Data Guide

TigerRAY February 2023 field testing

Version 1

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Summary of tests:

Date	February 6	February 7	February 8	February 10
Test location	Lake Washington	Lake Washington	Lake Washington	Puget Sound
Conditions	Hs = 0.4 m Tp = 2.5 s	Hs = 0.2 - 0.4 m Tp = 2 - 2.4 s	No waves, R/V Robertson wakes	Hs = 0.4 - 0.25 m Tp = 2.75 - 2.3 s
Actions	Dial in waterline - required adding mass to heave plate	Record more data in waves	Test heave plate at ~735 kg wet weight and ~820 kg wet weight with wakes, practice ROV piloting	Record more data in waves
UUV status	Docked, off	Docked, off	Docked during wakes, operated in calm conditions	Docked, off
PTO status	~ 1.5 hours on, 0.5 hours freewheel	~ 1.5 hours on, 2.5 hours freewheel	On for 50% of wakes, freewheel for 50% of wakes	~ 2 hours on, 2.5 hours freewheel

Data structure

Each .mat file contains one variable, ‘`data`’, a structure with the following fields:

Name	Description	Units	Frequency
data.t_naelec	Datetime timestamps for nacelle	UTC	200 Hz

	electronics data		
data.electronics	29 column variable with all data from nacelle electronics	See table below	200 Hz
data.t_encfor	Datetime timestamps for foreward float encoder data	UTC	40 Hz
data.encfor	Forward float encoder data (corresponds to PTO 1)	degrees	40 Hz
data.t_encaft	Datetime timestamps for aft float encoder data	UTC	40 Hz
data.encaft	Aft float encoder data (corresponds to PTO 2)	degrees	40 Hz
data.t_napres	Times in datetime format for the pressure sensors mounted to the nacelle. These only operate when the device is in freewheel	UTC	100 Hz
data.napressure	Pressures from the three pressure sensors mounted to the nacelle. The data has three columns, one for each sensor. Column 1 is the starboard yoke sensor, column 2 is the sensor on the mast (always in air) and column 3 is the port yoke sensor (mast side of nacelle)	psi	100 Hz
data.t_hp	Datetime timestamps for heave plate pressure sensors and load cell	UTC	100 Hz
data.hppressure	Heave plate pressure sensor data (2 pressure sensors, one in each column)	psi	100 Hz
data.loadcell	Load cell data	N	100 Hz
data.t_naimu	Nacelle IMU time stamps, in datetime format	UTC	50 Hz
data.nac_heave	Nacelle heave motion estimates from onboard IMU calcs, correlated to match data.t_naimu for the given data subset. +z is pointed down	m	50 Hz
data.t_hpimu	Heave plate IMU time stamps, in datetime format	UTC	50 Hz
data.hp_heave	Heave plate heave motion estimates, from onboard IMU calcs, trimmed to	m	50 Hz

	match data.t_hpIMU for the given data subset. +z is pointed down		
data.t_satcmp	Satellite compass timestamps	UTC	40 Hz
data.heading	Satellite compass heading	deg	40 Hz
data.hp_imu_raw	Heave plate IMU data for the entire day (raw data backup, not trimmed to match the rest of the data subsets)	Standard units (m, m/s, radians)	50 Hz
data.nac_imu_raw	Nacelle IMU data for the entire day (raw data backup, not trimmed to match the rest of the data subsets)	Standard units (m, m/s, radians)	50 Hz
data.satcmp_raw	Satellite compass data for the entire day (raw backup, not trimmed to match the rest of the data subsets)	Various	Various
data.swift##_t	Datetime timestamps for SWIFT heave measurements (#22-25) [V1 data release doesn't have accurate SWIFT heave time series]	UTC	5 Hz
data.swift##_z	SWIFT heave measurements (#22-25) (22 is closest to TigerRAY, 25 is furthest [V1 data release doesn't have accurate SWIFT heave time series]	m	5 Hz
data.swift##	Full swift dataset from each SWIFT. See SWIFT overview section for more detail	various	Every 12 min

data.electronics format		
Column	**Data product**	**Units**
1	Posix timestamps	
2	PTO 1 voltage input	V
3	PTO 1 voltage output	V
4	PTO 1 current input	A
5	PTO 1 current output	A

