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Pentalum SpiDAR Deployment at SWiFT FY17

Carsten Westergaard, Suhas Pol, Tassia Pereira, and Ricardo Castillo

Prepared by
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Authors:
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Abstract

The Texas Tech University (TTU) research group is actively studying the wake development of wind turbines, as part of developing innovative wake control strategies to improve the performance of wind farms. Recently, the team received a set of five new ground lidars to perform field measurements at the Sandia National Laboratories SWiFT site.

This document describes tests details including configurations, timeframe, hardware, and the required collaboration from the Sandia team. This test plan will facilitate the coordination between both TTU and the Sandia team in terms of site accessibility, staff training, and data sharing to meet the specific objectives of the tests.

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Nomenclature

SNL	Sandia National Laboratories
DOE	Department of Energy
TWD	Technical Work Document
SWiFT	Scaled Wind Farm Technology
TTU	Texas Tech University

APPROVALS

The following test plan may not be implemented until the following individuals approve by signing and dating below.

Approved by: David R Mitchell Date: 11/10/16

Dave Mitchell, SWiFT Site Supervisor

Approved by: Tim Crawford Date: 11/10/16

Tim Crawford, SWiFT Site Lead

Approved by: Date: 11/10/2016

Brian Naughton, Sandia Technical Liaison

Approved by: Date: 11/10/2016

Wesley Johnson, 6121 ES&H Coordinator

Approved by: Date: 11/10/16

Carsten Westergaard, Project PI

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1. INTRODUCTION

The TTU research group is actively studying the wake development of wind turbines, as part of developing innovative wake control strategies to improve the performance of wind farms. Recently, the team received a set of five new ground lidars (Pentalum SpiDAR) to perform field measurements at the Sandia SWiFT site.

This document describes tests details including configurations, timeframe, hardware, and the required collaboration from the Sandia team. This test plan will facilitate the coordination between both TTU and the Sandia team in terms of site accessibility, staff training, and data sharing to meet the specific objectives of the tests.

2. TEST OBJECTIVES AND SUCCESS CRITERIA

The following table summarizes the primary and secondary test objectives for the test plan along with the criteria used to evaluate the success of the test in achieving the objectives. Primary objectives are required to be completed while secondary objectives are only to be pursued after successful completion of the primary objectives.

Table 1. Test objectives and success criteria

Primary Test Objective(s) – Must be completed for a successful test	
PTO1 (Phase 1):	Characterization of the inflow and determination of the time correlation between the met tower (METa1) and SpiDARs.
Success Criteria:	• All the SpiDARs obtain data at higher than 80% data availability rate. • Comparison of SpiDAR and METa1data is conducted.
Secondary Test Objective(s) – May be completed after primary test objective is complete	
STO1:	Binning of data availability across various stability, wind speed and turbulence intensity conditions.
Success Criteria:	At this point, wind speed bins or turbulence levels are not priority. However, the functioning of the SpiDARs during various atmospheric conditions is.
Primary Test Objective(s) – Must be completed for a successful test	
PTO2 (Phase 2 & 3):	Comparison of wake measurements from nacelle and ground lidars.
Success Criteria:	• All SpiDARs obtain data at higher than 80% data rate. • Compare data obtained from ground based Lidars and nacelle mounted lidars for times when wake is captured by at least 1 one of the ground based SpiDARs.

3. ROLES AND RESPONSIBILITIES

Describe all the roles and responsibilities of the personnel that will be involved in all stages of the test plan.

Table 2. Roles and Responsibilities

Title	Name(s)	Responsibilities
Professor of practice	Carsten Westergaard	• Project PI
Research assistant professor	Suhas Pol	• TTU team field supervisor
Graduate research assistant	• Tassia Pereira • Ricardo Castillo	• Experimental setup • Data collection
SWiFT Site Supervisor	Dave Mitchell	• Provide physical access to SpiDARs • Communicate SWiFT site status to Project PI
SWiFT Lead	Tim Crawford	• Coordinate, and prioritize SWiFT site activities
Sandia Technical Liaison	• Brian Naughton • Tommy Herges	• Provide SWiFT instrumentation data (QA/QC) • Provide SpinnerLidar data processing and analysis

4. UNIQUE HAZARDS

The following table provides a high-level summary of major hazards that are unique to this test. Further information on hazards and controls for this test are provided in the safety documents.

Table 3. Unique Hazards

Hazard	Description
Laser hazard	Class 1M laser (see manual in ref 4). No specific PPE required. Class 1M laser systems have previously been approved for use at the SWiFT facility through the Management of Change process.

5. SCHEDULE

Describe the major phases of the test. This could be in the format of a calendar or other format that best conveys the information.

Table 4. Test Schedule

Dates	Description
Once approved, 3 to 5 weeks.	**Phase 1:** Place the SpiDARs according to the configuration shown in figure 1. The location of the SpiDARs was chosen taking into consideration the location of met tower guy wires.
Until installation of turbine WTGa2 starts	**Phase 2:** The SpiDARs will be placed in a row at a distance of 4D (108 m) away from the turbine WTGa1. The configuration of the SpiDARs is shown in figure 2.
During installation of turbine WTGa2	**Phase 3:** Likewise phase 2, the SpiDARs will be placed in a row, but closer to the turbine WTGa1 in order not to interfere with the construction of the turbine immediately downstream. The TTU team is considering placing the row of SpiDARs up to 2D (54 m) away from the turbine WTGa1, since this is the minimum distance that the DTU Spinner Lidar needs to cover the wake envelope.

6. CONFIGURATION

6.1. Definition of test area and conditions

<u>Test area and configuration</u>
Describe the test area boundary and provide maps or images to support.
Include any schematics of data, power, or other systems that are helpful.

