Thesis Draft Figures

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Figure 1

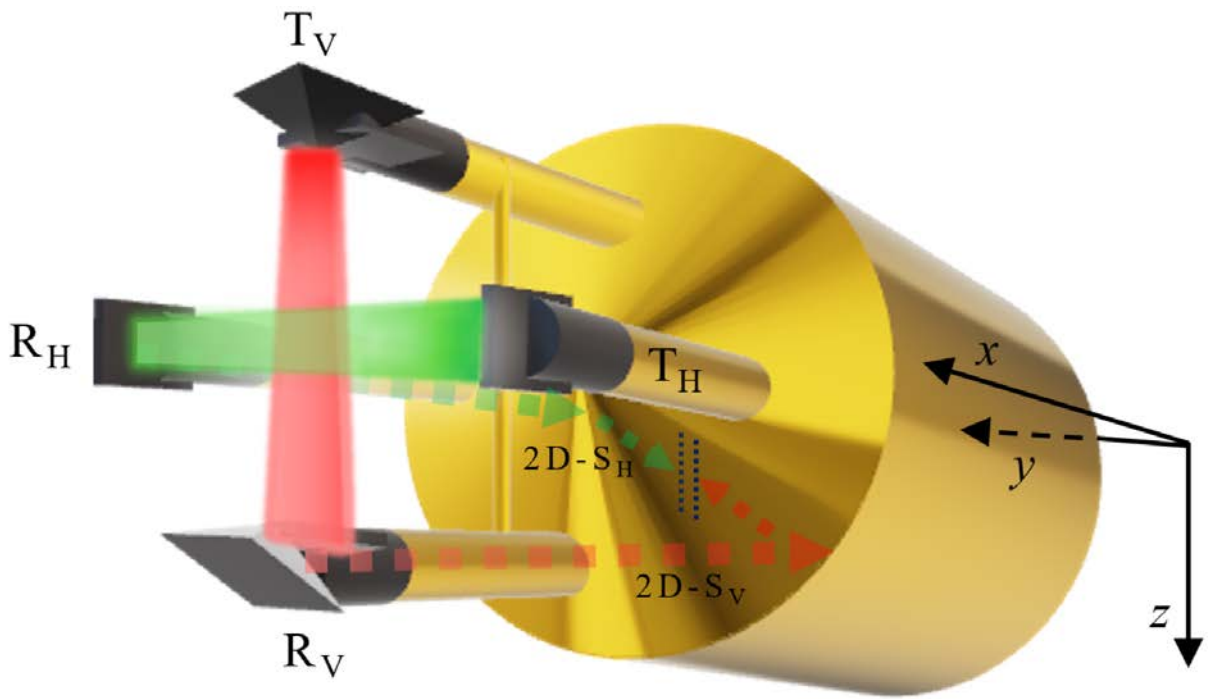

Figure 1

This diagram shows a simplified Two-Dimensional Stereo Optical Array Probe (2D-S) with the vertical channel (2D-S_V) laser path in red and the horizontal channel (2D-S_H) in green as it originates at the transmitting (T) arms and is sent through the receiving arms (R). The dashed lines show the path each channel takes inside the 2D-S as it is bent 90 degrees twice and is detected by an array of 128 photodiodes, represented by the dotted lines (blue) for each channel. The aircraft-relative reference frame is given, where the x-axis points forward along the direction of flight (aircraft nose), the y-axis points to the right (starboard) wingtip, and the z-axis points down.

Figure 2

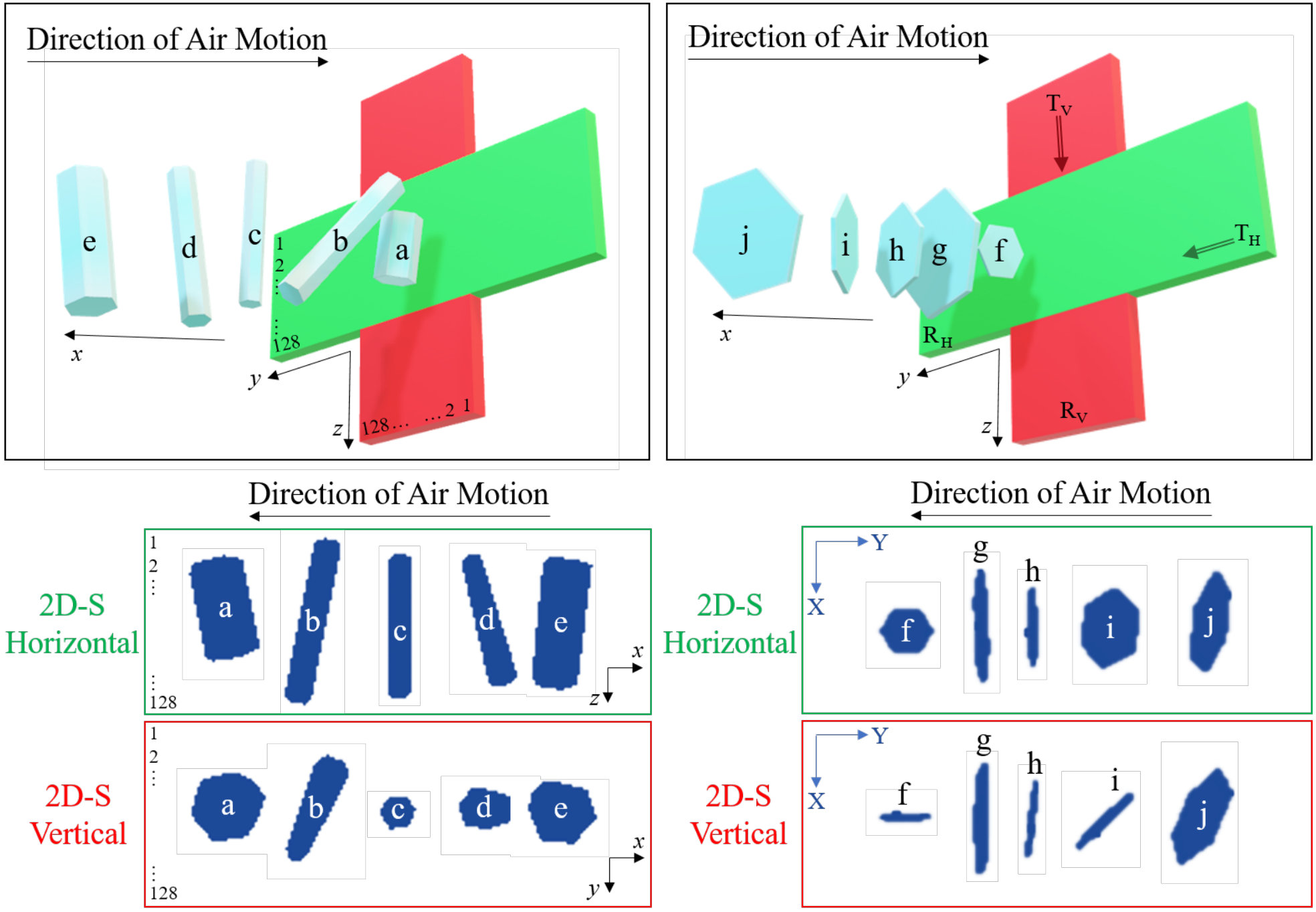
Direction of Air Motion
e
d
c
b
a
1
2
128
x
y
z
128 … … 2 1
Direction of Air Motion
j
i
h
g
f
T_V
T_H
R_H
R_V
x
y
z
Direction of Air Motion
2D-S Horizontal
2D-S Vertical
a
b
c
d
e
1
2
128
x
z
y
Direction of Air Motion
2D-S Horizontal
2D-S Vertical
X
Y
f
g
h
i
j

