Defense Threat Reduction Agency
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DTRA-TR-24-07

TECHNICAL REPORT

Initial Analyses of Flow Data from UAS Testing at Dugway Proving Ground April 2021

Prepared by Thomas Mazzola
Systems Planning and Analysis, Inc.
in support of DTRA Technical Reachback, RD-OPR
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14. ABSTRACT

In late April and early May of 2021, Dugway Proving Grounds executed Defense Threat Reduction Agency Unmanned Aerial System (UAS) Dispenser Modeling Test . This involved a series of chemical simulant releases from a UAS, both indoors and outdoors. This series is subsequently referred to by DTRA as Phase 1 UAS testing, as future testing is planned. Prior to testing of UAS dispensing chemicals, a series of flow measurements were conducted to capture some characteristics of the turbulent flow generated underneath the UAS. These measurements in the Joint Ambient Breeze Tunnel are the subject of this technical note.

15. SUBJECT TERMS

UAS, turbulent flow, rotor wash

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In late April and early May, Dugway Proving Grounds executed Defense Threat Reduction Agency (DTRA) Unmanned Aerial System (UAS) Dispenser Modeling Test[1]. This involved a series of chemical simulant releases from a UAS, both indoors and outdoors. This series is subsequently referred to by DTRA as Phase 1 UAS testing, as future testing is planned.

Planning and management of these tests was performed by Akeisha Owens, DTRA. The author is grateful to her for the chance to participate in these tests along with the team of scientists assembled by Dr. Owens.

The UAS system, customized for these tests was provided through U.S. Army Combat Capabilities Development Command – Army Research Laboratory under management of Mostafiz Chowdury by SURVICE Engineering led by Phil King. The author appreciates all the detailed information on the UAS provided by these offices.

The testing effort at Dugway was led by the Test Officer, Tonya Ashment, who provided great support and assistance during the flow testing in the JABT and afterwards as test data was provided to DTRA. The UAS rotor flow data analyzed in this report was collected by a team led by Daniel Ruth of the meteorology group at Dugway. He and others developed a customized test fixture and methodology to capture the data requested by DTRA, acquired the test data, quality controlled the data and provided it to DTRA in readily usable formats. These efforts and assistance after the data was delivered to find and interpret the data are greatly appreciated.

[1] US Army Test and Evaluation Command (ATEC) Project Number 2021-DT-DPG-JTAAR-H8705, West Desert Test Center (WDTC) Document Number WDTC-CTD-TPT-010

Introduction – In April of 2021, DTRA RD-OPR led testing of UAS systems releasing a chemical simulant, at Dugway Proving Grounds, Utah. This was conducted "indoors" in the Joint Ambient Breeze Tunnel (JABT) and later, in May of 2021, outdoors. Prior to testing of UAS dispensing chemicals in the JABT, a series of flow measurements were conducted to capture some characteristics of the turbulent flow generated underneath the UAS. No such flow measurements were made for the outdoor testing. These measurements in the JABT are the subject of this technical note.

Experiment Description – Measurements of the flow under the UAS tested at Dugway Proving Ground (DPG) were made during the Setup week at DPG on dates of 20-22 April 2021. The Survice engineers were setting up and testing the UAS this week and in times available, the DPG meteorology office made flow measurements. These were requested by DTRA to provide a basis for evaluating the physical mechanisms leading to the effects of so-called rotor wash on the initial dispersal of chemical simulants. These were not primary measurements for characterizing the chemical environment. Indeed, no chemical was released during flow tests to protect instrumentation. But data were collected to provide for high resolution analysis of the flow and dispersal that would undoubtedly follow.

The instruments used for flow measurements were DPG sonic anemometers[2]. These were chosen as they were readily available to the meteorology office and would provide some of the turbulent flow characteristics expected from the rotor wash under the UAS. The RM Young 81000 3D sonic anemometers provide full 3-axis wind speed as well as sound speed and derived sonic temperatures. See http://www.rmyoung.com for details. The parameters are averages over an air column between the sensor elements of 10 cm height and 10 cm diameter. DPG ran these instruments at 10 Hz and the turbulence characteristics are limited by that data rate (temporal) and air column volume (spatial). DPG suggested that hot-wire anemometers would provide for higher frequency turbulence measurements, but such measurements were out of scope for these tests and use of on-hand instruments was made.

Data files from the instruments were processed and quality controlled by DPG and provided to the test program as .dat text files. For ease of summarizing information, they also provided such files for 10 second average parameters. The analyses that follow in this note made use of the 10-second averaged data. For reference, a sample of such a file is in Appendix A.

Experiments – The experiments were conducted in the JABT, at about the midway point of the tunnel length. The JABT is a long tunnel that can allow flow down its length due to atmospheric conditions if the doors are open. For these tests, the doors were closed and there was no flow except for that generated by the UAS rotors.

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[2] Storwold, Donny, *JACK RABBIT II (2016) TEST PROGRAM, DUGWAY PROVING GROUND - WEST DESERT TEST CENTER, AUGUST / SEPTEMBER 2016, 32m Tower-Mounted Ultrasonic Anemometer Deployment (Updated: 10 December 2018)*

For reference, the JABT is approximately 150 feet long and 55 feet high, so the testing area was some 75 feet down the tunnel with doors closed for the flow tests. Here are some images from on line:

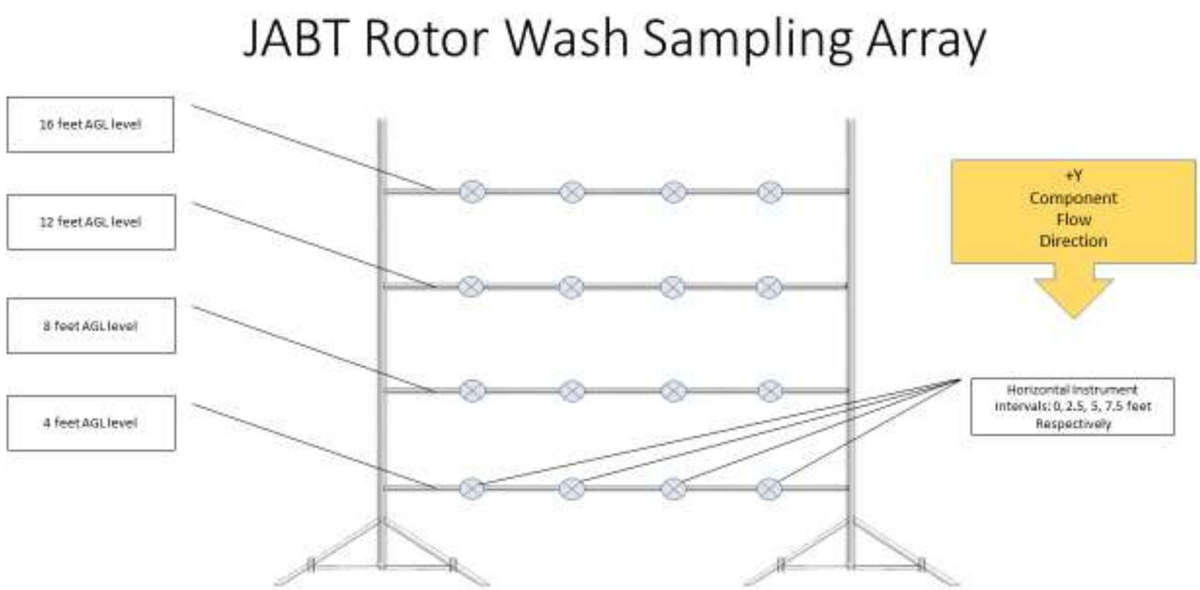
Looking down the long JABT from the west, inlet end.

An inside view of the JABT.

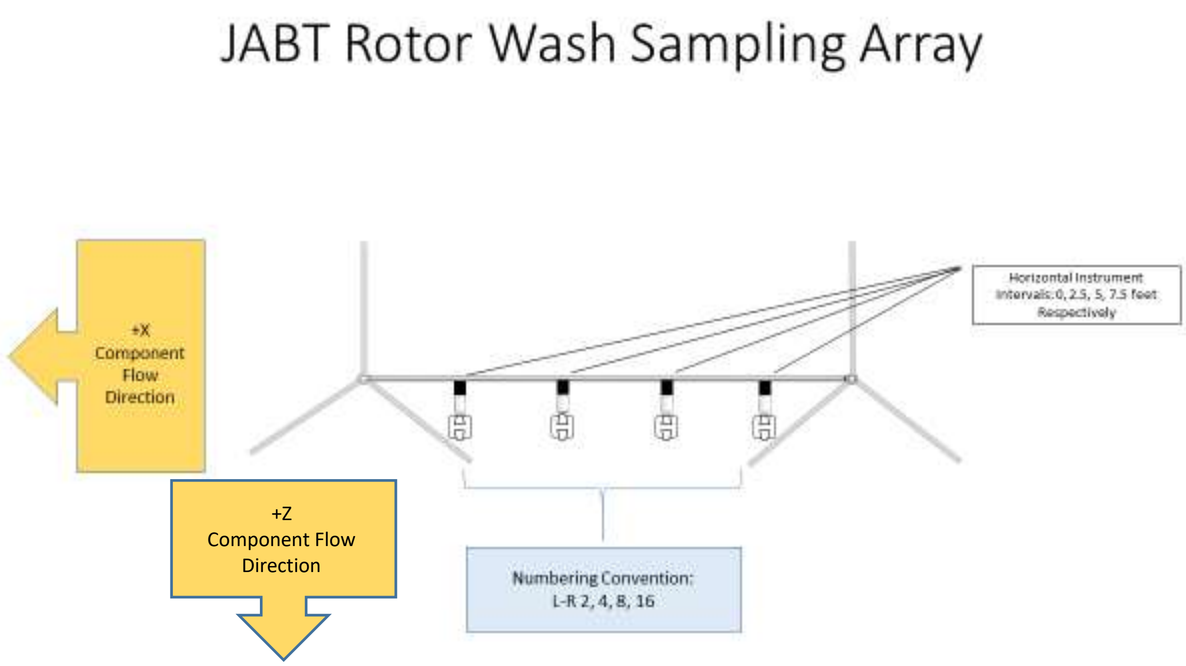
Anemometer Array - The array of sonic anemometers is depicted below and was midway down the long tunnel. Four anemometers were arranged at a fixed height for each test, positioned 2.5 feet apart from one another as indicated. Flow parameters were captured for one height for a given test and four tests were required to capture data for all four heights.

