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LIST/BMI Turbines Instrumentation and Infrastructure

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LIST/BMI Turbines
Instrumentation and Infrastructure

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ABSTRACT

In support of two major SNL programs, the Long-term Inflow and Structural Test (LIST) program and the Blade Manufacturing Initiative (BMI), three Micon 65/13M wind turbines have been erected at the USDA Agriculture Research Service (ARS) center in Bushland, Texas. The inflow and structural response of these turbines are being monitored with an array of 60 instruments: 34 to characterize the inflow, 19 to characterize structural response and 7 to characterize the time-varying state of the turbine. The primary characterization of the inflow into the LIST turbine relies upon an array of five sonic anemometers. Primary characterization of the structural response of the turbine uses several sets of strain gauges to measure bending loads on the blades and the tower and two accelerometers to measure the motion of the nacelle. Data are sampled at a rate of 30 Hz using a newly developed 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 turbines and their inflow.

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INTRODUCTION

In support of two major SNL programs, three Micon 65/13M wind turbines have been erected at the USDA Agriculture Research Service (ARS) center in Bushland, Texas. The inflow and structural response of these turbines are being monitored in support of the Long-term Inflow and Structural Test (LIST) program and the Blade Manufacturing Initiative (BMI). The former is collecting long-term, continuous inflow and structural response data to characterize the extreme loads on wind turbines.[1] The latter is developing new design and manufacturing techniques for reducing costs and increasing reliability of wind turbine blades.[2] As BMI blades are produced, they will be tested at this site.

The inflow and structural response of these turbines are being monitored with an array of 60 instruments: 34 to characterize the inflow, 19 to characterize structural response and 7 to characterize the time-varying state of the turbine. The primary characterization of the inflow into the LIST turbine relies upon an array of five sonic anemometers. Primary characterization of the structural response of the turbine uses several sets of strain gauges to measure bending loads on the blades and the tower and two accelerometers to measure the motion of the nacelle. Data from the various instruments are sampled at a rate of 30 Hz using a newly developed data acquisition system that features a time-synchronized continuous data stream that includes data telemetered from the turbine rotor.

This paper documents the instruments and infrastructure that has been developed at this site in support of LIST and BMI projects.

TEST SITE

The three turbines used in this experiment are located on the USDA-ARS site in Bushland, TX. This site is characteristic of a Great Plains site with essentially flat terrain. The test site is surrounded by farmland. On the NNW corner of the site is a reservoir with an approximately 1.2 m (4 ft) berm. As illustrated in the topographic map shown in Fig. 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 rosette for this site shows a secondary peak for winds from approximately due North.