Figure 2

This diagram illustrates how a variety of vertically oriented columnar and planar ice crystals would appear in the two-dimensional shadow image data of the Two-Dimensional Stereo Optical Array Probe (2D-S) if captured by both the horizontal (green) and vertical (red) channels. The ice crystal and laser beam depictions are not to scale. Each 3-D model of an ice crystal in this figure was given a 90 degree rotation to provide an accurate representation of orthogonal shadow image sampling. Note that the images appear on the 2D-S image strip in succession from left to right as the ice crystals pass through the sampling volume sequentially, which appears to be a mirrored image due to the viewing angle of the figure. The x, y, z labels in the diagram indicate the aircraft-relative coordinate system, whereas the X and Y labeled in blue on the image strip are relative to the 2D-S array axis. The array of 2D-S photodiodes are labeled as 1 to 128 in both the diagram and the image strips in the columnar example. The relative position of the transmitting (T) and receiving (R) arms of the 2D-S are labeled in the planar example for both the horizontal (H) and vertical (V) laser beams.

Figure 3

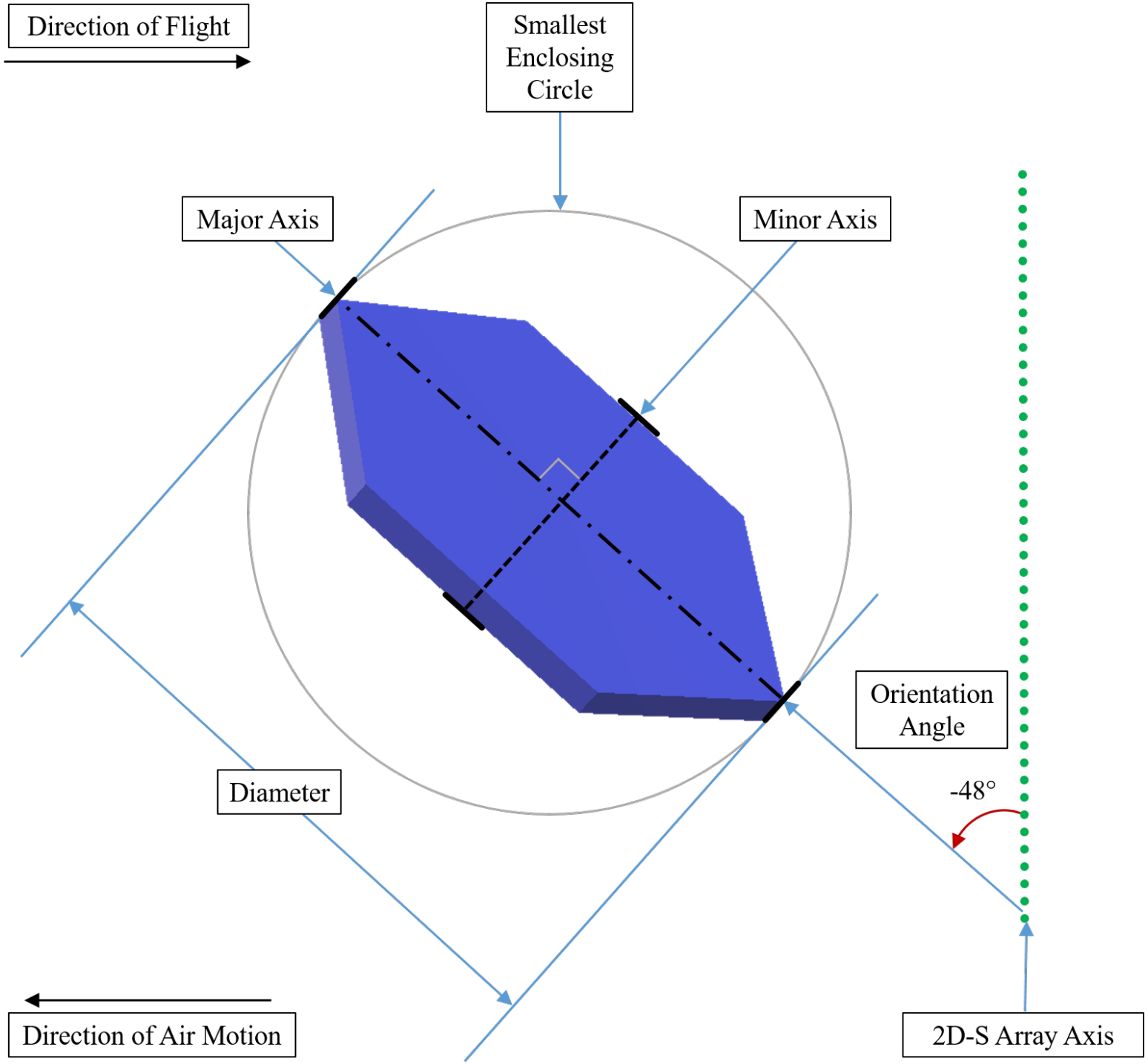
Direction of Flight
Smallest Enclosing Circle
Major Axis
Minor Axis
Orientation Angle
-48°
Diameter
Direction of Air Motion
2D-S Array Axis

Figure 3

Diagram showing how an in situ idealized hexagonal plate crystal encountering the sampling volume of the Two-Dimensional Stereo Optical Array Probe (2D-S) is recorded in the image data and parameterized by the System for Optical Array Probe (OAP) Data Analysis (SODA-2) processing software using the Fast Circle Method, which generates a smallest enclosing circle for each particle. The measured particle diameter is equal to the diameter of the smallest enclosing circle. The major axis of the particle is identified based on the maximum dimension and is equal to the particle diameter, and the minor axis is orthogonal to the major axis. The Orientation Angle parameter is the angle between the major axis and the 2D-S array axis, with clockwise rotations (towards the direction of flight) being positive angles and counterclockwise rotations being negative angles.