The anemometers were mounted "on their side" compared to their normal configuration on towers in the atmosphere. In this circumstance, x and y are in a plane from the floor to the ceiling through the anemometers with positive x component to the left wall as indicated, and positive y component downward as indicated. The positive z component comes out of the x, y plane towards the anemometers as shown in the second figure. These flow components are u, v and w for x, y and z, respectively, in Appendix A.

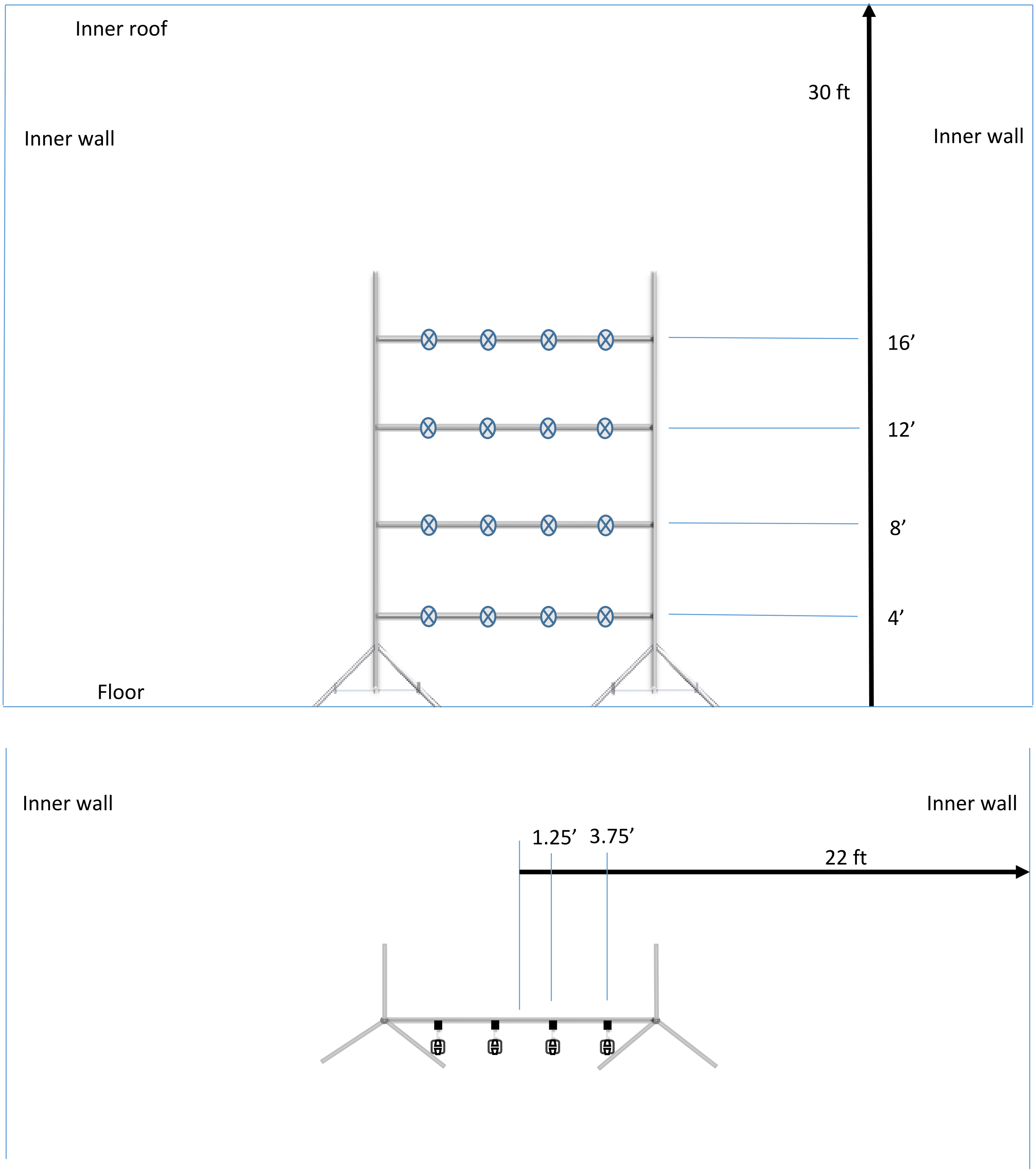
The anemometer array was positioned at the center of the JABT as shown in the lower two figures. The JABT had inner surfaces, with inner walls 44 feet apart and with the movable inner roof 30 feet above the rigid concrete floor, as shown.



The anemometer array looking down the tunnel with positions for four sonic anemometers at each of four levels above the floor.



The anemometer array looking downwards from the tunnel ceiling.

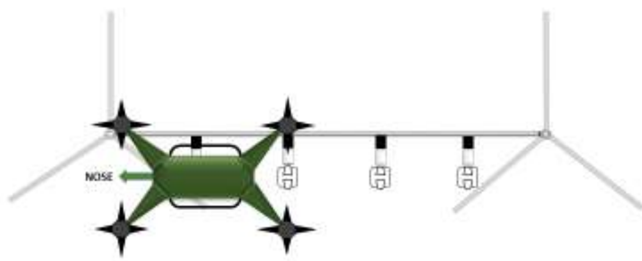


The anemometer array positioned in the JABT.

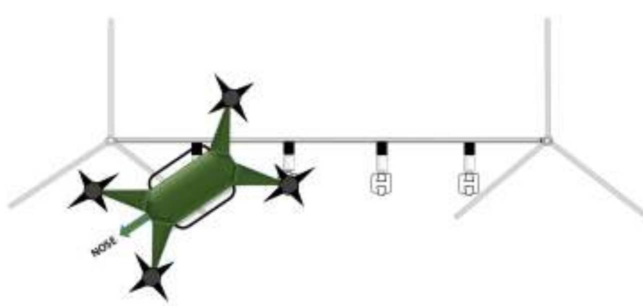
UAS Positioning - For the flow experiments, there were two UAS deployed, the TRV-150 and the TRV-80. Details of these systems are not presented here[3], but the positioning of them related to the sonic anemometers is described. A brief description is in Appendix B.

For these experiments, the TRVs were positioned at 20 feet above the floor (measured to the tip of the spray nozzle), so about 4 feet above the top line of anemometer positions. They were horizontally positioned as suggested below. For the Centerline Orientation, the second anemometer at 2.5 feet was between rotors. This left the first anemometer under the belly of the UAS, influenced strongly by all of the rotors. For the Rotor Radial Orientation, the second anemometer was directly under one rotor position and again the first was under the belly. The nose and forward direction is indicated to orient for UAS attitude. Positive pitch is nose up and positive roll is right wing/rotors down.

JABT Sampling Array (Above)
UAS Centerline Orientation

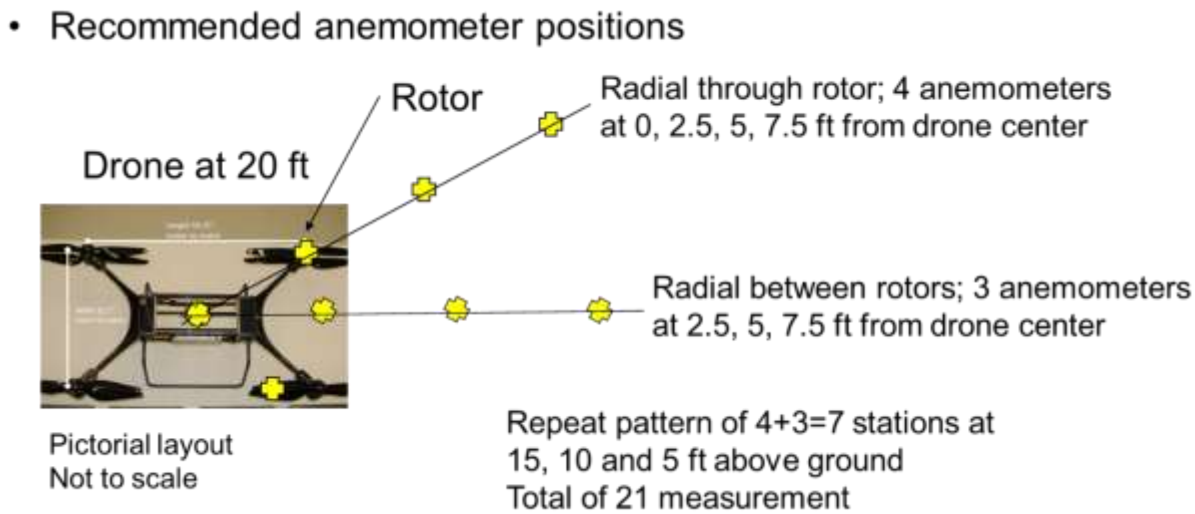


JABT Sampling Array (Above)
UAS Rotor Radial Orientation



[3] See http://www.survice.com

UAS Configuration for Testing – A few more details are presented on the dimensions of the UAS, rotors and anemometers. The proposed layout was as shown next.