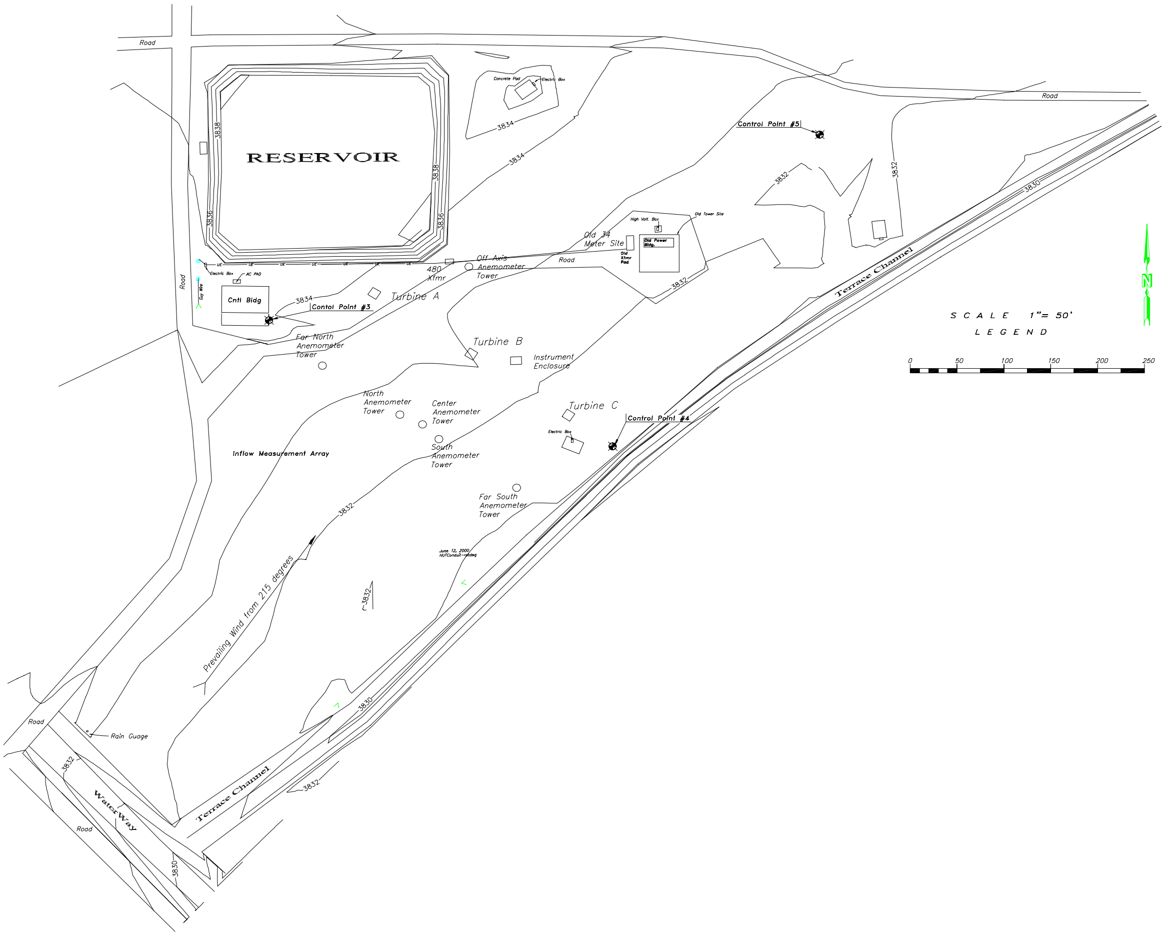

Fig. 1. Topographical Map of the USDA-ARS Site in Bushland , TX.

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

Site Plan

As shown in Fig. 2, the three turbines have been placed on this site in a straight line across the prevailing wind direction of 215°. The turbines are labeled A, B and C for convenience. The most heavily instrumented turbine is B. This turbine is the primary test turbine for the LIST portion of this experimental campaign.

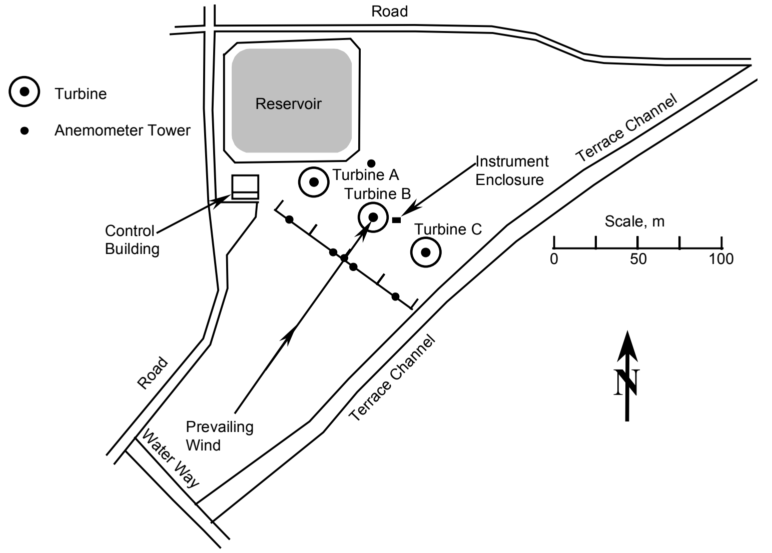

Fig. 2. A Schematic Overview of the Test Site.

