antenna and ground plate

   b. u-blox NEO-M8T USB Dongle – ultra portable, can connect directly to computer or use USB ext. cable
   c. u-blox NEO-M8T Pro Version - integrates active antenna and ground plate. Heavier than X-Series

3. **GNSS Antenna** - required with GNSS Receiver option (b)
   a. Tallysman 4721 antenna – multi GNSS, active, patch antenna, excellent directivity
   b. Maxtenna M1516HCT - GPS/GLONASS, passive, helical design, good EMI resiliency

4. **Rover USB Battery Pack** – dependency between battery weight and capacity (run time) should be considered
   a. 4400 mAh, 5VDC/2A
   b. 5000 mAh, 5VDC/2A
   c. 6000 mAh, 5VDC/2A

5. **USB Power Cable** - available in lengths from 1' to 3', select shortest cable installation will accommodate
   a. USB A-to-USB micro B, shielded

6. **USB Receiver Cable -** available in lengths from 6" to 6', select shortest cable installation will accommodate
   a. USB A-to-USB mini B, shielded

7. **64 GB micro SD card** – data storage media used in START Rover Control Computer. Multiple micro SD cards should be on-hand in order to switch out cards for data quality checks and data backup
8. **Mounting Hardware** – 3D printed parts for securing integrated GNSS receivers to vehicle
9. **Wireless "dongle" keyboard/touchpad** – for interfacing with START Rover Control Computer
10. **HDMI Field Monitor** – for interfacing with Start Rover Control Computer
11. **HDMI-to-mini HDMI cable** – connects field monitor to START Rover Control Computer
12. **HDMI(f)-to-HDMI(f) coupler** – required to connect HDMI cable to START Rover Control Computer
13. **Field Monitor USB Battery Pack** – 24000 mAh: to power Field Monitor, use with USB A-to-USB micro B or USB-C cable (depending on Field Monitor)

2.2.2 BASE Station

14. **Laptop Computer -** Windows OS, loaded with u-blox u-center v19.01 or later

15. **GNSS Receiver**
    a. u-blox NEO-M8T USB Dongle – preferred, can connect directly to laptop computer or use USB ext. cable
    b. u-blox NEO-M8T X-Series - integrates active antenna and ground plate
    c. u-blox NEO-M8T Pro Version - integrates active antenna and ground plate

16. **GNSS Antenna** – for use with GNSS Receiver option (a)
    a. Tallysman 4721 antenna – multi GNSS, active, patch antenna, excellent directivity

17. **Antenna Ground Plate** – Steel, 77 mm x 79 mm x 2 mm – for use with Tallysman 4721 antenna
18. 20 – 22 amp-hour sealed lead acid battery
19. **Power inverter** - 400 Watt minimum

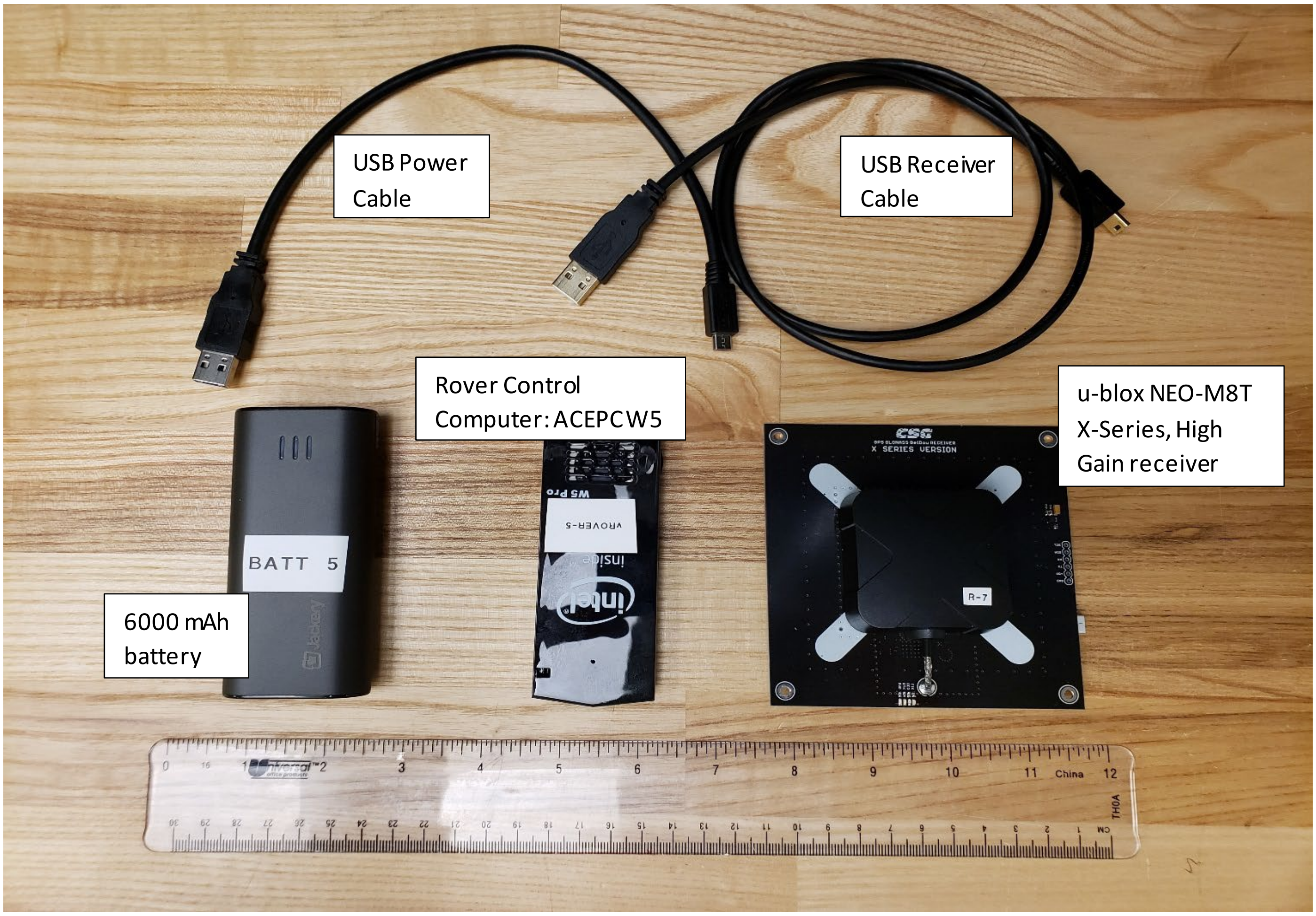


Figure 47 - START Rover hardware featuring integrated receiver/high gain antenna

Figure 48 - START Base Station configuration featuring M8T dongle receiver and Tallysman 4721 active antenna

3. Field procedures

3.1 Base Station deployment

The Base Station (Base) should be set up and initialized prior to the Rover. To achieve best performance, it is important that the Base be sited in an open area, free from large reflective surfaces. Allow the Base receiver to attain a 3D positioning solution and collect data for at least an hour prior to collecting Rover data. The Base should always be collecting data while the Rover is in use since concurrent data is required to process corrections. In the event that operating a local Base Station is impractical, an alternative ground reference station, such as a Continually Operating Reference Station (CORS) may be substituted during post-processing, however advance research is required to ensure suitable proximity to the test site. More information on the use of CORS is available in Volpe's "GNSS Data Processing Guidance". The following is a step-by-step setup procedure for the START Base Station.

1. **Connect Tallysman 4721 GNSS antenna to u-blox NEO-M8T USB dongle receiver** by rotating the SMA connector clock-wise onto the threaded coaxial connector at the receiver.

2. **Connect the u-blox receiver to the Base Station laptop** using a USB Mini B-to-USB A cable. The USB dongle version of the u-blox receiver may be plugged directly into the laptop USB port. Alternatively, the u-blox NEO-M8T X-Series integrated receiver, antenna and ground plate may be connected to the laptop USB port.
3. To ensure adequate runtime power, **connect a power inverter** (min. 400 Watts) to a 20 – 22 Ah, 12 volt sealed lead acid (SLA) battery. Next, plug in the laptop power supply at the inverter and insert power plug into the laptop power jack.
4. **Place the GNSS antenna on the ground plate** and mount on a tripod so that the plate is level and antenna is oriented to the sky. Position as far from other objects as the cables will comfortably allow.

   NOTE: Do not move this antenna once the Base Station antenna position has been established. If testing is occurring over the course of more than one day, it is critical to mark the position and accurately reestablish the Base antenna position and directional orientation each time the Base Station is setup.
5. **Turn on the laptop**. The laptop will supply power to the receiver and antenna via the USB connection.
6. Create a root-level data directory for the START Base Station file(s) to be written. **Name data folder using the following format: BASE_<test site name>_<date:mmddyyyy>**
7. **Set Com Port parameters in Windows**:
   a. From the Start menu, right click and select Device Manager.
      Note: Steps to access the Device Manager may vary slightly depending on the Windows OS.
   b. Scroll down the Device Manager to Ports (Com & LPT) and expand the menu. Depending on the driver, you will see the u-blox receiver listed as "u-blox GNSS Receiver", "USB Serial Device" or "u-blox virtual com port". Note the com port number assignment (Figure 49).
   c. Next, double click the receiver port assignment and select the Port Settings tab. Change the Bits per second setting to 115200, using the dropdown menu. Other settings should use defaults. Click OK and exit Device Manager.

8. **Open the u-center software** using the desktop shortcut.
   Note: for detailed information regarding u-center functionality, refer to u-center User's Guide which is located in the C:\Program Files(x86)\U-blox \u-center folder.
   a. Using u-center drop-down menus, go to Receiver > Connection. Select the com port that corresponds to the u-blox receiver (step 7b above).
   b. Next, go to Receiver > Baudrate and select 115200.
   c. Load the Base Station Configuration Settings: go to Tools > GNSS Configuration (Figure 51). Under Configuration file, use the Browse button to select "M8T_Integr_High+Dongle_Base_040221-10Hz" and press Open. Next, press File > GNSS button to load preconfigured settings to u-blox receiver.

NOTE: Although the receiver begins searching for satellites and converging on a positioning solution as soon as power is applied, a new solution must be attained each time a new settings configuration is loaded. This process can take up to several minutes. As satellites become visible, you will notice activity in the docking windows to the right.

d. The window in the upper-most right of u-center is the **Data View** and indicates current latitude/longitude, altitude (re: WGS84 ellipsoid) and Fix Mode, among other useful information. Desirable fixes include 3D or 3D/DGNSS, the latter of which indicates that WAAS satellites are being used in the solution. Other docking windows can be added (or removed) by clicking on their respective taskbar icon to display parameters of interest such as satellite level history and signal strength (Figure 52).
e. Next, **confirm critical device settings**. Go to View > Message View, then maximize the message window. At the left, there will be an expandable menu of parameters. Scroll down and expand the UBX section, then expand CFG (Config) sub-section which lists the receiver configuration parameters:
    i. Click NAV5 (Navigation 5). Under Navigation Modes, the Dynamic Model setting should be set according to the use case. Since the Base station is a fixed position, “Stationary” will be the appropriate setting (Figure 53).
    ii. Also in the NAV5 settings, under Navigation Input Filters, ensure that “Min SV Elevation” = 5 (degrees).
    iii. Go to RATE parameter and ensure that Time Source is set to UTC and Measurement Period = 100 ms.

NOTE: An expanded list of configuration settings with corresponding screenshots of the u-center interface can be referenced in Appendix D. Additionally, a detailed explanation of each setting can be found in the “u-blox8-M8_ReceiverDescrProtSpec (UBX-13003221)Public” interface manual (see Appendix F for link).

f. Next, expand the MON (Monitor) sub-section and check the following diagnostics:
    i. HW (Hardware Status): Jamming Status indicator should be green (OK) and CW Jamming Indicator value should generally be below 10%. If these parameters are not met, efforts should be made to mitigate the effects of EMI. Repositioning the Base Station antenna or using a USB extension cable when using the dongle receiver are recommended first steps.
    ii. TXBUF (TX Buffer): Pending Bytes column should be all zeros.
g. Expand the RXM (Receiver Manager) sub-section and check the following:
    i. Go to RAWX (Multi-GNSS Raw Measurement Data). Ensure stream of GNSS observations can be viewed. A new line of data should appear 10x/second.
    ii. Go to SFRBX (Subframe Data NG): Ensure data is updating every few seconds.
h. Once a 3D or 3D/GNSS Fix Mode (solution status) has been achieved and critical device settings (i.e. steps e, f, and g above) have been checked, begin data recording.

9. **To initiate data recording in u-center, press the record button (red circle) in “tape shuttle” control section located above the main data window.**

a. A "Save As" window will open with a default file name consisting of the com port number the receiver is connected to and the date and time corresponding to when the Record button was clicked.
b. Navigate to the Base Station data folder created in step 6 and **rename the default file name**, replacing the com port information with "Base_<site name>" and leaving the timestamp, e.g., Base_JBCC_220222_223540.
c. **Press Save**. When prompted to add receiver configuration to file, select **Yes**.
d. Base station data is now being stored is the form of GNSS observables (raw signal data from the available satellites). The Stop/Eject button, directly to the left of the Record button, should now appear black. This button will be gray and inactive when not in either Record or Playback mode.
e. The Base station must continue to collect data throughout the measurement period. It is recommended to occasionally monitor the u-center software to ensure that data is recording as expected and solution quality is sufficient as indicated by a 3D fix mode.
f. After measurement activities are complete for the day, click the **Stop/Eject** button (Figure 50) immediately to the left of the Record button. For large files, there may be a delay of a minute or more as u-center closes out and saves the data file**.** Once the Stop/Eject button turns gray and satellite data resumes streaming in the docking windows, **Exit** u-center.