This includes an image of the TRV-80. Given the dimensions shown, the 30-inch distance from the rotor hub towards the center falls just beyond the center which is at 29.65 inches from the hub. For the between rotor setting, as executed, the UAS was positioned so the second anemometer was between the two rotors which means that the first anemometer was 30-25.125 or 4.875 inches beyond the center of the belly of the UAS.

For the TRV-150, which is a larger UAS, the positioning works out a little differently. That vehicle is shown here.

With 40-inch diameter props, the distances between rotor hubs are 63 inches lengthwise and 42 inches widthwise. The second anemometer is in the same positions, either under one or between two rotors. The distances to the center of the system from one hub are then 36.86 inches to a hub and 31.5 inches from the position between two hubs for the TRV-150. So, the first anemometer is 6.86 inches short of the center with the rotor over the second anemometer. Similarly, the first sensor is 1.5 inches short of the system center when the second sensor is between two rotor hubs.

The spray nozzles were not in position for these flow tests which were spray-free to protect the anemometers. For those interested, please see Appendix C for photos and a short discussion about nozzle positions. For further details, contact DTRA Technical Reachback.

Testing – Tests were conducted over a three day period, 20-22 April, 2021. These proceeded to cover both UAS, the TRV-150 and the TRV-80. For the TRV-150, two series of tests were conducted, one with all eight rotors running in the normal configuration, and the second with only four rotors turning. Only the -150 had this capability to run four rotors, one of each stacked counter-rotating pair.

The test procedure involved positioning the four anemometers at a given height, then positioning the UAS with the second anemometers either under an aft rotor or between two aft rotors. Two tests were typically run like this for the TRV-150, with four and eight rotors running, while only one test was run for the TRV-80 with all eight rotors running. Then the row of anemometers would be moved to a new height and repeat. And so on.

The UAS systems were mounted to a lift and held in place above the anemometers, but they simulated a hover condition. In each case, the power setting and lift was matched to the weight of the UAS plus a full load of simulant. For the TRV-80 which held 1 gallon of liquid, the rotors ran at 3,130 RPM. For the TRV-150 which held 2 gallons of liquid, the rotors ran at 2,015 RPM.

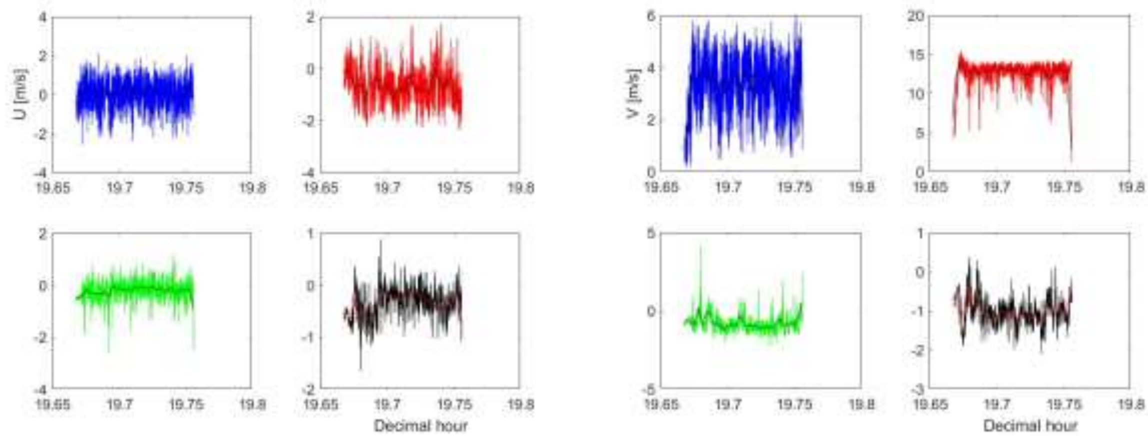
The full log of runs is given in Appendix D. Note some were interrupted due to an anomaly and then another test was run. Also note, when level attitude was not possible, the log notes the approximate pitch and roll angles during the test.

<u>Data Analysis Procedures</u> – As mentioned the processed data from the anemometers is available at full resolution as 10Hz data and for 10 second averages. The latter was provided for ease of initial interpretation. For this preliminary data analysis, the 10 second average data was used.

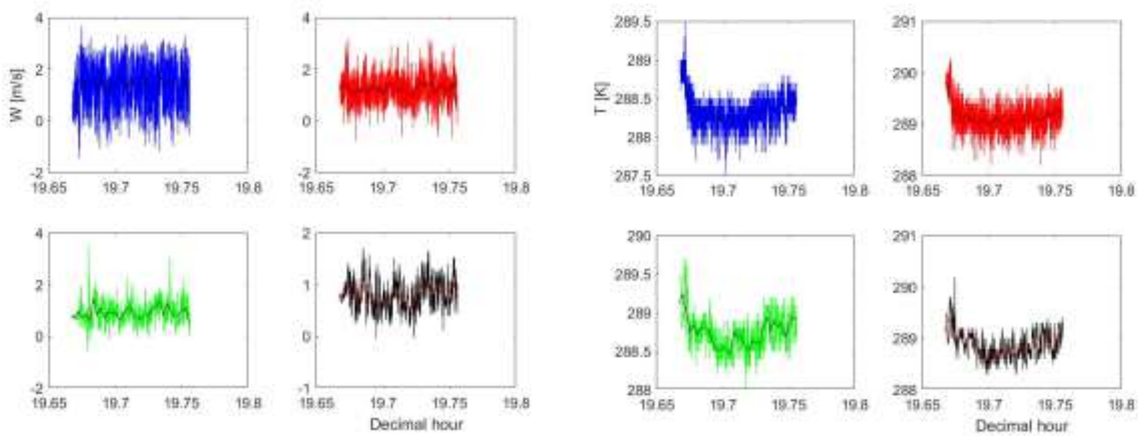
The Dugway meteorology staff provided plots of all sensor data, a few of which are shared here for illustration. Consider the TRV-150 with all 8 rotors turning and a pair of rotors over the second anemometers. This involves four trials, trials 2, 6, 10 and 12. Trial 2 has the anemometers up at the 16 foot elevation, just 4 feet below the UAS. The second anemometer, sid 4, is underneath a pair of tail rotors. The figures below depict the full 10 Hz signal as well as the 10 second averaged data. Note the predominant motion is downward as expected, as the v component. All components fluctuate significantly around a slowly drifting mean.

For purposes of an initial look at the data, this analyst processed the data further and examined graphically some one minute average parameters. This was done by taking a one minute window or six consecutive values of the 10 second average data and calculating the mean value. The one minute window was towards the second half of the 3 minute plus data period. For the sample plots below, the time period was 2 minutes 20 seconds into the trial, running for one minute. The resulting one minute averages are -0.72, 12.91, 1.23 m/s for U, V and W, and 289.1 K for T.

The one minute averages were calculated for all trials and then graphically analyzed in the next section. First, vertical distributions of downward velocity, v, are displayed for the highest speed flow through the second anemometers, sid = 4, from four trials. Then, by combining one minute averages of u and v from four trials, flow vector plots in the x, y plane are constructed and displayed, giving a coarse sense of the flow distribution.



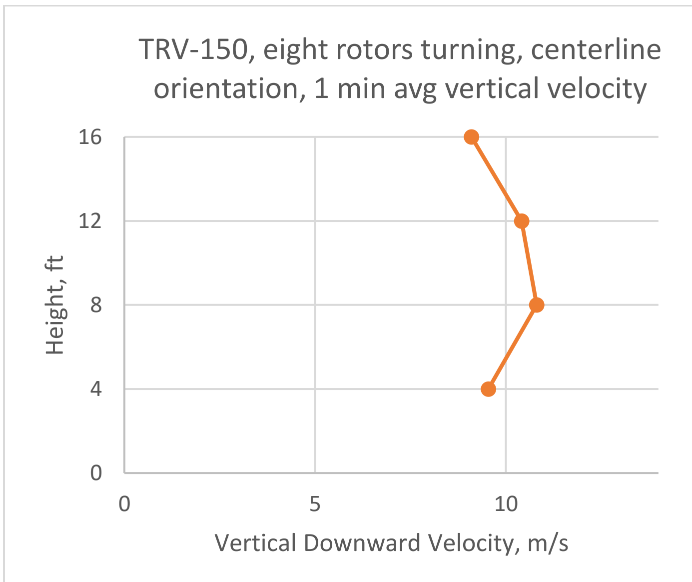
Flow velocity components u (left) and v (right) for trial 2 (sid 2, 4, 6 and 8 are blue, red, green and black, respectively). Low frequency lines are 10 second averages.