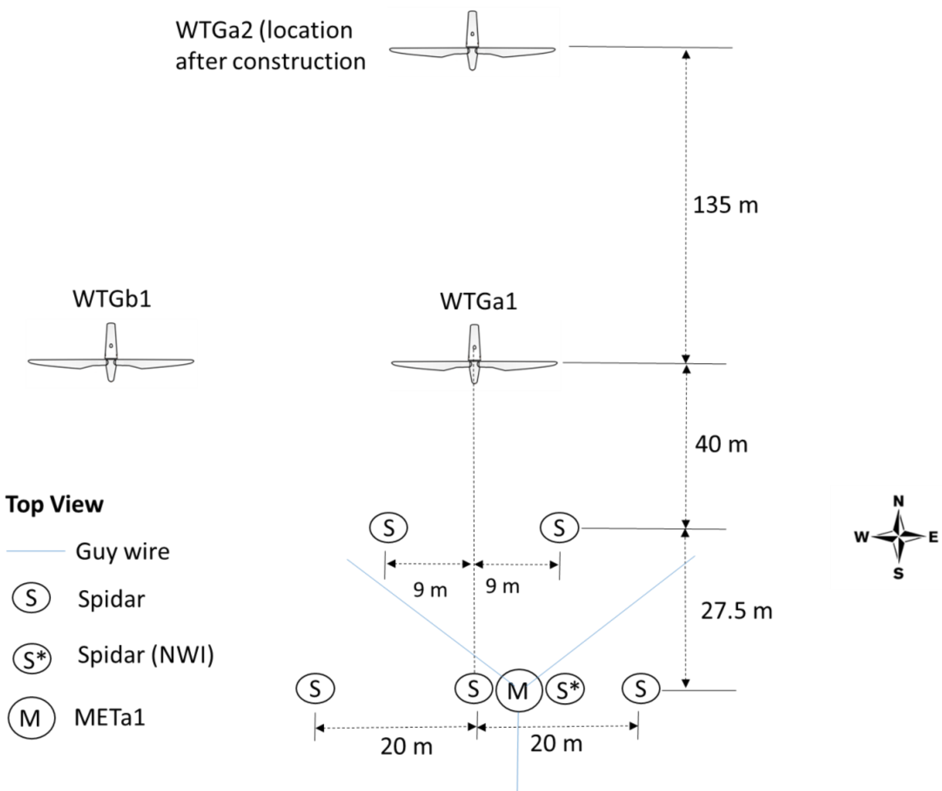

Figure 1. Phase 1 test configuration

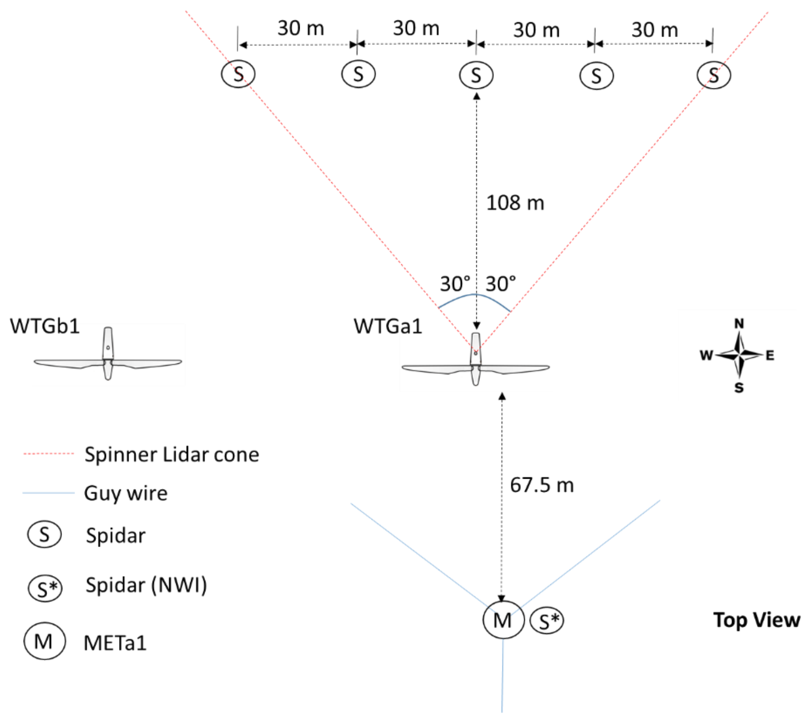

Figure 2. Phase 2 test configuration

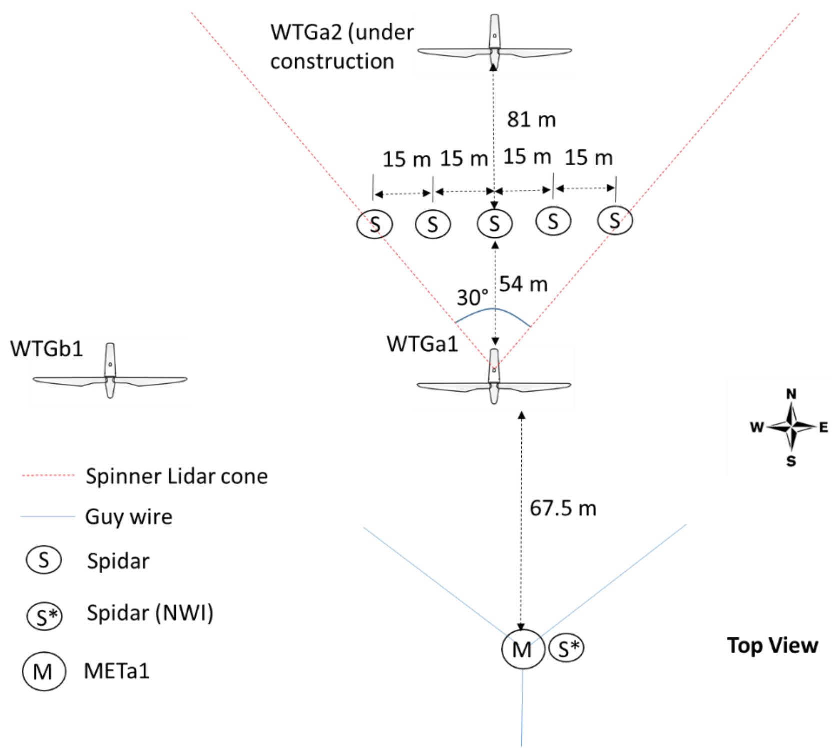

Figure 3. Phase 3 test configuration

Site conditions

All activities will take place under safe environmental conditions per current SWiFT facility guidelines (Ref. 1) and within equipment operational windows. Generally this includes wind speeds below 20 m/s, no lightning, or extreme weather.

6.2. Equipment, facilities, and materials

The following is a list of major equipment, facilities, and materials required for the test activities along with the supplier as indicated in the parentheses.

Equipment

- Ground lidar
    - Manufacturer: Pentalum
    - Model: SpiDAR
    - Laser: class 1M
    - Power requirement: 35W (up to 250W when heated)

  Further specifications can be found in section 1 of the SpiDAR user manual shown in Ref 4.