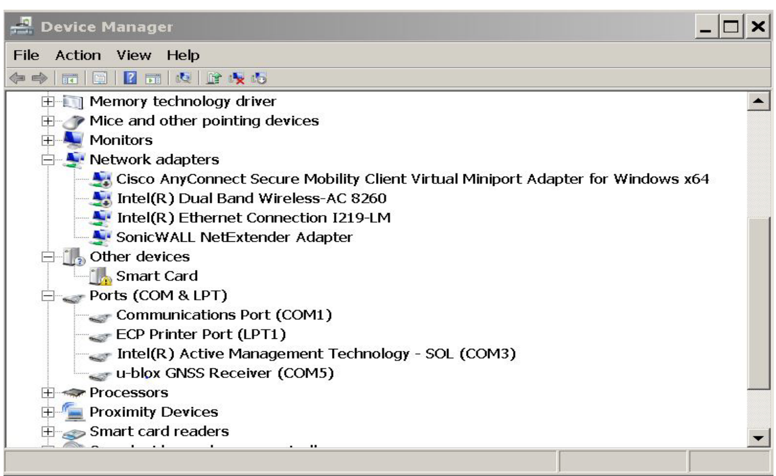


Figure 49 - Device Manager allows access to the u-blox GNSS receiver port settings

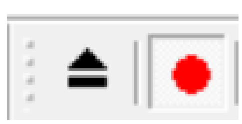


Figure 50 - Magnified view of Stop/Eject and Record buttons in u-center. The black Stop/Eject color indicates that data recording is active

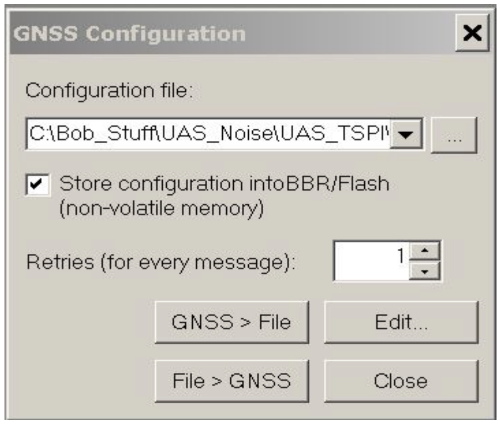


Figure 51 - GNSS Configuration tool can be used to load or save receiver configurations

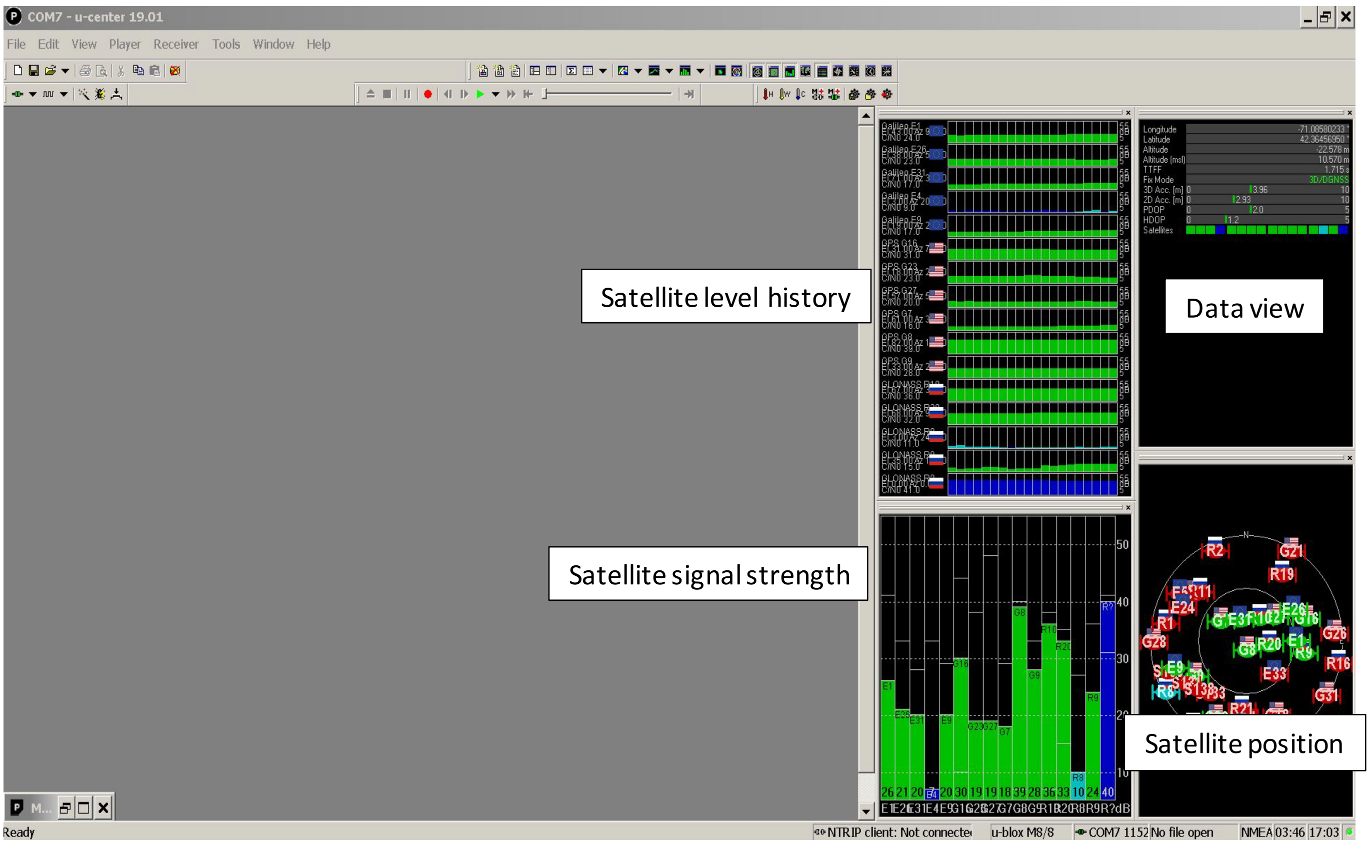


Figure 52 - u-center UI features configurable "docking windows" which display various parameters of interest

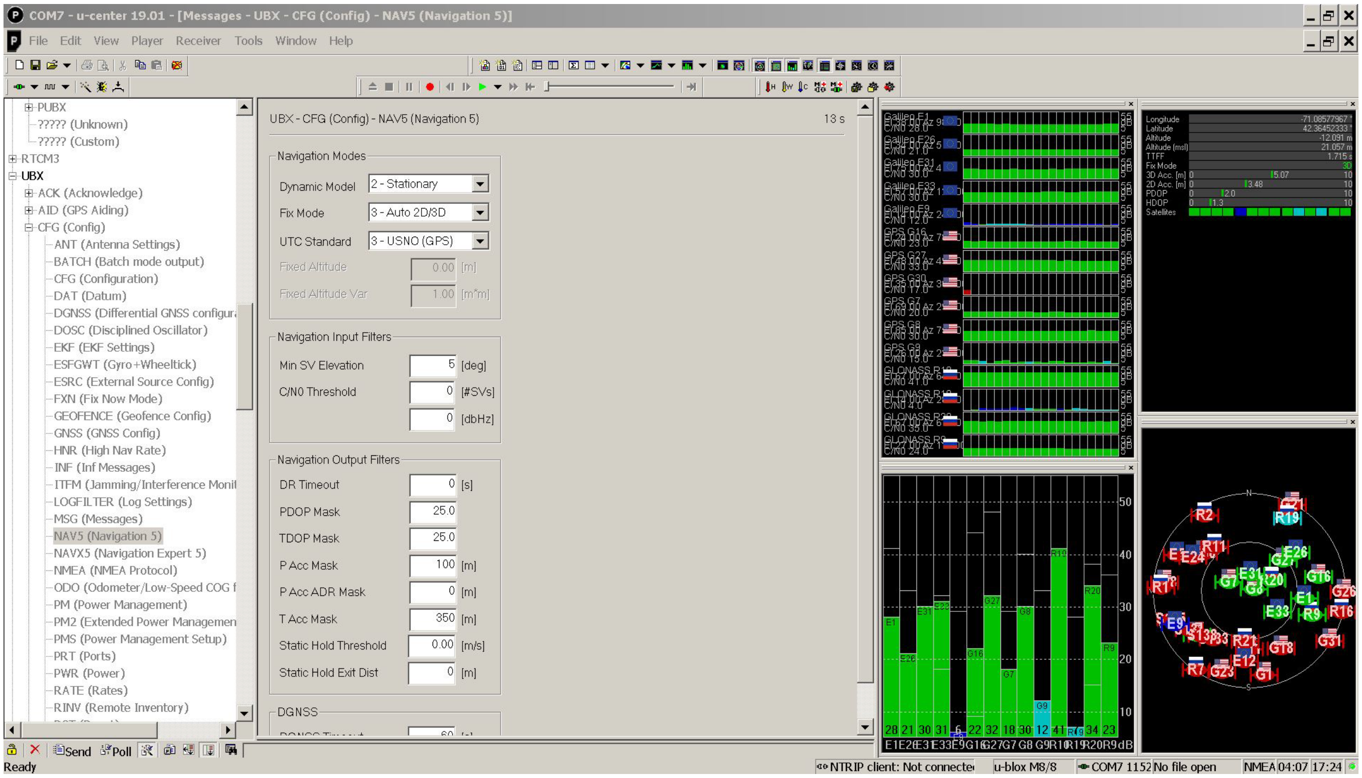


Figure 53 - Message View configuration menu (left) and NAV5 settings (center)

3.2 Rover deployment

As a best practice, it is advisable to test all START components prior to scheduled use. If multiple START systems will be required, core components (GNSS receiver/antenna, battery and START Control Computer) should be matched into complete START systems and tested to confirm functionality. The tested systems should be subsequently labeled so that the paired components can be easily identified for later Rover deployment.

An additional best practice is to keep a START log. A separate log should be kept for each deployment and, at a minimum, include test site, date, field operator, vehicle-under-test and/or survey being performed, components used in START deployment, data file name, and active times. For example, in the case of aircraft noise measurements, the takeoff and landing times within each data file are helpful for data processing. When performing position surveys, log the beginning and end time of data collection for each point surveyed. If START is to be deployed on vehicle, it is useful to measure and log the maximum levels of electromagnetic emissions taken at 1 foot (nominal) around the test vehicle. Such information will help inform the mounting position and could help explain potential data anomalies, if encountered. More information is available in Appendix II: Troubleshooting Guidance.

3.2.1 Vehicle mounting and considerations

If using the Rover for surveying static positions on the ground, e.g., microphone locations, then skip to section 3.2.2. If installing the Rover on a vehicle, then careful consideration must be given to the selection of components, cables and mounting aides when optimizing the hardware configuration. Access to test vehicles is highly recommended, in-advance of testing to, preferably, install START on all vehicles planned for next day's activities or alternatively, to evaluate options, plan mounting strategy and evaluate EMI, as each vehicle will present unique challenges which are best considered prior to test day. Either way, mounting START hardware is safety critical, mission critical and time consuming, hence there should be ample time scheduled for installations. Factors to consider include: vehicle size and weight, physical layout, payload capacity, aerodynamics, center of gravity and inertial properties (especially important in smaller vehicles), dedicated payload area or flat surfaces to be used as mounting points, ample clearance from rotors/engines and potential EMI sources, such as RF antennas. All mounting configurations should be tested with the vehicle powered so that potential EMI issues may be identified. Special care must be taken to ensure that, both, the host vehicle does not interfere with START GNSS reception and that START does not interfere with the operation of the host vehicle's avionics. For more information on troubleshooting EMI issues, refer to Appendix II.

Generally, the hardware components should be mounted first, with the GNSS antenna always positioned to maximize a clear view of the sky in both azimuth and elevation. Cable lengths should be no longer than required to link components, and safety concerns, such as blade clearance, should be assessed prior to the powering of system components. Cables should be secured in multiple locations with little to no slack. USB connections should be reinforced to prevent unintended dislodging or movement. All START hardware components should have a primary means of mounting and a secondary restraint or failsafe in the event a primary mount fails. For example, if the primary mounting technique relies on double-stick adhesive, then a secondary restraint may consist of cable ties fastened to tie-down points. Additionally, the placement and mounting of all START components must be approved by the vehicle pilot and Volpe START operator.

Since multiple test vehicles and START systems may be deployed for a given flight test, it is highly recommended to implement a "START readiness system" to ensure that each START system has been fully installed, secured, and that each test vehicle has been cleared for operation. A robust START readiness system should include multiple checks such as color-coded stickers to indicate "Ready/Not Ready" status for each test vehicle, as well as a radio call from the test director confirming readiness status. Appendix III contains additional recommendations for START Rover installation and illustrates examples of mounting aides and configurations.

3.2.2 Set up and initialization

The following steps apply whether START is mounted on a vehicle or being used to survey locations.

1. For most use cases, the u-blox NEO-M8T X-Series receiver, which integrates GNSS receiver, antenna and ground plate, is recommended. This option is generally preferred because it simplifies the setup, requires fewer cable connections, provides high signal gain and has flexible mounting hardware. For situations where the physical characteristics of the vehicle cannot accommodate an integrated receiver, a separate receiver, antenna and ground plate

may be used. If using separate components see steps (a) and (b) below. Otherwise, skip to step 2.

   a. Connect GNSS antenna to u-blox NEO-M8T receiver by rotating threaded coaxial connector to SMA jack on USB dongle receiver variant. The Tallysman 4721 is the preferred GNSS antenna, however the Maxtena antenna may be a better choice in space-constrained settings as it does not require a ground plane and may be oriented on or off axis.
   b. If using the Tallysman 4721 antenna, affix to largest diameter aluminum ground plate suitable for application.

2. Ensure that the GNSS antenna has clear line-of-site to open sky.
3. Connect the u-blox receiver to the START Rover Control Computer using a USB Mini B-to-USB A cable.
4. Connect START Rover Control Computer to fully charged USB Battery Pack using USB micro-B (Computer) to USB A (battery) cable. There are three START Rover battery capacities available: 4400, 5000 and 6000 mAh. In order to minimize down-time, it is generally advisable to use the highest capacity battery that the vehicle can safely carry without degrading its performance or reducing flight time to impractical durations. Appendix E contains a table with weights and dimensions of key system components, as well as weights for preferred configurations, as installed on vehicle.
5. **Power up system**:
   a. START Control Computer may automatically power up when battery is connected (step 4). If not;
   b. Press button on Rover battery pack (LEDs will illuminate).
   c. Then, power computer by holding side power button for 2 seconds, or until LED on the computer lights up. When booting up, it is typical for the START Control Computer LED to briefly illuminate then turn off for a few seconds before it reappears. Do not repeatedly press the power button.