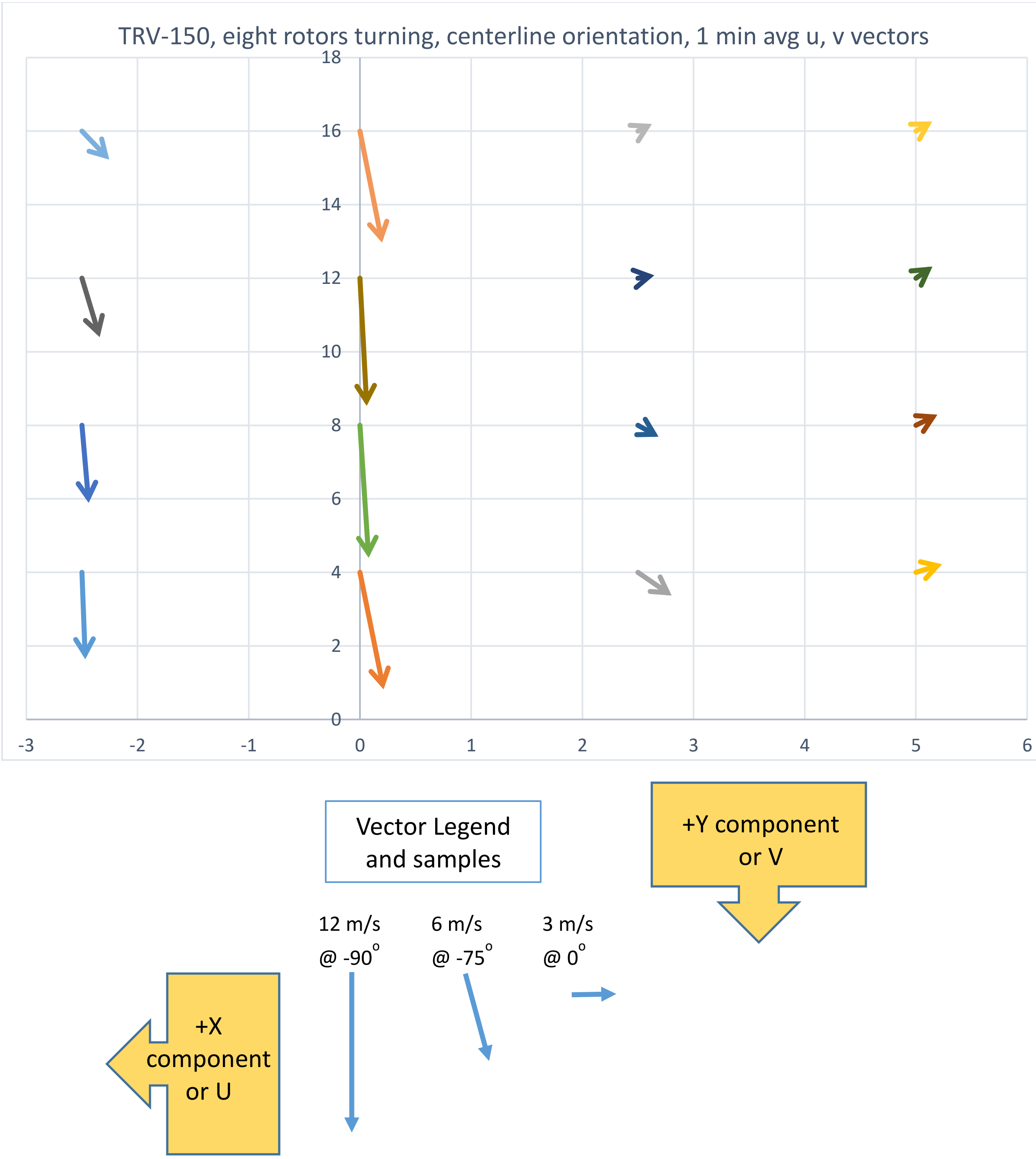


Flow velocity component w (left) and sonic temperature (right) for trial 2 (sid 2, 4, 6 and 8 are blue, red, green and black, respectively). Low frequency lines are 10 second averages.

<u>TRV-150 Flow Analysis Results</u> – This system was run in two modes; with all eight rotors turning, two per arm, and with only four rotors turning, one per arm. Also, there are two configurations (yaw) of the system relative to the anemometer array as shown in *UAS Positioning* section above. These are noted as UAS Centerline Orientation and UAS Rotor Radial Orientation.

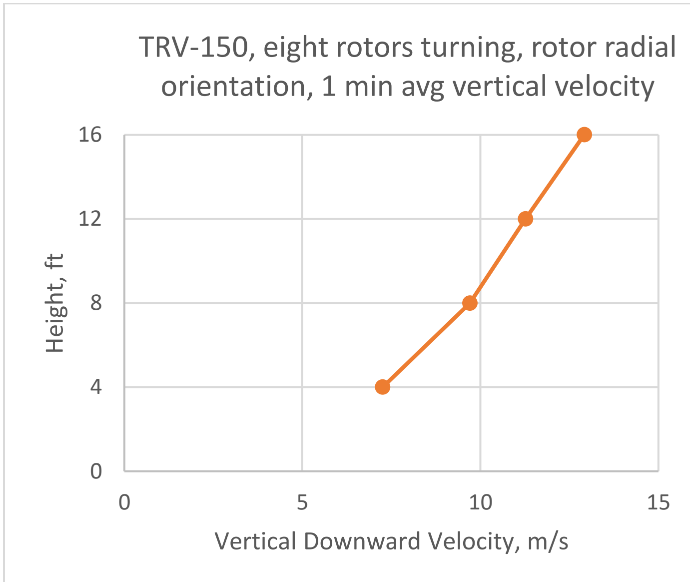
Eight Rotors Turning Centerline Orientation – Using the one minute average flow components and considering just the flow in the u, v plane, two graphs are shown. The first gives the maximum measured downward component velocity for sid = 4. The second shows u, v flow vectors. These are "pinned" at the anemometer positions of -2.5, 0, 2.5 and 5.0 feet horizontally and 4, 8, 12 and 16 feet vertically. The lengths are proportional to the velocity magnitude. A legend plot is given below this which applies to each vector plot.



