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Yuma 2022 Rotorcraft Acoustic Flight Test

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Abstract

A cooperative flight test campaign among the U.S. Navy, Army, Marine Corps, and NASA was performed at Marine Corps Air Station (MCAS) Yuma from 19 January to 15 February 2022. The primary purpose of testing military vehicles was to characterize the acoustic signature of the MV-22 rotorcraft and Stalker unmanned aerial system for typical mission gross weight, configuration, and for a range of typical mission operating conditions. Additionally, a civilian MD530 vehicle was tested to characterize the acoustic emissions for both legacy blades and S411 main rotor blades. This report provides an overview of the test, documents the data acquired, and describes the formats of the stored data.

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Acronyms and Nomenclature

AGL	Above Ground Level
FPA	Flight Path Angle
FPM	Feet Per Minute
GPS	Global Positioning System
GW	Gross Weight
$KIAS$	Knots Indicated Airspeed
$LaRC$	Langley Research Center
$NetCDF$	Network Common Data Form
$OASPL$	Overall Sound Pressure Level
p'	Acoustic pressure
$PAPI$	Precision Approach Path Indicator
R	Main rotor radius
SPL	Sound Pressure Level
UTC	Coordinated Universal Time
$WAMS$	Wireless Acoustic Measurement System
X	Ground fixed coordinate system with +X along the nominal direction of flight
Y	Ground fixed coordinate system with +Y rotated 90°s counter-clockwise from +x
Z	Vertical coordinate with +Z up.

1 Introduction

Human aural detection is the first step toward target acquisition of helicopters for small arms fire and RPG threats. As such, it is of primary concern to the DoD to understand and mitigate the acoustic signature of all military rotorcraft and unmanned aerial systems (UAS).

The US Navy's Naval Research Laboratory (NRL), US Army's Aviation & Missile Center (AvMC), and NASA Langley Research Center (LaRC) teamed together to acquire MV-22 and Stalker UAS source noise hemispheres for mission planning purposes. These source noise hemispheres can be used in mission and land use planning tools to predict ground noise and aural detection footprints due to vehicle operations. Further, they can be used to study helicopter source noise mechanisms and for validation of acoustic detection and prediction tools.

An MD530 was also tested at the same location to develop source noise hemispheres for community noise and land use planning tools. The MD530 was flown with legacy main rotor blades as well as newly developed S411 blades. This allowed for an 'A' to 'B' noise comparison of both blade sets to see if the acoustic emissions changed a significant amount.

All data acquired are available to authorized organizations with need to know and approval of relevant program office, organization, or company. This paper describes the testing of these vehicles, a description of the stored data format, and some sample data figures.

2 Description of Test Aircraft

The test was flown with a Bell Boeing MV-22 rotorcraft, a Lockheed Martin Stalker UAS, and a McDonnell Douglas 530 helicopter, all of which are described below.

2.1 MV-22 Test Aircraft

The MV-22, shown in Figure 1, is a multimission tiltrotor aircraft capable of transitioning from hover in helicopter mode, to high speed forward flight (275 knots) in airplane mode. This aircraft has two Rolls-Royce T406-AD-400 turboprop/turboshaft engines and entered full-rate production in 2005 after a protracted development process. MV-22 aircraft characteristics are shown in Table 1. Table 2 provides a list of vehicle state variables that were acquired during this test. During testing, state data were sampled continuously and uninterrupted throughout each flight at the maximum rate available from the integrated Mission Data Recorder. The MV-22 was flown with the cargo ramp both down, and up (stowed), to test the potential variation in noise caused by the configuration-induced drag change.

2.2 Stalker UAS Test Aircraft

The Stalker UAS, shown in Figure 2, is an intelligence, surveillance, and reconnaissance Group 1 UAS. The tested vehicle is battery operated with a tractor propeller, weighs around 45 pounds, and was provided by Trinity Bend. The Stalker was flown with a Bad Elf GPS puck on board which provided time-stamped latitude, longitude, and elevation at a rate of 10 Hz. Recorded data variables from the Bad Elf are provided in Table 3, while Table 1 provides vehicle specifications. Guidance for the Stalker was performed using the standard controls with a preprogrammed GPS path for each condition.

2.3 MD530 Test Aircraft

The MD530, shown in Figure 3, is a light-utility civilian vehicle with a single Rolls-Royce 250-C30 engine; additional MD530 aircraft characteristics are shown in Table 1. The MD530 was tested for acoustic emissions as well as certification data. This vehicle was flown with ballast on board to ensure sufficient weight during certification test points. Aircraft state data were measured with NASA's Aircraft Navigation and Tracking System (ANTS), and recorded variables are provided in Table 4.

3 Ground Instrumentation

3.1 Microphone Instrumentation

The NASA Mobile Acoustics Facility was used to acquire the acoustic data. This facility is comprised of a single 53-foot long semitrailer used to control the flight test and maintain, store, and charge the 80 Wireless Acoustic Measurement System version II (WAMS II) units. Each WAMS II unit consists of a microphone, ground board, radio antenna, GPS receiver, and onboard SD card for data recording. The

GPS receiver was used to obtain Coordinated Universal Time (UTC) stamps that synchronized all microphone, aircraft, and weather instrumentation. During this test, the standard WAMS II setup consisted of a GRAS 67AX microphone embedded in a 381-mm diameter round ground board, and is shown in Figure 4. Microphones are offset from the center of the ground board to minimize the edge effects. This microphone position and ground board configuration are based on the SAE Aerospace Recommended Practice ARP4055 [1]. All microphones are sampled simultaneously and uninterrupted throughout a run at 25 kHz and 24-bit resolution. Up to 63 of these systems were deployed at one time for this test.

Two additional, unique microphone setups were also deployed with the WAMS II data acquisition system, shown in Figure 5. One was a 1/2-inch Falcon (B&K 4189) microphone inverted with the diaphragm 6.35 mm above a 381-mm diameter round ground board at the center of the microphone array during some MD530 testing. Simultaneously, a 1/2-inch Falcon (B&K 4964) microphone was deployed at a 1.2-meter (4-foot) elevation at the same location, to capture certification relevant data.

Microphones were deployed in four interlaced arrays, as shown in Figure 6. Three arrays each featured three concentric circular patterns of microphones to capture an entire hemisphere at a single instant in time (called a "snapshot" array). A traditional linear array was also deployed to capture a hemisphere of data for an entire flyover. This combination of arrays allows for an interrogation into the steadiness of rotorcraft and UAS noise, throughout a single nominal flight condition. The flight track heading for this test was nominally 330° True (319° Magnetic). Microphone locations are provided in Table 5. Microphones were generally numbered sequentially from the negative 'X' direction to positive 'X', and positive 'Y' to negative 'Y'. Microphones 64 and 65 are the exception, as they are colocated with microphone 31 and were employed during MD530 testing only. Figure 7 is a satellite image with all equipment precisely located and identified. The locations of auxiliary equipment, described below, are provided in Table 6.

A Cartesian coordinate system is used with microphone 31 defined as the center of the coordinate system (X = Y = Z = 0). X is defined along the flight track and is positive in the primary flight direction; Y is defined perpendicular to the flight track and is positive to the aircraft port (left) side; Z is positive up. Microphone 31 is at the geometric center of the overall microphone array, and is shared by all four individual arrays.

Each of the three snapshot arrays consisted of 21 microphones. Figure 8 shows the ideal hemisphere coverage for a vehicle passing over the center of one snapshot array at an altitude of 61 meters (200 feet), along with the (azimuth, elevation) coordinates for each microphone (Z = 61 m). The figure shows the microphone locations on a Lambert projection, as a function of azimuth (counterclockwise around the center) and elevation (radially inward). Azimuth rotates with the direction of a conventional United States-built main rotor, where 0° is the tail, 90° is the right side of the vehicle, and so forth. Elevation starts at the horizon plane (0°) and decreases radially inward, such that -90° is directly beneath the vehicle.