Figure 4

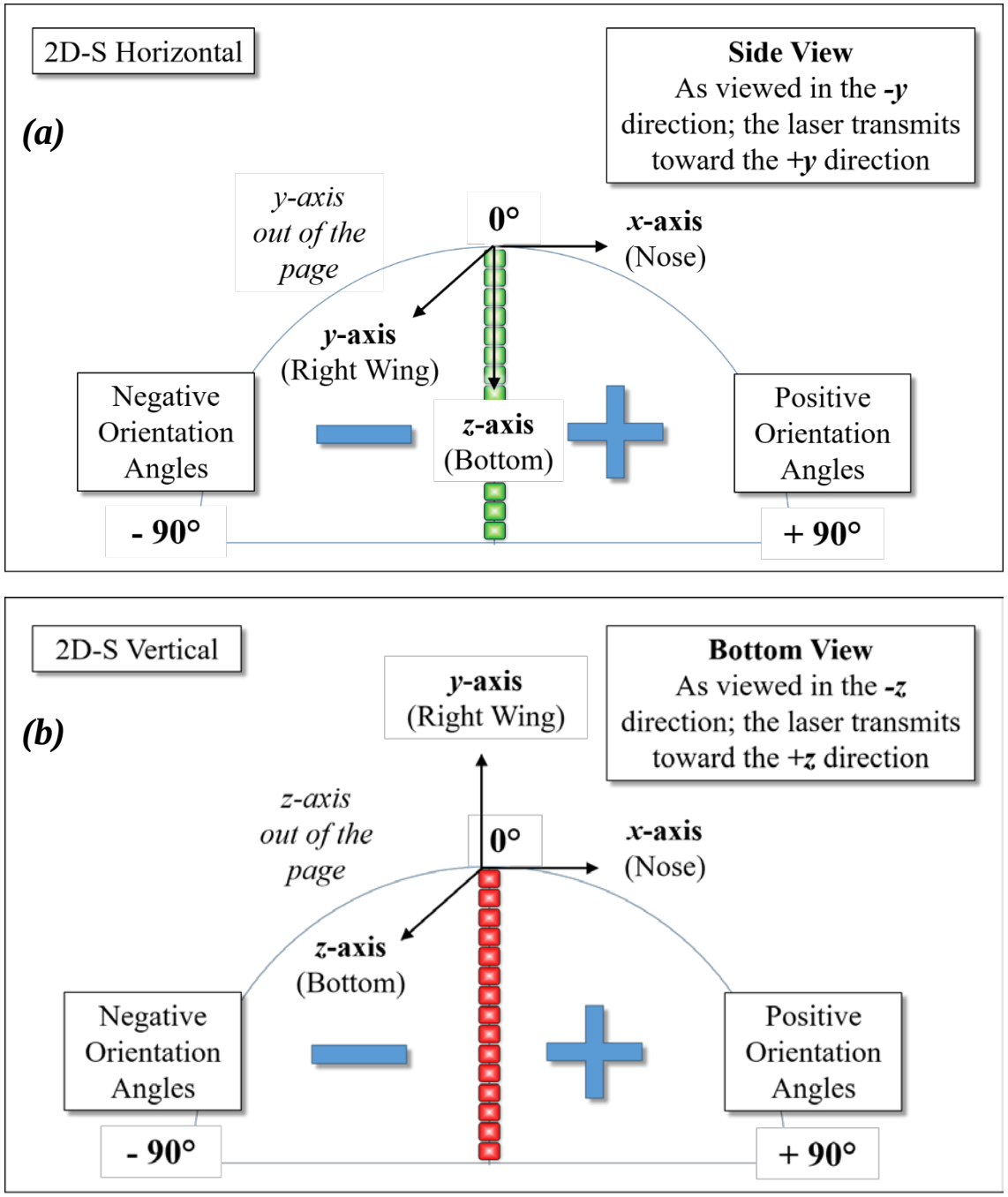
2D-S Horizontal
(a)
Side View
As viewed in the -y direction; the laser transmits toward the +y direction
y-axis out of the page
0°
x-axis
(Nose)
y-axis
(Right Wing)
Negative Orientation Angles
z-axis
(Bottom)
Positive Orientation Angles
- 90°
+ 90°
2D-S Vertical
(b)
Bottom View
As viewed in the -z direction; the laser transmits toward the +z direction
y-axis
(Right Wing)
z-axis out of the page
0°
x-axis
(Nose)
z-axis
(Bottom)
Negative Orientation Angles
Positive Orientation Angles
- 90°
+ 90°

Figure 4

This figure shows how particles sampled by the Two-Dimensional Stereo Optical Array Probe (2D-S) and parameterized by System for OAP Data Analysis (SODA-2) define the Orientation Angle parameter of each non-circular particle based on the angle between the major axis of the particle and the array of diodes that receives the laser beam across the sampling volume. A sampled particle that has a major axis parallel with the diode array will result in an Orientation Angle of zero degrees. A clockwise rotation away from the diode array axis is measured as a positive Orientation Angle, and a counterclockwise rotation away from the diode array is a negative Orientation Angle. The range of possible values includes -90 to +90 degree angles. The Orientation Angle is measured by both orthogonally-positioned channels of the 2D-S, with a depiction of the horizontal channel shown in (a) and the vertical channel shown in (b).

Figure 5

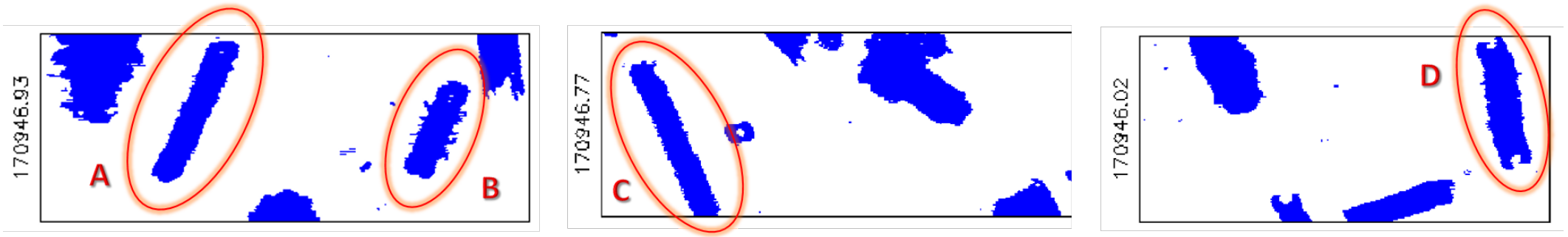

Table 1

2D-S Chan.	ID	Time (sec)	Diam. (µm)	Area Ratio	Aspect Ratio	Angle (degrees)	All In	X (µm)	Buffer Time (sec)	Y (µm)	IPT (sec)
H	A	61786.926	1097	0.22	0.24	-28.0	1	1000	61786.926	610	0.000671
H	B	61786.926	731	0.36	0.49	-33.7	1	670	61786.926	460	0.003619
V	C	61786.770	1214	0.19	0.25	29.3	0	1090	61786.770	640	0.001291
V	D	61786.020	927	0.29	0.33	6.9	0	920	61786.020	390	0.003834

Figure 5

Example shows randomly selected Two-Dimensional Stereo Optical Array Probe (2D-S) image data that corresponds with the attribute data shown in Table 1.

Table 1

Example shows Two-Dimensional Stereo Optical Array Probe (2D-S) attribute data as recorded in the particle-by-particle file corresponding to image data (Figure 5). Two examples are shown from the 2D-S horizontal (H) channel and two from the 2D-S vertical (V) channel. The three linear measurements given for each imaged particle include the particle diameter based on the fast circle method of processing, and an X and Y measurement, with X representing the dimension parallel to the array axis and Y representing the dimension parallel to the direction of flight. The “all in” flag is a 1 if the particle image is fully contained within the image strip and not in contact with array ends, and the flag is a 0 if the particle is only partially contained within the image strip. The inter-arrival time of each particle is shown in the last column as inter-particle time (IPT).