- DTU SpinnerLidar (SWiFT)

Power

- Extension cord:
    - Outdoor compatible (water proof, rodent proof)
    - Length: 50 ft.
    - Power capacity: 5 x 250W peak, 5 x 35W normal operation
    - 15 A, 125 V, y 1875W capacity

- Power cable guards if crossing roads
- Surge protector for each SpiDAR

Data

- METa1 sonic anemometer at all heights: this data is required in three phases.
- DTU Spinner Lidar: this data is required in both phase 2 and 3.
- Pentalum SpiDAR: this data is required in both phase 2 and 3
- WTGa1 data will be required in all phases. In phase 1, data will be used to prepare post-processing codes for subsequent experiments.

7. PROCEDURES

This section will present the major test procedures that will be used to achieve the test objectives. Details regarding specific steps related to safety should reference relevant safety documents (OP, JSA, TWD, etc.).

7.1. Setup

This section could describe the procedures involved with delivering and configuring the equipment on site.

Lidar placement: The ground will be mowed where the SpiDARs will be placed along with access paths to avoid the likelihood of snakes and other wildlife. The SpiDARs will be delivered to site by a truck. Each SpiDAR weighs approximately 75 kg. Therefore, to put the SpiDAR on the ground, based on previous experience of the TTU team, three people will be required:

- One person on the truck bed will be pushing the SpiDAR out of the bed.
- Two people on the ground will be holding the SpiDAR from its legs.
- Once there is only one leg left on the truck bed, the person on the truck bed will get off the truck and hold the third leg coming off the truck bed.

Once the SpiDAR is on the ground, three people will carry the SpiDAR to its final location by lifting it from its handles. The SpiDAR will be anchored to the ground by inserting an anchor rod through the outer hole of each foot pad (see SpiDAR manual, section 4.5). After the completion of each phase, the SpiDARs will be lifted by three people from its legs and located on the truck bed to be moved to their next location.

Electrical cables: Extension cables will be place according to the schematic for each testing phase. Extension cables will be protected by heavy duty rubber cable protectors anywhere cables must cross roads where vehicles will travel.

Access: Daily physical access by TTU staff and students will be required to the SpiDARs until they are fully configured and working. During the data collection stage, weekly access will be required to service the SpiDARs. This will be coordinated through the SWiFT Site Supervisor.

7.2. Testing and data collection

This section describes the major testing campaign and data collection details

Phase 1: The purpose of phase 1 is to test SpiDAR function and compare METa1 data. TTU team will move the SpiDARs to the location in figure 1. The configuration will also permit measuring horizontal variability of the inflow. Additionally, the SpiDAR's ability to measure turbulence will also be tested. The SpiDARs will be located in phase 1 configuration for a period of 3 weeks. The measurements and SpiDAR status will be monitored on daily basis (remotely if SpiDAR cellular communication is established). Data channels of METa1 as shown in Appendix A will be used for data comparison.

Phase 2: The purpose of phase 2 is to characterize the WTGa1 wake cross-section at 5D downstream, as shown in figure 2. Additionally, phase 2 will also test the SpiDAR's ability to measure in wake turbulence. Further, the TTU team will require access to the data from the DTU Spinner Lidar for comparison purposes. The TTU team also needs to know in advance the date the construction of the turbine WTGa2 (immediately downstream) will start in order to proceed relocating the SpiDARs. The SpiDARs will be located in phase 2 configuration until WTGa2 work will commence. The SpiDAR performance and data will be remotely monitored or if needed manually once every week. Data channels of METa1 and WTGa1 as shown in Appendix A will be utilized for the study.

Phase 3: The purpose of phase 3 is to characterize the WTGa1 wake cross-section at 2D downstream and the additional goals are same as phase 2. The SpiDARs configuration is shown in figure 3.

7.3. Teardown

Upon the completion of testing, all equipment and materials will be removed from the site and returned to their respective owners. The site will be returned to the pre-test state as much as possible.

8. REPORTING

This section describes the reporting requirements for the test and could include:

- Recording any safety incidents
- Reporting requirements to external groups or government agencies
- Interim reports on the status of sensors
- Deviations from the test plan
- A final report summarizing the test plan activities and success towards meeting the test objectives.
- A final test report at the conclusion of the experiment.

9. REFERENCES

References to related documents such as equipment spec sheets, technical reports, etc. to support more in-depth test plan understanding

1. Jonathan White, *Sandia SWiFT Facility Site Operations Manual*, SAND2016-0651, Sandia National Laboratories, Albuquerque, NM, January, 2016
2. Christopher L. Kelley, Brandon L. Ennis, *SWiFT Site Atmospheric Characterization*, SAND2016-0216, Sandia National Laboratories, Albuquerque, NM, January 2016
3. Jonathan White, *Sandia SWiFT Site Safe Work Planning Manual*, SAND2016-0857, Sandia National Laboratories, Albuquerque, NM, January, 2016
4. Pentalum, *SpiDAR ™ User's Manual*, Rev 03, Document Number 60-64000-A, April 2015

APPENDIX A: SWiFT DATA CHANNEL PRIORITY LISTS

The following two tables provide the full data channel list for the SWiFT met towers and the SWiFT turbines. The priority column represents the importance of the data channel for phase 1. The higher the priority (1 being highest priority), the more attention and resources that channel will receive if there are issues with the sensor.