6. **Set up the keyboard and monitor to interface with the Rover** (figure 10):
   a. Place the HDMI display on its stand and connect to the large, 24000 mAh, USB Battery Pack. Adhere the battery pack to the back of the monitor using the “Dual-Lock” faster strips.
   b. Connect the START Rover Control Computer to HDMI display using the fiber-optic HDMI-to-mini HDMI cable and female-to-female HDMI coupler.
   c. Plug in the wireless keyboard’s USB dongle to an open port of START Rover Control Computer. Turn on wireless keyboard/touchpad (front), then right-click to open Windows desktop environment.
   NOTE: if using multiple wireless keyboards to interface with multiple START systems, it recommended to color-code keyboards with their paired USB dongles.

7. **Adjust Windows time and date** and ensure that it is nominally synchronized (+/- 2 sec) to the designated "master clock":
    a. Place cursor over date/time field at lower right of display, right click, and select Adjust date/time.
    b. Check Time zone for appropriate setting.
    c. If enabled, turn off "Set time automatically".
    d. Next, click the Change button and use the popup to set the proper time, then close out of Settings.

8. Ensure that a microSD card with adequate storage capacity is loaded in the card slot.
9. **Create a root-level data directory on the C drive for the Rover files to be written.**
    a. A test site/date-specific directory should be created for each day of measurements.
    b. Within each daily directory, a folder should be created for every vehicle tested or survey performed. Name data folders using the following convention: ROVER_<vehicle name or survey point name>_<test site name>_<date:mmddyyyy>

10. **Set Com Port parameters in Windows**:
    a. From the Start menu, right click and select Device Manager.
    b. Scroll down the Device manager to Ports (Com & LPT) and expand the menu. Depending on the driver, you will see the u-blox receiver listed as "u-blox GNSS Receiver", "USB Serial Device" or "u-blox virtual com port". Note the com port number assignment.
    c. Next, double click the port assigned to the u-blox receiver and select the Port Settings tab. Change the Bits per second setting to 115200, using the dropdown menu. Other settings should use defaults. Click OK and exit Device Manager.

11. **Open u-center software** using the desktop shortcut:
    a. Using u-center drop-down menus go to Receiver > Connection. Select the com port that corresponds to the u-blox receiver listed in step 10b.
    b. Next, go to Receiver > Baudrate and select 115200.
    c. **Load the Rover Configuration Settings**: go to Tools > GNSS Configuration. Under Configuration file, use browse button to select "M8T_Integr_High+Dongle_Rover_040221-10Hz" and press Open. Next, press File > GNSS button to load preconfigured settings to u-blox receiver.

NOTE: Although the receiver begins searching for satellites and converging on a positioning solution as soon as power is applied, a new solution must be attained each time a new settings configuration is loaded. This process can take up to several minutes. As satellites become visible, you will note activity in the docking windows to the right.

    d. The docking window in the upper-most right of u-center is the Data View (figure 8) and indicates current latitude/longitude, altitude (re: WGS84 ellipsoid) and Fix Mode, among other useful information. Desirable fixes include 3D or 3D/DGNSS, the latter of which indicates that WAAS satellites are being used in the solution. Other docking windows can be added (or removed) to display parameters of interest such as satellite level history and signal strength.

e. Next, **confirm critical device settings**. Go to View > Message View, then maximize the message window. At the left, there will be an expandable menu of parameters. Scroll down and expand the UBX section, then expand CFG (Config) sub-section which lists the receiver configuration parameters:
   i. Click NAV5 (Navigation 5). *Under Navigation Modes, the Dynamic Model parameter should be set according to the Rover use case*. For most small UA, "Airborne < 1g" (acceleration) will be appropriate, however, this setting should be optimized for the specific end-use. For example, for very fast moving UA, "Airborne <2g" should be used. For surveying microphone positions, this setting should be changed to "Stationary".
   ii. Also in the NAV5 settings, under Navigation Input Filters, for any dynamic use case, ensure that "Min SV Elevation" = 0. For "stationary" applications, set to 5.
   iii. Go to RATE parameter and ensure that Time Source is set to UTC and Measurement Period = 100 ms.

NOTE: An expanded list of configuration settings with corresponding screenshots of the u-center interface can be referenced in Appendix D. Additionally, a detailed explanation of each setting can be found in the "u-blox8-M8_ReceiverDescrProtSpec (UBX-13003221)Public" interface manual (see Appendix F for link).

f. Next, expand the MON (Monitor) sub-section and check the following diagnostics:
   i. HW (Hardware Status): Jamming Status indicator should be green (OK), although yellow (warning) may also be acceptable. The CW Jamming Indicator value should generally be below 20%. If these parameters are not met, efforts should be made to mitigate the effects of EMI. Potential solutions include repositioning the Rover Control Computer to avoid EMI "hot spots", and/or applying shielding material. Appendix B: "Troubleshooting guidance", provides additional information as well as screenshots and tips regarding diagnostics and potential solutions to EMI induced issues.
   ii. TXBUF (TX Buffer): Pending Bytes column should be all zeros.

g. Expand the RXM (Receiver Manager) sub-section and check the following:
   i. Go to RAWX (Multi-GNSS Raw Measurement Data). Ensure stream of GNSS observations can be viewed. A new line of data should appear 10x/second.
   ii. Go to SFRBX (Subframe Data NG): Ensure data is updating every few seconds.

h. Once a 3D or 3D/GNSS Fix Mode (solution status) is achieved and critical device settings have been confirmed, perform a time check against the acoustic data collection system's reference time.

   i. To view START system time, use time display at lower right corner of u-center GUI and ensure that it
   matches the time of the acoustics system.
   ii. Record a "time hack" file by pressing Record button. When "Save as" window appears,

add prefix

"time_hack" to default file name and press Save. Select, Yes when prompted to load log file

and data capture will begin.

iii. Coordinate time check with acoustics operator. As the acoustics operator calls out the time, press the **Stop/Eject** button at the moment of the audible time mark. The last timestamp of the ""time Hack" file should match the time mark within a tolerance of 1 second.

i. Once synchronization between data collection systems has been confirmed, data recording can begin.

12. **To initiate data recording in u-center, press the record button (red circle) in "tape shuttle" control section located above the main data window.**
    a. A "Save As" window will open with a default file name consisting of the com port number the receiver is connected to and the date and time corresponding to when the Record button was clicked.
    b. Navigate to the Rover data directory created in step 9 and rename the default file name, replacing the com port information with "<vehicle name>_<sequential file #>" and leaving the timestamp, e.g., M210_1_220222_223540. Sequential file numbers should follow the vehicle name since there are typically several data files that will be recorded for each test vehicle.
    c. Press **Save**. When prompted to add receiver configuration to file, select **Yes**.
    d. Rover data is now being stored is the form of GNSS observables (raw signal data from the available satellites). When recording is in progress, the Stop/Eject button, directly to the left of the Record button, will appear black (figure 6). This button will appear gray and be inactive when not in either Record or Playback mode.
    e. It is recommended that the Rover collect data for at least 10 minutes prior to vehicle testing. When ready, disconnect the display monitor from the START Rover Control Computer and turn off the keyboard. To minimize handling and facilitate data card and/or battery swaps, the wireless keyboard dongle may be left in the Rover Control Computer. The Rover is now ready for use.

13. **Data integrity checks should be performed at moments of opportunity during and after a vehicle measurement**, e.g., vehicle battery changes or other down time during testing:
    a. Reconnect the HDMI display monitor to the Rover Control Computer and turn on the keyboard.
    b. Press the keypad to "wake up" the display monitor, then stop data recording by clicking the **Stop/Eject** button. There will be a delay as u-center closes the file. Wait for the Stop/Eject button to become inactive (gray).
    c. Eject the microSD card and replace it with a spare. If testing is still in progress, check the START Rover battery to confirm it has sufficient capacity, then initiate a new, sequentially

numbered, data file and begin recording. If the battery is running low, a shutdown will be required as the battery is not “hot swappable”.

d. Backup the START Rover data to a field laptop, then evaluate the data for completeness using the VerifyRINEX Software Utility, which should be installed on the field laptop. For step-by-step details on using VerifyRINEX, refer to Appendix A.

14. After measurement activities are complete for the day, click the **Stop/Eject** button immediately to the left of the Record button. For large files, there may be a delay of a minute or more as u-center closes and saves the data file**.** Once the Stop/Eject button becomes inactive (gray) and satellite data resumes streaming in the docking windows, **Exit** u-center.
15. START may be either extracted or left deployed on the test vehicle with consideration given to the test schedule and the number of available START components.

Figure 54 - Equipment used to interface with START Rover: configure and start/stop data collection

Appendix I: Verifying integrity of GNSS observations

To mitigate the potential for missing or incomplete START Rover GNSS data, it is recommended that the data contents be verified for completeness, both, during and after each vehicle is tested. Ideally, data verification should be performed during battery changes or refueling of test aircraft and after test events have been completed. The START Rover should not be extracted from the vehicle until data completeness has been verified. To accomplish this, VerifyRinex, a console application intended to quickly assess completeness and integrity of tracking system data has been developed by Volpe. The utility was written and tested for use with the RINEX v3.03 specification.

Following is a step by step procedure for GNSS data verification using VerifyRinex.

1. During testing "down time", remove micro SD card from START Rover Control Computer.
2. Insert card in designated field laptop (a USB card reader may be needed). Laptop should be preloaded with the RTKLIB suite of GNSS processing tools as well as VerifyRinex software (most recent revision available).
3. Convert proprietary u-blox ".ubx" data file of interest to standardized RINEX v3.03:
    a. Within the RTKLIB folder, **right click on "rtkconv.exe" and open as administrator**. For future ease of access, it is recommended to create a desktop shortcut.
    b. Select Rover data file as the input by clicking upper most directory button along right edge of user interface. Navigate to relevant data file and select. Directory location should be visible at top drop-down field, under "RTCM, RCV RAW or RINEX OBS" (Figure 55).
    c. Next, click directory button to the right of the "Output Directory" drop-down field and navigate to desired folder.
    d. Under "Format", to the right of the Output Directory field, use the drop-down menu to select "u-blox".
    e. Ensure checkbox under Output Directory (at far left of UI) is selected as well as top two checkboxes under RINEX OBS/NAV…
    f. Set options by clicking on "Options" button at center bottom of UI. Popup will appear.
    g. Set RINEX version to 3.03 using drop- down menu at top left (Figure 56).
    h. Ensure that "Scan Obs Types" is checked.
    i. Under Satellite Systems, check GPS, GLO, GAL and SBS.
    j. Check all boxes under Observation Types and ensure that L1 is checked under Frequencies. Click OK to close Options.
    k. Next, click the Convert button to generate RINEX v3.03 files to the output directory. The file with the ".obs" extension contains the GNSS observables and will be used with the VerifyRinex utility.
4. Copy the .obs RINEX file into the VerifyRinex folder, which contains the VerifyRinex executable, input configuration file (VRinput.txt), output file (VRoutput.txt) and logs of detailed timestamp information (timestamps.log & missing_timestamps.log).
5. Next, double-click the RINEX file, generated in step 3, to open. After the header information you will see timestamps with subsequent GNSS observables. To check the entire file, note the first and last timestamp. If a subset of data is being checked, such as events of interest from a field log, then enter those start/end times (UTC).
6. Open VRinput.txt and enter parameters for the data being verified. The input configuration file must be formatted according to Figure 57. The parameters include the name of the RINEX file (no spaces or special characters permitted), start/end dates and times of data to be verified, Rover data sampling rate (Hz), a minimum threshold number of satellites (recommend 8 -10) and a binary value to turn off/on the timestamp logs. See table A-1 for a summary of VRinput.txt fields and formatting. When complete, Save and close VRinput.txt.
7. Run the utility by double-clicking VerfifyRinex.exe. The utility parses the RINEX file while counting the number of timestamp records that fall within the user-specified window. Based on the sampling rate a certain number of records will be expected. The number of located records and the expected number of records are displayed on the screen and written to VRoutput.txt. Additionally, the number of satellite observations in each record is compared against the

minimum threshold value and the percentage of records in which the number of satellites meets the threshold is also reported. Optionally, both a list of timestamps and satellite counts for all records within the user-specified interval is written to the "timestamps.log" and a listing of all missing timestamp records (> 1 sec), including duration of gap and start and end points, is provided in the "missing_timestamps.log".

8. It is generally expected to have near 100% of anticipated records and at least 5 satellites per record. Data gaps, if any, should be no more than a few seconds. The timing of missing data points is the critical factor though. Special attention should be paid to times when the Rover was engaged in flight test events. Based on the completeness of data, a decision may be made to collect additional data.