Figure 6

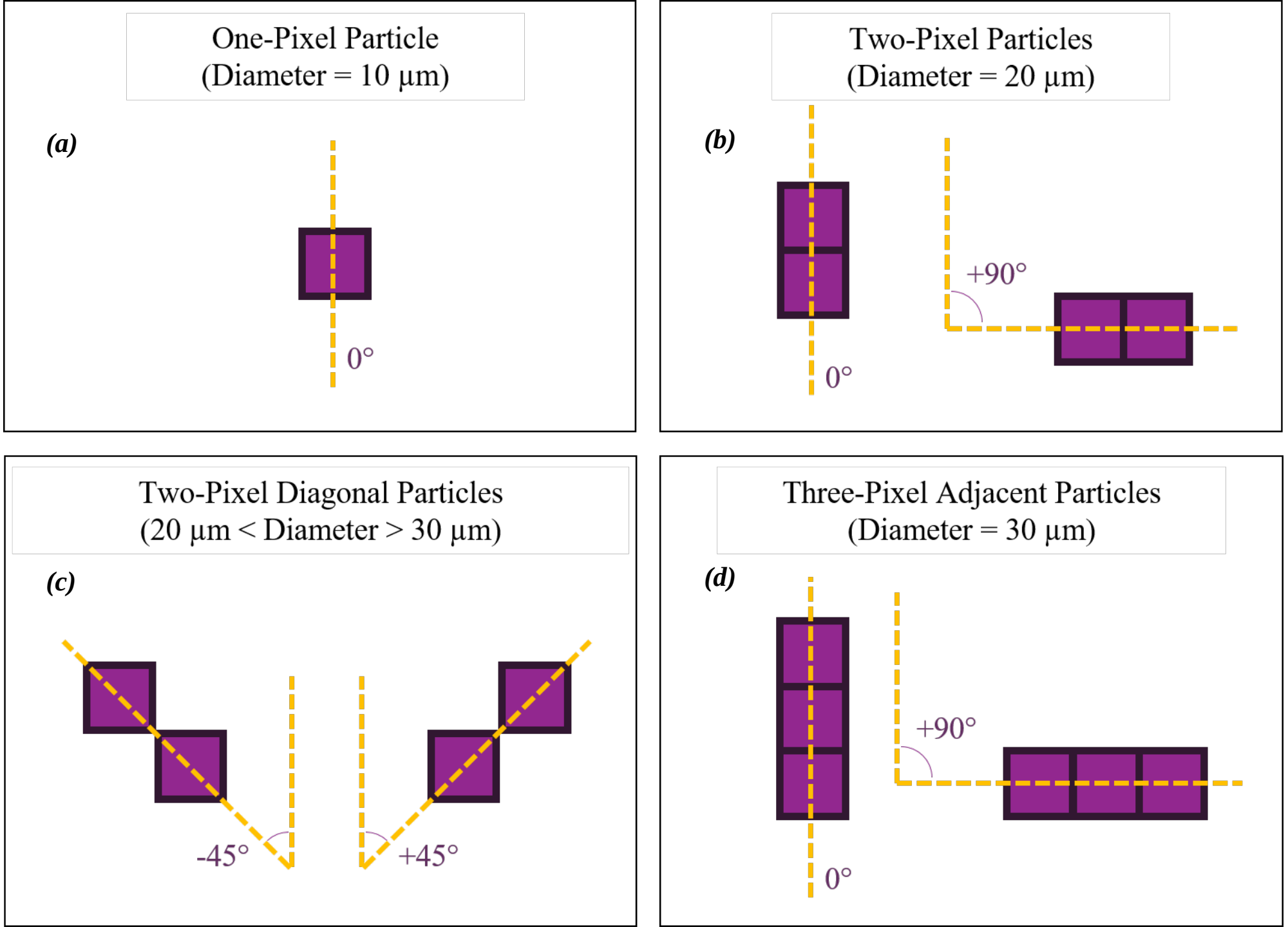
One-Pixel Particle
(Diameter = 10 µm)
(a)
0°
Two-Pixel Particles
(Diameter = 20 µm)
(b)
+90°
0°
Two-Pixel Diagonal Particles
(20 µm < Diameter > 30 µm)
(c)
-45°
+45°
Three-Pixel Adjacent Particles
(Diameter = 30 µm)
(d)
+90°
0°

Figure 6

Diagrams showing the possible shaded pixel configurations of single (a), dual (b) and (c), and up to three (d) pixel particles, as would be depicted in Two-Dimensional Stereo Optical Array Probe (2D-S) image data and the default orientation angles for each possible pixel configuration.

Figure 7

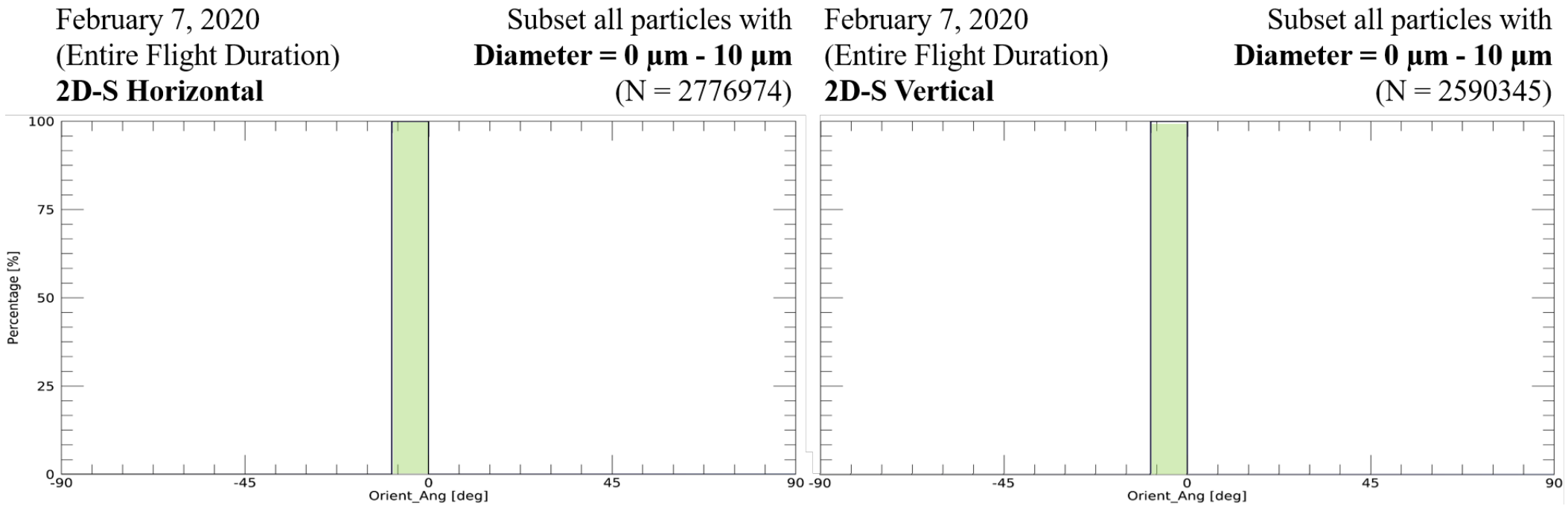
February 7, 2020
(Entire Flight Duration)
2D-S Horizontal
Subset all particles with
Diameter = 0 µm - 10 µm
(N = 2776974)
February 7, 2020
(Entire Flight Duration)
2D-S Vertical
Subset all particles with
Diameter = 0 µm - 10 µm
(N = 2590345)
Percentage [%]
100
75
50
25
0
-90
-45
0
45
90
Orient_Ang [deg]

Figure 7

Plot showing the orientation angle histogram for particles with diameters of 10 µm sampled during the February 7, 2020 flight for the Two-Dimensional Stereo Optical Array Probe (2D-S) horizontal (left) and vertical (right) channels.