Phase 1 Priority Data Channels

Table 5. Data channel list for METa1 along with priority for phase 1

Software ID	Description	Application	Priority
SonicU_58m	Sonic Anemometer at 58.5m height	Velocity 13 m above top of rotor disc, crucial for Lidar data comparison at 60m	1
SonicV_58m	Sonic Anemometer at 58.5m height	Velocity 13 m above top of rotor disc, crucial for Lidar data comparison at 60m	1
SonicW_58m	Sonic Anemometer at 58.5m height	Velocity 13 m above top of rotor disc, additional measure to completely characterize mean and turbulence at 60m	2
SonicT_58m	Sonic Anemometer at 58.5m height	Prerequisite for sonic anemometer measurement of velocity at this station	1
Sonicx_58m	Sonic Anemometer at 58.5m height	Part of ATI sonics; maybe useful if boom/tower vibration is suspected; signal now very low amplitude, under-resolved	3
Sonicy_58m	Sonic Anemometer at 58.5m height	Part of ATI sonics; maybe useful if boom/tower vibration is suspected; signal now very low amplitude, under-resolved	3
Sonicz_58m	Sonic Anemometer at 58.5m height	Part of ATI sonics; maybe useful if boom/tower vibration is suspected; signal now very low amplitude, under-resolved	3
SonicU_45m	Sonic Anemometer at 45m height	Velocity ~ 1 m below top of rotor disc, crucial for Lidar data comparison at 45m	1
SonicV_45m	Sonic Anemometer at 45m height	Velocity ~ 1 m below top of rotor disc, crucial for Lidar data comparison at 45m	1
SonicW_45m	Sonic Anemometer at 45m height	Velocity ~ 1 m below top of rotor disc, additional measure to completely characterize mean and turbulence at 45m	2
SonicT_45m	Sonic Anemometer at 45m height	Prerequisite for sonic anemometer measurement of velocity at this station	1
Sonicx_45m	Sonic Anemometer at 45m height	Part of ATI sonics; maybe useful if boom/tower vibration is suspected; signal now very low amplitude, under-resolved	3
Sonicy_45m	Sonic Anemometer at 45m height	Part of ATI sonics; maybe useful if boom/tower vibration is suspected; signal now very low amplitude, under-resolved	3
Sonicz_45m	Sonic Anemometer at 45m height	Part of ATI sonics; maybe useful if boom/tower vibration is suspected; signal now very low amplitude, under-resolved	3
SonicU_31m	Sonic Anemometer at 31.5m height	Velocity ~ 1 m below rotor hub height, crucial for Lidar data comparison at 30m	1
SonicV_31m	Sonic Anemometer at 31.5m height	Velocity ~ 1 m below rotor hub height, crucial for Lidar data comparison at 30m	1
SonicW_31m	Sonic Anemometer at 31.5m height	Velocity ~ 1 m below rotor hub height, additional measure to completely characterize mean and turbulence at 31m	2
SonicT_31m	Sonic Anemometer at 31.5m height	Prerequisite for sonic anemometer measurement of velocity at this station	1
Sonicx_31m	Sonic Anemometer at 31.5m height	Part of ATI sonics; maybe useful if boom/tower vibration is suspected; signal now very low amplitude, under-resolved	3
Sonicy_31m	Sonic Anemometer at 31.5m height	Part of ATI sonics; maybe useful if boom/tower vibration is suspected; signal now very low amplitude, under-resolved	3
Sonicz_31m	Sonic Anemometer at 31.5m height	Part of ATI sonics; maybe useful if boom/tower vibration is suspected; signal now very low amplitude, under-resolved	3
SonicU_18m	Sonic Anemometer at 18m height	Velocity ~ 1 m below bottom of rotor disc, crucial for Lidar data comparison at 20m, and characterize	1

SonicV_18m	Sonic Anemometer at 18m height	Velocity ~ 1 m below bottom of rotor disc, crucial for Lidar data comparison at 20m	1
SonicW_18m	Sonic Anemometer at 18m height	Velocity ~ 1 m below bottom of rotor disc, additional measure to completely characterize mean and turbulence at 18m	2
SonicT_18m	Sonic Anemometer at 18m height	Prerequisite for sonic anemometer measurement of velocity at this station	1
Sonicx_18m	Sonic Anemometer at 18m height	Part of ATI sonics; maybe useful if boom/tower vibration is suspected; signal now very low amplitude, under-resolved	3
Sonicy_18m	Sonic Anemometer at 18m height	Part of ATI sonics; maybe useful if boom/tower vibration is suspected; signal now very low amplitude, under-resolved	3
Sonicz_18m	Sonic Anemometer at 18m height	Part of ATI sonics; maybe useful if boom/tower vibration is suspected; signal now very low amplitude, under-resolved	3
SonicU_10m	Sonic Anemometer at 10m height	Velocity ~ 9 m below bottom of rotor disc, helpful for fully charactering sheer and veer of the boundary layer profile	2
SonicV_10m	Sonic Anemometer at 10m height	Velocity ~ 9 m below bottom of rotor disc, helpful for fully charactering sheer and veer of the boundary layer profile	2
SonicW_10m	Sonic Anemometer at 10m height	Velocity ~ 9 m below bottom of rotor disc, helpful for fully charactering sheer and veer of the boundary layer profile	2
SonicT_10m	Sonic Anemometer at 10m height	Prerequisite for sonic anemometer measurement of velocity at this station	2
Sonicx_10m	Sonic Anemometer at 10m height	Part of ATI sonics; maybe useful if boom/tower vibration is suspected; signal now very low amplitude, under-resolved	3
Sonicy_10m	Sonic Anemometer at 10m height	Part of ATI sonics; maybe useful if boom/tower vibration is suspected; signal now very low amplitude, under-resolved	3
Sonicz_10m	Sonic Anemometer at 10m height	Part of ATI sonics; maybe useful if boom/tower vibration is suspected; signal now very low amplitude, under-resolved	3
Cup_45m	Cup anemometer at 45m height	Useful for corroborating sonic anemometer speed measured at 45 m height	1
Cup_31m	Cup anemometer at 31.5m height	Useful for corroborating sonic anemometer speed measured at 31.5 m height	1
Cup_18m	Cup anemometer at 18m height	Useful for corroborating sonic anemometer speed measured at 18 m height	1
Vane_29m	Wind Direction Vane at 29m height	Useful for corroborating sonic anemometer direction measured at 31.5 m height	1
RH_58m	Relative Humidity at 58.5m height	With Temp_58m or onboard temp, may be able to get a virtual temperature profile, which is helpful for stability.	3
Temp_58m	Temperature at 58.5m height	Backup for sonic anemometer temperature measurement at 58.5 m height	1
BP_27m	Barometric Pressure at 27.5m height	Measure barometric pressure within 10 m of hub, for deriving air density for rotor flow, per IEC 61400-12	3
RH_27m	Relative Humidity at 27.5m height	Measure relative humidity within 10 m of hub, for correcting air density for rotor flow, per IEC 61400-12	3
Temp_27m	Temperature at 27.5m height	Measure temperature within 10 m of hub, for deriving air density for rotor flow, per IEC 61400-12	1
BP_2m	Barometric Pressure at 2m height	Back up for barometric pressure measurement at 27.5 m (see above)	3
RH_2m	Relative Humidity at 2m height	Back up for relative humidity measurement at 27.5 m (see above)	3
Temp_2m	Temperature at 2m height	Back up for air temperature measurement at 27.5 m (see above)	2

Table 6. Data channel list for WTGa1 along with priority ranking for phase 1.