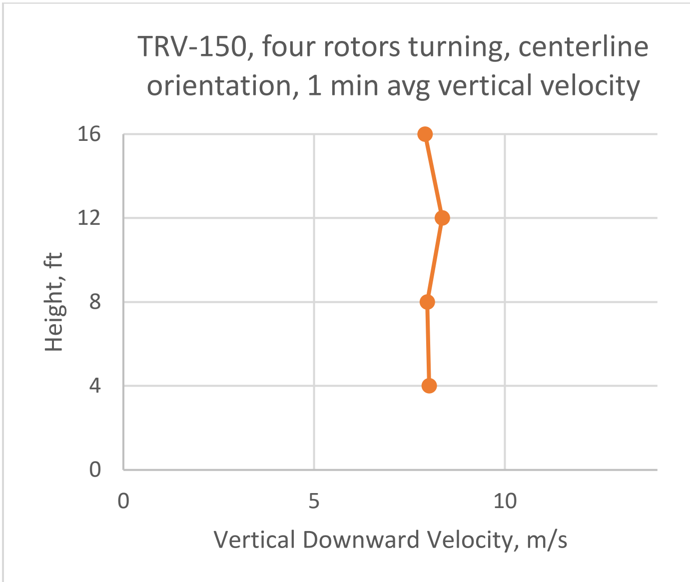


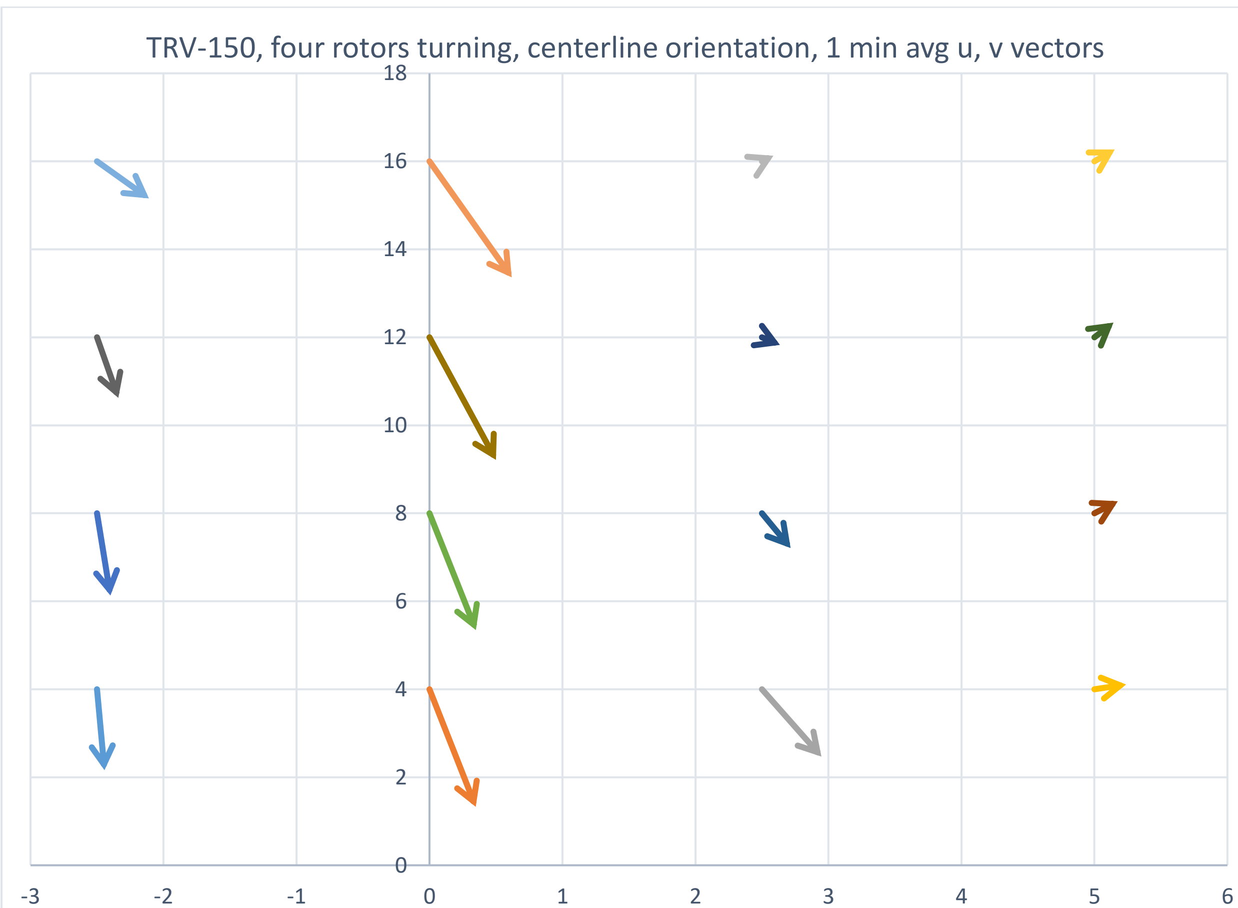
Legend for Vector Plots

Eight Rotors Turning Rotor Radial Orientation – The same type of graphs are provided, but now with sid = 4 anemometers under one of the rotors.

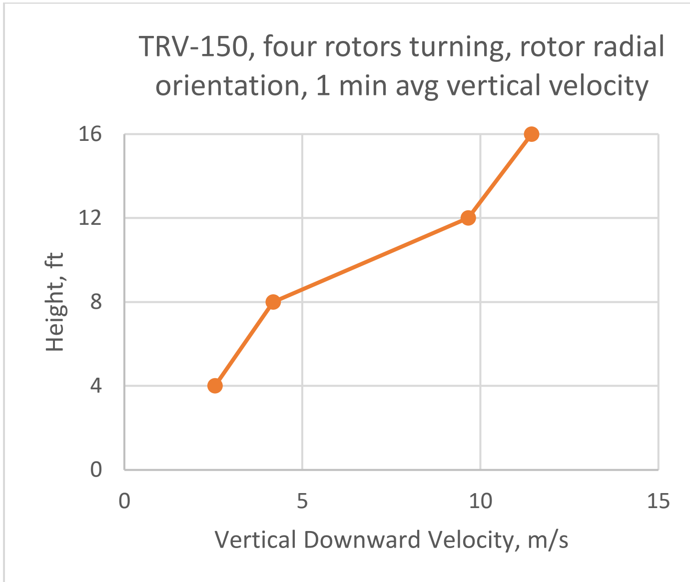


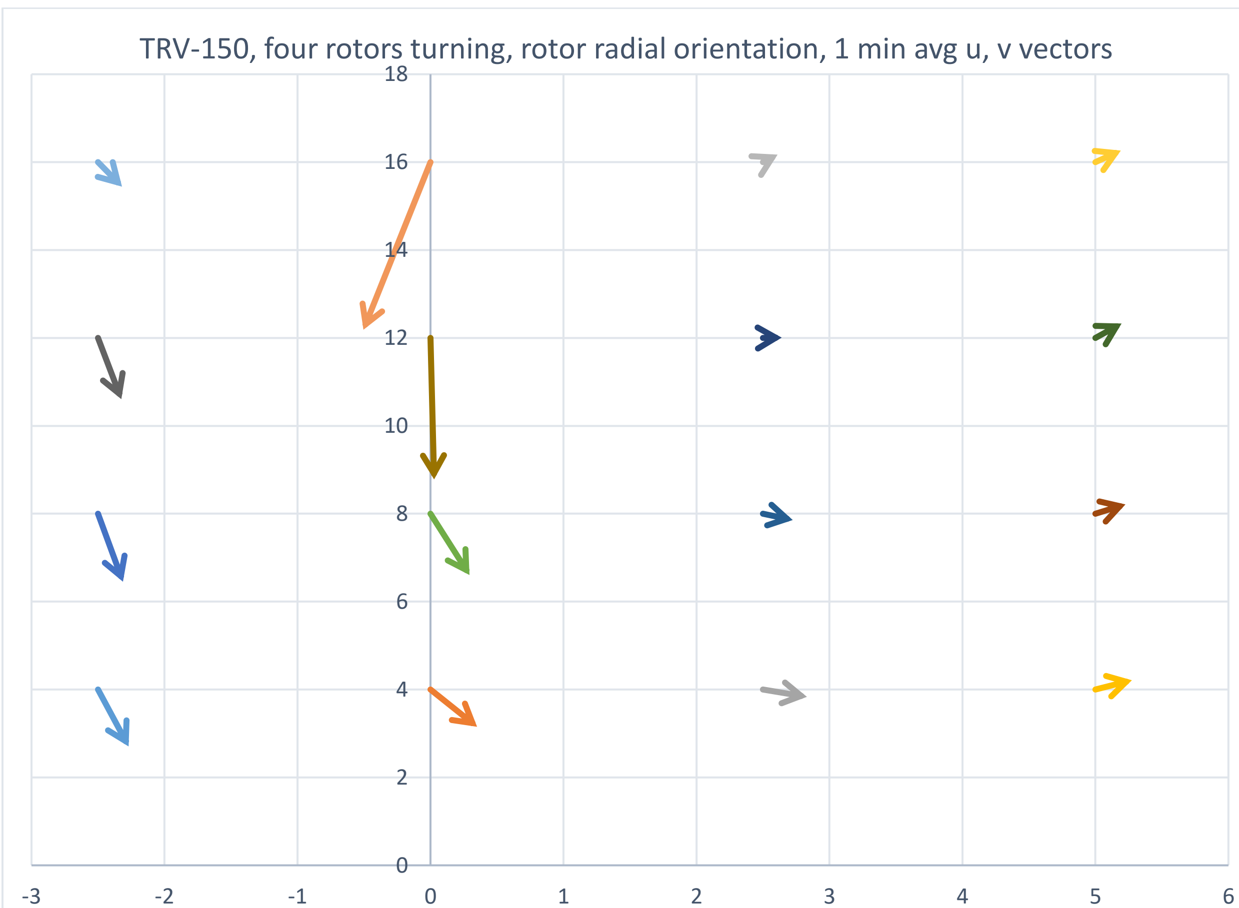
Four Rotors Turning Centerline Orientation – The same type of graphs are provided, but now with only four rotors turning and sid = 4 anemometers between two of the rotors.





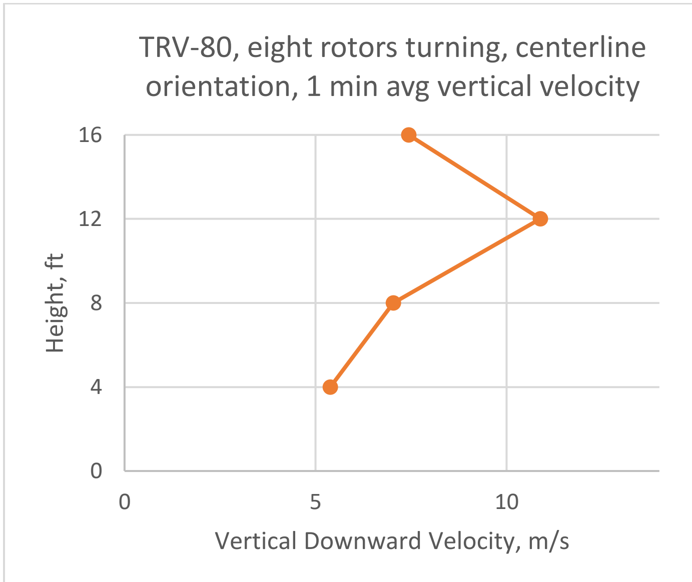
Four Rotors Turning Rotor Radial Orientation – The same type of graphs are provided, but now with only four rotors turning and sid = 4 anemometers under one of the rotors.