The linear array for capturing source noise hemispheres consisted of 13 microphones (numbered 25-37) deployed perpendicular to the nominal flight path, with microphone station 31 located on the flight trajectory. Each of the snapshot arrays was deployed at 345.6-meter (1134-feet) intervals along the flight track so that microphone locations could be shared among arrays.

A secondary experiment was also conducted where the MD530 was measured in hover. For part of that experiment, a unique microphone setup was employed, shown in Figure 9. This experiment will be discussed in detail in a future publication.

3.2 Weather Instrumentation

An extensive set of weather measurements were collected throughout the test. A tethered weather balloon system, seen in Figure 10, was located near the control trailer sufficiently far away from the flight path to not interfere with aircraft operations. The balloon altitude was fixed such that the balloon weather sonde was initially at 152 meters (500 feet) above ground level (AGL). The balloon altitude fluctuated throughout the day due to variation in wind speed.

A temperature profile was measured using a temperature string built by RST Instruments Ltd. The temperature string was hung below the weather sonde and has sensors every 10 feet of tether, with a quoted accuracy of $\pm$ 0.07°C. These sensors recorded temperature as function of time, with the deployed sensors acquiring samples every 1-2 minutes.

A ZephIR 300 portable IEC 60825-1 Class 1 eye-safe LIDAR system, shown in Figure 11, was also deployed during testing. The LIDAR system was placed along the flight line and measured wind speed and direction at 12 locations up to 300 meters AGL.

Additionally, six ground weather stations that measured wind speed, wind direction, pressure, temperature and humidity were placed around the test site. Five sensors were mounted on 2-meter (6-foot) tripods, located near microphones 1, 25, 31, 37, and 63. The last station was mounted approximately 10 meters above ground level at the Mobile Acoustics Facility trailer.

3.3 Precision Approach Path Indicator

A four-light, ground-based, precision approach path indicator (PAPI) system, shown in Figure 12 with location provided in Figure 7, was deployed approximately 226 meters (750 feet) past the reference microphone (X = 226 m). The PAPI system is radio controlled and can provide vehicle guidance for each descent angle requested up to 12 degree descent during the flight test. The PAPI system provided extra assistance for the pilot to help maintain the correct glide slope during approach conditions and required no instrumentation on board the vehicle.

4 Planned Test Conditions

4.1 MV-22 Steady Flight Source Noise Conditions

Level flyover test point conditions were intended to be flown at an altitude of 61 meters (200 feet, Z = 61 m) AGL at the reference microphone location, and are described in Table 7 along with their priority ranking. The aircraft was flown in a steady-state condition throughout the duration of acoustic data acquisition at the prescribed airspeed and along the nominal flight path. For all level flyovers, data-on and data-off were called 1219 meters (4000 feet, X = ±1219 m) before and after the reference microphone, respectively.

Approach test point conditions are also described in Table 7. All approaches begin with the pilot acquiring the prescribed flight path angle (FPA) and airspeed at a sufficient range to be in a steady-state operating condition when crossing the data-on location. The glide slope intersected the ground at the PAPI location, approximately 226 meters after the reference microphone. This steady-state approach condition was held for as long as possible throughout the descent to the PAPI, pulling out at the lowest possible altitude for safe flight operations. A 15 meter (50 foot) hard deck was implemented and followed by the pilots.

For approach conditions, data-on was called at 1219 meters before the microphone array, and data-off was called at the point of the pullout from the steady-state condition. Emphasis was given to the pilots on minimizing control inputs rather than on hitting the precise descent profile so the approach trajectories would be smooth.

4.2 MV-22 Specific Maneuvers

Three tactical landing maneuvers were also executed by the pilot. These dynamic maneuvers were tested to simulate battlefield landing environments to assess acoustic detection of the vehicle under such conditions. The target landing position for these maneuvers was 845 meters (2770 feet, X = -845 m) before the reference microphone. One tactical approach (T6) was also conducted such that the landing point was at the PAPI location, and was called 'T3'.

4.3 UAS Specific Directions

The Stalker UAS was intended to be flown under constant speed conditions in level flight and climbs. The Stalker UAS operates predominantly at two speeds, a cruise speed (30 knots) and a dash speed (40 knots). Climbs are typically performed at a maximum rate of climb for each speed, and the test was designed such that climbs would be initiated at the center of the array (Microphone 31) and at the start of the array (Microphone 1). Table 8 describes the UAS flight conditions and their associated priorities.

4.4 MD530 Steady Flight Source Noise Conditions

Identical to the MV-22 conditions, the MD530 level flyover test point conditions were planned to be flown at an altitude of 61 meters (200 feet, Z = 61 m) AGL at the reference microphone location, and are described in Table 9. The aircraft was flown in a steady-state condition throughout the duration of acoustic data acquisition, at the prescribed airspeed, along the primary flight path, as shown in Figure 6. For all level flyovers, data-on and data-off are called 1219 meters (4000 feet, X = ±1219 m) before and after the reference microphone, respectively. The approach conditions, also described in Table 9, had identical hard deck constraints, PAPI landing location, and pilot guidance to that provided for the MV-22.

4.5 MD530 Specific Maneuvers

The MD530 was also planned to be tested in an FAA approved manner to demonstrate no acoustical change between legacy main rotor blades and S411 main rotor blades. For these test conditions, the weather was monitored closely, along with vehicle weight. When parameters were within FAA-approved guidelines, then data were planned to be acquired. For these conditions, the vehicle would be flown at 150 meters (492 feet, Z = 150 m) AGL and the advancing side tip Mach number would be matched to standard sea-level conditions at 120 knots (0.9 V_h).

5 Executed Conditions

5.1 MV-22 Results

The MV-22 suffered significant vehicle maintenance issues and unseasonably poor weather during the test window. This resulted in the MV-22 flying only a total of 4.6 hours over the test arrays with 80 data runs acquired. Measured test conditions and number of points measured for each condition are found in Table 10. Both flight days had winds in excess of 10 knots at the ground and 15-23 knots at altitude. This limited flights to predominantly level conditions, where vehicle pitch and attitude could be maintained during each run. Postprocessing will be required to get maximum use of the recorded data.

5.2 Stalker Results

Due to the aforementioned unseasonably poor weather, the Stalker only flew a total of 3 hours over the test arrays with 25 data runs acquired. Measured test conditions and number of points measured for each condition are found in Table 11. The single flight day had winds at altitude ranging from 11 kts to 22 kts. This weather resulted in poor quality data, which will require substantial postprocessing to extract useful information.

5.3 MD530 Results

The MD530 testing occurred during a mixture of good and poor weather conditions. One day the weather was good with less than 10 knot winds; the remaining days had winds at altitude up to 25 knots. Overall, four days of testing were completed. Two days were flown with legacy main rotor blades and tail rotor blades. During those two days of forward flight testing, 2.6 hours were flown over the array completing 44 runs. One day was flown with the S411 main rotor blades and legacy tail rotor in forward flight. During that day, the MD530 flew for 3 hours over the array completing 56 runs in two flights. Measured test conditions and number of points measured for each condition and blade set are found in Table 12.

An example of the acoustic data recorded during the flight test is seen in Figure 13. Figure 13 shows the maximum overall sound pressure level recorded by the microphone array for run 042420, which is a 120 knot level flight condition ('L5'), of the MD530 with legacy main and tail rotors. The circles identify each microphone location, while the color provides the overall sound pressure level. The 10-minute averaged LIDAR winds are provided in Figure 14, which also includes the 95% confidence interval for that period. Figure 15 provides the temperature at each altitude measured during the 'L5' run condition.