Measurement Type	Software ID	Description	Application	Priority
Power	ActualPower	Current power	Not identified/explained	3
Power	ActualPower_10min	Power averaged over 10 minutes	Not identified/explained	3
Power	ActualPower_ABB	ABB signal TxPDO 1 – ACT3 (Power)	Not identified/explained	3
Power	ActualPower_W	ABB drive Actual Power	Not identified/explained	3
Power	PowerMean	Mean of Power Sample Data array	Not identified/explained	3
Power	PowerSTD	Standard Deviation of Power Sample Data array	Not identified/explained	3
Torque	ActualTorque_ABB	ABB signal TxPDO 1 – ACT2 (Torque)	Not identified/explained	3
Torque	ActualTorque_Nm	ABB drive Actual Torque	Not identified/explained	3
Torque	LSS_Torque	Torque on the Low Speed Shaft	Not identified/explained	3
RPM	Gen_RPM	Generator RPM	Need at least one generator RPM measurements, to get higher resolution LSS RPM measurement via gearbox ratio	3
RPM	GenRPM	High Speed Shaft RPM	Need at least one generator RPM measurements, to get higher resolution LSS RPM measurement via gearbox ratio	3
RPM	GenRPMSec	High Speed Shaft RPM (1 sec ave)	Need at least one generator RPM measurements, to get higher resolution LSS RPM measurement via gearbox ratio	3
RPM	GenRPMTick	Gen RPM (instant)	Need at least one generator RPM measurements, to get higher resolution LSS RPM measurement via gearbox ratio	3
RPM	GenSpeed_24ms	Gen RPM (24ms ave)	Need at least one generator RPM measurements, to get higher resolution LSS RPM measurement via gearbox ratio	
RPM	RotRPMSec	Low Speed Shaft RPM (One Sec Ave)	Crucial for defining rotor operating state pertaining to wake structure, specifically for deriving tip speed ratio	3
RPM	RotRPMTick	Low Speed Shaft RPM (Instant)	Crucial for defining rotor operating state pertaining to wake structure, specifically for deriving tip speed ratio	3
RPM	ActualSpeed_ABB	ABB signal TxPDO 1 – Transparent Actual Velocity	Not identified/explained	3
RPM	ActualSpeed_rpm	ABB drive Actual Speed	Need at least one generator RPM measurements, to get higher resolution LSS RPM measurement via gearbox ratio	3
Rotor azimuth		Rotor azimuth angle measurement via rotary encoder on LSS	Enable time accurate resolution & projection of blade root moments/forces for model validation/calibration	3
Rotor azimuth		Rotor azimuth reference using one-per-revolution reference pulse	Back up rotor azimuth angle measurement to be done using rotary shaft encoder on LSS	3
Voltage	ControlVoltageSTD	Standard deviation on the control voltage	Channel for machine safety/maintenance; no direct research utility for Wake Steering Project	3
Voltage	PitchActual	Pitch position A800 (volts) converted to degrees	Blade pitch angle resolved to 0.1 deg is crucial to accurate aero modeling, need either this channel or A800	3
	A800	Pitchposition	Blade pitch angle resolved to 0.1 deg is crucial to accurate aero modeling, need either this channel or PitchActual	3
Velocity	PitchVel	Pitch velocity	While blade pitch position is crucial, blade pitch velocity has no identifiable need	3
Velocity	PitchVel_Service	Pitch velocity during Pitch tests 4,5,7,8	While blade pitch position is crucial, blade pitch velocity has no identifiable need	3

Velocity	PitchVelExpected	Soft signal for use in Pitch Service Calibration	Not identified/explained	3
Pressure	HydrPressure	Hydraulic Oil Pressure	Channel for machine safety/maintenance; no direct research utility for Wake Steering Project	3
Temperature	OilTemp	Hydraulic Oil Temp (need to verify Tick or 10s ave)	Channel for machine safety/maintenance; no direct research utility for Wake Steering Project	3
Temperature	Temp_R206	Temperature hydraulic oil	Channel for machine safety/maintenance; no direct research utility for Wake Steering Project	3
Temperature	Temp_R300	Temperature ambient	Channel for machine safety/maintenance; no direct research utility for Wake Steering Project	3
Temperature	Temp_R300_10s	Temperature ambient 10s average (TenSecUx)	Channel for machine safety/maintenance; no direct research utility for Wake Steering Project	3
Temperature	Temp_R402	Temperature gear oil	Channel for machine safety/maintenance; no direct research utility for Wake Steering Project	3
Temperature	Temp_R402_10s	Gear Oil Temp (10 sec ave)	Channel for machine safety/maintenance; no direct research utility for Wake Steering Project	3
Temperature	Temp_R402_1s	Gear oil temperature averaged over 1 sec	Channel for machine safety/maintenance; no direct research utility for Wake Steering Project	3
Temperature	Temp_R451	Temperature Gear Bearing 1	Channel for machine safety/maintenance; no direct research utility for Wake Steering Project	3
Temperature	Temp_R451_10s	10s ave of Gear Bearing 1	Channel for machine safety/maintenance; no direct research utility for Wake Steering Project	3
Temperature	Temp_R452	Temperature Gear Bearing 2	Channel for machine safety/maintenance; no direct research utility for Wake Steering Project	3
Temperature	Temp_R452_10s	10s ave of Gear Bearing 2	Channel for machine safety/maintenance; no direct research utility for Wake Steering Project	3
Temperature	Temp_R503	Temperature generator 1	Channel for machine safety/maintenance; no direct research utility for Wake Steering Project	3
Temperature	Temp_R503_10s	Gen Temp 1 (10 sec ave)	Channel for machine safety/maintenance; no direct research utility for Wake Steering Project	3
Temperature	Temp_R503_1s	Generator temperature 1 averaged over 1 sec	Channel for machine safety/maintenance; no direct research utility for Wake Steering Project	3
Temperature	Temp_R504	Temperature generator 2	Channel for machine safety/maintenance; no direct research utility for Wake Steering Project	3
Temperature	Temp_R504_10s	Gen Temp 2 (10 sec ave)	Channel for machine safety/maintenance; no direct research utility for Wake Steering Project	3
Temperature	Temp_R504_1s	Do we have this signal???	Not identified/explained	3
Velocity	Wind_Speed	Wind speed	Nacelle wind speed corrupted by rotor and nacelle, but useful to corroborate met tower wind speed	1
Velocity	WindSpeed10s	IFSample.GenericProc(IFSample.WindSpeed, TenSecUx)	Nacelle wind speed corrupted by rotor and nacelle, will not be used. Met tower wind speed to be used instead.	3
Angle	Wind_Direction	Wind direction	Nacelle wind direction corrupted by rotor and nacelle, but useful to corroborate met tower wind direction	1
Angle	Wind_Direction_Filtered	Filtered wind direction	Nacelle wind direction corrupted by rotor and nacelle, will not be used. Met tower wind direction to be used instead.	3
Angle	YawHeading	Compass Direction of the Nacelle	Essential to deriving yaw misalignment, with wind direction measured at met tower.	1
Angle	NacIMUcompass	Magnetometer orientation of Nacelle	Corrupted by nacelle ferrous mass; not needed as "YawHeading" channel uses encoder ref'd to N-S survey line.	3
Number	YawRotations	Complete rotations of the turbine	Channel for machine safety/maintenance; no direct research utility for Wake Steering Project	3
Acceleration	NacIMUAx	Nacelle X acceleration	Might be useful for inferring rotor time varying loads in future phases of SWiFT project	3
Acceleration	NacIMUAy	Nacelle Y acceleration	Might be useful for inferring rotor time varying loads in future phases of SWiFT project	3