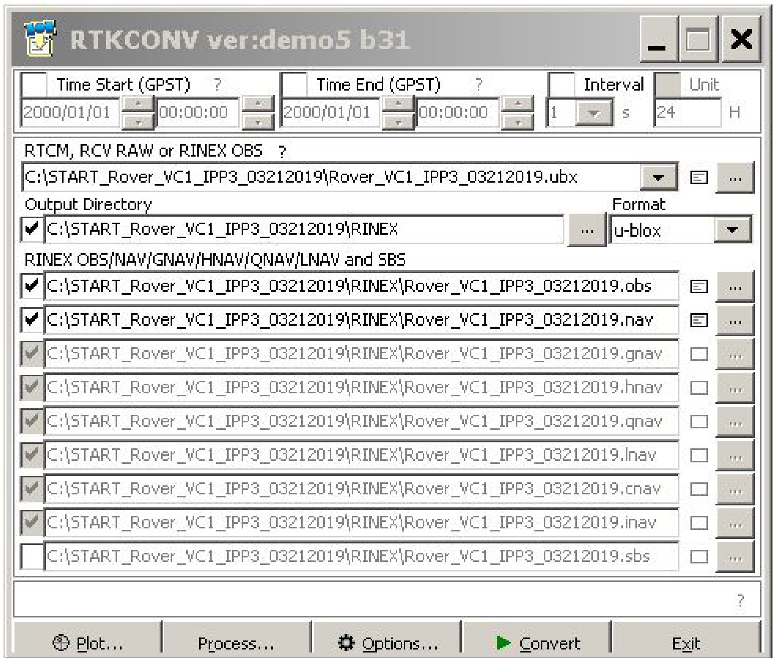


Figure 55 - RTKConv converts the u-blox GNSS data format to RINEX

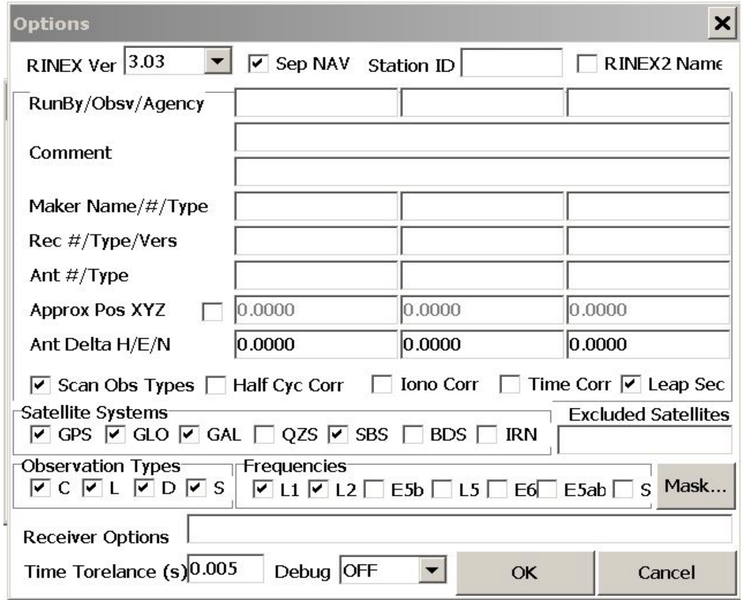
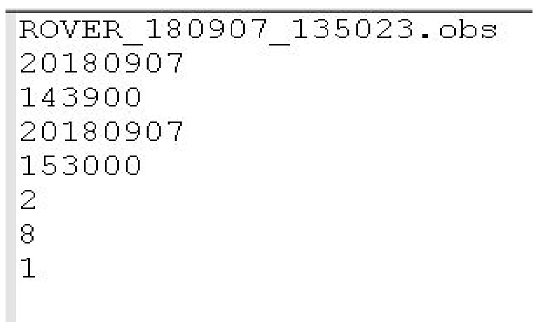


Figure 56 - RTKConv Options settings



```
ROVER_180907_135023.obs
20180907
143900
20180907
153000
2
8
1
```

Figure 57 - Required input parameters for VRinput.txt

Table 18 - Required format and contents of VRinput.txt

Line number	Input field	Format / units
1	RINEX file name	filename.obs
2	Start date	YYYYMMDD
3	Start time	HHMMSS
4	End date	YYYYMMDD
5	End time	HHMMSS
6	Sampling rate	Hz
7	Threshold number of satellites	Integer
8	Optional flag for timestamp output	1 (to write timestamp file) or blank

Appendix II: Troubleshooting guidance

The following section presents potential problems that could be encountered while using START. It is based on user experience and is by no means a comprehensive listing of every issue that could occur. For each issue presented below, guidance is given to solve or work around the obstacle at hand.

1. START Rover data dropouts are observed in, either, u-center's Satellite Level History display or discovered via the VerifyRinex data integrity check.

   Regardless of how the dropouts are discovered, it is likely that the dropout are being caused by electromagnetic interference (EMI) from the host aircraft. There are two general types of EMI to be concerned with, broad band and narrow band. This is important because they tend to have different sources within the aircraft and since the u-blox receiver monitors both, this feedback can be used to diagnose and remedy the issue. The goal is to mitigate interference levels to tolerable levels as it is generally not possible to completely eliminate it.
   The following procedures are recommended to mitigate EMI to levels that do not compromise data integrity:

   a. If not already running, **open u-center software** using the desktop shortcut.

   b. Go to View > Message View, then maximize the message window. At the left, there will be an expandable menu of parameters. Scroll down and expand the UBX section. Next, expand the MON (Monitor) sub-section and check the following diagnostics:

   c. HW (Hardware Status) (Figure 58): Jamming Status indicator should be green (OK), although yellow (warning) may also be acceptable. The CW Jamming Indicator value should generally be below 20% when the START Rover is onboard a powered aircraft. If these parameters are not met, efforts should be made to mitigate the effects of EMI. Potential solutions include repositioning or reorienting the START Rover Control Computer or the receiver, inserting an in-line noise filter between the Rover battery and START Rover Control Computer and applying shielding material.

   d. An iterative process using, both, an EMI detector (Figure 59) and the u-center HW jamming indicators in conjunction with mitigating efforts will be required to find the right solution or combination of solutions. To help accomplish this, a better understanding of key Hardware Status (HW) parameters is useful:

      (1) The Jamming Status indicator accounts for total radio frequency interference (RFI). This means that both broad and narrow band spectra are monitored. However, the indication is relative to the last time the receiver attained a valid solution with an "OK" jamming status. A default threshold of

3 dBHz is used. If the state changes from OK (green) to Warning (yellow), this means that >3 dBHz RF “noise” has been detected relative to the last time the receiver had a valid solution with an “OK” jamming status. A Warning (yellow) jamming status is not necessarily a problem though. This information must be considered along with the CW Jamming Indicator as well as satellite signal levels, as represented by the carrier-to-noise density ratio(s) (C/N_0)). A Jamming Status of Critical (red) is always a problem, however, and typically means that interference is preventing a valid fix from occurring.

(2) The CW (constant wave) Jamming Indicator monitors narrow-band EMI. A desirable value is generally under 15%, although this is not an absolute rule and can vary depending on local environment. In all cases though, the lowest value attainable is desired. Strong sources of CW interference are typically driven by telemetry occurring between the aircraft and controller. Most aircraft will have multiple antennae and more than one frequency used for communicating different types of data, e.g., control information versus video feed.

(3) Carrier-to-noise density ratio (C/N_0) is a measure of signal power expressed in decibel-Hertz (dBHz) and refers to the ratio of the carrier power and the noise power per unit bandwidth. C/N_0 values are available for every satellite received and can be viewed either in numerical or graphic form. The easiest way to monitor C/N_0 levels are via the Satellite-Levels docking window as indicated by the vertical bars at the lower right of Figure 58. Using the Satellite-Levels History window (window showing flags of origin for satellites), you can click on the horizontal signal level history bar to see a readout of satellite C/N_0 as well as its position. Generally speaking, 30 dBHz is an acceptable value. In optimal conditions, and depending on the receiver/antenna combination, there should be at least 5 satellites over this threshold. Low C/N_0 levels in open, outdoor conditions, are likely caused by EMI jamming.

e. An EMI Detector is recommended to identify the sources of EMI and where the electro-magnetic field is most intense. This information is useful in determining alternative mounting positions and orientations for START components.

Below are a few example scenarios to explain and explore mitigation options.

Scenario 1: Jamming Status = Warning, CW Jamming Indicator = 50%

In this case, the constant wave (narrowband) interference is considerably higher than normal and the jamming status of "warning" is likely being driven by the CW levels. The primary RF noise source is probably propagating from the various aircraft antennae which are often concealed in spaces like the landing gear or wings. An EMI detector should be used to locate the strongest source(s). Once sources are confirmed, it is recommended to reorient or reposition START Rover components away from the source. An iterative approach using the jamming indicators will be needed. The START Rover battery is the most susceptible component in terms of introducing stray RFI into the system, hence this is a practical starting point. The GNSS receiver/antenna may also receive stray RF. Repositioning can be effective laterally or vertically. Sometimes, simply rotating a component so that the USB connection faces another direction can be useful. The in-line noise filter may also be tried in conjunction with this approach. It has been seen to reduce some CW interference by as much as 50%. The RF resistant "Faraday Pouch" can also be a useful form of shielding, especially where there is not enough space to adequately separate START components from the EMI source.

Scenario 2: Jamming Status = Warning, CW Jamming Indicator = 20%

This is a borderline situation where, although there is considerable CW interference, repositioning components may not be necessary. It is not clear if the Jamming Status Warning is being caused by narrowband or broadband EMI. It may be a combination of both. Check the C/N_0 levels. If there are at least 6 or 7 satellites over 30 dBHz then the GNSS signal strength should be sufficiently high to enable robust data collection. If multiple signals are over 40 dBHz or higher, then confidence levels are even higher. It is, however, recommended to insert the in-line USB noise filter between the Rover battery and the Start Rover Control Computer. Recheck jamming indicators, as well as C/N_0 levels for indications of improvement.

Scenario 3: Jamming Status = Critical, CW Jamming Indicator = 40%

This scenario is interesting because data collection is failing but the CW Jamming, although considerable, is likely not high enough to cause a critical state on its own. The failure is probably being driven by broadband EMI. This makes it harder to pinpoint the source, however, using the EMI detector will help identify "hot spots". Typically, poor shielding on aircraft components, such as the motherboard, can emit a strong broad-spectrum EMI field. It is also possible for the START Control Computer to contribute to broad-spectrum EMI. For this reason it is always recommended to provide as much separation between the START Control Computer, battery, and receiver as the installation will allow. Iterative repositioning of components will be necessary and is generally the first line of defense to reduce EMI. Reposition components away from "hot spots" and check indicators and C/N_0 levels for improvement. If the Jamming Status is not improved and the CW Jamming indication reduced to at least 20%, then, raise the antenna/receiver assembly by stacking an additional mounting apparatus underneath. EMI typically propagates in a non-uniform manner so sometimes vertical repositioning may be more effective than lateral repositioning. Experimenting with START component placement and orientation should eliminate this type of issue, however consideration must be paid to proper load balancing.

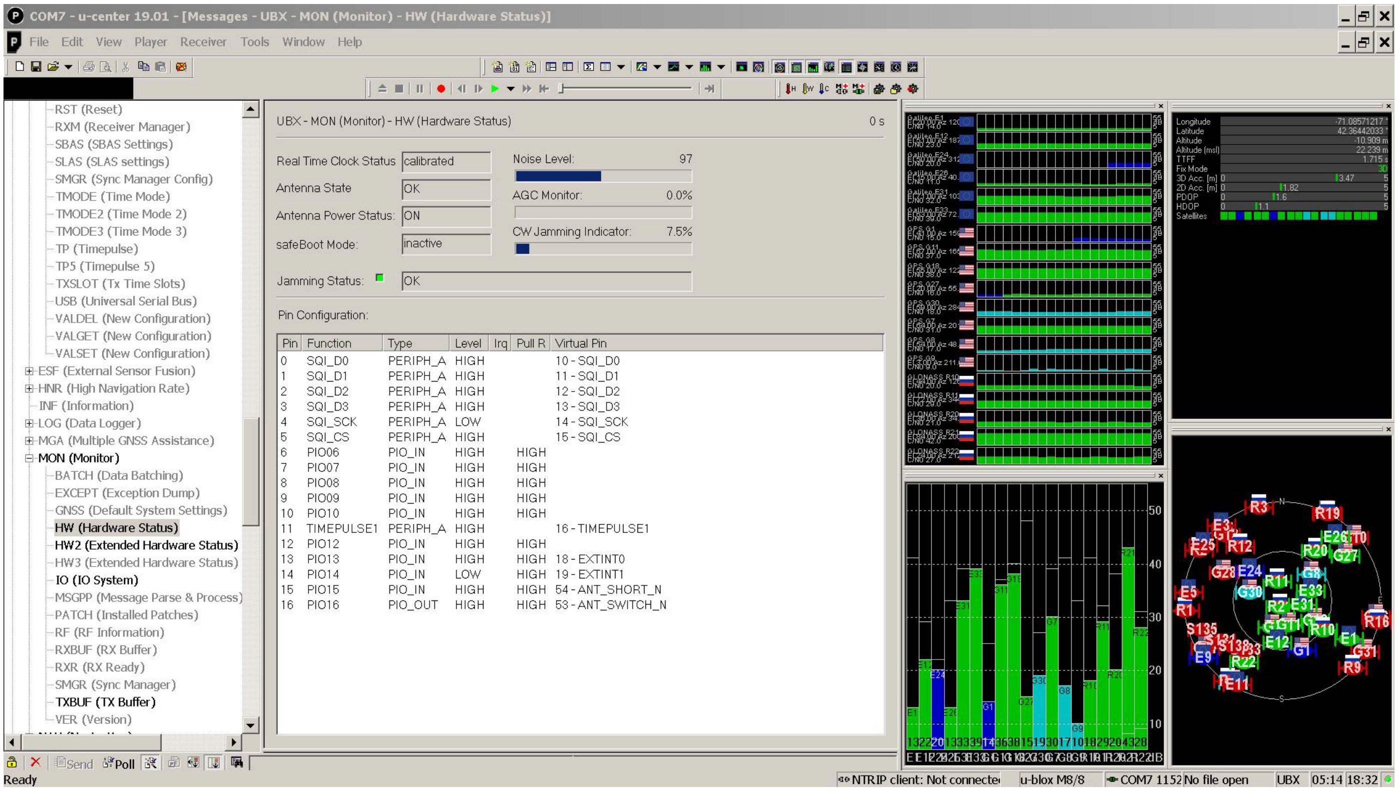


Figure 58 - u-center Hardware Status provides useful feedback for monitoring EMI

Figure 59 - EMI Detectors are helpful for identifying electro-magnetic "hotspots" during START Rover installations

2. START (either Base or Rover) has been properly setup, powered on, and configured but **no satellites are being received after several minutes of searching**.

   Ensure that GNSS antenna has a clear view of the sky. Within **u-center**, go to Receiver menu and select Debug Messages. This action will send debug messages to the receiver and activity should be seen in the docking windows within a few minutes.

3. **Forgot to initiate data recording.** While powered on and after attaining a solution, the u-blox receiver continuously collects data to a SQLite database on an internal 4MB flash memory. In the event that the recording of the data log was not initiated, it is still possible to recover the last, approximately, 5 minutes of data (limitation based on configuration settings and 4MB flash size). To recover, go to File > Save. A "Save As" pop up will appear. Rename the file according to protocol and choose appropriate directory, then press Save. Data from the last 5 minutes will be captured and new data will continue to record until the file is stopped or Ejected.

4. **Loading of START Configuration file fails.** This is a rarely seen issue. This is a u-blox bug and is best remedied by switching out the Start Rover Control Computer.

