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CX-100 and TX-100 Blade Field Tests

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Abstract

In support of the DOE Low Wind Speed Turbine (LWST) program two of the three Micon 65/13M wind turbines at the USDA Agricultural Research Service (ARS) center in Bushland, Texas will be used to test two sets of experimental blades, the CX-100 and TX-100. The blade aerodynamic and structural characterization, meteorological inflow and wind turbine structural response will be monitored with an array of 75 instruments: 33 to characterize the blades, 15 to characterize the inflow, and 27 to characterize the time-varying state of the turbine. For both tests, data will be sampled at a rate of 30 Hz using the ATLAS II (Accurate GPS Time-Linked Data Acquisition System) data acquisition system. The system features a time-synchronized continuous data stream and telemetered data from the turbine rotor. This paper documents the instruments and infrastructure that have been developed to monitor these blades, turbines and inflow.

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INTRODUCTION

In support of a major DOE program, two of the three Micon 65/13M wind turbines at the USDA Agriculture Research Service (ARS) center in Bushland, Texas, will be used in support of the Low Wind Speed Turbine (LWST) program. Testing of two novel concepts and manufacturing techniques for blades are the major goals of this program.

On both tests, the blade aerodynamic and structural characterization, meteorological inflow, and wind turbine structural response are being monitored with a total of 75 instruments: 33 to characterize the blades, 15 to characterize the inflow, and 27 to characterize the time-varying state of the turbine. The primary characterization of the inflow relies upon 1 sonic anemometer at hub height, 4 cup anemometers, 4 wind vanes, 2 temperature probes, and 1 barometer. The structural response of the turbine is being measured using several sets of strain gauges to measure bending loads on the hubs and towers. To describe the motion of the nacelles, six-axis inertial measurement units (IMUs) output both acceleration and velocity on all three axes. Data is sampled at a rate of 30 Hz using the ATLAS II (Accurate GPS Time-Linked Data Acquisition System) data acquisition system. The system features a time-synchronized continuous data stream and telemetered data from the turbine rotor.

This paper documents the instruments and infrastructure that have been developed to monitor these blades and turbines and their inflow.

TEST SITE

The two turbines used in this experiment are located on the USDA-ARS site in Bushland, Texas. This site is characteristic of the Great Plains with essentially flat terrain. The test site is surrounded by farmland. On the NNW corner of the test site is a reservoir surrounded by an approximately 1.2-m (4-ft)-high berm. As illustrated in the map shown in Figure 1, the site slopes down approximately 1 m (3 ft) to the SSE across the span of the turbine bases.

The primary wind direction at the site is from 215° with respect to true north.* The wind rose for this site shows a secondary peak for winds from approximately due north.

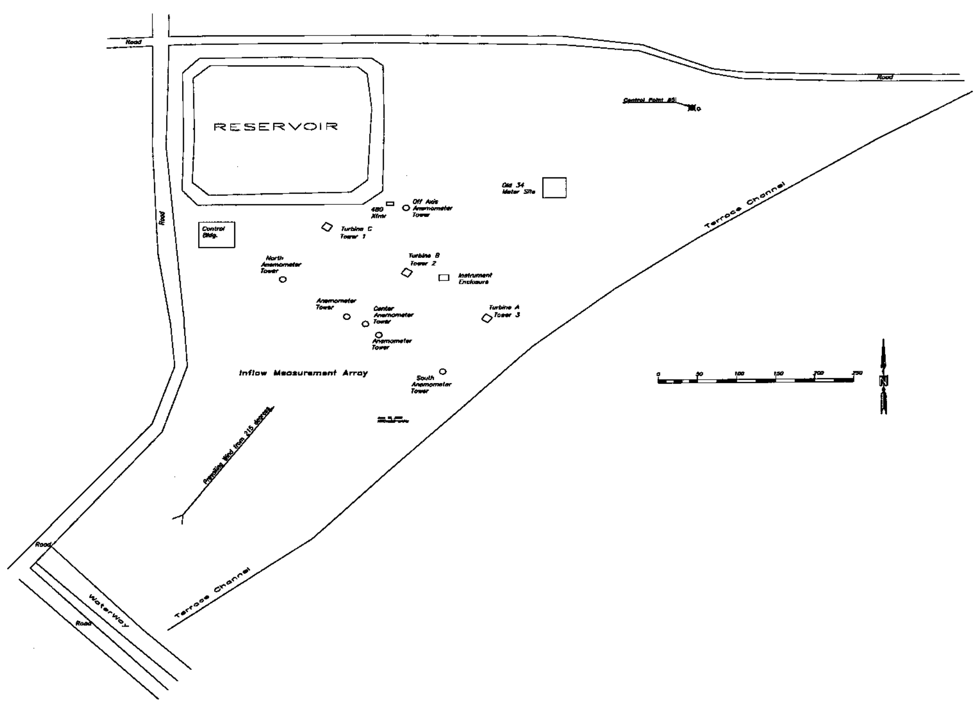


Figure 1. Layout Map of the USDA-ARS Site in Bushland, TX.

Site Plan

As shown in Figure 2, the three turbines have been placed on this site in a straight line across the prevailing wind direction of 215°. The towers are labeled 1, 2, and 3 and the nacelles are labeled A, B, and C.

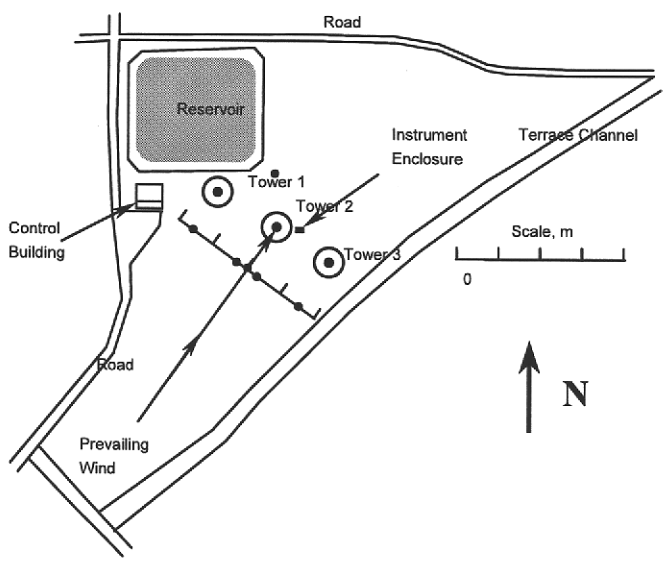


Figure 2. A Schematic Overview of the Test Site.

Upwind of the turbines (with respect to the prevailing winds) are five meteorological (met) towers. As reported previously[1], these towers were equipped with a large array of instrumentation that was used in the previous Long-Term Inflow and Structural Test (LIST) campaign. For the testing of both the CX-100 (Carbon eXperimental - 100kW) and the TX-100 (Twist-bend coupled eXperimental – 100 kW), only the met tower in front of the machine will be used. For the secondary prevailing wind direction (approximately north) a sixth meteorological tower is used. The nomenclature used to designate each of these towers is given in Fig. 3.

A detailed dimensional drawing of the position of the turbines and the meteorological towers is also given in Figure 3 .

Buildings

Two buildings are on the test site (see Figure 2). The main "Control Building" is west of Tower 1. A small "Instrumentation Building" is located east of Tower 2. The latter building provides environmental protection for a number of signal processors and wiring junction points in the data system. Neither the reservoir nor the buildings obstruct the inflow to the turbines from the prevailing wind direction. For inflow from the secondary wind direction (north), the turbines will also have an unobstructed inflow.

* All compass headings are given with respect to True North.

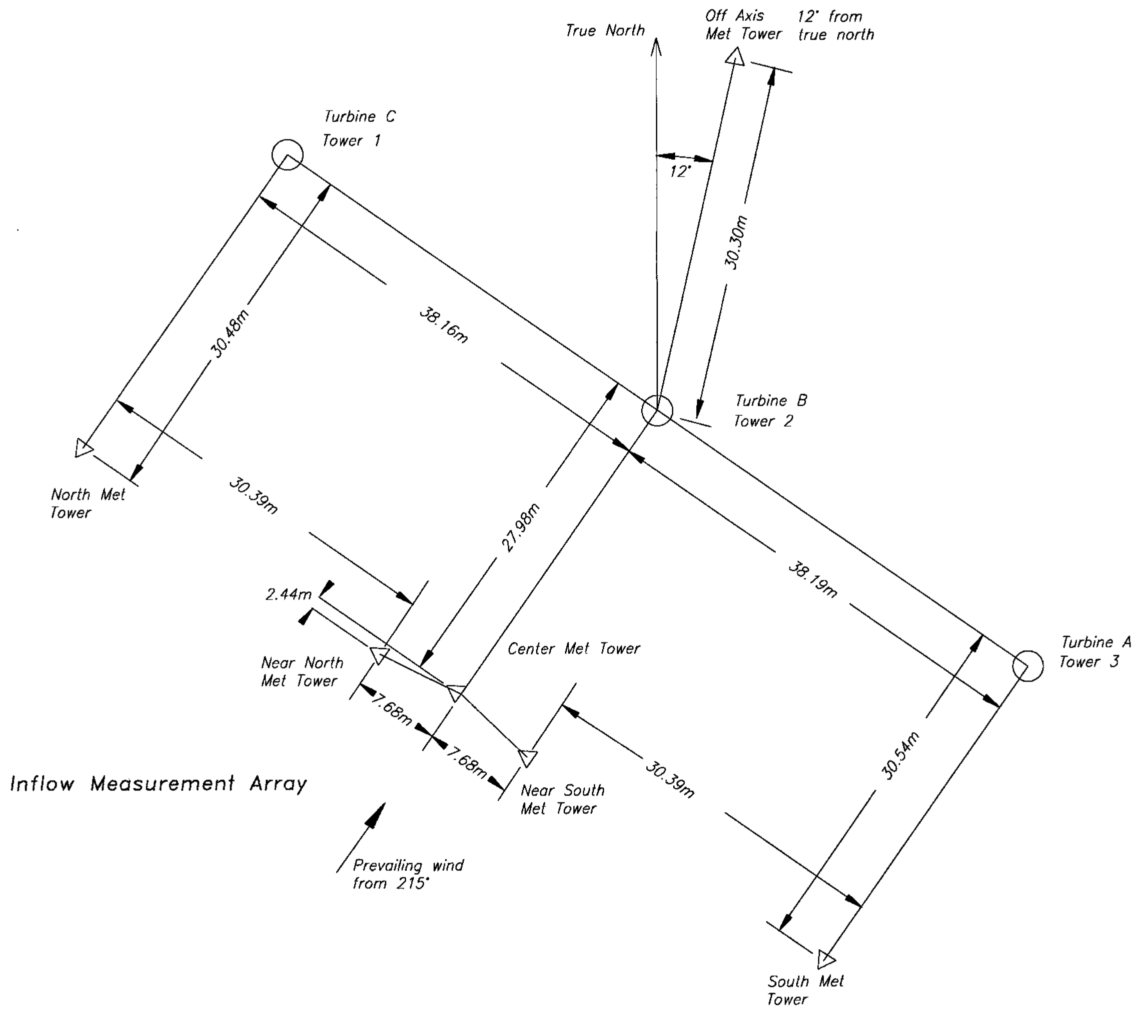


Figure 3. Site Plan with Detailed Dimensions.

THE TEST TURBINES

The turbines are a modified versions of the Micon 65/13 turbine (65/13M) (see Figure 4). Each turbine is designed as a three-bladed, fixed-pitch, upwind turbine using an induction generator. At hub height, the turbine stands 23 m (75 ft) tall on a tubular, three-piece steel tower that weighs approximately 64.5 kN (14,500 lb). The nacelle weight is approximately 42.7 kN (9,600 lb).

The turbines are used machines that ran in the Palm Springs (CA) area for approximately 15 years. During that period, several turbine subsystems were modified to increase performance and reliability. Modified subsystems include the brakes, gearbox, generator and blades. The new drive train is built around an induction, three-phase 480v generator rated at 115 kW. The generator operates at 1200 rpm while the blades turn at a nominal 55 rpm (the standard Micon 65/13 turbine rotates at 45 rpm). A detailed description of the placement of the turbines is provided in Figure 3.

Figure 4. The Test Turbines at the USDA-ARS Site in Bushland, TX.

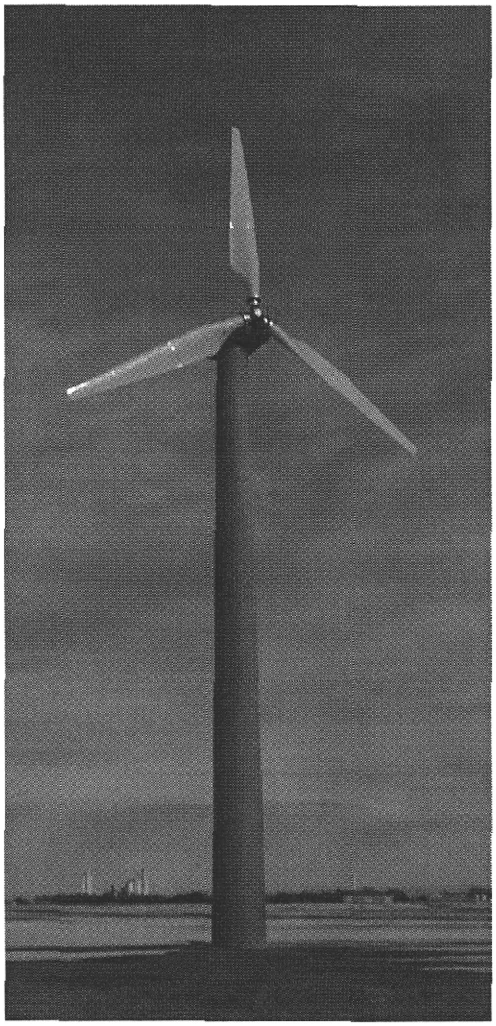


Figure 5. The LWST Turbine.

The Micon Turbines

The *Micon turbines* used in this experimental campaign are A and B nacelles on Towers 2 and 3 respectively (see Figures 3 and 5). From a mechanical standpoint, the main difference between the "B" turbine and its sister turbine "A" is the blade configuration. The "B" turbine is fitted with CX-100 blade. The CX-100 blades, based on ERS100 airfoils and platform, are 9 m (354.3 in) long, yielding a rotor diameter of 19.3 m (63.3 ft). The design consists of a fiberglass shell with a carbon fiber sparcap. The hub flange for mounting the blades is located 599 mm (23.6 in) from the centerline of the low-speed shaft. The hub is a fixed-pitch blade design. The blades are designed to have 0° pitch at the 75 percent span line. The "A" turbine is fitted with TX-100 blades that have the same dimensional and aerodynamic design as the CX-100. The primary difference between the two sets is that the TX-100 has off-axis carbon fiber in the skin to allow the blade to twist under load.

INSTRUMENTATION

The turbines and the meteorological inflow at the Bushland site are being monitored with a total of 75 instruments: 33 to characterize the blades, 15 to characterize inflow, and 27 to characterize the time-varying state of the turbine. Primary structural characterization of the blade response consists of 18 sets of strain gauges for the CX-100 and 15 gauges for the TX-100 to measure bending loads on the blades, and 9 instruments on each to measure the tower and nacelle motion. Most of these instruments are concentrated on the inflow towers and two test turbines. See the schematic diagrams shown in Figures 6 and 7.

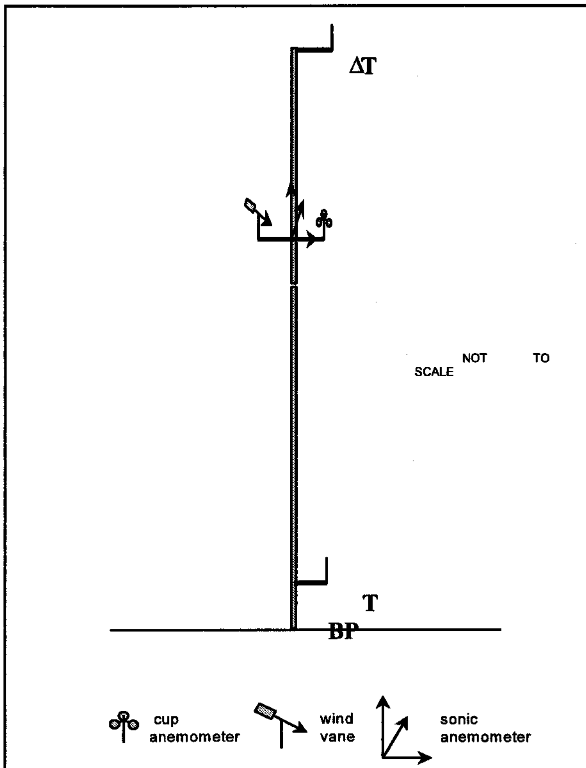


Figure 6. Diagram of the Inflow Instrumentation for the Micon "B" Turbine.

Instrumentation Summary and Nomenclature

A complete list of the 75 instruments used here is presented in Tables 1, 2 and 3. These tables divide the instruments into three general classifications: inflow, rotor, and nacelle. The nomenclature used to identify each gauge circuit is also included in these tables.

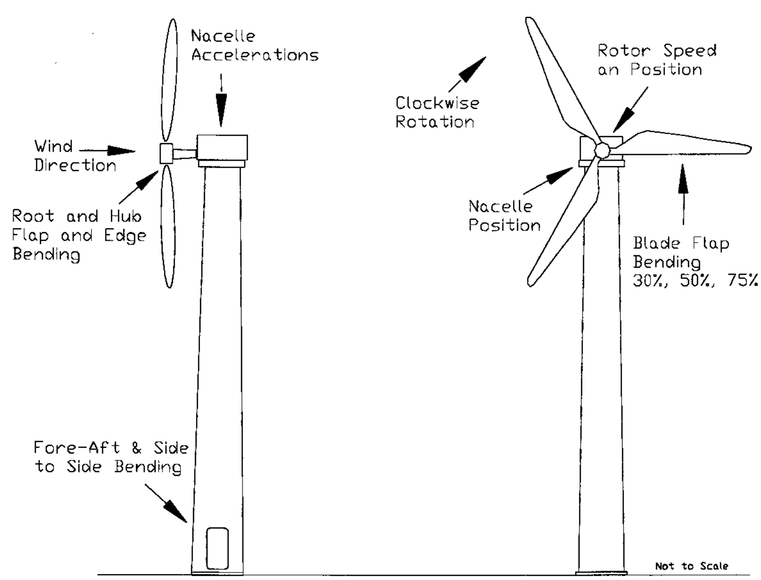


Figure 7. Diagram of the Structural Instrumentation for the Micon Turbines.

Table 1. Turbine Instrumentation.

DAS Channel	Instrument		Placement	Met Tower
BAHHC	Cup Anemometer		Hub Height	Center
BAHHV	Wind Vane			
BAHHATI	Ultrasonic Anemometer	U		
		V		
		W		
		T		
BATP	Temperature			
BADTP	Differential Temperature Δ T		2m to Top	
AAHHC	Cup Anemometer		Hub Height	North
AAHHV	Wind Vane		Hub Height	
CAHHC	Cup Anemometer		Hub Height	South
CAHHV	Wind Vane		Hub Height	
OHHC	Cup Anemometer		Hub Height	Off-Axis
OHHV	Wind Vane		Hub Height	
EPR	Barometric Pressure		2m	Instrument Building

Table 2. Turbine Instrumentation.

Turbine	DAS Channel	General Type	Measurement	Placement
Nacelle A, Tower 3	ATBFA	Tower Bending	Fore-Aft	Tower Bottom
	ATBSS		Side-to-Side	
	ATOO	Turbine Monitor	On/Off	Controller
	ATP	Total Power Production	Electric Power	Controller
	ATYAW	Yaw Position	Nacelle Position	Tower Top
	ATRA	Rotor Azimuth	Blade 1 Position	Main Shaft
	ATRS	Rotor Speed	Blade Speed	
	ATAX	Acceleration X	Acceleration Fore & Aft	Nacelle
	ATAY	Acceleration Y	Acceleration Side To Side	
	ATAZ	Acceleration Z	Acceleration Up & Down	
	ATRX	Pitch Rate	Pitch Rate	
	ATRY	Roll Rate	Roll Rate	
	ATRZ	Yaw Rate	Yaw Rate	
Nacelle B, Tower 2	BTBFA	Tower Bending	Fore-Aft	Tower Bottom
	BTBSS		Side-to-Side	
	BTOO	Turbine Monitor	On/Off	Controller
	BTP	Total Power Production	Electric Power	Controller
	BTYAW	Yaw Position	Nacelle Position	Tower Top
	BTRA	Rotor Azimuth	Blade 1 Position	Main Shaft
	BTRS	Rotor Speed	Blade Speed	
	BTAX	Acceleration X	Acceleration Fore & Aft	Nacelle
	BTAY	Acceleration Y	Acceleration Side To Side	
	BTAZ	Acceleration Z	Acceleration Up & Down	
	BTRX	Pitch Rate	Pitch Rate	
	BTRY	Roll Rate	Roll Rate	
	BTRZ	Yaw Rate	Yaw Rate	
Nacelle C	CTP	Total Power Production	Electric Power	Controller

Table 3. Rotor Instrumentation.

