Noise Measurement Report: Unconventional Aircraft - Choctaw Nation of Oklahoma; July 2019

FAA UAS National Airspace Integration Pilot Program

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Measurement and Initial Noise Data Report — May 2020

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This report discusses the processes and results of an acoustic measurement program conducted at the Choctaw Nation of Oklahoma's Integrated Pilot Program test site near Daisy, Oklahoma from July 15 to July 17, 2019. The test was conducted in support of the FAA's research into the inclusion of unconventional aircraft in the National Airspace System. Four small Unmanned Aerial Vehicles were measured – a DJI M200, a Yuneec Typhoon, a Gryphon Dynamics GD28X, and a Skywalker X-8. This report contains a summary of the noise metric results collected from Sound Level Meters 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. Reports on measurements made at other IPP sites will be reported separately.

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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
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		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
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		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
B&K	Brüel & Kjær (acoustic equipment manufacturer)
CFR	Code of Federal Regulations
CNO	Choctaw Nation of Oklahoma
CPA	Closest point of approach
DJI	Dà-Jiāng Innovations (sUAS manufacturer)
FAA	Federal Aviation Administration
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
IPP	Integrated Pilot Program
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)
LP	Lead Participant
OSU	Oklahoma State University
NAS	National Airspace System
SD	Sound Designs (acoustic equipment manufacturer)
SLM	Sound Level Meter
START	Survey and Tracking Apparatus for Research in Transportation
sUAS	Small Unmanned Aerial System (generally less than 55 pounds)
UAS	Unmanned Aerial System
UAV	Unmanned Aerial Vehicle
USDOT	United States Department of Transportation

Executive Summary

The U.S. Department of Transportation (USDOT) and the Federal Aviation Administration (FAA) announced the establishment of the Unmanned Aerial System (UAS) Integrated Pilot Program (IPP) in November, 2017. The IPP allows selected groups to participate in demonstrating methods of safely and efficiently using UAS vehicles in the National Airspace System (NAS). As part of the IPP, the Lead Participants (LP) for each selected group were asked to support noise measurements of their Unmanned Aerial Vehicles (UAV). This report is the first in an intended series of reports on the noise characteristic of the UAVs in the IPP, with one report for each of the IPPs.

A requirement to measure and report UAV noise levels was included in the IPP agreements due to potential concerns with noise from UAS operations in close proximity to communities. UAVs may operate much closer to people than conventional aircraft, leading to new concerns about their operations. In addition, UAV may have unusual and unique noise characteristics compared to manned aircraft. Finally, UAVs under 55 pounds are currently exempt from the noise certification requirements of manned aircraft when the UAV is operated under U.S. Code of Federal Regulation (CFR) Title 14, Part 107. UAV which operate outside this regulation currently must meet the noise requirements of CFR Title 14 Part 36. The FAA intends to use the data collected from the IPP noise measurements to determine the applicability of Part 36 to UAS operations, and possibly modify those requirements if the data support that decision.

The measurements were conducted by the USDOT's Volpe National Transportation Systems Center (Volpe). Volpe was selected to perform these measurement due to their experience with aircraft noise measurements and aircraft noise certification.

The FAA selected the Choctaw Nation of Oklahoma's (CNO) IPP group as the first participant for noise measurements due to a number of factors. The CNO has a test site which is conducive to noise testing due its low ambient noise and total control over access to the site. The CNO IPP operates a wide variety of UAS. The CNO has successfully demonstrated their ability to meet a number of objectives in their IPP agreement with the FAA.

The acoustic measurements took place at the CNO's Daisy Ranch near Daisy, Oklahoma on July 15th and July 16th, 2019. Four UAVs were measured: three multicopters ranging from 5 to 45 pounds and a fixed-wing vehicle with a wing span of about 7 feet. Measurements were conducted in a manner consistent with the existing noise certification requirements for light helicopters and small propeller-driven airplanes. Measurements were also taken with the vehicles operating on simulated missions unique to UAS capabilities. Over 100 unique events were captured on the four UAVs.

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

1 Introduction

This report is the first of an intended series. This series will present basic noise data and information regarding noise measurements performed by the USDOT's Volpe Center (Volpe) in support of the Federal Aviation Administration's Office of Environment & Energy. These measurements support the FAA's National Airspace UAS Integration Pilot Program (IPP). The purpose of the IPP is to facilitate and expedite the integration of UAS into the National Airspace (NAS) in a safe and effective manner.

One of the primary concerns regarding such integration is the issue of community noise, and how UAS may impact the public in daily operations. Before UAS are included in the NAS, the FAA needs to determine what, if any, limitations or requirements (e.g. certification) should be placed on UAS operations regarding noise. The FAA is seeking data to determine an appropriate way forward; this measurement program directly supports that goal.

This report documents the noise measurements performed at the Choctaw Nation of Oklahoma's (CNO) IPP site near Daisy, Oklahoma during July 2019, and provides information about the site, the Lead Participant's (LP) organization, agreed IPP mission, and typical operations of specific UAS, including measured noise levels during those typical operations. In addition to the provided noise levels, continuous, calibrated, full-bandwidth audio recordings were made during these operations.

The audio recordings from this measurement campaign, including those from other IPP measurement programs, and potentially from additional sources, could be used for further analysis and evaluation to aid FAA in determining appropriate specifications, procedures, metrics, and limits for noise certification of such aircraft.

In addition to the information in the body of the report, Appendix A provides information on Volpe's UAS noise measurement instrumentation specifications and setup procedures, which is common to all IPP LP sites. Appendix B presents the questionnaires sent to IPP lead participants regarding details of the measurement site and the aircraft to be tested, prior to the start of the measurement program. Appendix C provides instructions for setup and operation of Volpe's small, on-aircraft GPS tracking system. Appendix D provides the reader with information about individual aircraft events; these individual events are the basis for the data provided in the body of the report.

2 Noise Measurements of UAs at the Choctaw Nation of Oklahoma's IPP site

2.1 CNO IPP Information

2.1.1 Mission description

The IPP Mission for CNO focuses on agricultural, public safety, and infrastructure inspections. The CNO plans to conduct both Beyond Visual Line of Sight (BVLOS) operations over people and nighttime operations.

2.1.2 Partners

CNO is partnering in the IPP with the following organizations; this partnership includes operating the aircraft measured in this report and developing operational procedures for those aircraft:

- Noble Research Institute, Ardmore, Oklahoma: independent non-profit agricultural research organization, operators of a DJI M200 UAV
- University of Oklahoma, Norman, Oklahoma: public university, joint operators with CNO of a Yuneec Typhoon
- Oklahoma State University, Stillwater, Oklahoma: public university, operators of a Skywalker X-8 and Gryphon Dynamics GD28X.

2.1.3 Site description

The CNO IPP site is located on the CNO's Daisy Ranch, near Daisy, Oklahoma. The ranch covers over 44,000 acres. The IPP site is in the southwestern area of the ranch. The following sub-sections describe particular aspects of the IPP site.

2.1.3.1 Terrain

The terrain in the ranch is a mixture of mountains, prairie, and forest. The IPP site is in grassland primarily used for raising cattle. Figure 1 shows an overview of the area in the IPP used in this acoustic test; the figure uses the standard map convention of 'up' representing north. The site was mowed so that the microphones were located in a circularly mowed section of about 40 feet diameter. A north-south line was mowed to provide the UAV operators with a clear visual reference for the desired flight path over the microphones. A base station area – the yellow canopy in the figures – located about 80 feet to the east of the centerline microphone was used as the location of the acoustic measurement equipment and as the staging area for vehicle preparation. A detail of the site is provided in Figure 2, including the positions of the three microphones used in this measurement program. The centerline ground plane microphone was placed at the center of the mowed circle. A centerline pole-mounted microphone – with the microphone 4 feet from the ground – was placed 10 feet south of the centerline ground plane microphone. A second ground plane microphone was placed 20 feet to the west of the north-south centerline. The two ground plane microphones were installed in a manner consistent with the requirements of CFR Title 14, Part 36, Appendix G (U.S. Federal Government, 2019), the small propeller-driven airplane noise certification requirements document for the United States. The pole-mounted microphone was installed in a manner consistent with the requirements of Part 36, Appendix J (U.S. Federal Governement, 2019), the U.S. light helicopter noise certification requirements document. Note that as of this report, Appendices G and J are the only aircraft noise certification standards that might be considered to be applicable for noise certification of sUAS in the United States. More details of the acoustic data collection system are provided in Section 2.2.1 and in Appendix A.

In Figure 2, the white object between the sideline ground plane microphone (“Offset Grnd Mic” in the figure’s legend) and the Hover/Landing Point (the “pad”) is the Skywalker X-8 vehicle. The Hover/Landing point is the location where all multicopter operations started and ended. The X-8 vehicle was launched from the south of the measurement site using a bungee system.

Figure 3 shows the initial mowing of the test site, before the microphone and supporting equipment were put in place. Figure 3 was shot from the position of the base station, looking west at the measurement site.

Figure 4 shows a detail of one of the ground plane microphone installations. The microphone is suspended inverted over the ground plate with the prescribed Appendix G spacing between the plate and the microphone diaphragm. The microphone is offset from the ground plate center and the ground plate is faired in the surrounding surface to minimize the effects on the acoustic measurements of changing the surface impedance. The red line on the surface plate indicates the direction of the vehicle passes over the plate (north-south).

Figure 1, Overhead view of acoustic measurement site

Figure 2, Close-up of measurement site – with annotation

Figure 3, Preparing the measurement site by mowing

Figure 4, Detail of ground plane microphone installation

2.1.3.2 Weather

The weather during the measurements was generally dry and sunny. 2019's Hurricane Barry came ashore in the Southeastern United States in the days prior to the start of the measurement program; an increase in cloudy weather occurred, but there was no precipitation during the measurement period.

Winds were generally light in the morning, but strengthened during the day. Winds were strongest on the measurement day of 17 July. Local meteorological data (temperature, relative humidity, and wind speed and direction) were captured at a 2Hz sample rate (twice per second) during the entire measurement period for each aircraft pass-by event using a portable ultrasonic sensor. Wind data are included in Appendix D.

2.1.3.3 Ambient sound

Wind noise was the dominant ambient sound. For some aircraft flybys and for some microphones, the ambient noise levels were sufficiently high to prevent capture of the full 10 dBA rise and fall required for a valid Sound Exposure Level (SEL) measurement. The SEL data tables in Appendix D include information on the quality of the SEL measurements for each applicable event.

The measurement site is in the middle of an active cattle ranch. While no cattle came near the microphones, on the morning of July 16th, a cattle feeding operation took place in the vicinity of the measurements, see Figure 5 and Figure 6. During this period, the ambient noise of the cattle precluded the collection of UAV noise data. When the feeding operation concluded, the cattle noise diminished and the measurements continued.

The measurement site is in the vicinity of the McAlester Army Ammunition Plant. The plant detonates ammunition on a daily basis at known periods during the day. Explosions from the plant can be heard at the measurement site. However, since the time of the planned explosions are known, the acoustic measurements were suspended during this period.

Figure 5, Cattle near measurement site at start of the feeding operation

Figure 6, Cowboys near measurement site looking for stray cattle

2.1.4 UAVs operated by CNO

The Yuneec Typhoon is operated by CNO and the University of Oklahoma as part of the IPP.

2.1.4.1 Yuneec Typhoon

The Yuneec Typhon is an electrically powered hexcopter (six rotors) with a maximum takeoff weight (MTOW) of about 5.3 pounds. The largest dimension (rotor tip to rotor tip) is about 20.5 inches. The Typhoon was operated with its camera and gimbal removed and the Volpe START tracking system installed. Figure 7 shows an example of a Typhoon.

The Typhoon was flown on the morning on July 16, 2019. A summary of the results from the sound level meters (SLM) used in the measurement program are given in Table 1 through Table 12 in Section 3.2.

Figure 7, Yuneec Typhoon

2.1.5 UAVs operated by CNO partners

The DJI M200 is operated by the Noble Research Institute as part of the IPP. The Gryphon Dynamics GD28X and the Skywalker X-8 vehicles are operated by OSU. Each vehicle is discussed in the following sub-sections.

2.1.5.1 DJI M200

The DJI M200 is an electrically powered quadcopter (four rotors) with a MTOW of about 13.5 pounds and the tip-to-tip length of about 35 inches. The M200 was flown with its camera and gimbal still attached. Figure 8 shows an example of an M200.

The M200 was flown in the afternoon on July 16, 2019. A summary of the results from the SLMs used in the measurement program are given in Table 13 through Table 24 in Section 3.3.

Figure 8, DJI M200

2.1.5.2 Gryphon Dynamics GD28X

The GD28X, shown in Figure 9, was the heaviest vehicle participating in the measurement program. The GD28X is an electrically powered octocopter (eight rotors) which can be flown at an MTOW of 70 pounds, but for this test was limited to 45 pounds to comply with the FAA's Part 107 rules. The GD28X is over 4 and a half feet from rotor tip to rotor tip. Figure 10 shows the GD28X while the Volpe START system is being installed. Note that the GD28X is intended to be operated as a camera platform, but, like the Typhoon, had its camera and gimbal removed for this measurement program.

The GD28X was flown on the morning of July 17, 2019. A summary of the results from the SLMs used in the measurement program are given in Table 25 through Table 35 in Section 3.4.

Figure 9, Gryphon Dynamics GD28X

Figure 10, Installing START tracking equipment on the GD28X

2.1.5.3 Skywalker X-8

The Skywalker X-8 is a flying wing vehicle powered by a single pusher propeller driven by an electric motor. The X-8 has a maximum takeoff weight (MTOW) of about 6.6 pounds. The largest dimension (wing tip to wing tip) is about 7 feet. The X-8 was modified by OSU to include a forward-looking camera, but the camera was removed for this acoustic test and the Volpe START tracking system installed. Figure 11 shows an example of an X-8. This image doesn't convey the size of the aircraft; Figure 12 shows the vehicle prior to launch, with the vehicle's operators in the image for scale. The vehicle is launched with a bungee cord; the pusher propeller is designed with folding blades to reduce the possibility of damage to the propeller or motor during landings, as well as to the operator, during hand launches. In Figure 12, the propeller can be seen hanging with both blades folded back.

The GD28X was flown on the afternoon of July 17, 2019. A summary of the results from the SLMs used in the measurement program are given in Table 36 through Table 41 in Section 3.5.

Figure 11, Skywalker X-8

Figure 12, Preparing the X-8 for launch

2.2 Noise measurement procedures and instrumentation

This section provides an overview of the processes and equipment used in the CNO measurement program. A detailed description can be found in Appendix A.

2.2.1 Acoustic data collection system

As mentioned earlier in the report, the primary data collection system included three microphone positions. Each microphone position used a GRAS Model 40AO 1/2 inch pressure microphone.

2.2.1.1 Microphone locations

The centerline ground plane microphone was used as the local origin of coordinates. This microphone and its installation in the measurement area complied with the requirements of Part 36, Appendix G.

Also on the centerline of the flight paths was a pole-mounted microphone. This microphone was located 10 feet south of the primary ground plane microphone. This microphone was in compliance with Part 36, Appendix J.

The secondary ground plane microphone was located 20 feet to the west of the primary ground plane microphone. This microphone was included for research purposes. This microphone was set up as an Appendix G microphone, but its position offset from the flight path was not in compliance with certification requirements.

2.2.1.2 Sound Level Meters

For each of the three microphones, the acoustic signal was fed into a Larson-Davis 831 Type 1/Class 1 SLM capturing 0.5 second time histories of the slow response, A-weighted noise levels. These SLMs were the primary instruments used to provide the data presented in Section 3.

2.2.1.3 Digital Audio Recordings

In addition to the noise level data recorded by the SLMs, the audio data were also input to a Sound Devices 744T digital audio recorder. The signal from each microphone was split prior to the input of the SLM, with one signal path directly feeding the SLM, and the other signal path going through a gain-conditioning amplifier (in this case, a secondary SLM, used only to control signal gain), then input to the 744T. The 744T was set at a 48 kHz sample rate with 24-bit Analog to Digital Conversion.

A time synchronization signal from a dedicated GPS timecode receiver was also input to the 744T.

2.2.2 Vehicle tracking system

Due primarily to their smaller size and lower weight, sUAS are quieter than conventional aircraft, and therefore must fly closer to the microphones than specified in the Noise Certification rules to enable an adequate signal-to-noise ratio. However, the closer the vehicles fly to the microphones, the more the uncertainty in their position can influence the quality of the measured acoustic data. This topic is discussed in detail in a prior Volpe report (Senzig, Marsan, & Downs, UAS noise certification and measurement status report, 2017). To enable accurate tracking of the sUAS, the Volpe Center developed the START (Survey and Tracking Apparatus for Research in Transportation) system.

The START system is a lightweight (typically 1 lb. or less, varying with specific configuration) GNSS-based system that is capable of providing higher fidelity position information than a typical GPS system. The START system does this by retaining the raw satellite data from the GNSS system and storing those data for post-processing. This post-processing can improve position accuracy by accounting for atmospheric variations that can affect the GPS signal paths and which can’t be known at the time of the measurements. Post-processing can yield accuracies on the order of 5 to 10 centimeters.

The START system uses a rover and a base system. The base station did not move during the period of the tests, while the rover was attached to each of the flight vehicles for their flight sequence. The rover is a compact system based on a PC-on-a-stick, GPS antenna, battery, and supporting cabling. The START system is discussed in detail in Appendix C.

2.2.3 Meteorological data collection system

Meteorological data were also collected during the noise test. A Vaisala WXT-520 weather station supplied wind speed and direction, temperature, and relative humidity information directly into the primary microphone's SLM for concurrent recording of noise and meteorological data. The collection of wind, temperature, and relative humidity data was conducted in a manner compliant with CFR Title 14, Part 36, Appendices G and J.

2.3 Flight procedures

This section provides an overview of the flight procedures used in the CNO measurements. These procedures were intended to capture typical operations expected during actual use in the NAS. These uses were identified during discussions with CNO staff during the scoping visit to the IPP site on June 27th, 2019.

Both the multicopters and the fixed-wing aircraft flew a common set of level overflights at both slow and fast speeds. The low speed operations were intended to replicate a loitering operation where the vehicle is operated with the intension of conserving energy to the extent possible. The fast overflight operations were a dash at the maximum speed of the vehicle. These level overflights all took place at a height of 150 feet over the microphones. These slow and fast overflights were intended to be minimum and maximum power operations over the microphone to bracket any possible power settings.

The slow and fast overflights were done in alternating north-to-south then south-to-north passes. Between each pass, the vehicle was set into a loitering operation while the IPP measurement team determined the acceptability of the pass. Where possible, each type of operation was repeated until at least three acceptable passes had been measured.

In addition to these common operations, operations unique to the particular class of vehicle were also conducted. These are discussed in the following sub-sections.

2.3.1 Multicopter Flight Procedures

This section discusses the flight procedures used by the multicopter vehicles: the Typhoon, the M200, and the GD28X.

2.3.1.1 Vertical takeoff and landing operations

The vehicle operators flew each of the three multicopters through a series of simulated vertical takeoff and landings. The takeoffs originated at the Hover/Landing point shown in Figure 2 above. The operators flew the vehicles to an altitude of 150 feet with a vertical ascent, then proceeded due north far enough from the measurement sight that the vehicle was visible, but not readily audible. After loitering for enough time for the measurement team to determine the acceptability of the event, the vehicle was flown back to the measurement site, again at 150 feet AGL, and then vertically descended to the landing/hover point. The pair of operations (takeoff and landing) were repeated at least three times for each vehicle. Not-to-scale schematics of the takeoff and landing operations are shown in Figure 13 and Figure 14, respectively. Note that measurements and recordings captured the full duration of the takeoff and landing events, including motor start and spin-up for takeoffs, and spin-down for landings. This is in contrast to conventional noise certification takeoff or approach event requirements, where such events are simulated.

These takeoff and landing operating are intended to mimic potential operations in a community where landing and takeoff operations might be required, e.g. with package delivery systems.

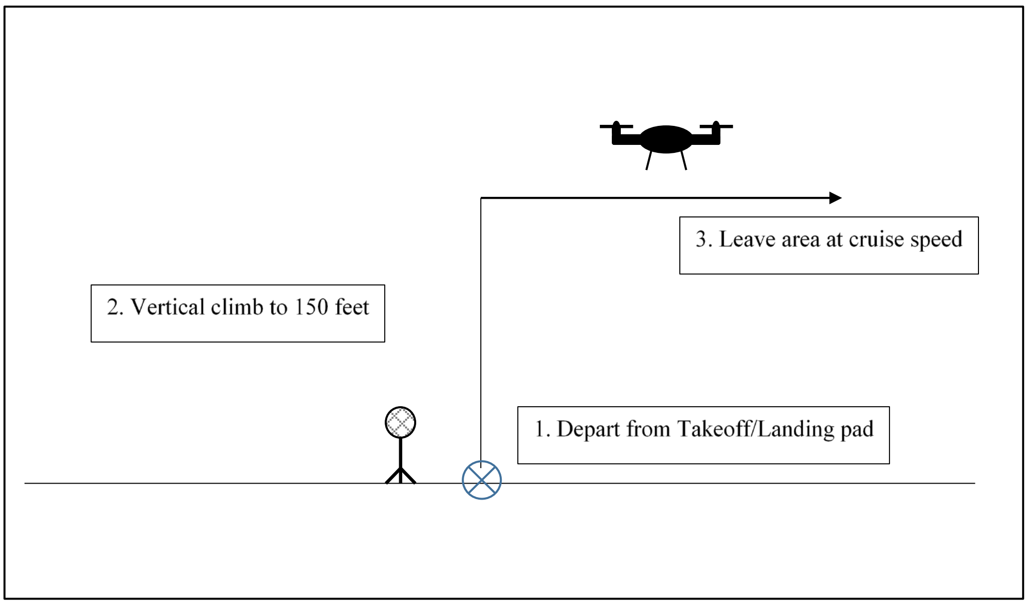

Figure 13, Schematic of vertical takeoff operation

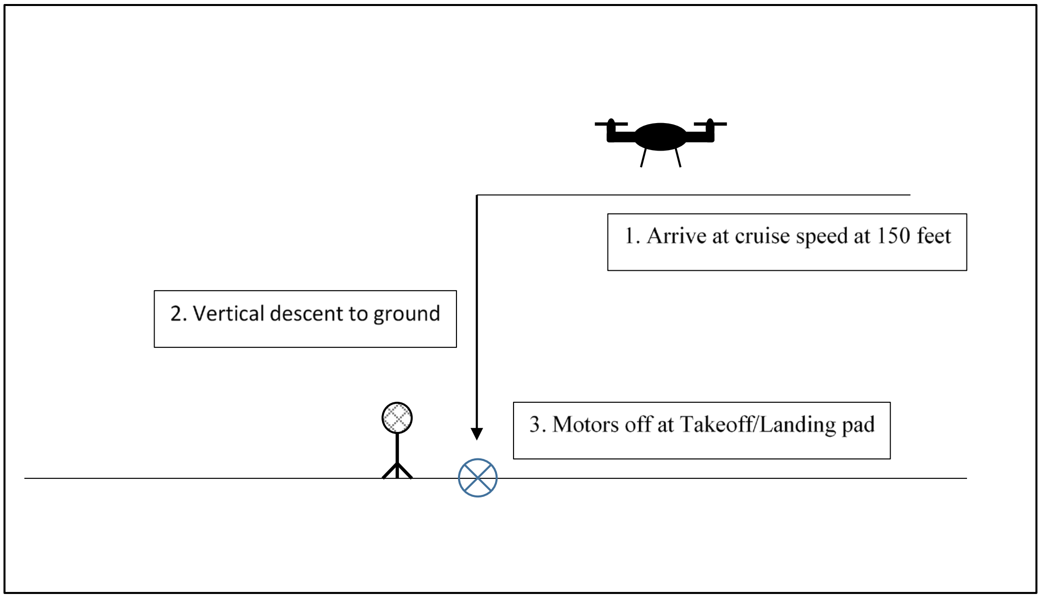

Figure 14, Schematic of vertical landing operation

2.3.1.2 Hover operations

Each of the multicopters were flown in hover operations at 4 feet AGL over the hover/Landing point. The hovers were conducted with the aircraft facing each of the four cardinal compass directions: the vehicles typically started with a hover facing north; this direction was held for 30 seconds, then the vehicle was rotated (i.e. yawed) 90 degrees and again held in that position for 30 seconds. The rotation was repeated two more times. The rotations on the yaw axis were done to determine the effects of wind on the noise of the vehicle in hover; researchers have noted that multicopters exhibit unsteady noise during hover (Cabell, McSwain, & Grosveld, 2016). The variation in noise may be related to the wind contributing to unsteady loading on the rotors, with the wind direction contributing relatively more to the fluctuation on the advancing blade than the retreating blade.

Where time and battery power permitted, some multicopters were also operated in hover, facing a single direction at multiple altitudes over the microphones. For these operations, the vehicles were held facing north, and vertically ascended over the hover/landing point at increments of 50 feet. At each 50 foot increment, the vehicle was hovered in place for 30 seconds.

2.3.1.3 Infrastructure inspection operations

Each of the multicopters was also operated for several series of simulated infrastructure inspection operations. For these operations, the vehicle was initially flown to a distance of at least 500 feet to the north of the hover/landing point at an altitude of 100 feet AGL. The vehicle was then flown back to the measurement area. Once over the hover/landing point, the vehicle was descended to 80 feet AGL, then held in a hover at that altitude for 30 seconds. At the end of the 30 seconds, the vehicle performed a vertical climb back to 100 feet AGL and then departed the measurement area at that altitude to the northern loiter area. A not-to-scale schematic of this type of operation is shown in Figure 15.

The Infrastructure inspection operation was intended to simulate an inspection process on a vertical structure such as a building, bridge, or an electrical power line tower.

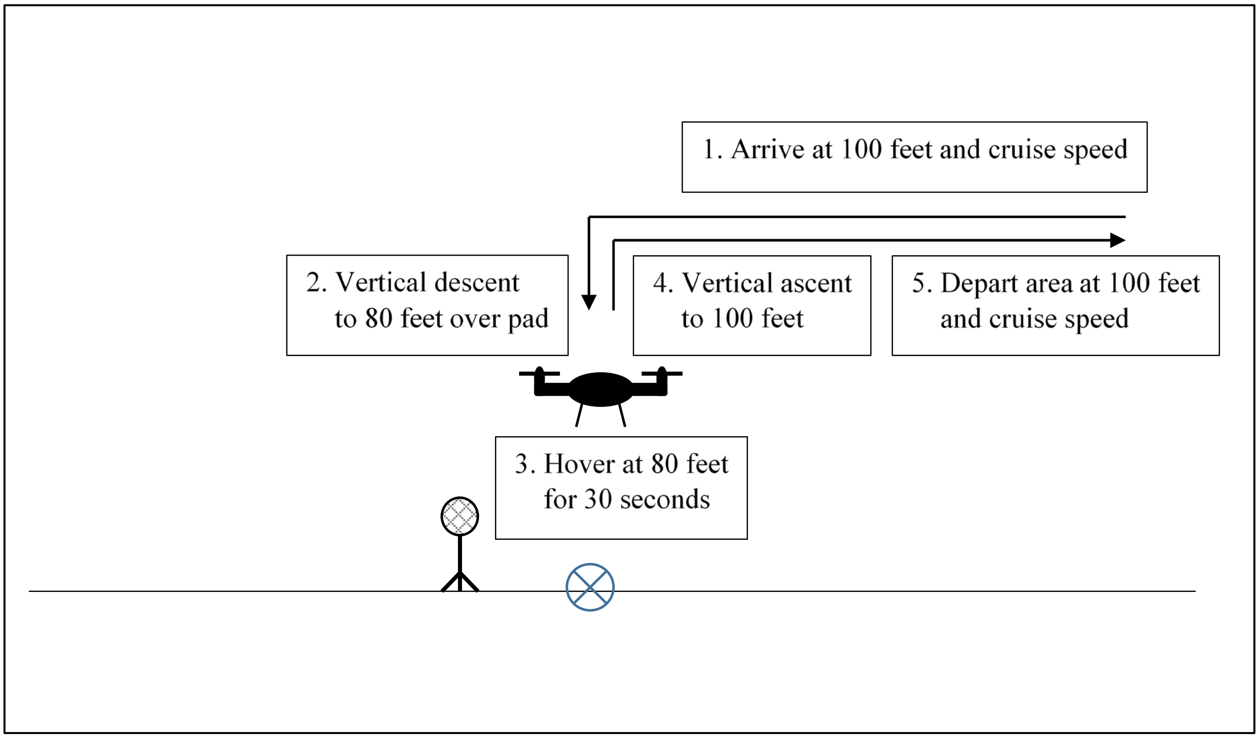

Figure 15, Schematic of infrastructure operation

2.3.2 Fixed-wing Flight Procedures

In addition to the common level flyovers, the fixed-wing X-8 was also tested on a series of simulated full-power takeoffs (T/O) targeted for 100' AGL at the microphones. Unlike the level flyovers which alternated direction, the simulated takeoffs all occurred as passes from north to south. In addition to launching into the prevailing wind, this enabled the vehicle operators to better estimate the point at which full power and a takeoff pitch change had to occur to bring the vehicle over the microphone near the target height of 100 feet.

2.3.3 General Philosophy Relating to Flight Procedures

For typical noise certification flight-testing, strict limits are provided for deviations from the target flight performance, including elements such as:

- Aircraft position deviation relative to target flight path;
- Aircraft speed and power deviation
- Rotor or propeller rotational speed deviation.

Experience has suggested that difficulties in maintaining performance within such limits can lead to a situation where the pilot is attempting frequent, sometimes extreme, course corrections that are not typical during conventional flight. Pilot fatigue and the learning curve required to attain the target accuracy can reduce the number of usable passes captured during a measurement period. It is also noted that for automated or automation-assisted flight operation, it may be impossible to prevent such corrections that may be initiated by the autopilot or piloting assists.

For these reasons, and in the interest of obtaining as much data as possible for research purposes, the CNO remote pilots were advised to operate the test aircraft in a normal manner. The priority for each operation was to attain stabilized flight conditions when near the microphone area, rather than achieving target performance or position accuracy.

This philosophy assumes that off-specification flights can provide useful data. This approach to measurements is dependent on the availability of high-precision position information. For this measurement program, such high-precision position information was provided by Volpe's START position tracking system.

One of the outcomes of such a measurement philosophy is that there is likely to be a wider variation in noise levels from flight to flight, which may require precise position information to be corrected or adjusted to more nominal flight paths. A quick look at the statistical data in Appendix D accompanying the measured results in this report suggests that the variation is not unreasonably greater than might be expected for such small off- the-shelf aircraft.