Figure 8

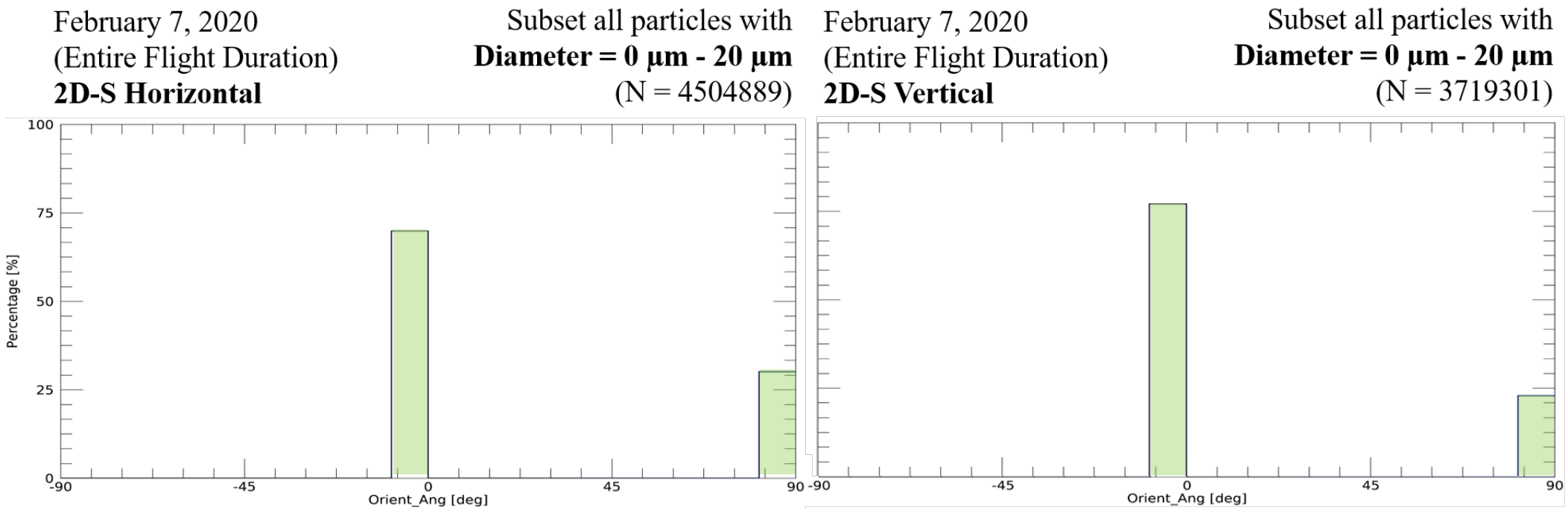
February 7, 2020
(Entire Flight Duration)
2D-S Horizontal
Subset all particles with
Diameter = 0 µm - 20 µm
(N = 4504889)
February 7, 2020
(Entire Flight Duration)
2D-S Vertical
Subset all particles with
Diameter = 0 µm - 20 µm
(N = 3719301)
Percentage [%]
100
75
50
25
0
-90
-45
0
45
90
Orient_Ang [deg]

Figure 8

Plot showing the orientation angle histogram for particles up to 20 µm diameter sampled during the February 7, 2020 flight for the Two-Dimensional Stereo (2D-S) Optical Array Probe (OAP) horizontal (left) and vertical (right) channels.

Figure 9

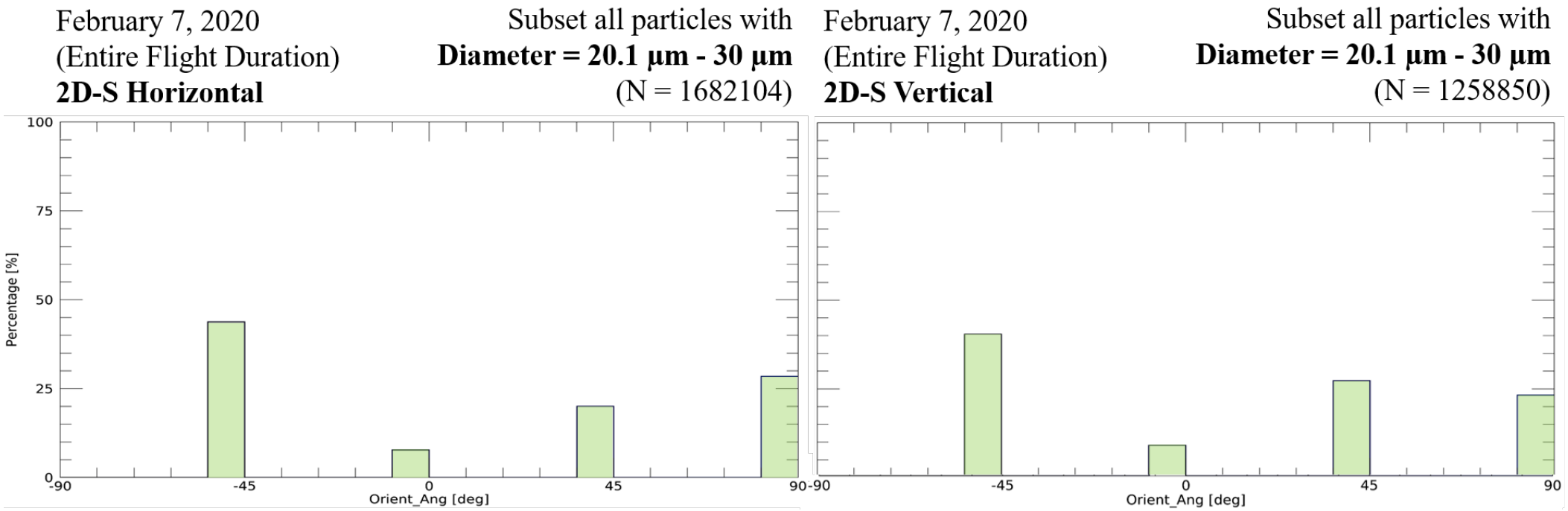
February 7, 2020
(Entire Flight Duration)
2D-S Horizontal
Subset all particles with
Diameter = 20.1 µm - 30 µm
(N = 1682104)
February 7, 2020
(Entire Flight Duration)
2D-S Vertical
Subset all particles with
Diameter = 20.1 µm - 30 µm
(N = 1258850)
Percentage [%]
100
75
50
25
0
-90
-45
0
45
90
Orient_Ang [deg]

Figure 9

Plot showing the orientation angle histogram for particles greater than 20 µm but less than or equal to 30 µm in diameter sampled during the February 7, 2020 flight for the Two-Dimensional Stereo Optical Array Probe (2D-S) horizontal (left) and vertical (right) channels.