6	PTO 1 power input	W
7	PTO 1 power output	W
8	PTO 1 SSR status	0 = disabled, 1 = enabled
9	PTO 1 command current	mA
10	PTO 1 target current	A
11	PTO 1 Kp	
12	PTO 1 Ki	
13	PTO 1 Kd	
14	PTO 1 max input current	A
15	PTO 1 cutoff voltage	V
16	PTO 2 voltage input	V
17	PTO 2 voltage output	V
18	PTO 2 current input	A
19	PTO 2 current output	A
20	PTO 2 power input	W
21	PTO 2 power output	W
22	PTO 2 SSR status	0 = disabled, 1 = enabled
23	PTO 2 command current	mA
24	PTO 2 target current	A
25	PTO 2 Kp	
26	PTO 2 Ki	
27	PTO 2 Kd	
28	PTO 2 max input current	A
29	PTO 2 cutoff voltage	V

Time bases, explained
There are five possible ‘time bases’ for the data streams that are included in this data set. For this data package, the time bases will all remain separate, since there are small possible differences in the initial clock syncs, which have not been accounted for in this processing.

Time base (what clock is providing timestamps)	**Time variable**	**Data sets on this time base**	**Note**
Nacelle pi NTP	data.t_nacelec	data.electronics	All PTO data (only records when PTO is on)
	data.t_encfor	data.encfor	Forward float encoder data
	data.t_encaft	data.encaft	Aft float encoder data
	data.t_napres	data.napressure	Nacelle pressure sensors (3 sensors - only record when in freewheel)
Heave plate pi NTP	data.t_hp	data.hppressure	Heave plate pressure data (2 sensors)
		data.loadcell	Load cell data
Nacelle IMU RTC	data.t_naimu	data.nac_heave	Nacelle IMU heave estimate
Heave plate IMU RTC	data.t_hpimu	data.hp_heave	Heave plate IMU heave estimate
Satellite compass GPS	data.t_satcmp	data.heading	Satellite compass heading
SWIFT GPS time	data.swift##_t	data.swift##_z	SWIFT heave measurements

Daily deployment timeline

(All times in PST, UTC - 8, unless otherwise specified)

February 6, 2023

Notes:

- Issues with SWIFT 22 bulk statistics

Start time (UTC-8)	**Action**	**Notes**
0900	Measure Tiger Ray dry weight at 1436 Kg	Fully assembled and as-built

0920	Depart APL	Head for Lake WA
0955	On station (Lake WA)	
1025	Tiger Ray deployed	Free decay drop (PTOs off) during deploy
1045	Measure heave plate dry weight at 940 Kg	
1100	Heave plate deployed	Water line too high (reads -2)
1140	Heave plate recovered, add 4 lead ingots (+100 Kg) Total dry weight now 1040 Kg	
1210	Full system deployed (with 4 SWIFTs in line)	PTOs on
1236	Switch to free wheel mode (PTOs off)	More float motion
1300	PTOs back on	Natural waves (0.4 m)
1400	Begin recovery	
1420	Heave plate recovered	
1435	Tiger Ray recovered	
1525	Back at APL dock	

February 7, 2023

Notes:

- Issues with SWIFT 22 bulk statistics

Start time (UTC-8)	**Action**	**Notes**
0830	Depart APL	Head for Lake WA
0917	Tiger Ray deployed	
0926	Heave plate in	Measured dry weight at 1040 Kg
0939	Fully deployed (including SWIFTs)	

1104	Begin Robertson wakes (5)	Free wheel
1126	More Robertson wakes (5)	PTO on
1140	M/V Arctic Pride wake (1)	PID controller was off
1146	More Robertson wakes (5?)	PTO on
1207	Back to natural waves	Free wheel mode
1340	Waves finally enough to move floats	
1346	PTOs on	
1434	Tiger Ray is 90 deg to waves	No explanation
1430-1440 ish	Output capacitor has dropped too low, thus Mini-wavey only	Does this explain orientation?
1445	Back to full PTO	Less motion
1500	Begin recovery	
1535	Fully recovered	
1625	APL dock	

February 8, 2023

Notes:

- Issues with SWIFT 22 bulk statistics

Start time (UTC-8)	**Action**	**Notes**
0910	Depart APL dock	Head for Lake WA
0940	On station (Lake WA)	Having trouble connecting to ROV Adjusting Tiger Ray pick point (add second large purple link)