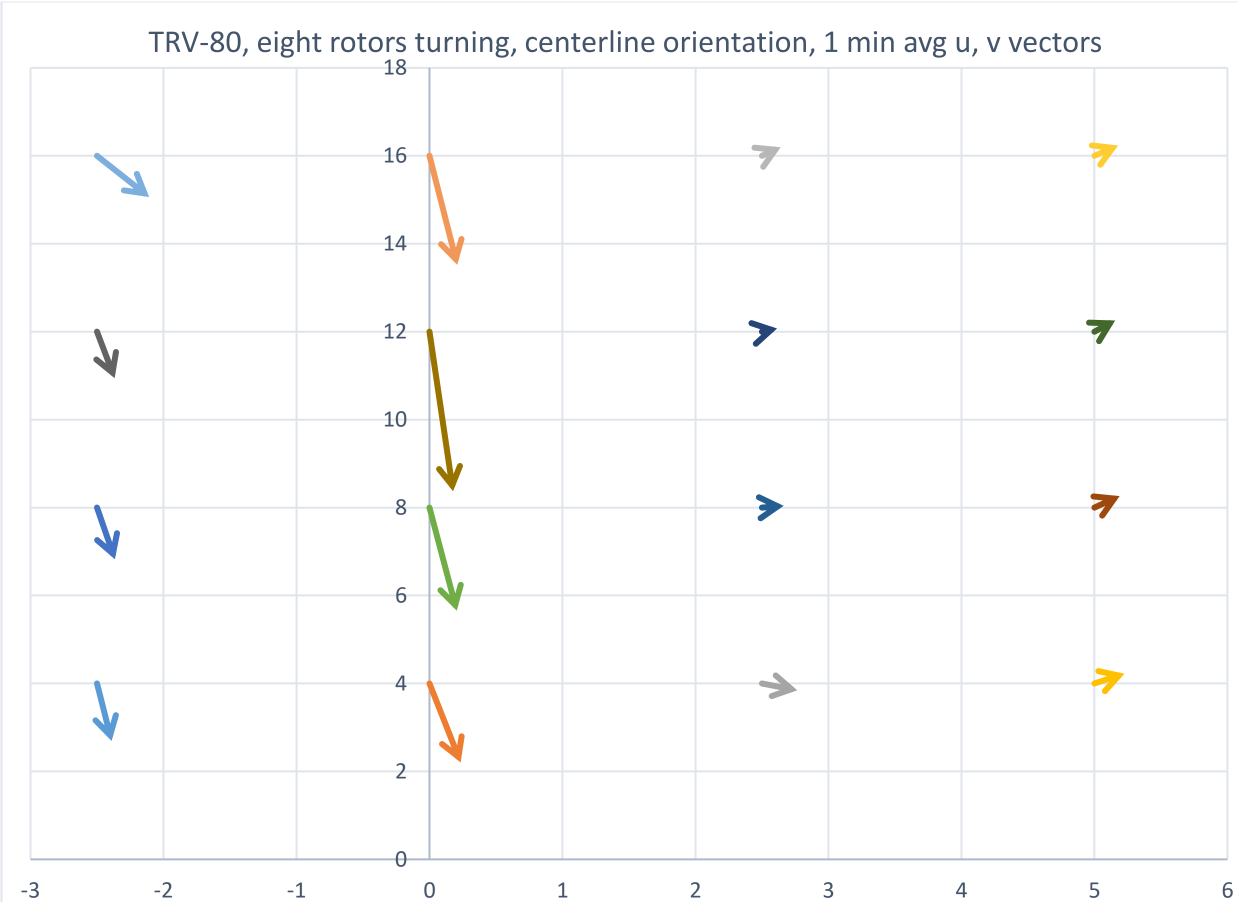




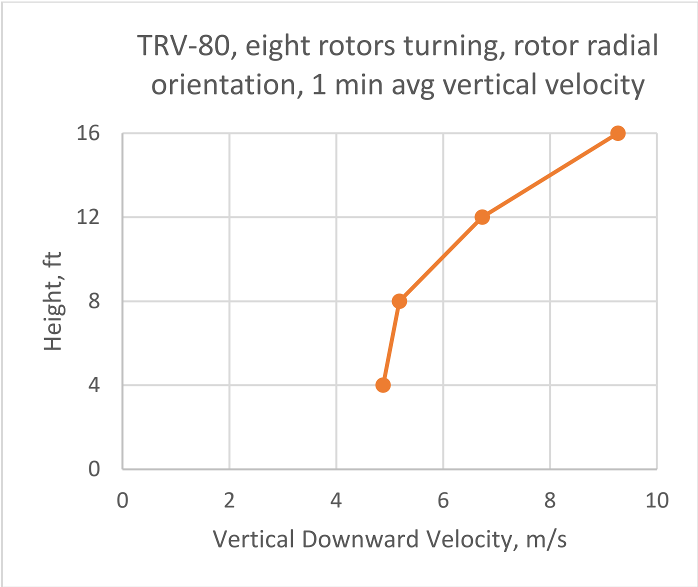
<u>TRV-80 Flow Analysis Results</u> – This system was run only with all eight rotors turning, two per arm. Also, there are two configurations (yaw) of the system relative to the anemometer array as shown in *UAS Positioning* section above. These are noted as UAS Centerline Orientation and UAS Rotor Radial Orientation.

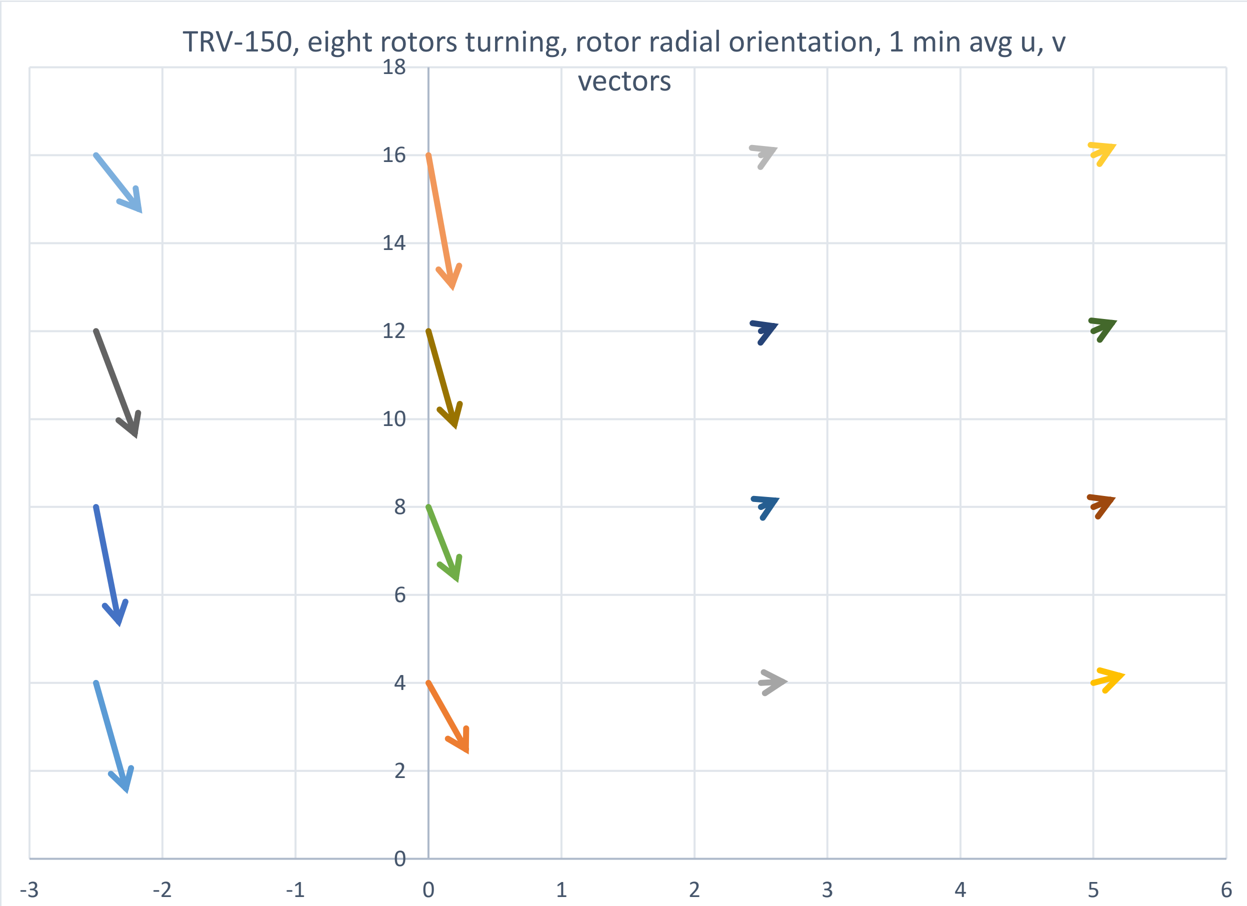
Eight Rotors Turning Centerline Orientation – The same type of graphs as above are provided, with eight rotors turning and sid = 4 anemometers between two of the rotors.




TRV-80, eight rotors turning, centerline orientation, 1 min avg u, v vectors
18
16
14
12
10
8
6
4
2
0
-3
-2
-1
0
1
2
3
4
5
6

Eight Rotors Turning Rotor Radial Orientation – The same type of graphs are provided, but now with sid = 4 anemometers under one of the rotors.





Conclusions – Initial graphical analyses of the DTRA UAS flow data for the Dugway tests in April 2021 has been provided. These are based on simple one minute averages of measured parameters.