Nacelle A

DAS Channel	Blade	General Measurement	Position
ATB1RFB	Blade 1	Root Flap Bending	Root
ATB1REB		Root Edge Bending	Root
ATB1FB30		Flap Bending	25% of Span
ATB1FB50		Flap Bending	50% of Span
ATB1FB75		Flap Bending	75% of Span
ATB1HFB		Hub Flap Bending	Hub
ATB1HEB		Hub Edge Bending	Hub
ATB2RFB	Blade 2	Root Flap Bending	Root
ATB2REB		Root Edge Bending	Root
ATB2HFB		Hub Flap Bending	Hub
ATB2HEB		Hub Edge Bending	Hub
ATB3RFB	Blade 3	Root Flap Bending	Root
ATB3REB		Root Edge Bending	Root
ATB3HFB		Hub Flap Bending	Hub
ATB3HEB		Hub Edge Bending	Hub

Nacelle B

DAS Channel	Blade	General Measurement	Position
BTB1RFB	Blade 1	Root Flap Bending	Root
BTB1REB		Root Edge Bending	Root
BTB1FB30		Flap Bending	25% of Span
BTB1FB50		Flap Bending	50% of Span
BTB1FB75		Flap Bending	75% of Span
BTB1HFB		Hub Flap Bending	Hub
BTB1HEB		Hub Edge Bending	Hub
BTB2RFB	Blade 2	Root Flap Bending	Root
BTB2REB		Root Edge Bending	Root
BTB2FB30		Flap Bending	25% of Span
BTB2FB50		Flap Bending	50% of Span
BTB2FB75		Flap Bending	75% of Span
BTB2HFB		Hub Flap Bending	Hub
BTB2HEB		Hub Edge Bending	Hub
BTB3RFB	Blade 3	Root Flap Bending	Root
BTB3REB		Root Edge Bending	Root
BTB3HFB		Hub Flap Bending	Hub
BTB3HEB		Hub Edge Bending	Hub

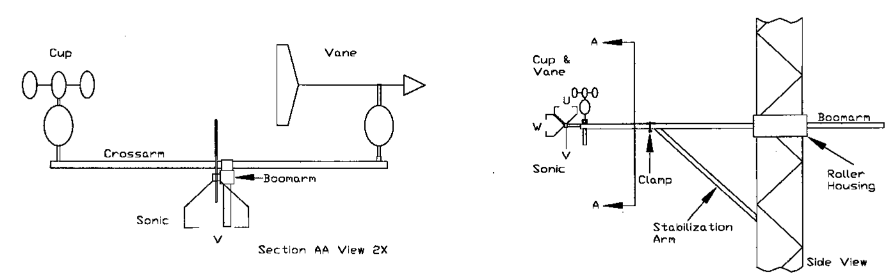
Inflow Instrumentation

The meteorological inflow for the three turbines is monitored with cup anemometers, wind vanes, and a sonic anemometer (see Figure 6). As noted above, this instrumentation is mounted on four meteorological towers. Figure 3 provides a detailed description of the position of each meteorological tower and its nomenclature. Appendix A provides a detailed diagram of each tower.

Most of the anemometry is located at approximately 30.7 m (101 ft) upwind (with respect to the prevailing wind) of the turbines. This dimension is equivalent to approximately 1.7 rotor diameters in front of the turbines.

There are three towers directly in front of the tower 2 "B" Nacelle (see Figure 3). The center tower is directly upwind (with respect to the prevailing wind) of the Micon turbine. The other two towers were used on previous tests, and will not be used for the CX-100 and TX-100 tests. The center meteorological tower has one cup anemometer, a wind vane, and a sonic anemometer mounted at hub height (see Figure 6). The inflow into the other test turbine ("A") is monitored with a hub-height cup anemometer and a wind vane on the south met tower as shown in Figure 3. The inflow for the other turbine ("C") is monitored with a hub-height cup anemometer and a wind vane on the north met tower. To monitor the secondary wind direction, a cup anemometer and a wind vane are mounted at hub height on the off axis met tower that is located at approximately 30.3 m directly north of Tower 2 (see Figure 3).

The inflow instrumentation on the center meteorological tower is mounted on the end of an extension arm to preclude blockage effects from the tower (see Figure 8). This extension or boom arm holds the instrumentation approximately 2.4 m (7.9 ft) in front of the meteorological tower, with respect to the primary prevailing winds. This is equivalent to 5 anemometer tower diameters. The arm is mounted in a roller support housing that permits the instrumentation to be rolled towards the tower for maintenance. The arm is stabilized vertically and horizontally with two supporting brackets. The center tower is set back to compensate for the extension provided by this boom (see Figure 3) to place all of the anemometry in the same plane perpendicular to the prevailing winds. The inflow instrumentation on the other towers is mounted on the top of the tower, and therefore no extension arms are required (see Figure 9 for a diagram of a typical installation).



(a) Front View. **(b) Side View.**

Figure 8. Mounting of the Inflow Instrumentation on an Extension Arm.

Cup Anemometer

Four cup anemometers are used to monitor the inflow. Three are placed at hub height in front (with respect to the primary prevailing winds) of each turbine and another is placed at hub height in the secondary wind direction (see Figure 6(.

The cup anemometer is a Wind Speed Transmitter (cup), Model 1564B, provided by Met One Instruments Incorporated.[2] A complete description of this instrument is provided in Appendix B. The mounting method is shown in Figure 8.

Wind Vane

A total of four wind vanes are used in this installation and all are placed at hub height. One is placed in front of each turbine (with respect to the primary prevailing winds), and the fourth is placed at hub height in the secondary wind direction.

The wind vane installations are shown in Fig. 8. The system used is a Wind Direction Transmitter, Model 1565C, provided by Met One Instruments Incorporated[2] (see Appendix B).

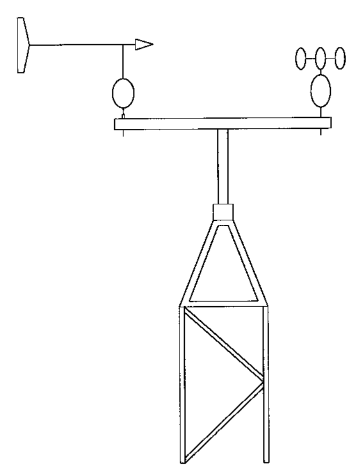


Figure 9. Tower-Top Mounting of a Cup and Vane.

Sonic Anemometers

One sonic anemometer is used in this installation positioned in front (with respect to the primary prevailing winds) of Tower 2. The location of this anemometer on the tower is shown in Figure 6.

The sonic anemometer installation is shown in Figure 8. The system is a model SATI/3K, Applied Technologies Incorporated[3] (see Appendix B). The unit measures three velocity components and the "sonic" temperature (calculated from the wind speed). The positive wind direction for the U component is 215°, the positive wind direction for the V component is 125°, and the positive wind direction for the W component is vertically up.

Temperature

The absolute temperature is measured at the center meteorological tower, approximately 1.6 m (5.1 ft) above ground level, by a four-wire platinum resistance temperature (PRT) detector, Met One Model No. 0631.[2] The temperature sensor is mounted with a solar shield on the end of a tubular arm at about 1 m from the tower in the primary prevailing wind direction of 215° (see Figure 10 and Appendix B).

Differential Temperature

The differential temperature is measured on the center meteorological tower, between the top of the tower at 33.6 m (110 ft) and at ground level 1.6 m (5.1 ft) by a four-wire platinum resistance temperature (PRT) detector (see above). A positive differential temperature reading indicates that the temperature at the top of the rotor is higher than the temperature at ground level.

Barometric Pressure

The absolute barometric pressure is measured at approximately 2.13 m (7 ft) above ground level, inside the Instrument Building (see Appendix B), using a sensor manufactured by Yellow Spring Instruments.[4]

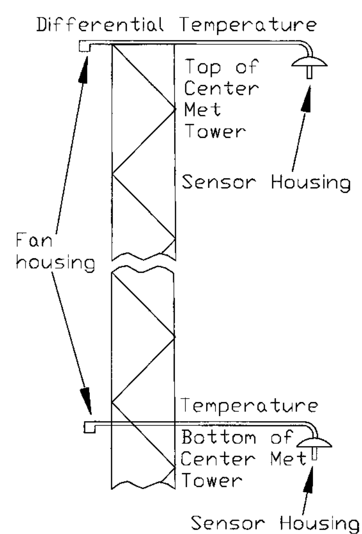


Figure 10. Mounting of the Temperature and Delta Temperature Probes.

Blade Instrumentation

The structural response of the blades on the rotor is measured with a variety of gauges, primarily strain gauges. A schematic of the strain measurement locations is shown in Figure 7.

Most of the strain gauge circuits are placed on the rotor. Each blade is instrumented at its root, and at least one blade from each series of blades is instrumented at approximately 25, 50, and 75 percent span station with strain gauge bridges that measure flap bending. After being mounted in the blade all strain gauges were calibrated by static loading the blade.

Strain Gauge Circuits

A total of 33 strain gauge circuits are used on each of the CX-100 and TX-100 blade tests (see Figure 7). A complete list of the strain gauge circuits is given in Table 4. A full bridge completion unit was used on all circuits.

Blade Strain Gauges

The strain gauges are dual–element, encapsulated 350-ohm gauges (Micro Measurements WK-06-250PD-350)[5] located at the root, 25, 50, and 75 percent of span of one blade and only at the root on the other two blades (see Figure 7 and Appendix B).

Hub Strain Gauges

The strain gauges are dual–element, encapsulated 350-ohm gauges (Micro Measurements WK-06-250PD-350)[5] located on each arm of the hub (see Figure 7 and Appendix B).

Table 4. Strain Gauge Circuits.

Tower 3 and Nacelle A

Type	Active Elements	Position	Gauge Type	Resistance (ohms)	DAS Channel	Direction
Bending	2	Tower	WK-06-250TM-350	350	BTBFA	Fore-Aft
					BTBSS	Side-to-Side
	4	Hub 1	WK-06-250PD-350	350	BTBIHFB	Hub Flap
					BTB1HEB	Hub Edge
		Blade 1	WK-06-250PD-350	350	BTB1RFB	Root Flap
					BTB1REB	Root Edge
					BTB1FB30	25 % Flap
					BTB1FB50	50 % Flap
					BTB1FB75	75 % Flap
		Hub 2	WK-06-250PD-350	350	BTB2HFB	Hub Flap
					BTB2HEB	Hub Edge
		Blade 2	WK-06-250PD-350	350	BTB2RFB	Root Flap
					BTB2REB	Root Edge
		Hub 3	WK-06-250PD-350	350	BTB3HFB	Hub Flap
					BTB3HEB	Hub Edge
		Blade 3	WK-06-250PD-350	350	BTB3RFB	Root Flap
					BTB3REB	Root Edge

Tower 2 and Nacelle B (continued)

Type	Active Elements	Position	Gauge Type	Resistance (ohms)	DAS Channel	Direction
Bending	2	Tower	WK-06-250TM-350	350	ATBFA	Fore-Aft
					ATBSS	Side-to-Side
	4	Hub 1	WK-06-250PD-350	350	ATB1HFB	Hub Flap
					ATB1HEB	Hub Edge
		Blade 1	WK-06-250PD-350	350	ATB1RFB	Root Flap
					ATB1REB	Root Edge
					ATB1FB30	25 % Flap
					ATB1FB50	50 % Flap
					ATB1FB75	75 % Flap
		Hub 2	WK-06-250PD-350	350	ATB2HFB	Hub Flap
					ATB2HEB	Hub Edge
		Blade 2	WK-06-250PD-350	350	ATB2RFB	Root Flap
					ATB2REB	Root Edge
					ATB2FB30	25 % Flap
					ATB2FB50	50 % Flap
					ATB2FB75	75 % Flap
		Hub 3	WK-06-250PD-350	350	ATB3HFB	Hub Flap
					ATB3HEB	Hub Edge
		Blade 3	WK-06-250PD-350	350	ATB3RFB	Root Flap
					ATB3REB	Root Edge

Tower Instrumentation

The towers are instrumented with dual-element, encapsulated 90° tee rosette, 350-ohm gauges. These bending circuits use Micro Measurements WK-06-250TM-350 strain gauges[5] (see Figure 7 and Appendix B). The gauges are located approximately 3.9 m (154 in) above the turbine base. One set measures tower fore-aft bending (along the prevailing wind direction) and the other measures side-to-side bending (across the prevailing wind direction).

Nacelle Motion

Each nacelle is instrumented with one Micro-Electro-Mechanical Systems (MEMS) device six-axis inertial measurement unit (IMU). The IMU measures the fore-aft, side-to-side, and up-down accelerations with three MEMS accelerometers, as well as pitch, roll, and yaw rates with three angular rate sensors consisting of vibrating ceramic plates that utilize the Coriolis force to output angular rate independent of acceleration. The instrument is a Crossbow Inertial Measurement Unit, IMU300CC-100,[6] and is located on the nacelle frame next to the gearbox (see Figure 7 and Appendix B).

Additional Instrumentation

In addition to the instrumentation cited above, several other turbine parameters are measured (see Table 2). These include nacelle yaw position, rotor position, rotor speed, turbine monitor (on-off switch), and electrical power output. The yaw and rotor positions are measured directly with 360° angle encoders. The turbine monitor indicates the state of the grid and turbine connection, i.e., whether or not the turbine is connected to the grid. The electrical power production for each of the three turbines is monitored using three-phase electrical power transducers.

Yaw Position

Nacelle yaw position is measured using a brushless rotary encoder, Computer Conversions Corporation model HSTDCC-PB16S-SE.[7] The encoder is located on the yaw drive gear box inside the nacelle (see Figure 11). The encoder shaft is connected to the yaw drive using a toothed belt pulley system. The sizes of the pulleys in this system were chosen to yield a 1:1 rotation ratio between the encoder and the yaw position (see Appendix B). The unit was calibrated to yield a yaw measurement of zero when the nacelle points to true north.

Rotor Azimuth and Velocity

Rotor azimuth and velocity are measured by a brushless rotary encoder (Model No. EVSTDCC-PB16VIC-SIRPS from Computer Conversions Corporation[7]). The encoder is located adjacent to the low speed shaft on the nacelle (see Figure 11). The encoder shaft is connected to the main drive shaft using a sprocket-chain drive gear system. The sizes of the gears in this system were chosen to yield a 1:1 rotation ratio between the encoder and the main shaft (see Appendix B). The unit was calibrated to yield a 0° signal output when Blade 1 is vertically up. The blade numbering sequence for the rotor is 1-3-2 clockwise as observed from the upwind direction.

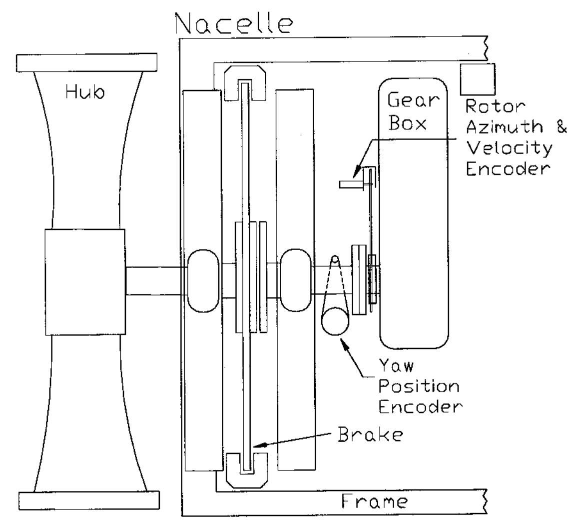


Figure 11. Rotor Azimuth, Velocity, and Nacelle Yaw Position.

Turbine Status

The turbine monitor circuit is an on/off signal that indicates if the turbine is connected to the grid; i.e., the turbine rotor rpm is up to speed and the generator is connected to the utility grid. This signal is derived from the controller signal that engages the generator-to-grid connection; an auxiliary power supply, driven by the control signal, is used to supply the on/off voltage signal to the data acquisition system. The relay, in the controller, is located in the turbine control junction box at the base of the turbine tower.

Power Production

The electrical power produced by each of the three turbines is monitored using precision self-powered voltage, current watt, volts amps reactive (VAR), and transducers from Ohio

Semitronics.[8] For this installation, only the total power (three-phase) is being recorded. As warranted, additional electrical measurements may or may not be added to the data record. The electrical instruments are located in the turbine control junction boxes at the base of each turbine tower (see Appendix B.)

DATA ACQUISITION SYSTEM

For both tests, the Accurate GPS Time-Linked Data Acquisition System[1,9] (ATLAS II) will be used. The ATLAS II is designed to acquire long-term, continuous, time-synchronized, multi-channel time series data from meteorological towers and an operating wind turbine. The 16-bit data stream from the ATLAS II hardware system is acquired and recorded using the ATLAS II software. The software segments the continuous data stream into 10-minute blocks and stores them for future processing. The data can be stored in raw state as the data is collected or it can be converted to engineering units using calibration factors.

For this series of experiments, the data sample rate is 30 Hz. This yields a Nyquist frequency of 15 Hz, which is sufficient for capturing the behavior of the inflow and the structural response of the turbine.

ATLAS II

For this experiment, two ATLAS II are used in the data acquisition system (DAS). The first ATLAS unit is a ground-based unit (GBU). This unit is located in the Instrument Enclosure near the base of Tower 2 (see Figure 2). The second is a rotor-based unit (RBU) that is mounted to the rotor.

The GBU is mounted in the "instrumentation rack" inside the instrument enclosure (see Appendix C). It monitors the instrument circuits cited in Tables 1and 2; i.e., all instruments except the strain gauge circuits on the rotors. The GBU has five 8-channel analog cards and one 8-channel bridge card. The bridge and analog circuits use a second-order anti-aliasing active filter followed by a programmable fifth-order Butterworth filter. The cut-off frequency for the latter filter was set to 15 Hz, the Nyquist frequency.

The rotor strain gauges are monitored with the RBU. This unit, called "Windy," contains three 8-channel bridge circuit cards that monitor the strain gauge circuits described in Table 3. Data from the RBU is telemetered to the master GBU. The GBU integrates the RBU data stream into the main data stream to form a single data stream that is then transmitted to the system computer (running ATLAS II software).

A total of 75 channels (timing, measurement, and synchronizing channels) are monitored with this system computer.

All of these units (GBU and RBU) are programmed using an ATLAS II software package developed by Zayas, Ortiz-Moyet and Jones.[1] The GBU can be programmed via a fiber-optic link, while the RBU is currently programmed through a wireless radio frequency connection.

Data Archival

The ATLAS II system PC is networked to a data archival and processing PC, also located in the Control Building. This data archival PC retrieves the data from the acquisition PC and performs a series of verifications to ensure data integrity in addition to calculating simple statistics on the data. This allows the data to be verified, ensuring that all channels are working.

Approximately once a week the site test engineer downloads the zipped data files to DVD for permanent storage and analysis. When the download is complete, the archived files are removed from the hard disk to free space for the next set of data files.

WIRING DIAGRAMS

The 75 instrument channels that are monitored in this measurement campaign are hardwired to the three ATLAS II units. The myriad of cables and junction boxes that are required to power and monitor the instrumentation are described here. Appendix C presents a complete set of the wiring diagrams for each cable bundle and junction box.

Instrument Enclosure

The large number of wires, "black boxes," power supplies, lightning protection, terminal strips, and telemetry signals are housed in the instrument enclosure (see Figure 12). This enclosure is sealed to protect the instruments from rain, dust, rodents, etc. Most of the hardwired circuits into and out of the enclosure have lightning protection. The instrument enclosure is a large electrical junction box 1.83 m (6 ft) wide by 1.83 m (6 ft) high by 0.61 m (2 ft) deep with circulation fans for cooling and environmental seals around its doors.

The enclosure is located in a small metal shed near the base of Tower 2 (see Figure 2). The shed is heated and cooled by a wall-mounted heat pump.

The enclosure is divided into two primary sections. The southwest side contains a slide-out instrument rack for mounting the data system and associated converters (signal processors) and power supplies. The rack is mounted on slides to permit the rack to be pulled out for easy access to front and rear control panels and wiring connections. The northeast side of the building contains connection boards and the lightning protection.

The enclosure also houses auxiliary power supplies and the uninterruptible power supply (UPS) unit that supplies AC power to all of the instrumentation and data systems.

The instrument rack, instrument enclosure, and the instrument building are grounded through a grid that is connected to the turbine towers, meteorological towers, guy wires, and test site buildings (see Appendix D).