5. **Host vehicle is experiencing EMI related issues, e.g., lack of GPS reception.**
   This interference is likely caused by EMI produced by the START system. First, disconnect the HDMI connection from the START Rover Control Computer to the display monitor and reevaluate the problem. The computer is the largest EMI emitter in the START system and its emissions are highest when driving the HDMI output. If the problem persists, then iteratively reposition the START components and solicit feedback from the vehicle operator until the issue is mitigated. Shielding material, such as "Faraday fabric" may be used to isolate the highest emitting components if repositioning alone is not effective.

Appendix III: Vehicle mounting solutions

The different configurations of the START Rover system allow for a wide variety of mounting solutions. There are, however, a few questions that should be asked to determine the optimal mounting solution.

- What to mount? Optimize START Rover hardware configuration based on vehicle characteristics, (e.g., EMI sources, size and weight constraints)
- Where to mount? Where will the START Rover components fit and are there features that can be used to secure components?
- How to mount? Choose the best aides to safely secure the system to the vehicle

There are a number of supplies and tools available. What works best will vary from vehicle to vehicle.

What to Mount

The current preferred component set uses the u-blox NEO-M8T High Gain integrated receiver and antenna, with the 4400 mAH Rover battery. This configuration provides the best performance with a relatively low system weight. If vehicle characteristics require scaling down size and weight, use shorter/lighter cables and minimize mounting hardware, if viable. If dimensions are an issue, switch to the u-blox NEO-M8T "Dongle" receiver and Tallysman 4721 antenna. This option has more flexibility to allow components to be placed in tighter spaces.

Where to Mount

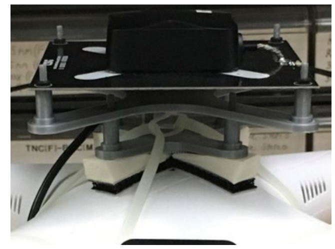
There are multiple goals in positioning the components on the aircraft. Key factors are:

- placing the antenna to allow a clear view of the sky in both azimuth and elevation
- finding locations on the vehicle that are flat and smooth (if available) and clear of propellers and other moving or functional features
- balancing the weight of the system on the vehicle as to not impact flight performance, e.g., aerodynamics, c.g. and inertial properties (especially important in smaller vehicles). Placing parts close to the center of the vehicle helps with balance, as does placing the heaviest components opposite of each other or opposite from heavy points on the aircraft (counter-balance).
- placing receiver/antenna away from known EMI sources, including the START Rover Control Computer, which should always be separated from other START components by as much distance as the vehicle will allow. Separating the computer and battery by mounting to opposing landing gear is often a viable way to achieve balance and control EMI.
- keeping components protected from environmental extremes is also an important consideration. In warm weather, measures should be taken to keep Rover Control Computer out of direct sunlight and away from heat generating sources. Consider mounting to the underside of vehicle if a suitable mounting point can be located.

How to Mount

Mounting must be temporary and should not mar or damage the vehicle, however, must also be secure with no chance of components coming loose during the test. Use materials that will accomplish this with the least amount of added weight and impact on the vehicle. Table 19 illustrates useful mounting aides and materials.

Table 19 - Vehicle mounting aides for the START Rover

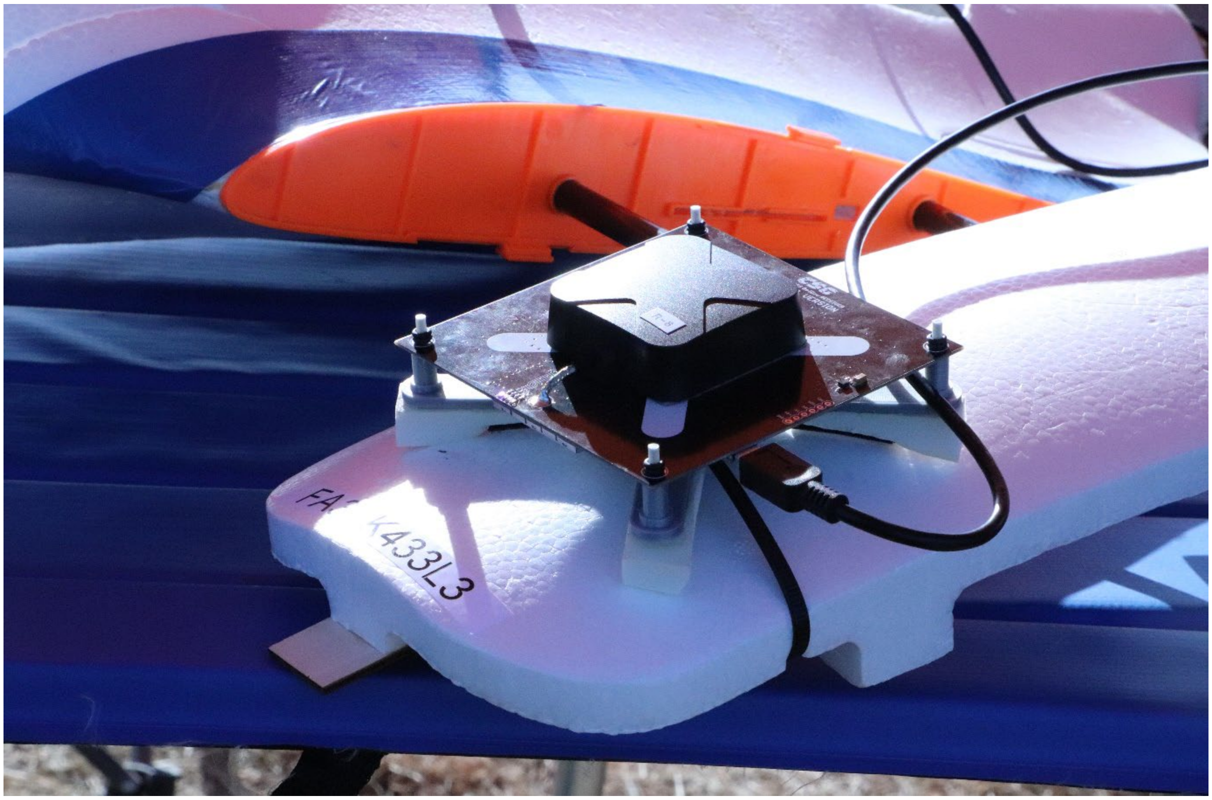
u-blox 45mm, 60mm and 90mm mounts – These 3D printed mounts are made at the Volpe Center for the u-blox hardware. They are stackable to provide flexibility to move the receiver away from the aircraft propellers and possible EMI sources.	 
"Dual Lock" fastener – This material is similar to Velcro and provides a strong grip with less play than fabric Velcro. It is available in regular and low profile.	 
Cable "zip" ties – Strong, versatile connections, but require a place of attachment. Smaller ties are important for managing cables.	 
Foam – High-density foam is important for filling gaps between curved and flat surfaces.	 

Important checks!

1. Keep clear of the props! Make sure all hardware, cables and mounting materials are clear of the propellers throughout their full range of motion.

2. Make sure you can access important buttons, connections, ports and card slots. This can be as simple as confirming the component is facing the right way.

Example START Rover Installations:


K433L3


ANT-6

Appendix IV: Receiver configuration settings

The u-blox NEO-M8T GNSS receiver is a complex device with numerous settings which can be optimized for a wide array of precise timing and positioning applications. In most cases, the settings are either not relevant for our end-use or the default value is sufficient. This section will illustrate the subset of settings that define the START configuration and are most important for the successful collection of GNSS observables. It is not recommended to stray from the settings of the START configuration files, unless there is a complete understanding of the parameter. Although there are a total of four START configuration files, only a few settings differentiate the four configurations. These differences are based on whether the application is static (Base Station/Point Survey) or dynamic (Rover), as well as the choice of receiver hardware. Configuration differences will be noted for the relevant parameters.

To access configuration settings, **Open u-center software** using the desktop shortcut:

1. Go to View > Message View, then maximize the message window. At the left, there will be an expandable menu of parameters. Scroll down and expand the UBX section, then expand CFG (Config) sub-section which lists the receiver configuration parameters. The following table (table D-1) lists the non-default configuration parameters for START. To access settings, click on CFG (Config) Parameter listed in the table. To apply any change in settings, the "Send" button in the lower left corner of u-center must be clicked subsequent to changing a parameter in the GUI. This action will send the new settings to the receiver.

NOTE: *Indicates parameters that vary across the four START configuration files.

Table 20 - Settings for START configuration

CFG (Config) Parameter	START Configuration Settings
GNSS (GNSS Config)	-Check "Enable" for GPS, min = 8, max = 16 -Check "Enable for SBAS, min = 1, max = 3 -Check "Enable" for Galileo, min = 4, max = 8 -Check "Enable for GLONASS, min = 4, max = 12
INF (Inf Messages)	Protocol – select NMEA, then in column #3, check Error, Warning, and Notice. No additional protocols require information messages
***ITFM (Jamming Interference Monitor)**	Ensure "enable jamming/interference monitor" is checked. *Antenna Type depends on hardware choices. Select "Active" for Tallysman 4721 and u-blox NEO-M8T High Gain integrated receiver/antenna (square plate design). Select "Passive" for other hardware options
LOGFILTER (Log Settings)	Check "Recording enabled"

MSG (Messages)	The following messages should be selected from the drop down menu and the USB box should be checked for each: MON-HW2, Mon-HW, Mon-IO, MON-TXBUF, NAV-PVT, NAV-SBAS, NAV-STATUS, NAV-SVINFO, RXM-RAWX, RXM-SFRBX, NMEA-GxGGA, NMEA-GxGGL, NMEA-GxGSA, NMEA-GxGSV, NMEA-GxRMC, NMEA-GxGVT, NMEA-GxZDA
***NAV5 (Navigation 5)**	*For Base Station & Survey applications set Dynamic Model to Stationary and Min SV Elevation to 5 (deg) *For Rover/Dynamic applications set Dynamic Model to Airborne <1g and Min SV Elevation to 0 (deg) Default values should be used for all other parameters
PMS (Power Management Setup)	Full Power or Balanced may be selected from drop down menu
PRT (Ports)	Select USB from the Target drop down menu. Protocol in & Protocol out should be set to UBX+NMEA. All other Targets should be set to None.
RATE (Rates)	Time Source = UTC time, Measurement Period = 500 ms Default values should be used for other parameters
SBAS (SBAS Settings)	Subsystem = Enabled, PRN Code – select WAAS. Default values should be used for other parameters
USB (Universal Serial Bus)	Power Mode – select Bus Powered, 100 mA Default values should be used for other parameters

Appendix V: START component dimensions & weights

Table 21 - Physical properties of START Rover components

Function	Component	Weight (g)	Length (mm)			Comments
			X	Y	Z	
Receiver	u-blox NEO-M8T USB Dongle	16	75	26	13	
Receiver	u-blox NEO-M8T High Gain: Pro Series (disc)	114	100	100	24	with integrated antenna + ground plate
Receiver	u-blox NEO-M8T High Gain: X-Series	80	100	100	25	with integrated antenna + ground plate
Rover Control Computer	ACEPC W5 Pro mini	52	114	40	15	
Rover Control Computer	Intel Compute Stick	60	113	38	12	
Rover Battery	4400 mAH Batteries	115	95	46	22	
Rover Battery	5000 mAH Batteries	124	98	47	22	
Rover Battery	6000 mAH Batteries	148	99	47	22	
GNSS Antenna	Tallysman 4721	72	38	38	14.3	use with PCB or Dongle receiver
u-blox mount	45mm mounting plate (all plastic)	7				
u-blox mount	60mm mounting plate (all plastic)	10				
uBox mount	90mm mounting plate (all plastic)	12				
USB Filter	Jitterbug USB Filter	10	39	19	13	
***USB interconnect cables not included**						

Table 22 - START Rover configuration weights, as installed

Typical Type 1 installation	Typical Type 2 installation
• u-blox NEO-M8T High Gain • 4400 mAH Battery • Intel Compute Stick • 45mm u-blox Mount • 90mm u-blox mount • Assorted cables, zip ties, velcro, and foam • Total with USB noise filter – **336g** • Total without USB noise filter – **326g**	• u-blox NEO-M8T High Gain Disc • 4400 mAH Battery • ACEPC W5 Pro mini • 60mm u-blox Mount • Assorted cables, zip ties, velcro, and foam • Total with USB noise filter – **354g** • Total without USB noise filter – **344g**

Typical Type 1 installation - with longer life battery	Typical Type 3 installation – separate antenna
• u-blox NEO-M8T High Gain • 6000 mAH Battery • ACEPC W5 Pro mini • 45mm u-blox Mount • 90mm u-blox mount • Assorted cables, zip ties, velcro, and foam • Total with USB noise filter – **362g** • Total without USB noise filter – **352g**	• u-blox NEO-M8T USB Dongle • Tallysman 4721 Antenna • 4400 mAH Battery • ACEPC W5 Pro mini • 45mm u-blox Mount • 90mm u-blox mount • Assorted cables, zip ties, velcro, and foam • Total wth USB noise filter – **355g** • Total without USB noise filter – **345g**

Appendix VI: Product resource links

1. **u-blox M8: Receiver Description, including Protocol and Specifications Documentation**: https://www.u-blox.com/sites/default/files/products/documents/u-blox8-M8_ReceiverDescrProtSpec_%28UBX-13003221%29_Public.pdf

2. **u-blox u-center software download (includes User Guide in installation):** https://www.u-blox.com/en/product-resources/field_file_category/evaluation-software-222/field_file_products%253Afield_product_tech/raw-data-172

3. RTK Explorer – very informative website and blog dealing with topics related to low cost GNSS receivers and
RTKLIB software
https://rtklibexplorer.wordpress.com/

10. Appendix C: VerifyRINEX Data Dropout Summaries

Mon Sep 27 08:24:26
M600_1_210927_111839.obs

5.7 sec gap between timestamps 2021-09-27 12:06:58.197 and 2021-09-27 12:07:03.896
2.0 sec gap between timestamps 2021-09-27 12:07:04.696 and 2021-09-27 12:07:06.703
2.0 sec gap between timestamps 2021-09-27 12:07:09.303 and 2021-09-27 12:07:11.293