Figure 10

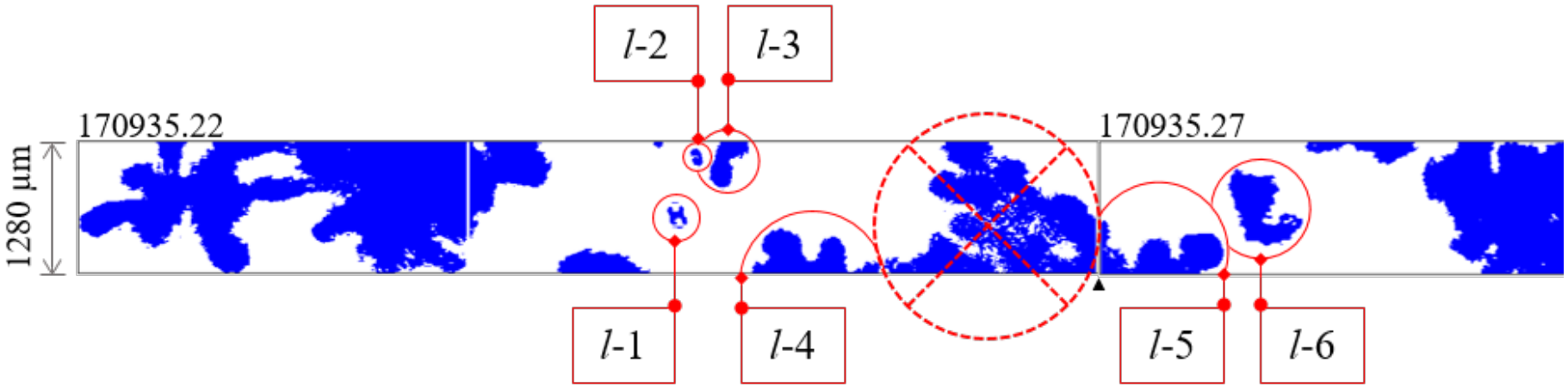

Figure 10

Plot showing buffer of Two-Dimensional Stereo Optical Array Probe (2D-S) images from the February 7, 2020 flight at 17:09:35 UTC for the vertical channel. The subsequent buffer is positioned to the right of the preceding buffer to demonstrate a case where an ice crystal was sampled near the end of a data buffer and continued in the next buffer. The black triangle along the bottom of the strip denotes the transition point between buffers, and the timestamp (HHMMSS.ss format and UTC time) is labeled along the top of each image strip.

Figure 11

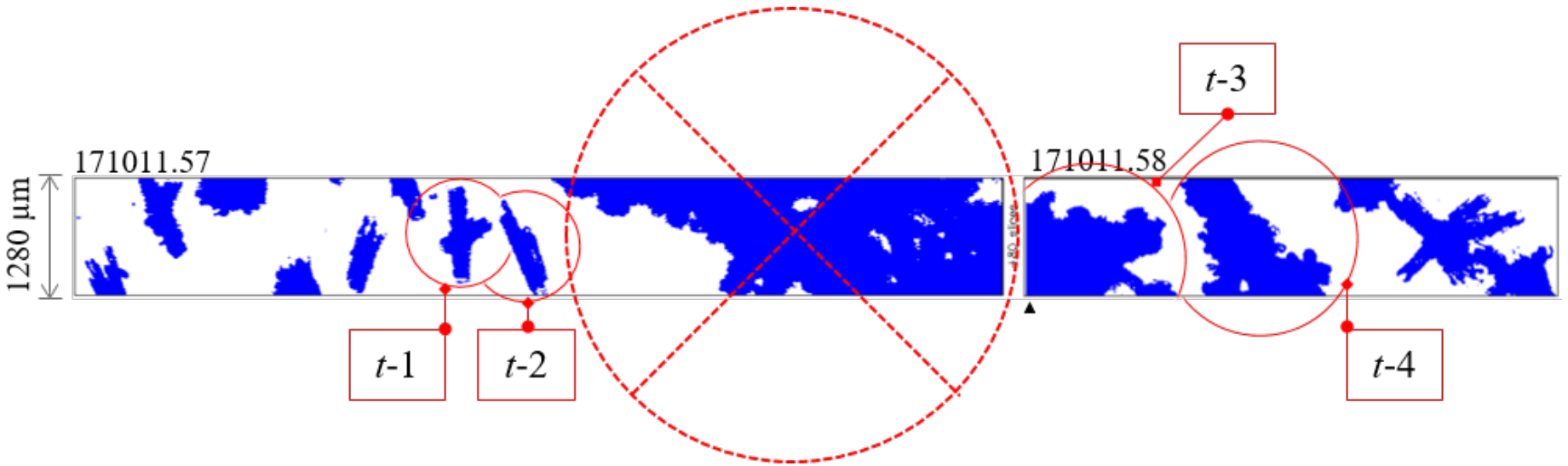

Figure 11

Plot showing buffer of Two-Dimensional Stereo Optical Array Probe (2D-S) images from the February 7, 2020 flight at 17:10:11 UTC for the vertical channel. The subsequent buffer is positioned to the right of the preceding buffer to demonstrate a case where an ice crystal was sampled near the end of a data buffer and continued in the next buffer. The black triangle along the bottom of the strip denotes the transition point between buffers, and the timestamp (HHMMSS.ss format and UTC time) is labeled along the top of each image strip.

Table 2

Ex.	Time [UTC]	ID	Time [sfm]	Diam. [μm]	Area Ratio	Aspect Ratio	Angle [deg]	All In	X [μm]	Buffer Time [sec]	Y [μm]	IPT [sec]
l	17:09:35	l-1	61775.2230	276	0.38	0.64	19.8	1	260	61775.2230	200	0.000112
		l-2	61775.2230	185	0.53	0.58	18.4	1	180	61775.2230	130	0.000512
		l-3	61775.2230	532	0.46	0.59	-32.5	0	470	61775.2230	380	0.004521
		l-4	61775.2230	1261	0.41	0.38	-87.3	0	430	61775.2230	1260	0.000841
		l-5	61775.2700	1260	0.36	0.41	87.7	0	510	61775.2700	1210	0.000026
		l-6	61775.2700	871	0.48	0.70	38.9	1	740	61775.2700	730	0.000412
			61775.2700	1110	0.22	0.20	89.5	0	220	61775.2700	1110	0.006587
t	17:10:11		61811.5670	161	0.68	0.58	-82.4	0	80	61811.5670	160	0.000681
			61811.5670	869	0.30	0.42	-9.7	1	860	61811.5670	440	0.000257
			61811.5670	579	0.43	0.57	39.3	0	470	61811.5670	400	0.000325
			61811.5670	95	0.57	0.82	69.4	1	60	61811.5670	90	0.002299
		t-1	61811.5670	1093	0.28	0.56	9.4	1	1080	61811.5670	580	0.000997
		t-2	61811.5670	1151	0.21	0.27	25.4	0	1040	61811.5670	540	0.003118
		t-3	61811.5820	1945	0.57	0.77	58.5	0	1150	61811.5820	1660	0.000428
		t-4	61811.5820	2030	0.48	0.59	52.8	0	1280	61811.5820	1680	0.00116
			61811.5820	2703	0.36	0.48	62.1	0	1280	61811.5820	2440	0.000949
			61811.5820	24	0.66	0.62	-45.0	1	20	61811.5820	20	0.000619

Table 2

Two-Dimensional Stereo Optical Array Probe (2D-S) particle-by-particle attribute data for February 7, 2020 Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Snowstorms (IMPACTS) flight, vertical channel, which corresponds to the images shown in Figure 10 and Figure 11. The time is given in a [HH:MM:SS] UTC format and a seconds-from-midnight (SSSSS.ss sfm) format. The three linear measurements given for each imaged particle include the particle diameter based on the fast circle method of processing, and an X and Y measurement, with X representing the dimension parallel to the array axis and Y representing the dimension parallel to the direction of flight. The “all in” flag is a 1 if the particle image is fully contained within the image strip and not in contact with array ends, and the flag is a 0 if the particle is only partially contained within the image strip. The inter-arrival time of each particle is shown in the last column as inter-particle time (IPT). More examples of buffer-spanning particles and associated particle attributes are detailed in Appendix B.