3 Noise Levels of UAS Measured at CNO IPP site

3.1 Noise Metric Definitions

The instrumentation used for noise measurement was configured to capture noise level data for selected metrics in the field. These data are presented in Section 3 and in Appendix D. The metric definitions and their associated nomenclature as used in this report are provided below. Metric calculations, equations, and detailed descriptions can be found in ASA/ANSI S1.1 (Acoustical Society of America, American National Standards Institute, 2013).

- **L_{ASmx}** (Maximum slow time-averaged A-weighted sound level, abbreviation: “LAMax”)
- **L_{AE}** (A-weighted sound exposure level, abbreviation: “SEL”)
- **L_{Aeq}** (A-weighted equivalent sound level, abbreviation “LEQ”)

Noise metrics are referenced by their formal names in all tables and charts, and are referred to by their abbreviations in the report text.

3.2 Noise Measurement data for Typhoon

The data in the following tables represent the arithmetic averages for all passes in a particular series. Data for individual passes are provided in Appendix D. Note that the normalized distance tables do not include a normalized SEL. Issues with normalizing SEL measurements are discussed in a prior Volpe document (Senzig, Marsan, Cutler, & Read, 2018).

3.2.1 Typhoon Slow Flyover measurements summary

Table 1. Typhoon series 100 noise levels average as measured; A-weighted

Series	Passes	Event Type	Mic	L_{ASmx} dB	L_{AE} dB	notes
100	7	Slow LFO 150’	CLG	57.9	68.6	Slow flight, level flyover at 150 foot nominal height above the microphones
			CLP	54.7	67.0	
			SLG	58.1	68.6	

Table 2. Typhoon series 100 noise levels average normalized to 400 feet CPA; A-weighted

Series	Passes	Event Type	Mic	L_{ASmx} dB	notes
100	7	Slow LFO 400’	CLG	49.7	Slow flight, level flyover normalized to 400 foot height above the microphones
			CLP	46.2	
			SLG	50.0	

3.2.2 Typhoon Fast Flyover measurements summary

Table 3. Typhoon series 200 noise levels average as measured; A-weighted

Series	Passes	Event Type	Mic	L_{ASmx} dB	L_{AE} dB	notes
200	4	Fast LFO 150’	CLG	58.9	66.1	Fast flight, level flyover at 150 foot nominal height above the microphones
			CLP	55.1	65.8	
			SLG	58.8	66.2	

Table 4. Typhoon series 200 noise levels average normalized to 400 feet CPA; A-weighted

Series	Passes	Event Type	Mic	L_{ASmx} dB	notes
200	4	Fast LFO 400’	CLG	50.1	Fast flight, level flyover normalized to 400 foot height above the microphones
			CLP	46.4	
			SLG	50.1	

3.2.3 Typhoon vertical takeoff measurements summary

Table 5. Typhoon series 300 noise levels average as measured; A-weighted

Series	Passes	Event Type	Mic	L_{ASmx} dB	notes
300	4	Takeoff	CLG	67.4	Takeoff from pad near microphones, vertical ascent to 100 feet, depart area to North
			CLP	60.0	
			SLG	63.5	

Table 6. Typhoon series 300 noise levels average normalized to 100 feet CPA; A-weighted

Series	Passes	Event Type	Mic	L_{ASmx} dB	notes
300	4	Takeoff	CLG	54.1	Takeoff normalized to 100 foot distance
			CLP	49.9	
			SLG	54.0	

3.2.4 Typhoon vertical landing measurements summary

Table 7. Typhoon series 301 noise levels average as measured; A-weighted

Series	Passes	Event Type	Mic	L_{ASmx} dB	notes
301	4	Landing	CLG	72.7	Arrive from North at 100 foot cruise, vertical descent to landing pad, motors to idle or off
			CLP	65.5	
			SLG	70.1	

Table 8. Typhoon series 301 noise levels average normalized to 100 feet CPA; A-weighted

Series	Passes	Event Type	Mic	L_{ASmx} dB	notes
301	4	Landing	CLG	61.1	Landing normalized to 100 foot distance
			CLP	57.3	
			SLG	62.2	

3.2.5 Typhoon Infrastructure Inspection measurements summary

Table 9. Typhoon series 400 noise levels average as measured; A-weighted

Series	Passes	Event Type	Mic	L_{ASmx} dB	notes
400	4	Inspect.	CLG	63.1	Infrastructure Inspection simulation. Arrive from north in 100 foot cruise; stop over pad; vertical descent to 80 feet AGL; hold position for 30 seconds, vertical ascent to 100 feet, depart area to North
			CLP	59.6	
			SLG	63.1	

Table 10. Typhoon series 400 noise levels average normalized to 100 feet CPA; A-weighted

Series	Passes	Event Type	Mic	L_{ASmx} dB	notes
400	4	Inspect.	CLG	62.5	Infrastructure Inspection normalized to 100 foot distance
			CLP	58.6	
			SLG	62.6	

3.2.6 Typhoon Hover measurements summary

Table 11. Typhoon series 500 noise levels average as measured; A-weighted

Series	Passes	Event Type	Mic	L_{Aeq} dB - North	L_{Aeq} dB - East	L_{Aeq} dB - South	L_{Aeq} dB - West	notes
500	2	Hover	CLG	58.9	56.7	55.9	56.9	See Below
			CLP	58.8	56.5	56.1	57.5	
			SLG	57.3	55.8	55.4	55.8	

Hover Notes: Hover over pad, 4 foot AGL; align with cardinal compass points and hold for approximately 30 seconds. The actual averaging times for the events are given in Appendix D.

Table 12. Typhoon series 500 noise levels average normalized to 100 feet; A-weighted

Series	Passes	Event Type	Mic	L_{Aeq} dB - North	L_{Aeq} dB - East	L_{Aeq} dB - South	L_{Aeq} dB - West	notes
500	2	Hover	CLG	45.8	43.9	42.9	43.9	Scaled to 100 feet
			CLP	48.8	46.9	46.4	47.9	
			SLG	47.2	45.6	45.0	45.8	

3.3 Noise Measurement data for M200

3.3.1 M200 Slow Flyover measurements summary

Table 13. M200 series 100 noise levels average as measured; A-weighted

Series	Passes	Event Type	Mic	L_{ASmx} dB	L_{AE} dB	notes
100	4	Slow LFO 150’	CLG	58.8	67.6	Slow flight, level flyover at 150 foot nominal height above the microphones
			CLP	54.7	65.2	
			SLG	59.0	67.9	

Table 14. M200 series 100 noise levels average normalized to 400 feet CPA; A-weighted

Series	Passes	Event Type	Mic	L_{ASmx} dB	notes
100	4	Slow LFO 400’	CLG	51.8	Slow flight, level flyover normalized to 400 foot height above the microphones
			CLP	47.5	
			SLG	51.9	

3.3.2 M200 Fast Flyover measurements summary

Table 15. M200 series 200 noise levels average as measured; A-weighted

Series	Passes	Event Type	Mic	L_{ASmx} dB	L_{AE} dB	notes
200	4	Fast LFO 150’	CLG	59.3	65.9	Fast flight, level flyover at 150 foot nominal height above the microphones
			CLP	55.7	62.9	
			SLG	59.5	66.1	

Table 16. M200 series 200 noise levels average normalized to 400 feet CPA; A-weighted

Series	Passes	Event Type	Mic	L_{ASmx} dB	notes
200	4	Fast LFO 400’	CLG	52.1	Fast flight, level flyover normalized to 400 foot height above the microphones
			CLP	48.2	
			SLG	52.3	

3.3.3 M200 vertical takeoff measurements summary

Table 17. M200 series 300 noise levels average as measured; A-weighted

Series	Passes	Event Type	Mic	L_{ASmx} dB	notes
300	4	Takeoff	CLG	67.1	Takeoff from pad near microphones, vertical ascent to 100 feet, depart area to North
			CLP	60.0	
			SLG	64.9	

Table 18. M200 series 300 noise levels average normalized to 100 feet CPA; A-weighted

Series	Passes	Event Type	Mic	L_{ASmx} dB	notes
300	4	Takeoff	CLG	57.1	Takeoff normalized to 100 foot distance
			CLP	51.9	
			SLG	57.7	

3.3.4 M200 vertical landing measurements summary

Table 19. M200 series 301 noise levels average as measured; A-weighted

Series	Passes	Event Type	Mic	L_{ASmx} dB	notes
301	4	Landing	CLG	74.5	Arrive from North at 100 foot cruise, vertical descent to landing pad, motors to idle or off
			CLP	67.1	
			SLG	72.0	

Table 20. M200 series 301 noise levels average normalized to 100 feet CPA; A-weighted

Series	Passes	Event Type	Mic	L_{ASmx} dB	notes
301	4	Landing	CLG	64.9	Landing normalized to 100 foot distance
			CLP	59.3	
			SLG	64.2	

3.3.5 M200 Infrastructure Inspection measurements summary

Table 21. M200 series 400 noise levels average as measured; A-weighted

Series	Passes	Event Type	Mic	L_{ASmx} dB	notes
400	3	Inspect.	CLG	66.1	Infrastructure Inspection simulation. Arrive from north in 100 foot cruise; stop over pad; vertical descent to 80 feet AGL; hold position for 30 seconds, vertical ascent to 100 feet, depart area to North
			CLP	61.9	
			SLG	65.8	

Table 22. M200 series 400 noise levels average normalized to 100 feet CPA; A-weighted

Series	Passes	Event Type	Mic	L_{ASmx} dB	notes
400	3	Inspect.	CLG	66.2	Infrastructure Inspection normalized to 100 foot distance
			CLP	62.0	
			SLG	66.1	

3.3.6 M200 Hover measurements summary

Table 23. M200 series 500 noise levels average as measured; A-weighted

Series	Passes	Event Type	Mic	L_{Aeq} dB - North	L_{Aeq} dB - East	L_{Aeq} dB - South	L_{Aeq} dB - West	notes
500	2	Hover	CLG	66.2	68.4	67.6	68.6	See Below
			CLP	57.9	59.6	59.2	59.7	
			SLG	60.5	60.7	61.1	61.6	

Hover Notes: Hover over pad, 4 foot AGL; align with cardinal compass points and hold for 30 seconds

Table 24. M200 series 500 noise levels average normalized to 100 feet CPA; A-weighted

Series	Passes	Event Type	Mic	L_{Aeq} dB - North	L_{Aeq} dB - East	L_{Aeq} dB - South	L_{Aeq} dB - West	notes
500	2	Hover	CLG	52.7	54.7	54.0	55.0	Scaled to 100 feet
			CLP	47.6	49.2	49.0	49.3	
			SLG	50.5	50.6	51.1	51.6	

3.4 Noise Measurement data for GD28X

3.4.1 GD28X Slow Flyover measurements summary

Table 25. GD28X series 100 noise average levels as measured; A-weighted

Series	Passes	Event Type	Mic	L_{ASmx} dB	L_{AE} dB	notes
100	8	Slow LFO 150’	CLG	70.5	79.2	Slow flight, level flyover at 150 foot nominal height above the microphones
			CLP	66.4	75.4	
			SLG	70.9	79.7	

Note the different number of runs in the as-measured and the normalized data. A tracking system failure in four of the runs prevented the calculation of accurate distances, so only the four passes with acceptable distance calculations were used in the normalization.

Table 26. GD28X series 100 noise levels average normalized to 400 feet CPA; A-weighted

Series	Passes	Event Type	Mic	L_{ASmx} dB	notes
100	4	Slow LFO 400’	CLG	62.0	Slow flight, level flyover normalized to 400 foot height above the microphones
			CLP	57.9	
			SLG	62.3	

3.4.2 GD28X Fast Flyover measurements summary

Table 27. GD28X series 200 noise levels average as measured; A-weighted

Series	Passes	Event Type	Mic	L_{ASmx} dB	L_{AE} dB	notes
200	5	Fast LFO 150’	CLG	73.2	80.0	Fast flight, level flyover at 150 foot nominal height above the microphones
			CLP	69.1	76.2	
			SLG	73.4	80.2	

Table 28. GD28X series 200 noise levels average normalized to 400 feet CPA; A-weighted

Series	Passes	Event Type	Mic	L_{ASmx} dB	notes
200	4	Fast LFO 400’	CLG	64.0	Fast flight, level flyover normalized to 400 foot height above the microphones
			CLP	59.9	
			SLG	64.1	

3.4.3 GD28X Vertical takeoff measurements summary

Table 29. GD28X series 300 noise levels average as measured; A-weighted

Series	Passes	Event Type	Mic	L_{ASmx} dB	notes
300	4	Takeoff	CLG	80.4	Takeoff from pad near microphones, vertical ascent to 100 feet, depart area to North
			CLP	73.2	
			SLG	80.5	

Table 30. GD28X series 300 noise levels average normalized to 100 feet CPA; A-weighted

Series	Passes	Event Type	Mic	L_{ASmx} dB	notes
300	4	Takeoff	CLG	69.7	Takeoff normalized to 100 foot distance
			CLP	67.5	
			SLG	71.9	

3.4.4 GD28X vertical landing measurements summary

Table 31. GD28X series 301 noise levels average as measured; A-weighted

Series	Passes	Event Type	Mic	L_{ASmx} dB	notes
301	4	Landing	CLG	79.7	Arrive from North at 100 foot cruise, vertical descent to landing pad, motors to idle or off
			CLP	72.8	
			SLG	81.9	

Table 32. GD28X series 301 noise levels average normalized to 100 feet CPA; A-weighted

Series	Passes	Event Type	Mic	L_{ASmx} dB	notes
301	4	Landing	CLG	67.8	Landing normalized to 100 foot distance
			CLP	66.0	
			SLG	69.6	

3.4.5 GD28X Infrastructure Inspection measurements summary

Table 33. GD28X series 400 noise levels average as measured; A-weighted

Series	Passes	Event Type	Mic	L_{ASmx} dB	notes
400	4	Inspect.	CLG	77.6	Infrastructure Inspection simulation. Arrive from north in 100 foot cruise; stop over pad; vertical descent to 80 feet AGL; hold position for 30 seconds, vertical ascent to 100 feet, depart area to North
			CLP	73.7	
			SLG	77.7	

Table 34. GD28X series 400 noise levels average normalized to 100 feet CPA; A-weighted

Series	Passes	Event Type	Mic	L_{ASmx} dB	notes
400	1	Inspect.	CLG	74.7	Infrastructure Inspection normalized to 100 foot distance
			CLP	70.0	
			SLG	75.0	

3.4.6 GD28X Hover measurements summary

Note that during the testing for the GD28X hover operations, the signal from the pole microphone was lost. Also, a problem with the Volpe START system during the hover tests led to no tracking data availability for determining the normalization data.

Table 35. GD28X series 500 noise levels average as measured; A-weighted

Series	Passes	Event Type	Mic	L_{Aeq} dB - North	L_{Aeq} dB - East	L_{Aeq} dB - South	L_{Aeq} dB - West	notes
500	2	Hover	CLG	77.3	77.6	77.4	77.3	See Below
			CLP	-	-	-	-	
			SLG	76.4	76.0	75.3	74.3	

Hover Notes: Hover over pad, 4 foot AGL; align with cardinal compass points and hold for 30 seconds

3.5 Noise Measurement data for X-8

3.5.1 X-8 Slow Flyover measurements summary

Table 36. X-8 series 100 noise levels average as measured; A-weighted

Series	Passes	Event Type	Mic	L_{ASmx} dB	L_{AE} dB	notes
100	8	Slow LFO 150’	CLG	53.2	61.4	Slow flight, level flyover at 150 foot nominal height above the microphones, see note below
			CLP	51.1	62.4	
			SLG	53.6	61.3	

Note that for this series, the Centerline Pole microphone did not measure an L_{ASmx} 10 dB above the ambient for any of the eight passes.

Table 37. X-8 series 100 noise levels average normalized to 400 feet CPA; A-weighted

Series	Passes	Event Type	Mic	L_{ASmx} dB	notes
100	8	Slow LFO 400’	CLG	44.0	Slow flight, level flyover normalized to 400 foot height above the microphones
			CLP	43.3	
			SLG	44.4	

3.5.2 X-8 Fast Flyover measurements summary

Table 38. X-8 series 200 noise levels average as measured; A-weighted

Series	Passes	Event Type	Mic	L_{ASmx} dB	L_{AE} dB	notes
200	8	Fast LFO 150’	CLG	61.6	67.9	Fast flight, level flyover at 150 foot nominal height above the microphones
			CLP	58.8	65.9	
			SLG	61.3	67.7	

Table 39. X-8 series 200 noise levels average normalized to 400 feet CPA; A-weighted

Series	Passes	Event Type	Mic	L_{ASmx} dB	notes
200	8	Fast LFO 400’	CLG	53.2	Fast flight, level flyover normalized to 400 foot height above the microphones
			CLP	53.7	
			SLG	54.3	

3.5.3 X-8 Takeoff measurements summary

Table 40. X-8 series 300 noise levels average as measured; A-weighted

Series	Passes	Event Type	Mic	L_{ASmx} dB	L_{AE} dB	notes
300	4	Takeoff	CLG	60.4	66.1	Simulated Appendix G takeoff, approach to microphones from the north
			CLP	58.2	64.6	
			SLG	61.1	67	

Table 41. X-8 series 300 noise levels average normalized to 400 feet CPA; A-weighted

Series	Passes	Event Type	Mic	L_{ASmx} dB	notes
300	4	Takeoff	CLG	52.7	Takeoff normalized to 400 foot distance
			CLP	52.1	
			SLG	54.7	

3.6 Comparison with other UAS noise data

Table 42 provides a rough comparison of noise level data from the current measurement campaign as well as data collected from previous sUAS noise measurements in which Volpe has participated and data collected from other programs. The noise levels in this table have been normalized (by applying a simple distance adjustment) to a common 400 foot distance for a number of vehicles. The two leftmost columns indicate the name and type of vehicle. The third column shows the weight of the vehicle in pounds. The fourth column indicates the operation type conducted during the particular noise test. “Takeoff” indicates that an operation similar to Part 36 Appendix G test was used. “Level overflight” indicates a straight-and-level pass over the microphone (only fast overflights are included); The fifth column indicates the type of microphone installation: “IGPM” is an Inverted Ground Plane Microphone, which is the type of installation explicitly specified in CFR Title 14, Part 36, Appendix G, and, for the CNO data, represents the average of the two ground plane microphones used in the test; “MOP” indicates a simpler ground plane installation, with the microphone and preamplifier body placed horizontally on a plate. The penultimate column represents the A-weighted maximum noise level normalized to a distance of 400 feet. The rightmost column provides an indication of measurement quality, where “Cert” indicates that the data were used in actual noise certification testing, “Cert Quality” indicates that the instrumentation performance characteristics and the measurement and testing procedures of CFR Title 14, Part 36, Appendix G or Appendix J were followed – with minor exceptions – in the test, and “Research” indicates that the data may be useful for research purposes, but were not collected with the same rigor as for noise certification.

Table 42. Comparison of UAS noise test data

Vehicle	Vehicle type	Weight (lb)	Operation	Microphone type	L_{ASmx} @ 400'	Data quality
AeroVironment PUMA	Fixed wing	13.4	Takeoff	IGPM	37.9	Cert
Insitu Scan Eagle	Fixed wing	46.0	Takeoff	IGPM	58.1	Cert
Navmar TigerShark	Fixed wing	397	Takeoff	IGPM	90.8	Cert Quality
Skywalker X-8	**Fixed wing**	**6.6**	**Takeoff**	**IGPM**	**53.7**	**Cert Quality**
Navmar TigerShark	Fixed wing	397	Level overflight	IGPM	88.2	Cert Quality
Skywalker X-8	**Fixed wing**	**6.6**	**Level – fast**	**IGPM**	**53.8**	**Cert Quality**
Edge 540 scale model	Fixed wing	25	Level overflight	MOP	53.4	Research
DJI Phantom 2	Quadcopter	3.5	Level overflight	MOP	44.9	Research
DJI M200	**Quadcopter**	**13.5**	**Level - fast**	**IGPM**	**52.2**	**Cert Quality**
Prioria Hex	Hexcopter	5.5	Level overflight	MOP	45.9	Research
Yuneec Typhoon	**Hexcopter**	**5.3**	**Level - fast**	**IGPM**	**50.1**	**Cert Quality**
GD28X	**Octocopter**	**45.0**	**Level - fast**	**IGPM**	**64.1**	**Cert Quality**

Data with **bold** font indicate vehicles from the CNO measurement program

Figure 16 illustrates the noise level vs. weight trend for fixed-wing vehicles. Note that the aircraft represented in this Figure were measured according to the Part 36, Appendix G standard.

Figure 17 illustrates the trend for rotary-wing vehicles during level overflight. Note that the LAMax noise metric presented for these aircraft in Table 42 and Figure 17 is not the time-integrated SEL metric that is required for Appendix J noise certification. Also, unlike Figure 16, this figure includes noise levels from research quality measurements.

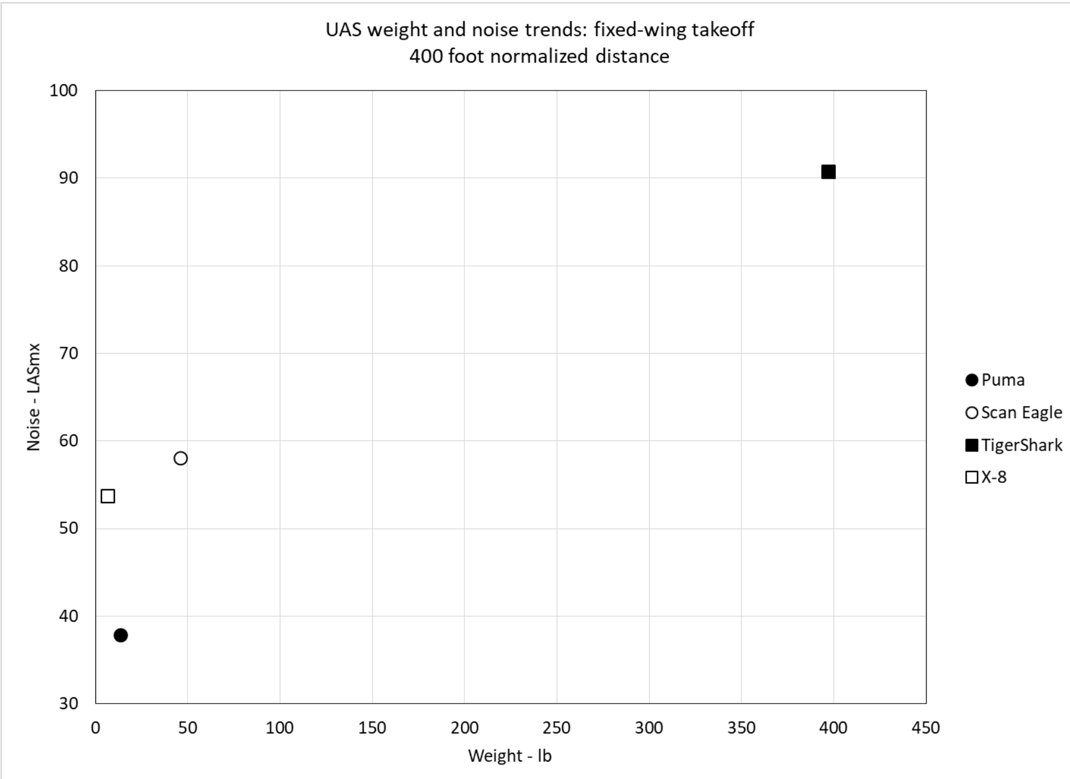

Figure 16, UAS noise comparison - fixed-wing takeoff

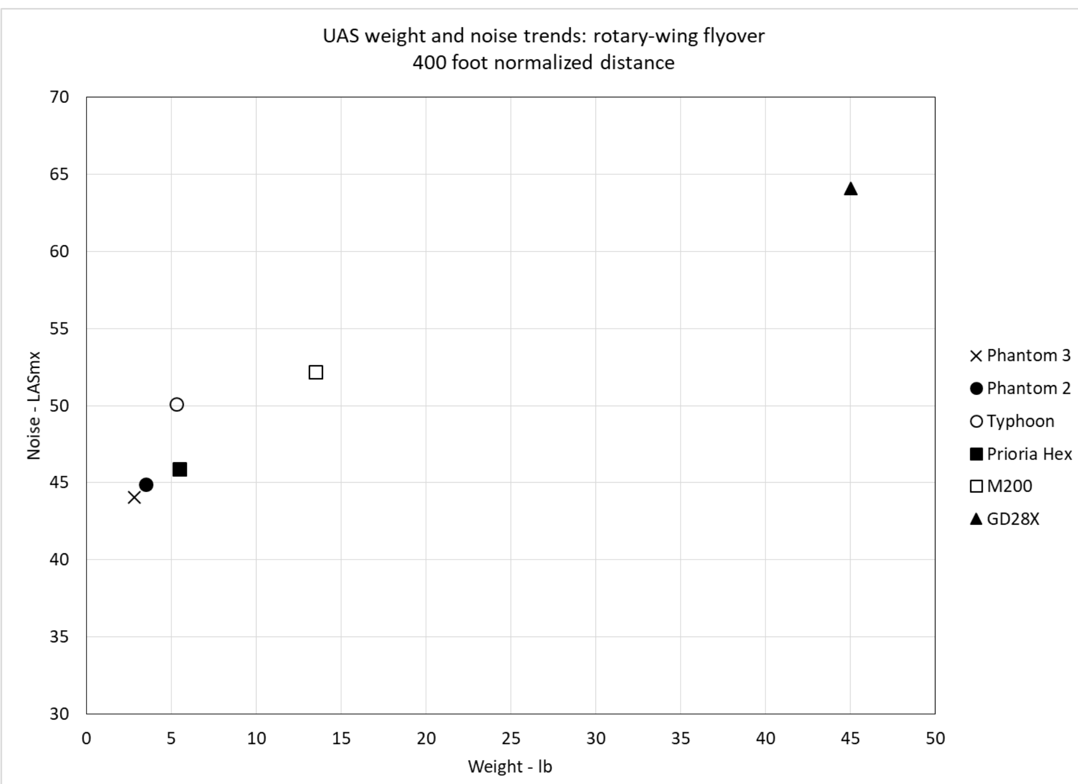

Figure 17, UAS noise Comparison - rotary-wing flyover

4 Conclusions and Next Steps

4.1 Observations

We note that in general, the LAMax levels for rotorcraft do not vary significantly between slow and fast flight. However, the X-8 fixed wing aircraft was significantly quieter in slow flight.

Within the multicopter group of vehicles, the GD28X (the heaviest UAV), was louder than the smaller two. The difference in noise levels for the Typhoon and the M200 (the smaller two multicopters) also followed the general trend of the heavier vehicle being slightly louder.

4.2 Lessons Learned

While the measurement program generally went without incident, a number of issues arose that could be improved.

4.2.1 START system installation

The START aircraft position tracking system appeared to be sensitive to Electro-Magnetic Interference (EMI) broadcast from the vehicles' own electronics, and was also impacted by overheating when mounted in certain configurations. Numerous mounting solutions for the START system were attempted for some vehicles before a final configuration was found, which allowed both the START system and the vehicle itself to operate correctly.

A method of mapping the EMI from the START system and of determining the EMI from the vehicle in the field should be found. EMI from the START system should be mitigated to the extent possible, however that mitigation must be within the weight constraints of the vehicle MTOWs.

START system mounting configurations should avoid the positioning of components (especially the CPU and battery) in such a way that exposes them to constant, direct sunlight. This configuration should be especially avoided if the mounting locations on the aircraft are particularly dark, and therefore heat absorbent.

Since returning from this measurement program, the team has identified and obtained detectors suitable for use in the field to aid in identifying such problems.

4.2.2 Flight log files

The flight log files used in the CNO measurement program were based on log files successfully used in manned aircraft measurements. Those flight logs were adequate for those flight operations which closely resembled manned aircraft operations, but did not work well for UAS operations which did not have a close correspondence with manned flight. In particular, the logs were not satisfactory when working with the hover operations. Revised logs will be used for future measurement programs to enable easier field documentation during these events.

4.3 Next Steps

4.3.1 Additional measurements

Similar noise measurements are planned for other sites, aircraft and participants in the IPP, as well as measurements though other venues, of other unconventional aircraft, including small and large UAVs, air-taxis, eVTOL aircraft, etc. The intention is to develop a meaningful database that will enable the identification of important noise characteristics across existing and potential aircraft that will or may operate in the NAS.

4.3.2 Data analysis

Any data analysis in this report has intentionally been kept to a minimum, and should be considered to be preliminary in nature. The authors anticipate that one or more follow-on reports featuring various analyses in more detail will be generated, perhaps after the end of the IPP program, when measurement data for other aircraft are available and more information is known about UAS operations in the NAS.

4.3.3 Modifications to the process

A determination should be made if the microphone position and number used in this measurement program are adequate for future IPP measurements.

A determination should also be made if the flight procedures are adequate, or if they need modification.

4.3.4 Potential analysis methods

Analysis methods for the final report are not yet known. While this report includes the traditional LAMax and SEL metrics common to aircraft noise measurements, additional metrics which may provide insight into human response to UAS noise may be included. In addition to metrics, narrowband acoustic analyses may also provide insight.

4.3.5 Modeling and simulation data

FAA and Volpe will need to consider how to model new and proposed UAS operations, similar to the current requirements for modeling manned aircraft operations.

5 References

Acoustical Society of America, American National Standards Institute. (2013). *S1.1 - American National Standard Acoustical Terminology.* Melville, NY.

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Appendix A: Acoustic Instrumentation

A.1 Instrumentation

Figure 18 shows a schematic component and signal flow layout of the acoustical instrumentation used for UAS IPP noise testing.