One day of testing included the S411 main rotor in hover with legacy tail rotor and S419 tail rotor, using the array shown in Figure 9. For the hover testing, the pilot started out facing microphone 4 (magnetic heading of 60°). The pilot held a hover in ground effect for one minute, then rotated clockwise 45° (magnetic heading of 105°) and held that condition for one minute. The pilot proceeded to rotate in 45° increments, and concluded with a repeat of a one-minute hold at a magnetic heading of 60°. This was first done with S411 main rotor and legacy tail rotor, then the tail rotor was swapped for the S419 tail rotor, and the process was then repeated. The results from this experiment will be analyzed in-depth in a future publication.

6 Electronic Data Description

The military vehicle aircraft data and acoustics are classified as either Confidential or Secret, and are limited distribution. These data are available with permission of the vehicle's office of primary responsibility and flight test partners. The MD530 data with legacy main and tail rotor blades are available to the public upon request. The S411 main rotor and S419 tail rotor data are limited distribution.

The request for data for all aircraft should be directed to James Stephenson, DEVCOM AvMC, Mail Stop 461, NASA Langley Research Center, 23681, james.h.stephenson23.civ@army.mil. The data are provided in standard American Standard Code for Information Interchange (ASCII) text, Microsoft Excel (XLSX), MATLAB® MAT and/or Network Common Data Format (NetCDF) formats, depending on data type. NetCDF is a "self-describing," packed binary format, which is platform independent.

Descriptions of the contents of each file type, including file naming convention and file format, are contained in the following subsections. Data are sorted based on combined run number `fffrrr`, where `fff` is the NASA flight number and `rrr` is the NASA run number. Each data run has a unique combined run number, where flight number is the Julian day of the year on which the data are acquired.

6.1 Acoustic Pressure Time History Data

Acoustic pressure time history data, in units of pascals, are in the NetCDF binary files contained in the `AcousticData/aaaaa_Acoustic` folders with `aaaaa` being the vehicle name. The filename format is `fffrrr_mm_pascal.nc` where `mm` is the microphone number. For example, file `042420_31_pascal.nc` is the file containing the acoustic pressure time history data in pascals for NASA flight number 042, NASA run number 420 and microphone number 31. Table 13 describes the variables contained in the acoustic pressure time history files. Note that the acoustic pressure in these files are as-measured data, not corrected for installation or atmospheric effects.

6.2 Microphone Location Files

The microphone GPS locations are contained in the comma delimited text file `Yuma22_Mic_Locations.csv`. This file has a row for each microphone, which contains the microphone number, latitude, and longitude in decimal degrees, and mean sea level and ellipsoid heights in feet, as well as local XYZ coordinates. Microphone location information is also stored in a MAT file titled `Yuma22_Mic_Locations.mat`. XYZ coordinates are stored in units of feet.

6.3 Aircraft Data Files

Data from the aircraft locations are contained in folders `Inflight_Processed`. There is one MAT file for each vehicle for each flight day. Data files are titled `FLTfff`.

6.4 Weather Data Files

The postprocessed weather data are contained in the folder `Weather_Processed`; raw weather data are available upon request. There are individual MAT files for each of the types of weather instrumentation. Altitudes listed in the weather files are in meters above ground level at the measurement location.

6.4.1 Weather Balloon Sonde

Descriptions of the data variables available from the balloon sonde are provided in Table 14. The balloon sonde data have been averaged across each run and stored as a function of combined run number in a MAT file titled `BalloonSonde`.

6.4.2 Temperature String

Temperature string data variables and their associated description are provided in Table 15. The nearest measured time stamp of the temperature data was identified and stored as a function of combined run number in a MAT file titled `TempString`. Due to the low sampling rate on the temperature string, the nearest measured time stamp is within 90 seconds of its associated run.

Figure 15 shows data from run 042420, during which a temperature inversion profile was measured. Temperature inversions occur when the ground is cooler than air temperature and typically occur in the early mornings. As the sun rises and the ground heats up, the temperature profile transitions from a temperature inversion, to a lapse profile. The lapse profile occurs when the ground is warmer than air temperature; this transition occurs an hour or two after sunrise, and the lapse profile is usually maintained until after sunset.

6.4.3 Weather Stations

Weather station variable description is provided in Table 16 and stored in a MAT file titled `WeatherStation`. The identity of the weather station is provided in the MAT file, and describes whether it is located at one of the microphone systems or on the MAF trailer.

6.4.4 LIDAR

LIDAR data variables are described in Table 17. Each LIDAR variable was averaged across the run and stored as a function of combined run number in a MAT file titled `LIDAR`. Figure 14 shows horizontal wind profile and 95% confidence interval for run 042420. Winds during this test were on the high side (in excess of 10 knots at flight altitude), but there are some limited data available in low wind conditions.

6.5 Run Logs

Run logs are recorded each day of testing in Microsoft® Excel format and are located in the folder named `RunLogs`.

7 Concluding Remarks

A cooperative flight test campaign among the U.S. Navy, U.S. Marine Corps, U.S. Army, and NASA was performed in January-February 2022. The main purpose of the testing was to acquire source noise hemispheres for the MV-22, Stalker UAS, and MD530. This test was performed at Marine Corps Air Station Yuma in Yuma, Arizona. A total of 13.2 data acquisition flight hours of all three vehicles were flown, totaling 205 individual runs. This report has described the test site, aircraft, instrumentation, conditions flown, data acquired and stored data formats. Additionally, sample acoustic and weather data were presented. Military vehicle data are available upon request to organizations with need to know, permission from the test partners, and permission of relevant Program Manager. Data from the MD530 with legacy main rotor blades are available to the public upon request; data with S411 main rotor blades are limited distribution.

References

1. Ground-Plane Microphone Configuration for Propeller-Driven Light-Aircraft Noise Measurement. ARP 4055, SAE, November 2007.

Tables

Table 1: Aircraft specifications.

	MV-22	Stalker UAS	MD530
No. Main Rotors (Propellers)	2	1	1
No. Main Rotor (Propeller) Blades	3	3	5
Main Rotor (Propeller) Diameter	12 m	0.43 m	8.38 m
Main Rotor (Propeller) RPM, BPF	-	Varies	477, 39.75 Hz
No. Tail Rotor Blades	-	-	2
Tail Rotor Diameter	-	-	1.55 m
Tail Rotor RPM, BPF	-	-	2,848, 94.9 Hz
Empty Weight	14,432 kg	19.3 kg	782 kg
Test Take Off Gross Weight	21,818 kg	$\tilde{1}9.5$ kg	1,520 kg

Table 2: MV-22 vehicle state data variables.

Variable Name	Description	Units	
GPS_LATITUDE	Current Latitude	decimal degrees	
GPS_LONGITUDE	Current Longitude	decimal degrees	
RADAR_ALT_VALID	Radar altitude measurement valid	(1=valid)	
RADAR_ALTIMETER_ALTITUDE	Radar altimeter altitude	ft	
LWINS1_17_PRESSURE_INERTIAL_ALT	Barometric altitude	ft	
GPS_ALTITUDE	GPS Altitude	ft	
LWINS1_17_PITCH_ANGLE	Pitch angle	°	
LWINS1_17_LWINS_PITCH_RATE	Pitch rate	semicircle/sec	*
LWINS1_17_ROLL_ANGLE	Roll angle	°	♭
LWINS1_17_LWINS_ROLL_RATE	Roll rate	semicircle/sec	*
LWINS1_17_VELOCITY_DOWN	Vertical velocity	ft/sec	•
LWINS1_17_VELOCITY_NORTH	Velocity in North direction	ft/sec	
LWINS1_17_VELOCITY_EAST	Velocity in East direction	ft/sec	
LWINS1_17_ACCELERATION_DOWN	Acceleration in vertical direction	ft/sec^2	•
LWINS1_17_ACCELERATION_NORTH	Acceleration in North direction	ft/sec^2	
LWINS1_17_ACCELERATION_EAST	Acceleration in East direction	ft/sec^2	
LWINS1_17_PRESENT_TRUE_HEADING	Heading relative to true North	°	
LWINS1_17_PRESENT_MAGNETIC_HEADING	Magnetic heading	°	
FCC1_5_LEFT_ROTOR_TORQUE	Rotor torque on left rotor	ft-lbs	
FCC1_5_RIGHT_ROTOR_TORQUE	Rotor torque on right rotor	ft-lbs	
VSLED_R11_LONG_STICK_POS	Longitudinal stick position	in	†
VSLED_R11_LAT_STICK_POS	Lateral stick position	in	‡
FCC1_4_MC_OUTSIDE_AIR_TEMP	Outside air temperature	°C	
GROSS_WEIGHT	Current gross weight	lbs	
FMU1_2_TOT_L_AVAIL_FUEL_QTY_DATA	Current fuel weight in left wing	lbs	
FMU2_4_TOT_R_AVAIL_FUEL_QTY_DATA	Current fuel weight in right wing	lbs	

Note *: Multiply by 180 for degrees/sec.
Note ♭: Positive roll is right wing down.
Note •: Positive down.
Note †: Positive forward.
Note ‡: Positive right.