Figure 12

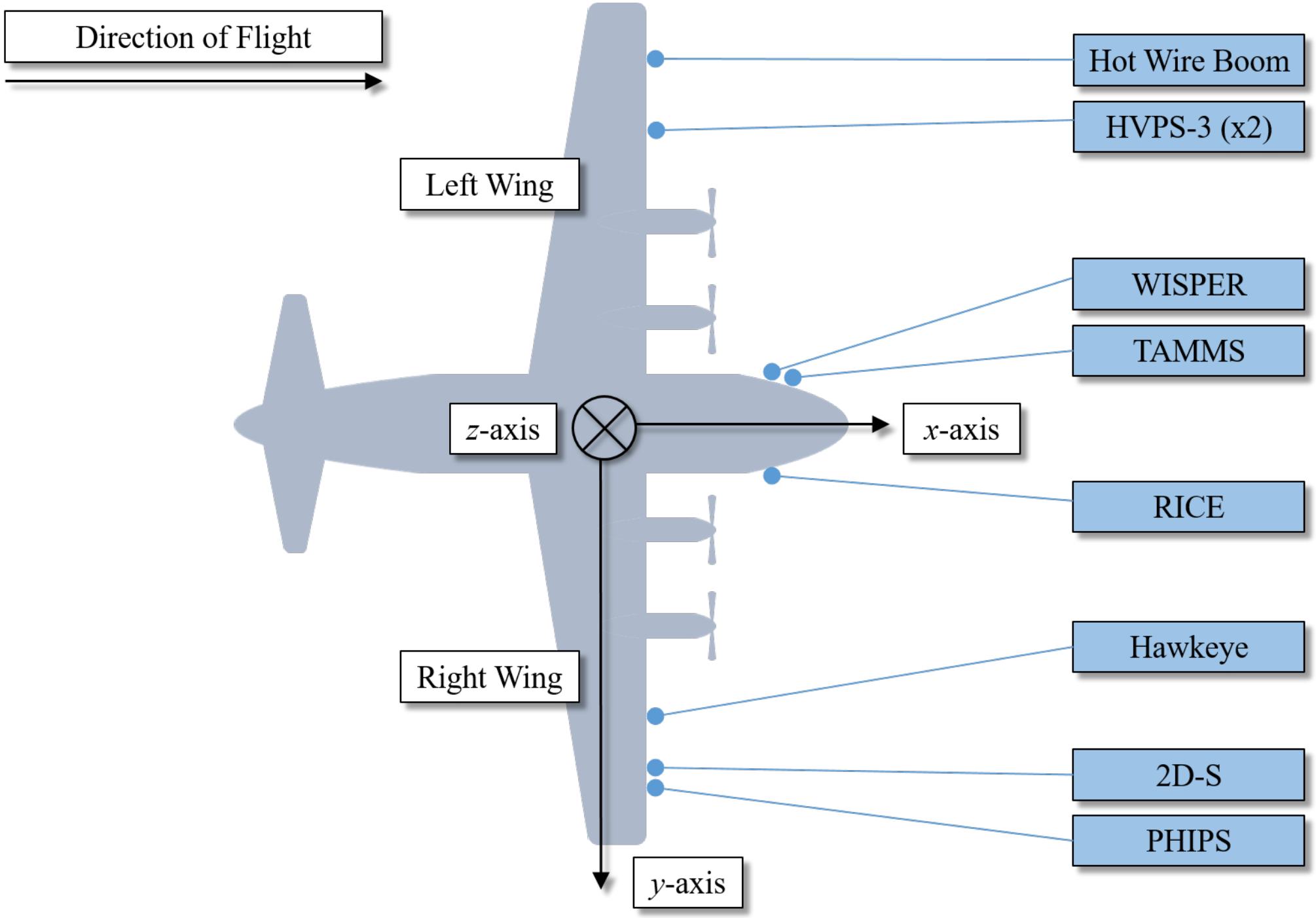
Direction of Flight
Hot Wire Boom
HVPS-3 (x2)
Left Wing
WISPER
TAMMS
z-axis
x-axis
RICE
Hawkeye
Right Wing
2D-S
PHIPS
y-axis

Figure 12

This depiction shows a top-view of the NASA P-3 Orion research aircraft and its local frame of reference coordinate system, where the x-axis points out the nose of the aircraft along the direction of flight, the y-axis is aligned with the right wing (starboard side) of the aircraft, and the z-axis points down towards the ground when in level flight. The instrument labels shown in blue mark the mounting locations of each probe assembly when configured for the Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Snowstorms (IMPACTS) campaign.

Figure 13


FLAMMABLE
KEEP FIRE AWAY
HAZMAT
NOTICE
FIRE DOOR
RECYCLABLE
5 MPH
© Kendra Sand

Figure 13

This photo depicts the mounting location of the Particle Habit Imaging and Polar Scattering (PHIPS) Probe and Two-Dimensional Stereo Optical Array Probe (2D-S) on the outer pylon of the starboard wing of the NASA P-3 aircraft during the Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Snowstorms (IMPACTS) 2020 field campaign.