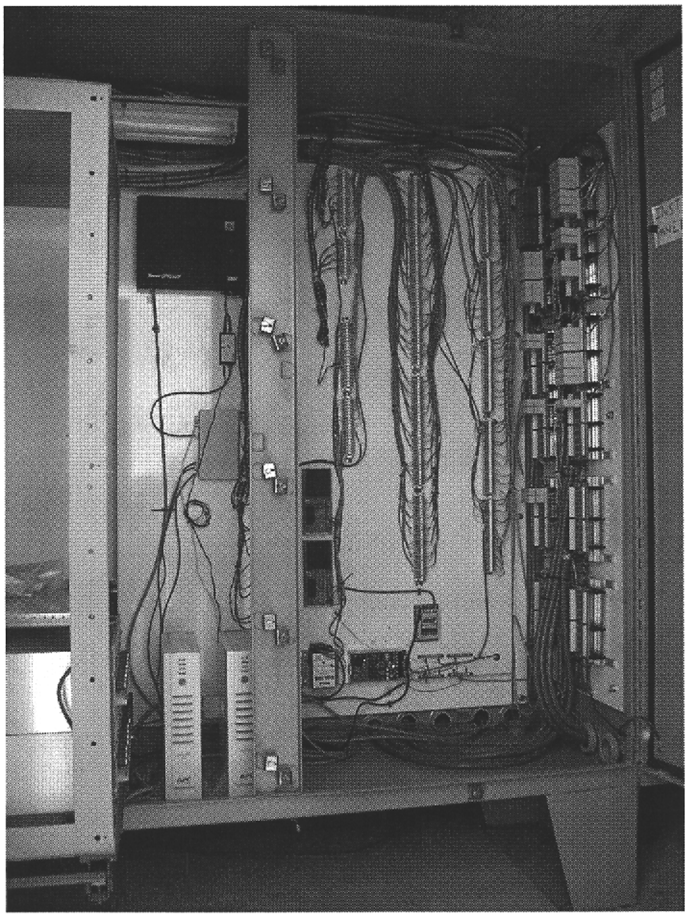


Figure 12. Instrumentation Rack Located in the Instrument Enclosure.

Lightning Protection

Because the Bushland test site is often subject to severe lightning storms, careful attention was paid to protecting the system from lightning damage. The first line of defense is the placement of an extensive ground grid that circles the site and each piece of equipment (see Appendix D). All instrument and circuit grounds and cable shields are connected to this ground grid.

Almost all of the electrical instrumentation leads into and out of the enclosure are protected with commercial high-speed gas tube/avalanche diode lightning protection circuits (Citel Inc.).[11] The specifications for these circuits are in Appendix C. The only circuit without lightning protection is a low-power data reception antenna lead connected to the data collection PC.

The ATLAS II units are connected to the main PC via fiber optics. This eliminates the susceptibility to lightning damage by isolating the instruments inside the instrument enclosure from the computers in the control room. Fiber optics units manufactured by Fiberplex[12] are used.

All circuits in the data acquisition system on the rotor are also protected using commercial high-speed gas tube/avalanche diode lightning protection circuits (Citel Inc.).

Cables

A large array of cables is used to power and monitor the various instruments. These cables were laid in conduits throughout the site (see Appendix D). All of the instrumentation cables are bundled 18-gauge twisted-pair cables with an overall shield and ground wires. In addition to the cables used for this measurement campaign, additional cables were laid in selected conduits to support future measurement campaigns on these turbines. A complete list of the instrument cables is provided in Tables 5, 6 and 7. The junction box wiring diagrams for these cables are provided in Appendix C.

Power cables used to connect the instrument building, center meteorological tower, and the turbines to the grid are laid in conduit separate from the conduit used for the instrumentation cables. The AC power cables are listed in Table 8. Wiring diagrams and specifications are provided in Appendix D.

Appendix D also provides conduit schedules for the cable system.

Table 5. Turbine Instrument Cables.

Tower Instrument Cables			
Tower	Name	Description	Routing
Tower 1	ATI1	15-Pair cable	Tower 1 to Instrument Enclosure
	ATI2	15-Pair cable (spare)	Tower 1 to Instrument Enclosure
	ATI3	15-Pair cable (spare)	Tower 1 to Instrument Enclosure
Tower 2	BTI1	15-Pair cable	Tower 2 to Instrument Enclosure
	BTI2	15-Pair cable (spare)	Tower 2 to Instrument Enclosure
	BTI3	15-Pair cable (spare)	Tower 2 to Instrument Enclosure
Tower 3	CTI1	15-Pair cable	Tower 3 to Instrument Enclosure
	CTI2	15-Pair cable (spare)	Tower 3 to Instrument Enclosure
	CTI3	15-Pair cable (spare)	Tower 3 to Instrument Enclosure

Table 6. Inflow Instrumentation Cables.

Inflow Instrument Cables			
Met Tower	Name	Description	Routing
Center Met Tower	BACI1	15-Pair cable	Center Met Tower to Instrument Enclosure
	BACI2	15-Pair cable	Center Met Tower to Instrument Enclosure
	BACI3	15-Pair cable (spare)	Center Met Tower to Instrument Enclosure
Near North Met Tower	BANI	9-Pair cable	Near North Met Tower to Center Met. Tower
Near South Met Tower	BASI	9-Pair cable	Near South Met Tower to Center Met. Tower
North Met Tower	AANI	9-Pair cable	North Met Tower to Instrument Enclosure
South Met Tower	CASI	9-Pair cable	South Met Tower to Instrument Enclosure
Off Axis Met Tower	OANI	9-Pair cable	Off Axis Met Tower to Instrument Enclosure

Table 7. Data Acquisition and Turbine Control Cables.

Data Acquisition Cables			
Control Building	Name	Description	Routing
Junction Box	ECI1	15-Pair cable	Control Building to Instrument Enclosure
Junction Box	ECI2	15-Pair cable	
Junction Box	ECI3	15-Pair cable	
Junction Box	ECI4	9-Pair cable (spare)	
Junction Box	ECI5	6-Pair cable	
Junction Box	ECIO1	Fiber Optic	
Junction Box	ECIO2	Fiber Optic (spare)	

Table 8. AC Power Cables.

AC Power Cables			
Turbine	Name	Description	Routing
Tower 1	ATP	4 ea. # 1 & 3 ea. # 10	Main Switch to Tower 1
Tower 2	BTP	4 ea. # 1 & 3 ea. # 10	Main Switch to Tower 2
Tower 2	BEP	6 ea. # 10	Transformer in Tower 2 to Inst. Bldg.
Tower 2	BACP	3 ea. # 10	Transformer in Tower 2 to Center Met Tower
Tower 3	CTP	4 ea. # 1 and 3 ea. # 10	Main Switch to Tower 3

Junction Boxes

At intermediate junctions, the instrumentation cables were connected to one another at various junction boxes typically placed at the base of the towers and in the instrument enclosure. The locations of these boxes are outlined in Appendix D and a wiring diagram for each is provided in Appendix C.

Ground Grid

An extensive earth ground grid was placed about the test site. Each turbine, each meteorological tower and its top guy-wires, the control building, and the instrument enclosure are all tied to this grid. The ground for the power grid is also tied to this grid. A diagram of this grid is presented in Appendix D.

CONCLUDING REMARKS

This report describes the instrumentation and infrastructure that has been developed to monitor the Micon turbines and their inflow at the Bushland test site. It also provides a detailed reference manual for those who choose to use this data in their studies of wind turbine behavior.

REFERENCES

1. Zayas, J.R., Jones, P.L., and Ortiz-Moyet, J., "Accurate GPS Time-Linked Data Acquisition System (ATLAS II) User's Manual," SAND2004-0491 February 2004.

2. Met One, Met One Instruments Inc., 1600 Washington Blvd., Grants Pass, OR 97526. http://www.metone.com/index.htm

3. Applied Technologies, Applied Technologies Inc., 1120 Delaware Ave. Longmont, CO 80501. http://www.apptech.com/index1.html

4. Yellow Springs Instruments, Inc., 1700/1725 Brannum Lane Yellow Spring, OH 45387. http://www.ysi.com/index.html

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6. Crossbow Technology, Incorporated. 4145 N. First Street, San Jose, CA 95134. http://www.xbow.com

7. Computer Conversions, Computer Conversions Corporation, 6 Dunton Court East Northport, NY 11731 USA. http://computerconversions.com/index.html

8. Ohio Semitronics, Ohio Semitronics Inc., 4242 Reynolds Dr. Hilliard, OH 43026. http://www.ohiosemitronics.com/

9. Berg, D.E., Rumsey, M.A., and Zayas, J.R., "Hardware and Software Developments for the Accurate Time-Linked Data Acquisition System," *2000ASME Wind Energy Symposium*, 200, p. 306.

10. Jones, Perry, Herbert J. Sutherland, and Byron A. Neal, "LIST/BMI Turbines Instrumentation and Infrastructure," SAND2001-1642 June 2001.

11. Citel Inc. Citel Inc., 1515 N W 167th Street - Suite 6-303, Miami, FL 33169. http://www.citelprotection.com/index.htm

12. Fiberplex, Fiberplex Inc,.10840-412 Guilford Road, Annapolis Junction, MD 20701. http://www.fiberplex.com/

13. Tower Systems, 17226 447th Ave, PO Box 1474, Watertown, SD 57201. http://www.towersystems.com/

APPENDIX A

DETAILED DIAGRAMS OF THE METEOROLOGICAL TOWERS

As noted above, there are a total of four meteorological (met) towers used in this experiment. Their locations at the site are described in Figure 3. Tower nomenclature is presented in Figure 3. This appendix describes in detail the position of the various instruments mounted on these towers.

Figure A-1 defines the symbols used on the met towers.

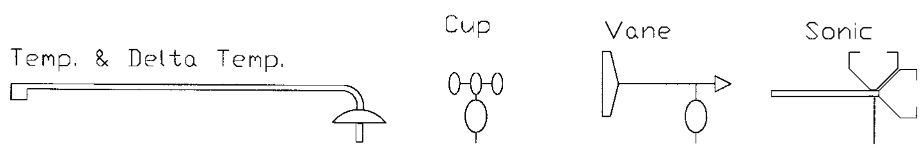

Figure A-1. Symbols Used on the Diagrams of the Meteorological Towers.

Center Meteorological Tower

A significant portion of instrumentation that characterizes the inflow is mounted on the center met tower. This tower is located directly in front, with respect to the prevailing wind of the LWST turbine (see Figure 3). The instrumentation includes one sonic anemometer, one cup anemometer, one wind vane, temperature and differential temperature. The position of all of these instruments is summarized in Figure A-2.

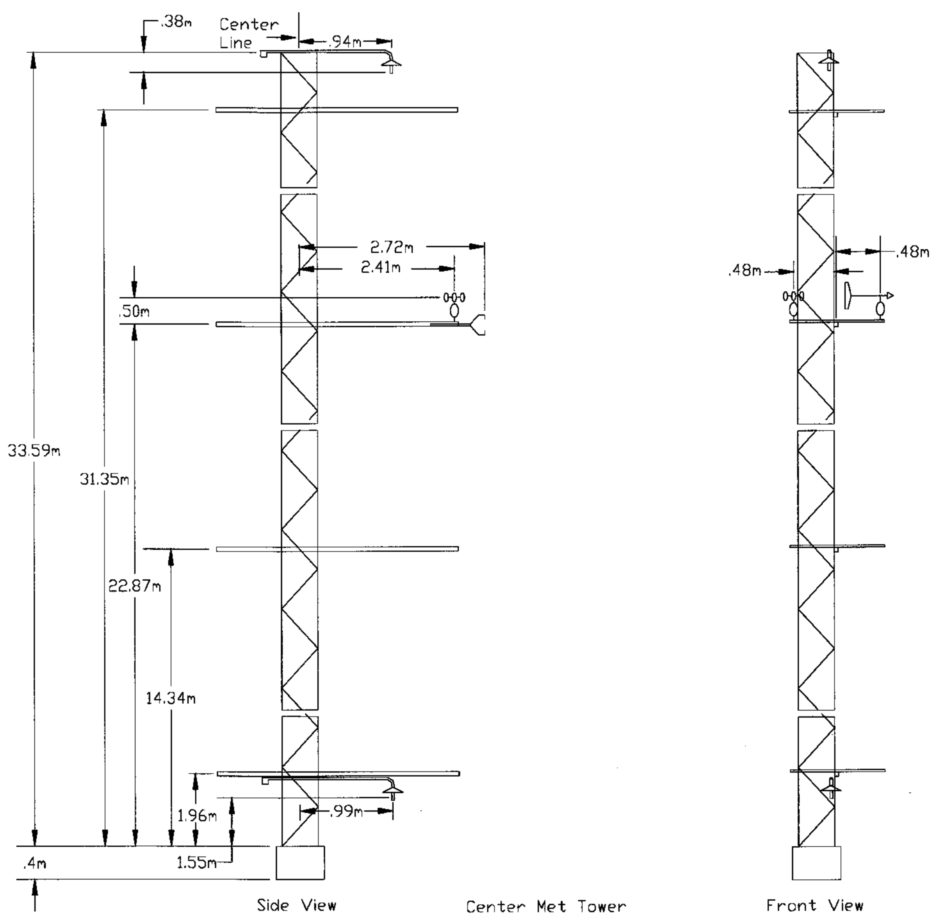

Figure A-2. Center Meteorological Tower.

North, South and Off-Axis Meteorological Towers

The remaining three towers (see Figure 3), have a cup anemometer and a wind vane mounted on their top. The position of these instruments is summarized in Figure A-3.

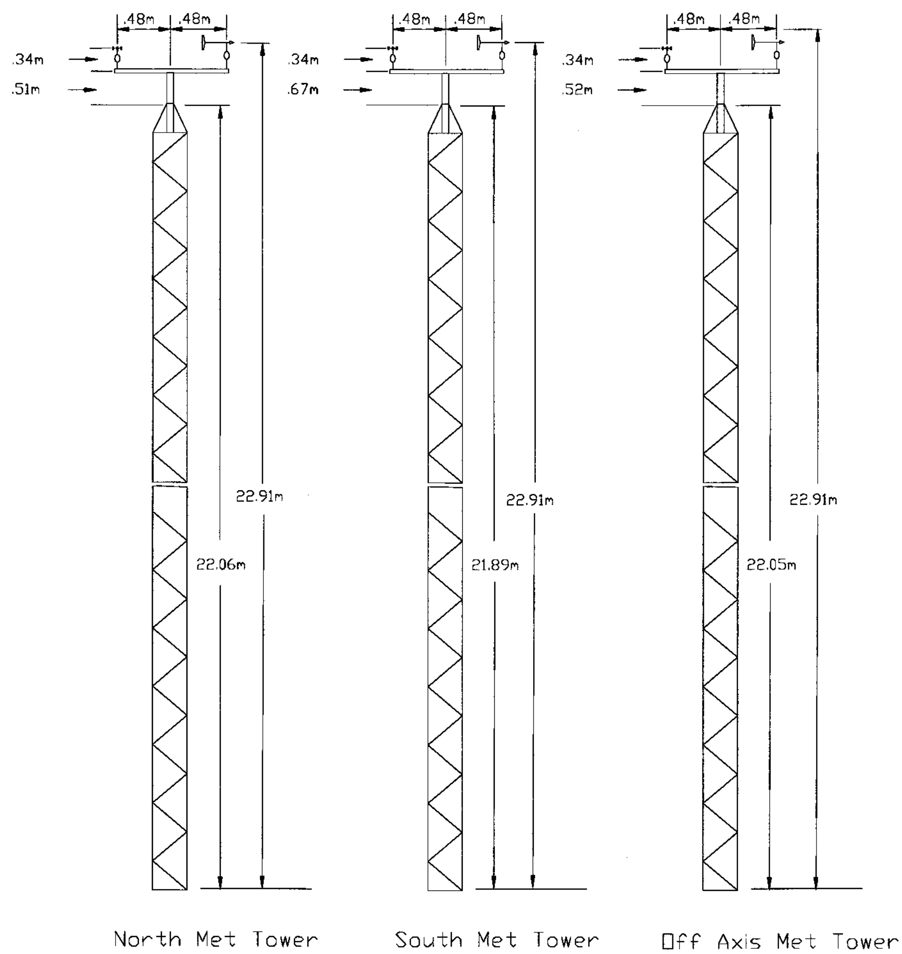

Figure A-3. North, South, and Off-Axis Meteorological Towers.

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APPENDIX B

INSTRUMENTATION SPECIFICATIONS

A complete list of the instrumentation circuits is given in Tables 1, 2 and 3. This appendix describes the instruments, their specification and their placement.

Met One Instrumentation

Met One Instruments Incorporated[2] wind speed, wind direction, temperature, differential temperature, and atmospheric pressure sensors are used here for the "standard" characterization of the inflow. The electronic packages that drive and process these sensors are rack-mounted units that are located in the instrument enclosure (see Appendix C).

The accuracy of the wind speed processor is ±0.1% of full scale and the accuracy of the wind direction processor is ± 0.1% of full scale.

Cup-and-Vane Anemometry

Cup Anemometer

Met One Model 1564B Wind Speed Transmitters[2] (cup) are used here for standard horizontal wind speed measurements. The accuracy of the instrument is ± 0.067 m/s or 1%, whichever is greater. The wind speed sensor uses highly reliable solid state optical sensing that is permanently aligned. The output of the sensor, a variable frequency signal, is sent to the signal processor. The output of the signal processor is an analog 0 to 5 VDC signal. For this installation, a 5-VDC output calibrates to a corresponding wind speed of 44.7 m/s (100 mph).

The cup anemometers are hardwired through junction boxes at the base of the met towers to the instrument enclosure. The signal processors for all of the cup anemometers are mounted in the bottom section of the instrumentation rack in the instrument enclosure inside the instrumentation building (see Appendix C).

Wind Vane

Met One Model 1565C Wind Direction Transmitters[2] (vane) are used for the standard horizontal wind direction measurements. The accuracy of the instrument is ±2%. The output of the sensor is a constant amplitude variable phase signal that is sent to the signal processor. The output of the signal processor is an analog 0 to 5 VDC signal, with 5 VDC corresponding to a full rotation of the vane.

The vanes are hardwired through junction boxes at the base of the met towers to the instrument enclosure. The signal processors for all of the cup anemometers are mounted in the bottom section of the instrumentation rack in the instrument enclosure inside the instrumentation building (see Appendix C).

Mounting Hardware

On the Center Tower, the cup and vane are mounted on cross arms that rotate 360° horizontally and adjust 0.52 m (1.5 ft) vertically. The cross arm is mounted at the end of an extendable boom arm made of aluminum tubing 5.08 cm (2 in.) square by 0.635 cm (0.25 in.) wall by 3.048 m (10 ft) long. The boom arm is mounted on the tower in a roller housing (Tower Systems Inc.)[13] that allows the boom arm to roll in and out of the roller housing. The arm is braced with 5.08-cm (2-inch) aluminum angle attached at the tower and clamped at about 1.22 m (4 ft) out on the arm (see Figure 8).

On the other towers (North, South and Off-Axis), the cup and vane cross arms are mounted directly to the top of the tower (see Figure 9).

Temperature Measurements

Absolute Temperature

The temperature is measured at approximately 1.6 m (5.1 ft) above ground level by a four-wire platinum resistance temperature detector (PRT), Met One Model No. 063-1.[2] The PRT produces a large output resistance change for a small input temperature change. The range of the PRT is ±50 °C with a quoted linearity of ±0.15 °C and an accuracy of ±0.1 °C. The output of the signal processor is an analog 0 to 5 VDC signal, with 0 volts corresponding to -50 °C and 5 VDC corresponding to 50 °C.

The temperature sensor is hardwired through a junction box at the base of the Center Tower to the instrument enclosure. The signal processor is mounted in the bottom section of the instrumentation rack in the instrument enclosure inside the instrumentation building (see Appendix C).

Differential Temperature

The differential temperature is measured between the top of the rotor [33.6 m (110 ft)], and the ground level [1.6 m (5.1 ft.)], with two four-wire PRTs, Met One Model No. 063-1[2] (see the discussion above; the lower differential temperature sensor is also the temperature sensor). The two signals are processed using a differential signal processor. The output of the signal processor is an analog 0 to 5 VDC signal, with 0 volts corresponding to -5 °C and 5 VDC corresponding to 15°C.

The temperature sensors are hardwired through a junction box at the base of the Center Tower to the instrument enclosure. The signal processor is mounted in the bottom section of the instrumentation rack in the instrument enclosure inside the instrumentation building (see Appendix C).

Mounting Hardware

The temperature sensors are mounted on the end a tubular arm with a solar shield over the sensor at about 1 m from the tower and aligned with the prevailing wind direction of 215° (see Figure 10). The temperature sensor is kept at ambient temperature by a 110-VAC fan at the opposite end of the tubular arm. Air is drawn over the sensor and exits at the fan end. The tubular arm is held in place by "U" bolts that attach it to the tower. The PRT is hardwired to a junction box at the base of the met tower and then wired to the instrument enclosure.

Barometric Pressure

The barometric pressure is measured at approximately 2.13 m (7 ft) above ground level, inside the instrument building. The instrument is a Yellow Springs Instruments Inc. Model 2014-75/1050.[4] The instrument range is 74.5 to 105 kPa with an accuracy of ± 0.125% of full scale.

The sensor is hardwired directly to the instrument enclosure. A Met One[2] signal processor is used to monitor this gauge. The Met One processor is mounted in the bottom section of the instrumentation rack in the instrument enclosure inside the instrumentation building (see Appendix C).