Table 3: Stalker vehicle state data variables.

Variable Name	Description	Units
GPSTime	Time from GPS receiver in UTC seconds after midnight	s
Lat	Vehicle latitude	°
Lon	Vehicle longitude	°
Altitude	Vehicle altitude	ft

Table 4: MD530 vehicle state data variables from ANTS.

Variable Name	Description	Units
utcsec	UTC seconds after midnight	second
latitude	Current vehicle latitude	decimal degrees
longitude	Current vehicle longitude	decimal degrees
heading	Current vehicle heading relative to magnetic North	°
altitude	Current altitude	meter
x	Vehicle location in local 'X' coordinate	meter
y	Vehicle location in local 'Y' coordinate	meter
z	Vehicle location in local 'Z' coordinate	meter
velocity_down	Vehicle speed in down direction	meter/second
velocity_easting	Vehicle speed in East direction	meter/second
velocity_northing	Vehicle speed in North direction	meter/second
velocity_x	Vehicle speed in local 'X' direction	meter/second
velocity_y	Vehicle speed in local 'Y' direction	meter/second
velocity_z	Vehicle speed in local 'Z' direction	meter/second
acceleration_x	Vehicle acceleration in local 'X' direction	meter/second^2
acceleration_y	Vehicle acceleration in local 'Y' direction	meter/second^2
acceleration_z	Vehicle acceleration in local 'Z' direction	meter/second^2
pitch	Vehicle pitch	°
roll	Vehicle roll	°

Table 5: Microphone positions for flight test.

Mic. Num.	X [m]	Y [m]	Z [m]	Latitude [°]	Longitude [°]	Mean Sea Level Height [m]	Ellipsoid Height [m]
1	-686.46	-1.78	0.20	32.50869602	-114.4639305	100.92	66.79
2	-513.78	299.22	-0.57	32.50868753	-114.4676234	100.14	66.00
3	-516.79	-300.72	2.06	32.51136887	-114.4620781	102.78	68.66
4	-407.38	36.50	0.42	32.51070291	-114.4657682	101.12	66.99
5	-406.12	-37.21	0.88	32.51104507	-114.4650956	101.58	67.45
6	-358.66	14.92	0.40	32.51118066	-114.4658286	101.10	66.97
7	-357.92	-17.88	0.49	32.51133434	-114.4655302	101.18	67.06
8	-341.39	345.44	-1.09	32.50982533	-114.4689666	99.62	65.48
9	-342.30	71.87	0.09	32.5110517	-114.4664405	100.78	66.65
10	-342.42	-0.63	0.11	32.51137762	-114.4657717	100.81	66.68
11	-344.65	-73.38	0.35	32.51168816	-114.4650893	101.05	66.92
12	-343.52	-347.38	2.67	32.51293232	-114.46257	103.38	69.26
13	-327.33	14.78	0.48	32.51142596	-114.465994	101.18	67.05
14	-327.08	-16.15	0.37	32.51156735	-114.4657103	101.07	66.94
15	-279.98	35.39	0.16	32.51170281	-114.4664359	100.85	66.72
16	-280.34	-36.94	0.38	32.5120261	-114.4657673	101.08	66.95
17	-169.02	299.12	-1.16	32.51138028	-114.4694569	99.53	65.39
18	-172.43	-299.31	1.85	32.51405174	-114.4639234	102.55	68.43
19	-62.80	35.41	0.10	32.51339874	-114.4675917	100.79	66.66
20	-64.22	-36.96	0.66	32.51371395	-114.4669171	101.35	67.22
21	-46.92	172.67	-0.72	32.51290388	-114.4689412	99.97	65.83
22	-47.13	-173.60	1.10	32.51446348	-114.4657487	101.79	67.67
23	-15.25	14.43	0.37	32.51386466	-114.4676513	101.06	66.92
24	-17.29	-15.96	0.55	32.51398572	-114.4673604	101.23	67.10
25	4.68	610.40	-2.55	32.51133315	-114.47325	98.16	64.01
26	0.38	347.38	-1.54	32.51248554	-114.4708032	99.15	65.01
27	0.68	238.23	-1.06	32.51298002	-114.4697987	99.63	65.50
28	0.46	131.26	-0.69	32.51346056	-114.4688117	100.00	65.87
29	0.51	72.06	0.18	32.51372789	-114.4682664	100.87	66.74
30	0.08	34.18	0.32	32.51389533	-114.467915	101.00	66.87
31	0.00	0.00	0.00	32.51404882	-114.4675995	100.68	66.56
32	-0.34	-34.34	0.54	32.51420102	-114.4672812	101.22	67.09
33	0.02	-72.37	1.10	32.51437521	-114.4669326	101.79	67.66
34	-0.85	-133.06	-0.04	32.51464212	-114.4663686	100.65	66.53
35	-1.34	-240.03	1.02	32.51512059	-114.4653801	101.71	67.59
36	-2.41	-346.17	2.31	32.51559071	-114.4643961	103.00	68.88
37	2.94	-611.82	4.44	32.51683009	-114.4619761	105.15	71.04
38	14.58	14.81	0.06	32.51409588	-114.4678136	100.74	66.61
39	15.07	-16.04	0.34	32.51423879	-114.4675319	101.03	66.90
40	62.95	35.66	-0.34	32.51437961	-114.4682631	100.35	66.22
41	62.05	-36.87	-1.34	32.51469963	-114.4675899	99.35	65.22
42	175.85	302.44	-1.64	32.51405841	-114.4713227	99.06	64.92
43	175.52	-296.88	1.54	32.51675805	-114.4657972	102.23	68.11
44	285.20	36.04	0.11	32.51611348	-114.4694493	100.81	66.67
45	285.24	-35.48	0.27	32.51643631	-114.4687903	100.96	66.84
46	301.77	172.41	-0.78	32.51562804	-114.4707944	99.91	65.78
47	302.20	-174.14	1.23	32.51719386	-114.4676026	101.93	67.81
48	330.98	15.78	-0.23	32.51656239	-114.4695062	100.46	66.33
49	330.80	-15.72	0.02	32.51670301	-114.4692149	100.72	66.59
50	348.88	344.71	-1.60	32.51521901	-114.4726331	99.10	64.96

Table 5 (cont): Microphone positions for flight test.