1010	Begin deploy	
1015	Tiger Ray in	Free decay drop test
1025	Heave plate in	
1035	Fully deployed (inc. SWIFTs)	Nacelle water line ~ 0
1050-1105	Six wakes with PTO off	Tried some axial… what is best orientation?
1114-1130	Six wakes with PTO on	Last one was axial
1140-1147	ROV docking test #1 (success)	New cameras much better
1149-1158	ROV docking test #2 (success)	Mild ship wake came through
1210-1225	Recover heave plate (only)	ROV tether is poorly seated on drum (got too loose)
1230	Add 91 Kg additional ballast to heave plate	
12xx	Measure heave plate dry weight at 1091 Kg	
1245	Fully redeployed	Heave plate wet weight now 818 Kg Nacelle water line now +4
1248-1301	Six wakes (PTO on)	Last wake was axial (mast end)
1312-1325	Six wakes (PTO off)	First two at lower power, last two axial
1333	Distant ship wake passing	
1339	Begin recovery	
1355	Heave plate recovered	
1407	Tiger Ray recovered	
1445	APL dock	

February 10, 2023

Notes:

- SWIFT 23 did not produce usable data on Feb 10

Time (UTC - 8)	Action	Notes
0700	Depart APL	Head for Puget Sound
0750	locks	
0810	On station (Puget Sound)	
0820	Tiger Ray deployed	Free decay drop with PTO on
0840	Fully deployed, PTO on	SWIFT 24 tangled pennant line
0907	Fixed pennant on 24	
1042	Switch to freewheel	
1123	Tug wake passes	40 deg rotation observed in encoder data
1203	microFloat test	
1257	Begin recovery	
1312	Heave plate recovered	
1322	Tiger ray recovered	Total drift 3.3 nm
1435	Locks	
1520	APL dock	