Sonic Anemometer

One Applied Technologies Incorporated Sonic Anemometer/thermometer[3] model SATI/3K is used here for the "detailed" inflow measurement. This unit measures three velocity components (two horizontal, U and V, and one vertical, W) and the sonic temperature. Its accuracy is ± 0.05 m/sec on wind velocity and ±1° above 2 m/sec on wind direction, ±0.05 °C on sonic temperature, and ±2° absolute temperature. Resolution is 0.01 m/sec on wind velocity, 0.1° on wind direction, and 0.01 °C on temperature. The sample rate is 200 Hz with 12 bit resolution digital output. The output of its analog signal processor ranges from -5 VDC to +5 VDC. For the U and V components of wind speed, 5 volts corresponds to a 50 m/s (111.85 mph) wind speed. For W, it corresponds to 15 m/s (33.55 mph).

The sonic anemometer is hardwired through junction boxes at the base of the met tower to the instrument enclosure. The signal processor for the sonic anemometer is mounted in the middle of the instrumentation rack (see Appendix C).

The sonic anemometer is mounted on the Center Tower on an extendable boom arm made of aluminum tubing 5.08 cm (2 in.) square by 0.635 cm (0.25 inch) wall by 3.048 m (10 ft) long. The boom arm is mounted at the tower in a roller housing (Tower Systems Inc.)[13] allowing for the arm to freely roll in and out. The arm is braced with 5.08-cm (2-in.) aluminum angle attached at the tower with "U" bolts and clamped at about 1.22 m (4 ft) out on the arm with a toggle clamp (see Figure 8).

Strain Gauges

A total of 15 strain gauge circuits and two six-axis motion sensing units are used here to monitor the structural performance of the Micon turbine (see Figure 7). A complete list of the strain gauge circuits is given in Table 4. All of these circuits use full bridges built from strain gauges manufactured by Micro Measurements (Measurements Group).[5]

The strain gauge circuits use internal bridge card circuitry in the ATLAS II units.[1] This circuitry supplies both the excitation voltages and the balancing circuits for the strain gauge bridges. For the circuits used here, excitation voltages are ±5, ±3.75 or ±2.5 VDC. The monitoring circuits used multipliers of 2000, 1000, or 50. The choice of excitation voltage and multiplier for each circuit was based on the excited output of that circuit. Offsets for the monitoring circuits were set individually.

The strain-gauge circuits that are mounted to components of the rotor are hardwired to Windy, the rotor-based unit of ATLAS II.[12] Since the wire runs are relatively short, the excitation voltage can be monitored at Windy rather than at the bridge. The gauges mounted to the tower are hardwired to a GBU in the instrument enclosure. As this run is approximately 35 m (114.84 ft), the excitation voltage to each bridge was monitored at the "completion tabs" for the bridge, using the "six-wire" bridge circuit capabilities of the ATLAS II bridge circuit cards.

Blade Gauges

Each turbine blade on the LWST turbine was instrumented with strain circuits wired to measure bending stresses, one each in flap and edge directions at the blade root. Additional gauges on two blades of the CX100 are at 25%, 50%, and 75% of span. Additional gauges for one of the TX100 blades are at 25%, 50%, and 75% of span. The gauges used for these installations are dual-element, encapsulated 350-ohm gauges (WK-06-250PD-350) (see Figure B-1). The root gauges are mounted in the flap and edge configuration at 350 mm (13.8 in.) from the root flange. The flap gauges are mounted at the position of maximum thickness of the airfoil; namely, at 2550 mm (100.4 in.) from the root flange, 4500 mm (177.2 in.) from the root flange, and 6750 mm (266.1 in.) from the root flange. The strain gauge circuit for each set is wired as a full bridge with four active elements.

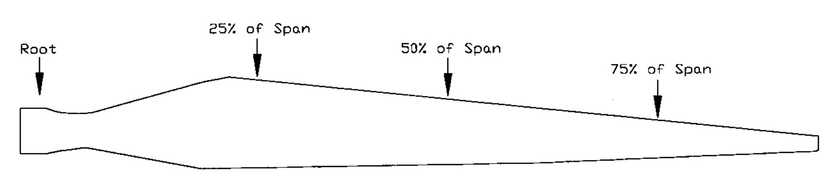

Figure B-1. Blade Strain Gauges.

The gauges are mounted internally to the blade and the wiring between the gauges and Windy is routed through the interior of the blades.

Hub Gauges

The hub on the LWST turbine was instrumented with six bending strain gauge circuits: one each used to measure the flap and edge bending in each of the three blade mounting arms (see Figure B-2). Dual-element, encapsulated 350-ohm gauges (WK-06-250PD-350) are used for these bending bridge circuits. The strain gauges are located on the exterior of the hub at approximately 0.165 m (6.5 in.) from the blade-mounting flange. This dimension corresponds to 0.435 m (17.1 in.) from the centerline of the main shaft.

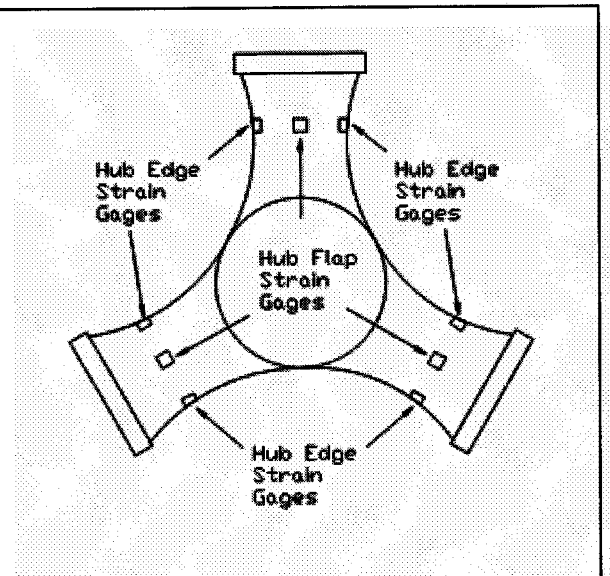

Figure B-2. Hub Strain Gauges.

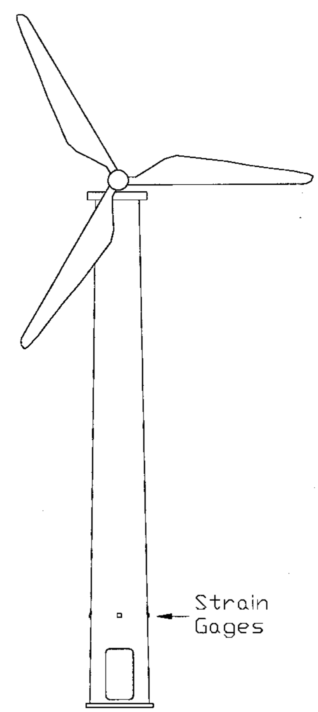

Figure B-3. Tower Strain Gauges.

Tower Bending

Tower Bending is measured with dual–element, encapsulated 90° tee rosette 350-ohm gauges (WK-06-250TM-350). One set measures fore-aft bending and the other side-to-side bending. They are aligned with the prevailing winds at 215°. The gauges are mounted inside of the tower at about 3.9 m (154 in.) above the turbine base (see Figure B-3).

Accelerations Measurement System

The nacelle is instrumented with one micro-machined (MEMS) device six-axis measuring system. It measures fore-aft, side-to-side, and up-down accelerations with three MEMS accelerometers as well as pitch, roll, and yaw rates with three angular rate sensors consisting of vibrating ceramic plates that utilize the Coriolis force to output angular rate independent of acceleration. The instrument is a Crossbow IMU300CC-100,[6] and is located on the nacelle frame next to the gearbox.

The accelerometers are located in a small junction box on the nacelle frame next to the gear box on the turbine (see Figure B-4). The units are hardwired through a junction box located in the base of the turbine to the instrument enclosure.

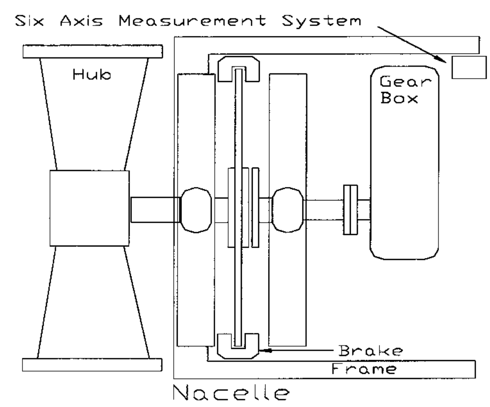

Figure B-4. Acceleration Measurement System

Additional Instruments

Yaw Position

The angular position of the nacelle, i.e., the yaw position, is measured with a brushless rotary encoder, model number HSTDCC-PB16S-SE, Computer Conversions Corporation.[7] Its resolution is 0.025% with an accuracy of ±12 arc-minutes. Uni-directional repeatability is 0.028%; bi-directional is ± 0.028%. Output ripple is 5 millivolts peak to peak (P-P) maximum.

The encoder is mounted to the top of the yaw drive gear box inside the nacelle. Pulleys, connected using a toothed belt, are used to attach the encoder to the yaw drive (see Figure 11). The size of the pulleys was chosen to yield a yaw position that is directly proportional to the output of the encoder.

The encoder is hardwired through a junction box in the bottom of the tower to a servo-loop signal processing decoding card in the instrument enclosure. The decoder card converts the angle signals from DC signal voltage. The output voltage ranges from 0 to 5 during a revolution of the nacelle. Excitation for the encoder is ±15 VDC. The power supply and the signal processing decoder are located near the bottom of the instrument enclosure (see Appendix C).

Rotor Azimuth and Velocity

The angular position and velocity are measured by a brushless rotary encoder, model EVSTDCC-PB16VIC-SIRPS, manufactured by Computer Conversions Corporation.[7] Uni-directional repeatability is 0.028%; bi-directional is ± 0.028%. Output ripple is 5 millivolts P-P maximum. A 5-volt output corresponds to an angular velocity of one rps with an accuracy of 0.1% over one revolution

The encoder is mounted to the nacelle near the front of the gear box (see Figure 11). Sprockets, connected with a roller chain, are used to attach the main shaft to the encoder. The size of the sprockets was chosen to yield a rotor position that is directly proportional to the output of the encoder.

The encoder is hardwired through a junction box in the bottom of the tower to a servo-loop signal processing decoding card in the instrument enclosure. The decoder card converts the DC signal voltage to an angle signal. The signal for rotary position ranges from 0 to 5 during a revolution of the blades. Excitation for the encoder is ±15 VDC. The power supply and the signal processing decoder are located near the bottom of the instrument enclosure (see Appendix C).

Power

The power produced by the turbines is monitored using a model GWV5-006AY precision WATT/VAR transducer by Ohio Semitronics Inc.[8] The instrument is designed for three-phase operation at 380-550 volt, 0-100 amp, and 0-80 KV/VAR. The instrument measures three-phase voltage, current, total power and volts amps reactive (VAR). For this installation, the unit is only used to monitor the total power produced by the turbine. A 5-VDC output from the transducer is equal to 600 VAC and 4000 WATT/VAR with an accuracy of ± 0.2% of reading and ± 0.05% full scale.

The non-contact current transformers (coils), the primary sensors used by this instrument, are placed around the three-phase, 480-volt power wires that connect the turbine generator to the grid. The coils, located inside the turbine control panel at the base of the turbine, are hard-wired to a monitoring unit also located inside the control panel. The units are hardwired through the junction box in the base of the turbine to the instrument enclosure.

Control Switch

The Control Switch is a signal that indicates when the turbine is up to speed, producing power and connected to the utility grid. Using the controller signal that connects the generator to the grid, an auxiliary relay is used to supply an on/off signal. A 5-VDC power supply output is switched through the relay to provide the on/off signal to the data acquisition system. The relay and the power supply are located in the turbine control junction box in the base of the turbine tower.

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APPENDIX C

WIRING DIAGRAMS

Instrument Enclosure

The instrument enclosure is a large metal junction box 1.83 m (6 ft) wide by 1.83 m (6 ft) high by 0.61m (2 ft) deep with two doors and is located in the instrument building. This unit was designed so that it can be utilized at other wind turbine sites by disconnecting the input signal lines at the lightning protection interface. It then can be transported to another site with all the interconnections intact and then be reconnected to the instrumentation at the new site. It is shown in Figure 12.

AC Power Supply

AC power is provided to all instrumentation via an uninterruptible power supply (UPS).

DC Power Supplies

The ATLAS II power and the ATI power are provided by two ±12-volt power supplies. The Crossbow Acceleration measurement system is powered by a 15-volt power supply. The yaw position, rotor velocity, rotor position encoders and their electronics boards are powered by a ±15-volt power supply (see Figures C-1 and C-2).

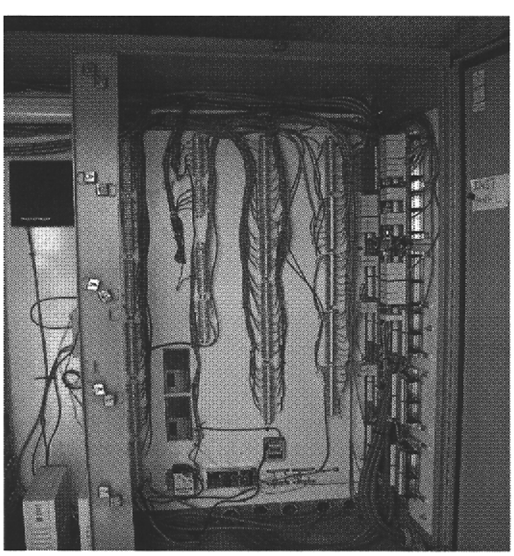

Figure C-1. Power Supplies and Back Panel of the Instrument Enclosure.

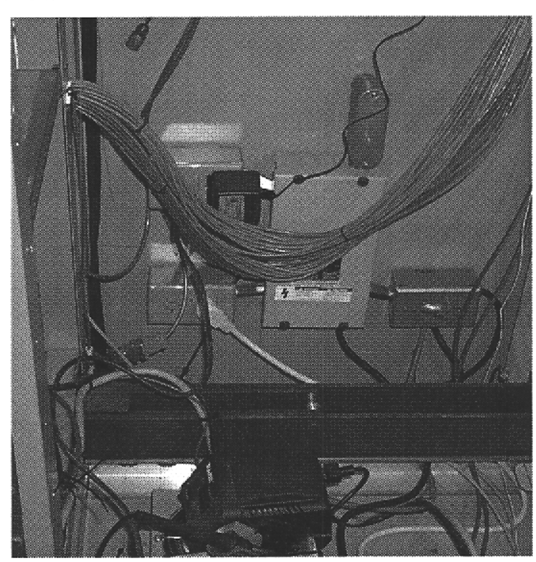

Figure C-2. AC Power Distribution in the Instrument Enclosure.

Lightning Protection

Lightning protection is provided for all of the instrumentation and electronic equipment used at the site to protect the hardware. The majority of the lightning protection is mounted in the instrument enclosure (see Figures C-3 and C-4). All of the data and signal lines have shield wires that are grounded to a common ground before the data and signal lines are passed through the lightning protection circuit.

Citel Inc.[11] manufactured the lightning protection units. Each unit consists of a base circuit board that can hold up to eight plug-in modules. Each module protects two pairs of wires. The circuitry incorporates a high-speed gas tube/avalanche diode with a one-nanosecond surge arrest time. They can dissipate up to 10,000 amperes. Modules come with clamping voltages of 6 and 12 volts, and they can be interspersed about the circuit board as required.

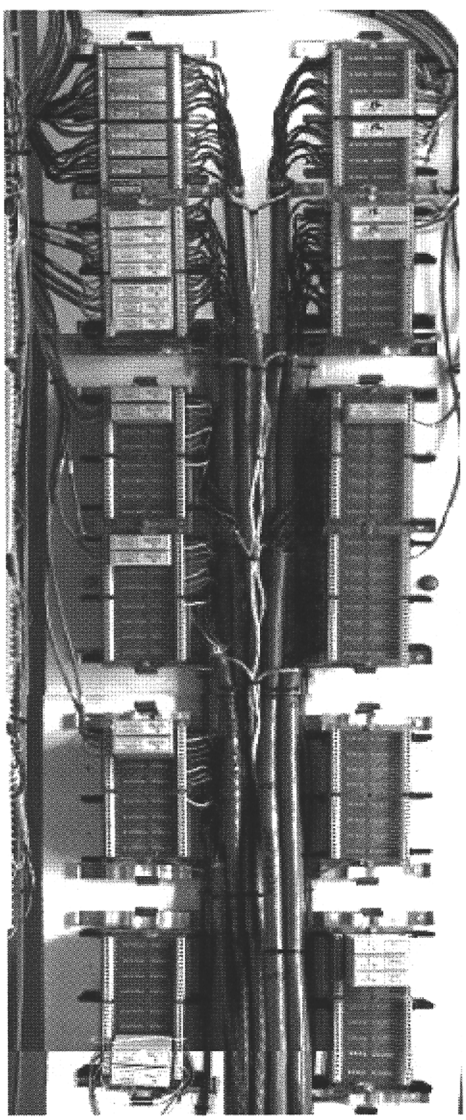

Figure C-3. Lightning Protection Panels in the Instrument Enclosure.

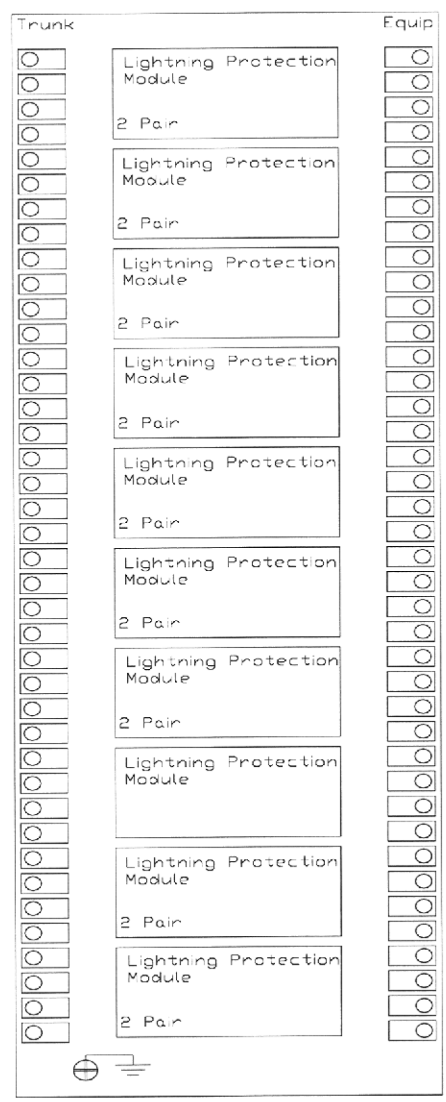

Figure C-4. Typical Lightning Protection Circuit Board.

Instrument Rack

The slide out rack (see Figures C-5 and C-6) houses the ATLAS II Ground Based Unit, the Met One[2] signal processors and power supply racks, and the ATI sonic anemometers digital-to-analog converters. Power strips located in the bottom of the rack provide AC power. The rack is on slides that allow the rack to move in and out 24 inches to gain access to the front and back of the rack and the AC power distribution located on the left wall of the enclosure.

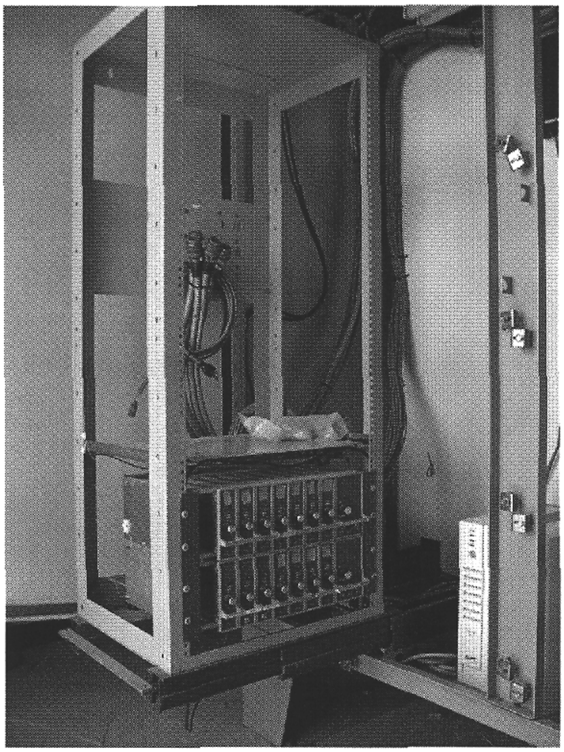

Figure C-5. Front View of the Instrument Rack.

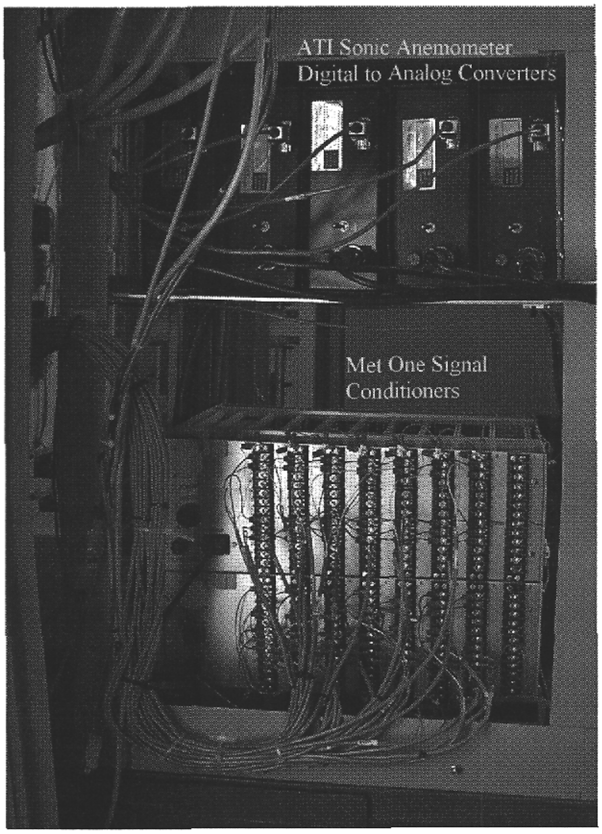

Figure C-6. Rear View of the Instrument Rack.