The anemometer data set is much richer than shown here. It is hoped that this provides an introduction to that data. The full data set is available and may be requested from DTRA. This dataset includes:

- The full 10 Hz anemometer data as text formatted .dat files,
- The 10 second average parameter data as text formatted .dat files,
- Jpeg plots of the above data by component and by anemometer,
- A readme file for above data files,
- Excel workbooks that derive the one minute data and graphs provided here,
- The overview presentation provided by the Dugway met staff,
- The DTRA UAS Sonic Study Data Log, and
- The footnote 1 anemometer readme file by Storwold.

Appendix A – Sample of 10 second average output data file. This one is for Trial 1. The parameters are 3 velocity components (u, v, w) in m/s and sonic temperature in K. Sid is an ID for the sonic instrument. In the normal deployment on a tower, these would be at heights of 2, 4, 8 and 16 m above ground, hence the labels here. Four were deployed simultaneously as described in the body of the report.

year	month	day	hour	min	sec	sid	u	v	w	t
2021	4	20	19	31	20	2	-0.5209	0.1973	1.1008	287.35
2021	4	20	19	31	20	4	-0.1402	5.6139	1.6483	288.06
2021	4	20	19	31	20	8	-0.567	-0.7894	0.666	287.51
2021	4	20	19	31	20	16	-0.6866	-0.8224	0.8938	287.67
2021	4	20	19	31	30	2	-0.5119	0.9337	1.249	287.399
2021	4	20	19	31	30	4	0.8608	9.5065	2.1397	288.118
2021	4	20	19	31	30	8	-0.5151	-0.622	0.6576	287.493
2021	4	20	19	31	30	16	-0.6425	-0.6408	0.768	287.792
2021	4	20	19	31	40	2	-0.88	1.4004	0.8503	287.752
2021	4	20	19	31	40	4	1.3191	10.7386	2.5681	288.621
2021	4	20	19	31	40	8	-0.4205	-0.5255	0.8685	287.944
2021	4	20	19	31	40	16	-0.6181	-0.5302	0.8592	288.05
2021	4	20	19	31	50	2	-0.2927	0.9806	0.1452	287.533
2021	4	20	19	31	50	4	0.8972	10.1423	1.7913	288.254
2021	4	20	19	31	50	8	-0.5891	-0.5715	0.4882	287.998
2021	4	20	19	31	50	16	-0.7555	-0.9774	0.9178	288.296
2021	4	20	19	32	0	2	-0.5025	1.9416	0.5917	287.553
2021	4	20	19	32	0	4	1.0057	11.1562	2.477	288.388
2021	4	20	19	32	0	8	-0.3564	-0.9133	0.7652	288.034
2021	4	20	19	32	0	16	-0.5742	-0.9715	0.9454	288.221
2021	4	20	19	32	10	2	-0.7551	1.4064	0.7396	287.527
2021	4	20	19	32	10	4	1.3742	10.9383	0.7515	288.366
2021	4	20	19	32	10	8	-0.4028	-0.1493	0.773	288.06
2021	4	20	19	32	10	16	-0.6411	-0.6956	0.7315	288.22

Appendix B – Tactical Resupply Vehicle Brochure

SURVICE ENGINEERING COMPANY

THE TACTICAL RESUPPLY VEHICLE (TRV)

ABOUT SURVICE

SURVICE Engineering has over 35 years of experience in supporting the U.S. Department of Defense and industry clients with specialty engineering services and design expertise. Our Applied Technology Operation focuses on leading-edge research and development across engineering disciplines. We tap into our company's extensive science and technology bench and collaborate with industry, academic, and government partners to develop disruptive next-generation technologies.

DISRUPTIVE WARFIGHTER TECHNOLOGIES

SURVICE partners with leading-edge companies around the world to develop and deliver innovative, disruptive new technologies. Our work in unmanned aircraft systems development and testing is an example of providing new game-changing capabilities to the Warfighter for transportation and logistics.

The TRV family of drones, developed in collaboration with UK-based Malloy Aeronautics, represents field-proven capability at tactically-significant payloads and ranges.

ADVANCED COMPUTING AND CYBER TECHNOLOGIES

SURVICE is the only small business in the world to be accredited by NVIDIA as a GPU Research Center. We leverage this expertise to develop custom, highly-optimized software implementing neural networks and machine-learning technologies across a broad spectrum of applications to include computer vision techniques to automate drone operations. We have also developed and implemented NIST-approved secure and global communications, allowing operations to be conducted and overseen anywhere in the world.

WORLD-CLASS INDUSTRIAL DESIGN

Our Industrial Design and Robotics Team has experience in a broad range of hardware and software technologies, allowing us to develop and fabricate tailored solutions to meet unique end-user requirements.

	PLATFORM RANGE (KM)*		
PAYLOAD (LBS)	TRV-80**	TRV-150*	TRV-400*
0	45**	45**	45
25	28**	35	42
50	16**	30**	40
100	-	18**	35
150	-	8	30
400	-	-	20

** Theoretical range at sea level on ISO day*

*** Demonstrated/validated (to date)*

THE TACTICAL RESUPPLY VEHICLE

TRV OBJECTIVES

- Objective capabilities:
  - 50-400+ lbs load capacity
- Multirole autonomous unmanned missions focus on assured logistics resupply in a tactical environment
- Augmentation of existing assets for "last mile" logistics for assured resupply

ONGOING SPIRAL DEVELOPMENT EFFORTS

- ***Military Commercial-Off-The-Shelf (COTS) Transition*** – Increase hardening while maintaining low-cost COTS subcomponents
- ***Spiral Technology Development*** – Continuously improve and evolve tactical capabilities
- ***Autonomy*** – Develop/enhance autonomous operations and supporting technologies
- ***Vehicle Intelligence*** – Enable ground combat element Marine operators
- ***Interface Standardization*** – Establish interface standards to streamline payload integration
- ***Testing & Evaluation*** – Validate/refine performance with Warfighter involvement

continued...

THE TACTICAL RESUPPLY VEHICLE (TRV)

TRV PLATFORMS

TRV-80

The TRV-80 is a tested and validated drone platform that has undergone extensive testing both in the laboratory and in the field, with experimental field testing done at ITX 18-3 at 29 Palms, CA.

The TRV-80 has also been featured at AEWE 2020 and has sucessfully been tested in all weather conditions (rain, wind, desert, snow, and >10,000 ft altitude).

TRV-150

The TRV-150 is another variant in the Malloy Aeronautics TRV family of tactical drones specifically designed to support assured logistics resupply. The vehicle's performance was designed around the ability to deliver enhanced speed bags. This platform is under development and has already met key milestones, such as demonstrated flight with maximum payload.

The TRV-150 won 1st place at the PMA-263 prize challenge and has been featured at the AEWE 2020. It has been successfully tested in all weather conditions (rain, wind, desert, and snow).

TRV-400

While the initial commercial design thrust was for personnel transport, the TRV-400 platform has been undergoing testing for logistical resupply. Recent refactoring includes migration to a U.S.-based supplier for high-powered motor controllers used in the electrical drivetrain of the vehicle.

TRV-80 (U.S. Marine Corps Photo)

TRV-80 (U.S. Marine Corps Photo)

TRV-150 (Malloy Aeronautics Photo)

TRV-150 (Malloy Aeronautics Photo)

TRV-400 (Malloy Aeronautics Photo)

TRV-400 (Malloy Aeronautics Photo)