Upwind of the turbines (with-respect-to the prevailing winds) are five meteorological towers. As discussed in detail below, these towers are equipped with a large array of instrumentation that is designed to characterize the inflow. In the secondary direction (approximately North) is a sixth meteorological tower. 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 are also given in Fig. 3 .

Buildings

Two buildings are on the test site, see Fig. 2. The first is the main "Control Building" that is west of the turbines. The second is a small instrumentation building that is located east of Turbine B. The latter building provides environmental protection for the "Instrument Enclosure" that houses 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 LIST turbine will also have an essentially unobstructed inflow.

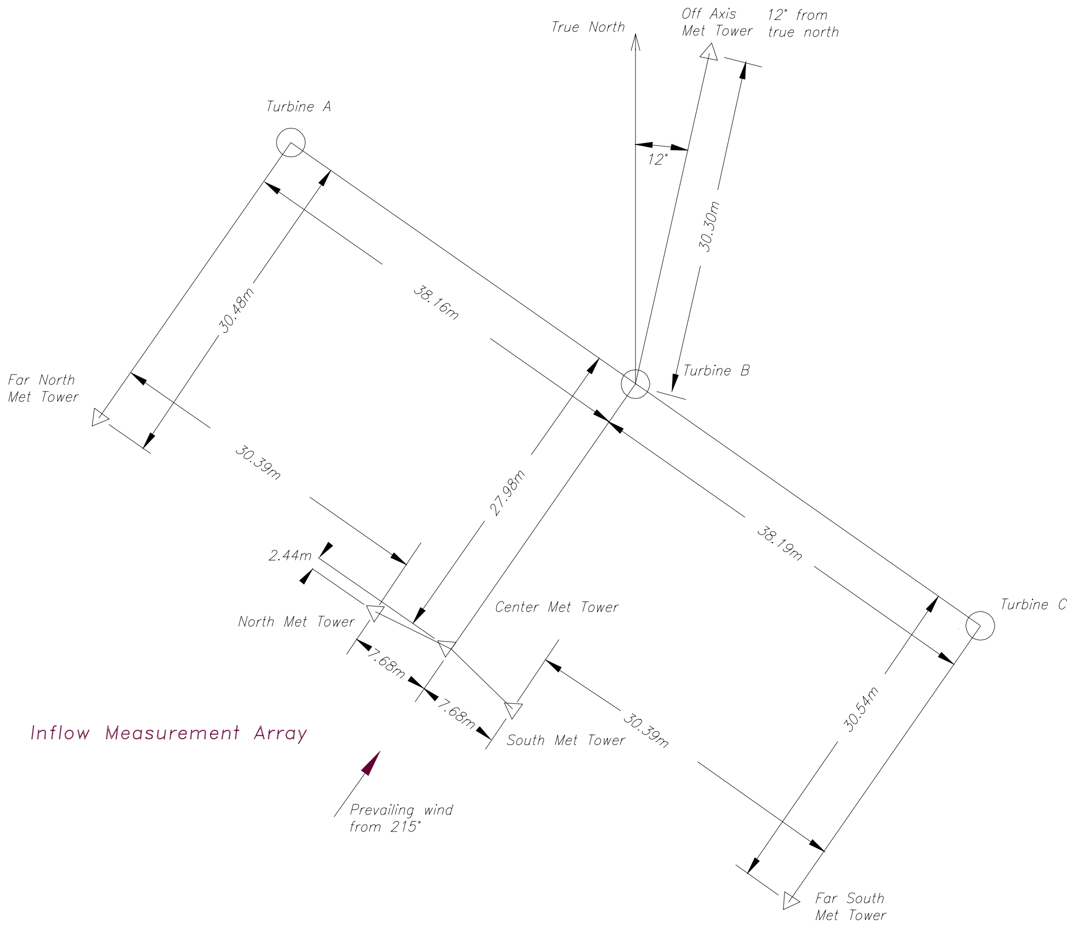

Fig. 3. Site Plan with Detailed Dimensions.