System Configuration

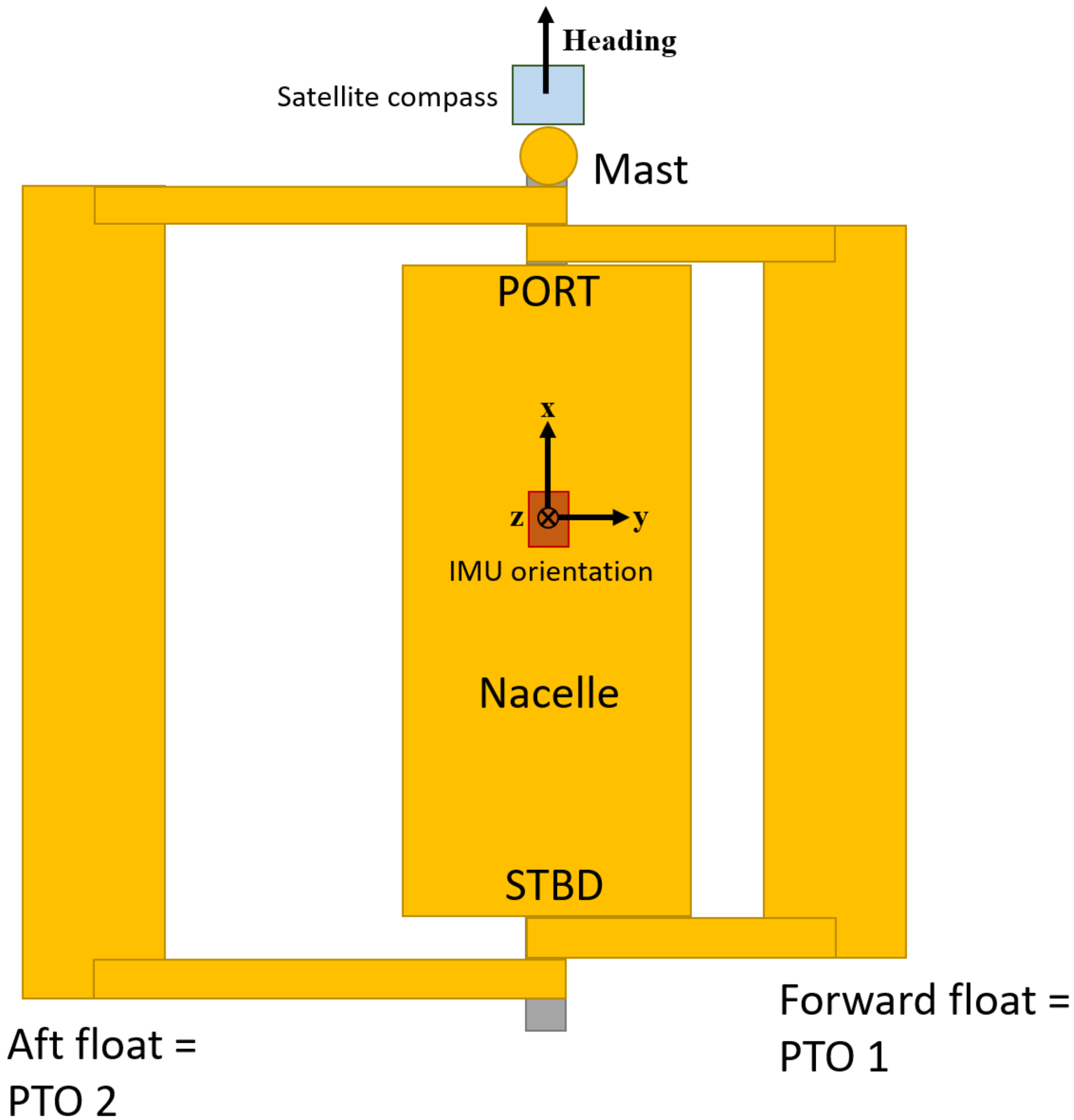

Fig. 1: Top-down view of TigerRAY, noting the orientation of the IMU and satellite compass

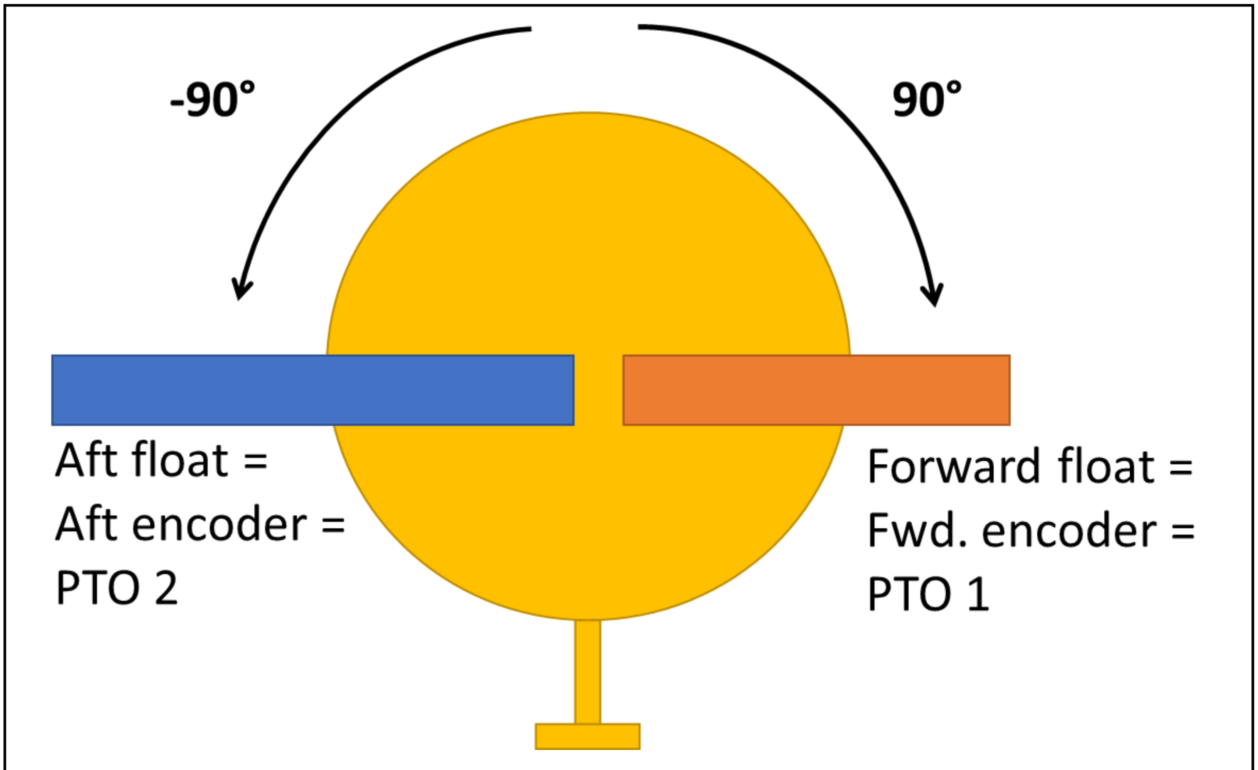

Fig. 2: Side-view, with example of encoder readings for the case where the arms are oriented horizontally