Figure 30

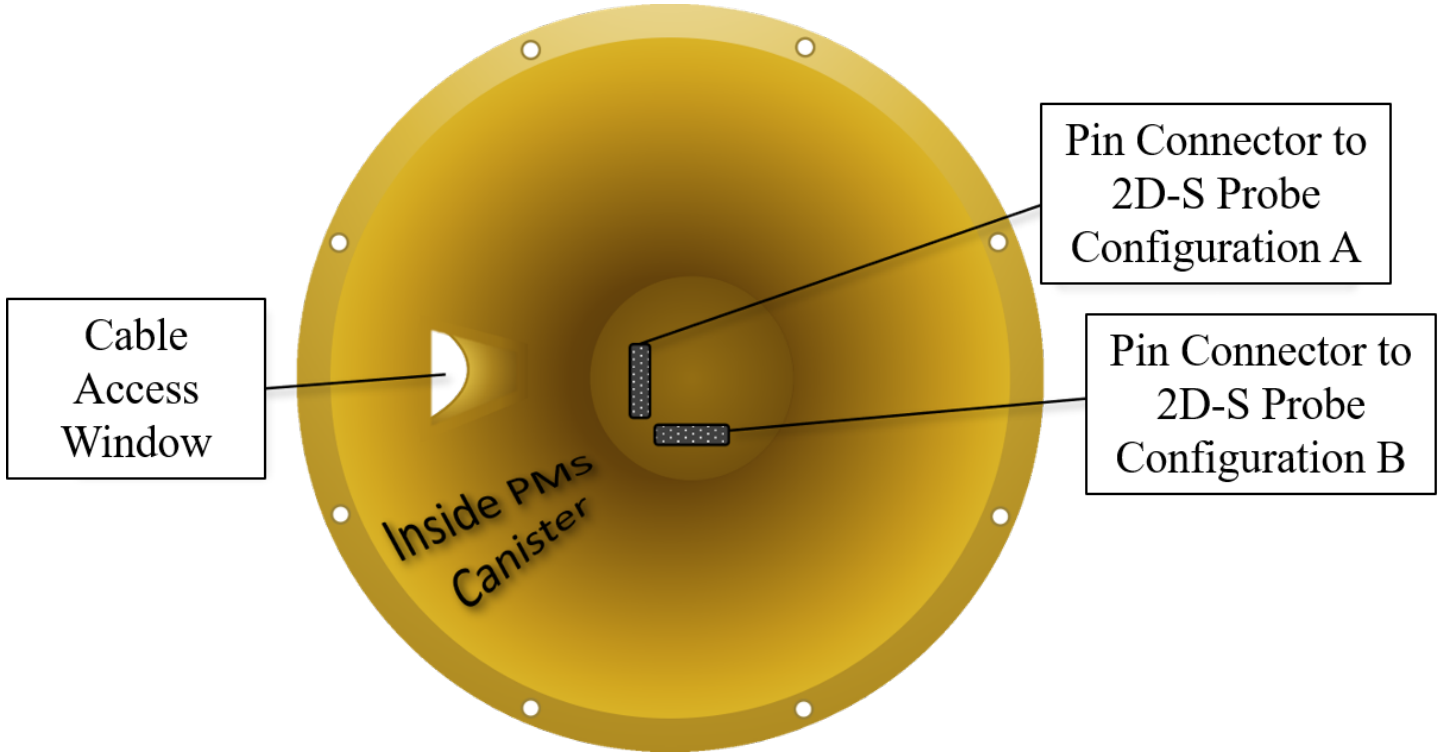
Cable Access Window
Pin Connector to 2D-S Probe Configuration A
Pin Connector to 2D-S Probe Configuration B
Inside PMS Canister

Figure 30

This figure shows that the interior of a Particle Measuring Systems (PMS) canister includes two possible configurations for connecting the pin connecter on the Two-Dimensional Stereo Optical Array Probe (2D-S) to the pin connector on the PMS canister. Configuration A is a connection to the vertical pin connecter, while Configuration B is a connection to the horizontal pin connector. While this provides for flexibility in how the 2D-S probe is installed, it can result in ambiguity as to the orientation of the horizontal and vertical sampling arms. The correct configuration is Configuration A, because it will result in the 2D-S Horizontal Transmitter and Horizontal Receiver arms being parallel with the ground.

Figure 31

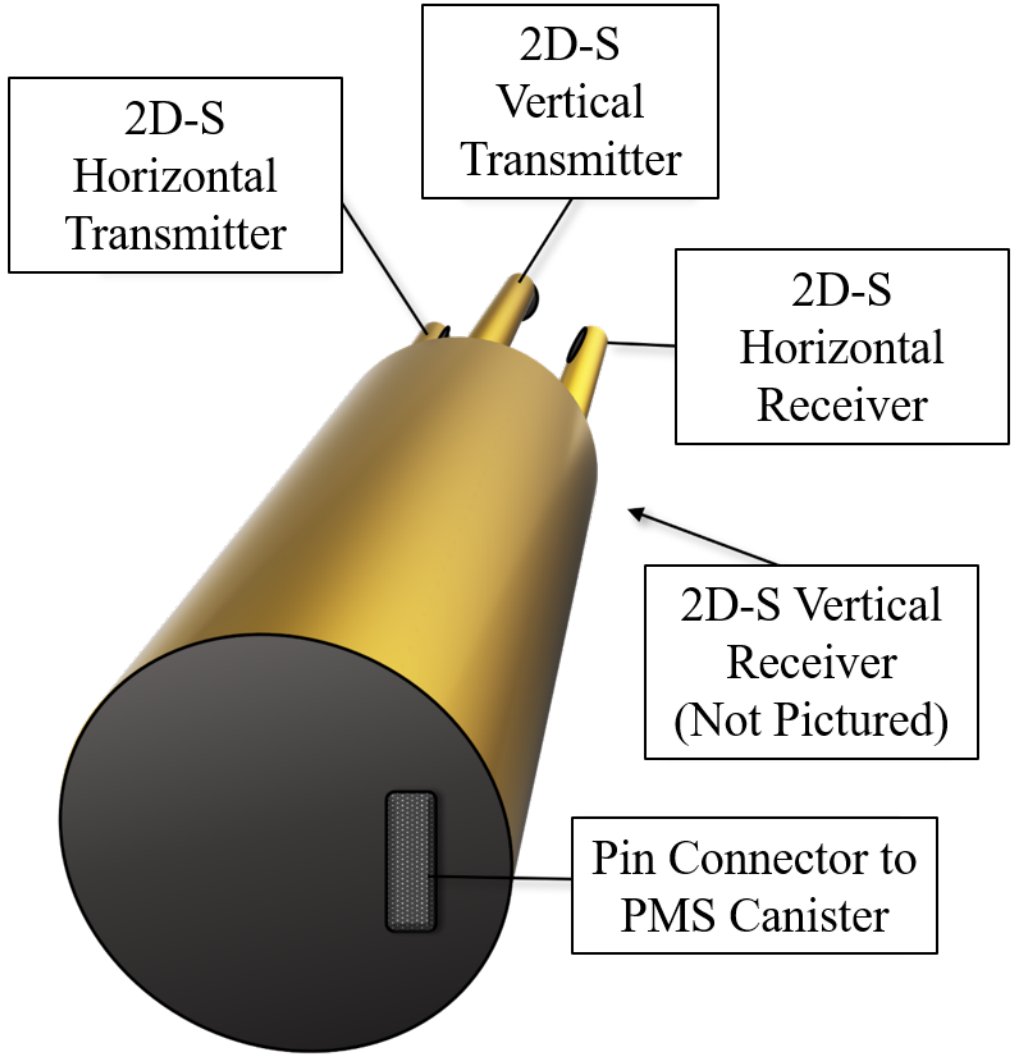
2D-S
Horizontal
Transmitter
2D-S
Vertical
Transmitter
2D-S
Horizontal
Receiver
2D-S Vertical
Receiver
(Not Pictured)
Pin Connector to
PMS Canister

Figure 31

This figure depicts a simplified view of the back of a Two-Dimensional Stereo Optical Array Probe (2D-S), where a pin connector is located. The pin connector provides the necessary connection to the Particle Measuring Systems (PMS) canister probe housing during installation. The PMS canister is then connected to the aircraft wiring, and this is the means by which the 2D-S probe receives power and transmits data during flight. There is only one pin connector on the back of the 2D-S probe, but there are two ways it can be oriented in order to connect with the PMS canister pin connector.