Mon Sep 27 09:25:58
M600_2_210927_121419.obs

219.8 sec gap between timestamps 2021-09-27 12:48:26.393 and 2021-09-27 12:52:06.199
2.6 sec gap between timestamps 2021-09-27 12:54:15.399 and 2021-09-27 12:54:17.990
4.7 sec gap between timestamps 2021-09-27 12:54:23.311 and 2021-09-27 12:54:27.999
2.2 sec gap between timestamps 2021-09-27 12:54:30.499 and 2021-09-27 12:54:32.696
0.3 sec gap between timestamps 2021-09-27 13:12:37.996 and 2021-09-27 13:12:38.296

Mon Sep 27 22:12:29
M600_6_210928_111806.obs

1.9 sec gap between timestamps 2021-09-28 11:56:37.297 and 2021-09-28 11:56:39.199
1.9 sec gap between timestamps 2021-09-28 11:59:16.899 and 2021-09-28 11:59:18.794
1.9 sec gap between timestamps 2021-09-28 12:00:28.294 and 2021-09-28 12:00:30.192
1.9 sec gap between timestamps 2021-09-28 12:05:59.192 and 2021-09-28 12:06:01.098
1.9 sec gap between timestamps 2021-09-28 12:10:52.898 and 2021-09-28 12:10:54.803
2.0 sec gap between timestamps 2021-09-28 12:10:55.103 and 2021-09-28 12:10:57.089

Mon Sep 27 23:06:13
Transition_1_210928_124536.obs

517.9 sec gap between timestamp 2021-09-28 13:40:47.101 and end of user window

Wed Sep 29 17:17:13
M600_8_210929_193238.obs

2.0 sec gap between timestamps 2021-09-29 21:04:42.703 and 2021-09-29 21:04:44.697
0.3 sec gap between timestamps 2021-09-29 21:08:08.097 and 2021-09-29 21:08:08.397

Wed Sep 29 18:52:30
M600_9_210929_213829.obs

1.8 sec gap between timestamps 2021-09-29 22:04:54.789 and 2021-09-29 22:04:56.591
21.1 sec gap between timestamps 2021-09-29 22:05:43.891 and 2021-09-29 22:06:04.991
1.8 sec gap between timestamps 2021-09-29 22:08:49.491 and 2021-09-29 22:08:51.289
1.8 sec gap between timestamps 2021-09-29 22:08:51.889 and 2021-09-29 22:08:53.699
1.7 sec gap between timestamps 2021-09-29 22:09:02.799 and 2021-09-29 22:09:04.496
2.9 sec gap between timestamps 2021-09-29 22:09:15.296 and 2021-09-29 22:09:18.202
1.7 sec gap between timestamps 2021-09-29 22:09:21.602 and 2021-09-29 22:09:23.304
2.0 sec gap between timestamps 2021-09-29 22:22:25.204 and 2021-09-29 22:22:27.206
228.6 sec gap between timestamps 2021-09-29 22:24:00.706 and 2021-09-29 22:27:49.295
170.0 sec gap between timestamps 2021-09-29 22:27:53.295 and 2021-09-29 22:30:43.290
0.5 sec gap between timestamps 2021-09-29 22:32:54.990 and 2021-09-29 22:32:55.490
0.5 sec gap between timestamps 2021-09-29 22:32:55.590 and 2021-09-29 22:32:56.090

Wed Sep 29 20:59:33
M600_9_210929_213829.obs

1.8 sec gap between timestamps 2021-09-29 22:04:54.789 and 2021-09-29 22:04:56.591
21.1 sec gap between timestamps 2021-09-29 22:05:43.891 and 2021-09-29 22:06:04.991
1.8 sec gap between timestamps 2021-09-29 22:08:49.491 and 2021-09-29 22:08:51.289
1.8 sec gap between timestamps 2021-09-29 22:08:51.889 and 2021-09-29 22:08:53.699
1.7 sec gap between timestamps 2021-09-29 22:09:02.799 and 2021-09-29 22:09:04.496
2.9 sec gap between timestamps 2021-09-29 22:09:15.296 and 2021-09-29 22:09:18.202
1.7 sec gap between timestamps 2021-09-29 22:09:21.602 and 2021-09-29 22:09:23.304
2.0 sec gap between timestamps 2021-09-29 22:22:25.204 and 2021-09-29 22:22:27.206
228.6 sec gap between timestamps 2021-09-29 22:24:00.706 and 2021-09-29 22:27:49.295
170.0 sec gap between timestamps 2021-09-29 22:27:53.295 and 2021-09-29 22:30:43.290
0.5 sec gap between timestamps 2021-09-29 22:32:54.990 and 2021-09-29 22:32:55.490
0.5 sec gap between timestamps 2021-09-29 22:32:55.590 and 2021-09-29 22:32:56.090

Thu Sep 30 10:38:34
Transition_2_210930_115650.obs

0.5 sec gap between timestamps 2021-09-30 13:52:52.710 and 2021-09-30 13:52:53.210

Thu Sep 30 10:51:46
M600_10_210930_134958.obs

1.9 sec gap between timestamps 2021-09-30 14:24:04.303 and 2021-09-30 14:24:06.207
1.9 sec gap between timestamps 2021-09-30 14:36:26.007 and 2021-09-30 14:36:27.904

1.9 sec gap between timestamps 2021-09-30 14:36:40.004 and 2021-09-30 14:36:41.911
1.9 sec gap between timestamps 2021-09-30 14:36:47.711 and 2021-09-30 14:36:49.594
2.9 sec gap between timestamps 2021-09-30 14:38:52.694 and 2021-09-30 14:38:55.600
2.0 sec gap between timestamps 2021-09-30 14:38:58.400 and 2021-09-30 14:39:00.395
3.3 sec gap between timestamps 2021-09-30 14:39:05.895 and 2021-09-30 14:39:09.200
6.1 sec gap between timestamps 2021-09-30 14:39:12.000 and 2021-09-30 14:39:18.099
2.0 sec gap between timestamps 2021-09-30 14:39:34.699 and 2021-09-30 14:39:36.710

Thu Sep 30 12:37:43
M600_11_210930_144501.obs

361.8 sec gap between timestamps 2021-09-30 15:47:50.811 and 2021-09-30 15:53:52.593
2.3 sec gap between timestamps 2021-09-30 15:54:22.093 and 2021-09-30 15:54:24.399
66.3 sec gap between timestamps 2021-09-30 15:55:06.799 and 2021-09-30 15:56:13.094
29.9 sec gap between timestamps 2021-09-30 15:56:13.994 and 2021-09-30 15:56:43.892
2.3 sec gap between timestamps 2021-09-30 15:57:01.992 and 2021-09-30 15:57:04.291
2.8 sec gap between timestamps 2021-09-30 15:57:07.191 and 2021-09-30 15:57:09.998
3.8 sec gap between timestamps 2021-09-30 15:57:14.098 and 2021-09-30 15:57:17.891
49.0 sec gap between timestamps 2021-09-30 15:57:23.991 and 2021-09-30 15:58:13.003
90.2 sec gap between timestamps 2021-09-30 16:09:13.603 and 2021-09-30 16:10:43.798
65.7 sec gap between timestamps 2021-09-30 16:12:00.298 and 2021-09-30 16:13:05.997
172.9 sec gap between timestamps 2021-09-30 16:14:23.197 and 2021-09-30 16:17:16.106
1.8 sec gap between timestamps 2021-09-30 16:18:07.606 and 2021-09-30 16:18:09.389

Thu Sep 30 15:53:35
M210_3_210930_181239.obs

0.5 sec gap between timestamps 2021-09-30 19:39:33.593 and 2021-09-30 19:39:34.093

Thu Sep 30 17:48:02
M210_4_210930_211646.obs

0.3 sec gap between timestamps 2021-09-30 21:17:34.995 and 2021-09-30 21:17:35.295
0.4 sec gap between timestamps 2021-09-30 21:38:54.396 and 2021-09-30 21:38:54.796

Fri Oct 1 11:35:27
Phantom4_2_211001_141011.obs

1.9 sec gap between timestamps 2021-10-01 14:23:15.901 and 2021-10-01 14:23:17.799
1.9 sec gap between timestamps 2021-10-01 14:25:59.999 and 2021-10-01 14:26:01.900
2.0 sec gap between timestamps 2021-10-01 14:42:23.401 and 2021-10-01 14:42:25.406
2.1 sec gap between timestamps 2021-10-01 14:42:35.206 and 2021-10-01 14:42:37.305

4.3 sec gap between timestamps 2021-10-01 14:43:40.505 and 2021-10-01 14:43:44.806
13.4 sec gap between timestamps 2021-10-01 14:43:46.706 and 2021-10-01 14:44:00.106
2.7 sec gap between timestamps 2021-10-01 14:44:02.106 and 2021-10-01 14:44:04.788
1.9 sec gap between timestamps 2021-10-01 14:44:06.088 and 2021-10-01 14:44:07.999
3.6 sec gap between timestamps 2021-10-01 14:44:09.499 and 2021-10-01 14:44:13.106
2.5 sec gap between timestamps 2021-10-01 14:44:17.306 and 2021-10-01 14:44:19.797
8.1 sec gap between timestamps 2021-10-01 14:44:27.297 and 2021-10-01 14:44:35.401
4.3 sec gap between timestamps 2021-10-01 14:44:38.501 and 2021-10-01 14:44:42.799
4.3 sec gap between timestamps 2021-10-01 14:44:55.399 and 2021-10-01 14:44:59.688

11. Appendix D: Data Dictionary

Table 23 - Full Data Dictionary Table

Table Name	Column Name	Column Description	DataTypeName	MaxLength	Is Nullable?	In Identity?	Key Description
Aircraft	Aircraft_ID	Unique ID assigned to each aircraft model	int	4	0	1	Primary Key
Aircraft	Aircraft_Name	Aircraft Name	varchar	8000	1	0	
Aircraft	Aircraft_Type	Description of Aircraft	varchar	8000	1	0	
Master_List	Index	Index number of tables derived from the csv file listed in the File_Name column	int	4	0	0	Primary Key
Master_List	Meter_Name	Volpe designated name for the sound level meter system	varchar	8000	1	0	
Master_List	Drone_Name	Name of aircraft recorded or designation for calibration and ambient recordings	varchar	8000	1	0	
Master_List	Test_Date	Date that measurement file was recorded	date	3	1	0	
Master_List	File_Name	Name of measurement file output by the sound level meter on the date in the Test_Date column by the SLM in the Meter_Name	varchar	8000	1	0	
Master_List	Wav_File_Path	File path to the wav file recorded with the SLM file in the File_Name column	varchar	8000	1	0	
Calibration_History	Index	Index number - reference to source file in Master_List table	int	4	1	0	Foreign Key
Calibration_History	Pre_Amp	Serial Number of the Pre-amplifier used with the system described by the Meter_Name in Master_List table - or direct input	varchar	8000	1	0	
Calibration_History	Date_Time	Date and Time that calibration history was recorded	varchar	8000	1	0	
Calibration_History	dB re. 1V/Pa	Nominal sensitivity of mic in dB at reference of 1V/Pa	decimal	17	1	0	
Calibration_History	6.3	Calibration noise level for 1/3 octave band centered on 6.3 Hertz (dB)	decimal	17	1	0	
Calibration_History	8	Calibration noise level for 1/3 octave band centered on 8 Hertz (dB)	decimal	17	1	0	
Calibration_History	10	Calibration noise level for 1/3 octave band centered on 10 Hertz (dB)	decimal	17	1	0	
Calibration_History	12.5	Calibration noise level for 1/3 octave band centered on 12.5 Hertz (dB)	decimal	17	1	0	

Calibration_History	16	Calibration noise level for 1/3 octave band centered on 16 Hertz (dB)	decimal	17	1	0	
Calibration_History	20	Calibration noise level for 1/3 octave band centered on 20 Hertz (dB)	decimal	17	1	0	
Calibration_History	25	Calibration noise level for 1/3 octave band centered on 25 Hertz (dB)	decimal	17	1	0	
Calibration_History	31.5	Calibration noise level for 1/3 octave band centered on 31.5 Hertz (dB)	decimal	17	1	0	
Calibration_History	40	Calibration noise level for 1/3 octave band centered on 40 Hertz (dB)	decimal	17	1	0	
Calibration_History	50	Calibration noise level for 1/3 octave band centered on 50 Hertz (dB)	decimal	17	1	0	
Calibration_History	63	Calibration noise level for 1/3 octave band centered on 63 Hertz (dB)	decimal	17	1	0	
Calibration_History	80	Calibration noise level for 1/3 octave band centered on 80 Hertz (dB)	decimal	17	1	0	
Calibration_History	100	Calibration noise level for 1/3 octave band centered on 100 Hertz (dB)	decimal	17	1	0	
Calibration_History	125	Calibration noise level for 1/3 octave band centered on 125 Hertz (dB)	decimal	17	1	0	
Calibration_History	160	Calibration noise level for 1/3 octave band centered on 160 Hertz (dB)	decimal	17	1	0	
Calibration_History	200	Calibration noise level for 1/3 octave band centered on 200 Hertz (dB)	decimal	17	1	0	
Calibration_History	250	Calibration noise level for 1/3 octave band centered on 250 Hertz (dB)	decimal	17	1	0	
Calibration_History	315	Calibration noise level for 1/3 octave band centered on 315 Hertz (dB)	decimal	17	1	0	
Calibration_History	400	Calibration noise level for 1/3 octave band centered on 400 Hertz (dB)	decimal	17	1	0	
Calibration_History	500	Calibration noise level for 1/3 octave band centered on 500 Hertz (dB)	decimal	17	1	0	
Calibration_History	630	Calibration noise level for 1/3 octave band centered on 630 Hertz (dB)	decimal	17	1	0	
Calibration_History	800	Calibration noise level for 1/3 octave band centered on 800 Hertz (dB)	decimal	17	1	0	
Calibration_History	1000	Calibration noise level for 1/3 octave band centered on 1000 Hertz (dB)	decimal	17	1	0	
Calibration_History	1250	Calibration noise level for 1/3 octave band centered on 1250 Hertz (dB)	decimal	17	1	0	