THE TURBINES

The turbines used in this experimental investigation are a modified version of the Micon 65/13 turbine (65/13M), see Fig. 4. This turbine is a fixed-pitch, 3-bladed up-wind turbine with an asynchronous generator. At hub height, the turbine stands 23 m (75 ft) tall on a tubular, 3-piece steel tower that weighs approximately 64.5 kN (14,500 lbs). The nacelle weight is approximately 42.7 kN (9,600 lbs).

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. These subsystems include the brakes, gearbox, generator and blades. The new drive train is built around an asynchronous, three-phase 480v generator rated at 115 kW. The generator operates at 1200 rpm while the blades turn at a fixed 55-rpm (the standard Micon 65/13 turbine rotates at a fixed 45 rpm). A detailed description of the placement of the turbines is provided in Fig. 3

.

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

Fig. 5. The LIST Turbine.

The LIST Turbine

The LIST Turbine or Turbine B is the center and primary turbine used in this experimental campaign, see Fig. 5. From a mechanical standpoint, the main difference between this turbine and its sister turbines is the blade configuration. The LIST turbine is fitted with Phoenix 8-m blades that are based on Solar Energy Research Institute (SERI)[†] airfoils. These "SERI" blades are 7.9 m (312 in) long, yielding a rotor diameter of 17.1 m (55.9 ft). The blades are equipped with tip brakes. The split line for these brakes is located at 6.5 m (256 in) from the blade flange. The hub flange for mounting the blades is located 599 mm (23.6 in) from the centerline of the low-speed shaft. The blades are a fixed-pitch design. They were set to approximately 2.2° pitch towards feather at the 75 percent span line, per the recommendations of J. Tangler.[3]

Sister Turbines

The other two Micon 65/13M turbines erected at this test site, Turbines A and C, are equipped with Aerostar 7.5 m (292 in) blades, yielding a rotor diameter of 16 m (52.6 ft). These blades are also a fixed-pitch design and equipped with tip brakes. The blades were pitched to their maximum power position.

[†] SERI is now the National Renewable Energy Laboratory (NREL).

INSTRUMENTATION

The turbines and the inflow at the Bushland site are being monitored with a total of 60 instruments: 34 to characterize the inflow, 19 to characterize structural response and 7 to characterize the time-varying state of the turbine. The primary characterization of the inflow into the LIST turbine relies upon an array of five sonic anemometers. Primary characterization of the structural response of the turbine uses several sets of strain gauges to measure bending loads on the blades and the tower and two accelerometers to measure the motion of the nacelle. Most of these instruments are concentrated on the LIST turbine, see the schematic diagrams shown in Figs. 6 and 7.

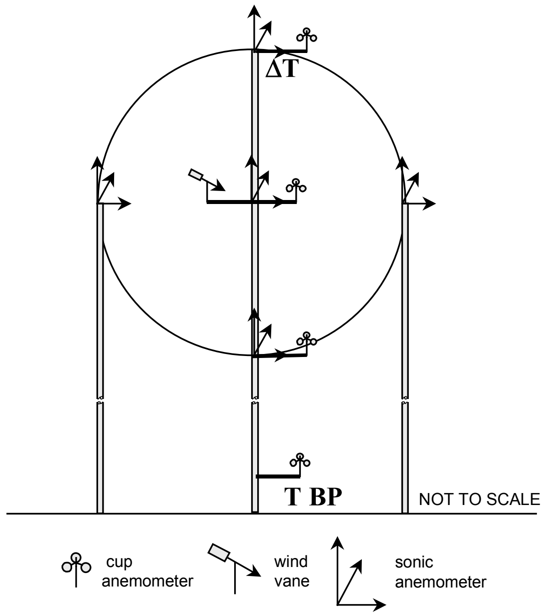

Fig. 6. Schematic Diagram of the Inflow Instrumentation for the LIST Turbine.

Instrumentation Summary and Nomenclature

A complete list of the 60 instruments used here is presented in Tables I, II and III. These tables divide the instruments into three general classifications: inflow, nacelle and rotor instrumentation. The nomenclature used to identify each gauge circuit is also included in these tables.