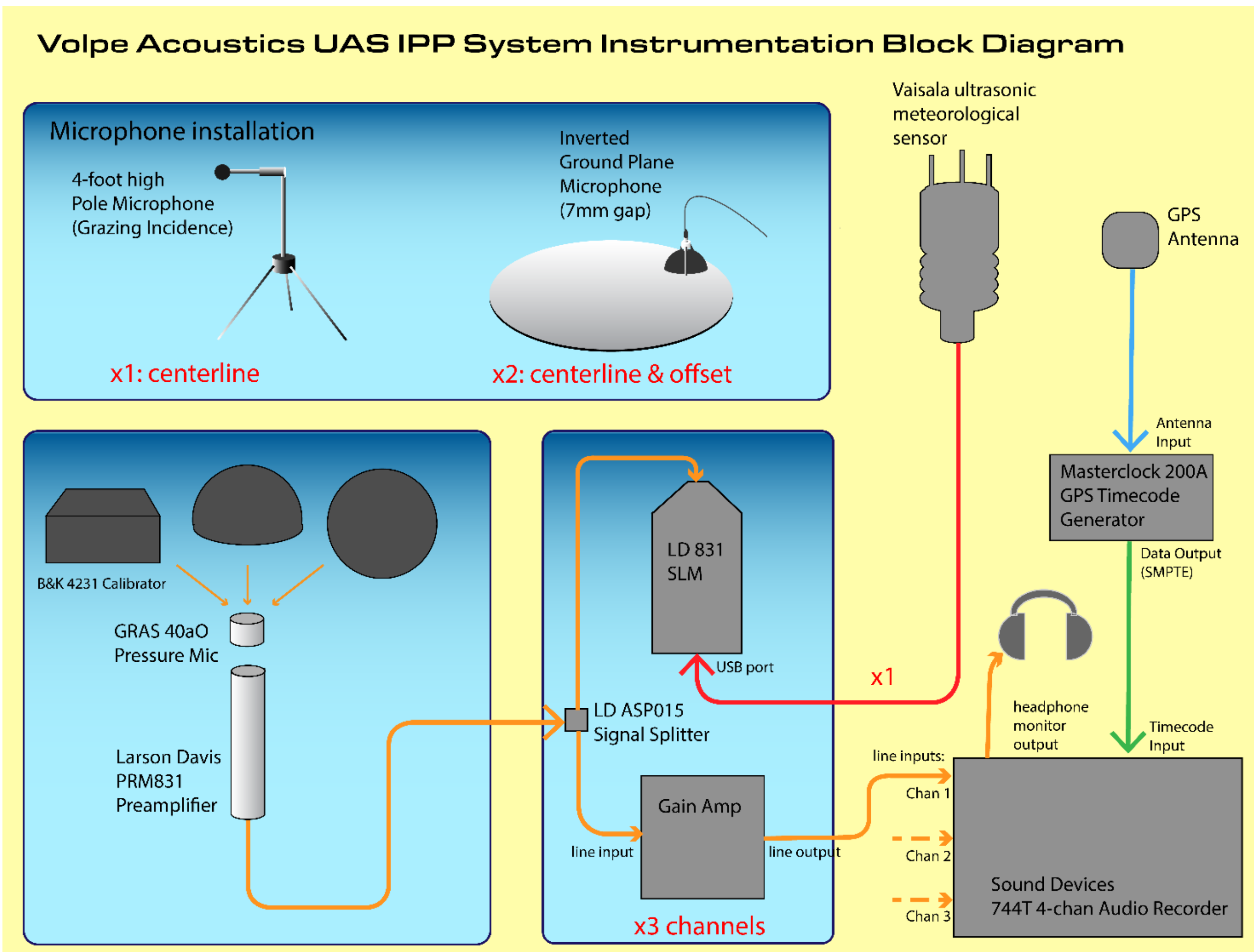


Figure 18, Schematic of acoustic equipment

The individual components of the system are discussed in detail below.

GRAS 40 AO microphones

The GRAS 40 AO microphone has a frequency range from 3.15 Hz to 20 kHz. It requires no external polarization voltage. This microphone is not as sensitive as other microphones used by the Volpe center, but it has a predominantly flat, extended upper frequency response. This ability to capture higher frequencies than microphones normally used for conventional aircraft measurement was considered important due to the potential close proximity of UAS operations to people – at these close distances, the higher frequency components of the vehicle noise may not be attenuated as much as they are for the greater propagation distances encountered with conventional aircraft.

Larson-Davis 831 SLM
The LD 831 is a Class 1 SLM. It has a large amount of built in memory (2Gb). In addition to its functions as an SLM, The LD 831 can also store weather data obtained externally, which is output from the Vaisala WTX-520 weather monitor. It can be powered via internal or external batteries. The unit can be controlled from other devices via its USB connections.

Larson-Davis 824 SLM
The LD 824 is also a Class 1 SLM. The unit has 2 Mb of standard memory. It can powered from internal or external batteries. The unit can be control from other devices via a serial I/O port which conforms to RS-422.

In the equipment set-up used at the CNO IPP, LD 824 Sound Level Meters were employed as gain amplifiers for the audio signals feeding into the Sound Designs 744T digital audio recorder.

After the CNO measurement trip, Volpe staff replaced the LD 824 SLMs with dedicated GRAS 12AQ gain amplifiers.

Vaisala WXT-520 weather station
The Viasala WXT-520 weather station provides wind speed, wind direction, temperature, and relative humidity information. The unit can also provide atmospheric pressure and precipitation readings. The unit outputs data in a number of serial data transmittal standards.

The WXT-520 was used at CNO to provide weather information which was stored on the SLM of the primary system (the centerline ground plane microphone).

Sound Designs 744T digital audio recorder
The SD 744T is a digital audio recorder which records and plays back audio to and from its internal hard drive, CompactFlash, or external drives. It writes and reads uncompressed PCM audio at 16 or 24 bits with sampling rates between 32 kHz and 192 kHz. It also writes and reads data compressed FLAC and audio compressed MP2 and MP3 files.

In the CNO measurements, the SD 744T was used to provide high fidelity digital records of the sUAS for possible later analyses. Information recorded by the SD744T are not included in this report.

A.2 Set-up

This section describes the methods of setting up the equipment used at CNO.

1. General Equipment Setup

I. 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.

II. Microphone Setup

i. Screw (3) spider legs into mic preamp collar assembly.

ii. Attach microphone to LD preamplifier – back preamp through spider collar before connecting cable.

iii. Attach 100' microphone cable to preamplifier, and suspend cable above plate using cable support inserted into ground adjacent to plate.

iv. Route 100' mic cable to instrument table and connect to top input of (blue) splitter device.

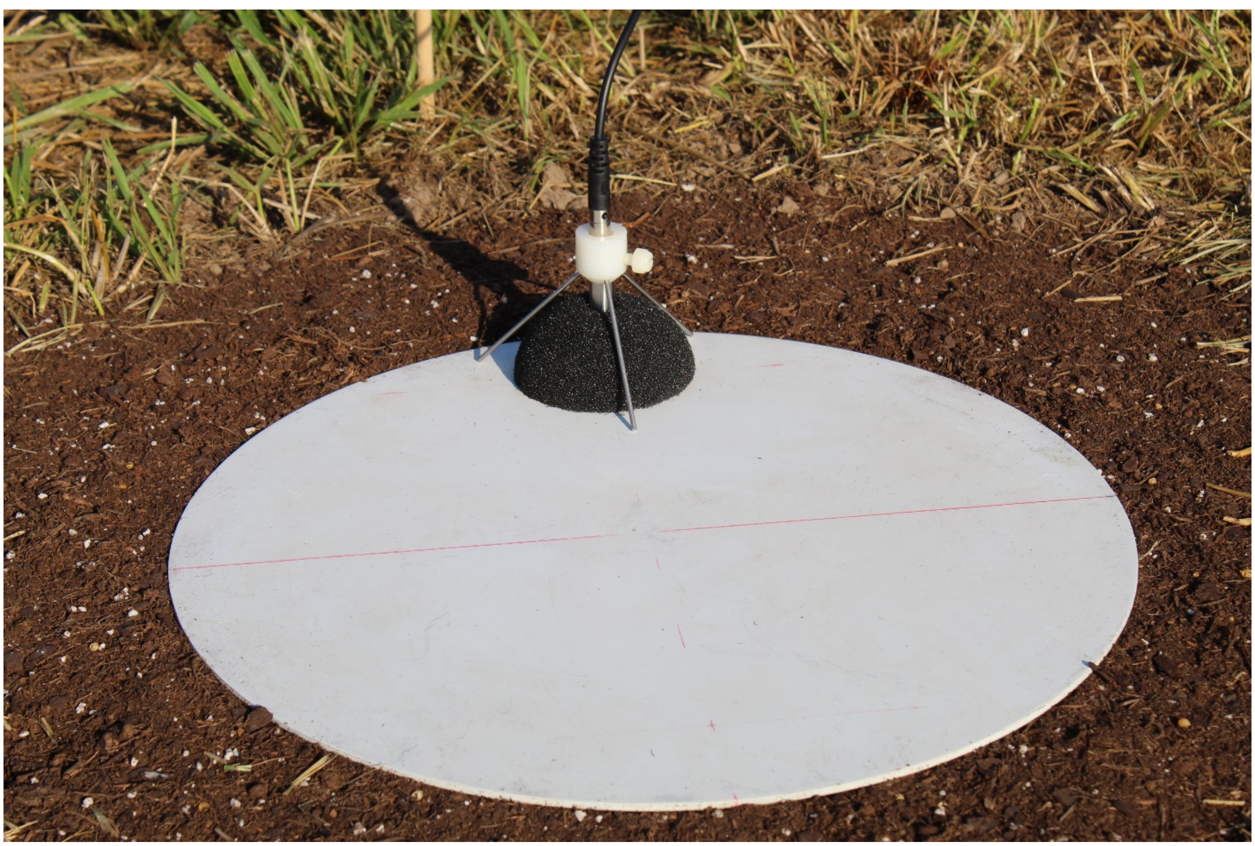


Figure 19, Ground plate & Mic Setup

III. Pole Microphone Setup

i. Extend tripod and place at predetermined, surveyed, location.
ii. Attach two-piece plastic mic holder to tripod.
iii. Unscrew upper section of mic holder and run end of 100' LD mic cable through cut-away in lower section of mic holder and thread through upper section.
iv. Screw upper section of mic holder back onto lower section and tighten set screw after preamp has been moved as far upward as it will go.
v. Remove protective cap from preamplifier and carefully mount microphone capsule by rotating CW until connection is firm. (Do not over-tighten.)
vi. Position microphone for grazing incidence – for centerline microphone, this means the body of the preamp will be parallel to the ground and perpendicular to the ground track; for sideline locations, the angle will be dependent upon the intended altitude of the aircraft and the sideline distance (this should be determined in advance, and a protractor should be provided in the mic kit, if anything other than 45 degrees.)
vii. Adjust tripod height so that mic diaphragm is 4 ft. above ground level.
viii. Install foam windscreen on microphone.
ix. Secure tripod (using stakes, weights and zip ties, as needed).

Figure 20, Tripod Microphone Setup

2. Instrument Table Setup

I. Time Code 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. Insert DC power cable to DC input jack at rear of 200A (using the cigarette-to-alligator clip assembly).
   iv. Connect the RS232 to BNC adapter to the RS-232 output (rear) of the 200A; connect the time code BNC to LEMO cable to the RS232 to BNC adapter.
   v. Turn on 200A time code generator by attaching alligator clips to appropriate terminals of battery (red to red, black to black: red = positive voltage). A solid green light indicates power (small alligator clips shown in Figure 22, the bigger alligator clips belong to the 744T recorder).

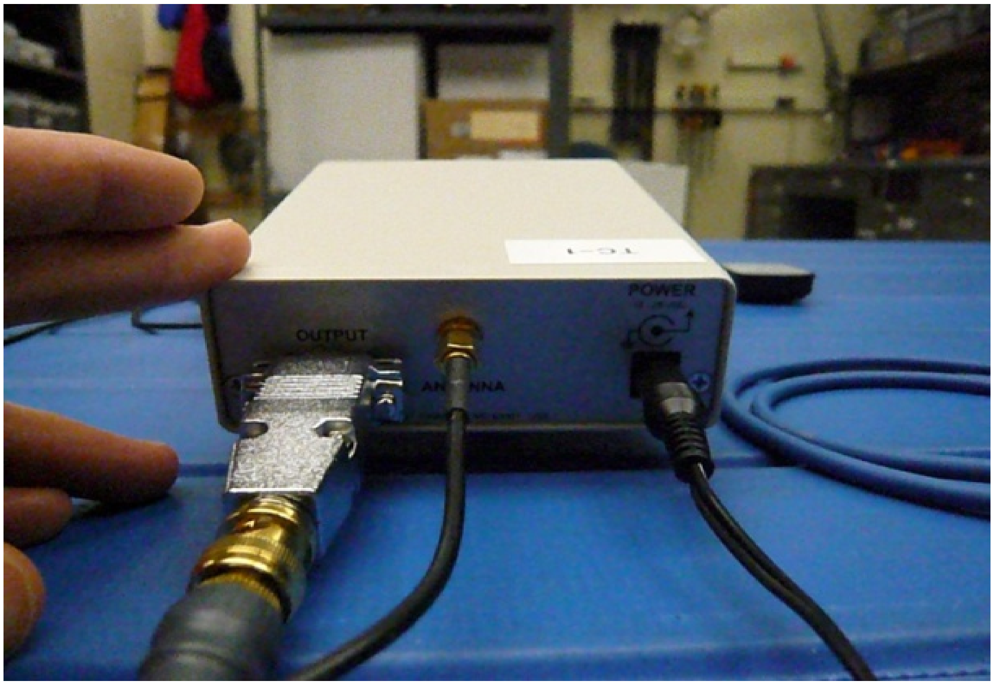


Figure 21, MasterClock Time Code Generator

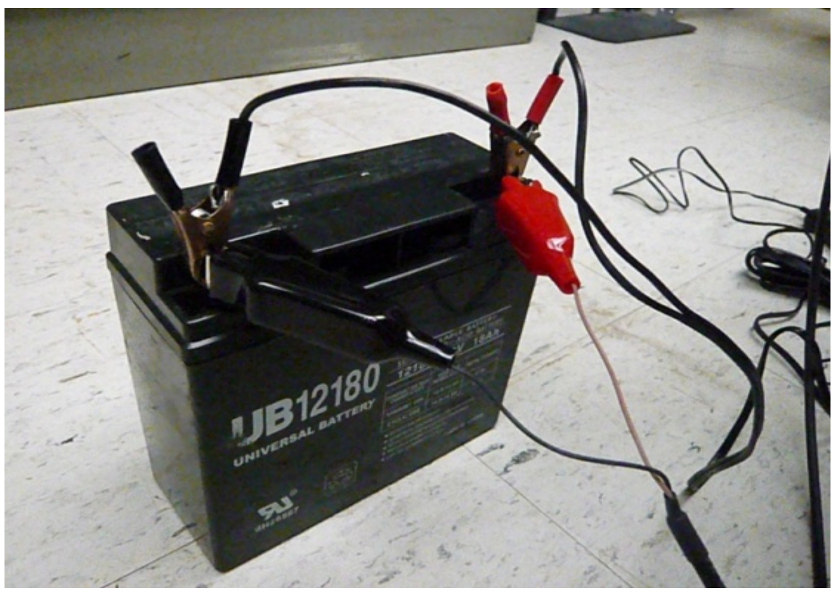


Figure 22, MasterClock Time Code Generator battery connection - Step v

3. 744T Recorder

I. Place a blank SDHC flash media card into the SD-to-CF adapter.
II. Carefully orient the loaded SDHC-to-CF adapter with the label facing up and pin slots facing the 744T, then insert into the compact flash slot at the rear of the 744T. Do not force as the connector pins are delicate.

NOTE: To avoid potential data corruption, it is good practice to install and remove the SDHC media card only when the 744T is turned off.

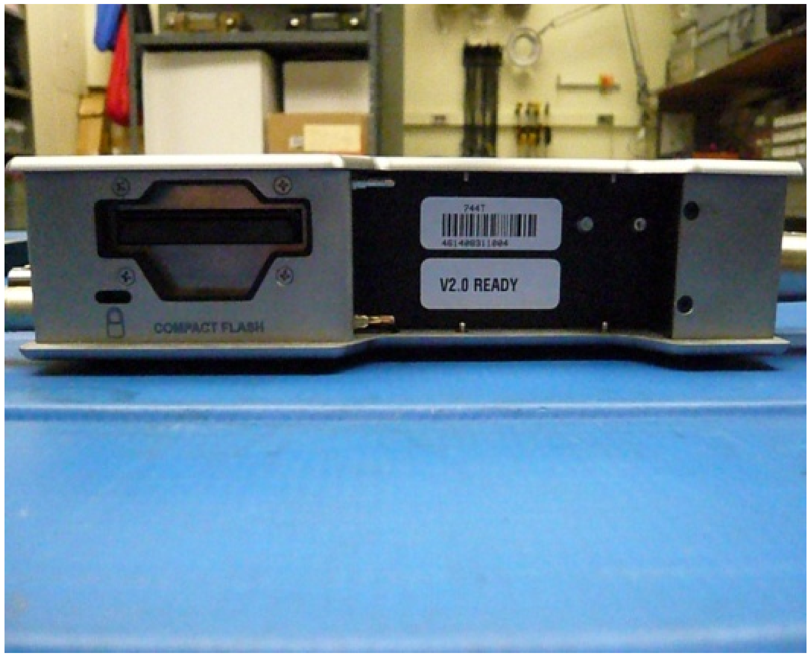


Figure 23, 744T Recorder – CF slot

III. Attach the 4-pin LEMO connector end of the 744T power cable to the DC input jack on the right side of the 744T.
IV. Connect BNC to XLR adapters to the input connectors for channels 1 & 2.
V. Use small BNC cables to connect signals from each microphone from (blue) signal splitter output to 744T input adapters.

Figure 24, 744T Recorder - Right Side Jacks for Power & Time Code

Figure 25, Table Setup

4. 744T Audio Recorder

I. Turn on the 744T by holding the power button for 1 second.
II. A complete configuration file has been pre-loaded to the 744T. To restore/reload the configuration, go to MENU>Quick Setup>Load from INHDD, press check mark button to load. Additionally, a separate 744T settings table has been provided for reference.
III. Time Synchronization
    i. The time code generator does not set date, however, the correct date should have been set during equipment preparation. Check front panel, top right corner, to confirm. If date is incorrect, set manually. Go to MENU > Time/Date: Set (parameter #62).
    ii.
    iii. Next, synchronize clock to UTC. Ensure that the green light on the front panel of the MasterClock 200A flashes 1x/second.
        1. This indicates that GPS lock has been obtained. In the event that the light is solid, or flashing 2x/second, reposition the GPS antenna until GPS lock has been obtained.
    iv. Connect the LEMO end of the BNC to 5-pin LEMO cable (from the MasterClock 200A) to the timecode input of the recorder. The 744T will automatically jam its

internal system time with the GPS time as soon as the TimeCode generator is connected.

NOTE: It is recommended to check time synchronization across all systems, included those systems being used by partner organizations participating in the same noise measurement.

5. LD 831 Sound Level Meter(s)

I. Insert fresh batteries and power device on.
II. Set the Clock and Date manually, using 744T display as reference.
    i. Navigate to the Time/Date settings page in the LD831 menu
    ii. Manually adjust the LD831 system time to the nearest (future) rounded minute, and wait for the 744T to arrive at the chosen time.
    iii. Select the "Save" option as soon as the 744T display time arrives at the time entered in the LD831 menu.
    iv. Confirm the difference in displayed system times on the LD831 and 744T is less than 1.5 seconds.

6. Calibrate

Figure 26, Field calibration of inverted ground plane microphone

Use the "Deployment Calibration" log-sheet to document levels and recording times

a. Meter Calibration(s)
   i. Apply the calibrator to the microphone system.
   ii. Turn the calibrator on to generate a **94 dB, 1 kHz** tone.
   iii. Press **TOOLS** button on the meter. Use ↑↓ to highlight **Calibration**. Press √ to select.
   iv. Press √ again to enter **Calibration** menu. Ensure that **Cal Level** is set to desired level (**94 dB**). If not, select (√) **Cal Level**; use arrow keys to change value, and √ to enter appropriate level.

v. Use ↑↓ to highlight **Calibrate**, and then (√**)**. You will be prompted to make sure calibrator is active. If so, select (√) **YES**. Wait while calibration adjustment is performed.
vi. **Calibration** is complete when the screen displays the **Calibration** readout with date, time and offset. Log offset to calibration log sheet.
vii. Use right soft key to go to Sensitivity tab and log measured sensitivity (mV/Pa). A reading of 10 to 13 mV/Pa would be considered adequate.

b. Set Reference Level Range on 744T

i. Apply the calibrator to the microphone system and generate a **94 dB, 1 kHz** tone (see above). Allow system to settle for 1 minute. The signal will be visible on the front-panel input level meter on the 744T when connected properly.
ii. Ensure that switch above input is set to "MIC".
iii. Adjust the input level.
    1. Use 744T menu parameters 31 - 33 and adjustment knob on the right side panel of the 744T to adjust the system gain as necessary (roughly -4dB FS).

Note: Once set, this level range will be used for data collection and must not be readjusted without recording a new 94 dB SPL calibration reference tone at the new gain setting and a clear notation in the log of when the change occurred.

c. Dummy Mic Test (Optional)

i. Remove the microphone from the preamp and temporarily place back in case.
ii. Attach the dummy microphone in place of the microphone.
iii. Wait 1 minute and record system noise floor for at least 30 seconds on both the 744T and LD 831.
iv. Note levels for LAMax, LZS.
v. Check 1/3 octave band page for frequency "spikes". Also, you may attach headphones or earbuds to check for audible noise interference.
Note: you will need to adjust the headphone setting using Menu select knob (right side) to monitor appropriate inputs/tracks. Headphone volume knob is located on left side.
vi. Remove dummy mic and reapply microphone. Wait 1 minute.

d. Record Calibration Tones on All Devices

i. Press **Run/REC** on **both** the 744T and the LD 831**,** and collect at least 30 seconds of the calibration signal. Ensure that the levels indicated on both devices are as expected and note in calibration log. Press ■(Stop) on both devices when complete.

e. 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/preamp into place.

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

Additional Information

744T:

Use the headphones to occasionally monitor the input signal(s) to ensure that there is no audible noise interference or anomalies. For proper headphone signal routing, the control knob on the right side of the 744T may need to be toggled.

There are a number of helpful indicators on the front panel LCD display. It is recommended to occasionally monitor the following parameters:

1) Battery Level Indicator (upper left corner) – shows voltage level of external power source.
2) File Name Display (upper center) – for log entries
3) Time Code Display (center)
4) Storage Media Status (left row) – indicates record time remaining on available media. CF = removable Compact Flash; IN = internal hard disk drive, and EX = external drive. An asterisk to the left of each media indicates that the medium is selected to record.
5) SD/Compact Flash card in the 744T is NOT hot-swappable. 744T must be powered down before extracting the external storage card.
6) Input Peak Warning LED (upper left of front panel, second row of lights from top) – This row of four red LEDs corresponds to each input channel and serves as a (-3 dB) warning that the input signal is approaching an overload condition.
7) To start a new file while the 744T is recording (file split), press the “REC” button on the front of the console.

LD 831:

From the “Live” tab, use up/down arrows to toggle to additional displays such as 1/3 octave-band and date/time, power, memory, etc.

Appendix B: Volpe IPP Site and Aircraft Information Questionnaires

Volpe Acoustics
Unconventional Aircraft
Noise Research Team

IPP Noise Research Test Site Questionnaire

03MAY2019

I. Please provide availability for scheduling a site-scoping visit (1 day) for Volpe personnel to visit, observe, and evaluate the site and communicate and coordinate with LP technical staff on security, safety, communications, conductance of flight testing, test-fitting of tracking system on aircraft, etc.

II. Please provide responses to the following questions/requests:

A. Noise Research Test Site:

For the noise flight testing, Volpe requires a location that is controlled by the Lead Participant that is suitable for noise research testing: a large, flat, open area, free from obstructions, line-of-sight blockages and noise reflecting surfaces, accessible to – and safe for – Volpe team personnel, with low background noise.

1. Please provide a description of the site, including photos if possible, indicating suggested location for microphones and operator stations
2. Please provide latitude/longitude coordinates for the site (high resolution, if available, as we will use these to predict the GPS constellation availability during our research visit.)
3. Is there room for aircraft to cycle through takeoff, landing, flyover and other operational procedures such as: hovering, orbiting, station-keeping, simulated delivery, etc.
4. Can we access the research site via rental vehicles? (Are there security procedures we need to follow? Are off-road/ 4WD vehicles required/recommended?)
5. Are there any other security procedures, aside from site access? (Do we need to obtain personnel clearances in advance? Are there limits on times when site is accessible? i.e., how early/late can work be conducted? Is there a regular grounds keeping schedule – mowing, watering, etc?)
6. What are the communications protocols for the site? (Is there cell phone coverage? Do we need aircraft radios? If needed, can LP provide Volpe personnel with radios?)
7. Are WAAS or other DGPS correction signals available?
8. Would our field equipment be secure if unattended?

9. Is there access to toilets?
10. Is there access to food and water in the local area?
11. Is there an accessible indoor area that can be secured for equipment staging, storage, battery charging, etc?
12. Where is the closest accessible indoor area that can be used for shelter from hazardous weather?
13. Is AC power available in the field, i.e., at testing locations? (Not needed, but could be useful.)
14. Are there days of the week that your IPP site has lower vehicle traffic/use? Is it possible to restrict IPP-related (and any other) activities on those days to focus on the vehicles being researched? How far in advance would you recommend posting a notice that the site will have restricted vehicle traffic on the research days?
15. What issues have you had operating UAVs at this site? (Interference from birds or other wildlife? Human activity? Anything that might interrupt testing?)
16. Please list other dominant noise sources in the area (i.e., generators, roadway noise, train tracks, etc.)
17. What is the nearest source of manned aircraft activity? Is there any expectation of interference with our planned operations?
18. Are there any concerns or prohibitions on photography? Volpe typically uses photography to aid in characterizing the environment at the site, provide illustration of the vehicles being tested, and for documentation and marketing of the research team activity.
19. Please provide a contact and location info for shipping one to two pallets of instrumentation and supplies for up to two weeks prior to measurement trip (Volpe team will need access to these materials upon arrival. If a suitable storage location is not available, we may be able to have equipment delivered to local hotel.)

B. Locale:

1. Please provide local hotel recommendations, considering proximity, local traffic conditions, construction, major events, etc.
2. What is the nearest major airport to the site?
3. Travel time by car from nearest major airport to site?
4. Name and address of nearest medical facility?
5. Any other location-specific concerns we should be aware of?

IPP Noise Research Aircraft Questionnaire

03MAY2019

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

1. Vehicle manufacturer:____
2. Vehicle model (and version):_______________________________________
3. Registration number: ____
4. Modified?☐ yes (if yes, describe on separate page)☐ no
5. 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)
6. Power method:

   ☐ Electric

   ☐ Internal combustion

   ☐ gas turbine

   ☐ hybriddescribe: (on separate page)

   ☐ otherdescribe: (on separate page)
7. Flight Controls:

   ☐ Movable aero surfaces

   ☐ Differential thrust

   ☐ Vectored thrust:☐ tilt-rotor

   ☐ tilt-wing (or other mounting surface)

   ☐ other describe: (on separate page)
8. Mass properties:

   Dry weight without payload____

   Maximum TOW____

   Maximum payload capacity____

   CG Range Limits: Lateral:____Longitudinal:____

9. Size:
   Maximum dimension____☐ diameter
   ☐ wingspan
   ☐ length
   ☐ height
   ☐ width
10. Payload accommodation: ☐ none
   ☐ internaldescribe: (on separate page)
   ☐ externaldescribe: (on separate page)
11. 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
12. 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?____

13. 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:

Dave Read
USDOT Volpe Center
310-544-9222 (California)
617-494-6343 (Massachusetts – forwards to CA)
David.Read@DOT.Gov

Appendix C: Volpe START Aircraft Position Tracking System User Guide

C.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 which relies on 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 miniaturizing a system capable of collecting and storing raw satellite observations suitable for post-processing. With one system on the ground (Base Station) and another, 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 of survey points and dynamic tracking data will be within 5 – 10 cm accuracy. 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. This become especially important where the relative distances are less than those of standard aircraft tests.

The following guidance will identify the hardware component options and then 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, START component dimensions/weights, and links to technical resources for more detailed information regarding system components.

C.2. Hardware

The following section provides system diagrams for the Rover and Base station setups, 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 generic components required for a functional system configuration and the lettered items indicate the available options. Photos of various hardware components are also provided.