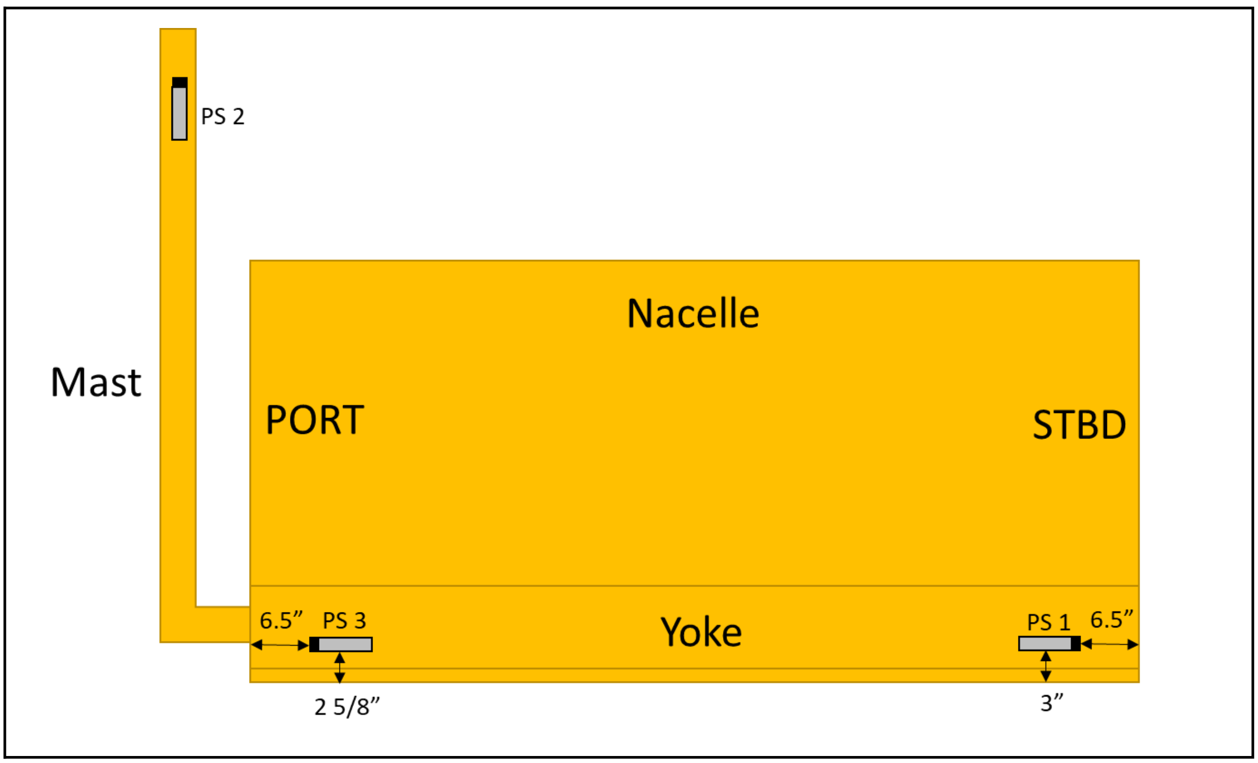

Fig. 3: Side view of TigerRAY nacelle with pressure sensor locations noted

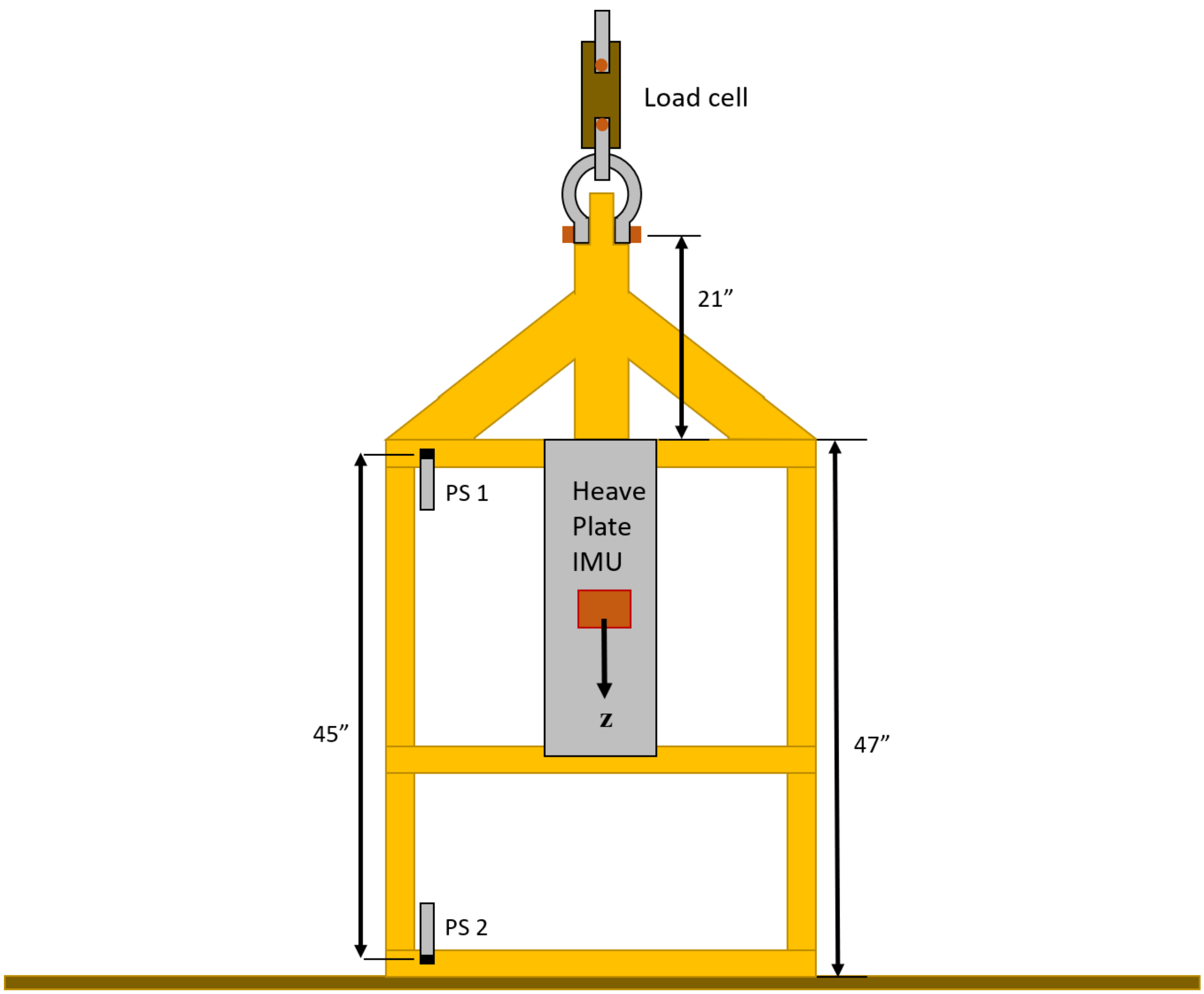

Fig. 4: Pressure sensor locations relative to heave plate frame, IMU orientation relative to heave plate frame, and load cell position during deployment.

Masses

TigerRAY measured dry mass = 1436 kg (this includes nacelle, floats, arms, mast and internal electronics boxes

Heave plate dry mass = 1040 kg
Wet mass at depth = 735 kg (freshwater) **From load cell reading, which may vary with depth (hydrostatic pressure acts in compression on load cell, reducing the measured force). Actual wet mass may be closer to 760 kg, further analysis is required.**

Appendix A: Notes on data products

Encoders

Raw encoder data is sent through two main processing steps to generate a smooth finished data product with a usable sampling rate. Raw encoder data is reported at ~3.3 kHz, but there are two issues with the incoming data product. 1) Corrupted data points snap to encoder positions that are often far from the most recently measured data points (see Fig. A1). This is smoothed through median filtering, using the moving median filter with a window size of 50 points. 2) Though the encoder position is collected at ~3.3 kHz, the data is only time stamped at ~40 Hz. This results in a wide range of encoder positions with nearly identical timestamps. This is seen in Fig. A2, where the data appears 'stepped'. Each vertical step consists of a large number of encoder position data points that are time stamped at the time that they were queried, rather than the time they were recorded. As such, it is believed that the point with the most accurate timestamp is the final encoder position in each step, so the final data product uses the final data point in each step, yielding an average sampling frequency of 40 Hz.

The encoder data has also been re-referenced relative to measured arm and nacelle angles when TigerRAY was on-deck on Friday, February 10, 2023. Based on these measurements, a value of 346.7 degrees was subtracted from aft encoder data, and the forward encoder data was subtracted from a value of 170.5 degrees. After completing these calculations, the reference angles for both encoders becomes 0 degrees = vertical, as depicted in Fig. 2.