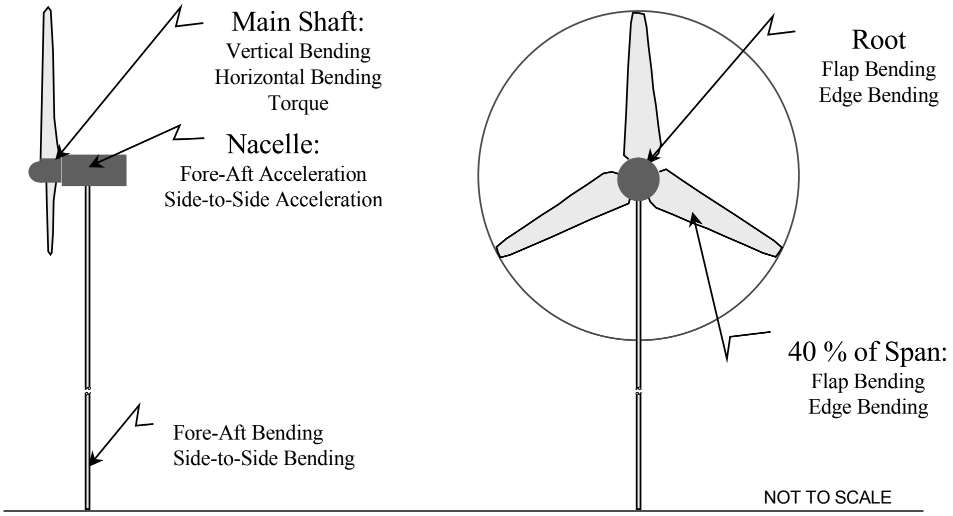

Fig. 7. Schematic Diagram of the Structural Instrumentation for the LIST Turbine.

Table I. Inflow Instrumentation.

Name	Instrument		Placement	Met Tower
BACTATI	Ultrasonic Anemometer	U	Top of Rotor	Center
		V		
		W		
		T		
BACTC	Cup			
BACCC	Cup		Hub Height	
BACCV	Wind Vane			
BACCATI	Ultrasonic Anemometer	U		
		V		
		W		
		T		
BACBATI	Ultrasonic Anemometer	U	Bottom of Rotor	
		V		
		W		
		T		
BACBC	Cup			
BAC2C	Cup		2m	
BACTP	Temperature			
BACDTP	Differential Temperature		2m to Top	
BANATI	Ultrasonic Anemometer	U	Hub Height	North
		V		
		W		
		T		
BASATI	Ultrasonic Anemometer	U	Hub Height	South
		V		
		W		
		T		
AANC	Cup		Hub Height	Far-North
AANV	Wind Vane		Hub Height	
CASC	Cup		Hub Height	Far-South
CASV	Wind Vane		Hub Height	
OC	Cup		Hub Height	Off-Axis
OV	Wind Vane		Hub Height	
EPR	Barometric Pressure		2m	Instrument Building

Table II. Turbine Instrumentation.

Turbine	Name	General Type	Measurement	Placement
Turbine B	BTBFA	Tower Bending	Fore-Aft	Tower Bottom
	BTBSS		Side-to-Side	
	BTOO	Turbine Monitor	On/Off	Controller
	BTP	Total Power Production	Electric Power	
	BTYAW	Yaw Position		Tower Top
	BTAFA	Acceleration	Fore-Aft	Nacelle
	BTASS		Side-to-Side	
	BTRA	Rotor Azimuth		Main Shaft
	BTRS	Rotor Speed		
A Turbine	ATP	Total Power Production	Electric Power	Controller
C Turbine	CTP			

Table III. Rotor Instrumentation.