C.2.1 Hardware diagrams

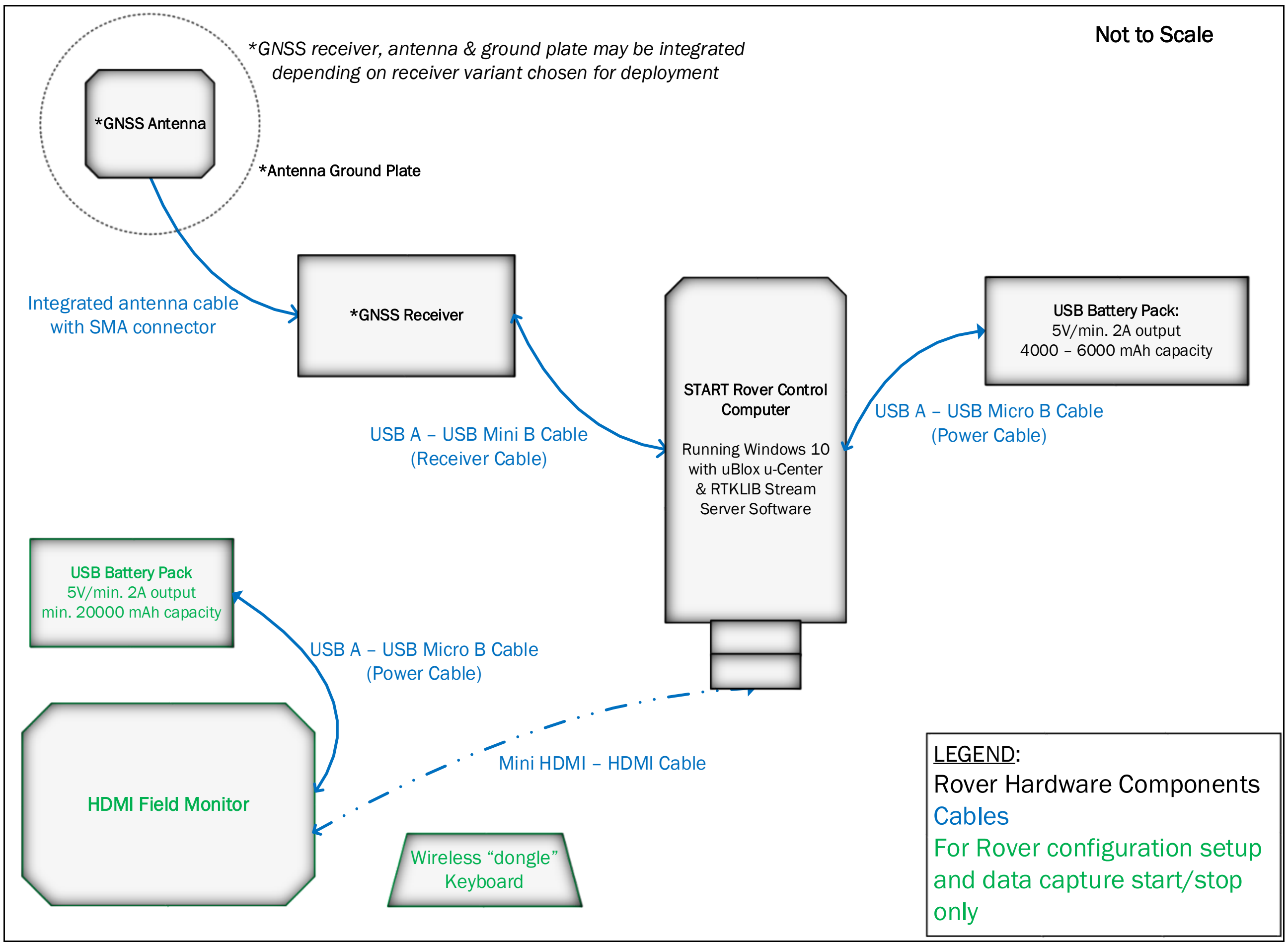


Figure 27, START Rover Configuration

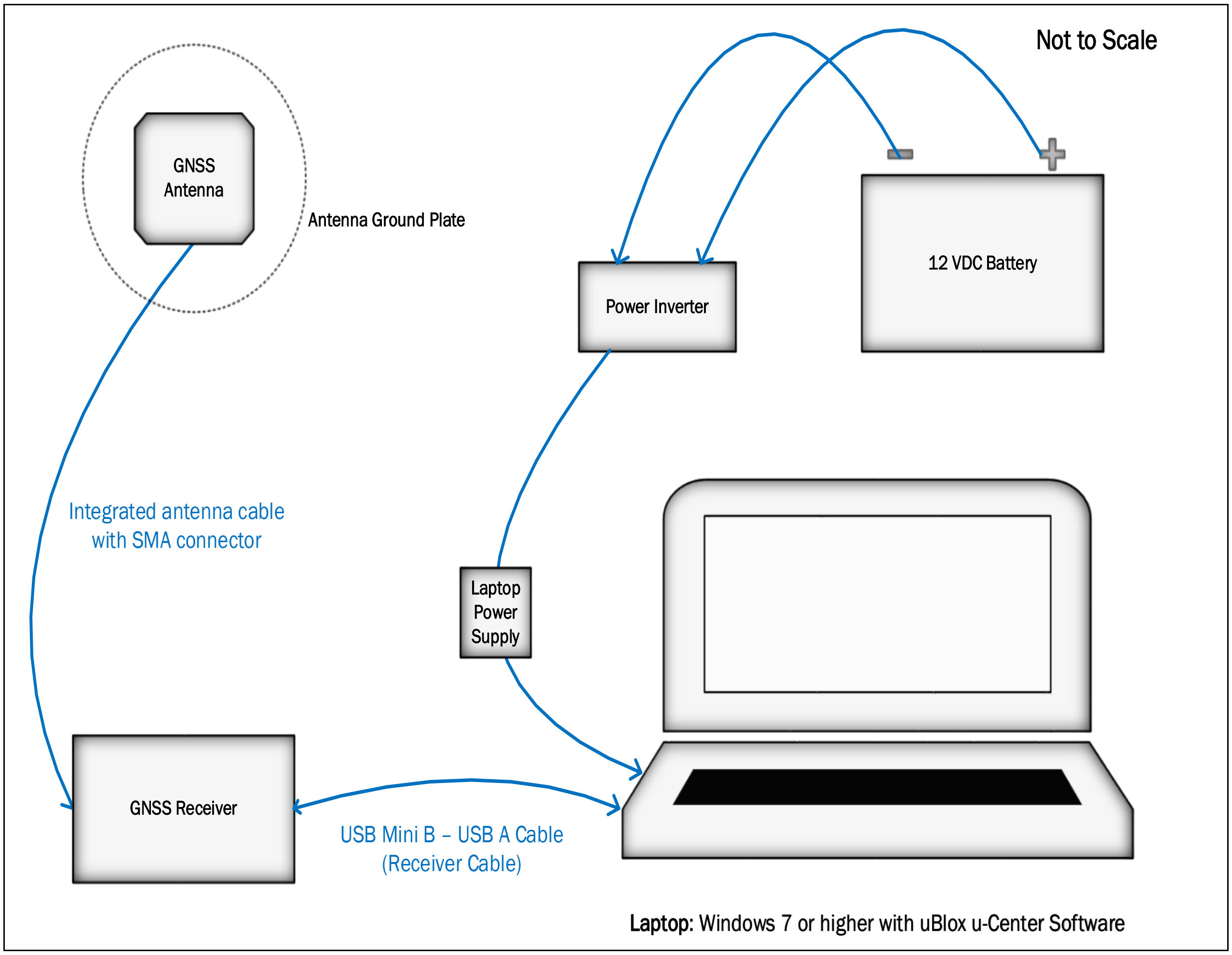


Figure 28, START Base Station Configuration

C.2.2 START components list with available options

C.2.2.1 ROVER

NOTE: Vehicle operators will require the physical properties of the START Rover configuration to be installed on their vehicle. Refer to Appendix C: Start component dimensions/weights, for details regarding typical configuration weights as well as a breakdown of discrete component weights and dimensions.

1. START Rover Control Computer: Windows 10 OS, loaded with uBlox u-Center v19.04 and RTKLIB demo 5 b31 or later
    a. ACEPC W5 Pro mini - primary
    b. MeeGoPad T02 – backup

2. GNSS Receiver
    a. uBlox NEO-M8T PCB – requires enclosure, portable
    b. uBlox NEO-M8T USB Dongle – ultra portable , can connect directly to computer or use USB ext. cable
    c. uBlox NEO-M8T Disc - integrates antenna and ground plate. Enhanced EMI protection
    d. uBlox NEO-M8T High Gain - integrates antenna and ground plate. Enhanced EMI protection

3. GNSS Antenna: not required with GNSS Receiver options (c) & (d)
    a. Tallysman 4721 antenna – multi GNSS, active, patch antenna, excellent directivity
    b. Maxtenna M1516HCT - GPS/GLONASS, passive, helical design, good EMI resiliency

4. Antenna Ground Plate: not required with GNSS Receiver options (c) & (d)
    a. Aluminum, 2.5” Diameter, 1/16” thickness
    b. Aluminum, 3” Diameter, 1/16” thickness
    c. Aluminum, 3.5” Diameter, 1/16” thickness

5. Rover USB Battery Pack – tradeoff between battery weight and capacity should be considered
    a. 4400 mAh, 5VDC/2A
    b. 5000 mAh, 5VDC/2A
    c. 6000 mAh, 5VDC/2A

6. USB Power Cable: available in lengths from 1’ to 3’, select lengths have right angle connector options
    a. USB A-to-USB micro B, shielded

7. USB Receiver Cable: available in lengths from 6” to 6’, select lengths have right angle connector options
    a. USB A-to-USB mini B, shielded

8. 64 GB micro SD card – second storage medium for parallel data recording
9. Mini wireless “dongle” keyboard/touchpad – for interfacing with Start Rover Control Computer during configuration
10. HDMI Field Monitor – used for deployment setup and data capture start/stop only
11. HDMI-to-mini HDMI cable – connects display to START Rover Control Computer
12. HDMI(f)-to-HDMI(f) coupler – required to connect HDMI cable to START Rover Control Computer
13. Display Monitor USB Battery Pack – 24000 mAh: for HDMI Monitor, use with any USB A-to-USB micro B cable

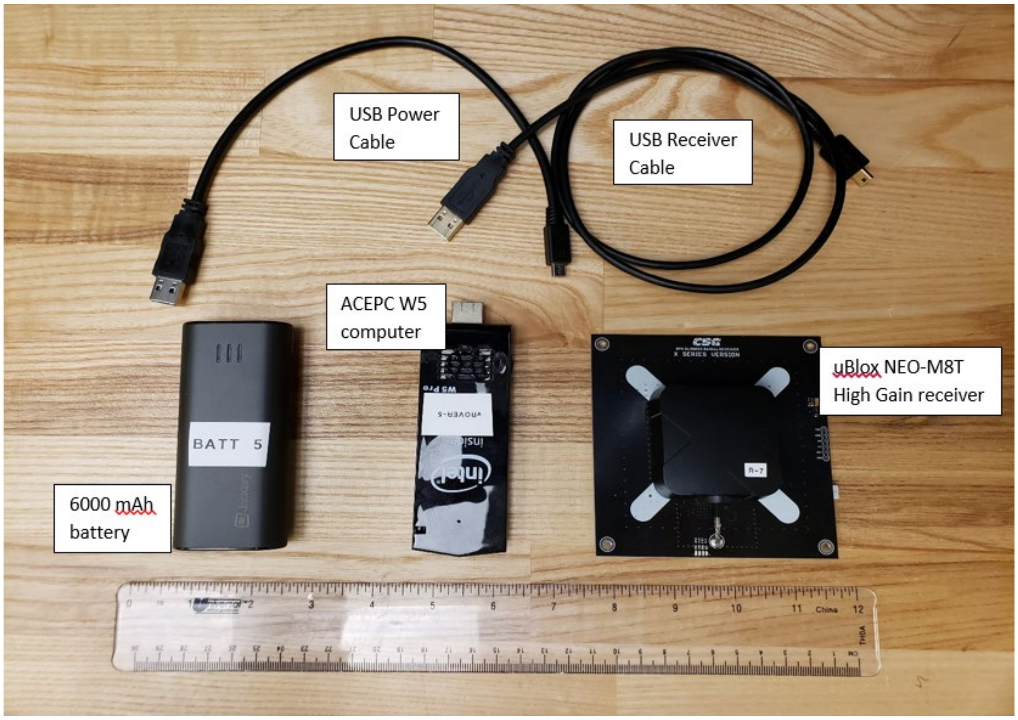


Figure 29, START Rover Configuration with uBlox receiver/antenna

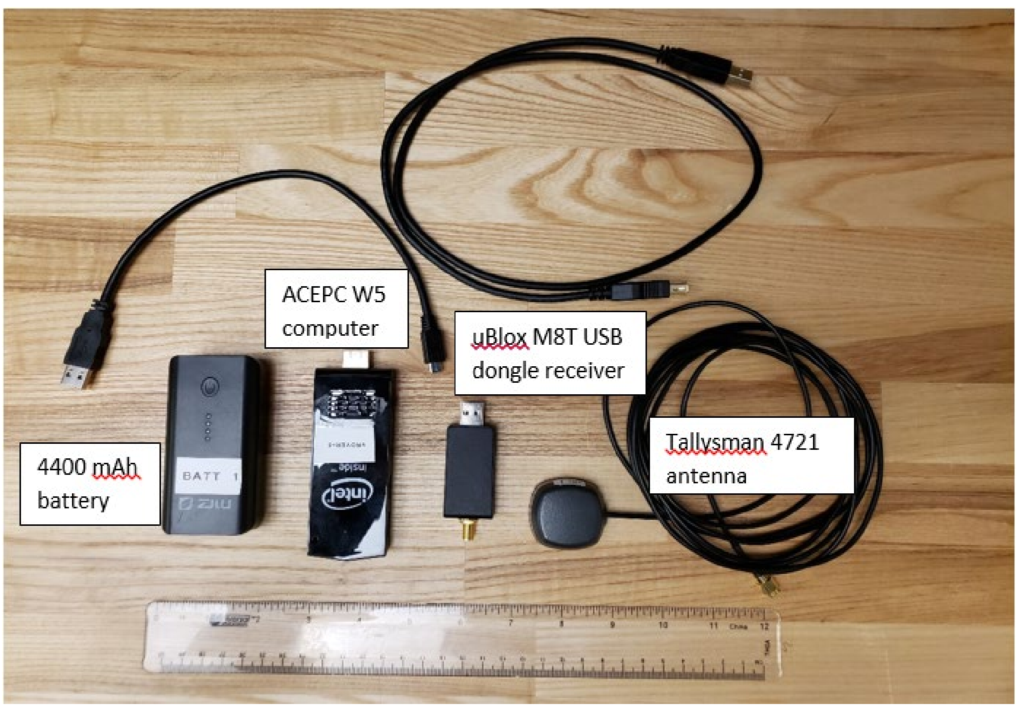


Figure 30, START Rover Configuration with Tallysman antenna

C.2.2.2 BASE Station

1. Laptop Computer: Windows OS, loaded with uBlox u-Center v19.04 and RTKLIB demo 5 b31 or later

2. GNSS Receiver
   a. uBlox NEO-M8T PCB – requires enclosure and USB A-to-USB mini B
   b. uBlox NEO-M8T USB Dongle – ultra portable, can connect directly to computer or use USB ext. cable

3. GNSS Antenna
   a. Tallysman 4721 antenna – multi GNSS, active, patch antenna, excellent directivity

4. Antenna Ground Plate – use full size microphone ground plate, if available
5. 20 – 22 amp-hour sealed lead acid battery
6. Power inverter, 400 Watt minimum.

Figure 31, START Base Station Configuration

C.3. Field procedures

C.3.1 Base Station deployment

The Base Station should be set up and initialized prior to the Rover. To achieve best performance, it is important that the Base Station be sited in an open area, free from large reflective surfaces. Allow the Base Station receiver to attain a 3D 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. The following is a step-by-step setup procedure.

1. Connect Tallysman 4721 GNSS antenna to uBlox NEO-M8T pcb or USB dongle variant by rotating the SMA connector clock-wise onto the threaded coaxial connector at the receiver.
2. Connect the uBlox receiver to the Base Station laptop using a USB Mini B-to-USB A cable. The USB dongle version of the uBlox receiver may be plugged directly into 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 laptop power jack.
4. Place the GNSS antenna on a ground plate and 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 files 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 version of Windows.
   b. Scroll down the Device manager to Ports (Com & LPT) and expand the menu. Depending on the driver, you will see the uBlox receiver listed as "uBlox GNSS Receiver", "USB Serial Device" or "uBlox virtual com port". Note the com port number assignment (Figure 32).
   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)\Ublox \u-Center folder.

a. Using u-Center drop-down menus, go to Receiver > Connection. Select the com port that corresponds to the uBlox 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 33). Under Configuration file, use browse button to select "M8T_PCB_Base_030419" or "M8T_Integr_High+Dongle_Base_030119", depending on which hardware version of the receiver is being used, and press Open. Next, press File > GNSS button to load preconfigured settings to uBlox 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 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 34).
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 35).
    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 = 500 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 20%. If these parameters are not met, efforts should be made to mitigate the effects of EMI. Potential solutions include repositioning the Base Station or inserting an in-line USB noise filter between the laptop and receiver.
    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 2x/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 recording data:
   i. Click the red dot on the Log File toolbar. You will be prompted to choose a directory location for the file. Use the location previously established in step 6. Add the prefix "Base" to the default uBlox naming convention which indicates the com port and date and time that the file was initiated. For example, "BASE_comX_yymmdd_hhmmss.ubx".
   ii. Click Save; you will be prompted to download a log file. Select Yes to begin recording. Note that the formerly grayed out buttons on the Log File toolbar, i.e., "tape shuttle controls" are now active.

i. The Base station must collect data throughout the measurement. To stop Base station data recording and close the active file at the end of the measurements, click the Eject button at the far left of the Log File toolbar. This should only be performed after the Rover data collection has been completed.

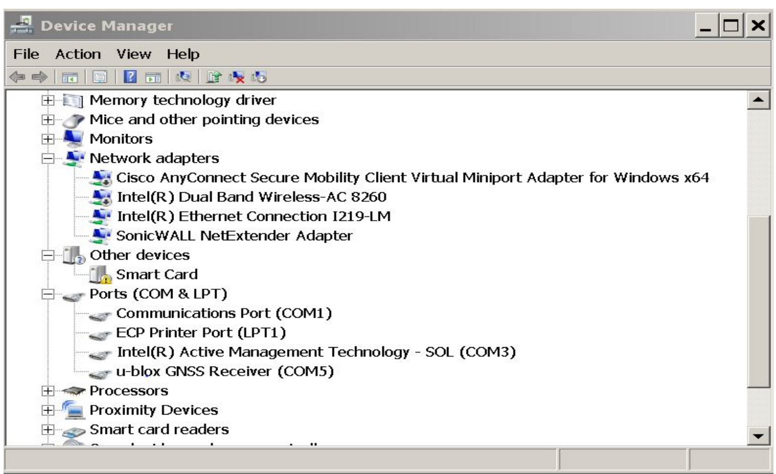


Figure 32, uBlox Device Manager

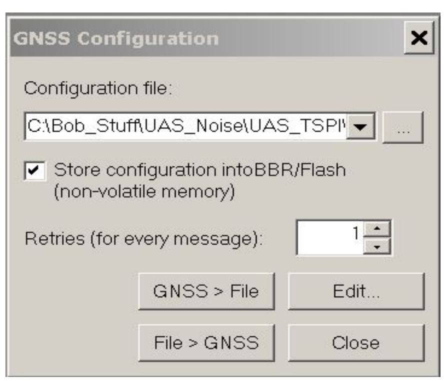


Figure 33, uBlox GNSS Configuration tool

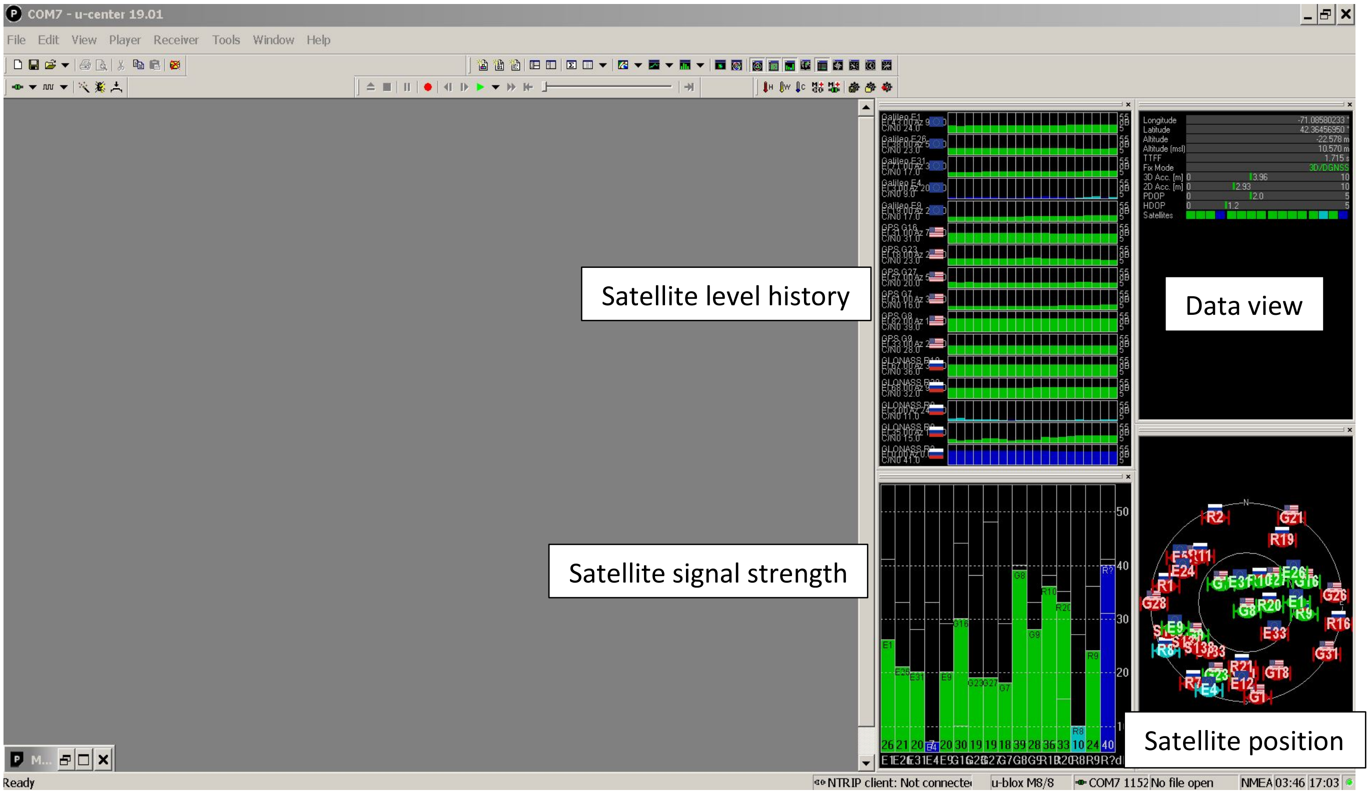


Figure 34, uBlox u-center docking windows

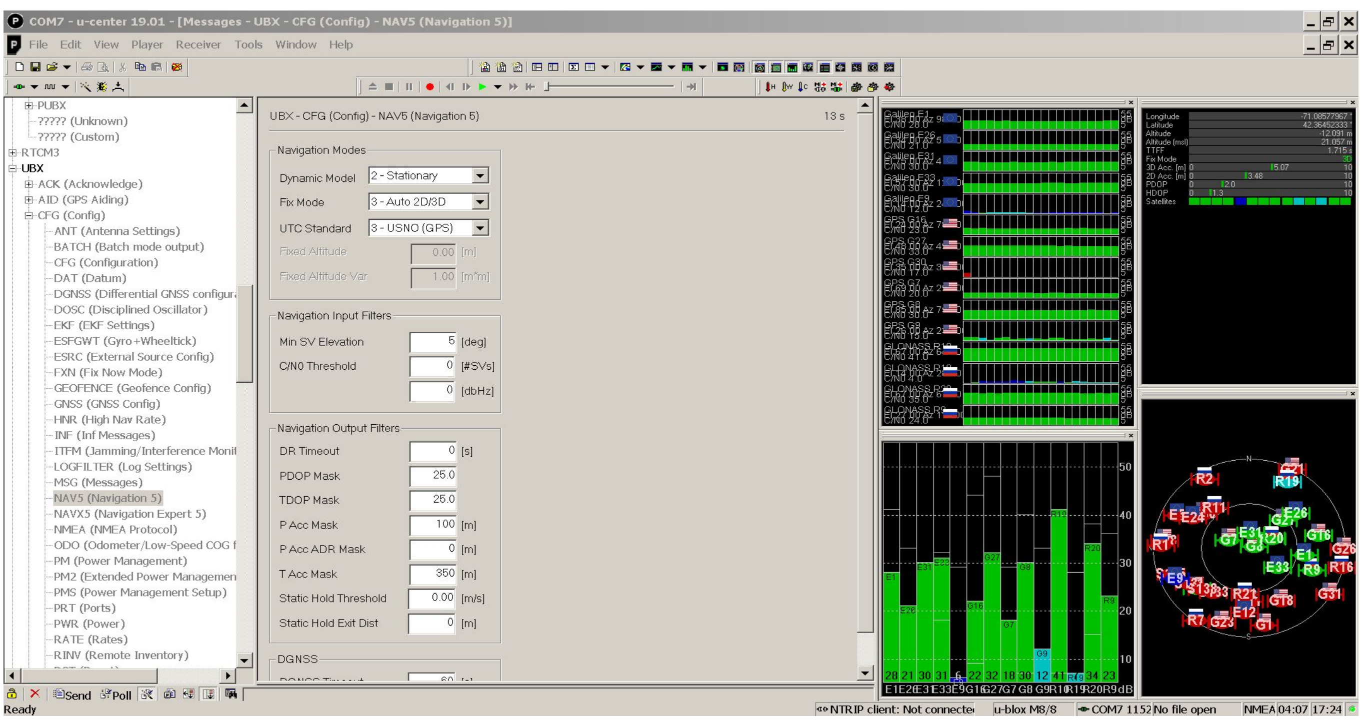


Figure 35, uBlox u-center Message View menu

C.3.2 Rover deployment

C.3.2.1 Vehicle mounting and considerations

If using Rover independent of vehicle, e.g., surveying fixed positions, then skip to section 3.2.2. If installing Rover on a vehicle, then careful consideration must be given to the selection of components and cables when optimizing the hardware configuration. Access to test vehicles is recommended, in-advance of data collection to evaluate and plan mounting strategy as each vehicle will present unique challenges. Factors to consider include: vehicle size and weight, payload capacity, aerodynamics, c.g. and inertial properties (especially important in smaller vehicles), dedicated payload area or flat surfaces to be used as natural mounting points, ample clearance from rotors/engines and potential EMI sources, such as RF antennae. All mounting methods should be tested with the vehicle powered so that potential EMI issues may be identified. All START components and their placement must be approved by the vehicle operator.

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 selected should be no longer than required to link components, and safety concerns, such as blade clearance, should be assessed prior to the connection of system components. Fine tuning the fit and finish of the Rover installation should occur only after functional and safety concerns have been addressed. Appendix C contains additional recommendations for START Rover installation and illustrates examples of mounting aides and configurations.

C.3.2.2 Set up and initialization

The following steps apply whether the system is mounted on a vehicle or being used independently to survey points.

1. Connect GNSS antenna to uBlox NEO-M8T receiver by rotating threaded coaxial connector to SMA jack on receiver printed circuit board (PCB) or 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.

   NOTE: If volume and weight are not limiting factors, it is recommended to use one of the integrated receiver + antenna and ground-plane options which feature enhanced EMI resilience and higher gain, which improves signal to noise ratio.

2. If using the Tallysman 4721 antenna, affix to largest diameter aluminum ground plate suitable for application.
3. Ensure that GNSS antenna has clear line-of-site to open sky.
4. Connect the uBlox receiver to the START Rover Control Computer using a USB Mini B-to-USB A cable.
5. 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 6000mAh, however higher capacity means more weight. It is

generally advisable to use the highest capacity battery that the vehicle can safely carry without degrading its performance. Appendix C.8 contains a table with weights and dimensions of key system components, as well as weights for preferred configurations, as installed on vehicle.

6. Power up system:
    a. Press button on Rover battery pack (LEDs will illuminate).
    b. Then, power computer by holding side power button for 2 seconds, or until LED on the computer lights up. When booted up, it is typical for the LED to briefly illuminate then turn off for a few seconds before it reappears. Do not repeatedly press the power button.
7. Next, set up the equipment to interface with the Rover (Figure 36):
    a. Place the HDMI display on its stand and connect to the large, 24000mAh USB Battery Pack.
    b. Connect START Rover Control Computer to HDMI display using the HDMI-to-mini HDMI cable and flexible female-to-female HDMI coupler.
    c. Plug in USB dongle for wireless keyboard to open port on START Rover Control Computer. Turn on wireless keyboard/touchpad (bottom), then right-click screen to open desktop environment.
8. Check Windows time and date and ensure that it is nominally synchronized (+/- 2 sec) to the designated “master clock”. If not:
    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.
9. Ensure that a microSD card with adequate storage capacity is loaded in the card slot.
10. 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>
11. Next, copy and paste the rover data directory to the D drive (microSD card) and add the prefix “Backup_”. The Rover data will be recorded in parallel to both directories.
12. 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 version of Windows.
    b. Scroll down the Device manager to Ports (Com & LPT) and expand the menu. Depending on the driver, you will see the uBlox receiver listed as “uBlox GNSS Receiver”, “USB Serial Device” or “uBlox virtual com port”. Note the com port number assignment.

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.

13. **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 uBlox receiver in step 12b.
    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_PCB_Rover_030419", "M8T_Integr_Rover_030119" or "M8T_Integr_High+Dongle_Rover_030119", depending on which hardware version of the receiver is being used, and press Open. Next, press File > GNSS button to load preconfigured settings to uBlox 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 window in the upper-most right of u-Center is the Data View (Figure 34) 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). <u>*Under Navigation Modes, the Dynamic Model parameter should be set according to the Rover use case.*</u> 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 = 500 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 30%. If these parameters are not met, efforts should be made to mitigate the effects of EMI. Potential solutions include repositioning the Rover battery, inserting an in-line USB noise filter between the Rover battery and START Rover Control Computer and applying shielding material.

NOTE: Appendix B: “Troubleshooting guidance”, provides additional information as well as screenshots and tips regarding Monitor diagnostics and potential solutions to issues induced by EMI.

   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 2x/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 system reference time and record a “time hack” event:
   i. To view START time, go to the NMEA section at the top of the message view and select GxGGA (Global Positioning System Fix Data). UTC time will be displayed at the top.
   ii. Press Record, when prompted, add prefix “time_hack” to default file name, then press Save to begin recording.
   iii. Coordinate time check and “hack” with acoustics operator. Ensure that the record **Stop** button is pressed at the moment of the audible time hack.

i. **Exit u-Center software** via the File menu.

14. To begin data recording, **open RTKLIB “STRSVR” software** via the desktop shortcut. Right click the icon and select “Open as administrator”. This software functions as a data stream server which routes the receiver’s GNSS data from the incoming com port of the START Rover Control Computer to directory locations for file recording.
   a. The top row of settings is for the Input Stream. Under the “Type” heading, use the drop down menu to select “Serial”.
   b. Under the “Opt” heading, click the button corresponding to the input stream. A popup menu will appear to set the input stream serial parameters. Use the drop down menu to select the receiver com port (from step 12b) and set the Bitrate (bps) to 115200. Use defaults for other settings. Press OK (Figure 37).
   c. Next, set (1) Output Type to “File” using the drop down menu.
   d. Click the corresponding “Opt” button. Using the popup menu, set the output file path to the appropriate directory folder established in step 10b. A Windows popup will allow you to map to the appropriate directory.

e. Enter the File name manually using the following convention: ROVER_<vehicle name or survey point name>_<test site name>_<date:mmddyyyy>.ubx (Figure 38). If more than one data file is collected for the same vehicle or survey point, then add a sequential numerical suffix at the end of the vehicle name. *If a new recording is initiated without changing the file name, you will be prompted to rename the file or have the existing file overwritten.
f. Click Save, then OK to close Output File Path popup.
g. Set (2) Output Type to “File” using the drop down menu.
h. Click the corresponding “Opt” button. Using the popup menu, set the second output file path to the backup data directory located on the microSD card. Using the Windows Explorer popup, select the appropriate folder on the “SecureDigital Storage Device (D)”.
i. Enter the File name manually using the following format: Backup_ROVER_<vehicle name or survey point name>_<test site name>_<date:mmddyyyy>.ubx. If more than one file is needed for the same vehicle or survey point, then add a sequential numerical suffix at the end of the vehicle name.
j. Click Save, then OK to close Output File Path popup.
k. Next, click the Options button at the bottom of the STRSVR interface. At the top of the options menu, set Buffer Size to 64000 and Period of rate (ms) to 500. Leave defaults for other parameters. Press OK.
l. To begin Rover data collection, click the Start button at the bottom of the STRSVR application. Assuming the STRSVR has been properly configured and the receiver is sending data, you should observe flashing green status buttons to the left of the stream settings. The bytes transferred and bits per second should also be observable on the right. Output streams 1 and 2 should indicate the same amount of bytes transferred (Figure 39).
m. It is recommended to allow the Rover to collect data for at least 5 minutes before deploying. When ready, disconnect the display monitor from the START Rover Control Computer, remove the wireless keyboard USB dongle and turn off the keyboard. The Rover is now ready to deploy.
n. When finished using the ROVER, reconnect the HDMI computer to the display monitor, insert the wireless keyboard dongle and turn on the keyboard.
o. Click the Stop button on the STRSVR software, then **exit**.