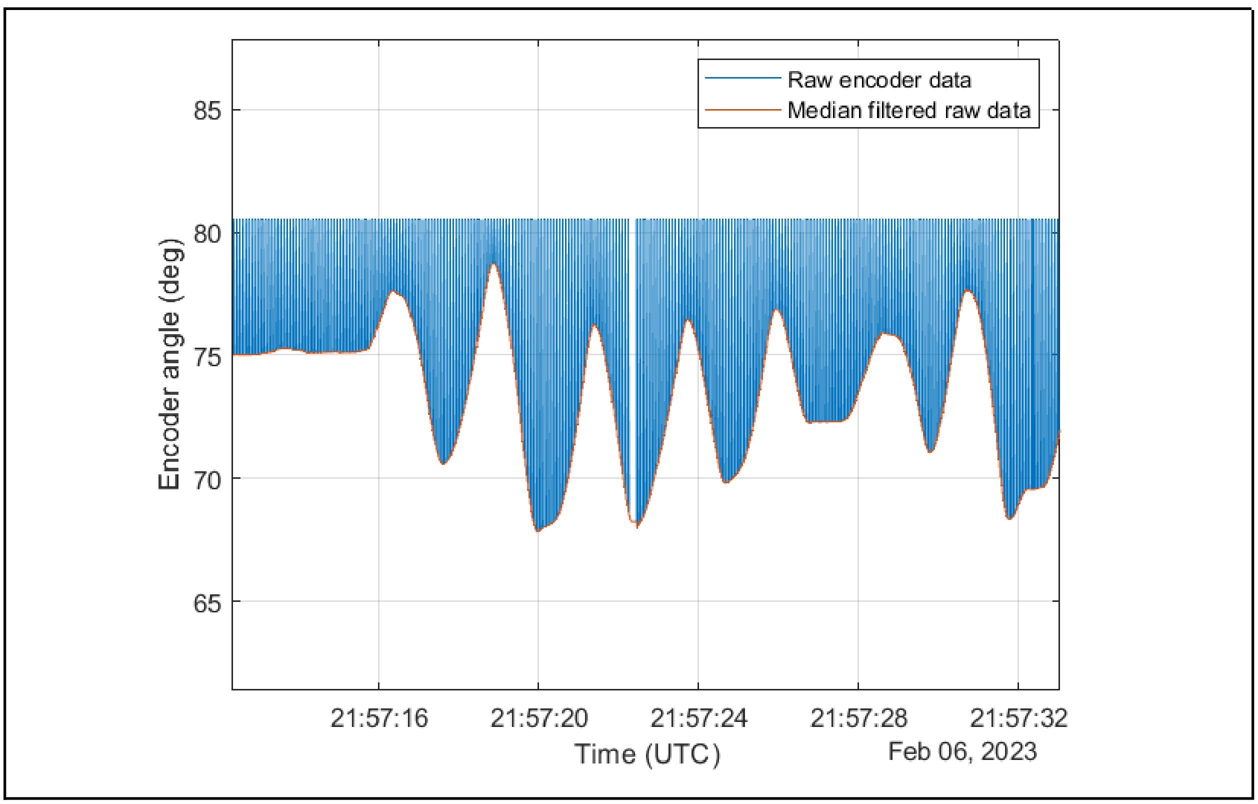

Fig. A1: Raw encoder data, smoothed using median filtering

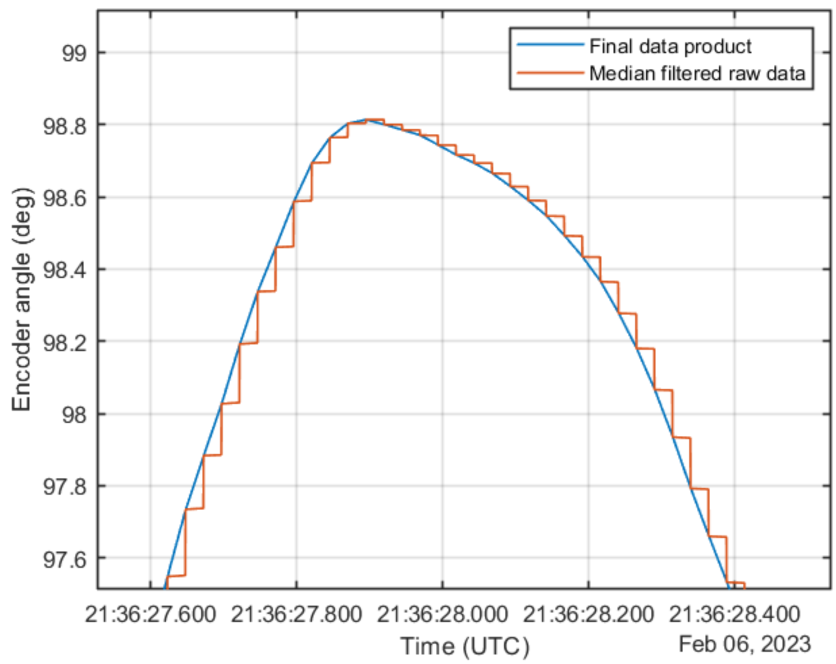

Fig A2: Final data product, defined using the final point in each ‘step’ of the data bursts.