Tower Boxes and Wiring

Tower 1 Junction Box

The junction box at the base of Tower 1 connects the instrument that monitors the power produced by this turbine to the Instrument Enclosure. Cable ATP1 is connected to cable ATI1 in this junction box. Cable ATI1 is connected to the lightning protection in the instrument enclosure (see Figure C-7). Spare wires in the cables are terminated on the terminal strips.

Towere-1 JB

	Cable ATP2	CableATI1	
	n/c 1	1 blk pr	
	n/c 2	2 red 1	
	n/c 3	3 blk pr	
	n/c 4	4 red 2	
	n/c 5	5 blk pr	
	n/c 6	6 red 3	
ATP	V out + red 7	7 blk pr Vout+	*To*
From Micon	V ou t- blk 8	8 red 4 Vout-	*LP-6 Inst.*
controller	I out + red 9	9 blk pr Iout+	*Enclo.*
	I out - blk 10	10 red 5 Iout-	
	W att out+ red 11	11 blk pr W att+	
	W att out- blk 12	12 red 6 W att-	
	Var out + red 13	13 blk pr Var+	
	Var out - blk 14	14 red 7 Var-	
	15	15 blk pr	
	16	16 red 8	
	17	17 blk pr	
	18	18 red 9	
	19	19 blk pr	
	20	20 red 10	
	21	21 blk pr	
	22	22 red 11	
	23	23 blk pr	
	24	24 red 12	
	25	25 blk pr	
	26	26 red 13	
	27	27 blk pr	
	28	28 red 14	
	29	29 blk pr	
	30	30 red 15	
	31	31	
	32	32	
	33	33	

Shields n/c

Figure C-7. Junction Box for Tower 1.

Tower 2 Junction Box

The junction box for Tower 2 contains the turbine power monitoring wiring, yaw nacelle position, rotor velocity and position, nacelle accelerations and rates fore-and-aft and side-to-side, up-and-down, tower strain fore-and-aft and side-to-side, and turbine-state (on/off) (see Figure C-8). Cables BTI1 and BTI2 connect this junction box to the lightning protection in the instrument enclosure.

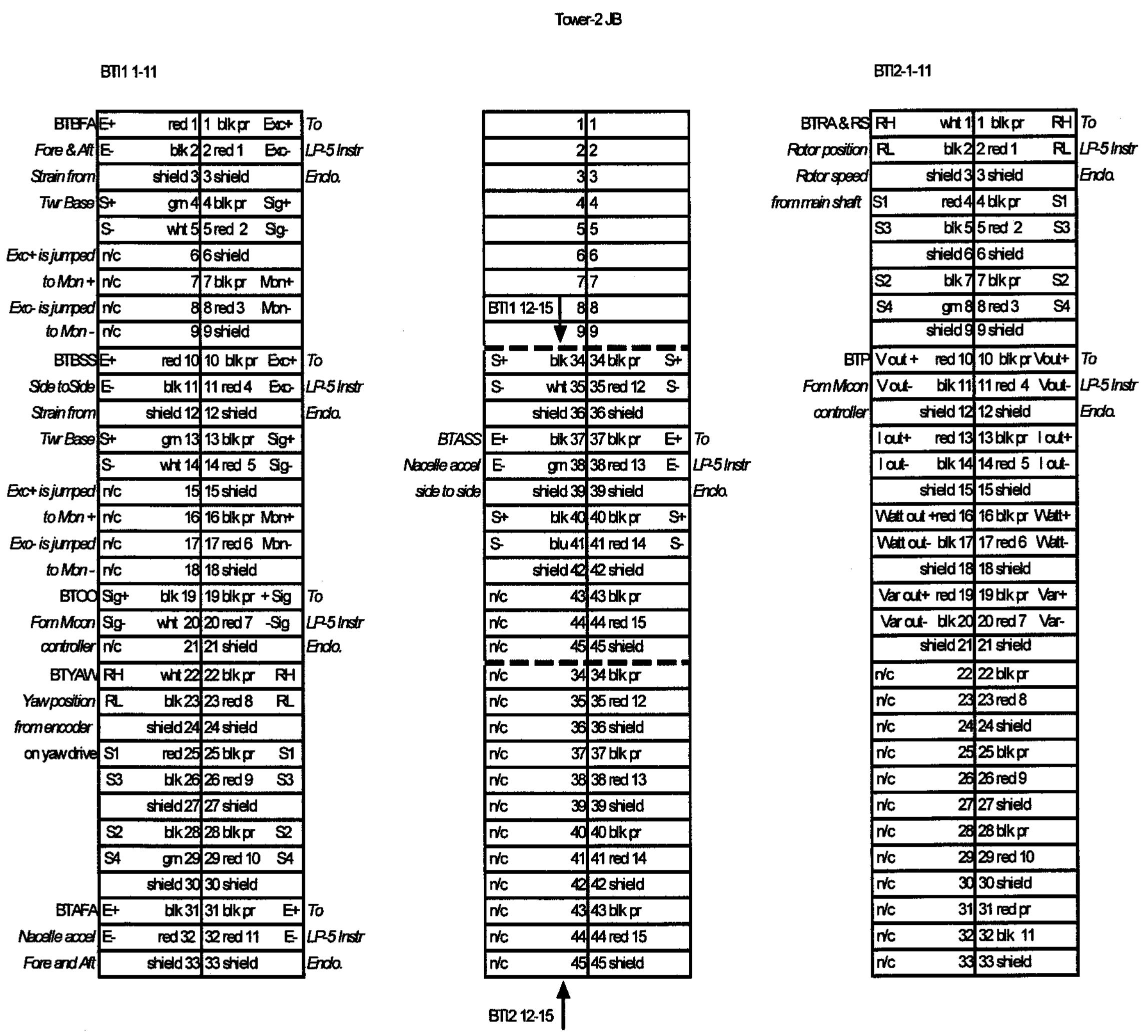

Figure C-8. Junction Box for Tower 2.

Tower 3 Junction Box

The junction box at the base of Tower 3 connects the instrument that monitors the power produced by this turbine to the instrument enclosure. Cable CTP1 is connected to cable CTI1 in this junction box. Cable CTI1 is connected to the lightning protection in the instrument enclosure (see Figure C-9).

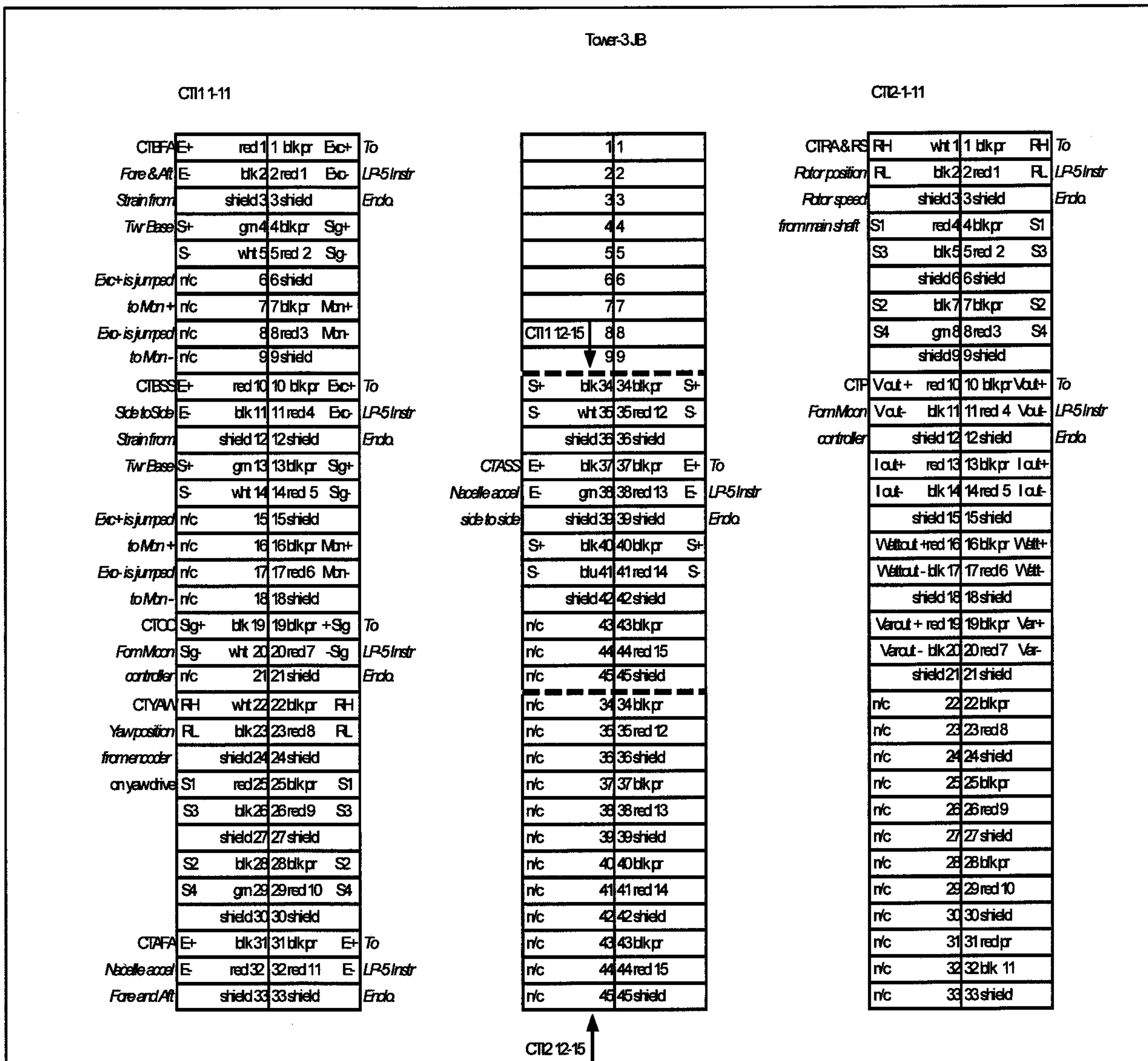

Figure C-9. Junction Box for Tower 3.

Met Tower Junction Boxes and Wiring

Center Met Tower Junction Box

The junction box at the base of the center met tower contains the wiring from the sonic anemometers on the center met towers. The cup anemometers, wind direction vanes, temperature and delta temperature wiring from the center met tower are also connected in this junction box. Cables BACI1 and BACI2 connect this junction box to the lightning protection in the instrument enclosure (see Figure C-10).

Center Met Tower JB

	TB-1	Cable BACI1	
BACTATI	12 volts red 1	1 blk pair	BACTATI
Instrument	gnd blk 2	2 red 1	*Cable*
From ATI	receive blk 3	3 blk pair	*To Instrument*
Top of Rotor	transmit wht 4	4 red 2	*Enclosure LP-1*
	signal gnd grn 5	5 blk pair	
	n/c blk 6	6 red 3	
BACCATI	12 volts red 7	7 blk pair	BACCATI
Instrument	gnd blk 8	8 red 4	*Cable*
From ATI	receive blk 9	9 blk pair	*To Instrument*
Hub Height	transmit wht 10	10 red 5	*Enclosure LP-1*
	Sig gnd grn 11	11 blk pair	
	n/c blk 12	12 red 6	
BACBATI	12 volts red 13	13 blk pair	BACBATI
Instrument	gnd blk 14	14 red 7	*Cable*
From ATI	receive blk 15	15 blk pair	*To Instrument*
Bottom of	transmit wht 16	16 red 8	*Enclosure LP-1*
Rotor	sig gnd grn 17	17 blk pair	
	n/c blk 18	18 red 9	
BANATI	12 volts blk 19	19 blk pair	BANATI
Instrument	gnd red 20	20 red 10	*Cable*
From ATI	receive blk 21	21 blk pair	*To Instrument*
N. Met Twr	transmit wht 22	22 red 11	*Enclosure LP-1*
Hub Height	sig gnd blk 23	23 blk pair	
	n/c grn 24	24 red 12	
BASATI	12 volts blk 25	25 blk pair	BASATI
Instrument	gnd red 26	26 red 13	*Cable*
From ATI	receive blk 27	27 blk pair	*To Instrument*
S. Met Twr	transmit wht 28	28 red 14	*Enclosure LP-1*
Hub Height	sig gnd blk 29	29 blk pair	
	n/c grn 30	30 red 15	
	31	31	
	32	32	

	TB-2	Cable BACI2	
BACTC	pair blk 1	1 red Exc+	BACTC
Cable	1 red 2	2 wht Sig+	*Instrument*
To Instrument	pair blk 3	3 blk Sig com	*From Cup*
Enclosure LP-1	2 red 4	4 grn n/c	*Top of Rotor*
BACCC	pair blk 5	5 red Exc+	BACCC
Cable	3 red 6	6 wht Sig+	*Instrument*
To Instrument	pair blk 7	7 blk Sig com	*From Cup*
Enclosure LP-1	4 red 8	8 brn n/c	*Hub Height*
BACBC	pair blk 9	9 red Exc+	BACBC
Cable	5 red 10	10 wht Sig+	*Instrument*
To Instrument	pair blk 11	11 blk Sig com	*From Cup*
Enclosure LP-1	6 red 12	12 grn n/c	*Bottom of Rot*
BAC2C	pairblk 13	13 red Exc+	BAC2C
Cable	7 red 14	14 wht Sig+	*Instrument*
To Instrument	pair blk 15	15 blk Sig com	*From Cup*
Enclosure LP-1	8 red 16	16 grn n/c	*2-Meter*
BACCV	pair blk 17	17 red Exc+	BACCV
Cable	9 red 18	18 wht Sig+	*Instrument*
To Instrument	pair blk 19	19 blk Sig com	*From Vane*
Enclosure LP-1	10 red 20	20 brn n/c	*Hub Height*
BACTP	pair blk 21	21 red I+	BACTP
Cable	11 red 22	22 blk E-	*Instrument*
To Instrument	pair blk 23	23 wht I-	*From Temp*
Enclosure LP-1	12 red 24	24 grn E+	*2-Meter*
BACDTP	pair blk 25	25 red I+	BACDTP
Cable	13 red 26	26 blk E-	*Instrument*
To Instrument	pair blk 27	27 wht I-	*From D-Temp*
Enclosure LP-1	14 red 28	28 grn E+	*Twr Top*
	pair blk 29		
	15 red 30		
	31	31	
	32	32	

Figure C-10. Junction Box on the Center Met Tower.

South Met Tower Junction Box

The junction box at the base of the south met tower contains the wiring from a cup anemometer and a wind direction vane on the South met tower. Cable CASI in this junction box is connected to the lightning protection in the instrument enclosure (see Figure C-11).

South Met Tower JB

	Cable CASI			TB-1			
CASC	Exc+	blk	1	1	red	Exc+	CASC
cable	Sig+	red	2	2	wht	Sig+	*Instrument*
To Instrument		shield	3	3			*From Cup*
Enclosure LP-2	sig com	blk	4	4	blk	Sig com	*Top of Twr*
	n/c	wht	5	5	brn	n/c	
		shield	6	6			
CASV	Exc+	blk	7	7	red	Exc+	CASV
cable	Sig+	grn	8	8	wht	Sig+	*Instrument*
To Instrument		shield	9	9			*From Vane*
Enclosure LP-2	Sig com	blk	10	10	blk	Sig com	*Top of Twr*
	n/c	blu	11	11	grn	n/c	
		shield	12	12			
		blk	13	13			
		brn	14	14			
		shield	15	15			
		blk	16	16			
		yel	17	17			
		shield	18	18			
		blk	19	19			
		org	20	20			
		shield	21	21			
		red	22	22			
		grn	23	23			
		shield	24	24			
		red	25	25			
		wht	26	26			
		shield	27	27			
			28	28			
			29	29			
			30	30			

Instrument side gnd shields tied to JB gnd. Cable side gnd shields left open

Figure C-11. South Met Tower Junction Box.

North Met Tower Junction Box

The junction box at the base of the north met tower contains the wiring from a cup anemometer and wind direction vane on the north met tower. Cable AANI in this junction box is connected to the lightning protection in the instrument enclosure (see Figure C-12).

North Met Tower JB

	Cable AANI			TB-1			
AANC	Exc+	blk	1	1	red	Exc+	AANC
cable	Sig+	red	2	2	wht	Sig+	*Instrument*
To Instrument		shield	3	3			*From Cup*
Enclosure LP-2	sig com	blk	4	4	blk	Sig com	*Top of Twr*
	n/c	wht	5	5	brn	n/c	
		shield	6	6			
AANV	Exc+	blk	7	7	red	Exc+	AANV
cable	Sig+	grn	8	8	wht	Sig+	*Instrument*
To Instrument		shield	9	9			*From Vane*
Enclosure LP-2	Sig com	blk	10	10	blk	Sig com	*Top of Twr*
	n/c	blu	11	11	grn	n/c	
		shield	12	12			
		blk	13	13			
		brn	14	14			
		shield	15	15			
		blk	16	16			
		yel	17	17			
		shield	18	18			
		blk	19	19			
		org	20	20			
		shield	21	21			
		red	22	22			
		grn	23	23			
		shield	24	24			
		red	25	25			
		wht	26	26			
		shield	27	27			
			28	28			
			29	29			
			30	30			

Instrument side gnd shields tied to JB gnd. Cable side gnd shields left open

Figure C-12. North Met Tower Junction Box.

Off-Axis Met Tower Junction Box

The junction box at the base of the off-axis met tower contains the wiring from a cup anemometer and wind direction vane on the off-axis met tower. Cable OANI in this junction box is connected to the lightning protection in the instrument enclosure (see Figure C-13).

Off Axis Met Tower JB

	Cable OANI			TB-1			
OC	Exc+	blk	1	1	red	Exc+	OC
cable	Sig+	red	2	2	wht	Sig+	*Instrument*
To Instrument		shield	3	3			*From Cup*
Enclosure LP-3	sig com	blk	4	4	blk	Sig com	*Top of Twr*
	n/c	wht	5	5	brn	n/c	
		shield	6	6			
OV	Exc+	blk	7	7	red	Exc+	OV
cable	Sig+	grn	8	8	wht	Sig+	*Instrument*
To Instrument		shield	9	9			*From Vane*
Enclosure LP-3	Sig com	blk	10	10	blk	Sig com	*Top of Twr*
	n/c	blu	11	11	brn	n/c	
		shield	12	12			
		blk	13	13			
		brn	14	14			
		shield	15	15			
		blk	16	16			
		yel	17	17			
		shield	18	18			
		blk	19	19			
		org	20	20			
		shield	21	21			
		red	22	22			
		grn	23	23			
		shield	24	24			
		red	25	25			
		wht	26	26			
		shield	27	27			
			28	28			
			29	29			
			30	30			

Instrument side gnd shields tied to JB gnd. Cable side gnd shields left open

Figure C-13. Off-Axis Met Tower Junction Box.

Wiring Diagram for the Acceleration Measurement System

This wire list covers the wiring from the accelerometers to the data acquisition system (DAS) in the instrument enclosure (see Figure C-14).

Name	B Turbine Accelerometer Fore-Aft					2262-25G SN KL03										
BTAFA	Accel Cable		Nacelle JB/TB-1		Nacelle JB/Conn		Turb base JB/TB1		Inst Encl/LP-5-in		Inst Encl/LP-5-out		Inst Encl/Strain-in		Inst Encl/Strn-upro	
DC + 5	Red		Red		Red	A	Black	31	Black	pair 1	Black	Exc +	Black	Exc +	Black	Exc +
DC -5	Black		Black		Black	B	Red	32	Red	pair 1	Red	Exc-	Red	Exc-	Red	Exc-
Gnd	Gnd		Gnd		Gnd	E	Gnd	33	Gnd		Black	Sig +	Gnd	shield	Gnd	shield
Sig (+)	Green		White		White	C	Black	34	Black	pair2	Wht	Sig -	Black	Sig +	Black	Sig +
Sig (-)	Wht		Black		Black	D	White	35	Red	pair 2	Black	Mon +	Wht	Sig -	Wht	Sig -
					Gnd	E	Gnd	36	Gnd		Grn	Mon-	Gnd	shield	Gnd	shield
	Jumction Box on Nacelle												Black	Mon +	Black	Mon +
													Grn	Mon-	Grn	Mon-
													Gnd	shield	Gnd	shield
Name	B Turbine Accelerometer Side-Side					2262-25G SN TJ45										
BTASS	Accel Cable		Nacelle JB/TB-1		Nacelle JB/Conn		Turb base JB/TB1		Inst Encl/LP-5-in		Inst Encl/LP-5-out		Inst Encl/Strain-in		Inst Encl/Strn-upro	
DC + 5	Red		Brn		Green	F	Black	37	Black	pair 1	Black	Exc +	Black	Exc +	Black	Exc +
DC -5	Black		Black		Black	G	Green	38	Red	pair 1	Red	Exc-	Red	Exc-	Red	Exc-
Gnd	Gnd		Gnd		Gnd	K	Gnd	39	Gnd		Black	Sig +	Gnd	shield	Gnd	shield
Sig (+)	Green		Blue		Blue	H	Black	40	Black	pair2	Wht	Sig -	Black	Sig +	Black	Sig +
Sig (-)	Wht		Black		Black	J	Blue	41	Red	pair2	Black	Mon +	Wht	Sig -	Wht	Sig -
					Gnd	K	Gnd	42	Gnd		Grn	Mon-	Gnd	shield	Gnd	shield
	Jumction Box on Nacelle												Black	Mon +	Black	Mon +
													Grn	Mon-	Grn	Mon-
													Gnd	shield	Gnd	shield

Figure C-14. Accelerometer Wiring Diagram.