NOTES:

(1) It is recommended that data integrity checks be performed at pre-planned intervals. This may be accomplished by ejecting the microSD media, copying the START Rover data to a field laptop, returning the microSD media to the START Rover, then analyzing the data file using the VerifyRINEX Software Utility. This process is detailed in Appendix A.

(2) If you will be redeploying the Rover for continued data collection, assuming adequate START Rover battery power is remaining, it is recommended that the Rover remain powered on in order to maintain the best possible GNSS solution. However, if the battery is running low, a shutdown will be required as the battery is not “hot swappable”.

(3) Due to the limited storage space on the START Rover Control Computer, it is recommended that data be transferred and archived to both external hard drives and field laptops at the end of each day.

Figure 36, Rover interface equipment

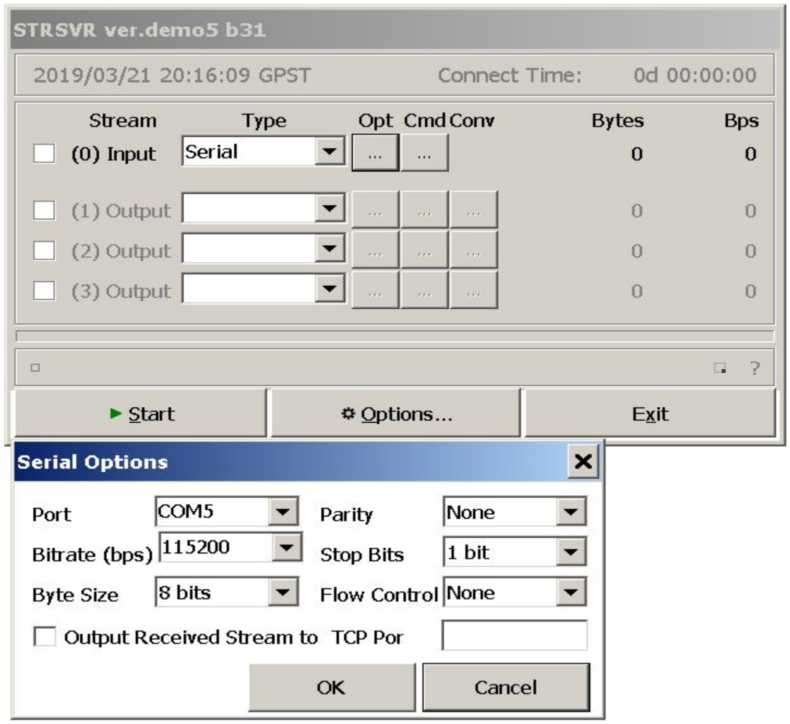


Figure 37, STRSVR input stream options window

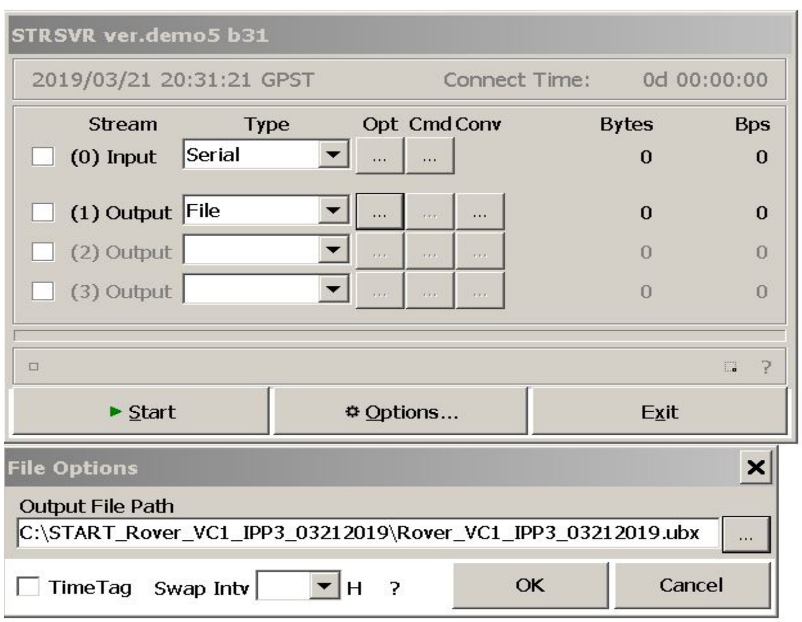


Figure 38, STRSVR output stream options window

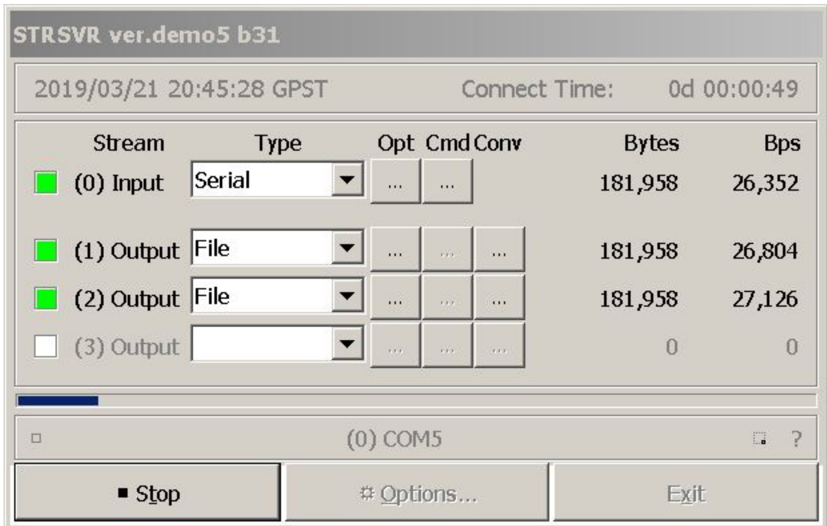


Figure 39, STRSVR window during data capture

C.4. Verifying integrity of GNSS observations

To mitigate the potential for missing or incomplete Rover GNSS data, it is recommended that the data contents be verified for completeness at preplanned or opportunistic times during data collection. For example, during battery changes or refueling of test aircraft. 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 microSD card from START Rover Control Computer.
2. Insert card in designated field laptop (a USB card reader will likely 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 uBlox ".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. Map 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 40).
    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 41).
    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 VerfifyRinex folder, which contains the VerfiyRinex 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 times (UTC).
6. Open VRinput.txt and enter parameters for the data being verified. The input configuration file must be formatted according to Figure 42. The parameters include the name of the RINEX file (no spaces or special characters permitted), starting/ending dates and times of data to be verified, Rover data sampling rate (Hz), a threshold minimum number of satellites (recommend 6 – 8) and a binary value to turn off/on the timestamp logs. See Table 43 for a summary of required format and parameters. 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 a 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.

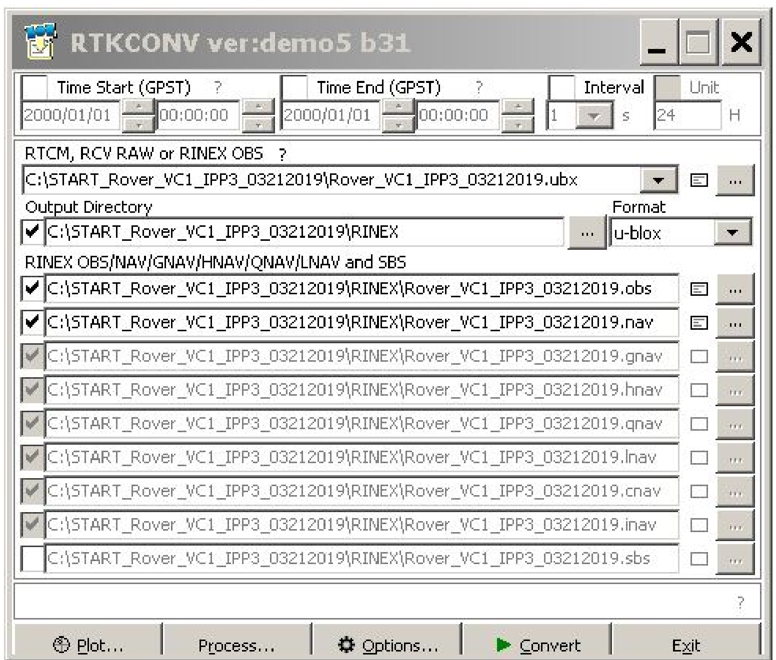


Figure 40, RTKConv main window

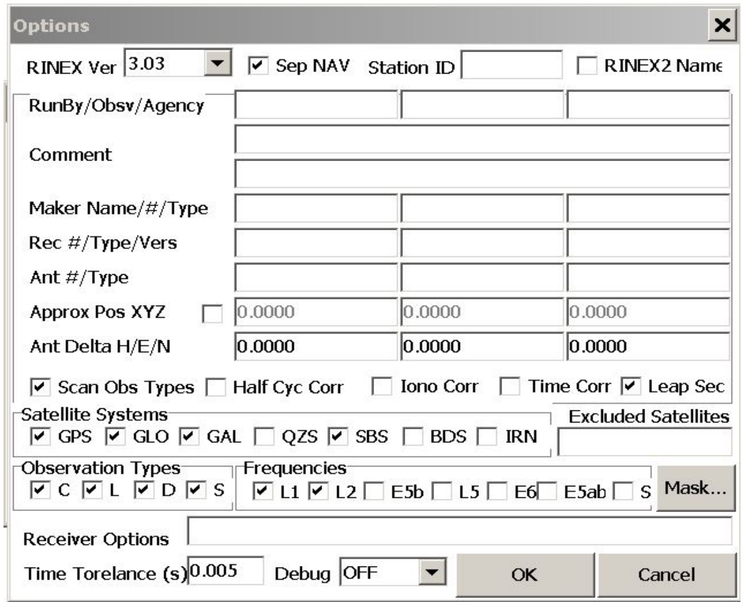
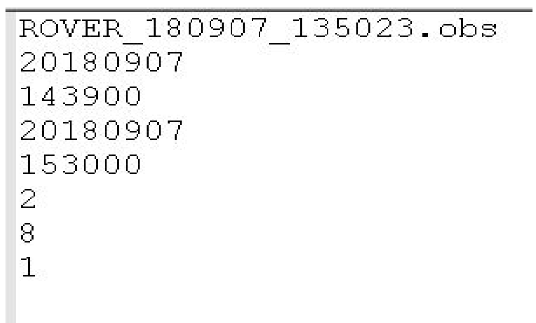


Figure 41, RTKConv options window



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

Figure 42, Sample input parameters for VRinput,txt

Table 43. VRinput.txt format

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

C.5. 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.

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 uBlox 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 complete 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 43): Jamming Status indicator should be green (OK), although yellow (warning) may also be acceptable. The CW Jamming Indicator value should generally be below 25% 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 Rover battery, inserting an in-line noise filter between the Rover battery and START Rover Control Computer and applying shielding material.

   d. An iterative process using the 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:

   e. 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.

f. 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.

g. 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 see C/N_0 levels are via the Satellite-Levels docking window as indicated by the vertical bars at the lower right of Figure 43. 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 a good 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.

Now that we have a basic understanding of the available diagnostics, here are a few example scenarios to explain and explore mitigation options.

<u>Scenario 1: Jamming Status = Warning, CW Jamming Indicator = 50%</u>

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. If antenna placement can be determined, 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 should 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" may also be a useful form of shielding for the battery, however, payload considerations must be considered when adding components to the START configuration.

Scenario 2: Jamming Status = Warning, CW Jamming Indicator = 25%

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, poor shielding on aircraft components, such as the motherboard, can emit a strong broad-spectrum EMI field. C/N_0 levels would be expected to be very low in these conditions. Installing the in-line USB noise filter and "Faraday Pouch" are still the first line of defense. Check indicators and C/N_0 levels for improvement. If the Jamming Status is not improved to Warning and the CW Jamming reduced to 20%, then iterative repositioning of components will be necessary. If aircraft appropriate, raise the antenna/receiver assembly by stacking an additional mounting apparatus. Experimenting with Rover battery mounting orientation or position is also recommended but consideration must be paid to proper load balancing.

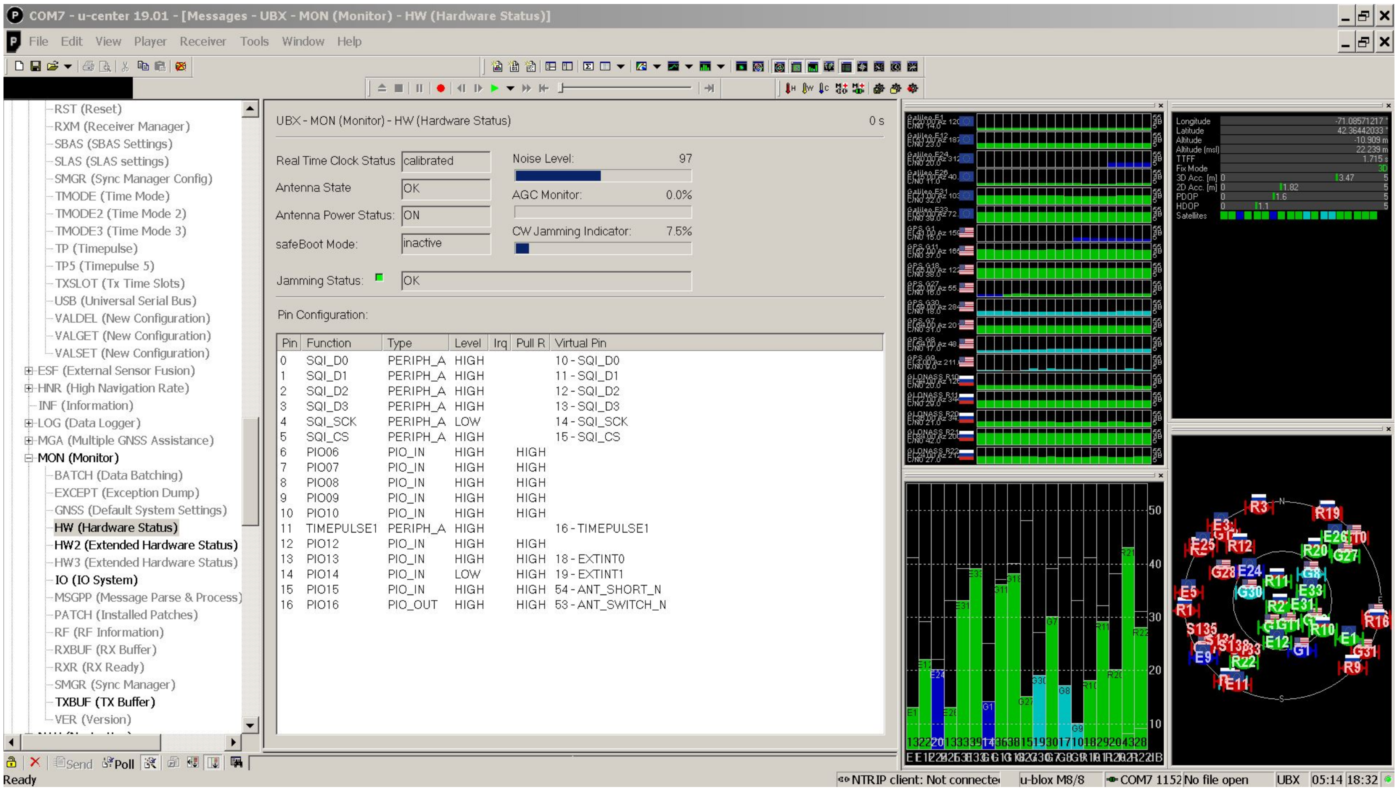


Figure 43, u-Center hardware status window

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 uBlox 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 uBlox bug and is best remedied by switching out the Start Rover Control Computer.

C.6. Tracking system mounting methods

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? Determine what will fit on the aircraft dimensionally, and what parts of the aircraft can be used as attachment points
- 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 uBlox 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. To further reduce weight, use shorter/lighter cables and minimize attaching hardware, if viable. If weight is still an issue, switch to the uBlox NEO-M8T Disc. This option has less weight and a simpler mount.

Where to Mount

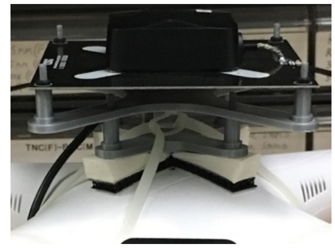
There are multiple goals in positioning the components on the aircraft. Key factors are:

- 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 and antenna away from known EMI sources

How to Mount

Mounting must be temporary and should not mar or damage the vehicle, however, must also be secure to the aircraft with no chance of components coming loose during the test. Use materials that will accomplish this with the least impact on the vehicle. Table 44 below shows various mounting tools and materials.

Table 44. Tracking system mounting aids

Components and materials	Examples
uBlox 45mm and 90mm mounts – These 3D printed mounts are made at the Volpe Center for the uBlox 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.	 

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

Figure 44, START component mounting examples

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.

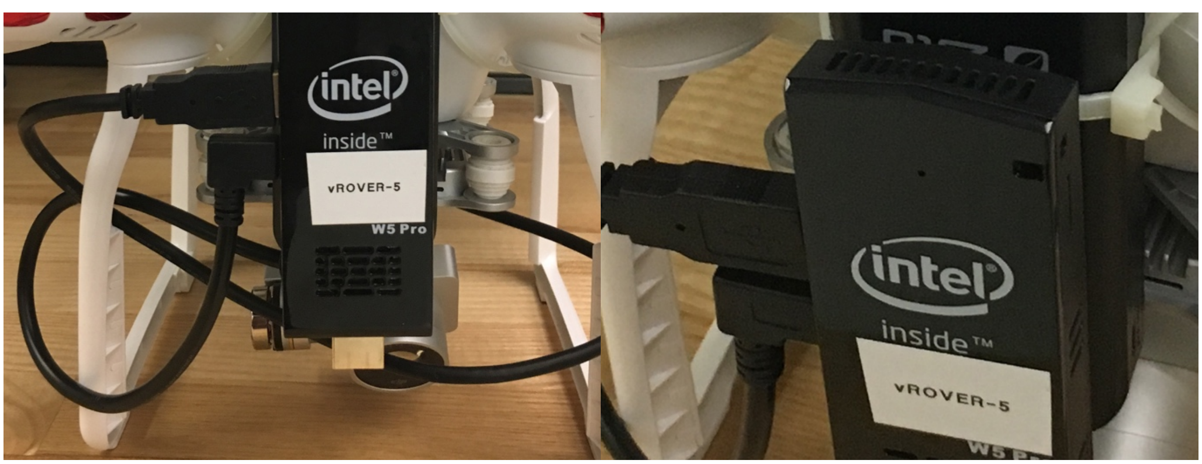


Figure 45, START computer mounting example

Figure 46, START High Gain antenna mounting example

uBlox NEO-M8T High Gain integrated receiver

Figure 47, START uBlox integrated receiver/antenna example

Figure 48, START with Tallysman antenna mounting example

C.7. Receiver configuration settings

The uBlox 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. Table 45 below 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 45. START configuration settings

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 uBlox NEO-M8T High Gain integrated receiver/antenna (square plate design). Select "Passive" for other hardware options
LOGFILTER (Log Settings)	Check "Recording enabled"

CFG (Config) Parameter	START Configuration Settings
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

C.8. START component dimensions & weights

Table 46. START component physical properties

Function	Component	Weight (g)	Length (mm)			Comments
			X	Y	Z	
Receiver	Ublox NEO-M8T PCB (no enclosure)	9	49	19	16	No enclosure
Receiver	uBlox NEO-M8T USB Dongle	16	75	26	13	
Receiver	uBlox NEO-M8T Disc	45	80	80	14	with integrated antenna + ground plate
Receiver	uBlox NEO-M8T High Gain	80	100	100	25	with integrated antenna + ground plate
Rover Control Computer	ACEPC W5 Pro mini	52	114	40	15	
Rover Control Computer	MeeGoPad T02	50	116	44	11	
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
uBlox mount	45mm mounting plate (all plastic)	7				
uBox mount	90mm mounting plate (all plastic)	12				
USB Filter	Jitterbug USB Filter	10				
*USB interconnect cables not included						

Table 47. As-installed weights

Installation examples	
Typical Type 1 installation • uBlox NEO-M8T High Gain • 4400 mAH Battery • ACEPC W5 Pro mini • 45mm uBlox Mount • 90mm uBlox mount • Assorted cables, zip ties, velcro, and foam • Total with USB noise filter – **328g** • Total without USB noise filter – **318g**	Typical Type 2 installation – lightweight configuration • uBlox NEO-M8T Disc • 4400 mAH Battery • ACEPC W5 Pro mini • 45mm uBlox Mount • Assorted cables, zip ties, velcro, and foam • Total with USB noise filter – **282g** • Total without USB noise filter – **272g**

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

C.9. Product resource links

uBlox 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

uBlox 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

RTK Explorer:
https://rtklibexplorer.wordpress.com/

Appendix D: Individual Event Noise Measurement Data

D.1. Measurement data introduction

Acoustic and meteorological data collected during the noise measurement program for each individual aircraft noise event are presented on the following pages. These data were used to obtain the average value data per aircraft and event type that are provided in the body of the report in section 3. A uniform data presentation format is used in this appendix for the three rotary-wing vehicles; the fixed-wing X-8 format is slightly different due to differences in takeoff operations between rotary- and fixed-wing vehicles.

D.2 Rotary-wing Vehicles

The rotary-wing vehicles have data presented in two different groups: one set of tables for fully dynamic operations and other set for operations which contain a mix of static and dynamic components. The fully dynamic operations are the slow and fast overflights. The operations which contain a mix of dynamic and static components – referred to below as 'semi-static' – are the takeoff, landing, and infrastructure inspection operations.

D.2.1 Dynamic operations

The dynamic operations – the slow and fast overflights – each have four tables. The first three tables show data for the LAMax (one table) and SEL (two tables) metrics with a record of data (i.e. a row in each of the tables) for each pass. The fourth table shows a set of statistical data for the passes. These tables are described below.

D.2.1.1 LAMax table

These tables provide the maximum A-weighted, slow time-averaged noise level for each pass. The tables show the same type of information for each of the three microphones. Note that these tables use the symbol "L_{ASmx}" in the header.

The leftmost column provides the pass ID number that was used by test personnel to coordinate logging information during the measurement. The next column provides the time of the event as logged by the Flight Director.

The next column shows the time at which the LAMax for that event occurred. Note that values in this column indicate the time of sound reception, not emission. (For the relatively small sound propagation distances typical for this testing, the difference between emission and reception time should be extremely small.) The values are those stored in the LD831 SLM data files. The next column provides the measured LAMax values. The next column provides these levels extrapolated to a normalizing distance of 400 feet. This extrapolation only accounts for the spherical spreading of sound, based on the measured aircraft position relative to each microphone at the time of LAMax; no other adjustments, such as for atmospheric absorption, are included. Note that this normalization distance is the common distance used in a number of prior Volpe/FAA reports to allow simple comparison of different UAS vehicles at a common distance. The last column in each microphone set is the three-dimensional slant distance between the microphone and the aircraft at the time of LAMax.

D.2.1.2 SEL table

The Sound Exposure Level tables are formatted in a similar manner to the LAMax tables, with the Pass ID and the logged event times repeated from the LAMax table. Noise data are provided in the middle columns, and the rightmost columns provide the aircraft speed and direction of flight. Note that these tables use the symbol "L_{AE}" in the header.

For each microphone, the first column provides the duration of the event. SEL is a time-integrated metric where the sound energy for the entire noise event is normalized to a reference duration of one second. The actual duration is determined by identifying the "10 dB down" points, relative to the LAMax level for the event. For this study, the SEL values were computed by automated post-processing of the stored A-weighted time history values from the SLM using an in-house Fortran utility. The process starts 25 seconds before the time of LAMax and ends 25 seconds afterward. If the time-history levels within this period do not exhibit a clear 10 dB rise and fall then the SEL event duration is set to 50 seconds and the associated data quality column (labelled "10dBA?") is set to "no". Passes where the 10 dB down criterion was met contain the word "yes" in this column. The next column shows the SEL level itself. Note that the calculated SEL is still shown, even if the 10 dB down criterion was not met.

Aircraft ground speed ("GS") and true airspeed ("KTAS"), both in knots, and direction of flight, either south-bound ("S") or north-bound ("N"), are also provided. Note that for SEL, higher levels tend to correlate with flights into the wind, where vehicle ground speeds were lower. Prevailing winds during testing were from the south. The ground speed values are taken from the Volpe START system – this is a GPS-based measurement of the speed of the vehicle over the ground derived from the sequential position information and the time period between each position measurement. The KTAS data values are derived from the vectors of the ground speed and the wind speed as recorded by the Volpe meteorological station at the measurement site.

D.2.1.3 Additional SEL data and wind table

The third table in the set contains additional SEL information not shown in the prior table due to space considerations. As before, the first two columns show the pass ID and the Flight Director's logged time for the pass. The microphone data columns provide event starting and ending times from which the duration in the primary SEL table was obtained. Also provided is an estimate of the ambient noise level at the start of each event; the value is based on a five second average of the one second LEQ levels at the start of the SEL testing period. Ambient levels reported in these tables each represent an average of the LEQ levels from 30 to 25 seconds prior to the LAMax of the event.

The wind data in the right-most three columns shows the average wind as measured at the meteorological station at the site. The average is calculated from the ten seconds around the LAMax time. The average crosswind ("Avg X-wind (kts)" in the table) is calculated from the dot product of the vectors of the vehicle and wind velocity vectors. The "wind OK?" criterion is met if the average wind speed was less than ten knots and the average cross wind speed was less than 5 knots during the pass.

D.2.1.4 Statistical data table

This table provides a statistical summary for each series of passes. As before, each microphone has its own set of data. The metrics for which the statistics are compiled are the LAMax (as measured), the LAMax normalized to a distance of 400 feet, and the SEL. The data for each of the metrics include the mean and standard deviation for the passes, and the upper and lower 90% confidence intervals.

D.2.2 Semi-static operations

The semi-static operations are the take-off, landing, and infrastructure inspection operations. As with the dynamic operations, there are four data tables associated with each pass series. The first data table provides data for the LAMax metric and is identical in structure and format to the dynamic LAMax table. The next two tables provide detailed information about the distance and position of the vehicle at the time of the LAMax level. The fourth table provides statistical data for the passes. The major difference between the presentations for the dynamic and semi-static data sets is that the Dynamic data contains SEL information, the semi-static operations do not – the semi-static operations have no meaningful SEL data because the static part of the operation is of undetermined time. Tables for semi-static operations do provide additional information on aircraft position and distance to help identify vehicle location at the time of LAMax.

D.2.2.1 LAMax table

The tables for Maximum A-weighted Level (LAMax) present the data for each pass. The semi-static LAMax data presentation is identical to the dynamic LAMax data presentation, with the exception that distances for the semi-static operations are normalized to a reference distance of 100 feet. This shorter distance is assumed to be more appropriate for operations which are likely to occur in close proximity to people – so, for example, a package delivery operation with landing and takeoff components is better represented at a 100 foot distance rather than the 400 foot distance used for dynamic operations.

D.2.2.2 Distance and wind table

The Distance and Wind tables use a format generally similar to the LAMax tables. The pass ID is again the left-most column. The three microphone data set occupy the middle of the table, and wind data can be found in the right-most three columns, as discussed below.

The microphone data sets are comprised of four columns each. The first column repeats the LAMax time from the LAMax table. The second column repeats the distance from the vehicle to the microphone at the time of LAMax. Additional information columns include the time when the vehicle was at the closest point of approach (CPA) to the particular microphone and the slant distance of that CPA. This facilitates comparisons of between distance at the time of LAMax and CPA: Large differences indicate the noisiest configuration does not occur at the closest point of approach to the microphone.

The wind data in the right-most three columns are the same as those in the SEL additional data table in dynamic operations.

D.2.2.3 LAMax position data table

The third table in the semi-static operation set contains additional position data. For each pass, in addition to the LAMax time and distance information repeated from the prior tables, the three dimensional position of the vehicle at the LAMax time is given for each microphone. Note that the X, Y, and Z positions given in the table are in the local coordinate system used at CNO where the X axis is aligned with North, the Y axis is aligned with West, and Z increases with vertical height. For this measurement campaign, the local coordinate system used the centerline ground plane microphone as the coordinate origin.

D.2.2.4 Statistical data table

This table contains a statistical summary for each series of passes. As before, each microphone has its own set of data. The metrics for which the statistics are compiled are the LAMax (as measured) and the LAMax normalized to a distance of 100 feet. The data for each of the metrics include the mean and standard deviation for the passes, and the upper and lower 90% confidence intervals.

D.2.3 Hover operations

Each hover data table contains a record (i.e. a row) for each nominal 30-second interval with the vehicle heading oriented toward a cardinal compass direction during the particular series. Data columns include the starting time when the vehicle was stable - pointed in a particular direction, and an ending time immediately before the vehicle began yawing to the next compass direction. The difference between these two times – used as the averaging period – is used to determine the LEQ of the event from the measured half-second LEQ values. These event LEQ values and the LEQ normalized to 100 feet are also presented in the tables. The normalized LEQ are calculated based on the position of the vehicle at *each* half second during the averaging period – the calculation is *not* based on the average vehicle position during the averaging period.