Acceleration	NacIMUAz	Nacelle Z acceleration	Might be useful for inferring rotor time varying loads in future phases of SWiFT project	3
Angular Velocity	NacIMUrVx	Nacelle X angular velocity	Might be useful for inferring rotor time varying loads in future phases of SWiFT project	3
Angular Velocity	NacIMUrVy	Nacelle Y angular velocity	Might be useful for inferring rotor time varying loads in future phases of SWiFT project	3
Angular Velocity	NacIMUrVz	Nacelle Z angular velocity	Might be useful for inferring rotor time varying loads in future phases of SWiFT project	3
Strain	TowerNS	Strain in the North-South direction	Could compare disc thrust induced moments with model predictions; compensating errors, differential heating likely	3
Strain	TowerEW	Strain in the East-West direction	Could compare disc thrust induced moments with model predictions; compensating errors, differential heating likely	3
Strain	TowerNESW	Strain in the NE-SW direction	Could compare disc thrust induced moments with model predictions; compensating errors, differential heating likely	3
Strain	TowerNWSE	Strain in the NW-SE direction	Could compare disc thrust induced moments with model predictions; compensating errors, differential heating likely	3
Strain	B1_Strain	Blade 1 Flap and edge root bending from Micron optics	Flap/edge bending induced moments could be compared with model predictions, but compensating errors likely	3
Strain	B2_Strain	Blade 2 Flap and edge root bending from Micron optics	Flap/edge bending induced moments could be compared with model predictions, but compensating errors likely	3
Strain	B3_Strain	Blade 3 Flap and edge root bending from Micron optics	Flap/edge bending induced moments could be compared with model predictions, but compensating errors likely	3

Phase 2 and 3 Priority Data Channels

Table 7. Data channel list for METa1 along with priority for phase 2 and 3

Software ID	Description	Application	Priority
SonicU_58m	Sonic Anemometer at 58.5m height	Velocity 13 m above top of rotor disc, crucial to characterize turbine inflow and perhaps wake freestream interaction	1
SonicV_58m	Sonic Anemometer at 58.5m height	Velocity 13 m above top of rotor disc, crucial to characterize turbine inflow and perhaps wake freestream interaction	1
SonicW_58m	Sonic Anemometer at 58.5m height	Velocity 13 m above top of rotor disc, crucial to characterize turbine inflow and perhaps wake freestream interaction	1
SonicT_58m	Sonic Anemometer at 58.5m height	Prerequisite for sonic anemometer measurement of velocity at this station	1
Sonicx_58m	Sonic Anemometer at 58.5m height	Part of ATI sonics; maybe useful if boom/tower vibration is suspected; signal now very low amplitude, under-resolved	3
Sonicy_58m	Sonic Anemometer at 58.5m height	Part of ATI sonics; maybe useful if boom/tower vibration is suspected; signal now very low amplitude, under-resolved	3
Sonicz_58m	Sonic Anemometer at 58.5m height	Part of ATI sonics; maybe useful if boom/tower vibration is suspected; signal now very low amplitude, under-resolved	3
SonicU_45m	Sonic Anemometer at 45m height	Velocity ~ 1 m below top of rotor disc, crucial to characterize turbine inflow, shear, veer distributions	1
SonicV_45m	Sonic Anemometer at 45m height	Velocity ~ 1 m below top of rotor disc, crucial to characterize turbine inflow, shear, veer distributions	1
SonicW_45m	Sonic Anemometer at 45m height	Velocity ~ 1 m below top of rotor disc, crucial to characterize turbine inflow, shear, veer distributions	1
SonicT_45m	Sonic Anemometer at 45m height	Prerequisite for sonic anemometer measurement of velocity at this station	1
Sonicx_45m	Sonic Anemometer at 45m height	Part of ATI sonics; maybe useful if boom/tower vibration is suspected; signal now very low amplitude, under-resolved	3
Sonicy_45m	Sonic Anemometer at 45m height	Part of ATI sonics; maybe useful if boom/tower vibration is suspected; signal now very low amplitude, under-resolved	3
Sonicz_45m	Sonic Anemometer at 45m height	Part of ATI sonics; maybe useful if boom/tower vibration is suspected; signal now very low amplitude, under-resolved	3
SonicU_31m	Sonic Anemometer at 31.5m height	Velocity ~ 1 m below rotor hub height, crucial to characterize turbine inflow, shear, veer distributions	1
SonicV_31m	Sonic Anemometer at 31.5m height	Velocity ~ 1 m below rotor hub height, crucial to characterize turbine inflow, shear, veer distributions	1
SonicW_31m	Sonic Anemometer at 31.5m height	Velocity ~ 1 m below rotor hub height, crucial to characterize turbine inflow, shear, veer distributions	1
SonicT_31m	Sonic Anemometer at 31.5m height	Prerequisite for sonic anemometer measurement of velocity at this station	1
Sonicx_31m	Sonic Anemometer at 31.5m height	Part of ATI sonics; maybe useful if boom/tower vibration is suspected; signal now very low amplitude, under-resolved	3
Sonicy_31m	Sonic Anemometer at 31.5m height	Part of ATI sonics; maybe useful if boom/tower vibration is suspected; signal now very low amplitude, under-resolved	3
Sonicz_31m	Sonic Anemometer at 31.5m height	Part of ATI sonics; maybe useful if boom/tower vibration is suspected; signal now very low amplitude, under-resolved	3
SonicU_18m	Sonic Anemometer at 18m height	Velocity ~ 1 m below bottom of rotor disc, crucial to characterize turbine inflow, shear, veer distributions	1
SonicV_18m	Sonic Anemometer at 18m height	Velocity ~ 1 m below bottom of rotor disc, crucial to characterize turbine inflow, shear, veer distributions	1
SonicW_18m	Sonic Anemometer at 18m height	Velocity ~ 1 m below bottom of rotor disc, crucial to characterize turbine inflow, shear, veer distributions	1
SonicT_18m	Sonic Anemometer at 18m height	Prerequisite for sonic anemometer measurement of velocity at this station	1
Sonicx_18m	Sonic Anemometer at 18m height	Part of ATI sonics; maybe useful if boom/tower vibration is suspected; signal now very low amplitude, under-resolved	3