Name	Blade/Shaft	General Measurement	Position
BTB1RFB	Blade 1	Flap Bending	Root
BTB1REB		Edge Bending	Root
BTB1SFB		Flap Bending	40% of Chord
BTB1SEB		Edge Bending	40% of Chord
BTB2RFB	Blade 2	Flap Bending	Root
BTB2REB		Edge Bending	Root
BTB2SFB		Flap Bending	40% of Chord
BTB2SEB		Edge Bending	40% of Chord
BTB3RFB	Blade 3	Flap Bending	Root
BTB3REB		Edge Bending	Root
BTB3SFB		Flap Bending	40% of Chord
BTB3SEB		Edge Bending	40% of Chord
BTMSVB	Main Shaft	Vertical Bending	Outside Main Bearing
BTMSHB		Horizontal Bending	
BTMST		Shaft Torque	

Inflow Instrumentation

The inflow into the three turbines is heavily monitored with both sonic and cup anemometers and with wind vanes, see Fig. 6. As noted above, this instrumentation is mounted on six 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 1.9 diameters for the standard Aerostar blade set and 1.8 diameters for the SERI blade set.

There are three towers directly in front of the LIST turbine, see Fig. 6. The center tower is directly upwind, with-respect-to the prevailing wind, of the LIST turbine. The other two towers are one rotor-disk radius to the left and right, respectively, of the center tower. Four cup anemometers are mounted to the center tower (designated the “Center Met Tower”): one is mounted at the height of the top of the rotor circle (hub height plus one rotor-disk radius), the second at the bottom of the rotor circle (hub height minus one rotor-disk radius), the third at hub height and the fourth at approximately 1.6 m (5.1 ft) above ground level. A wind vane is mounted to this tower at hub height. Five sonic anemometers are also mounted to the three towers. On the center tower, one each is mounted at the top, middle (hub height) and bottom of the rotor circle. On the other two towers, the anemometers are mounted at hub height. Thus, the sonic anemometers are mounted in a circular pattern equal to that of the turbine rotor 1.8 diameters in front of the LIST turbine.

The inflow into the other two turbines is monitored with hub-height cup anemometers and wind vanes. They are located 1.9 rotor diameters, 30.5 m (102.6 ft), upwind of each turbine.

To monitor the secondary wind direction, a cup anemometer is mounted at hub height on a tower that is located at approximately 30.3 m from the LIST turbine, see Fig. 3.

On the center meteorological tower, the inflow instrumentation is mounted on the end of an extension arm to preclude blockage effects of the tower, see Fig. 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 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 to the tower for maintenance. The arm is stabilized vertically and horizontally with 2 supporting brackets. To place all of the anemometry in the same plane with-respect-to the prevailing winds, the center tower is set back to compensate for the extension provided by this boom, see Fig. 3. The inflow instrumentation on the other towers are mounted on the top of the tower, and therefore no extension arms are required, see Figs. 9 and 10 for diagrams of typical installations.

Cup Anemometer

Seven cup anemometers are used to monitor the inflow into the three turbines. Three are placed at hub height in front, (with-respect-to the prevailing winds), of each turbine and another is place at hub height with (respect-to the secondary wind direction). The remaining three are mounted in front of the LIST turbine and aligned with the top and bottom of its rotor, and at 1.6 m (5.1 ft) above ground level, see Fig. 6.

The cup anemometer used in this measurement campaign is a Wind Speed Transmitter (cup), Model 1564B provided by Met One Instruments Incorporated.[4] A complete description of this instrument is provided in Appendix B. The two types of mounting methods are shown in Figs. 8 and 10.

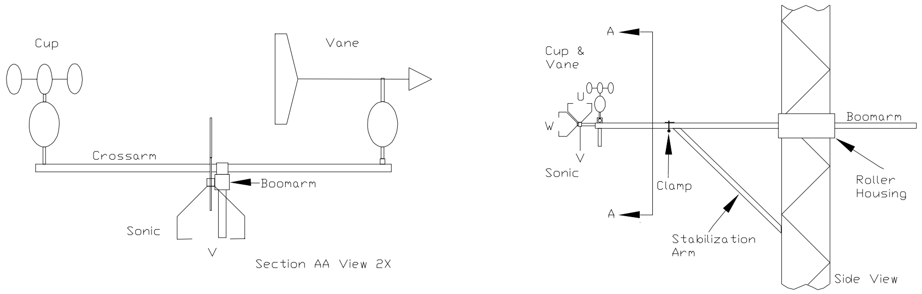

Fig. 8a. Front View. **Fig. 8b. Side View.**

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

Wind Vane

A total of 4 wind vanes are used in this installation. All are placed at hub height. One each is placed in front of each turbine (with-respect-to the prevailing winds), and the fourth is placed in the direction of the secondary wind direction.