TYPHOON

Slow LFO (1st series)

Table 48, Typhoon slow overflight, Maximum A-weighted Levels, first series

Typhoon	SLO	Centerline Ground Mic.				Centerline Pole Mic.				Sideline Ground Mic.			
Pass ID	Log Time	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm400	Distance at L_{ASmx} (ft)	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm400	Distance at L_{ASmx} (ft)	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm400	Distance at L_{ASmx} (ft)
110	15:02:11.0	15:02:15.5	58.6	50.38	155.2	15:02:15.0	55.1	46.65	151.3	15:02:15.5	58.2	50.16	158.5
120	15:03:29.0	15:03:29.5	57.9	50.17	164.3	15:03:30.5	55	46.59	152	15:03:30.5	57.6	49.67	160.5
130	15:05:00.0	15:05:06.5	59.5	51.03	150.9	15:05:06.0	56.2	47.71	150.4	15:05:07.5	59.2	50.96	155
140	15:06:20.0	15:06:17.0	55.9	47.47	151.6	15:06:20.0	53.4	44.79	148.4	15:06:18.5	57	48.5	150.3
150	15:08:20.0	15:08:32.0	59.3	50.91	152.2	15:08:31.5	55.8	47.2	148.6	15:08:32.5	59.1	50.98	157.1

Table 49, Typhoon slow overflight, A-weighted Sound Exposure Levels, first series

Typhoon	SLO	Centerline Ground Mic.			Centerline Pole Mic.			Sideline Ground Mic.			speed & direction		
Pass ID	Log Time	Duration (sec.)	L_{AE}	10dBA OK?	Duration (sec.)	L_{AE}	10dBA OK?	Duration (sec.)	L_{AE}	10dBA OK?	GS (kts)	KTAS	direction
110	15:02:11.0	32.5	70.3	Yes	50	68.2	No	34.5	70.1	Yes	9.3	12.2	S
120	15:03:29.0	15	66.7	Yes	50	66.9	No	15.5	66.6	Yes	16.3	10.7	N
130	15:05:00.0	25	70.2	Yes	50	68.3	No	26	69.9	Yes	10.7	17.8	S
140	15:06:20.0	22.5	66.2	Yes	50	65.9	No	19	66.9	Yes	13.3	10.3	N
150	15:08:20.0	29.5	70.1	Yes	50	68.1	No	29.5	69.9	Yes	9.1	13.9	S

TYPHOON

Slow LFO (1st series)

Table 50, Typhoon slow overflight, additional Sound Exposure Level and wind data, first series

Typhoon	SLO	Centerline Ground Mic.			Centerline Pole Mic.			Sideline Ground Mic.			Avg winds & criteria		
Pass ID	Log Time	L_{AE} Start Time	L_{AE} End Time	Ambient dBA	L_{AE} Start Time	L_{AE} End Time	Ambient dBA	L_{AE} Start Time	L_{AE} End Time	Ambient dBA	Avg Wind (kts)	Avg X-Wind (kts)	Wind OK?
110	15:02:11.0	15:01:59.5	15:02:32.0	40.6	15:01:50.0	15:02:40.0	46.9	15:01:58.5	15:02:33.0	40.8	3.7	1.7	Yes
120	15:03:29.0	15:03:25.0	15:03:40.0	35.8	15:03:05.5	15:03:55.5	48	15:03:24.5	15:03:40.0	37.1	6.1	0.4	Yes
130	15:05:00.0	15:04:55.0	15:05:20.0	36.2	15:04:42.5	15:05:32.5	46.9	15:04:55.0	15:05:21.0	37.8	7.2	2.2	Yes
140	15:06:20.0	15:06:07.5	15:06:30.0	36.2	15:05:55.0	15:06:45.0	46.4	15:06:09.5	15:06:28.5	35.9	4.3	2.4	Yes
150	15:08:20.0	15:08:16.5	15:08:46.0	42.3	15:08:06.5	15:08:56.5	47.1	15:08:15.5	15:08:45.0	42.7	5.2	1.5	Yes

Table 51, Typhoon slow overflight, statistical data, first series

Typhoon SLO	Centerline Ground Mic.			Centerline Pole Mic.			Sideline Ground Mic.		
Metric	L_{ASmx}	L_{ASmx} Norm400	L_{AE}	L_{ASmx}	L_{ASmx} Norm400	L_{AE}	L_{ASmx}	L_{ASmx} Norm400	L_{AE}
Mean	58.2	50	68.7	55.1	46.6	67.5	58.2	50.1	68.7
Stand. Dev.	1.5	1.5	2.1	1.1	1.1	1.1	0.9	1	1.8
90% CI	1.4	1.4	2	1	1.1	1	0.9	1	1.7
CI Low	56.9	48.6	66.7	54.1	45.5	66.5	57.3	49.1	67
CI High	59.6	51.4	70.7	56.1	47.6	68.5	59.1	51	70.4

TYPHOON
Fast LFO series

Table 52, Typhoon fast overflight, Maximum A-weighted Levels

Typhoon	FLO	Centerline Ground Mic.				Centerline Pole Mic.				Sideline Ground Mic.			
Pass ID	Log Time	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm400	Distance at L_{ASmx} (ft)	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm400	Distance at L_{ASmx} (ft)	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm400	Distance at L_{ASmx} (ft)
210	15:10:10.0	15:10:13.0	58.0	49.2	145.3	15:10:13.0	55.1	46.12	142.2	15:10:13.0	57.8	49.14	147.6
220	15:11:10.0	15:11:10.0	59.7	50.81	143.8	15:11:09.0	55.8	46.94	144.2	15:11:10.0	59.3	50.56	146.2
230	15:12:05.0	15:12:11.5	58.4	50.13	154.4	15:12:11.0	54.5	46	150.3	15:12:11.0	58.8	50.37	151.5
240	15:13:00.0	15:12:59.5	59.3	50.38	143.2	15:12:59.0	55.2	46.51	147.1	15:13:00.0	59.3	50.5	145.3

Table 53, Typhoon fast overflight, A-weighted Sound Exposure Levels

Typhoon	FLO	Centerline Ground Mic.			Centerline Pole Mic.			Sideline Ground Mic.			speed & direction		
Pass ID	Log Time	Duration (sec.)	L_{AE}	10dBA OK?	Duration (sec.)	L_{AE}	10dBA OK?	Duration (sec.)	L_{AE}	10dBA OK?	GS (kts)	KTAS	direction
210	15:10:10.0	11	65.1	Yes	50	65.8	No	11.5	65.1	Yes	25.1	22.7	N
220	15:11:10.0	11.5	67.2	Yes	50	66.4	No	11.5	67	Yes	25	31	S
230	15:12:05.0	10.5	64.9	Yes	50	65.2	No	11	65.7	Yes	24.6	19.8	N
240	15:13:00.0	12.5	67.1	Yes	50	66	No	12	67.1	Yes	24.8	30	S

TYPHOON

Fast LFO series

Table 54, Typhoon fast overflight, additional Sound Exposure Level and wind data

Typhoon	FLO	Centerline Ground Mic.			Centerline Pole Mic.			Sideline Ground Mic.			Avg winds & criteria		
Pass ID	Log Time	L_{AE} Start Time	L_{AE} End Time	Ambient dBA	L_{AE} Start Time	L_{AE} End Time	Ambient dBA	L_{AE} Start Time	L_{AE} End Time	Ambient dBA	Avg Wind (kts)	Avg X-Wind (kts)	Wind OK?
210	15:10:10.0	15:10:08.0	15:10:19.0	33	15:09:48.0	15:10:38.0	46.3	15:10:07.5	15:10:19.0	33.4	3.1	1.5	Yes
220	15:11:10.0	15:11:04.5	15:11:16.0	33.4	15:10:44.0	15:11:34.0	46.9	15:11:04.5	15:11:16.0	34.2	6.5	2.2	Yes
230	15:12:05.0	15:12:07.5	15:12:18.0	32.6	15:11:46.0	15:12:36.0	46.3	15:12:07.5	15:12:18.5	33.9	5.4	0.3	Yes
240	15:13:00.0	15:12:54.5	15:13:07.0	35	15:12:34.5	15:13:24.5	46.1	15:12:54.5	15:13:06.5	35	5.6	0.7	Yes

Table 55, Typhoon fast overflight, statistical data

Typhoon FLO	Centerline Ground Mic.			Centerline Pole Mic.			Sideline Ground Mic.		
Metric	L_{ASmx}	L_{ASmx} Norm400	L_{AE}	L_{ASmx}	L_{ASmx} Norm400	L_{AE}	L_{ASmx}	L_{ASmx} Norm400	L_{AE}
Mean	58.9	50.1	66.1	55.1	46.4	65.8	58.8	50.1	66.2
Stand. Dev.	0.8	0.7	1.3	0.5	0.4	0.5	0.7	0.7	1
90% CI	0.9	0.8	1.5	0.6	0.5	0.6	0.8	0.8	1.1
CI Low	57.9	49.3	64.6	54.5	45.9	65.2	58	49.4	65.1
CI High	59.8	50.9	67.5	55.8	46.9	66.4	59.6	50.9	67.4

TYPHOON

Vertical takeoff series

Table 56, Typhoon vertical takeoff, Maximum A-weighted Levels

Typhoon	TAK	Centerline Ground Mic.				Centerline Pole Mic.				Sideline Ground Mic.			
Pass ID	Log Time	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm100	Distance at L_{ASmx} (ft)	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm100	Distance at L_{ASmx} (ft)	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm100	Distance at L_{ASmx} (ft)
310	15:23:45.0	15:23:48.0	66.2	52.01	19.5	15:23:48.0	59.7	49.18	29.8	15:23:48.5	63	52.29	29.1
320	15:27:18.0	15:27:18.0	67.7	55.08	23.4	15:27:18.0	60.4	50	30.2	15:27:19.0	63.2	55.19	39.8
330	15:30:08.0	15:30:09.0	67.1	53.83	21.7	15:30:10.0	59.3	50.42	36	15:30:10.0	63	54.33	36.9
340	15:32:47.0	15:32:49.5	68.8	55.52	21.7	15:32:49.5	60.6	49.94	29.3	15:32:49.5	64.8	54.18	29.5

Table 57, Typhoon vertical takeoff, distance and wind data

Typhoon TAK	Centerline Ground Mic.				Centerline Pole Mic.				Sideline Ground Mic.				Avg winds & criteria		
Pass ID	L_{ASmx} Time	L_{ASmx} Dist. (ft)	CPA Time	CPA (ft)	L_{ASmx} Time	L_{ASmx} Dist. (ft)	CPA Time	CPA (ft)	L_{ASmx} Time	L_{ASmx} Dist. (ft)	CPA Time	CPA (ft)	Avg Wind (kts)	Avg X-Wind (kts)	Wind OK?
310	15:23:48.0	19.5	15:23:48.0	19.5	15:23:48.0	29.8	15:23:48.0	29.8	15:23:48.5	29.1	15:23:48.0	28.2	6	1.1	Yes
320	15:27:18.0	23.4	15:27:18.0	23.4	15:27:18.0	30.2	15:27:18.0	30.2	15:27:19.0	39.8	15:27:18.0	30.7	5.3	0.5	Yes
330	15:30:09.0	21.7	15:30:08.0	19.3	15:30:10.0	36	15:30:08.0	29.9	15:30:10.0	36.9	15:30:08.0	28.4	4.8	0.3	Yes
340	15:32:49.5	21.7	15:32:47.0	15.8	15:32:49.5	29.3	15:32:47.0	26.5	15:32:49.5	29.5	15:32:47.0	25.4	8.4	1.1	Yes

TYPHOON

Vertical takeoff series

Table 58, Typhoon vertical takeoff Maximum A-weighted Levels position data

Typhoon TAK	Centerline Ground Mic.					Centerline Pole Mic.					Sideline Ground Mic.				
Pass ID	L_{ASmx} Time	L_{ASmx} Dist. (ft)	X (ft)	Y (ft)	Z (ft)	L_{ASmx} Time	L_{ASmx} Dist. (ft)	X (ft)	Y (ft)	Z (ft)	L_{ASmx} Time	L_{ASmx} Dist. (ft)	X (ft)	Y (ft)	Z (ft)
310	15:23:48.0	19.5	19.1	-2.2	3.3	15:23:48.0	29.8	19.1	-2.2	3.3	15:23:48.5	29.1	18.9	-2	9
320	15:27:18.0	23.4	17.2	-1.7	15.8	15:27:18.0	30.2	17.2	-1.7	15.8	15:27:19.0	39.8	17.6	-2.3	29.1
330	15:30:09.0	21.7	19.7	-2.7	8.6	15:30:10.0	36	20	-2.9	22.7	15:30:10.0	36.9	20	-2.9	22.7
340	15:32:49.5	21.7	17.3	-1.7	13	15:32:49.5	29.3	17.3	-1.7	13	15:32:49.5	29.5	17.3	-1.7	13

Table 59, Typhoon vertical takeoff, statistical data

Typhoon TAK	Centerline Ground Mic.		Centerline Pole Mic.		Sideline Ground Mic.	
Metric	L_{ASmx}	L_{ASmx} Norm100	L_{ASmx}	L_{ASmx} Norm100	L_{ASmx}	L_{ASmx} Norm100
Mean	67.4	54.1	60	49.9	63.5	54
Stand. Dev.	1.1	1.6	0.6	0.5	0.9	1.2
90% CI	1.3	1.8	0.7	0.6	1	1.4
CI Low	66.2	52.3	59.3	49.3	62.5	52.6
CI High	68.7	56	60.7	50.5	64.5	55.4

TYPHOON

Vertical landing series

Table 60, Typhoon vertical landing, Maximum A-weighted Levels

Typhoon	LND	Centerline Ground Mic.				Centerline Pole Mic.				Sideline Ground Mic.			
Pass ID	Log Time	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm100	Distance at L_{ASmx} (ft)	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm100	Distance at L_{ASmx} (ft)	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm100	Distance at L_{ASmx} (ft)
311	15:26:10.0	15:26:32.0	72.5	58.87	20.8	15:26:28.0	64.2	55.54	36.9	15:26:28.0	69.5	60.71	36.4
321	15:28:40.0	15:29:00.5	72.7	62.18	29.8	15:28:59.5	66.4	57.97	37.9	15:28:59.5	70.3	62.28	39.7
331	15:31:40.0	15:32:03.0	74.1	62.24	25.5	15:32:01.5	66.3	57.23	35.2	15:32:02.5	70.8	61.53	34.4
341	15:34:15.0	15:34:41.0	71.4	61.03	30.3	15:34:38.0	65.2	58.26	45	15:34:37.0	69.8	64.16	52.3

Table 61, Typhoon vertical landing, distance and wind data

Typhoon LND	Centerline Ground Mic.				Centerline Pole Mic.				Sideline Ground Mic.				Avg winds & criteria		
Pass ID	L_{ASmx} Time	L_{ASmx} Dist. (ft)	CPA Time	CPA (ft)	L_{ASmx} Time	L_{ASmx} Dist. (ft)	CPA Time	CPA (ft)	L_{ASmx} Time	L_{ASmx} Dist. (ft)	CPA Time	CPA (ft)	Avg Wind (kts)	Avg X-Wind (kts)	Wind OK?
311	15:26:32.0	20.8	15:26:36.5	15.9	15:26:28.0	36.9	15:26:35.5	26.3	15:26:28.0	36.4	15:26:36.5	25.3	4.7	1.9	Yes
321	15:29:00.5	29.8	15:29:11.0	19.2	15:28:59.5	37.9	15:29:10.0	29.8	15:28:59.5	39.7	15:29:19.5	28.4	4.3	0.1	Yes
331	15:32:03.0	25.5	15:32:11.0	15.3	15:32:01.5	35.2	15:32:08.5	25.8	15:32:02.5	34.4	15:32:11.0	25.1	6.1	0.3	Yes
341	15:34:41.0	30.3	15:34:50.0	22.3	15:34:38.0	45	15:34:46.0	32.7	15:34:37.0	52.3	15:34:50.0	29.5	6.1	0.5	Yes

TYPHOON

Vertical landing series

Table 62, Typhoon vertical landing, Maximum A-weighted Levels position data

Typhoon LND	Centerline Ground Mic.					Centerline Pole Mic.					Sideline Ground Mic.				
Pass ID	L_{ASmx} Time	L_{ASmx} Dist. (ft)	X (ft)	Y (ft)	Z (ft)	L_{ASmx} Time	L_{ASmx} Dist. (ft)	X (ft)	Y (ft)	Z (ft)	L_{ASmx} Time	L_{ASmx} Dist. (ft)	X (ft)	Y (ft)	Z (ft)
311	15:26:32.0	20.8	16.3	-2.1	12.8	15:26:28.0	36.9	22.7	-2.5	19.7	15:26:28.0	36.4	22.7	-2.5	19.7
321	15:29:00.5	29.8	19.4	-3.6	22.3	15:28:59.5	37.9	19.5	-3.8	26.6	15:28:59.5	39.7	19.5	-3.8	26.6
331	15:32:03.0	25.5	15.5	-2.4	20.1	15:32:01.5	35.2	16.4	-2.8	26.4	15:32:02.5	34.4	15.6	-2.5	22.3
341	15:34:41.0	30.3	22.5	-2.4	20.1	15:34:38.0	45	22.2	-2.6	34.7	15:34:37.0	52.3	22.1	-2.3	42.8

Table 63, Typhoon vertical landing, statistical data

Typhoon LND	Centerline Ground Mic.		Centerline Pole Mic.		Sideline Ground Mic.	
Metric	L_{ASmx}	L_{ASmx} Norm100	L_{ASmx}	L_{ASmx} Norm100	L_{ASmx}	L_{ASmx} Norm100
Mean	72.7	61.1	65.5	57.3	70.1	62.2
Stand. Dev.	1.1	1.6	1	1.2	0.6	1.5
90% CI	1.3	1.8	1.2	1.4	0.7	1.7
CI Low	71.4	59.2	64.3	55.8	69.4	60.4
CI High	74	62.9	66.7	58.7	70.8	63.9

TYPHOON
“Infrastructure” series

Table 64, Typhoon infrastructure, Maximum A-weighted Levels

Typhoon	INF	Centerline Ground Mic.				Centerline Pole Mic.				Sideline Ground Mic.			
Pass ID	Log Time	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm100	Distance at L_{ASmx} (ft)	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm100	Distance at L_{ASmx} (ft)	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm100	Distance at L_{ASmx} (ft)
410	15:54:20.0	15:54:07.5	62.7	62.05	92.8	15:54:07.0	59.5	58.51	89.3	15:54:08.5	63.3	62.59	92.2
420	15:56:20.0	15:55:55.0	62.8	62.27	94.1	15:55:55.0	59	58.1	90.1	15:55:55.0	62.4	62.19	97.6
430	15:58:20.0	15:58:00.0	63.9	63.16	91.8	15:57:59.5	60.2	59.05	87.6	15:58:00.0	63.5	63.09	95.4

Table 65, Typhoon infrastructure, distance and wind data

Typhoon INF	Centerline Ground Mic.				Centerline Pole Mic.				Sideline Ground Mic.				Avg winds & criteria		
Pass ID	L_{ASmx} Time	L_{ASmx} Dist. (ft)	CPA Time	CPA (ft)	L_{ASmx} Time	L_{ASmx} Dist. (ft)	CPA Time	CPA (ft)	L_{ASmx} Time	L_{ASmx} Dist. (ft)	CPA Time	CPA (ft)	Avg Wind (kts)	Avg X-Wind (kts)	Wind OK?
410	15:54:07.5	92.8	15:54:20.0	93.2	15:54:07.0	89.3	15:54:20.0	89.9	15:54:08.5	92.2	15:54:20.0	92.6	4.4	0.8	Yes
420	15:55:55.0	94.1	15:56:20.0	94.7	15:55:55.0	90.1	15:56:20.0	90.8	15:55:55.0	97.6	15:56:20.0	97.9	4.3	0.3	Yes
430	15:58:00.0	91.8	15:58:20.0	91.5	15:57:59.5	87.6	15:58:20.0	87.2	15:58:00.0	95.4	15:58:20.0	94.8	3.6	0.2	Yes

TYPHOON

“Infrastructure” series

Table 66, Typhoon Infrastructure, Maximum A-weighted Levels position data

Typhoon INF	Centerline Ground Mic.					Centerline Pole Mic.					Sideline Ground Mic.				
Pass ID	L_{ASmx} Time	L_{ASmx} Dist. (ft)	X (ft)	Y (ft)	Z (ft)	L_{ASmx} Time	L_{ASmx} Dist. (ft)	X (ft)	Y (ft)	Z (ft)	L_{ASmx} Time	L_{ASmx} Dist. (ft)	X (ft)	Y (ft)	Z (ft)
410	15:54:07.5	92.8	0.1	13.1	91.9	15:54:07.0	89.3	-0.1	13	91.9	15:54:08.5	92.2	0.4	13	92
420	15:55:55.0	94.1	-5.9	-6.7	93.6	15:55:55.0	90.1	-5.9	-6.7	93.6	15:55:55.0	97.6	-5.9	-6.7	93.6
430	15:58:00.0	91.8	-8.4	-6.2	91.2	15:57:59.5	87.6	-8.6	-6.5	91.2	15:58:00.0	95.4	-8.4	-6.2	91.2

Table 67, Typhoon infrastructure, statistical data

Typhoon INF	Centerline Ground Mic.		Centerline Pole Mic.		Sideline Ground Mic.	
Metric	L_{ASmx}	L_{ASmx} Norm100	L_{ASmx}	L_{ASmx} Norm100	L_{ASmx}	L_{ASmx} Norm100
Mean	63.1	62.5	59.6	58.6	63.1	62.6
Stand. Dev.	0.7	0.6	0.6	0.5	0.6	0.5
90% CI	1.1	1	1	0.8	1	0.8
CI Low	62	61.5	58.6	57.8	62.1	61.9
CI High	64.3	63.5	60.6	59.4	64.1	63.4

TYPHOON
Slow LFO (2nd series)

Table 68, Typhoon slow overflight, Maximum A-weighted Levels, second series

Typhoon	SLO	Centerline Ground Mic.				Centerline Pole Mic.				Sideline Ground Mic.			
Pass ID	Log Time	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm400	Distance at L_{ASmx} (ft)	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm400	Distance at L_{ASmx} (ft)	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm400	Distance at L_{ASmx} (ft)
160	16:36:00.0	16:36:02.0	58.2	50.24	160	16:36:03.5	54.5	46.16	153.1	16:36:03.5	58.1	50.01	157.6
170	16:37:05.0	16:37:08.0	56	47.96	158.4	16:37:10.5	52.9	44.2	146.9	16:37:08.5	57.2	49.11	157.6

Table 69, Typhoon slow overflight, A-weighted Sound Exposure Levels, second series

Typhoon	SLO	Centerline Ground Mic.			Centerline Pole Mic.			Sideline Ground Mic.			speed & direction		
Pass ID	Log Time	Duration (sec.)	L_{AE}	10dBA OK?	Duration (sec.)	L_{AE}	10dBA OK?	Duration (sec.)	L_{AE}	10dBA OK?	GS (kts)	KTAS	direction
160	16:36:00.0	31	69.7	Yes	47	66.7	Yes	30	69.6	Yes	10.7	16.2	S
170	16:37:05.0	25	67	Yes	50	65.1	No	23.5	67.2	Yes	12.9	9	N

TYPHOON

Slow LFO (2nd series)

Table 70, Typhoon slow overflight, additional Sound Exposure Level and wind data, second series

Typhoon	SLO	Centerline Ground Mic.			Centerline Pole Mic.			Sideline Ground Mic.			Avg winds & criteria		
Pass ID	Log Time	L_{AE} Start Time	L_{AE} End Time	Ambient dBA	L_{AE} Start Time	L_{AE} End Time	Ambient dBA	L_{AE} Start Time	L_{AE} End Time	Ambient dBA	Avg Wind (kts)	Avg X-Wind (kts)	Wind OK?
160	16:36:00.0	16:35:47.5	16:36:18.5	38.6	16:35:40.5	16:36:27.5	44	16:35:49.0	16:36:19.0	38.6	6	3.1	Yes
170	16:37:05.0	16:36:57.5	16:37:22.5	37.5	16:36:45.5	16:37:35.5	44	16:36:58.0	16:37:21.5	38	4.8	2.1	Yes

Table 71, Typhoon slow overflight, statistical data, second series

Typhoon SLO	Centerline Ground Mic.			Centerline Pole Mic.			Sideline Ground Mic.		
Metric	L_{ASmx}	L_{ASmx} Norm400	L_{AE}	L_{ASmx}	L_{ASmx} Norm400	L_{AE}	L_{ASmx}	L_{ASmx} Norm400	L_{AE}
Mean	57.1	49.1	68.3	53.7	45.2	65.9	57.7	49.6	68.4
Stand. Dev.	1.6	1.6	1.9	1.1	1.4	1.1	0.6	0.6	1.7
90% CI	6.9	7.2	8.4	5.1	6.2	5.1	2.8	2.8	7.8
CI Low	50.2	41.9	59.9	48.6	39	60.8	54.8	46.7	60.7
CI High	64	56.3	76.7	58.8	51.4	71	60.5	52.4	76.2

TYPHOON

Hovers

Table 72, Typhoon hover, Equivalent Continuous Sound Level, first series

Typhoon Hover	Times			Centerline Ground Mic.		Centerline Pole Mic.		Sideline Ground Mic.	
Pass ID	Start Time	End Time	Averaging Time (sec.)	L_{Aeq}	L_{Aeq} Norm100	L_{Aeq}	L_{Aeq} Norm100	L_{Aeq}	L_{Aeq} Norm100
50N	16:00:04.0	16:00:32.0	28	57.6	45.7	57.2	48.2	55.4	45.5
50W	16:00:39.0	16:01:06.0	27	55.0	43.6	56.7	48.1	54.0	44.1
50S	16:01:14.0	16:01:40.0	26	53.9	42.6	54.5	46.0	52.4	42.6
50E	16:01:50.0	16:02:22.0	32	56.1	44.4	55.7	46.9	54.0	44.1

Table 73, Typhoon hover, Equivalent Continuous Sound Level, second series

Typhoon Hover	Times			Centerline Ground Mic.		Centerline Pole Mic.		Sideline Ground Mic.	
Pass ID	Start Time	End Time	Averaging Time (sec.)	L_{Aeq}	L_{Aeq} Norm100	L_{Aeq}	L_{Aeq} Norm100	L_{Aeq}	L_{Aeq} Norm100
51N	16:41:08.0	16:41:32.0	24	59.9	45.8	59.9	49.4	58.6	48.4
51E	16:41:43.0	16:42:12.0	29	58.2	44.2	58.2	47.7	57.0	47.0
51S	16:42:20.0	16:42:56.0	36	57.3	43.1	57.3	46.7	57.1	46.6
51W	16:43:00.0	16:43:20.0	20	57.2	43.3	57.2	46.8	57.0	46.7

M200

Slow LFO series

Table 74, M200 slow overflight, Maximum A-weighted Levels

M200	SLO	Centerline Ground Mic.				Centerline Pole Mic.				Sideline Ground Mic.			
Pass ID	Log Time	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm400	Distance at L_{ASmx} (ft)	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm400	Distance at L_{ASmx} (ft)	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm400	Distance at L_{ASmx} (ft)
110	17:04:13.0	17:04:14.0	57.8	51.63	196.6	17:04:14.0	53.7	47.36	192.8	17:04:14.0	58.4	51.84	188
120	17:06:05.0	17:06:12.5	56.8	50.16	186.2	17:06:12.5	52.6	45.77	182.2	17:06:11.5	57.2	50.36	182
130	17:07:30.0	17:07:32.5	61	53.88	176.2	17:07:32.0	57.1	49.78	172.2	17:07:33.0	61	53.84	175.5
140	17:08:50.0	17:08:37.5	58.3	50.95	171.6	17:08:37.5	53.6	45.98	166.4	17:08:36.5	58.3	51.02	173
150	17:09:54.0	17:09:55.0	60.3	52.94	171.4	17:09:55.0	56.5	48.99	168.4	17:09:56.0	59.7	52.52	174.9

Table 75, M200 slow overflight, A-weighted Sound Exposure Levels

M200	SLO	Centerline Ground Mic.			Centerline Pole Mic.			Sideline Ground Mic.			speed & direction		
Pass ID	Log Time	Duration (sec.)	L_{AE}	10dBA OK?	Duration (sec.)	L_{AE}	10dBA OK?	Duration (sec.)	L_{AE}	10dBA OK?	GS (kts)	KTAS	direction
110	17:04:13.0	12.5	66	Yes	50	64.9	No	13	66.7	Yes	22.3	27.4	S
120	17:06:05.0	14.5	65.3	Yes	50	64.2	No	15	66.1	Yes	18	13	N
130	17:07:30.0	15	69.8	Yes	20	66.2	Yes	15.5	69.9	Yes	16	22	S
140	17:08:50.0	20	67.8	Yes	50	65.5	No	21	68.2	Yes	11.8	8	N
150	17:09:54.0	16	69.4	Yes	21	66	Yes	17.5	69.3	Yes	16.7	19.1	S
160	17:11:03.0	14.5	67.2	Yes	41	64.4	Yes	15	67.1	Yes	15.4	12	N

M200
Slow LFO series

Table 76, M200 slow overflight, additional Sound Exposure Level and wind data

M200	SLO	Centerline Ground Mic.			Centerline Pole Mic.			Sideline Ground Mic.			Avg winds & criteria		
Pass ID	Log Time	L_{AE} Start Time	L_{AE} End Time	Ambient dBA	L_{AE} Start Time	L_{AE} End Time	Ambient dBA	L_{AE} Start Time	L_{AE} End Time	Ambient dBA	Avg Wind (kts)	Avg X-Wind (kts)	Wind OK?
110	17:04:13.0	17:04:08.0	17:04:20.5	38.5	17:03:49.0	17:04:39.0	44.4	17:04:08.0	17:04:21.0	38.5	5.2	1.3	Yes
120	17:06:05.0	17:06:05.5	17:06:20.0	39	17:05:47.5	17:06:37.5	44.4	17:06:05.5	17:06:20.5	39.6	5.8	1.4	Yes
130	17:07:30.0	17:07:25.5	17:07:40.5	35.4	17:07:25.0	17:07:45.0	44	17:07:25.5	17:07:41.0	35.1	6.1	0.9	Yes
140	17:08:50.0	17:08:28.5	17:08:48.5	38.7	17:08:12.5	17:09:02.5	45.2	17:08:28.0	17:08:49.0	39.9	4	0	Yes
150	17:09:54.0	17:09:49.0	17:10:05.0	34.1	17:09:48.0	17:10:09.0	44.1	17:09:48.5	17:10:06.0	33.9	3.2	2.4	Yes
160	17:11:03.0	17:10:55.0	17:11:09.5	33.3	17:10:47.5	17:11:28.5	43.5	17:10:54.5	17:11:09.5	34	3.5	1.1	Yes

Table 77, M200 slow overflight, statistical data

M200 SLO	Centerline Ground Mic.			Centerline Pole Mic.			Sideline Ground Mic.		
Metric	L_{ASmx}	L_{ASmx} Norm400	L_{AE}	L_{ASmx}	L_{ASmx} Norm400	L_{AE}	L_{ASmx}	L_{ASmx} Norm400	L_{AE}
Mean	58.8	51.8	67.6	54.7	47.5	65.2	59	51.9	67.9
Stand. Dev.	1.6	1.4	1.8	1.8	1.6	0.8	1.3	1.2	1.5
90% CI	1.3	1.1	1.5	1.5	1.3	0.7	1.1	1	1.2
CI Low	57.5	50.6	66.1	53.2	46.1	64.5	57.9	50.9	66.7
CI High	60.1	52.9	69.1	56.2	48.8	65.9	60.1	52.9	69.1