Mic. Num.	X [m]	Y [m]	Z [m]	Latitude [°]	Longitude [°]	Mean Sea Level Height [m]	Ellipsoid Height [m]
51	347.72	68.97	-0.01	32.51645328	-114.4700855	100.68	66.55
52	347.26	-0.91	-0.22	32.51676473	-114.469439	100.47	66.34
53	346.58	-73.08	0.09	32.51708487	-114.4687702	100.78	66.65
54	345.80	-346.33	1.85	32.51831075	-114.4662476	102.56	68.44
55	363.55	15.27	-0.24	32.51681898	-114.4696748	100.46	66.33
56	362.16	-15.59	-0.12	32.51694728	-114.469383	100.58	66.45
57	410.09	35.90	-0.12	32.51708942	-114.4701126	100.57	66.44
58	410.53	-37.19	0.14	32.51742243	-114.4694413	100.84	66.71
59	519.88	297.83	-1.62	32.51676576	-114.473111	99.09	64.95
60	519.77	-299.87	1.17	32.51945986	-114.4676015	101.88	67.76
61	645.79	172.02	-0.80	32.51831631	-114.4726216	99.92	65.78
62	646.11	-173.21	0.44	32.5198754	-114.4694413	101.16	67.04
63	692.55	-1.10	-0.40	32.51946197	-114.4712748	100.32	66.19
64	0.00	0.01	0.00	32.51404881	-114.4675996	100.69	66.56
65	-0.09	0.45	0.02	32.51404608	-114.4676031	100.71	66.58

Table 6: Auxiliary equipment locations.

Item Name	X [m]	Y [m]	Z [m]	Latitude [°]	Longitude [°]	Mean Sea Level Height [m]	Ellipsoid Height [m]
Data On	-1217.82	-0.86	1.08	32.5045423	-114.4611120	101.77	67.6
LIDAR	-963.68	0.13	0.31	32.5065225	-114.4624732	101.00	66.9
MidPanel 1	-131.38	-11.75	0.48	32.5130758	-114.4667922	101.17	67.0
MidPanel 2	229.48	-0.22	-0.69	32.5158419	-114.4688187	99.99	65.9
PAPI 1	227.01	-17.15	-1.27	32.5158989	-114.4686495	99.42	65.3
PAPI 2	226.40	-26.43	-1.36	32.5159360	-114.4685607	99.32	65.2
PAPI 3	225.55	-35.63	-1.35	32.5159708	-114.4684714	99.34	65.2
PAPI 4	225.16	-44.66	-1.11	32.5160085	-114.4683861	99.58	65.4
Data Off	1223.46	-0.23	-0.10	32.5236040	-114.4741084	100.58	66.7
Balloon	-1017.85	1753.41	-5.47	32.4981942	-114.4783420	95.21	61.0
MAF	-1038.53	1515.26	-5.33	32.4991066	-114.4760374	95.36	61.2

Table 7: Planned MV-22 test condition codes (with priorities).

Speed [kts]	**40**	**60**	**80**	**100**	**120**	**125**	**140**	**160**	**180**	**200**	**220**	**240**	**260**
FPA Nacelle Angle [°]	**87**	**85**	**80**	**60**	**60**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
3°		C1 (4)	C2 (4)										
0° – Ramp Down	L1 (3)	L2 (2)	L3 (1)	L4 (2)	L5 (1)	L6 (1)	L7 (2)	L8 (1)	L9 (2)	L10 (1)	L11 (1)		
0° – Ramp Up	L12 (4)	L13 (3)	L14 (1)	L15 (4)	L16 (1)	L17 (1)	L18 (4)	L19 (1)	L20 (4)	L21 (1)	L22 (1)	L23 (2)	L24 (2)
−4°		D1 (3)	D2 (3)	D3 (4)									
−7°		D4 (3)	D5 (3)										
−10°		D6 (3)	D7 (3)										
Tactical – Straight Landing											T4 (1)		
Tactical – 90° **Landing**											T5 (1)		
Tactical – 180° **Landing**											T6 (1)		

Table 8: Planned Stalker UAS test condition codes (with priorities).

FPA	**30 kt**	**40 kt**
Max rate of climb at microphone 31	C3 (1)	C4 (1)
Max rate of climb at microphone 1	C1 (2)	C2 (2)
0°	L1 (1)	L2 (1)

Table 9: Planned MD530 test condition codes (with priorities). Repeat each code with new (S411) and old (legacy) blades.

FPA	**40 kt**	**60 kt**	**80 kt**	**100 kt**	**120 kt**	**0.9 $\mathbf{V_h}$**
3°		C1 (3)	C2 (3)			
0°	L1 (1)	L2 (1)	L3 (1)	L4 (1)	L5 (1)	FAA (1)
−3°	D1 (2)	D2 (2)	D3 (2)	D4 (2)		
−6°	D5 (2)	D6 (2)	D7 (2)	D8 (3)		
−9°	D9 (2)	D10 (2)	D11 (3)	D12 (3)		

Table 10: MV-22 test conditions flown (with number of runs each).

Speed [kts] **FPA Nacelle Angle [°]**	**40** **87**	**60** **85**	**80** **80**	**100** **60**	**120** **60**	**125** **0**	**140** **0**	**160** **0**	**180** **0**	**200** **0**	**220** **0**	**240** **0**	**260** **0**
3°		C1 (0)	C2 (0)										
0° – Ramp Down	L1 (0)	L2 (2)	L3 (3)	L4 (3)	L5 (5)	L6 (3)	L7 (0)	L8 (3)	L9 (3)	L10 (3)	L11 (5)		
0° – Ramp Up	L12 (0)	L13 (0)	L14 (3)	L15 (0)	L16 (5)	L17 (3)	L18 (0)	L19 (3)	L20 (0)	L21 (3)	L22 (3)	L23 (3)	L24 (3)
−4°		D1 (2)	D2 (2)	D3 (2)									
−7°		D4 (3)	D5 (2)										
−10°		D6 (3)	D7 (0)										
Tactical – 180° **Landing at PAPI**											T3 (2)		
Tactical – Straight Landing											T4 (2)		
Tactical – 90° **Landing**											T5 (4)		
Tactical – 180° **Landing**											T6 (2)		

Table 11: Stalker UAS test conditions flown (with number of runs each).

FPA	**30 kt**	**40 kt**
Max rate of climb at microphone 31	C3 (5)	C4 (5)
Max rate of climb at microphone 1	C1 (5)	C2 (0)
0°	L1 (5)	L2 (5)

Table 12: MD530 test conditions flown (with number of runs each for legacy, S411 main rotor blades).

FPA	**40 kt**	**60 kt**	**80 kt**	**100 kt**	**120 kt**	**0.9 $\mathbf{V_h}$**
3°		C1 (0,0)	C2 (0,0)			
0°	L1 (3, 0)	L2 (6, 3)	L3 (6, 5)	L4 (6, 5)	L5 (8, 8)	FAA (0, 0)
−3°	D1 (0, 0)	D2 (3, 3)	D3 (3, 4)	D4 (0, 3)		
−6°	D5 (0, 0)	D6 (0, 3)	D7 (0, 3)	D8 (0, 3)		
−9°	D9 (0, 0)	D10 (0, 3)	D11 (0, 3)	D12 (0, 3)		

Table 13: Acoustic pressure time history file contents.

Variable Name	Description	Units
pressure.data	Acoustic pressure as measured	pascals
global.test	Test description	
global.location	Test location	
global.date	Date of test	
global.run_number	NASA combined run number	
global.sensortype	Name or pressure sensor	
global.noise_source	Aircraft measured	
global.mic_number	Microphone number	
global.Latitude	Latitude of WAMS II box	decimal degrees
global.Longitude	Longitude of WAMS II box	decimal degrees
global.sample_rate	Samples per second of pressure data	Hz
global.start_time	Local seconds from midnight of first sample	s
global.number_samples	Number of data samples	
X	Mic X location in rotated coordinate frame	feet
Y	Mic Y location in rotated coordinate frame	feet
Z	Mic Z location in rotated coordinate frame	feet

Table 14: Weather Balloon Sonde file contents.

Variable Name	Description	Units
UTCTime	UTC Time	hh:mm:ss
Latitude	Latitude	Decimal degrees
Longitude	Longitude	Decimal degrees
Alt	Altitude above ground	m
P	Static pressure	mbar
T	Air temperature	°C
%RH	Relative humidity	%
Wind	Wind speed	kts
Wind	Wind direction	°

Table 15: Temperature String file contents.