Wiring Diagram for the Met One Back Panel

The Met One back panel has all the wiring associated with the cups, vanes, temperature, delta te pressure (see Figure C-15).

Met One Racks

Top Rack Cup Anemometers
Slot 1 Blank
Slot 2 OC Off Axis Met Tower Cup
Slot 3 CASC South Met Tower Cup
Slot 4 BAC2C Center Met Tower 2 Meter Cup
Slot 5 BACBC Center Met Tower Bottom of Rotor Cup
Slot 6 BACCC Center Met Tower Center Of Rotor Cup
Slot 7 BACTC Center Met Tower Top of Rotor Cup
Slot 8 AANC North Met Tower Cup

Bottom Rack Vanes, Temps, Pressure
Slot 1 Blank
Slot 2 EPR Barometric Pressure
Slot 3 BACDTP Delta Temp.
Slot 4 BACTP Temp.
Slot 5 OV Off Axis Met Tower Vane
Slot 6 CASV South Met Tower Vane
Slot 7 BACCV Center Met Tower Vane
Slot 8 AANV North Met Tower Vane

	OC	CASC	BAC2C	BACBC	BACCC	BACTC
From	*TB-CV-1*	*TB-CV-1*	*TB-CV-1*	*TB-CV-1*	*TB-CV-1*	*TB-CV-1*
1	blk sig In	blk sig In	blk sig In	blk sig In	blk sig In	blk sig In
2	wht ga com	wht ga com	wht ga com	wht ga com	wht ga com	wht ga com
3	n/c	n/c	n/c	n/c	n/c	n/c
4	n/c	n/c	n/c	n/c	n/c	n/c
5	n/c	n/c	n/c	n/c	n/c	n/c
6	n/c	n/c	n/c	n/c	n/c	n/c
7	red ga pwr	red ga pwr	red ga pwr	red ga pwr	red ga pwr	red ga pwr
8	red com	red com	red com	red com	red com	red com
9	blk sig out	blk sig out	blk sig out	blk sig out	blk sig out	blk sig out
10	n/c	n/c	n/c	n/c	n/c	n/c
11	n/c	n/c	n/c	n/c	n/c	n/c
12	n/c	n/c	n/c	n/c	n/c	n/c
To	*ANA-4*	*ANA-4*	*ANA-3*	*ANA-3*	*ANA-3*	*ANA-3*

	EPR	BACDTP	BACTP	OV	CASV	BACCV
From	*TB-CV-3*	*TB-CV-3*	*TB-CV-3*	*TB-CV-2*	*TB-CV-2*	*TB-CV-2*
1	blk sig In	jmp to temp 4	n/c	blk ref	blk ref	blk ref
2	blk ga com	blk gage E-	blk gage E-	n/c	n/c	n/c
3	n/c	grn gage E+	grn gage E+	jmp 6 com	jmp 6 com	jmp 6 com
4	n/c	n/c	jmp to Δ T- 1	wht phase	wht phase	wht phase
5	n/c	wht gage I-	wht gage I-	n/c	n/c	n/c
6	n/c	red gage I+	red gage I+	jmp 3-8 com	jmp 3-8	jmp 3-8 com
7	red ga pwr			red ga pwr	red ga pwr	red ga pwr
8	red com	red com	red com	red com	red com	red com
9	blk sig out	blk sig out	blk sig out	blk sig out	blk sig out	blk sig out
10	n/c	n/c	n/c	n/c	n/c	n/c
11	n/c	n/c	n/c	n/c	n/c	n/c
12	n/c	n/c	n/c	n/c	n/c	n/c
To	*ANA-5*	*ANA-5*	*ANA-5*	*ANA-4*	*ANA-4*	*ANA-4*

Figure C-15. Wiring Diagram for the Met One Back Panel.

Instrumentation Enclosure Wiring Diagram

Lightning Protection

The cables from the instrumentation are routed in the center of lightning protection boards. The signals are then passed through the lightning protection and on to the DAS (see Figures C-16a, C-16b and C-16c).

Lightning Prot.
LP-1

BACTATI	12 volts blk 1	1 blk pair	BACI1
To	gnd red 2	2 red 1	
TB-ATI-1	receive blk 3	3 blk pair	
	transmit wht 4	4 red 2	
	signal gnd blk 5	5 blk pair	
	n/c grn 6	6 red 3	
BACCATI	12 volts blk 7	7 blk pair	
To	gnd red 8	8 red 4	
TB-ATI-2	receive blk 9	9 blk pair	
	transmit wht 10	10 red 5	
	Sig gnd blk 11	11 blk pair	
	n/c grn 12	12 red 6	
BACBATI	12 volts blk 13	13 blk pair	
To	gnd red 14	14 red 7	
TB-ATI-3	receive blk 15	15 blk pair	
	transmit wht 16	16 red 8	
	sig gnd blk 17	17 blk pair	
	n/c grn 18	18 red 9	
BANATI	12 volts blk 19	19 blk pair	
To	gnd red 20	20 red 10	
TB-ATI-4	receive blk 21	21 blk pair	
	transmit wht 22	22 red 11	
	sig gnd blk 23	23 blk pair	
	n/c grn 24	24 red 12	
BASATI	12 volts blk 25	25 blk pair	
To	gnd red 26	26 red 13	
TB-ATI-5	receive blk 27	27 blk pair	
	transmit wht 28	28 red 14	
	sig gnd blk 29	29 blk pair	
	n/c grn 30	30 red 15	
	31	31	
	32	32	
BACTC	Exc+ red 1	1 blk pair	BACI2
To	Sig+ blk 2	2 red 1	
TB-C/V-1	common wht 3	3 blk pair	
	n/c grn 4	4 red 2	
BACCC	Exc+ red 5	5 blk pair	
To	Sig+ blk 6	6 red 3	
TB-C/V-1	common wht 7	7 blk pair	
	n/c grn 8	8 red 4	
BACBC	Exc+ red 9	9 blk pair	
To	Sig+ blk 10	10 red 5	
TB-C/V-1	common wht 11	11 blk pair	
	n/c grn 12	12 red 6	
BAC2C	Exc+ red 13	13 blk pair	
To	Sig+ blk 14	14 red 7	
TB-C/V-1	common wht 15	15 blk pair	
	n/c grn 16	16 red 8	
BACCV	Exc+ red 17	17 blk pair	
To	Sig+ blk 18	18 red 9	
TB-C/V-2	common wht 19	19 blk pair	
	n/c grn 20	20 red 10	
BACTP	I+ red 21	21 blk pair	
To	E- blk 22	22 red 11	
TB-TP-1	I- wht 23	23 blk pair	
	E+ grn 24	24 red 12	
BACDTP	I+ red 25	25 blk pair	
To	E- blk 26	26 red 13	
TB-TP-1	I- wht 27	27 blk pair	
	E+ grn 28	28 red 14	
	29	29 blk pair	
	30	30 red 15	
	31	31	
	32	32	
	To DAS		

Lightning Prot.
LP-5

BTI1	pair blk 1	1 blk Exc+	BTBFA
	1 red 2	2 red Exc-	*To*
	pair blk 3	3 blk Sig+	*Strain-1*
	2 red 4	4 wht Sig-	
	pair blk 5	5 blk Mon+	
	3 red 6	6 grn Mon-	
	pair blk 7	7 blk Exc+	BTBSS
	4 red 8	8 red Exc-	
	pair blk 9	9 blk Sig+	
	5 red 10	10 wht Sig-	
	pair blk 11	11 blk Mon+	
	6 red 12	12 grn Mon-	
	pair blk 13	13 blk Sig +	BTOO
	7 red 14	14 red Sig-	
	pair blk 15	15 red RH	BTYAW
	8 red 16	16 blk RL	*TO-BB*
	pair blk 17	17 red S1	
	9 red 18	18 wht S3	
	pair blk 19	19 red S2	
	10 red 20	20 grn S4	
	pair blk 21	21 red Exc+	BTAFA
	11 red 22	22 blk Exc-	
	pair blk 23	23 wht Sig+	
	12 red 24	24 grn Sig-	
	pair blk 25	25 red Exc+	BTASS
	13 red 26	26 blk Exc-	
	pair blk 27	27 wht Sig+	
	14 red 28	28 grn Sig-	
	pair blk 29	29	
	15 red 30	30	
	31	31	
	32	32	
BTI2	pair blk 1	1 blk RH	BTRA
	1 red 2	2 red RL	&
	pair blk 3	3 blk S1	BTRS
	2 red 4	4 wht S3	*TO-BB*
	pair blk 5	5 blk S2	
	3 red 6	6 grn S4	
	pair blk 7	7 blk Sig+	BTP
	4 red 8	8 red Sig-	
	pair blk 9	9	
	5 red 10	10	
	pair blk 11	11	
	6 red 12	12	
	pair blk 13	13	
	7 red 14	14	
	pair blk 15	15	
	8 red 16	16	
	pair blk 17	17	
	9 red 18	18	
	pair blk 19	19	
	10 red 20	20	
	pair blk 21	21	
	11 red 22	22	
	pair blk 23	23	
	12 red 24	24	
	pair blk 25	25	
	13 red 26	26	
	pair blk 27	27	
	14 red 28	28	
	pair blk 29	29	
	15 red 30	30	
		31	
		32	
		To DAS	

From Instruments

Figure C-16a. Panel 1: Lightning Protection Wiring Diagram.

Lightning Protection
LP-2

AANC	Exc+	red 1	1 blk	Exc+	AANI
To	Sig+	blk 2	2 red	Sig+	
TB-C/V-1	com	wht 3	3 blk	Sig com	
	n/ c	grn 4	4 wht	n/c	
AANV	Exc	red 5	5 blk	Exc+	
To	Sig+	blk 6	6 grn	Sig+	
TB-C/V-2	com	wht 7	7 blk	Sig com	
	n/c	grn 8	8 blu	n/c	
		9	9 blk		
		10	10 brn		
		11	11 blk		
		12	12 yel		
		13	13 blk		
		14	14 org		
		15	15 red		
		16	16 grn		
		17	17 red		
		18	18 wht		
		19	19		
		20	20		
		21	21		
		22	22		
		23	23		
		24	24		
		25	25		
		26	26		
		27	27		
		28	28		
		29	29		
		30	30		
		31	31		
		32	32		

CASC	Exc+	red 1	1 blk	Exc+	CASI
To	Sig+	blk 2	2 red	Sig+	
TB-C/V-1	com	wht 3	3 blk	Sig com	
	n/c	grn 4	4 wht	n/c	
CASV	Exc+	red 5	5 blk	Exc+	
To	Sig+	blk 6	6 grn	Sig+	
TB-C/V-2	com	wht 7	7 blk	Sig com	
	n/c	grn 8	8 blu	n/c	
		9	9 blk		
		10	10 brn		
		11	11 blk		
		12	12 yel		
		13	13 blk		
		14	14 org		
		15	15 red		
		16	16 grn		
		17	17 red		
		18	18 wht		
		19	19		
		20	20		
		21	21		
		22	22		
		23	23		
		24	24		
		25	25		
		26	26		
		27	27		
		28	28		
		29	29		
		30	30		
		31	31		
		32	32		

To DAS

Lightning Protection
LP-6

ATI1	pair	blk 1	1 blk	ATRA
	1	red 2	2 red	&
	pair	blk 3	3 blk	ATRS
	2	red 4	4 wht	
	pair	blk 5	5 blk	
	3	red 6	6 grn	
	pair	blk 7	7 blk	ATP
	4	red 8	8 blu	
	pair	blk 9	9	
	5	red 10	10	
	pair	blk 11	11	
	6	red 12	12	
	pair	blk 13	13	
	7	red 14	14	
	pair	blk 15	15	
	8	red 16	16	
	pair	blk 17	17	
	9	red 18	18	
	pair	blk 19	19	
	10	red 20	20	
	pair	blk 21	21	
	11	red 22	22	
	pair	blk 23	23	
	12	red 24	24	
	pair	blk 25	25	
	13	red 26	26	
	pair	blk 27	27	
	14	red 28	28	
	pair	blk 29	29	
	15	red 30	30	
		31	31	
		32	32	

CTI1	pair	blk 1	1 blk	CTRA
	1	red 2	2 red	&
	pair	blk 3	3 blk	CTRS
	2	red 4	4 wht	
	pair	blk 5	5 blk	
	3	red 6	6 grn	
	pair	blk 7	7 blk	CTP
	4	red 8	8 blu	
	pair	blk 9	9	
	5	red 10	10	
	pair	blk 11	11	
	6	red 12	12	
	pair	blk 13	13	
	7	red 14	14	
	pair	blk 15	15	
	8	red 16	16	
	pair	blk 17	17	
	9	red 18	18	
	pair	blk 19	19	
	10	red 20	20	
	pair	blk 21	21	
	11	red 22	22	
	pair	blk 23	23	
	12	red 24	24	
	pair	blk 25	25	
	13	red 26	26	
	pair	blk 27	27	
	14	red 28	28	
	pair	blk 29	29	
	15	red 30	30	
		31	31	
		32	32	

Fron Instruments

To DAS

Figure C-16b. Panel 2: Lightning Protection Wiring Diagram.

Lightning Protection
LP-3

OC	Exc+	red 1	1 blk	Exc+	OANI
To	Sig+	blk 2	2 red	Sig+	
TB-C/V-1	com	wht 3	3 blk	Sig com	
	n/c	grn 4	4 wht	n/c	
OV	Exc+	red 5	5 blk	Exc+	
To	Sig+	blk 6	6 grn	Sig+	
TB-C/V-2	com	wht 7	7 blk	Sig com	
	n/c	grn 8	8 blu	n/c	
		blk 9	9 blk		
		wht 10	10 brn		
		blk 11	11 blk		
		grn 12	12 yel		
		blk 13	13 blk		
		red 14	14 org		
		blk 15	15 red		
		wht 16	16 grn		
		blk 17	17 red		
		grn 18	18 wht		
		blk 19	19		
		red 20	20		
		blk 21	21		
		wht 22	22		
		blk 23	23		
		grn 24	24		
		blk 25	25		
		red 26	26		
		blk 27	27		
		wht 28	28		
		blk 29	29		
		grn 30	30		
		31	31		
		32	32		

Lightning Protection
LP-7

B-TBCTL	pair	blk 1	1 blk	pair	B-TBCTL
From	1	red 2	2 red	1	*To*
B-turb	pair	blk 3	3 blk	pair	*Cntl bldg*
	2	red 4	4 red	2	
	pair	blk 5	5 blk	pair	
	3	red 6	6 red	3	
	pair	blk 7	7 blk	pair	
	4	red 8	8 red	4	
	pair	blk 9	9 blk	pair	
	5	red 10	10 red	5	
	pair	blk 11	11 blk	pair	
	6	red 12	12 red	6	
	pair	blk 13	13 blk	pair	
	7	red 14	14 red	7	
	pair	blk 15	15 blk	pair	
	8	red 16	16 red	8	
	pair	blk 17	17 blk	pair	
	9	red 18	18 red	9	
	pair	blk 19	19 blk	pair	
	10	red 20	20 red	10	
	pair	blk 21	21 blk	pair	
	11	red 22	22 red	11	
	pair	blk 23	23 blk	pair	
	12	red 24	24 red	12	
	pair	blk 25	25 blk	pair	
	13	red 26	26 red	13	
	pair	blk 27	27 blk	pair	
	14	red 28	28 red	14	
	pair	blk 29	29 blk	pair	
	15	red 30	30 red	15	
		31	31		
		32	32		

LP-4

A-TBCTL	pair	blk 1	1 blk	pair	A-TBCTL
To	1	red 2	2 red	1	*From*
Cntl bldg	pair	blk 3	3 blk	pair	*A-turb*
	2	red 4	4 red	2	
	pair	blk 5	5 blk	pair	
	3	red 6	6 red	3	
	pair	blk 7	7 blk	pair	
	4	red 8	8 red	4	
	pair	blk 9	9 blk	pair	
	5	red 10	10 red	5	
	pair	blk 11	11 blk	pair	
	6	red 12	12 red	6	
	pair	blk 13	13 blk	pair	
	7	red 14	14 red	7	
	pair	blk 15	15 blk	pair	
	8	red 16	16 red	8	
	pair	blk 17	17 blk	pair	
	9	red 18	18 red	9	
	pair	blk 19	19 blk	pair	
	10	red 20	20 red	10	
	pair	blk 21	21 blk	pair	
	11	red 22	22 red	11	
	pair	blk 23	23 blk	pair	
	12	red 24	24 red	12	
	pair	blk 25	25 blk	pair	
	13	red 26	26 red	13	
	pair	blk 27	27 blk	pair	
	14	red 28	28 red	14	
	pair	blk 29	29 blk	pair	
	15	red 30	30 red	15	
		31	31		
		32	32		

To DAS

LP-8

C-TBCTL	pair	blk 1	1 blk	pair	C-TBCTL
From	1	red 2	2 red	1	*To*
C-turb	pair	blk 3	3 blk	pair	*Cntl bldg*
	2	red 4	4 red	2	
	pair	blk 5	5 blk	pair	
	3	red 6	6 red	3	
	pair	blk 7	7 blk	pair	
	4	red 8	8 red	4	
	pair	blk 9	9 blk	pair	
	5	red 10	10 red	5	
	pair	blk 11	11 blk	pair	
	6	red 12	12 red	6	
	pair	blk 13	13 blk	pair	
	7	red 14	14 red	7	
	pair	blk 15	15 blk	pair	
	8	red 16	16 red	8	
	pair	blk 17	17 blk	pair	
	9	red 18	18 red	9	
	pair	blk 19	19 blk	pair	
	10	red 20	20 red	10	
	pair	blk 21	21 blk	pair	
	11	red 22	22 red	11	
	pair	blk 23	23 blk	pair	
	12	red 24	24 red	12	
	pair	blk 25	25 blk	pair	
	13	red 26	26 red	13	
	pair	blk 27	27 blk	pair	
	14	red 28	28 red	14	
	pair	blk 29	29 blk	pair	
	15	red 30	30 red	15	
		31	31		
		32	32		

From Instruments

To DAS

Figure C-16c. Panel 3: Lightning Protection Wiring Diagram.

Sonic Anemometer

The sonic anemometer input signal wiring from the lightning protection comes in the right side of the terminal blocks and out the left side to the signal conditioning. Then the return signals from the signal conditioning come in the left side and out the right side to the DAS (see Figure C-17).