M200
Fast LFO series

Table 78, M200 fast overflight, Maximum A-weighted Levels

M200	FLO	Centerline Ground Mic.				Centerline Pole Mic.				Sideline Ground Mic.			
Pass ID	Log Time	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm400	Distance at L_{ASmx} (ft)	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm400	Distance at L_{ASmx} (ft)	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm400	Distance at L_{ASmx} (ft)
210	17:12:05.0	17:12:07.0	58.1	50.88	174.3	17:12:07.0	54.6	47.27	172	17:12:07.0	57.9	50.84	177.5
220	17:12:55.0	17:12:59.5	59.1	51.62	169	17:12:59.5	55.4	47.76	166	17:12:59.0	59.4	51.92	169
230	17:13:47.0	17:13:48.0	61.2	54.08	176.2	17:13:48.0	57.2	49.94	173.4	17:13:48.0	61.4	54.26	175.8
240	17:14:35.0	17:14:36.5	58.9	51.65	173.6	17:14:35.5	55.4	47.7	164.9	17:14:35.0	59.4	52.11	172.8

Table 79, M200 fast overflight, A-weighted Sound Exposure Levels

M200	SLO	Centerline Ground Mic.			Centerline Pole Mic.			Sideline Ground Mic.			speed & direction		
Pass ID	Log Time	Duration (sec.)	L_{AE}	10dBA OK?	Duration (sec.)	L_{AE}	10dBA OK?	Duration (sec.)	L_{AE}	10dBA OK?	GS (kts)	KTAS	direction
210	17:12:05.0	10	65.1	Yes	33.5	63.3	Yes	10.5	65.1	Yes	30	31.8	S
220	17:12:55.0	9	65.5	Yes	14.5	62.4	Yes	9	65.9	Yes	30.3	27.2	N
230	17:13:47.0	8.5	67.3	Yes	10	63.8	Yes	8.5	67.6	Yes	30	36	S
240	17:14:35.0	9.5	65.8	Yes	30	62.3	Yes	8.5	65.9	Yes	30.1	26.5	N

M200

Fast LFO series

Table 80, M200 fast overflight, additional Sound Exposure Level and wind data

M200	FLO	Centerline Ground Mic.			Centerline Pole Mic.			Sideline Ground Mic.			Avg winds & criteria		
Pass ID	Log Time	L_{AE} Start Time	L_{AE} End Time	Ambient dBA	L_{AE} Start Time	L_{AE} End Time	Ambient dBA	L_{AE} Start Time	L_{AE} End Time	Ambient dBA	Avg Wind (kts)	Avg X-Wind (kts)	Wind OK?
210	17:12:05.0	17:12:03.5	17:12:13.5	33.5	17:11:44.5	17:12:18.0	43.9	17:12:03.0	17:12:13.5	34.2	2.1	1.1	Yes
220	17:12:55.0	17:12:56.0	17:13:05.0	35	17:12:52.0	17:13:06.5	44.1	17:12:55.5	17:13:04.5	37.3	3.3	0.6	Yes
230	17:13:47.0	17:13:44.5	17:13:53.0	34	17:13:44.0	17:13:54.0	43.8	17:13:44.5	17:13:53.0	34.2	6.2	0.7	Yes
240	17:14:35.0	17:14:32.0	17:14:41.5	35.6	17:14:31.0	17:15:01.0	43.7	17:14:32.0	17:14:40.5	36.6	3.7	0.4	Yes

Table 81, M200 fast overflight, statistical data

M200 FLO	Centerline Ground Mic.			Centerline Pole Mic.			Sideline Ground Mic.		
Metric	L_{ASmx}	L_{ASmx} Norm400	L_{AE}	L_{ASmx}	L_{ASmx} Norm400	L_{AE}	L_{ASmx}	L_{ASmx} Norm400	L_{AE}
Mean	59.3	52.1	65.9	55.7	48.2	62.9	59.5	52.3	66.1
Stand. Dev.	1.3	1.4	1	1.1	1.2	0.7	1.4	1.4	1
90% CI	1.6	1.6	1.1	1.3	1.4	0.8	1.7	1.7	1.2
CI Low	57.8	50.4	64.8	54.4	46.8	62.1	57.8	50.6	64.9
CI High	60.9	53.7	67.1	56.9	49.6	63.8	61.2	54	67.3

M200

Vertical takeoff series

Table 82, M200 vertical takeoff, Maximum A-weighted Levels

M200	TAK	Centerline Ground Mic.				Centerline Pole Mic.				Sideline Ground Mic.			
Pass ID	Log Time	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm100	Distance at L_{ASmx} (ft)	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm100	Distance at L_{ASmx} (ft)	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm100	Distance at L_{ASmx} (ft)
310	17:24:46.0	17:24:53.0	67.8	60.99	45.7	17:24:52.5	61.2	54.26	45	17:24:53.0	66.6	60.62	50.2
320	17:27:17.0	17:27:19.0	67.6	56.84	29	17:27:21.5	60.6	54.22	48	17:27:21.5	65.3	59.32	50.2
330	17:29:24.0	17:29:29.0	67.7	56.96	29	17:29:29.0	59.9	50.98	35.8	17:29:29.0	65.4	56.51	35.9
340	17:31:23.0	17:31:27.0	65.2	53.43	25.8	17:31:23.5	58.3	48.1	30.9	17:31:28.0	62.4	54.21	38.9

Table 83, M200 vertical takeoff, distance and wind data

M200 TAK	Centerline Ground Mic.				Centerline Pole Mic.				Sideline Ground Mic.				Avg winds & criteria		
Pass ID	L_{ASmx} Time	L_{ASmx} Dist. (ft)	CPA Time	CPA (ft)	L_{ASmx} Time	L_{ASmx} Dist. (ft)	CPA Time	CPA (ft)	L_{ASmx} Time	L_{ASmx} Dist. (ft)	CPA Time	CPA (ft)	Avg Wind (kts)	Avg X-Wind (kts)	Wind OK?
310	17:24:53.0	45.7	17:24:46.0	19.9	17:24:52.5	45	17:24:46.0	30.5	17:24:53.0	50.2	17:24:46.5	28.9	7.6	0.2	Yes
320	17:27:19.0	29	17:27:17.0	22.6	17:27:21.5	48	17:27:17.0	32.3	17:27:21.5	50.2	17:27:17.0	31.7	7.6	0.9	Yes
330	17:29:29.0	29	17:29:24.0	21.4	17:29:29.0	35.8	17:29:24.0	32	17:29:29.0	35.9	17:29:24.0	30.4	5	0.3	Yes
340	17:31:27.0	25.8	17:31:23.5	20.3	17:31:23.5	30.9	17:31:23.5	30.9	17:31:28.0	38.9	17:31:23.0	29.9	4.7	0.3	Yes

M200
Vertical takeoff series

Table 84, M200 Vertical takeoff, Maximum A-weighted Levels position data

M200 TAK	Centerline Ground Mic.					Centerline Pole Mic.					Sideline Ground Mic.				
Pass ID	L_{ASmx} Time	L_{ASmx} Dist. (ft)	X (ft)	Y (ft)	Z (ft)	L_{ASmx} Time	L_{ASmx} Dist. (ft)	X (ft)	Y (ft)	Z (ft)	L_{ASmx} Time	L_{ASmx} Dist. (ft)	X (ft)	Y (ft)	Z (ft)
310	17:24:53.0	45.7	20.2	-3	40.8	17:24:52.5	45	20.2	-3	36.6	17:24:53.0	50.2	20.2	-3	40.8
320	17:27:19.0	29	21.4	-4.4	19	17:27:21.5	48	21.1	-4.2	39.7	17:27:21.5	50.2	21.1	-4.2	39.7
330	17:29:29.0	29	21.7	-3.3	19	17:29:29.0	35.8	21.7	-3.3	19	17:29:29.0	35.9	21.7	-3.3	19
340	17:31:27.0	25.8	20.4	-5	15	17:31:23.5	30.9	19.9	-4	1.3	17:31:28.0	38.9	20.3	-5	23.7

Table 85, M200 vertical takeoff, statistical data

M200 TAK	Centerline Ground Mic.		Centerline Pole Mic.		Sideline Ground Mic.	
Metric	L_{ASmx}	L_{ASmx} Norm100	L_{ASmx}	L_{ASmx} Norm100	L_{ASmx}	L_{ASmx} Norm100
Mean	67.1	57.1	60	51.9	64.9	57.7
Stand. Dev.	1.3	3.1	1.3	3	1.8	2.9
90% CI	1.5	3.6	1.5	3.5	2.1	3.4
CI Low	65.6	53.4	58.5	48.4	62.8	54.3
CI High	68.5	60.7	61.5	55.4	67	61

M200

Vertical landing series

Table 86, M200 vertical landing, Maximum A-weighted Levels

M200	LND	Centerline Ground Mic.				Centerline Pole Mic.				Sideline Ground Mic.			
Pass ID	Log Time	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm100	Distance at L_{ASmx} (ft)	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm100	Distance at L_{ASmx} (ft)	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm100	Distance at L_{ASmx} (ft)
311	17:26:45.0	17:26:38.5	75	63.77	27.4	17:26:36.5	67	59.7	43.2	17:26:38.5	72.4	63.25	34.9
321	17:29:00.0	17:28:56.5	74.4	64.85	33.3	17:28:56.0	66.8	58.95	40.5	17:28:55.5	71.8	64.71	44.2
331	17:30:30.0	17:30:47.5	75.2	67.41	40.8	17:30:47.5	68.4	61.32	44.3	17:30:47.5	73.5	66.8	46.2
341	17:32:49.0	17:32:44.0	73.6	63.58	31.6	17:32:44.0	66	57.25	36.5	17:32:44.0	70.1	61.92	39

Table 87, M200 vertical landing, distance and wind data

M200 LND	Centerline Ground Mic.				Centerline Pole Mic.				Sideline Ground Mic.				Avg winds & criteria		
Pass ID	L_{ASmx} Time	L_{ASmx} Dist. (ft)	CPA Time	CPA (ft)	L_{ASmx} Time	L_{ASmx} Dist. (ft)	CPA Time	CPA (ft)	L_{ASmx} Time	L_{ASmx} Dist. (ft)	CPA Time	CPA (ft)	Avg Wind (kts)	Avg X-Wind (kts)	Wind OK?
311	17:26:38.5	27.4	17:27:00.0	19.7	17:26:36.5	43.2	17:27:00.0	30.2	17:26:38.5	34.9	17:27:09.0	29.2	8	0.4	Yes
321	17:28:56.5	33.3	17:29:18.5	21.4	17:28:56.0	40.5	17:29:18.5	32	17:28:55.5	44.2	17:29:24.0	30.4	6.4	0.1	Yes
331	17:30:47.5	40.8	17:31:17.0	20.3	17:30:47.5	44.3	17:31:17.0	30.9	17:30:47.5	46.2	17:30:54.0	29.9	5.8	0.7	Yes
341	17:32:44.0	31.6	17:32:49.5	19.8	17:32:44.0	36.5	17:32:49.0	30.3	17:32:44.0	39	17:32:49.5	30.8	4.5	0.1	Yes

M200
Vertical landing series

Table 88, M200 vertical landing, Maximum A-weighted Levels position data

M200 LND	Centerline Ground Mic.					Centerline Pole Mic.					Sideline Ground Mic.				
Pass ID	L_{ASmx} Time	L_{ASmx} Dist. (ft)	X (ft)	Y (ft)	Z (ft)	L_{ASmx} Time	L_{ASmx} Dist. (ft)	X (ft)	Y (ft)	Z (ft)	L_{ASmx} Time	L_{ASmx} Dist. (ft)	X (ft)	Y (ft)	Z (ft)
311	17:26:38.5	27.4	20.4	-3.6	18	17:26:36.5	43.2	19.9	-3.6	34.3	17:26:38.5	34.9	20.4	-3.6	18
321	17:28:56.5	33.3	21.5	-4.1	25.1	17:28:56.0	40.5	21.4	-4.1	28.4	17:28:55.5	44.2	21.4	-4	31.7
331	17:30:47.5	40.8	20.8	-4	34.8	17:30:47.5	44.3	20.8	-4	34.8	17:30:47.5	46.2	20.8	-4	34.8
341	17:32:44.0	31.6	18.9	-5.1	24.8	17:32:44.0	36.5	18.9	-5.1	24.8	17:32:44.0	39	18.9	-5.1	24.8

Table 89, M200 vertical landing, statistical data

M200 LND	Centerline Ground Mic.		Centerline Pole Mic.		Sideline Ground Mic.	
Metric	L_{ASmx}	L_{ASmx} Norm100	L_{ASmx}	L_{ASmx} Norm100	L_{ASmx}	L_{ASmx} Norm100
Mean	74.5	64.9	67.1	59.3	72	64.2
Stand. Dev.	0.7	1.8	1	1.7	1.4	2.1
90% CI	0.8	2.1	1.2	2	1.7	2.5
CI Low	73.7	62.8	65.9	57.3	70.3	61.7
CI High	75.4	67	68.2	61.3	73.6	66.6

M200
"Infrastructure" series

Table 90, M200 infrastructure, Maximum A-weighted Levels

M200	INF	Centerline Ground Mic.				Centerline Pole Mic.				Sideline Ground Mic.			
Pass ID	Log Time	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm100	Distance at L_{ASmx} (ft)	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm100	Distance at L_{ASmx} (ft)	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm100	Distance at L_{ASmx} (ft)
410	17:59:30.0	18:00:12.5	65.8	66.66	110.4	18:00:07.0	62.8	63.7	110.9	18:00:07.0	65.7	66.85	114.2
420	18:02:00.0	18:02:39.0	65.7	66.59	110.8	18:02:38.5	61.4	62.18	109.3	18:02:38.5	65.4	66.36	111.7
430	18:03:30.0	18:03:58.0	66.7	65.43	86.4	18:03:58.0	61.5	60.14	85.5	18:03:58.0	66.4	65.22	87.3

Table 91, M200 infrastructure, distance and wind data

M200 INF	Centerline Ground Mic.				Centerline Pole Mic.				Sideline Ground Mic.				Avg winds & criteria		
Pass ID	L_{ASmx} Time	L_{ASmx} Dist. (ft)	CPA Time	CPA (ft)	L_{ASmx} Time	L_{ASmx} Dist. (ft)	CPA Time	CPA (ft)	L_{ASmx} Time	L_{ASmx} Dist. (ft)	CPA Time	CPA (ft)	Avg Wind (kts)	Avg X-Wind (kts)	Wind OK?
410	18:00:12.5	110.4	18:00:20.0	107.8	18:00:07.0	110.9	18:00:20.0	106.3	18:00:07.0	114.2	18:00:20.0	109.5	6	0.2	Yes
420	18:02:39.0	110.8	18:02:31.0	89	18:02:38.5	109.3	18:02:31.0	88.8	18:02:38.5	111.7	18:02:31.0	90.9	5.4	0.5	Yes
430	18:03:58.0	86.4	18:03:59.5	86.3	18:03:58.0	85.5	18:03:59.5	85.4	18:03:58.0	87.3	18:03:59.5	87.2	3.7	0.1	Yes

M200
"Infrastructure" series

Table 92, M200 Infrastructure, Maximum A-weighted Levels position data

M200 INF	Centerline Ground Mic.					Centerline Pole Mic.					Sideline Ground Mic.				
Pass ID	L_{ASmx} Time	L_{ASmx} Dist. (ft)	X (ft)	Y (ft)	Z (ft)	L_{ASmx} Time	L_{ASmx} Dist. (ft)	X (ft)	Y (ft)	Z (ft)	L_{ASmx} Time	L_{ASmx} Dist. (ft)	X (ft)	Y (ft)	Z (ft)
410	18:00:12.5	110.4	15.3	-0.6	109.3	18:00:07.0	110.9	18	-1.2	111.1	18:00:07.0	114.2	18	-1.2	111.1
420	18:02:39.0	110.8	28.2	-1.4	107.1	18:02:38.5	109.3	25.9	-1	107.1	18:02:38.5	111.7	25.9	-1	107.1
430	18:03:58.0	86.4	19	4.3	84.2	18:03:58.0	85.5	19	4.3	84.2	18:03:58.0	87.3	19	4.3	84.2

Table 93, M200 infrastructure, statistical data

M200 INF	Centerline Ground Mic.		Centerline Pole Mic.		Sideline Ground Mic.	
Metric	L_{ASmx}	L_{ASmx} Norm100	L_{ASmx}	L_{ASmx} Norm100	L_{ASmx}	L_{ASmx} Norm100
Mean	66.1	66.2	61.9	62	65.8	66.1
Stand. Dev.	0.6	0.7	0.8	1.8	0.5	0.8
90% CI	0.9	1.2	1.3	3	0.9	1.4
CI Low	65.1	65.1	60.6	59	65	64.7
CI High	67	67.4	63.2	65	66.7	67.6

M200

Hovers

Table 94, M200 hover, Equivalent Continuous Sound Level, first series

Typhoon Hover	Times			Centerline Ground Mic.		Centerline Pole Mic.		Sideline Ground Mic.	
Pass ID	Start Time	End Time	Averaging Time (sec.)	L_{Aeq}	L_{Aeq} Norm100	L_{Aeq}	L_{Aeq} Norm100	L_{Aeq}	L_{Aeq} Norm100
50N	17:37:48.0	17:38:16.0	28	65.7	52.1	57.5	47.2	60.0	50.0
50E	17:38:25.0	17:38:56.0	31	68.2	54.5	59.4	49.0	60.5	50.4
50S	17:39:02.0	17:39:30.0	28	67.4	53.9	59.2	49.0	61.0	51.0
50W	17:39:37.0	17:40:07.0	30	68.4	54.8	59.6	49.2	61.6	51.5

Table 95, M200 hover, Equivalent Continuous Sound Level, second series

Typhoon Hover	Times			Centerline Ground Mic.		Centerline Pole Mic.		Sideline Ground Mic.	
Pass ID	Start Time	End Time	Averaging Time (sec.)	L_{Aeq}	L_{Aeq} Norm100	L_{Aeq}	L_{Aeq} Norm100	L_{Aeq}	L_{Aeq} Norm100
51N	17:42:50.0	17:43:21.0	31	66.7	53.2	58.3	48.0	61.0	51.0
51E	17:43:33.0	17:44:01.0	28	68.5	54.9	59.7	49.3	60.9	50.8
51S	17:44:08.0	17:44:40.0	32	67.7	54.1	59.2	48.9	61.1	51.1
51W	17:44:48.0	17:45:17.0	29	68.7	55.2	59.7	49.4	61.6	51.6

GD28X
Slow LFO series

Table 96, GD28X slow overflight, Maximum A-weighted Levels

GD28X	SLO	Centerline Ground Mic.				Centerline Pole Mic.				Sideline Ground Mic.			
Pass ID	Log Time	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm400	Distance at L_{ASmx} (ft)	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm400	Distance at L_{ASmx} (ft)	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm400	Distance at L_{ASmx} (ft)
110	15:32:25.0	15:32:25.0	71.6	63.4	155.6	15:32:24.0	67.7	58.98	146.5	15:32:23.5	71.1	62.85	154.6
120	15:33:30.0	15:33:33.5	69.1	61	157.5	15:33:35.0	65.3	57.89	170.4	15:33:34.5	69.7	61.9	162.9
130	15:34:34.0	15:34:32.0	71.3	63.08	155.2	15:34:35.0	67.4	58.55	144.4	15:34:33.0	71.8	63.39	152
140	15:35:25.0	15:35:33.5	68.6	60.49	157.3	15:35:35.0	63.9	56.15	164	15:35:33.0	69.2	60.98	155.3

Table 97, GD28X slow overflight, A-weighted Sound Exposure Levels

GD28X	SLO	Centerline Ground Mic.			Centerline Pole Mic.			Sideline Ground Mic.			speed & direction		
Pass ID	Log Time	Duration (sec.)	L_{AE}	10dBA OK?	Duration (sec.)	L_{AE}	10dBA OK?	Duration (sec.)	L_{AE}	10dBA OK?	GS (kts)	KTAS	direction
110	15:32:25.0	22	81.3	Yes	22	77.7	Yes	21.5	81.1	Yes	15.7	24.1	S
120	15:33:30.0	14	77.8	Yes	15	74.1	Yes	14	78.4	Yes	19.9	10.2	N
130	15:34:34.0	20.5	81.2	Yes	20.5	77.5	Yes	20	81.4	Yes	13.4	21.9	S
140	15:35:25.0	15.5	77.3	Yes	17	73.1	Yes	15	78.2	Yes	18.7	12.8	N

GD28X
Slow LFO series

Table 98, GD28X slow overflight, Sound Exposure Level and wind data

GD28X	SLO	Centerline Ground Mic.			Centerline Pole Mic.			Sideline Ground Mic.			Avg winds & criteria		
Pass ID	Log Time	L_{AE} Start Time	L_{AE} End Time	Ambient dBA	L_{AE} Start Time	L_{AE} End Time	Ambient dBA	L_{AE} Start Time	L_{AE} End Time	Ambient dBA	Avg Wind (kts)	Avg X-Wind (kts)	Wind OK?
110	15:32:25.0	15:32:14.5	15:32:36.5	47.9	15:32:17.0	15:32:39.0	47.5	15:32:15.0	15:32:36.5	46.5	8.7	2.7	Yes
120	15:33:30.0	15:33:25.5	15:33:39.5	42.3	15:33:26.5	15:33:41.5	47.2	15:33:26.5	15:33:40.5	44	10.0	3.1	No
130	15:34:34.0	15:34:24.0	15:34:44.5	45.9	15:34:26.5	15:34:47.0	48.1	15:34:25.5	15:34:45.5	44.9	9.1	5.8	No
140	15:35:25.0	15:35:25.5	15:35:41.0	47.0	15:35:25.5	15:35:42.5	48.2	15:35:26.5	15:35:41.5	48.1	7.4	4.5	Yes

Table 99, GD28X slow overflight, statistical data

GD28X SLO	Centerline Ground Mic.			Centerline Pole Mic.			Sideline Ground Mic.		
Metric	L_{ASmx}	L_{ASmx} Norm400	L_{AE}	L_{ASmx}	L_{ASmx} Norm400	L_{AE}	L_{ASmx}	L_{ASmx} Norm400	L_{AE}
Mean	70.2	62	79.4	66.1	57.9	75.6	70.4	62.3	79.8
Stand. Dev.	1.5	1.5	2.2	1.8	1.2	2.3	1.2	1.1	1.7
90% CI	1.8	1.7	2.5	2.1	1.5	2.7	1.4	1.2	2.0
CI Low	68.4	60.3	76.9	64	56.4	72.9	69	61	77.7
CI High	71.9	63.7	82	68.2	59.4	78.4	71.9	63.5	81.8

GD28X
Fast LFO series

Table 100, GD28X fast overflight, Maximum A-weighted Levels

GD28X	FLO	Centerline Ground Mic.				Centerline Pole Mic.				Sideline Ground Mic.			
Pass ID	Log Time	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm400	Distance at L_{ASmx} (ft)	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm400	Distance at L_{ASmx} (ft)	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm400	Distance at L_{ASmx} (ft)
210	15:36:45.0	15:36:44.0	74.6	66.2	152.1	15:36:45.5	70.3	61.7	148.6	15:36:45.0	74.9	66.27	148
220	15:37:15.0	15:37:21.0	69.1	60.92	156	15:37:23.0	65.3	57.37	160.6	15:37:22.5	69.9	61.58	153.6
230	15:38:00.0	15:37:59.0	74.6	66.08	149.9	15:38:00.0	70.4	62.18	155.2	15:38:00.0	74.8	67.01	163.1
240	15:38:55.0	15:38:38.0	71.1	62.6	150.4	15:38:39.0	66.7	58.21	150.5	15:38:39.5	69.5	61.38	157.1

Table 101, GD28X fast overflight, A-weighted Sound Exposure Levels

GD28X	SLO	Centerline Ground Mic.			Centerline Pole Mic.			Sideline Ground Mic.			speed & direction		
Pass ID	Log Time	Duration (sec.)	L_{AE}	10dBA OK?	Duration (sec.)	L_{AE}	10dBA OK?	Duration (sec.)	L_{AE}	10dBA OK?	GS (kts)	KTAS	direction
210	15:36:45.0	9.5	81.1	Yes	10.5	77.3	Yes	10	81.6	Yes	25.8	34.9	S
220	15:37:15.0	9.5	75.9	No	10.5	72.2	No	9	76.4	Yes	26.9	17.8	N
230	15:38:00.0	11.5	81.8	Yes	13	78.1	Yes	12	81.9	Yes	25.3	33.9	S
240	15:38:55.0	8.5	77.1	Yes	9	73.0	Yes	8.5	76.2	Yes	26.8	18.5	N

GD28X
Fast LFO series

Table 102, GD28X fast overflight, additional Sound Exposure Level and wind data

GD28X	FLO	Centerline Ground Mic.			Centerline Pole Mic.			Sideline Ground Mic.			Avg winds & criteria		
Pass ID	Log Time	L_{AE} Start Time	L_{AE} End Time	Ambient dBA	L_{AE} Start Time	L_{AE} End Time	Ambient dBA	L_{AE} Start Time	L_{AE} End Time	Ambient dBA	Avg Wind (kts)	Avg X-Wind (kts)	Wind OK?
210	15:36:45.0	15:36:41.5	15:36:51.0	45.1	15:36:42.5	15:36:53.0	47.7	15:36:42.0	15:36:52.0	45.5	9.3	1.3	Yes
220	15:37:15.0	15:37:17.0	15:37:26.5	60.6	15:37:18.0	15:37:28.5	57.5	15:37:18.5	15:37:27.5	59.8	9.3	0.4	Yes
230	15:38:00.0	15:37:54.5	15:38:06.0	50.5	15:37:55.5	15:38:08.5	49.6	15:37:54.5	15:38:06.5	50.3	8.6	0.6	Yes
240	15:38:55.0	15:38:34.5	15:38:43.0	54.5	15:38:35.5	15:38:44.5	52.7	15:38:35.5	15:38:44.0	52.3	10.2	2.1	No

Table 103, GD28X fast overflight, statistical data

GD28X FLO	Centerline Ground Mic.			Centerline Pole Mic.			Sideline Ground Mic.		
Metric	L_{ASmx}	L_{ASmx} Norm400	L_{AE}	L_{ASmx}	L_{ASmx} Norm400	L_{AE}	L_{ASmx}	L_{ASmx} Norm400	L_{AE}
Mean	72.3	64	79	68.2	59.9	75.2	72.3	64.1	79
Stand. Dev.	2.7	2.6	2.9	2.6	2.4	3	3	3	3.2
90% CI	3.2	3.1	3.4	3	2.9	3.5	3.5	3.5	3.7
CI Low	69.1	60.9	75.5	65.1	57	71.6	68.8	60.5	75.3
CI High	75.6	67	82.4	71.2	62.7	78.7	75.8	67.6	82.7

GD28X
Vertical takeoff series

Table 104, GD28X vertical takeoff, Maximum A-weighted Levels

GD28X	TAK	Centerline Ground Mic.				Centerline Pole Mic.				Sideline Ground Mic.			
Pass ID	Log Time	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm100	Distance at L_{ASmx} (ft)	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm100	Distance at L_{ASmx} (ft)	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm100	Distance at L_{ASmx} (ft)
310	15:52:12.0	15:52:18.0	77.6	70.37	43.5	15:52:21.0	71.2	67.47	65.1	15:52:18.5	77.7	71.04	46.5
320	15:55:03.0	15:55:06.5	82.1	68.5	20.9	15:55:09.5	74.4	67.48	45.1	15:55:08.0	81.8	71.68	31.2
330	15:58:36.0	15:58:40.5	81.5	71.68	32.3	15:58:43.0	74.6	69.09	53	15:58:41.0	83.5	73.87	33
340	16:01:40.0	16:01:47.0	79.7	69.93	32.5	16:01:49.0	72.6	66.61	50.2	16:01:47.5	79.8	71.59	38.9
350	16:04:37.0	16:04:39.5	81.1	68.22	22.7	16:04:42.5	73.4	66.99	47.8	16:04:41.5	79.7	71.37	38.3

Table 105, GD28X vertical takeoff, distance and wind data

GD28X TAK	Centerline Ground Mic.				Centerline Pole Mic.				Sideline Ground Mic.				Avg winds & criteria		
Pass ID	L_{ASmx} Time	L_{ASmx} Dist. (ft)	CPA Time	CPA (ft)	L_{ASmx} Time	L_{ASmx} Dist. (ft)	CPA Time	CPA (ft)	L_{ASmx} Time	L_{ASmx} Dist. (ft)	CPA Time	CPA (ft)	Avg Wind (kts)	Avg X-Wind (kts)	Wind OK?
310	15:52:18.0	43.5	15:52:12.0	20.6	15:52:21.0	65.1	15:52:12.0	30.9	15:52:18.5	46.5	15:52:12.0	29.4	10.5	0.6	No
320	15:55:06.5	20.9	15:55:03.5	13.3	15:55:09.5	45.1	15:55:03.5	22.9	15:55:08.0	31.2	15:55:03.0	18.8	8	0.9	Yes
330	15:58:40.5	32.3	15:58:36.0	17.8	15:58:43.0	53	15:58:36.0	25.9	15:58:41.0	33	15:58:36.0	15	8.4	1	Yes
340	16:01:47.0	32.5	16:01:40.0	19.4	16:01:49.0	50.2	16:01:41.0	29.6	16:01:47.5	38.9	16:01:41.0	25.5	6.1	0.4	Yes
350	16:04:39.5	22.7	16:04:37.0	16.1	16:04:42.5	47.8	16:04:37.0	26.4	16:04:41.5	38.3	16:04:37.5	25.6	10.9	1	No

GD28X
Vertical takeoff series

Table 106, GD28X vertical takeoff, Maximum A-weighted Levels position data

GD28X TAK	Centerline Ground Mic.					Centerline Pole Mic.					Sideline Ground Mic.				
Pass ID	L_{ASmx} Time	L_{ASmx} Dist. (ft)	X (ft)	Y (ft)	Z (ft)	L_{ASmx} Time	L_{ASmx} Dist. (ft)	X (ft)	Y (ft)	Z (ft)	L_{ASmx} Time	L_{ASmx} Dist. (ft)	X (ft)	Y (ft)	Z (ft)
310	15:52:18.0	43.5	34.4	4.8	26.2	15:52:21.0	65.1	37.8	9	47	15:52:18.5	46.5	35.2	6.1	29.2
320	15:55:06.5	20.9	18.4	4.1	9.1	15:55:09.5	45.1	23.6	6.8	33	15:55:08.0	31.2	21.1	5.4	19.8
330	15:58:40.5	32.3	24.2	12	17.7	15:58:43.0	53	26.7	11.1	40.6	15:58:41.0	33	25.2	11.8	21.7
340	16:01:47.0	32.5	26.8	0.9	18.2	16:01:49.0	50.2	28.7	1.5	35.4	16:01:47.5	38.9	27.5	1.1	22.4
350	16:04:39.5	22.7	21	0.5	8.7	16:04:42.5	47.8	27	2.7	33.7	16:04:41.5	38.3	25.4	1.9	24.2