Load cell

The load cell (Submersible Tension Link Load Cell, P/N 12177-10, 5,000 lbf Capacity, 0.1 to 10.1 VDC Output, from Sensing Systems Corporation), outputs a voltage signal. This signal was converted to a force in pounds by multiplying the voltage by 500 and subtracting 50, and then converted to Newtons by multiplying by 4.44822.

Heave plate pressure sensors

The heave plate pressure sensor variable has two columns. As shown in Fig. 4, the first column is data from the pressure sensor on the top bar of the winch frame, and the second column is the data from the pressure sensor on the bottom bar of the winch frame. Heave plate pressure sensor data is collected using Omega absolute pressure sensors. For the heave plate pressure sensors, the output signal was converted to PSI using the following equation: 11.234 * V - 6.224, where V is the output voltage from the pressure sensor.

Nacelle pressure sensors

The nacelle pressure sensor variable has three columns. As shown in Fig. 3, the first column is data from the pressure sensor on the starboard side of the yoke, the second column is data from the pressure sensor on the mast, and the third column is data from the port side of the yoke. This data is also collected using Omega absolute pressure sensors. For the nacelle pressure sensors, the output voltage was converted to PSI using: 5.617*V - 3.112, where V is the output voltage from the pressure sensor.

The nacelle pressure sensors only record data when the device is in freewheel, since they occupy the same port as the nacelle PTO electronics on the computer collecting data. This means that there is no pressure sensor data from the nacelle when the generators are turned on.

Heave plate IMU

The heave plate IMU is an SBG ellipse. It has onboard processing and outputs a wide range of data, including heave estimates. The full IMU dataset is included in data.hp_imu_raw. It should be noted that most data sets contain a large number of NaN values. The timestamps are recorded at 100 Hz, but no data streams are recorded at that speed. Heave estimates are at 50 Hz, and have been processed to remove all NaN values (access via data.t_hpimu and data.hp_heave). Most other data streams in the IMU are collected at 10 Hz. The validity of the yaw data is questionable, which appears to be affected by proximity to steel. To plot data from the imu, use code as follows (replacing ‘variable’ with your variable of interest).

```
ids = find(~isnan(data.hp_imu_raw.variable));
figure
plot(data.hp_imu_raw.ts(ids),data.hp_imu_raw.variable(ids));
```

Nacelle IMU

The nacelle IMU is also an SBG ellipse. See heave plate IMU section for more details. The nacelle IMU also uses an antenna that is mounted on the mast to perform calculations more accurately. The nacelle IMU orientation is depicted in Fig. 1. For the nacelle IMU, we had to define a couple of parameters to help it make more accurate calculations. We defined the center of mass of the nacelle as 4 cm below the shaft line at the center of the nacelle. Then, we define lever arm offsets FROM the SBG to this center of mass (x = -34.3 cm, y = -13.0 cm, z= -21.4 cm) and offsets FROM SBG to the GPS antenna (x = 132.1 cm, y = -13.0 cm, z = -152.4 cm). See the “ellipse operating handbook - use in marine applications” for details on this information.

Satellite compass

The satellite compass mounted to the TigerRAY mast is a Furuno SCX21. While the compass provides a range of measurements, only the heading (and associated timestamps) are included in this dataset. A heading of 0 degrees would indicate that TigerRAY is oriented with the port side pointed to the north. A heading of 90 degrees would indicate that TigerRAY is oriented with the port side to the east.

SWIFTs

Four SWIFTs (v4) were attached to TigerRAY for the duration of all deployments. They were tethered to TigerRAY and to one another, and tended to drift downwind of TigerRAY in a straight line. They were attached in numerical order, with SWIFT 22 closest to TigerRAY, and SWIFT 25 furthest. SWIFT 23 did not record data on February 10. SWIFT 22 has questionable bulk statistics for Feb 6, 7, and 8 - raw displacements are likely fine, but bulk statistics from SWIFT 22 on those days should not be trusted. SWIFTs report data in 9 minute bursts followed by 3 minutes of downtime while they process the data. The full datasets for each swift are saved in the data structure, containing bulk wave statistics and calculated spectra. In addition, raw heave estimates during each burst are saved, and have been collected in the data.swift##_z variables (to be plotted using data.swift##_t).