Variable Name	Description	Units
RunID	NASA combined run number	#
Altitudes	Current sensor altitude	meters
TempC	Current sensor temperature	°C

Note: Sensor 1 at top of sonde, sensor 50 at bottom. Linearly interpolated from altitude to ground to find each sensor height.

Table 16: Weather Station file contents.

Variable Name	Description	Units
Identity	Weather station number	
Date	Date	MM/DD/YYYY
Time	UTC Time	HH:mm:ss
Run Number	NASA run number	#
Temperature	Air temperature	°C
Humidity	Relative humidity	%
Pressure	Static pressure	kPa
Wind Speed	Wind speed	knots
Wind Direction	Wind magnetic direction	°
DewPoint	Dew point	°C

Table 17: LIDAR file contents.

Variable Name	Description	Units
RunID	NASA combined run number	#
Altitudes	Measurement altitude	meters
AveWindSpd	10-minute average of horizontal wind speed	meters/second
MinWindSpd	10-minute minimum of horizontal wind speed	meters/second
MaxWindSpd	10-minute maximum of horizontal wind speed	meters/second
StdWindSpd	10-minute standard deviation of horizontal wind speed	meters/second
VertWindSpd	10-minute average of vertical wind speed	meters/second
WindDir	wind direction relative to magnetic North	$^\circ$
TI	Turbulence Intensity	%

Note: LIDAR samples data at 12 altitudes, including ground, at a rate slightly more than 1 altitude sampled each second.
Note: Data provided are averaged recording over 10 minutes (approximately 50 samples at each altitude).

Figures

Figure 1: MV-22 vehicle in flight over test range.

Figure 2: Stalker UAS at test range.

Figure 3: MD530 vehicle in flight over test range.

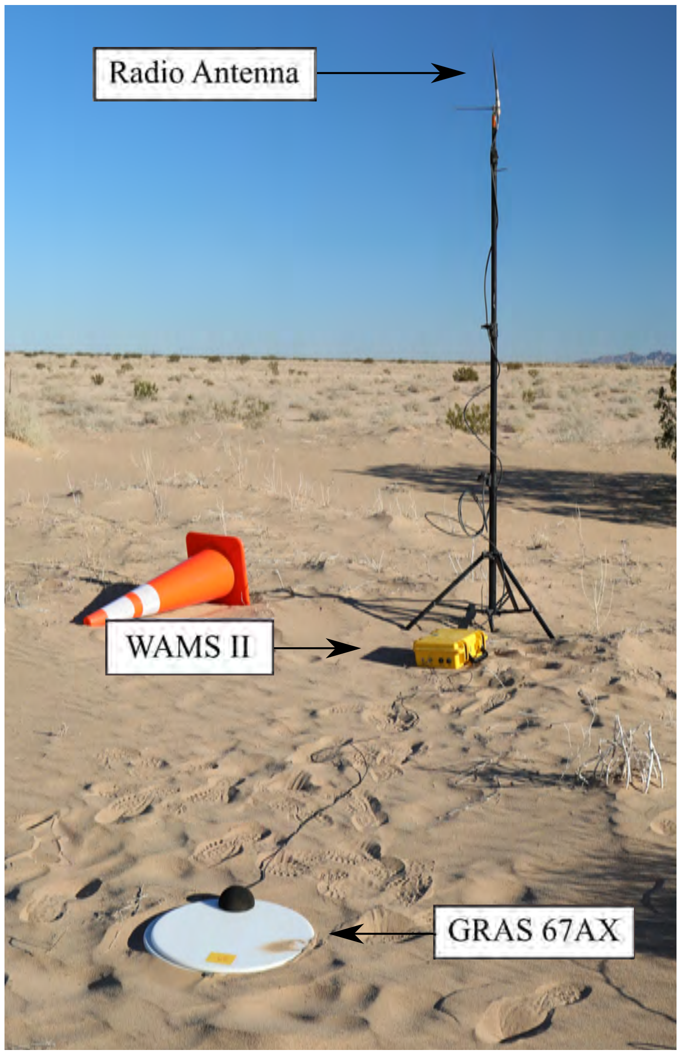

Figure 4: WAMS II setup with GRAS 67AX microphone.

Figure 5: Tri-located microphone setup for microphones 31 (GRAS 67AX), 64 (B&K 4189 inverted), and 65 (B&K 4964 on 4 foot tripod).

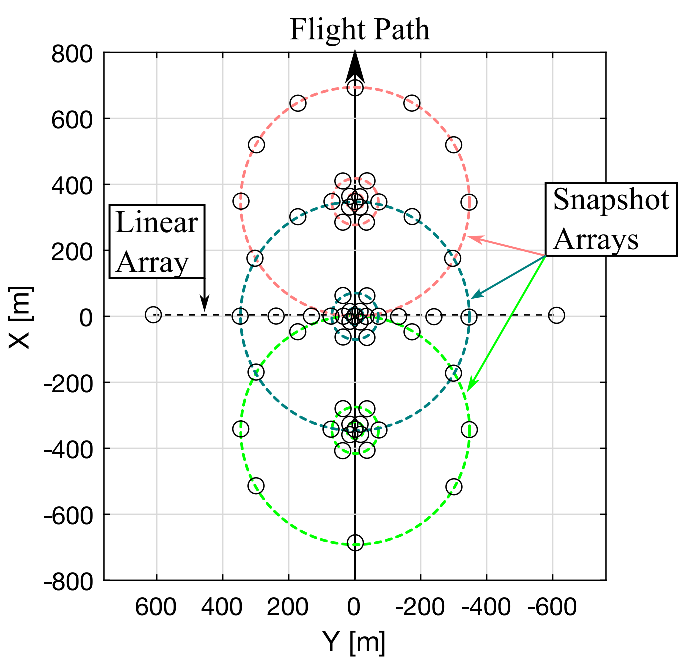

Figure 6: Microphone locations.