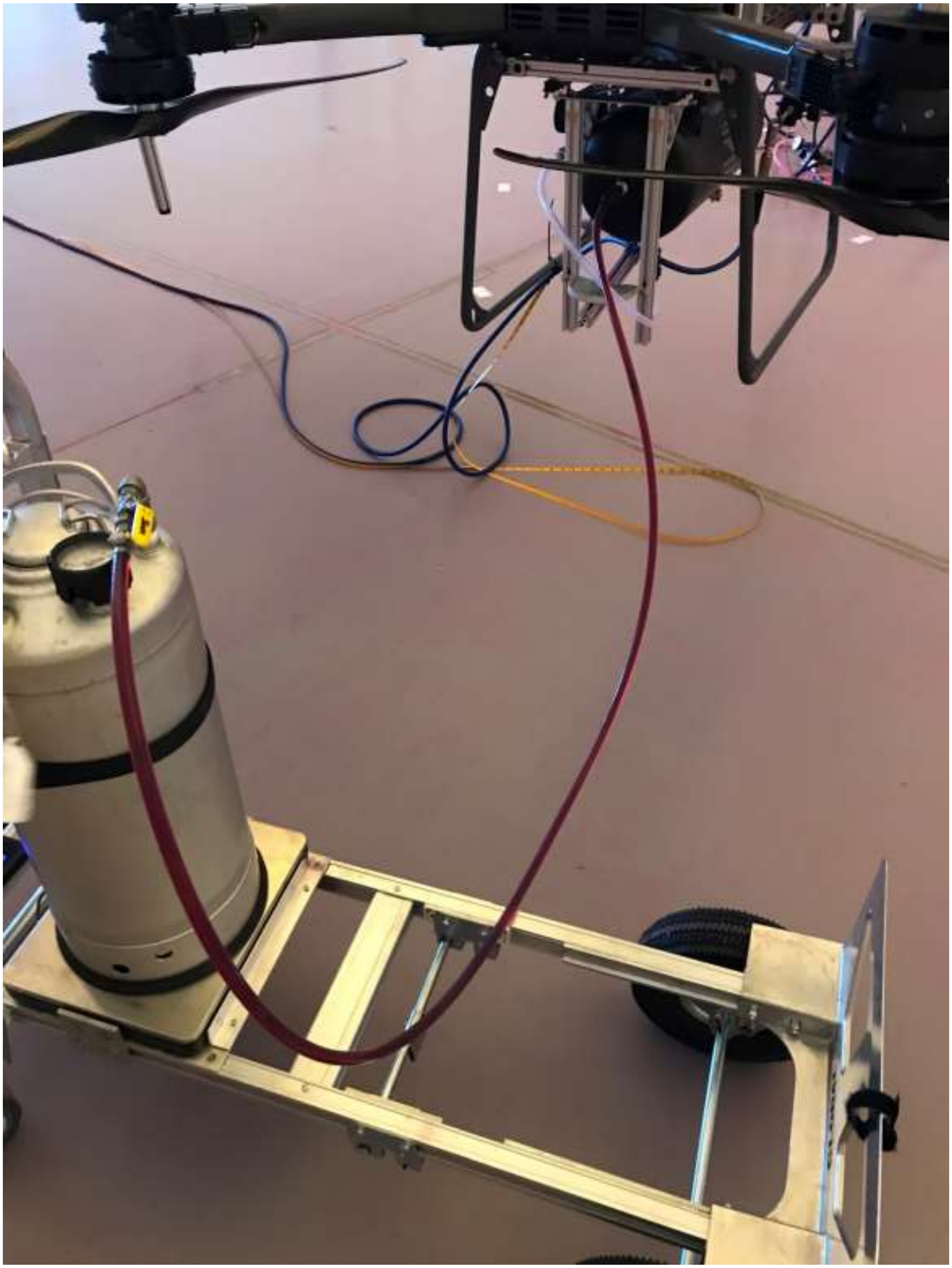
OUR PARTNERSHIP

The TRV family of tactical drones is being collaboratively developed by the UK-based Malloy Aeronautics and the Maryland-based SURVICE Engineering Company under contract with the U.S. Department of Defense. The vehicle is one of the leading concepts providing unmanned assured logistics resupply in an aerial platform organic to traditional ground-based units.

MALLOY AERONAUTICS LTD

Appendix C – UAS Nozzle Positions – Tests began with the nozzle below a rotor as shown in the first image below. The tip of the nozzle appears to be about 6 inches below the bottom rotor. Contact DTRA Reachback for more precise information.

After a few tests with MeS, the nozzle was moved under the center of the UAS belly as suggested below. This position was used for the remainder of testing. Contact DTRA Reachback for more precise information.



Appendix D – DTRA UAS Run Log

04/20/2021

Trial 01: TRV-150

19:31:29 power up – 19:37:13 power down

16ft measurement, rotor radial, 4 rotors turning, + 1.0° pitch, 0.0° roll

Trial 02: TRV-150

19:40:04 power up – 19:40:20 flight power - 19:45:20 power down

16ft measurement, rotor radial, 8 rotors turning, + 1.0° pitch, 0.0° roll

Trial 03: TRV-150

20:09:35 power up – 20:09:54 flight power - 20:12:26 power down

Note: Throttle power continued up, Pilot throttled down at T+40s

12ft measurement, rotor radial, 4 rotors turning, + 1.0° pitch, 0.0° roll

Trial 04: TRV-150

20:15:04 power up – 20:15:35 flight power - 20:17:18 power down

Note: Powered down early due to battery voltage

12ft measurement, rotor radial, 8 rotors turning, + 1.0° pitch, 0.0° roll

Trial 05: TRV-150

20:32:46 power up – 20:33:26 flight power - 20:36:29 power down

12ft measurement, rotor radial, 4 rotors turning, + 1.0° pitch, 0.0° roll

Trial 06: TRV-150

20:38:06 power up – 20:38:24 flight power - 20:41:27 power down

12ft measurement, rotor radial, 8 rotors turning, + 1.0° pitch, 0.0° roll

Trial 07: TRV-150

21:01:05 power up – 21:01:34 flight power - 21:04:36 power down

8ft measurement, rotor radial, 4 rotors turning, + 1.0° pitch, 0.0° roll

Trial 08: TRV-150

21:07:27 power up – 21:08:03 flight power - 21:11:01 power down

Note: Sonic array # 04 & # 08 shifted downward slightly to an increased +W component during trial

8ft measurement, rotor radial, 8 rotors turning, + 1.0° pitch, 0.0° roll

Trial 09: TRV-150

21:25:10 power up – 21:25:34 flight power - 21:28:33 power down

8ft measurement, rotor radial, 4 rotors turning, + 1.0° pitch, 0.0° roll

Trial 10: TRV-150

21:30:01 power up – 21:30:27 flight power - 21:33:25 power down

8ft measurement, rotor radial, 8 rotors turning, + 1.0° pitch, 0.0° roll

Trial 11: TRV-150

21:45:24 power up – 21:46:00 flight power - 21:49:00 power down

4ft measurement, rotor radial, 4 rotors turning, + 1.0° pitch, 0.0° roll

Trial 12: TRV-150

21:50:33 power up – 21:51:00 flight power - 21:54:01 power down

4ft measurement, rotor radial, 8 rotors turning, + 1.0° pitch, 0.0° roll

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Trial 13: TRV-150

14:02:40 power up – 14:03:45 trial abort

14:05:23 power up – 14:05:43 flight power - 14:08:46 power down

Note: Trail aborted for a UAS setting change

4ft measurement, centerline, 4 rotors turning, + 1.0° pitch, 0.0° roll

Trial 14: TRV-150

14:22:17 power up – 14:22:34 flight power - 14:25:35 power down

4ft measurement, centerline, 8 rotors turning, + 2.25° pitch, 0.0° roll

Trial 15: TRV-150

14:51:18 power up – 14:51:38 flight power - 14:54:39 power down

8ft measurement, centerline, 4 rotors turning, + 3.25° increasing to <4.0° pitch, 0.0° roll

Trial 16: TRV-150

14:57:40 power up – 14:57:40 flight power - 15:00:50 power down

8ft measurement, centerline, 8 rotors turning, + 3.3° pitch, 0.0° roll

Trial 17: TRV-150

15:15:45 power up – 15:16:05 flight power - 15:19:03 power down

12ft measurement, centerline, 4 rotors turning, + 2.75° increasing to 3.5° pitch, 0.0° roll

Trial 18: TRV-150

15:21:20 power up – 15:21:41 flight power - 15:24:39 power down

12ft measurement, centerline, 8 rotors turning, + 3.3° pitch, 0.0° roll

Trial 19: TRV-150

15:48:26 power up – 14:48:42 flight power – 15:51:40 power down

16ft measurement, centerline, 4 rotors turning, + 3.0° increasing to 4.0° pitch, 0.0° roll

Trial 20: TRV-150

15:56:41 power up – 15:56:54 flight power - 15:59:51 power down

16ft measurement, centerline, 8 rotors turning, + 3.5° pitch, 0.0° roll

UAS Change

Trial 21: TRV-80

18:41:38 power up – 18:42:02 abort

-Power up aborted for setting change-

18:44:19 power up – 18:44:33 flight power - 18:47:32 power down

16ft measurement, centerline, 8 rotors turning, + 3.25° increasing to 4.0° pitch, 0.0° roll

Trial 22: TRV-80

19:45:19 power up – 19:45:43 flight power

-@ 19:45:43 flight power reached but fluctuated recount started at 19:46:43-

19:46:43 flight power - 19:49:40 power down

12ft measurement, centerline, 8 rotors turning, + 2.35° pitch, 0.0° roll

Trial 23: TRV-80

20:05:10 power up – 20:05:37 flight power - 20:08:37 power down

8ft measurement, centerline, 8 rotors turning, + 4.0° decreasing to 2.8° pitch, 0.0° roll

Trial 24: TRV-80

20:24:10 power up – 20:24:30 flight power - 20:27:29 power down

4ft measurement, centerline, 8 rotors turning, + 4.0° in last 30 seconds decreasing to 3.15° pitch, 0.0° roll

Trial 25: TRV-80

20:24:05 power up – Aborted to check system

4ft measurement, rotor radial, 8 rotors turning, + 4.0° decreasing to 3.15° pitch, 0.0° roll

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Trial 26: TRV-80

15:50:13 power up – 15:50:34 flight power - 15:53:33 power down

4ft measurement, rotor radial, 8 rotors turning, - 0.5° pitch, -0.8° (starboard higher) roll

Trial 27: TRV-80

16:08:00 power up – 16:08:19 flight power - 16:11:18 power down

8ft measurement, rotor radial, 8 rotors turning, - 0.5° pitch, -0.9° (starboard higher) roll

Trial 28: TRV-80

16:27:22 power up – 16:27:41 flight power - 16:30:40 power down

Note: Slight downward tilt to Sonic 08 noted, adjusted for Trial 29

12ft measurement, rotor radial, 8 rotors turning, - 0.5° pitch, -0.9° (starboard higher) roll

Trial 29: TRV-80

16:43:46 power up – 16:44:03 flight power - 16:47:05 power down

16ft measurement, rotor radial, 8 rotors turning, - 0.5° pitch, -0.9° (starboard higher) roll