Sonicy_18m	Sonic Anemometer at 18m height	Part of ATI sonics; maybe useful if boom/tower vibration is suspected; signal now very low amplitude, under-resolved	3
Sonicz_18m	Sonic Anemometer at 18m height	Part of ATI sonics; maybe useful if boom/tower vibration is suspected; signal now very low amplitude, under-resolved	3
SonicU_10m	Sonic Anemometer at 10m height	Velocity ~ 9 m below bottom of rotor disc, helpful adjunct for characterizing inflow, shear, veer distributions	2
SonicV_10m	Sonic Anemometer at 10m height	Velocity ~ 9 m below bottom of rotor disc, helpful adjunct for characterizing inflow, shear, veer distributions	2
SonicW_10m	Sonic Anemometer at 10m height	Velocity ~ 9 m below bottom of rotor disc, helpful adjunct for characterizing inflow, shear, veer distributions	2
SonicT_10m	Sonic Anemometer at 10m height	Prerequisite for sonic anemometer measurement of velocity at this station	2
Sonicx_10m	Sonic Anemometer at 10m height	Part of ATI sonics; maybe useful if boom/tower vibration is suspected; signal now very low amplitude, under-resolved	3
Sonicy_10m	Sonic Anemometer at 10m height	Part of ATI sonics; maybe useful if boom/tower vibration is suspected; signal now very low amplitude, under-resolved	3
Sonicz_10m	Sonic Anemometer at 10m height	Part of ATI sonics; maybe useful if boom/tower vibration is suspected; signal now very low amplitude, under-resolved	3
Cup_45m	Cup anemometer at 45m height	Useful for corroborating sonic anemometer speed measured at 45 m height	2
Cup_31m	Cup anemometer at 31.5m height	Useful for corroborating sonic anemometer speed measured at 31.5 m height	2
Cup_18m	Cup anemometer at 18m height	Useful for corroborating sonic anemometer speed measured at 18 m height	2
Vane_29m	Wind Direction Vane at 29m height	Useful for corroborating sonic anemometer direction measured at 31.5 m height	2
RH_58m	Relative Humidity at 58.5m height	With Temp_58m or onboard temp, may be able to get a virtual temperature profile, which is helpful for stability.	2
Temp_58m	Temperature at 58.5m height	Backup for sonic anemometer temperature measurement at 58.5 m height	1
BP_27m	Barometric Pressure at 27.5m height	Measure barometric pressure within 10 m of hub, for deriving air density for rotor flow, per IEC 61400-12	2
RH_27m	Relative Humidity at 27.5m height	Measure relative humidity within 10 m of hub, for correcting air density for rotor flow, per IEC 61400-12	2
Temp_27m	Temperature at 27.5m height	Measure temperature within 10 m of hub, for deriving air density for rotor flow, per IEC 61400-12	1
BP_2m	Barometric Pressure at 2m height	Back up for barometric pressure measurement at 27.5 m (see above)	2
RH_2m	Relative Humidity at 2m height	Back up for relative humidity measurement at 27.5 m (see above)	2
Temp_2m	Temperature at 2m height	Back up for air temperature measurement at 27.5 m (see above)	2

Table 8. Data channel list for WTGa1 along with priority ranking for phase 2 and 3.

Measurement Type	Software ID	Description	Application	Priority
Power	ActualPower	Current power	Crucial for estimating C_P	1
Power	ActualPower_10min	Power averaged over 10 minutes	Crucial for estimating C_P	1
Power	ActualPower_ABB	ABB signal TxPDO 1 – ACT3 (Power)	Not identified/explained	2
Power	ActualPower_W	ABB drive Actual Power	Not identified/explained	2
Power	PowerMean	Mean of Power Sample Data array	Not identified/explained	2
Power	PowerSTD	Standard Deviation	Not identified/explained	2

		of Power Sample Data array		
Torque	ActualTorque_ABB	ABB signal TxPDO 1 – ACT2 (Torque)	Verify turbine performance.	1
Torque	ActualTorque_Nm	ABB drive Actual Torque	Back up measurement to previous	2
Torque	LSS_Torque	Torque on the Low Speed Shaft	Not identified/explained	2
RPM	Gen_RPM	Generator RPM	Need at least one generator RPM measurements, to get higher resolution LSS RPM measurement via gearbox ratio	2
RPM	GenRPM	High Speed Shaft RPM	Need at least one generator RPM measurements, to get higher resolution LSS RPM measurement via gearbox ratio	2
RPM	GenRPMSec	High Speed Shaft RPM (1 sec ave)	Need at least one generator RPM measurements, to get higher resolution LSS RPM measurement via gearbox ratio	2
RPM	GenRPMTick	Gen RPM (instant)	Need at least one generator RPM measurements, to get higher resolution LSS RPM measurement via gearbox ratio	2
RPM	GenSpeed_24ms	Gen RPM (24ms ave)	Need at least one generator RPM measurements, to get higher resolution LSS RPM measurement via gearbox ratio	2
RPM	RotRPMSec	Low Speed Shaft RPM (One Sec Ave)	Crucial for defining rotor operating state pertaining to wake structure, specifically for deriving tip speed ratio	1
RPM	RotRPMTick	Low Speed Shaft RPM (Instant)	Crucial for defining rotor operating state pertaining to wake structure, specifically for deriving tip speed ratio	1
RPM	ActualSpeed_ABB	ABB signal TxPDO 1 – Transparent Actual Velocity	Not identified/explained	2
RPM	ActualSpeed_rpm	ABB drive Actual Speed	Need at least one generator RPM measurements, to get higher resolution LSS RPM measurement via gearbox ratio	2
Rotor azimuth		Rotor azimuth angle measurement via rotary encoder on LSS	Enable time accurate resolution & projection of blade root moments/forces for model validation/calibration	3
Rotor azimuth		Rotor azimuth reference using one-per-revolution reference pulse	Back up rotor azimuth angle measurement to be done using rotary shaft encoder on LSS	3
Voltage	ControlVoltageSTD	Standard deviation on the control voltage	Channel for machine safety/maintenance; no direct research utility for Wake Steering Project	3
Voltage	PitchActual	Pitch position A800 (volts) converted to degrees	Blade pitch angle resolved to 0.1 deg is crucial to accurate aero modeling (perhaps estimate C_T), need either this channel or A800	1
	A800	Pitchposition	Blade pitch angle resolved to 0.1 deg is crucial to accurate aero modeling, need either this channel or PitchActual	3
Velocity	PitchVel	Pitch velocity	While blade pitch position is crucial, blade pitch velocity has no identifiable need	3
Velocity	PitchVel_Service	Pitch velocity during Pitch tests 4,5,7,8	While blade pitch position is crucial, blade pitch velocity has no identifiable need	3
Velocity	PitchVelExpected	Soft signal for use in Pitch Service Calibration	Not identified/explained	3
Pressure	HydrPressure	Hydraulic Oil Pressure	Channel for machine safety/maintenance; no direct research utility for Wake Steering Project	3
Temperature	OilTemp	Hydraulic Oil Temp (need to verify Tick or 10s ave)	Channel for machine safety/maintenance; no direct research utility for Wake Steering Project	3
Temperature	Temp_R206	Temperature hydraulic oil	Channel for machine safety/maintenance; no direct research utility for Wake Steering Project	3
Temperature	Temp_R300	Temperature ambient	Channel for machine safety/maintenance; no direct research utility for Wake Steering Project	3
Temperature	Temp_R300_10s	Temperature ambient 10s	Channel for machine safety/maintenance; no direct research utility for Wake Steering Project	3