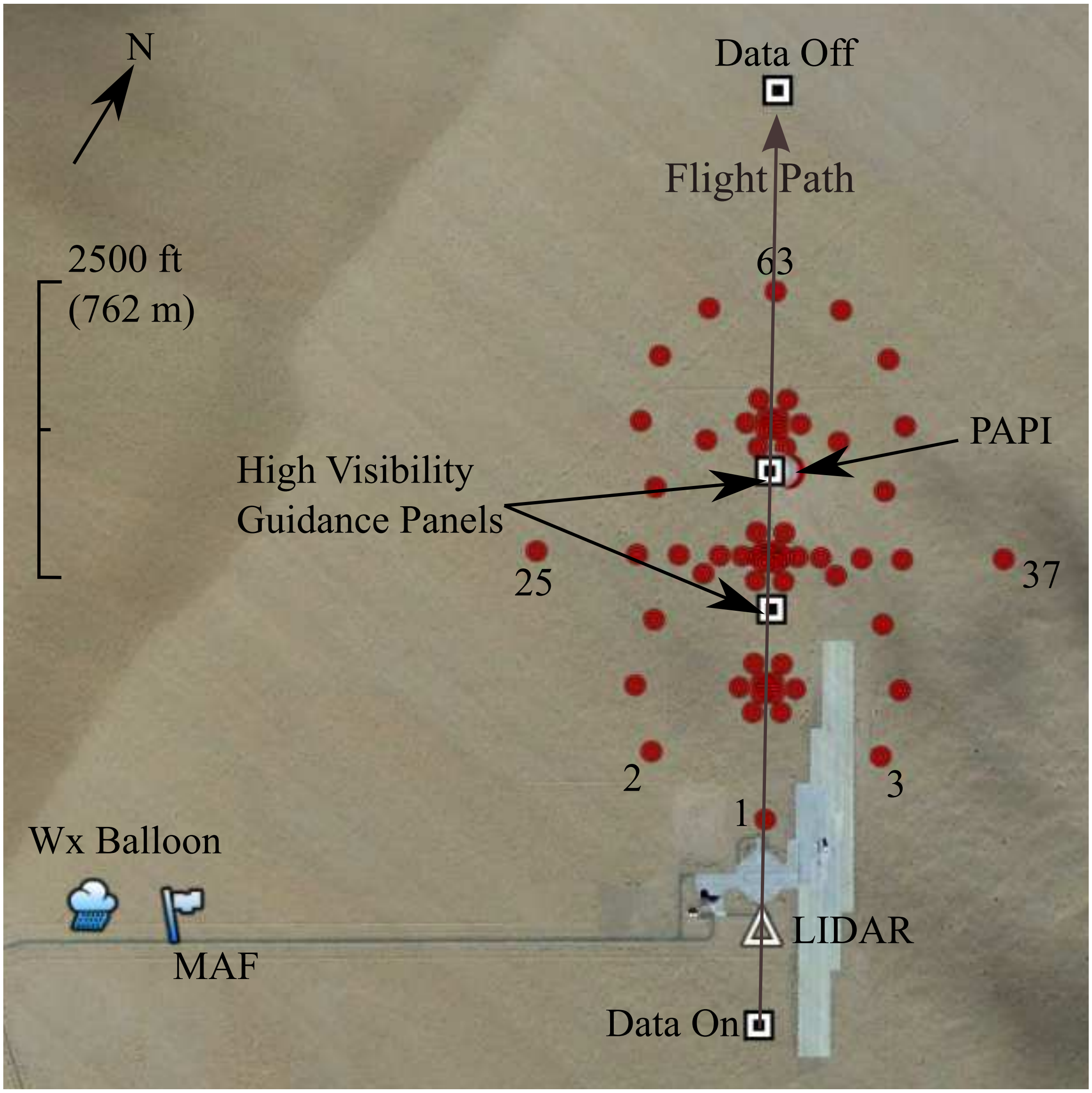

Figure 7: Satellite photo of test location with equipment identified.

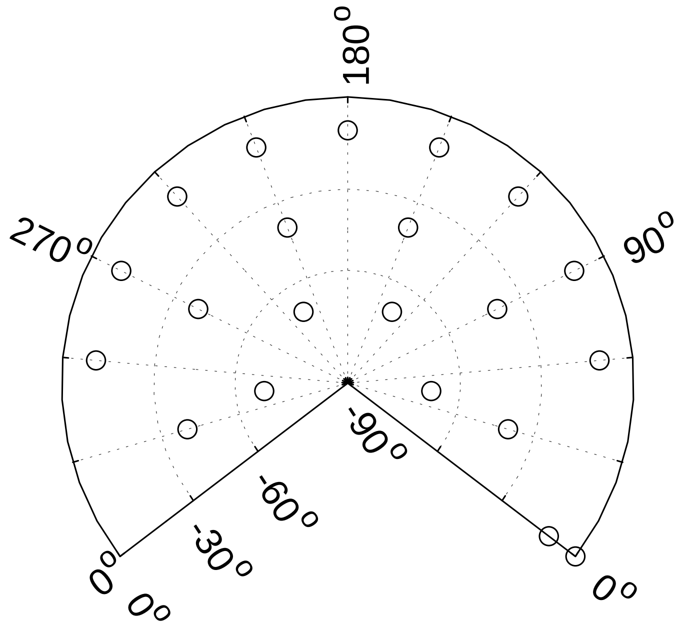

Figure 8: Lambert projection of a single snapshot array.

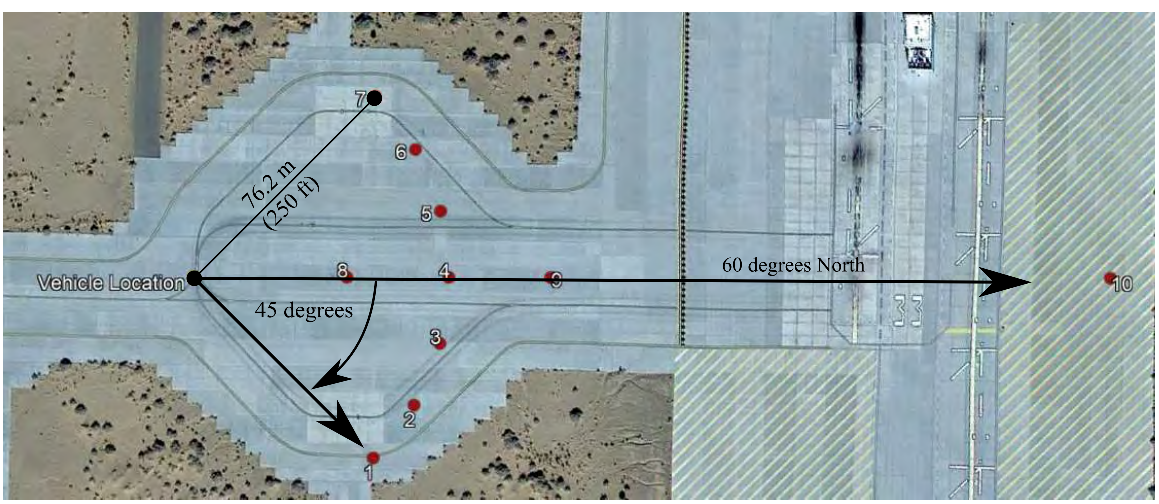

Figure 9: Microphone array for tail rotor noise analysis.

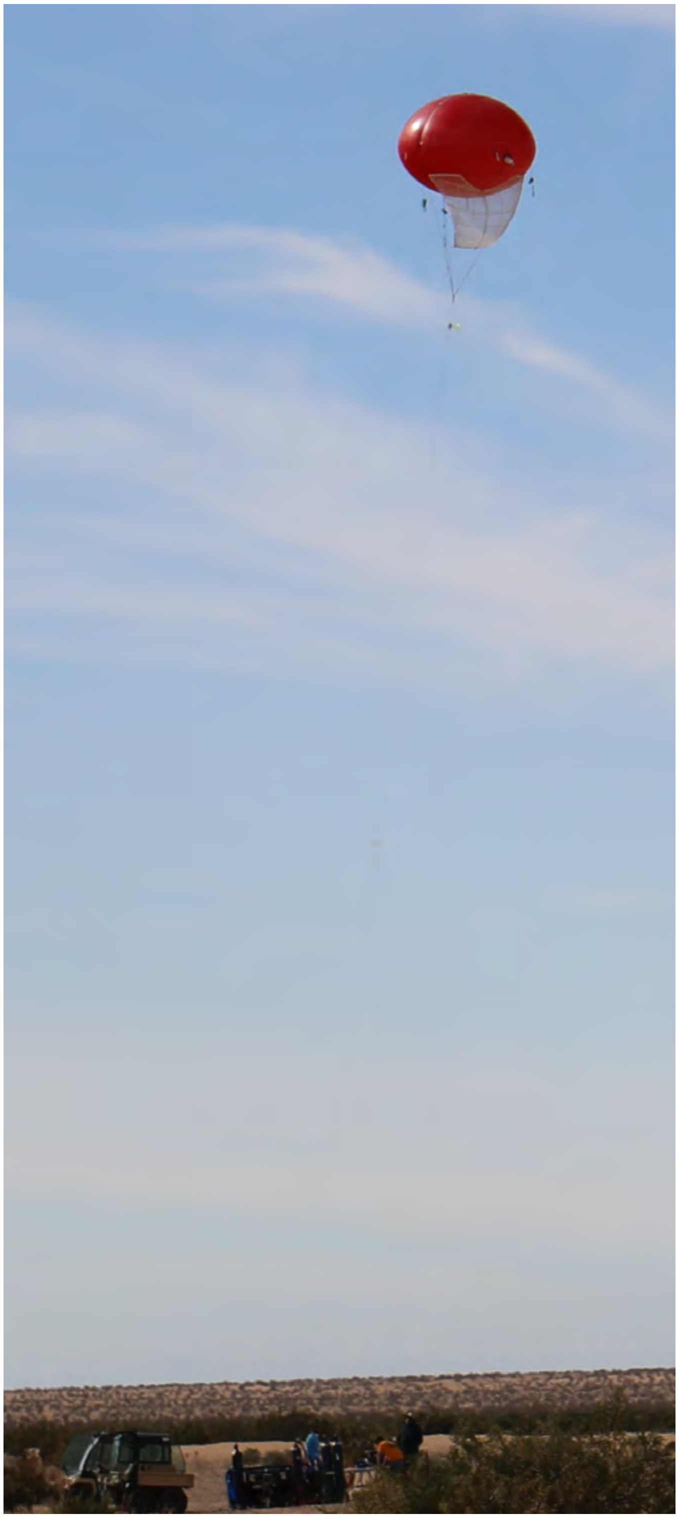

Figure 10: Tethered weather balloon being deployed.