Calibration_History	1600	Calibration noise level for 1/3 octave band centered on 1600 Hertz (dB)	decimal	17	1	0	
Calibration_History	2000	Calibration noise level for 1/3 octave band centered on 2000 Hertz (dB)	decimal	17	1	0	
Calibration_History	2500	Calibration noise level for 1/3 octave band centered on 2500 Hertz (dB)	decimal	17	1	0	
Calibration_History	3150	Calibration noise level for 1/3 octave band centered on 3150 Hertz (dB)	decimal	17	1	0	
Calibration_History	4000	Calibration noise level for 1/3 octave band centered on 4000 Hertz (dB)	decimal	17	1	0	
Calibration_History	5000	Calibration noise level for 1/3 octave band centered on 5000 Hertz (dB)	decimal	17	1	0	
Calibration_History	6300	Calibration noise level for 1/3 octave band centered on 6300 Hertz (dB)	decimal	17	1	0	
Calibration_History	8000	Calibration noise level for 1/3 octave band centered on 8000 Hertz (dB)	decimal	17	1	0	
Calibration_History	10000	Calibration noise level for 1/3 octave band centered on 10000 Hertz (dB)	decimal	17	1	0	
Calibration_History	12500	Calibration noise level for 1/3 octave band centered on 12500 Hertz (dB)	decimal	17	1	0	
Calibration_History	16000	Calibration noise level for 1/3 octave band centered on 16000 Hertz (dB)	decimal	17	1	0	
Calibration_History	20000	Calibration noise level for 1/3 octave band centered on 20000 Hertz (dB)	decimal	17	1	0	
Overall_Settings	Index	Index number - reference to source file in Master_List table	int	4	1	0	Foreign Key
Overall_Settings	PeakWeight	Weighting filter applied peak SPL	varchar	8000	1	0	
Overall_Settings	Detector	Averaging method	varchar	8000	1	0	
Overall_Settings	Preamp	Serial Number of the Pre-amplifier used with the system described by the Meter_Name in Master_List table - or direct input	varchar	8000	1	0	
Overall_Settings	MicrophoneCorrection	Is microphone correction on or off	varchar	8000	1	0	
Overall_Settings	IntegrationMethod	Integration Method Applied ('Linear' or 'Expoential')	varchar	8000	1	0	
Overall_Settings	OBARange	Octave Band Analysis Range ('Low' or 'Normal'). Normal Range, typically 45 to 140 dB • Low Range, typically 19 to 107 dB	varchar	8000	1	0	
Overall_Settings	OBABandwidth	Octave Band Analysis Bandwidth (1/3, 1/12)	varchar	8000	1	0	
Overall_Settings	OBAFreq.Weighting	Octave Band Analysis Frequency Weighting Filter Applied	varchar	8000	1	0	

Overall_Settings	OBAMaxSpectrum	Octave Band Analysis Maximum Spectrum	varchar	8000	1	0	
Overall_Settings	Gain	Input Gain (dB)	varchar	8000	1	0	
Overall_Settings	Overload	Overload Level (dB Peak)	decimal	17	1	0	
Session_Log	Index	Index number - reference to source file in Master_List table	int	4	1	0	Foreign Key
Session_Log	Record #	Unique ID for each index in record in Session_Log table by order of date and time	int	4	1	0	
Session_Log	Date	Date on which session log record was recorded	varchar	8000	1	0	
Session_Log	Time	Time at which session log record was recorded	time	5	1	0	
Session_Log	Record Type	Indicates the selection of 'Run' or 'Stop' on Acoustic Measurement Device	varchar	8000	1	0	
Session_Log	Num	N/A	varchar	8000	1	0	
Session_Log	TH Record	Foreign Key to Record # in Time_History table	int	4	1	0	
Session_Log	Cause	Indicates the action that causes the acoustic measurement device to perform the function in the Record Type field	varchar	8000	1	0	
Time_History	Index	Index number - reference to source file in Master_List table	int	4	1	0	Foreign Key
Time_History	Record #	Unique ID for each index in record in Time_History table by order of date and time	int	4	1	0	
Time_History	Date	Date on which Time History record was recorded	date	3	1	0	
Time_History	Time	Time at which Time History record was recorded	time	5	1	0	
Time_History	LASeq	Average Sound Level over Time period, A-weighted	varchar	8000	1	0	
Time_History	LASmax	Maximum noise level, A-weighted	varchar	8000	1	0	
Time_History	LZSeq	Average Sound Level over Time period, Z-weighted	decimal	17	1	0	
Time_History	Battery	Battery level at Time of Recording	decimal	17	1	0	
Time_History	Int. Temp (F)	Internal Temperature of SLM in degrees Fahrenheit	decimal	17	1	0	
Time_History	Wind Spd.	Wind Speed in meters per second	decimal	17	1	0	
Time_History	Gust Dir. (° Degrees)	Wind Gust Direction in Degrees	decimal	17	1	0	
Time_History	Avg Temp	Average Temperature in degrees Fahrenheit	decimal	17	1	0	
Time_History	Avg Humidity	Average Percent Humidity	decimal	17	1	0	
Time_History	6.3	Half-second, A-weighted, slow time-averaged noise level for 1/3 octave band centered on 6.3 Hertz (dB LAS)	decimal	17	1	0	

Time_History	8	Half-second, A-weighted, slow time-averaged noise level for 1/3 octave band centered on 8 Hertz (dB LAS)	decimal	17	1	0	
Time_History	10	Half-second, A-weighted, slow time-averaged noise level for 1/3 octave band centered on 10 Hertz (dB LAS)	decimal	17	1	0	
Time_History	12.5	Half-second, A-weighted, slow time-averaged noise level for 1/3 octave band centered on 12.5 Hertz (dB LAS)	decimal	17	1	0	
Time_History	16	Half-second, A-weighted, slow time-averaged noise level for 1/3 octave band centered on 16 Hertz (dB LAS)	decimal	17	1	0	
Time_History	20	Half-second, A-weighted, slow time-averaged noise level for 1/3 octave band centered on 20 Hertz (dB LAS)	decimal	17	1	0	
Time_History	25	Half-second, A-weighted, slow time-averaged noise level for 1/3 octave band centered on 25 Hertz (dB LAS)	decimal	17	1	0	
Time_History	31.5	Half-second, A-weighted, slow time-averaged noise level for 1/3 octave band centered on 31.5 Hertz (dB LAS)	decimal	17	1	0	
Time_History	40	Half-second, A-weighted, slow time-averaged noise level for 1/3 octave band centered on 40 Hertz (dB LAS)	decimal	17	1	0	
Time_History	50	Half-second, A-weighted, slow time-averaged noise level for 1/3 octave band centered on 50 Hertz (dB LAS)	decimal	17	1	0	
Time_History	63	Half-second, A-weighted, slow time-averaged noise level for 1/3 octave band centered on 63 Hertz (dB LAS)	decimal	17	1	0	
Time_History	80	Half-second, A-weighted, slow time-averaged noise level for 1/3 octave band centered on 80 Hertz (dB LAS)	decimal	17	1	0	
Time_History	100	Half-second, A-weighted, slow time-averaged noise level for 1/3 octave band centered on 100 Hertz (dB LAS)	decimal	17	1	0	
Time_History	125	Half-second, A-weighted, slow time-averaged noise level for 1/3 octave band centered on 125 Hertz (dB LAS)	decimal	17	1	0	
Time_History	160	Half-second, A-weighted, slow time-averaged noise level for 1/3 octave band centered on 160 Hertz (dB LAS)	decimal	17	1	0	
Time_History	200	Half-second, A-weighted, slow time-averaged noise level for 1/3 octave band centered on 200 Hertz (dB LAS)	decimal	17	1	0	
Time_History	250	Half-second, A-weighted, slow time-averaged noise level for 1/3 octave band centered on 250 Hertz (dB LAS)	decimal	17	1	0	
Time_History	315	Half-second, A-weighted, slow time-averaged noise level for 1/3 octave band centered on 315 Hertz (dB LAS)	decimal	17	1	0	

Time_History	400	Half-second, A-weighted, slow time-averaged noise level for 1/3 octave band centered on 400 Hertz (dB LAS)	decimal	17	1	0	
Time_History	500	Half-second, A-weighted, slow time-averaged noise level for 1/3 octave band centered on 500 Hertz (dB LAS)	decimal	17	1	0	
Time_History	630	Half-second, A-weighted, slow time-averaged noise level for 1/3 octave band centered on 630 Hertz (dB LAS)	decimal	17	1	0	
Time_History	800	Half-second, A-weighted, slow time-averaged noise level for 1/3 octave band centered on 800 Hertz (dB LAS)	decimal	17	1	0	
Time_History	1000	Half-second, A-weighted, slow time-averaged noise level for 1/3 octave band centered on 1000 Hertz (dB LAS)	decimal	17	1	0	
Time_History	1250	Half-second, A-weighted, slow time-averaged noise level for 1/3 octave band centered on 1250 Hertz (dB LAS)	decimal	17	1	0	
Time_History	1600	Half-second, A-weighted, slow time-averaged noise level for 1/3 octave band centered on 1600 Hertz (dB LAS)	decimal	17	1	0	
Time_History	2000	Half-second, A-weighted, slow time-averaged noise level for 1/3 octave band centered on 2000 Hertz (dB LAS)	decimal	17	1	0	
Time_History	2500	Half-second, A-weighted, slow time-averaged noise level for 1/3 octave band centered on 2500 Hertz (dB LAS)	decimal	17	1	0	
Time_History	3150	Half-second, A-weighted, slow time-averaged noise level for 1/3 octave band centered on 3150 Hertz (dB LAS)	decimal	17	1	0	
Time_History	4000	Half-second, A-weighted, slow time-averaged noise level for 1/3 octave band centered on 4000 Hertz (dB LAS)	decimal	17	1	0	
Time_History	5000	Half-second, A-weighted, slow time-averaged noise level for 1/3 octave band centered on 5000 Hertz (dB LAS)	decimal	17	1	0	
Time_History	6300	Half-second, A-weighted, slow time-averaged noise level for 1/3 octave band centered on 6300 Hertz (dB LAS)	decimal	17	1	0	
Time_History	8000	Half-second, A-weighted, slow time-averaged noise level for 1/3 octave band centered on 8000 Hertz (dB LAS)	decimal	17	1	0	
Time_History	10000	Half-second, A-weighted, slow time-averaged noise level for 1/3 octave band centered on 10000 Hertz (dB LAS)	decimal	17	1	0	

Time_History	12500	Half-second, A-weighted, slow time-averaged noise level for 1/3 octave band centered on 12500 Hertz (dB LAS)	decimal	17	1	0	
Time_History	16000	Half-second, A-weighted, slow time-averaged noise level for 1/3 octave band centered on 16000 Hertz (dB LAS)	decimal	17	1	0	
Time_History	20000	Half-second, A-weighted, slow time-averaged noise level for 1/3 octave band centered on 20000 Hertz (dB LAS)	decimal	17	1	0	
Time_History	Gust Spd.	Max wind speed collected over a one second interval - units depend on device settings	decimal	17	1	0	
Time_History	Max Temp	Mximum Temperature - units depend on device settings	decimal	17	1	0	
Time_History	Min Temp	Minimum Temperature - units depend on device settings	decimal	17	1	0	
Time_History	Weather4	Additional Weather Field (optional)	decimal	17	1	0	
Time_History	Ovrld.	Indicates a preamp input signal that exceeds the calibrated range of the Acoustic Measurement device (yes/no)	varchar	8000	1	0	
Time_History	OBA Ovrld.	Indicates input to Octave Band Analyzer has been overloaded (yes/no)	varchar	8000	1	0	
Time_History	Marker	used to define the marker names and enable sound recorder options	varchar	8000	1	0	
Time_History	Key	Indicates the key pushed on the acoustic measurement device at the time of the record	varchar	8000	1	0	
Weather	Index	Index number - reference to source file in Master_List table	int	4	1	0	Foreign Key
Weather	Avg Wind Speed(mi/h)	Average Wind Speed over the interval of the time stamp in Miles per Hour	decimal	17	1	0	
Weather	Gust Speed(mi/h)	Peak Wind Speed over the interval of the time stamp in Miles per Hour	decimal	17	1	0	
Weather	Min Wind Speed(mi/h)	Minimum Wind Speed over the interval of the time stamp in Miles per Hour	decimal	17	1	0	
Weather_Expanded	Index	Index number - reference to source file in Master_List table	int	4	1	0	Foreign Key
Weather_Expanded	Avg Temp(°F)	Average air temperature over time-history duration in degrees Fahrenheit	decimal	17	1	0	
Weather_Expanded	Max Temp(°F)	Maximum air temperature over time-history duration in degrees Fahrenheit	decimal	17	1	0	
Weather_Expanded	Min Temp(°F)	Minimum air temperature over time-history duration in degrees Fahrenheit	decimal	17	1	0	
Weather_Expanded	Avg Humidity(%RH)	Average humidity over time-history duration in percent relative humidity	decimal	17	1	0	

Weather_Expanded	Max Humidity(%RH)	Maximum humidity over time-history duration in percent relative humidity	decimal	17	1	0	
Weather_Expanded	Min Humidity(%RH)	Minimum humidity over time-history duration in percent relative humidity	decimal	17	1	0	
Weather_Expanded	Barometer Avg(hPa)	Average barometric pressure over time-history duration in hectopascals	decimal	17	1	0	
Weather_Expanded	Barometer High(hPa)	Maximum (high) barometric pressure over time-story duration in hectopascals	decimal	17	1	0	
Weather_Expanded	Barometer Low(hPa)	Minimum (low) barometric pressure over time-history duration in hectopascals	decimal	17	1	0	
Weather_Expanded	Rain Accumulation(in)	Cumulative accumulation of rainfall in inches in a 60 squared cm area after the latest automatic or manual reset	decimal	17	1	0	
Weather_Expanded	Rain Max Rate(in/hr)	Maximum rate of accumulation of rainfall in inches per hour	decimal	17	1	0	
Weather_Expanded	Rain Duration(s)	Duration of Rainfall in seconds, counting each 10-second increment whenever droplet detected	decimal	17	1	0	
Weather_Expanded	Hail Accumulation(hits/in²)	cumulative amount of hits against collecting surface in hits per squared inch	decimal	17	1	0	
Weather_Expanded	Hail Max Rate(hits/in²h)	One-minute running average of hits per squared inch hour	decimal	17	1	0	
Weather_Expanded	Hail Duration(s)	counting each 10-second increment whenever hailstone detected	decimal	17	1	0	
Tracking	Rec	Tracking data record number	int	4	1	0	
Tracking	Source	Tracking Sytem from which data was sourced	varchar	8000	1	0	
Tracking	Date	UTC Date in mm/dd/yyyy format	date	3	1	0	
Tracking	Time	UTC Time in yyy-mm-dd hh:mm:ss format (with erroneous date)	time	5	1	0	
Tracking	latitude(deg)	Latitude position of aircraft in decimal degrees	decimal	17	1	0	
Tracking	longitude(deg)	Longitude position of aircraft in decimal degrees	decimal	17	1	0	
Tracking	height(m)	Height (z component) in meters	decimal	17	1	0	
Tracking	Q	Quality Flag indicating solution quality	varchar	8000	1	0	
Tracking	ns	Number of valid satellites 1 : Fixed, solution by carrier-based relative positioning and the integer ambiguity is properly resolved. 2 : Float, solution by carrier-based relative positioning but the integer ambiguity is not resolved. 3 : Reserve	int	4	1	0	
Tracking	sdn(m)	Standard deviation of north component of the solution in meters assuming a priori error model	float	8	1	0	