Table 107, GD28X vertical takeoff, statistical data

GD28X TAK	Centerline Ground Mic.		Centerline Pole Mic.		Sideline Ground Mic.	
Metric	L_{ASmx}	L_{ASmx} Norm100	L_{ASmx}	L_{ASmx} Norm100	L_{ASmx}	L_{ASmx} Norm100
Mean	80.4	69.7	73.2	67.5	80.5	71.9
Stand. Dev.	1.8	1.4	1.4	0.9	2.2	1.1
90% CI	1.7	1.4	1.3	0.9	2.1	1.1
CI Low	78.7	68.4	71.9	66.6	78.4	70.8
CI High	82.1	71.1	74.6	68.4	82.6	73

GD28X
Vertical landing series

Table 108, GD28X vertical landing, Maximum A-weighted Levels

GD28X	LND	Centerline Ground Mic.				Centerline Pole Mic.				Sideline Ground Mic.			
Pass ID	Log Time	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm100	Distance at L_{ASmx} (ft)	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm100	Distance at L_{ASmx} (ft)	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm100	Distance at L_{ASmx} (ft)
311	15:54:35.0	15:54:32.0	80.3	64.55	16.3	15:54:22.5	73.3	65.64	41.4	15:54:26.5	85.7	70.32	17
321	15:57:22.0	15:56:56.5	80.2	68.21	25.1	15:56:52.5	73.2	65.6	41.7	15:57:09.5	84.4	66.09	12.1
331	16:00:37.0	16:00:30.5	77.3	66.03	27.3	16:00:21.0	71.4	66.91	59.6	16:00:24.0	79.8	71.7	39.4
341	16:03:45.0	16:03:35.0	81.3	70.63	29.3	16:03:33.5	73.1	64.85	38.7	16:03:36.0	80.3	70.05	30.7
351	16:06:28.0	16:06:19.0	79.3	69.81	33.5	16:06:15.0	72.8	66.97	51.1	16:06:19.5	79.4	70.03	34

Table 109, GD28X vertical landing, distance and wind data

GD28X LND	Centerline Ground Mic.				Centerline Pole Mic.				Sideline Ground Mic.				Avg winds & criteria		
Pass ID	L_{ASmx} Time	L_{ASmx} Dist. (ft)	CPA Time	CPA (ft)	L_{ASmx} Time	L_{ASmx} Dist. (ft)	CPA Time	CPA (ft)	L_{ASmx} Time	L_{ASmx} Dist. (ft)	CPA Time	CPA (ft)	Avg Wind (kts)	Avg X-Wind (kts)	Wind OK?
311	15:54:32.0	16.3	15:54:35.0	13.3	15:54:22.5	41.4	15:54:35.0	22.8	15:54:26.5	17	15:54:35.0	18.8	7.6	2.6	Yes
321	15:56:56.5	25.1	15:57:23.0	17.7	15:56:52.5	41.7	15:57:23.0	25.9	15:57:09.5	12.1	15:57:23.0	14.9	8.6	1.8	Yes
331	16:00:30.5	27.3	16:00:37.5	19.4	16:00:21.0	59.6	16:00:37.5	29.5	16:00:24.0	39.4	16:00:37.5	25.3	9.8	4.6	Yes
341	16:03:35.0	29.3	16:03:45.5	15.9	16:03:33.5	38.7	16:03:45.5	26.2	16:03:36.0	30.7	16:03:45.5	25.5	9.8	1	Yes
351	16:06:19.0	33.5	16:06:29.5	16	16:06:15.0	51.1	16:06:28.0	25.7	16:06:19.5	34	16:06:28.0	21.2	9.1	0.8	Yes

GD28X
Landing series

Table 110, GD28X vertical landing, Maximum A-weighted Levels position data

GD28X LND	Centerline Ground Mic.					Centerline Pole Mic.					Sideline Ground Mic.				
Pass ID	L_{ASmx} Time	L_{ASmx} Dist. (ft)	X (ft)	Y (ft)	Z (ft)	L_{ASmx} Time	L_{ASmx} Dist. (ft)	X (ft)	Y (ft)	Z (ft)	L_{ASmx} Time	L_{ASmx} Dist. (ft)	X (ft)	Y (ft)	Z (ft)
311	15:54:32.0	16.3	14.5	4.6	5.8	15:54:22.5	41.4	21.5	21.7	20.7	15:54:26.5	17	15.7	16.6	9.3
321	15:56:56.5	25.1	19.5	8.5	13.3	15:56:52.5	41.7	21.1	15	27.6	15:57:09.5	12.1	11.2	13.3	4.1
331	16:00:30.5	27.3	24.8	3	11.2	16:00:21.0	59.6	29.5	25	41.5	16:00:24.0	39.4	29.3	24.4	27.7
341	16:03:35.0	29.3	22	2.2	19.2	16:03:33.5	38.7	21.9	1.9	25.2	16:03:36.0	30.7	21.7	2.2	15.4
351	16:06:19.0	33.5	25.5	4.3	21.4	16:06:15.0	51.1	26.4	5	39.2	16:06:19.5	34	25.1	4.5	19.4

Table 111, GD28X vertical landing, statistical data

GD28X LND	Centerline Ground Mic.		Centerline Pole Mic.		Sideline Ground Mic.	
Metric	L_{ASmx}	L_{ASmx} Norm100	L_{ASmx}	L_{ASmx} Norm100	L_{ASmx}	L_{ASmx} Norm100
Mean	79.7	67.8	72.8	66	81.9	69.6
Stand. Dev.	1.5	2.5	0.8	0.9	2.9	2.1
90% CI	1.4	2.4	0.7	0.9	2.8	2
CI Low	78.2	65.4	72	65.1	79.1	67.6
CI High	81.1	70.3	73.5	66.9	84.7	71.6

GD28X
“Infrastructure” series

Table 112, GD28X infrastructure, Maximum A-weighted Levels

GD28X	SLO	Centerline Ground Mic.				Centerline Pole Mic.				Sideline Ground Mic.			
Pass ID	Log Time	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm100	Distance at L_{ASmx} (ft)	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm100	Distance at L_{ASmx} (ft)	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm100	Distance at L_{ASmx} (ft)
410	16:21:15.0	16:21:32.0	76.9	74.66	77.3	16:21:33.0	72.9	70.04	71.9	16:21:46.5	76.9	74.97	80.1

Table 113, GD28X infrastructure, distance and wind data

GD28X TAK	Centerline Ground Mic.				Centerline Pole Mic.				Sideline Ground Mic.				Avg winds & criteria		
Pass ID	L_{ASmx} Time	L_{ASmx} Dist. (ft)	CPA Time	CPA (ft)	L_{ASmx} Time	L_{ASmx} Dist. (ft)	CPA Time	CPA (ft)	L_{ASmx} Time	L_{ASmx} Dist. (ft)	CPA Time	CPA (ft)	Avg Wind (kts)	Avg X-Wind (kts)	Wind OK?
410	16:21:32.0	77.3	16:21:29.5	77.1	16:21:33.0	71.9	16:21:30.0	71.8	16:21:46.5	80.1	16:21:29.5	78	6.6	0.7	Yes

Table 114, GD28X Infrastructure, Maximum A-weighted Levels position data

GD28X INF	Centerline Ground Mic.					Centerline Pole Mic.					Sideline Ground Mic.				
Pass ID	L_{ASmx} Time	L_{ASmx} Dist. (ft)	X (ft)	Y (ft)	Z (ft)	L_{ASmx} Time	L_{ASmx} Dist. (ft)	X (ft)	Y (ft)	Z (ft)	L_{ASmx} Time	L_{ASmx} Dist. (ft)	X (ft)	Y (ft)	Z (ft)
410	16:21:32.0	77.3	-15.1	6.1	75.5	16:21:33.0	71.9	-14.9	6.5	75.6	16:21:46.5	80.1	-14.8	8	77.5

GC28X
Hovers

Table 115, GD28X hover, Equivalent Continuous Sound Level, first series

Typhoon Hover	Times			Centerline Ground Mic.		Centerline Pole Mic.		Sideline Ground Mic.	
Pass ID	Start Time	End Time	Averaging Time (sec.)	L_{Aeq}	L_{Aeq} Norm100	L_{Aeq}	L_{Aeq} Norm100	L_{Aeq}	L_{Aeq} Norm100
50N	16:28:55.0	16:29:37.0	42	79.1	-	-	-	80.5	-
50E	16:29:52.0	16:30:21.0	29	77.5	-	-	-	77.5	-
50S	16:30:28.0	16:31:00.0	32	77.3	-	-	-	73.7	-
50W	16:31:07.0	16:31:44.0	37	80.3	-	-	-	75.9	-

Table 116, GD28X hover, Equivalent Continuous Sound Level, second series

Typhoon Hover	Times			Centerline Ground Mic.		Centerline Pole Mic.		Sideline Ground Mic.	
Pass ID	Start Time	End Time	Averaging Time (sec.)	L_{Aeq}	L_{Aeq} Norm100	L_{Aeq}	L_{Aeq} Norm100	L_{Aeq}	L_{Aeq} Norm100
51N	16:46:42.0	16:47:00.0	18	77.2	-	-	-	74.6	-
51E	16:47:10.0	16:47:35.0	25	78	-	-	-	77	-
51S	16:47:42.0	16:48:12.0	30	74.7	-	-	-	72.9	-
51W	16:48:23.0	16:48:53.0	30	75.8	-	-	-	72.7	-

Tracking data during the GD28X hover operations were not available, so L_{Aeq} values at the normalized distance could not be determined. Also, the signal from the centerline pole microphone was lost during these events.

D.3 Fixed-wing Vehicles

The X-8 fixed-wing vehicle performed only dynamic operations. For this vehicle, unlike the rotary-wing vehicles, takeoff is a fully dynamic operation. The tables for these takeoffs, as well as for the slow and fast overflights, are structured and formatted in the same manner as for the dynamic operations discussed above for the rotary-wing vehicles.

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X-8
Slow LFO (1st series)

Table 117, X-8 slow overflight, Maximum A-weighted Levels, first series

X-8	SLO	Centerline Ground Mic.				Centerline Pole Mic.				Sideline Ground Mic.			
Pass ID	Log Time	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm400	Distance at L_{ASmx} (ft)	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm400	Distance at L_{ASmx} (ft)	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm400	Distance at L_{ASmx} (ft)
110	17:25:18.0	17:25:15.0	51	44.23	183.4	17:25:16.0	49.5	41.79	164.6	17:25:16.0	50.9	43.21	165
120	17:26:30.0	17:26:32.5	52.9	46.97	202.2	17:26:34.0	50	47.88	313.4	17:26:31.5	52.9	44.71	155.9
130	17:27:45.0	17:27:48.5	54.7	46.18	150	17:27:50.0	50.4	43.55	181.7	17:27:49.5	54.6	47.68	180.3
140	17:29:00.0	17:29:01.5	51.8	45.73	198.8	17:29:03.0	48.9	46.62	307.8	17:28:59.5	51.3	42.91	152.2

Table 118, X-8 slow overflight, A-weighted Sound Exposure Levels, first series

X-8	SLO	Centerline Ground Mic.			Centerline Pole Mic.			Sideline Ground Mic.			speed & direction		
Pass ID	Log Time	Duration (sec.)	L_{AE}	10dBA OK?	Duration (sec.)	L_{AE}	10dBA OK?	Duration (sec.)	L_{AE}	10dBA OK?	GS (kts)	KTAS	direction
110	17:25:18.0	28.5	61.3	Yes	50	62.9	No	25	61.3	Yes	25.3	33.5	S
120	17:26:30.0	11	60.2	Yes	50	61.7	No	10	59.8	Yes	50.1	44.8	N
130	17:27:45.0	16	62.5	Yes	50	63.3	No	18	62.7	Yes	25.2	33.2	S
140	17:29:00.0	11	59.6	Yes	50	61.4	No	12.5	60	Yes	49.9	43.4	N

X-8
Slow LFO (1st series)

Table 119, X-8 slow overflight, additional Sound Exposure Level and wind data, first series

X-8	SLO	Centerline Ground Mic.			Centerline Pole Mic.			Sideline Ground Mic.			Avg winds & criteria		
Pass ID	Log Time	L_{AE} Start Time	L_{AE} End Time	Ambient dBA	L_{AE} Start Time	L_{AE} End Time	Ambient dBA	L_{AE} Start Time	L_{AE} End Time	Ambient dBA	Avg Wind (kts)	Avg X-Wind (kts)	Wind OK?
110	17:25:18.0	17:25:01.5	17:25:30.0	38.6	17:24:51.0	17:25:41.0	43.9	17:25:06.5	17:25:31.5	36.7	8.4	1	Yes
120	17:26:30.0	17:26:26.5	17:26:37.5	36.7	17:26:09.0	17:26:59.0	44.1	17:26:28.0	17:26:38.0	37.4	5.4	0.9	Yes
130	17:27:45.0	17:27:39.5	17:27:55.5	33.8	17:27:25.0	17:28:15.0	43.1	17:27:38.5	17:27:56.5	33.8	7.9	0.9	Yes
140	17:29:00.0	17:28:56.0	17:29:07.0	34.6	17:28:38.5	17:29:28.5	43.1	17:28:56.5	17:29:09.0	36.3	6.9	2.5	Yes

Table 120, X-8 slow overflight, statistical data, first series

X-8 SLO	Centerline Ground Mic.			Centerline Pole Mic.			Sideline Ground Mic.		
Metric	L_{ASmx}	L_{ASmx} Norm400	L_{AE}	L_{ASmx}	L_{ASmx} Norm400	L_{AE}	L_{ASmx}	L_{ASmx} Norm400	L_{AE}
Mean	52.6	45.8	60.9	49.7	45	62.3	52.4	44.6	60.9
Stand. Dev.	1.6	1.2	1.3	0.6	2.8	0.9	1.7	2.2	1.3
90% CI	1.9	1.4	1.5	0.8	3.3	1.1	2	2.6	1.6
CI Low	50.7	44.4	59.4	48.9	41.7	61.2	50.4	42.1	59.4
CI High	54.5	47.1	62.4	50.5	48.2	63.4	54.4	47.2	62.5

X-8
Fast LFO (1st series)

Table 121, X-8 fast overflight, Maximum A-weighted Levels, first series

GD28X	FLO	Centerline Ground Mic.				Centerline Pole Mic.				Sideline Ground Mic.			
Pass ID	Log Time	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm400	Distance at L_{ASmx} (ft)	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm400	Distance at L_{ASmx} (ft)	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm400	Distance at L_{ASmx} (ft)
210	17:30:04.0	17:30:04.5	62.2	56.3	202.7	17:30:05.5	58.8	54.96	257	17:30:05.5	61.8	58.47	272.7
220	17:31:05.0	17:31:03.5	58.8	51.84	179.5	17:31:05.0	55.4	47.97	170.1	17:31:04.5	58.2	50.08	157
230	17:32:05.0	17:32:08.0	60.9	54.35	188.1	17:32:09.0	57.9	53.02	228	17:32:10.0	61.6	59.19	303.1
240	17:33:05.0	17:33:05.5	59.7	52.01	165	17:33:25.0	59	68.66	1216.6	17:33:06.5	60	52.03	159.9

Table 122, X-8 fast overflight, A-weighted Sound Exposure Levels, first series

X-8	SLO	Centerline Ground Mic.			Centerline Pole Mic.			Sideline Ground Mic.			speed & direction		
Pass ID	Log Time	Duration (sec.)	L_{AE}	10dBA OK?	Duration (sec.)	L_{AE}	10dBA OK?	Duration (sec.)	L_{AE}	10dBA OK?	GS (kts)	KTAS	direction
210	17:30:04.0	10.5	68.4	Yes	12.5	66	Yes	10.5	68.3	Yes	45.9	52.7	S
220	17:31:05.0	7.5	65	Yes	13.5	63	Yes	9	64.8	Yes	63.7	58.7	N
230	17:32:05.0	12	69.3	Yes	19	67.2	Yes	12.5	69.5	Yes	41.8	51.1	S
240	17:33:05.0	21.5	66.4	Yes	26	65.9	Yes	8.5	66.3	Yes	56.1	51.8	N

X-8

Fast LFO (1st series)

Table 123, X-8 fast overflight, additional Sound Exposure Level and wind data, first series

X-8	FLO	Centerline Ground Mic.			Centerline Pole Mic.			Sideline Ground Mic.			Avg winds & criteria		
Pass ID	Log Time	L_{AE} Start Time	L_{AE} End Time	Ambient dBA	L_{AE} Start Time	L_{AE} End Time	Ambient dBA	L_{AE} Start Time	L_{AE} End Time	Ambient dBA	Avg Wind (kts)	Avg X-Wind (kts)	Wind OK?
210	17:30:04.0	17:29:58.0	17:30:08.5	34.3	17:29:58.0	17:30:10.5	43	17:29:59.0	17:30:09.5	35.5	6.9	0.8	Yes
220	17:31:05.0	17:31:02.0	17:31:09.5	36.8	17:31:00.0	17:31:13.5	42.3	17:31:02.5	17:31:11.5	36.5	5.1	0.5	Yes
230	17:32:05.0	17:32:01.0	17:32:13.0	37.6	17:31:58.5	17:32:17.5	43.4	17:32:02.0	17:32:14.5	35.2	9.5	0.5	Yes
240	17:33:05.0	17:33:03.0	17:33:24.5	40.6	17:33:04.5	17:33:30.5	42.9	17:33:04.0	17:33:12.5	40.4	7.6	1.9	Yes

Table 124, X-8 fast overflight, statistical data, first series

X-8 FLO	Centerline Ground Mic.			Centerline Pole Mic.			Sideline Ground Mic.		
Metric	L_{ASmx}	L_{ASmx} Norm400	L_{AE}	L_{ASmx}	L_{ASmx} Norm400	L_{AE}	L_{ASmx}	L_{ASmx} Norm400	L_{AE}
Mean	60.4	53.6	67.3	57.8	56.2	65.5	60.4	54.9	67.2
Stand. Dev.	1.5	2.1	1.9	1.7	8.8	1.8	1.7	4.6	2.1
90% CI	1.7	2.5	2.3	1.9	10.4	2.1	2	5.4	2.5
CI Low	58.7	51.1	65	55.8	45.7	63.4	58.4	49.6	64.8
CI High	62.1	56.1	69.6	59.7	66.6	67.6	62.4	60.3	69.7

X-8
Takeoff

Table 125, X-8 takeoff, Maximum A-weighted Levels

GD28X	SLO	Centerline Ground Mic.				Centerline Pole Mic.				Sideline Ground Mic.			
Pass ID	Log Time	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm400	Distance at L_{ASmx} (ft)	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm400	Distance at L_{ASmx} (ft)	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm400	Distance at L_{ASmx} (ft)
310	17:34:45.0	17:34:45.5	56.9	51.55	216	17:34:46.5	55.1	50.81	244	17:34:46.0	57.3	52.52	230.7
320	17:35:33.0	17:35:37.0	59.3	52.35	179.8	17:35:38.5	57.1	52.46	234.4	17:35:38.5	59.6	55.1	238.1
330	17:36:19.0	17:36:20.5	62.7	53.99	146.8	17:36:21.0	60.4	52.39	159	17:36:21.0	63.3	55.8	168.6
340	17:36:58.0	17:36:59.0	62.8	52.9	128	17:37:00.0	60.4	52.68	164.6	17:36:59.5	64.2	55.48	146.6

Table 126, X-8 takeoff, A-weighted Sound Exposure Levels

X-8	SLO	Centerline Ground Mic.			Centerline Pole Mic.			Sideline Ground Mic.			speed & direction		
Pass ID	Log Time	Duration (sec.)	L_{AE}	10dBA OK?	Duration (sec.)	L_{AE}	10dBA OK?	Duration (sec.)	L_{AE}	10dBA OK?	GS (kts)	KTAS	direction
310	17:34:45.0	5	61.8	No	6.5	60.9	No	5.5	62.8	No	26.1	32.1	S
320	17:35:33.0	8	65.8	Yes	9	64.1	Yes	8.5	66.3	Yes	27.3	34.8	S
330	17:36:19.0	5.5	68.4	No	7	66.8	No	6	69.2	No	30	39.6	S
340	17:36:58.0	6	68.4	No	7	66.7	No	6.5	69.7	No	30.8	36	S

X-8
Takeoff

Table 127, X-8 takeoff, additional Sound Exposure Level and wind data

X-8	TAK	Centerline Ground Mic.			Centerline Pole Mic.			Sideline Ground Mic.			Avg winds & criteria		
Pass ID	Log Time	L_{AE} Start Time	L_{AE} End Time	Ambient dBA	L_{AE} Start Time	L_{AE} End Time	Ambient dBA	L_{AE} Start Time	L_{AE} End Time	Ambient dBA	Avg Wind (kts)	Avg X-Wind (kts)	Wind OK?
310	17:34:45.0	17:34:45.0	17:34:50.0	53.9	17:34:45.0	17:34:51.5	51.2	17:34:45.0	17:34:50.5	53.2	6.1	1.2	Yes
320	17:35:33.0	17:35:33.0	17:35:41.0	45.5	17:35:33.5	17:35:42.5	42.9	17:35:33.5	17:35:42.0	39.9	7.7	3.5	Yes
330	17:36:19.0	17:36:19.0	17:36:24.5	56.9	17:36:19.0	17:36:26.0	53.3	17:36:19.0	17:36:25.0	55.7	10.6	3.6	No
340	17:36:58.0	17:36:58.0	17:37:04.0	57.8	17:36:58.0	17:37:05.0	54.6	17:36:58.0	17:37:04.5	56.7	8.1	6.5	Yes

Table 128, X-8 takeoff, statistical data

X-8 TAK	Centerline Ground Mic.			Centerline Pole Mic.			Sideline Ground Mic.		
Metric	L_{ASmx}	L_{ASmx} Norm400	L_{AE}	L_{ASmx}	L_{ASmx} Norm400	L_{AE}	L_{ASmx}	L_{ASmx} Norm400	L_{AE}
Mean	60.4	52.7	66.1	58.2	52.1	64.6	61.1	54.7	67
Stand. Dev.	2.9	1	3.1	2.6	0.9	2.8	3.2	1.5	3.2
90% CI	3.4	1.2	3.6	3.1	1	3.3	3.8	1.8	3.7
CI Low	57.1	51.5	62.5	55.2	51.1	61.3	57.3	53	63.3
CI High	63.8	53.9	69.7	61.3	53.1	67.9	64.9	56.5	70.7

X-8
Slow LFO (2nd series)

Table 129, X-8 slow overflight, Maximum A-weighted Levels, second series

GD28X	SLO	Centerline Ground Mic.				Centerline Pole Mic.				Sideline Ground Mic.			
Pass ID	Log Time	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm400	Distance at L_{ASmx} (ft)	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm400	Distance at L_{ASmx} (ft)	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm400	Distance at L_{ASmx} (ft)
150	17:56:00.0	17:56:01.0	53.1	41.24	102.1	17:56:00.5	49.8	37.79	100.4	17:56:02.5	53.1	43.63	134.5
160	17:57:15.0	17:57:15.5	54.1	42.3	102.8	17:57:15.0	51.4	39.56	102.3	17:57:16.5	53.9	45.2	147
170	17:58:40.0	17:58:42.5	53.7	42.55	110.8	17:58:45.5	51.9	45.21	185.1	17:58:44.0	53.1	44.62	150.7
180	17:59:53.0	17:59:53.0	54.2	42.26	101.1	17:59:54.5	51.4	43.68	164.5	17:59:52.5	54.2	43.47	116.2

Table 130, X-8 slow overflight, A-weighted Sound Exposure Levels, second series

X-8	SLO	Centerline Ground Mic.			Centerline Pole Mic.			Sideline Ground Mic.			speed & direction		
Pass ID	Log Time	Duration (sec.)	L_{AE}	10dBA OK?	Duration (sec.)	L_{AE}	10dBA OK?	Duration (sec.)	L_{AE}	10dBA OK?	GS (kts)	KTAS	direction
150	17:56:00.0	15.5	62.1	Yes	50	61.9	No	15.5	62	Yes	28	33.1	S
160	17:57:15.0	9	61.2	Yes	47	62.4	No	8.5	60.7	Yes	55	46.1	N
170	17:58:40.0	18	63.1	Yes	50	62.9	No	17.5	62.7	Yes	25.4	33.9	S
180	17:59:53.0	9	61	Yes	50	62.4	No	31.5	61.7	No	48.3	40.4	N

X-8
Slow LFO (2nd series)

Table 131, X-8 slow overflight, additional Sound Exposure Level and wind data, second series

X-8	SLO	Centerline Ground Mic.			Centerline Pole Mic.			Sideline Ground Mic.			Avg winds & criteria		
Pass ID	Log Time	L_{AE} Start Time	L_{AE} End Time	Ambient dBA	L_{AE} Start Time	L_{AE} End Time	Ambient dBA	L_{AE} Start Time	L_{AE} End Time	Ambient dBA	Avg Wind (kts)	Avg X-Wind (kts)	Wind OK?
150	17:56:00.0	17:55:52.5	17:56:08.0	37.8	17:55:35.5	17:56:25.5	42.4	17:55:54.0	17:56:09.5	35.9	5.5	1.6	Yes
160	17:57:15.0	17:57:11.5	17:57:20.5	34.8	17:56:53.0	17:57:40.0	42.2	17:57:12.5	17:57:21.0	35.2	9.4	2.4	Yes
170	17:58:40.0	17:58:31.0	17:58:49.0	37.1	17:58:20.5	17:59:10.5	42.1	17:58:33.0	17:58:50.5	36.7	8.7	2.2	Yes
180	17:59:53.0	17:59:49.0	17:59:58.0	36	17:59:30.0	18:00:20.0	42.4	17:59:27.5	17:59:59.0	48.7	9.9	6.3	Yes

Table 132, X-8 slow overflight, statistical data, second series

X-8 SLO	Centerline Ground Mic.			Centerline Pole Mic.			Sideline Ground Mic.		
Metric	L_{ASmx}	L_{ASmx} Norm400	L_{AE}	L_{ASmx}	L_{ASmx} Norm400	L_{AE}	L_{ASmx}	L_{ASmx} Norm400	L_{AE}
Mean	53.8	42.1	61.8	51.1	41.6	62.4	53.6	44.2	61.7
Stand. Dev.	0.5	0.6	0.9	0.9	3.5	0.4	0.6	0.8	0.8
90% CI	0.6	0.7	1.1	1.1	4.1	0.5	0.7	1	1
CI Low	53.2	41.4	60.7	50	37.5	61.9	52.9	43.3	60.8
CI High	54.4	42.8	62.9	52.2	45.6	62.9	54.2	45.2	62.7

X-8
Fast LFO (2nd series)

Table 133, X-8 fast overflight, Maximum A-weighted Levels, second series

GD28X	FLO	Centerline Ground Mic.				Centerline Pole Mic.				Sideline Ground Mic.			
Pass ID	Log Time	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm400	Distance at L_{ASmx} (ft)	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm400	Distance at L_{ASmx} (ft)	Time L_{ASmx}	L_{ASmx}	L_{ASmx} Norm400	Distance at L_{ASmx} (ft)
250	18:00:56.0	18:00:57.5	64.3	52.94	108.1	18:00:59.0	61	53.2	162.9	18:00:58.5	63.3	54.91	152.3
260	18:02:03.0	18:02:01.5	59.7	53.31	191.6	18:02:02.5	57.3	46.52	115.7	18:02:02.0	59.7	51.54	156.3
270	18:03:05.0	18:03:06.5	63.6	52.39	110	18:03:08.0	60	51.94	158.1	18:03:08.0	62.9	55.72	175
280	18:04:12.0	18:04:11.5	63.2	52.47	116.2	18:04:13.0	60.6	53.21	170.9	18:04:12.5	62.4	52.54	128.5

Table 134, X-8 fast overflight, A-weighted Sound Exposure Levels, second series

X-8	SLO	Centerline Ground Mic.			Centerline Pole Mic.			Sideline Ground Mic.			speed & direction		
Pass ID	Log Time	Duration (sec.)	L_{AE}	10dBA OK?	Duration (sec.)	L_{AE}	10dBA OK?	Duration (sec.)	L_{AE}	10dBA OK?	GS (kts)	KTAS	direction
250	18:00:56.0	8	70.4	Yes	13	68.2	Yes	9	69.9	Yes	43	51.3	S
260	18:02:03.0	8	65.6	Yes	12	64.3	Yes	8.5	65.9	Yes	64.5	57.4	N
270	18:03:05.0	8	69.8	Yes	12	67	Yes	9	69.5	Yes	40.9	47.5	S
280	18:04:12.0	6	68.1	Yes	16.5	65.9	Yes	6	67.4	Yes	68.3	58.3	N

X-8
Fast LFO (2nd series)

Table 135, X-8 fast overflight, additional Sound Exposure Level and wind data, second series

X-8	FLO	Centerline Ground Mic.			Centerline Pole Mic.			Sideline Ground Mic.			Avg winds & criteria		
Pass ID	Log Time	L_{AE} Start Time	L_{AE} End Time	Ambient dBA	L_{AE} Start Time	L_{AE} End Time	Ambient dBA	L_{AE} Start Time	L_{AE} End Time	Ambient dBA	Avg Wind (kts)	Avg X-Wind (kts)	Wind OK?
250	18:00:56.0	18:00:53.0	18:01:01.0	36.4	18:00:50.5	18:01:03.5	43.9	18:00:53.5	18:01:02.5	36.5	9.1	4.8	Yes
260	18:02:03.0	18:01:58.5	18:02:06.5	37.9	18:01:59.0	18:02:11.0	43.4	18:02:00.0	18:02:08.5	37.6	7.1	0.1	Yes
270	18:03:05.0	18:03:02.5	18:03:10.5	37.8	18:03:01.5	18:03:13.5	42	18:03:03.5	18:03:12.5	35.9	7.9	3.5	Yes
280	18:04:12.0	18:04:09.0	18:04:15.0	36.6	18:04:10.0	18:04:26.5	42.9	18:04:10.0	18:04:16.0	37.1	11.1	3.3	No

Table 136, X-8 fast overflight, statistical data, second series

X-8 FLO	Centerline Ground Mic.			Centerline Pole Mic.			Sideline Ground Mic.		
Metric	L_{ASmx}	L_{ASmx} Norm400	L_{AE}	L_{ASmx}	L_{ASmx} Norm400	L_{AE}	L_{ASmx}	L_{ASmx} Norm400	L_{AE}
Mean	62.7	52.8	68.5	59.7	51.2	66.3	62.1	53.7	68.2
Stand. Dev.	2.1	0.4	2.2	1.7	3.2	1.7	1.6	2	1.9
90% CI	2.4	0.5	2.6	2	3.7	1.9	1.9	2.3	2.2
CI Low	60.3	52.3	65.9	57.8	47.5	64.4	60.2	51.4	65.9
CI High	65.1	53.3	71.1	61.7	55	68.3	64	56	70.4

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