		average (TenSecUx)		
Temperature	Temp_R402	Temperature gear oil	Channel for machine safety/maintenance; no direct research utility for Wake Steering Project	3
Temperature	Temp_R402_10s	Gear Oil Temp (10 sec ave)	Channel for machine safety/maintenance; no direct research utility for Wake Steering Project	3
Temperature	Temp_R402_1s	Gear oil temperature averaged over 1 sec	Channel for machine safety/maintenance; no direct research utility for Wake Steering Project	3
Temperature	Temp_R451	Temperature Gear Bearing 1	Channel for machine safety/maintenance; no direct research utility for Wake Steering Project	3
Temperature	Temp_R451_10s	10s ave of Gear Bearing 1	Channel for machine safety/maintenance; no direct research utility for Wake Steering Project	3
Temperature	Temp_R452	Temperature Gear Bearing 2	Channel for machine safety/maintenance; no direct research utility for Wake Steering Project	3
Temperature	Temp_R452_10s	10s ave of Gear Bearing 2	Channel for machine safety/maintenance; no direct research utility for Wake Steering Project	3
Temperature	Temp_R503	Temperature generator 1	Channel for machine safety/maintenance; no direct research utility for Wake Steering Project	3
Temperature	Temp_R503_10s	Gen Temp 1 (10 sec ave)	Channel for machine safety/maintenance; no direct research utility for Wake Steering Project	3
Temperature	Temp_R503_1s	Generator temperature 1 averaged over 1 sec	Channel for machine safety/maintenance; no direct research utility for Wake Steering Project	3
Temperature	Temp_R504	Temperature generator 2	Channel for machine safety/maintenance; no direct research utility for Wake Steering Project	3
Temperature	Temp_R504_10s	Gen Temp 2 (10 sec ave)	Channel for machine safety/maintenance; no direct research utility for Wake Steering Project	3
Temperature	Temp_R504_1s	Do we have this signal???	Not identified/explained	3
Velocity	Wind_Speed	Wind speed	Nacelle wind speed corrupted by rotor and nacelle, but useful to corroborate met tower wind speed	1
Velocity	WindSpeed10s	IFSample.GenericProc(IFSample.WindSpeed, TenSecUx)	Nacelle wind speed corrupted by rotor and nacelle, will not be used. Met tower wind speed to be used instead.	3
Angle	Wind_Direction	Wind direction	Nacelle wind direction corrupted by rotor and nacelle, but useful to corroborate met tower wind direction	1
Angle	Wind_Direction_Filtered	Filtered wind direction	Nacelle wind direction corrupted by rotor and nacelle, will not be used. Met tower wind direction to be used instead.	3
Angle	YawHeading	Compass Direction of the Nacelle	Essential to deriving yaw misalignment, with wind direction measured at met tower.	1
Angle	NacIMUcompass	Magnetometer orientation of Nacelle	Corrupted by nacelle ferrous mass; not needed as "YawHeading" channel uses encoder ref'd to N-S survey line.	3
Number	YawRotations	Complete rotations of the turbine	Channel for machine safety/maintenance; no direct research utility for Wake Steering Project	3
Acceleration	NacIMUAx	Nacelle X acceleration	Might be useful for inferring rotor time varying loads in future phases of SWiFT project	3
Acceleration	NacIMUAy	Nacelle Y acceleration	Might be useful for inferring rotor time varying loads in future phases of SWiFT project	3
Acceleration	NacIMUAz	Nacelle Z acceleration	Might be useful for inferring rotor time varying loads in future phases of SWiFT project	3
Angular Velocity	NacIMUrVx	Nacelle X angular velocity	Might be useful for inferring rotor time varying loads in future phases of SWiFT project	3
Angular Velocity	NacIMUrVy	Nacelle Y angular velocity	Might be useful for inferring rotor time varying loads in future phases of SWiFT project	3
Angular Velocity	NacIMUrVz	Nacelle Z angular velocity	Might be useful for inferring rotor time varying loads in future phases of SWiFT project	3
Strain	TowerNS	Strain in the North-South direction	Could compare disc thrust induced moments with model predictions; compensating errors, differential heating likely	3
Strain	TowerEW	Strain in the East-West direction	Could compare disc thrust induced moments with model predictions; compensating errors, differential heating likely	3
Strain	TowerNESW	Strain in the NE-SW direction	Could compare disc thrust induced moments with model predictions; compensating errors, differential heating likely	3

Strain	TowerNWSE	Strain in the NW-SE direction	Could compare disc thrust induced moments with model predictions; compensating errors, differential heating likely	3
Strain	B1_Strain	Blade 1 Flap and edge root bending from Micron optics	Flap/edge bending induced moments could be compared with model predictions, but compensating errors likely	3
Strain	B2_Strain	Blade 2 Flap and edge root bending from Micron optics	Flap/edge bending induced moments could be compared with model predictions, but compensating errors likely	3
Strain	B3_Strain	Blade 3 Flap and edge root bending from Micron optics	Flap/edge bending induced moments could be compared with model predictions, but compensating errors likely	3

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