ATI

TB-ATI-1

BACTATI	12 volts	red 1	1 blk	12 volts	BACTATI
To	gnd	blk 2	2 red	gnd	*From*
Pwr strip	shield	shield 3	3 gnd	shield	*LP-1*
To	receive	red 4	4 blk	receive	
ATI-BB-1	transmit	blk 5	5 wht	transmit	
	gnd	shield 6	6 gnd	shield	
	sig gnd	grn 7	7 blk	signal gnd	
	n/c	wht 8	8 grn	n/c	
	n/c	shield 9	9 gnd	shield	
From	U+	blk 10	10 blk	U+	*To*
ATI-BB-1	U-	red 11	11 red	U-	*ANA-1*
	gnd	shield 12	12 gnd	shield	
	V+	blk 13	13 blk	V+	
	V-	wht 14	14 wht	V-	
	gnd	shield 15	15 gnd	shield	
	W+	blk 16	16 blk	W+	
	W-	grn 17	17grn	W-	
	gnd	shield 18	18 gnd	shield	
	T+	blk 19	19 blk	T+	
	T-	blu 20	20 blu	T-	
	gnd	shield 21	21 gnd	shield	
	n/c	blk 22	22	n/c	
	n/c	yel 23	23	n/c	
	n/c	gnd 24	24	n/c	

TB-ATI-2

BACCATI	12 volts	red 1	1 blk	12 volts	BACCATI
To	gnd	blk 2	2 red	gnd	*From*
Pwr strip	shield	shield 3	3 gnd	shield	*LP-1*
To	receive	red 4	4 blk	receive	
ATI-BB-2	transmit	blk 5	5 wht	transmit	
	gnd	shield 6	6 gnd	shield	
	sig gnd	grn 7	7 blk	signal gnd	
	n/c	wht 8	8 grn	n/c	
	n/c	shield 9	9 gnd	shield	
From	U+	blk 10	10 blk	U+	To
ATI-BB-2	U-	red 11	11 red	U-	ANA-1
	gnd	shield 12	12 gnd	shield	
	V+	blk 13	13 blk	V+	
	V-	wht 14	14 wht	V-	
	gnd	shield 15	15 gnd	shield	
	W+	blk 16	16 blk	W+	
	W-	grn 17	17grn	W-	
	gnd	shield 18	18 gnd	shield	
	T+	blk 19	19 blk	T+	
	T-	blu 20	20 blu	T-	
	gnd	shield 21	21 gnd	shield	
	n/c	blk 22	22	n/c	
	n/c	yel 23	23	n/c	
	n/c	gnd 24	24	n/c	

TB-ATI-3

BACBATI	12 volts	red 1	1 blk	12 volts	BACBATI
To	gnd	blk 2	2 red	gnd	*From*
Pwr strip	shield	shield 3	3 gnd	shield	*LP-1*
To	receive	red 4	4 blk	receive	
ATI-BB-3	transmit	blk 5	5 wht	transmit	
	gnd	shield 6	6 gnd	shield	
	sig gnd	grn 7	7 blk	signal gnd	
	n/c	wht 8	8 grn	n/c	
	n/c	shield 9	9 gnd	shield	
From	U+	blk 10	10 blk	U+	*To*
ATI-BB-3	U-	red 11	11 red	U-	*ANA-2*
	gnd	shield 12	12 gnd	shield	
	V+	blk 13	13 blk	V+	
	V-	wht 14	14 wht	V-	
	gnd	shield 15	15 gnd	shield	
	W+	blk 16	16 blk	W+	
	W-	grn 17	17grn	W-	
	gnd	shield 18	18 gnd	shield	
	T+	blk 19	19 blk	T+	
	T-	blu 20	20 blu	T-	
	gnd	shield 21	21 gnd	shield	
	n/c	blk 22	22	n/c	
	n/c	yel 23	23	n/c	
	n/c	gnd 24	24	n/c	

TB-ATI-4

BANATI	12 volts	red 1	1 blk	12 volts	BANATI
To	gnd	blk 2	2 red	gnd	*From*
Pwr strip	shield	shield 3	3 gnd	shield	*LP-1*
To	receive	red 4	4 blk	receive	
ATI-BB-4	transmit	blk 5	5 wht	transmit	
	gnd	shield 6	6 gnd	shield	
	signal gnd	grn 7	7 blk	sig gnd	
	n/c	wht 8	8 grn	n/c	
	n/c	shield 9	9 gnd	shield	
From	U+	blk 10	10 blk	U+	*To*
ATI-BB-4	U-	red 11	11 red	U-	*ANA-2*
	gnd	shield 12	12 gnd	shield	
	V+	blk 13	13 blk	V+	
	V-	wht 14	14 wht	V-	
	gnd	shield 15	15 gnd	shield	
	W+	blk 16	16 blk	W+	
	W-	grn 17	17grn	W-	
	gnd	shield 18	18 gnd	shield	
	T+	blk 19	19 blk	T+	
	T-	blu 20	20 blu	T-	
	gnd	shield 21	21 gnd	shield	
		blk 22	22	n/c	
		yel 23	23	n/c	
		gnd 24	24	n/c	

TB-ATI-5

BASATI	12 volts	red 1	1 blk	12 volts	BASATI
To	gnd	blk 2	2 red	gnd	*From*
Pwr strip	shield	shield 3	3 gnd	shield	*LP-1*
To	receive	red 4	4 blk	receive	
ATI-BB-5	transmit	blk 5	5 wht	transmit	
	gnd	shield 6	6 gnd	shield	
	sig gnd	grn 7	7 blk	sig gnd	
	n/c	wht 8	8 grn	n/c	
	n/c	shield 9	9 gnd	shield	
From	U+	blk 10	10 blk	U+	*To*
ATI-BB-5	U-	red 11	11 red	U-	*ANA-3*
	gnd	shield 12	12 gnd	shield	
	V+	blk 13	13 blk	V+	
	V-	wht 14	14 wht	V-	
	gnd	shield 15	15 gnd	shield	
	W+	blk 16	16 blk	W+	
	W-	grn 17	17grn	W-	
	gnd	shield 18	18 gnd	shield	
	T+	blk 19	19 blk	T+	
	T-	blu 20	20 blu	T-	
	gnd	shield 21	21 gnd	shield	
		blk 22	22	n/c	
		yel 23	23	n/c	
		gnd 24	24	n/c	

Figure C-17. Sonic Anemometer Wiring Diagram.

Cups and Vanes

The cup anemometers and wind vanes input signal wiring from the lightning protection comes in the right side of the terminal blocks and out the left side to the signal conditioning. Then the return signals from the signal conditioning come in the left side and out the right side to the DAS (see Figure C-18).

Cup & Vane

TB-C/V-1

BACTC	Exc+	red 1	1 red	Exc+	BACTC
TO-BB	Sig+	blk 2	2 blk	Sig+	*From*
	com	wht 3	3 wht	com	*LP-1*
	n/c	grn 4	4 grn	n/c	
	gnd	shield 5	5 shield	gnd	
From-BB	Exc+	blk 6	6 blk	Exc+	*To*
	Sig+	red 7	7 red	Sig+	*ANA-3*
	gnd	shield 8	8 shield	gnd	
		9	9		
BACCC	Exc+	red 10	10 red	Exc+	BACCC
TO-BB	Sig+	blk 11	11 blk	Sig+	*From*
	com	wht 12	12 wht	com	*LP-1*
	n/c	grn 13	13 grn	n/c	
	gnd	shield 14	14 shield	gnd	
From-BB	Exc+	blk 15	15 blk	Exc+	*To*
	Sig+	red 16	16 red	Sig+	*ANA-3*
	gnd	shield 17	17 shield	gnd	
		18	18		
BACBC	Exc+	red 19	19 red	Exc+	BACBC
TO-BB	Sig+	blk 20	20 blk	Sig+	*From*
	com	wht 21	21 wht	com	*LP-1*
	n/c	grn 22	22 grn	n/c	
	gnd	shield 23	23 shield	gnd	
From-BB	Exc+	blk 24	24 blk	Exc+	*To*
	Sig+	red 25	25 red	Sig+	*ANA-3*
	gnd	shield 26	26 shield	gnd	
		27	27		
BAC2C	Exc+	red 28	28 red	Exc+	BAC2C
TO-BB	Sig+	blk 29	29 blk	Sig+	*From*
	com	wht 30	30 wht	com	*LP-1*
	n/c	grn 31	31 grn	n/c	
	gnd	shield 32	32 shield	gnd	
From-BB	Exc+	blk 33	33 blk	Exc+	*To*
	Sig+	red 34	34 red	Sig+	*ANA-3*
	gnd	shield 35	35 shield	gnd	
		36	36		
OC	Exc+	red 37	37 red	Exc+	OC
TO-BB	Sig+	blk 38	38 blk	Sig+	*From*
	com	wht 39	39 wht	com	*LP-3*
	n/c	grn 40	40 grn	n/c	
	gnd	shield 41	41 shield	gnd	
From-BB	Exc+	blk 42	42 blk	Exc+	*To*
	Sig+	red 43	43 red	Sig+	*ANA-4*
	gnd	shield 44	44 shield	gnd	
		45	45		
AANC	Exc+	red 46	46 red	Exc+	AANC
TO-BB	Sig+	blk 47	47 blk	Sig+	*From*
	com	wht 48	48 wht	com	*LP-2*
	n/c	grn 49	49 grn	n/c	
	gnd	shield 50	50 shield	gnd	
From-BB	Exc+	blk 51	51 blk	Exc+	*To*
	Sig+	red 43	52 red	Sig+	*ANA-4*
	gnd	shield 44	53 shield	gnd	
		54	54		
CASC	Exc+	red 55	55 red	Exc+	CASC
TO-BB	Sig+	blk 56	56 blk	Sig+	*From*
	common	wht 57	57 wht	com	*LP-2*
	n/c	grn 58	58 grn	n/c	
	gnd	shield 59	59 shield	gnd	
From-BB	Exc+	blk 60	60 blk	Exc+	*To*
	Sig+	red 61	61 red	Sig+	*ANA-4*
	gnd	shield 62	62 shield	gnd	
		63	63		
		64	64		

TB-C/V-2

BACCV	Exc+	red 1	1 red	Exc+	BACCV
TO-BB	Sig+	blk 2	2 blk	Sig+	*From*
	com	wht 3	3 wht	com	*LP-1*
	n/c	grn 4	4 grn	n/c	
	gnd	shield 5	5 shield	gnd	
From-BB	Exc+	blk 6	6 blk	Exc+	*To-Das*
	Sig+	red 7	7 red	Sig+	
	gnd	shield 8	8 shield	gnd	
		9	9		
OV	Exc+	red 10	10 red	E	OV
TO-BB	Sig+	blk 11	11 blk	Sig+	*From*
	com	wht 12	12 wht	com	*LP-3*
	n/c	grn 13	13 grn	n/c	
	gnd	shield 14	14 shield	gnd	
From-BB	Exc	+blk 15	15 blk	Exc+	*To-Das*
	Sig+	red 16	16 red	Sig+	
	gnd	shield 17	17 shield	gnd	
		18	18		
AANV	Exc+	red 19	19 red	Exc+	AANV
TO-BB	Sig+	blk 20	20 blk	Sig+	*From*
	com	wht 21	21 wht	com	*LP-2*
	n/c	grn 22	22 grn	n/c	
	gnd	shield 23	23 shield	gnd	
From-BB	Exc+	blk 24	24 blk	Exc+	*To-Das*
	Sig+	red 25	25 red	Sig+	
	gnd	shield 26	26 shield	gnd	
		27	27		
CASV	Exc+	red 28	28 red	Exc+	CASV
TO-BB	Sig+	blk 29	29 blk	Sig+	*From*
	com	wht 30	30 wht	com	*LP-2*
	n/c	grn 31	31 grn	n/c	
	gnd	shield 32	32 shield	gnd	
From-BB	Exc+	blk 33	33 blk	Exc+	*To-Das*
	Sig+	red 34	34 red	Sig+	
	gnd	shield 35	35 shield	gnd	
		36	36		

Figure C-18. Cup and Vane Wiring Diagram.

Strain Gauges

The strain gauges, accelerometers, nacelle azimuth, rotor velocity/azimuth, temperature/delta temperature, barometric pressure, and turbine power input signal wiring from the lightning protection comes in the right side of the terminal blocks out the left side to the signal conditioning. Then the return signals from the signal conditioning come in the left side and out the right side to the DAS (see Figure C-19).

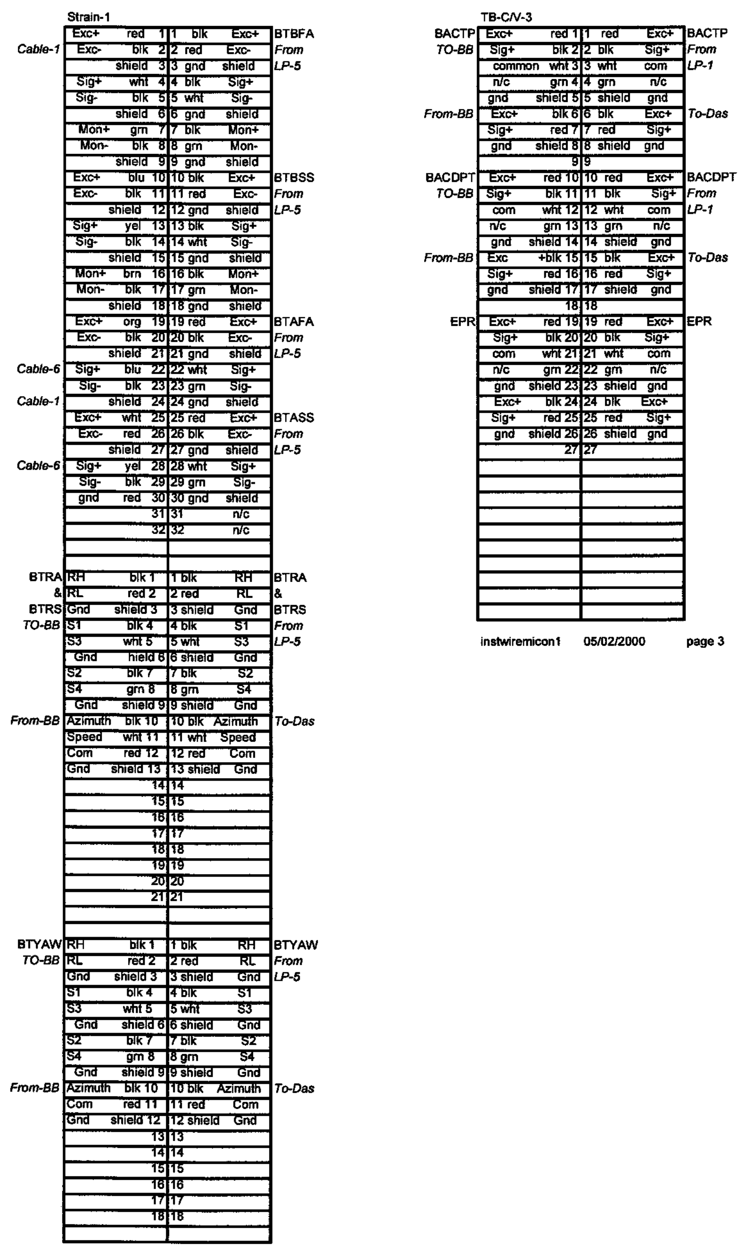

Figure C-19. Accelerometer and Strain Gauge Wiring Diagram.

Data Acquisition

All of the signal wiring from the sensors and the signal conditioning comes in the right side of the terminal block and out the left side to the DAS (see Figure C-20).

ANA-4

To	Sig+	red	1	1	blk	Sig+	OC
DAS	Sig-	blk	2	2	red	Sig-	*From*
	gnd	shield	3	3	gnd	shield	*TB-C/V-1*
To	Sig+	wht	4	4	blk	Sig+	AANC
DAS	Sig-	blk	5	5	wht	Sig-	*From*
	gnd	shield	6	6	gnd	shield	*TB-C/V-1*
To	Sig+	grn	7	7	blk	Sig+	CASC
DAS	Sig-	blk	8	8	grn	Sig-	*From*
	gnd	shield	9	9	gnd	shield	*TB-C/V-1*
			10	10		n/c	
			11	11		n/c	
	gnd	shield	12	12	gnd	n/c	
To	Sig+	yel	13	13	blk	Sig+	BACCV
DAS	Sig-	blk	14	14	red	Sig-	*From*
	gnd	shield	15	15	gnd	shield	*TB-C/V-2*
To	Sig+	brn	16	16	blk	Sig+	OV
DAS	Sig-	blk	17	17	wht	Sig-	*From*
	gnd	shield	18	18	gnd	shield	*TB-C/V-2*
To	Sig+	org	19	19	blk	Sig+	AANV
DAS	Sig-	blk	20	20	grn	Sig-	*From*
	gnd	shield	21	21	gnd	shield	*TB-C/V-2*
To	Sig+	wht	22	22	blk	Sig+	CASV
DAS	Sig-	red	23	23	blu	Sig-	*From*
	gnd	shield	24	24	gnd	shield	*TB-C/V-2*

ANA-5

To	Sig+	red	1	1	blk	Sig+	BACTP
DAS	Sig-	blk	2	2	red	Sig-	*From*
	gnd	shield	3	3	gnd	shield	*TB-C/V-3*
To	Sig+	wht	4	4	blk	Sig+	BACDTP
DAS	Sig-	blk	5	5	wht	Sig-	*From*
	gnd	shield	6	6	gnd	shield	*TB-C/V-3*
To	Sig+	grn	7	7	blk	Sig+	EPR
DAS	Sig-	blk	8	8	grn	Sig-	*From*
	gnd	shield	9	9	gnd	shield	*TB-C/V-3*
			10	10		n/c	
			11	11		n/c	
	gnd	shield	12	12	gnd	n/c	
To	Sig+	yel	13	13	blk	Sig+	BTOO
DAS	Sig-	blk	14	14	red	Sig-	
	gnd	shield	15	15	gnd	shield	
To	Sig+	brn	16	16	blk	Sig+	ATP
DAS	Sig-	blk	17	17	wht	Sig-	
	gnd	shield	18	18	gnd	shield	
To	Sig+	org	19	19	blk	Sig+	BTP
DAS	Sig-	blk	20	20	grn	Sig-	
	gnd	shield	21	21	gnd	shield	
To	Sig+	wht	22	22	blk	Sig+	CTP
DAS	Sig-	red	23	23	blu	Sig-	
	gnd	shield	24	24	gnd	shield	

ANA-6

To	Sig+	red	1	1	blk	Sig+	BTYAW
DAS	Sig-	blk	2	2	red	Sig-	*From-BB*
	gnd	shield	3	3	gnd	shield	
To	Sig+	wht	4	4	blk	Sig+	BTRA
DAS	Sig-	blk	5	5	wht	Sig-	*From-BB*
	gnd	shield	6	6	gnd	shield	
To	Sig+	grn	7	7	blk	Sig+	BTRS
DAS	Sig-	blk	8	8	grn	Sig-	*From-BB*
	gnd	shield	9	9	gnd	shield	
			10	10	blk	pcm +	RS 422
			11	11	red	pcm -	*to cntl*
			12	12	gnd	n/c	*bldg*
			13	13	blk	clk +	
			14	14	red	clk -	
			15	15	gnd	n/c	
			16	16	blk	xmit	
			17	17	wht	rcv	
			18	18	gnd	n/c	
			19	19	blk	spare	
			20	20	blu	spare	
			21	21		n/c	
			22	22		n/c	
			23	23		n/c	
			24	24		n/c	

ANA-1

To	U+	red	1	1	blk	U+	BACTAT1
DAS	U-	blk	2	2	red	U-	*From*
	gnd	shield	3	3	gnd	shield	*TB-ATI-1*
	V+	wht	4	4	blk	V+	
	V-	blk	5	5	wht	V-	
	gnd	shield	6	6	gnd	shield	
	W+	grn	7	7	blk	W+	
	W-	blk	8	8	grn	W-	
	gnd	shield	9	9	gnd	shield	
	T+	blu	10	10	blk	T+	
	T-	blk	11	11	blu	T-	
	gnd	shield	12	12	gnd	shield	
To	U+	yel	13	13	blk	U+	BACCATI
DAS	U-	blk	14	14	red	U-	*From*
	gnd	shield	15	15	gnd	shield	*TB-ATI-2*
	V+	brn	16	16	blk	V+	
	V-	blk	17	17	wht	V-	
	gnd	shield	18	18	gnd	shield	
	W+	org	19	19	blk	W+	
	W-	blk	20	20	grn	W-	
	gnd	shield	21	21	gnd	shield	
	T+	wht	22	22	blk	T+	
	T-	red	23	23	blu	T-	
	gnd	shield	24	24	gnd	shield	

ANA-2

To	U+	red	1	1	blk	U+	BACBATI
DAS	U-	blk	2	2	red	U-	*From*
	gnd	shield	3	3	gnd	shield	*TB-ATI-3*
	V+	wht	4	4	blk	V+	
	V-	blk	5	5	wht	V-	
	gnd	shield	6	6	gnd	shield	
	W+	grn	7	7	blk	W+	
	W-	blk	8	8	grn	W-	
	gnd	shield	9	9	gnd	shield	
	T+	blu	10	10	blk	T+	
	T-	blk	11	11	blu	T-	
	gnd	shield	12	12	gnd	shield	
To	U+	yel	13	13	blk	U+	BANATI
DAS	U-	blk	14	14	red	U-	*From*
	gnd	shield	15	15	gnd	shield	*TB-ATI-4*
	V+	brn	16	16	blk	V+	
	V-	blk	17	17	wht	V-	
	gnd	shield	18	18	gnd	shield	
	W+	org	19	19	blk	W+	
	W-	blk	20	20	grn	W-	
	gnd	shield	21	21	gnd	shield	
	T+	wht	22	22	blk	T+	
	T-	red	23	23	blu	T-	
	gnd	shield	24	24	gnd	shield	

ANA-3

To	U+	red	1	1	blk	U+	BASATI
DAS	U-	blk	2	2	red		*From*
	gnd	shield	3	3	gnd	shield	*TB-ATI-5*
	V+	wht	4	4	blk	V+	
	V-	blk	5	5	wht	V-	
	gnd	shield	6	6	gnd	shield	
	W+	grn	7	7	blk	W+	
	W-	blk	8	8	grn	W-	
	gnd	shield	9	9	gnd	shield	
	T+	blu	10	10	blk	T+	
	T-	blk	11	11	blu	T-	
	gnd	shield	12	12	gnd	shield	
To	Sig+	yel	13	13	blk	Sig+	BACTC
DAS	Sig-	blk	14	14	red	Sig-	*From*
	gnd	shield	15	15	gnd	shield	*TB-C/V-1*
	Sig+	brn	16	16	blk	Sig+	BACCC
	Sig-	blk	17	17	red	Sig-	*From*
	gnd	shield	18	18	gnd	shield	*TB-C/V-1*
	Sig+	org	19	19	blk	Sig+	BACBC
	Sig-	blk	20	20	red	Sig-	*From*
	gnd	shield	21	21	gnd	shield	*TB-C/V-1*
	Sig+	wht	22	22	blk	Sig+	BAC2C
	Sig-	red	23	23	red	Sig-	*From*
	gnd	shield	24	24	gnd	shield	*TB-C/V-1*

Figure C-20. Data Acquisition Wiring Diagram.