Figure 11: LIDAR, as deployed.

Figure 12: Four PAPI lights with red beam visible at night on the ground.

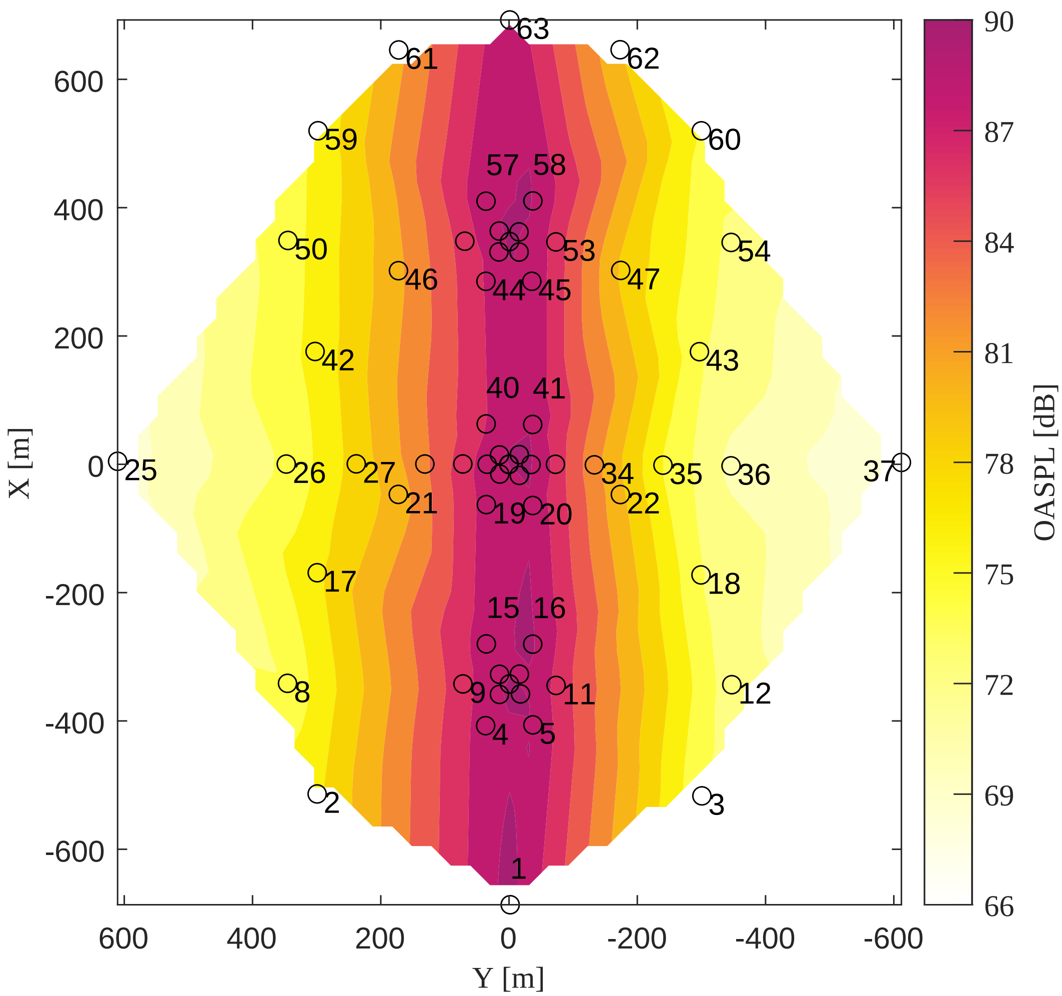

Figure 13: Maximum overall sound pressure level for run 042420, in decibels (ref. 20 micropascals).

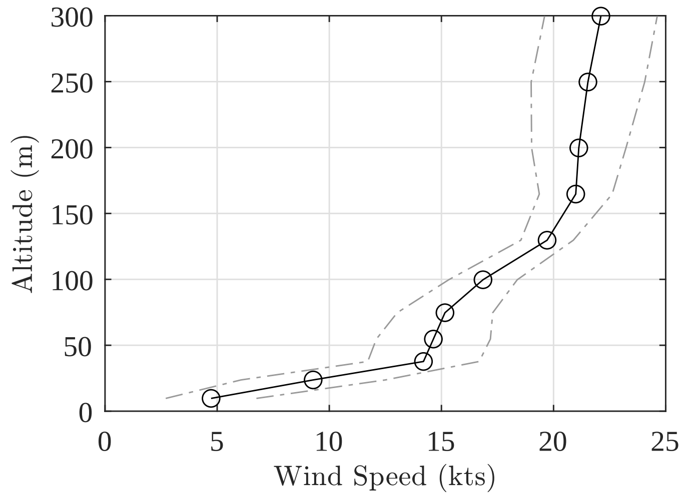

Figure 14: Measured wind profile from LIDAR for run 042420. Solid line shows averaged profile, while dashed lines denote 95% confidence limits. Circles identify the location of each measured altitude.

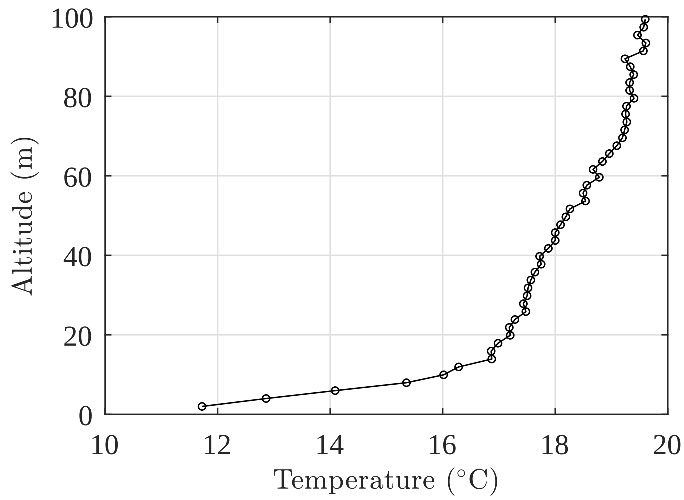

Figure 15: Measured temperature profile from temperature string for run 042420.

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14. ABSTRACT
A cooperative flight test campaign among the U.S. Navy, Army, Marine Corps, and NASA was performed at Marine Corps Air Station (MCAS) Yuma from 19 January to 15 February 2022. The primary purpose of testing military vehicles was to characterize the acoustic signature of the MV-22 rotorcraft and Stalker unmanned aerial system for typical mission gross weight, configuration, and for a range of typical mission operating conditions. Additionally, a civilian MD530 vehicle was tested to characterize the acoustic emissions for both legacy blades and S411 main rotor blades. This report provides an overview of the test, documents the data acquired, and describes the formats of the stored data.

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