Tracking	sde(m)	Standard deviation of east component of the solution in meters assuming a priori error model	float	8	1	0	
Tracking	sdu(m)	Standard deviation of up (height) component of the solution in meters assuming a priori error model	float	8	1	0	
Tracking	sdne(m)	Square root of the standard deviation of North component in meters. Sign indicates the sign of covarience.	float	8	1	0	
Tracking	sdeu(m)	Square root of the standard deviation of East component in meters. Sign indicates the sign of covarience.	float	8	1	0	
Tracking	sdun(m)	Square root of the standard deviation of Up (height) component in meters. Sign indicates the sign of covarience.	float	8	1	0	
Tracking	age(s)	Age of differential: The time difference between the observation data epochs of the rover receiver and the base station in seconds	float	8	1	0	
Tracking	ratio	The ratio factor of "ratio-test" for standard integer ambiguity validation strategy. The value means the ratio of the squared sum of the residuals with the second best integer vector to with the best integer vector	float	8	1	0	
Tracking	UTC	Time of day using Universal Coordinated Time (UTC) in hh:mm:ss format	time	5	1	0	
Tracking	TimeStamp	Combined Date and Time, where date uses mm/dd/yyyy and time in UTC uses hh:mm:ss	datetime	8	1	0	
Tracking	y_0	Variable 1 used in offset angle calculation	float	8	1	0	
Tracking	x	Variable 2 used in offset angle calculation	float	8	1	0	
Tracking	y	Variable 3 used in offset angle calculation	float	8	1	0	
Tracking	x_local_m	X coordinate in local coordinate system where primary microphone is (0, 0, 0) and +Y is the North direction on the flight path, in meters	float	8	1	0	
Tracking	y_local_m	Y coordinate in local coordinate system where primary microphone is (0, 0, 0) and +Y is the North direction on the flight path, in meters	float	8	1	0	
Tracking	z_local_m	Z coordinate in local coordinate system where primary microphone is (0, 0, 0) and +Y is the North direction on the flight path, in meters	float	8	1	0	
Tracking	x_local_ft	X coordinate in local coordinate system where primary microphone is (0, 0, 0) and +Y is the North direction on the flight path, in feet	float	8	1	0	

Tracking	y_local_ft	Y coordinate in local coordinate system where primary microphone is (0, 0, 0) and +Y is the North direction on the flight path, in feet	float	8	1	0	
Tracking	z_local_ft	Z coordinate in local coordinate system where primary microphone is (0, 0, 0) and +Y is the North direction on the flight path, in feet	float	8	1	0	
Tracking	x_RH_ft	x position in feet adjusted to right hand rule convention	float	8	1	0	
Tracking	y_RH_ft	y position in feet adjusted to right hand rule convention	float	8	1	0	
Tracking	SR_ft	Slant range from source to origin in feet	float	8	1	0	
Tracking	Del_x_ft	Change in x position between records in feet	float	8	1	0	
Tracking	Del_y_ft	Change in y position between records in feet	float	8	1	0	
Tracking	Del_xy_ft	Change in the resultant of xy between records in feet	float	8	1	0	
Tracking	GrndSpd_fps	Ground speed in feet per second	float	8	1	0	
Tracking	GrndSpd_mph	Ground Speed in miles per hour	float	8	1	0	
Tracking	GrndSpd_ms	Ground Speed in meters per second	float	8	1	0	
Tracking	GrndSpd_kts	Ground Speed in Knots	float	8	1	0	
Tracking	Aircraft_ID	Aircraft unique ID - assigned when data is imported to database	int	4	0	0	Foreign Key
Tracking	Aircraft_Name	Aircraft Name	varchar	8000	1	0	

12. Appendix D: Volpe Aircraft Information Questionnaires

(Please complete one form for each aircraft to be tested.)

1. Vehicle manufacturer:_______________________________________
2. Vehicle model (and version):__________________________________
3. Modified? ☐ yes (if yes, describe on separate page) ☐ no
4. Vehicle configuration:
   - ☐ Rotorcraft: # of rotors_____ # of blades per rotor_____
     - Rotor diameter_____
     - Ducted? ☐ yes ☐ no
     - Co-axial, counter-rotating? ☐ yes ☐ no
   - ☐ Fixed-wing: ☐ prop # of props____
     - Configuration: ☐ pusher
       - ☐ tractor
       - ☐ hybrid
     - ☐ otherspecify: (describe on separate page)
   - ☐ Hybrid: describe: (on separate page)
5. Power method:
   - ☐ Electric
   - ☐ Internal combustion
   - ☐ gas turbine
   - ☐ hybrid describe: (on separate page)
   - ☐ otherdescribe: (on separate page)
6. Flight Controls:
   - ☐ Movable aero surfaces
   - ☐ Differential thrust
   - ☐ Vectored thrust: ☐ tilt-rotor
     - ☐ tilt-wing (or other mounting surface)
     - ☐ other describe: (on separate page)
7. Mass properties:
   - Dry weight without payload____
   - Maximum TOW____
   - Maximum payload capacity____
   - CG Range Limits: Lateral:____ Longitudinal:____
8. Size:
   - Maximum dimension____ ☐ diameter
     - ☐ wingspan
     - ☐ length

9. Payload accommodation:

- ☐ height
- ☐ width
- ☐ none
- ☐ internal describe: (on separate page)
- ☐ external describe: (on separate page)

10. Flight performance:

- ☐ VTOL
- ☐ STOL
- ☐ CTOL (conventional horizontal flight)

Are any external aids, mechanisms, or procedures required for Takeoff or Landing?

☐ yes describe: (on separate page) ☐ no

Is there a physical transition to horizontal flight?

☐ yes describe: (on separate page) ☐ no

11. Endurance:

What is the maximum available flight duration between refueling/battery swaps? ____

Expected flight duration w/ 1-pound payload?____

What is the turnaround time for refueling / battery swap? ____

What is the availability of fuel refills / batteries?____

12. Altitude (ft. AGL)

- ☐ Maximum Altitude ____
- ☐ Hover Altitude ____
- ☐ Operational Altitude ____
- ☐ Lower Altitude Limit (if applicable) ____

13. Speed

- ☐ V_{max} _____
- ☐ V_{Cruise} _____
- ☐ V_{min} (if applicable) ____
- ☐ $V_{Operational}$ _____

14. Please describe any other unique or unusual characteristics: (on separate page)

If possible, please provide photos or technical drawings – overhead and profile.
For clarification, comments, etc. please contact:

Chris Cutler-Wood
USDOT Volpe Center
617-494-2817 (Massachusetts)
Chris.Cutler-Wood@dot.gov

13. Appendix E: Flight Event Communication Order of Operations

1. **Pilot** confirms with **Test Director** go for takeoff
2. (radio) **Test Director** announces takeoff
3. AIRCRAFT TAKEOFF
4. AIRCRAFT FLIES TO INITIAL START POSITION
5. (radio) **Test Director** confirms with **Pilot** and announces upcoming Event ID
6. AIRCRAFT BEGINS FLIGHT EVENT
7. (radio) **Test Director** signals Data On
8. **Documentation Support FT** logs "Data On" UTC timestamp
   a. **Acoustics Support FT** logs Data On UTC timestamp
9. **Documentation Support FT** logs Time Overhead @ Mic Array
   a. **Acoustics Support FT** logs Time Overhead @ Mic Array
10. **Documentation Support FT** logs "Data Off" UTC timestamp
    a. **Acoustics Support FT** logs "Data Off" UTC timestamp
11. (radio) **Test Director** signals Data Off
12. AIRCRAFT PAUSE/CIRCLE BEFORE NEXT EVENT
13. **Test Director** confirms successful Event with Pilot & Acoustics Lead, marks Flight Card
    a. (radio) **Acoustics Lead** announces any system issues, or "acoustics system nominal"
14. (radio) **Test Director** announces next Event ID
15. AIRCRAFT BEGINS NEXT EVENT

[repeat from Step 7]

14. Appendix F: Volpe Team Roles and Responsibilities Documentation

Test Director

The test director shall be responsible for the communication between all team members at a high level, before, during, and after the field measurements. The test director shall make the final decisions with respect to go/no-go criteria (weather, etc.) the night prior to each measurement day. During the measurements, the test director shall be in direct contact with the pilot(s) and the acoustics lead to ensure that the correct flight events have been flown, and that satisfactory acoustic data is captured for each event. The test director shall announce each flight event prior to execution and confirm with both the pilot and acoustics lead that the event was flown within acceptable limits and acoustic data was captured to a satisfactory level before moving on to the next flight event. The test director shall be responsible for decisions made with respect to which aircraft are flown during a particular measurement day, as well as which microphone array configuration to have set up.

Acoustics Lead

The acoustics lead shall be responsible for the successful operation of the NI / LabVIEW acoustics system, communication to the test director with respect to event data quality, and with the field technicians during setup and calibration. The acoustics lead shall be responsible for the setup of the table-based hardware for the NI / LabVIEW system including but not limited to the gain amplifiers, timecode generator, and solid-state storage media. The acoustics lead shall confer with the test director after acoustics system setup to confirm successful installation and operation of all acoustics system components prior to flight operations. The acoustics lead may call upon the acoustics support field technician to perform physical setup tasks as necessary. The acoustics lead will be in communication with acoustics support field technician to direct data downloads and post-event data quality checks, and hardware troubleshooting, as necessary. The acoustics lead will be in direct communication with the test director during the measurement, specifically to communicate the successful capture of acoustics data and reporting of overloaded data channels (if any) for each flight event before moving to the next flight event. The acoustics lead shall also be responsible for communication with any and all field technicians who may be assisting with pre- and post-test calibration recordings at the microphones. The acoustics lead has full authority to request a pause in flight operations and/or request repeat flight events at any point during the measurement if data collection and/or data quality has been compromised.

Tracking System Lead

The tracking system lead shall be responsible for the successful operation of the START tracking system used to capture high-quality satellite data from on-board the aircraft. The tracking system lead shall be responsible for the safe and secure mounting and installation of the START system on all aircraft to be flown during the measurement campaign. The tracking system lead shall be responsible for communicating any requirements for the safe and secure installation of START system hardware prior to each aircraft's respective measurement day. The acoustics lead shall confer with the test director after acoustics system setup to confirm successful installation and operation of all START system components prior to flight operations. The tracking system lead shall have authority to request a pause in flight operations in order to perform data quality checks as they deem necessary. The tracking system lead shall have authority to pause flight operations and/or request repeat flight events at any point in the measurement if they determine the tracking data collection or data quality has been compromised. The tracking system lead shall be in communication with the test director and pilot(s) to determine which aircraft and at what point in time require the START system to be mounted and installed.

Field Technicians

All field technicians shall be capable of performing basic hardware setup and installation tasks related to the acoustics system. Such tasks may include (but are not limited to) ground plate installation, microphone cable running and coiling, microphone and preamp assembly, inverted microphone holder assembly and installation, and elevated mic array deployment. All field technicians shall also be capable of performing microphone calibration procedures at the direction of the acoustics lead. Field technicians may have specific support roles as well, described below.

Acoustics Support

Acoustics support field technicians shall be responsible for directly supporting the acoustics lead in the setup and operations of the NI / LabVIEW acoustics system. Acoustics support field technicians shall have a comparable understanding of the hardware and software components of the NI / LabVIEW system as the acoustics lead, so that they may assist the acoustics lead with any task as requested, including temporary operation of the NI / LabVIEW system, if necessary. During flight events, the acoustics support field technician shall be responsible for post-event acoustics data quality checks and communicating any potential data quality issues directly to the acoustics lead for consideration. The acoustics support field technician shall also be responsible for keeping a detailed log of relevant acoustics and flight event information such as overloads, data on/off times, and other general acoustics system notes. These log sheets will be considered backup to the primary logs captured by the documentation support field technician.

Tracking Support

Tracking support field technicians shall be responsible for directly supporting the tracking system lead in the setup and operations of the START tracking system. Tracking system field technicians shall have a comparable level of understanding of the hardware and software components of the START system as the tracking system lead so that they may assist the tracking system lead with any tasks as requested, including temporary operation of the START system, if necessary. During aircraft flight events, when the tracking system lead may not be available, the tracking support field technicians shall be responsible for the mounting, installation, and troubleshooting of the START system on aircraft scheduled to be flown.

Documentation Support

Documentation support field technicians shall be responsible for maintaining detailed log sheets of all relevant information during flight operations, including but not limited to, UTC times for event start/stop and aircraft overhead point, flight event description, flight event number, aircraft flown, weather conditions, anomalous test conditions (nearby sounds, wind gusts, talking during flight events, etc.). The documentation support field technician shall be positioned during the flight test to collect this information as easily as possible and shall be listening to any/all communication between the various team leads. The documentation support field technician shall be responsible for maintaining meticulous logs throughout each measurement day and sharing them with the full Volpe team at the end of each measurement day. The documentation support field technicians shall be responsible for collecting, digitizing, and organizing all other log sheets (such as the pilot/test director flight cards, calibration logs, tracking system logs) at the end of each measurement day and distributing to the full team.

15. Appendix G: AWRF Meteorological Analysis Slides

AWRF Wind Speed Measurements
March 2019 – January 2020

Carl Snyder (V-345)

4/12/2021

(Double-click the slide image to begin slideshow)

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