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APPENDIX D

ELECTRICAL INFRASTRUCTURE

The electrical infrastructure for the test site is made up of underground and aboveground instrumentation cables, DC and AC electrical wiring, grounding grid, power grid, power transformers, junction boxes, and turbine controls. The underground cables are run in PVC conduit in the pattern shown in Figure D-1. The AC power is run in separate conduit from the instrumentation and DC wires to limit the AC noise that could affect the instrument signals and DC signal and power wiring. A grounding grid is connected to all of the buildings, turbines, meteorological towers, and instrumentation grounds for lightning protection and earth ground (see Figure D-5).

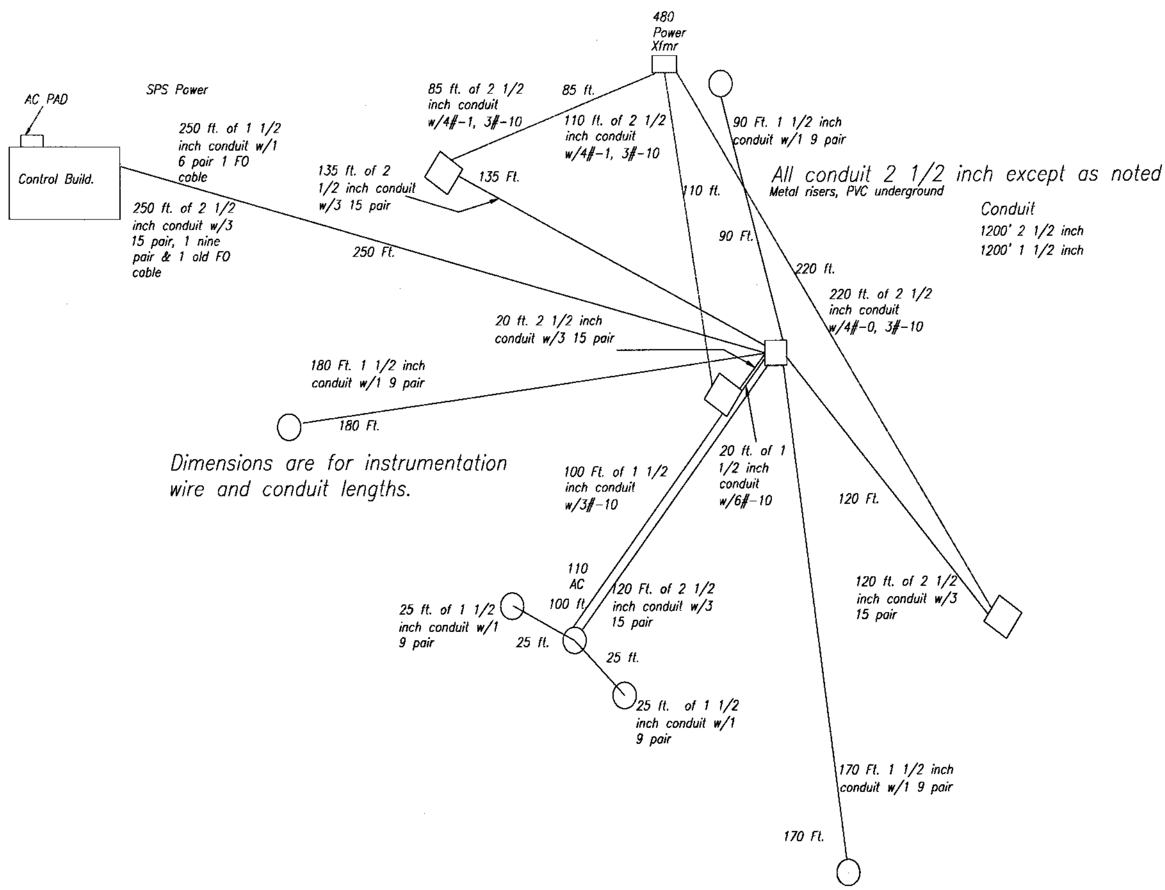

Figure D-1. Conduit Schedule for the Site.

Meteorological Tower Cable Types, Lengths, and Junction Boxes

A variety of cable lengths and type of cable are used to connect the meteorological instrumentation to the data acquisition system. Wires in the bundled cable consists of 18-gauge wire with an overall shield and a bare copper ground wire. The interconnections on terminal strips are located in the junction boxes. See Figure D-2 for conduit locations and lengths.

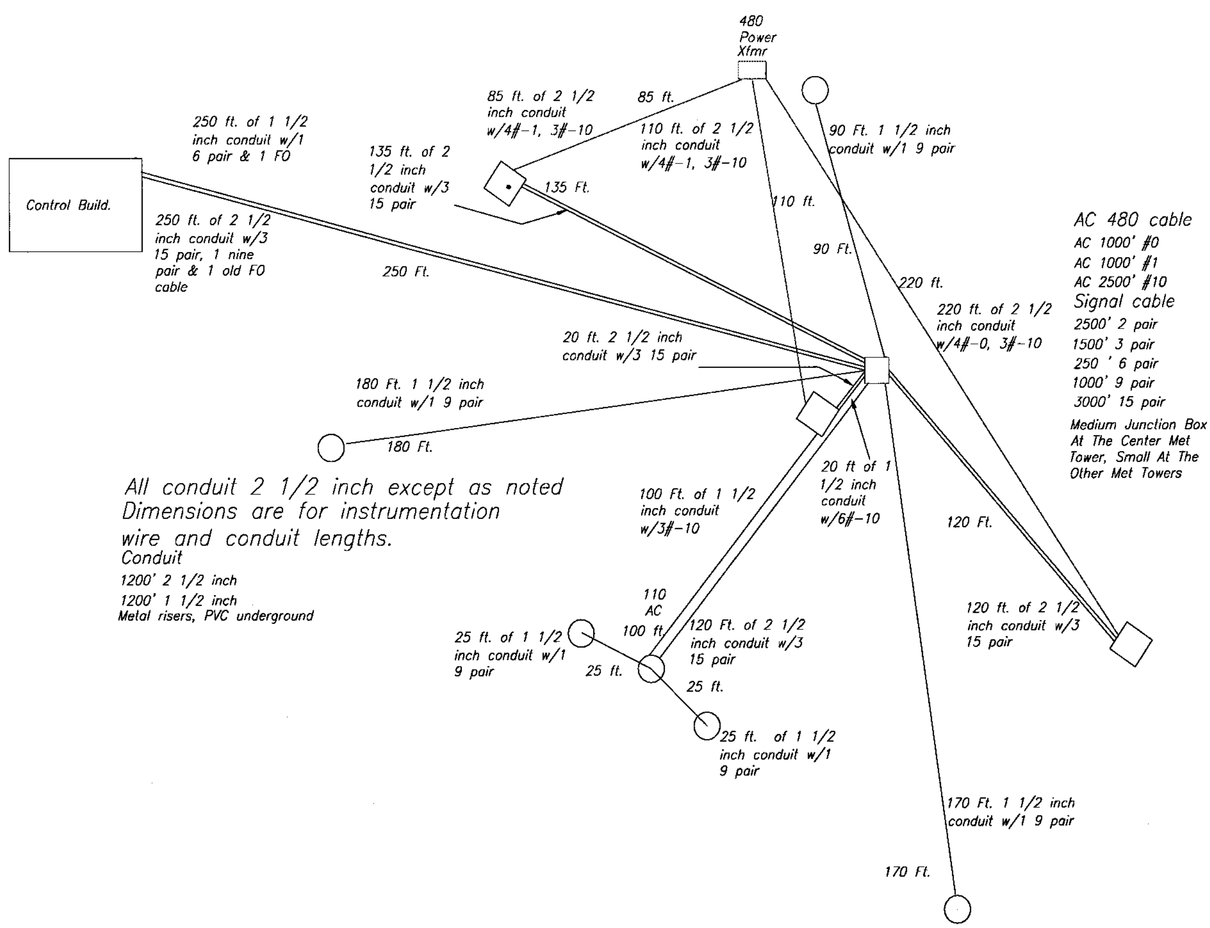

Figure D-2. Instrumentation Wires from the Met Towers.

Turbine Instrument Wires and Junction Boxes

A variety of cables are used to connect the turbine instrumentation to the data acquisition units. Wires bundled in the cable are 18 gauge with an overall shield and a bare copper ground wire. The interconnections on terminal strips are located in the junction boxes (see Figure D-3).

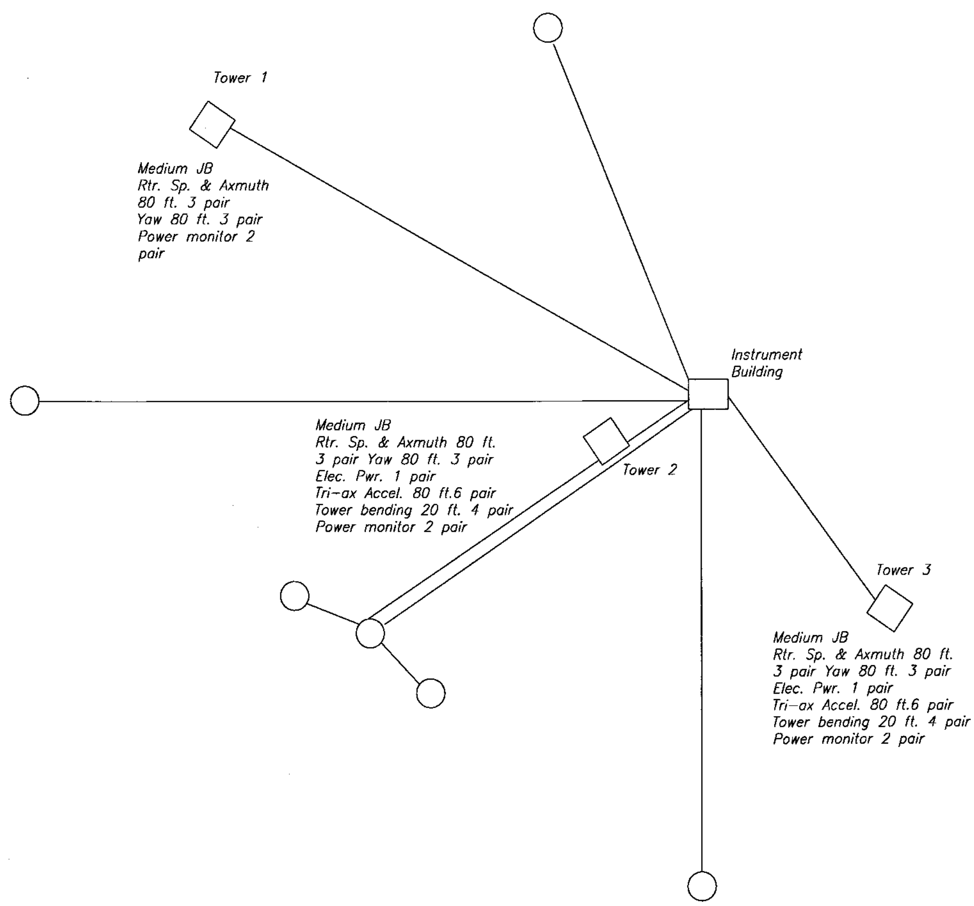

Figure D-3. Instrument Wires from the Towers.

Test Site AC Power

AC Power for the Bushland test site grid connection is provided by the local utility, Excel, and through the main 13.2-kVAC to 480/277-VAC, 300-kVA, 3 phase, grounded-Y transformer. Power from this transformer, the turbine transformers, and the instrument enclosure is run in PVC conduit underground. Each turbine has a separate 120-VAC transformer with a switch and breaker panel. The instrument building heating and cooling are on one transformer. The instrument enclosure fans, lights, UPS, instrument power and nacelle B are on another transformer. Nacelle A and nacelle C are on their own separate transformers. Power generated by each of the turbines is sent through fuses and a breaker in the turbine control junction box and then to the main 480-VAC site transformer and out to the Excel power grid (see Figure D-4).

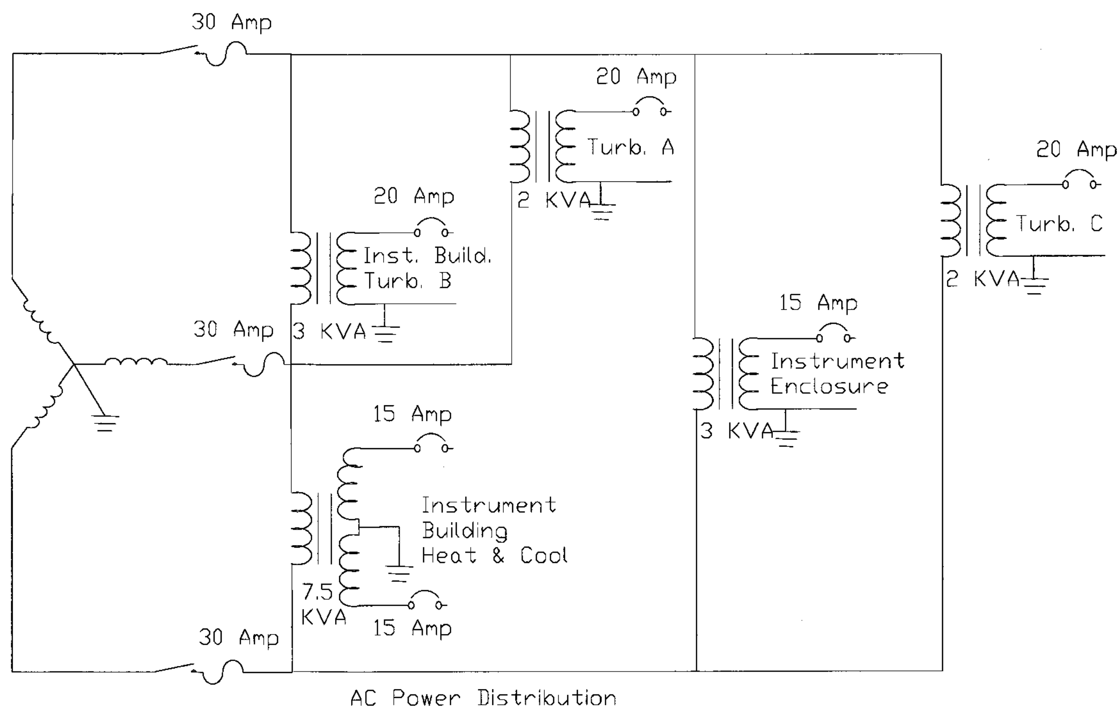

Figure D-4. Grid Connections and Auxiliary AC Power.

Grounding Grid

The grounding grid is made up of bare, braided #00, copper cable cad welded at each connection to the ¾-inch copper clad ground rods and the grounding lugs. The grounding lugs are bolted to the turbine towers and buildings, and clamped to the met tower guy wires. All of the electrical grounds and instrument grounds are connected to the ground grid. The grid layout also shows the met tower guy wires and the ground grid (see Figure D-5).

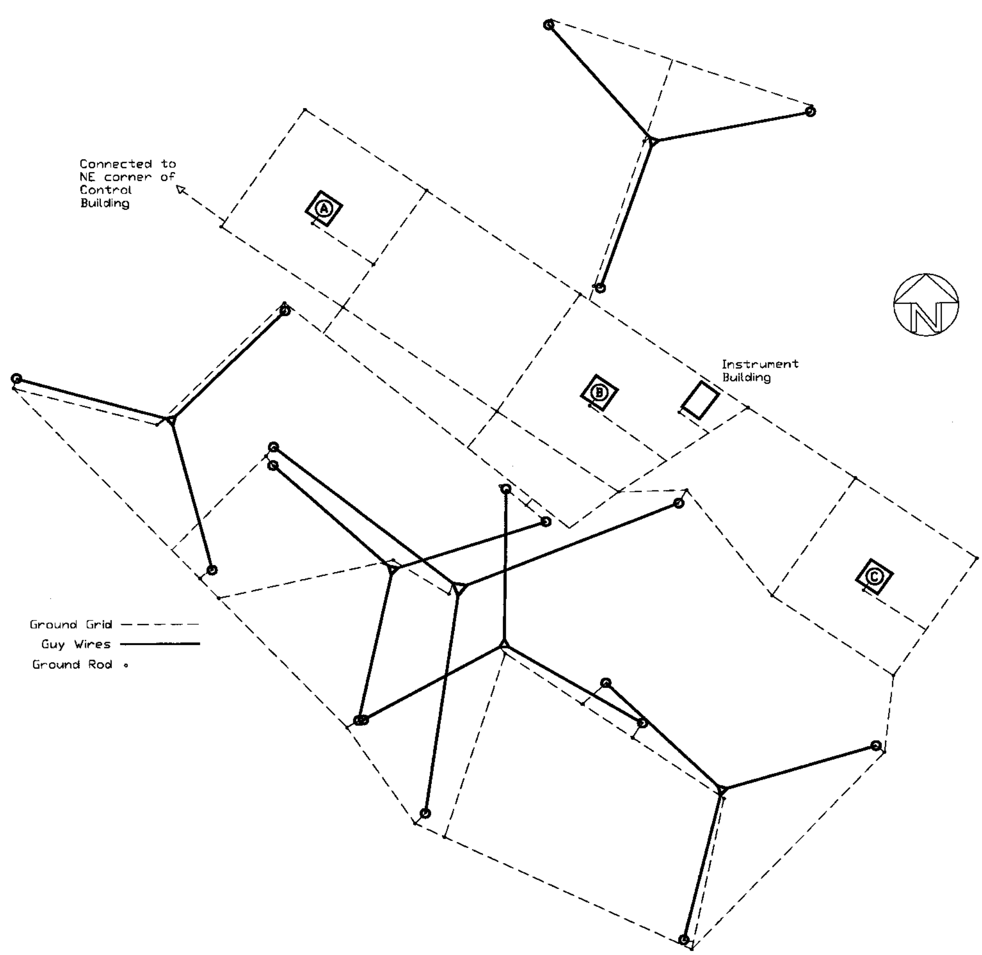

Figure D-5. Ground Grid.

AC Power in Instrument Building

Instrument building and instrument enclosure power is brought in from the main 480-volt transformer to separate 110-volt and 220-volt transformers (see Figure D-6). One 110-volt transformer provides the power to the instrument building utility outlets, lights, the instrument enclosure fans, lights, and utility outlets. Another 110-volt transformer is used for power to the uninterruptible power supply (UPS) which is used for the instrumentation power for each of the Micon turbines. The 220-volt transformer is for the instrument building heating and air conditioning.

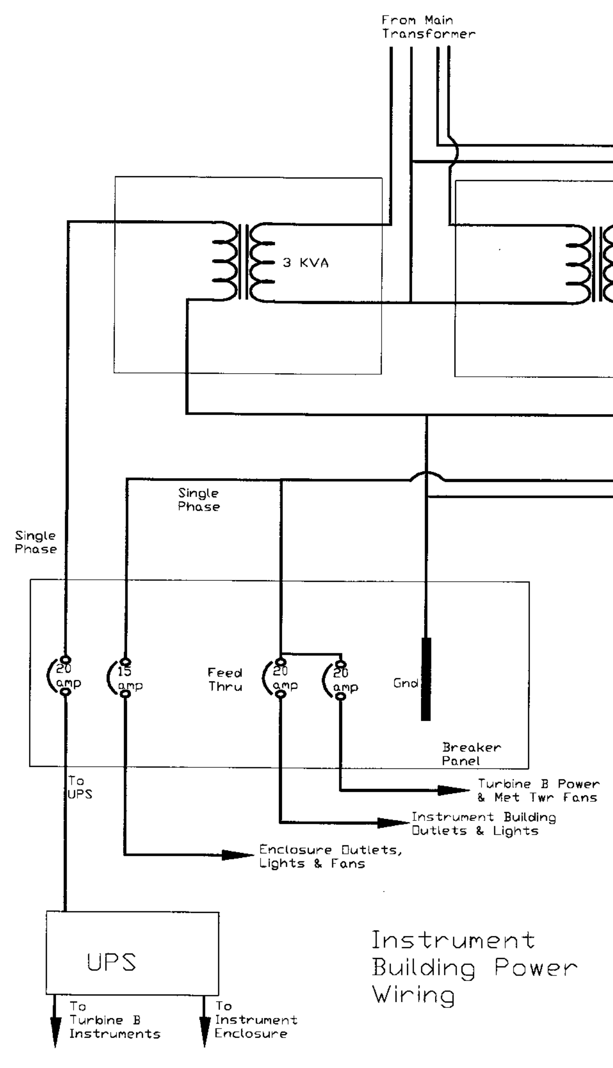

Figure D-6. AC-Power Wiring Diagram for the Instrument Building and Enclosure.

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