The wind vane installations are shown in Figs. 8 and 10. The system used here is a Wind Direction Transmitter (vane), Model 1565C provided by Met One Instruments Incorporated,[4] see Appendix B.

Sonic Anemometers

A total of 5 sonic anemometers are used in this installation. All are located in front (with-respect-to the prevailing winds), of the LIST turbine. These anemometers form a circular pattern as shown in Fig. 6. The diameter of the circle is the same as the diameter of the turbine rotor. All of these instruments are aligned with the prevailing wind direction of 215°.

The sonic anemometer installations are shown in Figs. 8 and 9. The system used here is a model SATI/3K, Applied Technologies Incorporated,[5] see Appendix C. Each 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 up wind direction is the "W" component.

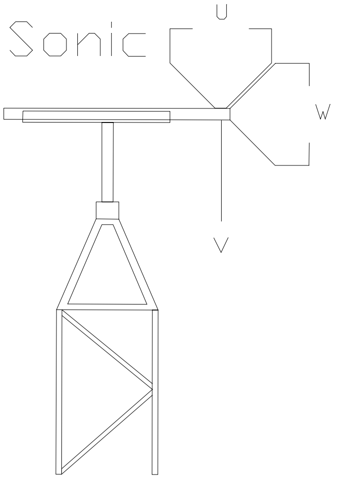

Fig. 9. Tower-Top Mounting of a Sonic Anemometer.

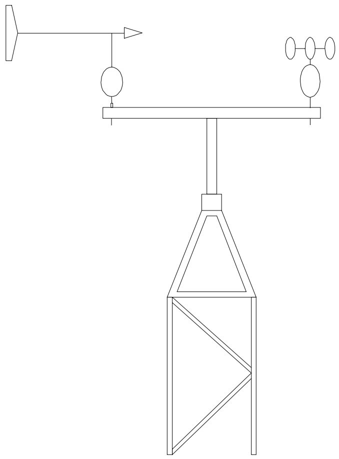

Fig. 10. Tower-Top Mounting of a Cup and Vane.

Temperature

The absolute temperature is measured at the center meteorological tower, [approximately 1.6 m (5.1 ft) above ground level] by a 4 wire platinum resistance temperature detector (PRT), Met One Model No. 0631.[4] The temperature sensor is mounted on the end of 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 Fig. 11 and Appendix B.

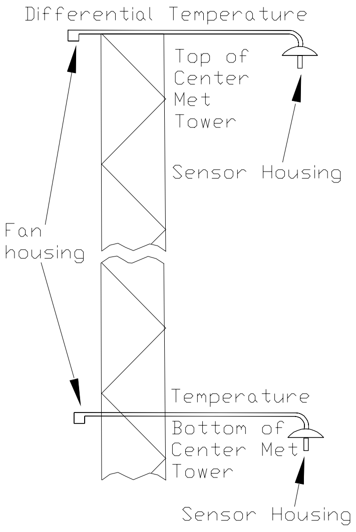

Fig. 11. Mounting of the Temperature & Delta Temperature Probes.

Differential Temperature

The differential temperature is measured on the center meteorological tower, between the top of the tower [33.6 m (110 ft)] and ground level (1.6 m) by a 4 wire platinum resistance temperature detector (PRT), Met One Model No. 063-1.[4] The temperature sensor is mounted on the end of a tubular arm with a solar shield over the sensor at about 1 m from the tower and aligned at 215° see, Fig. 11 and Appendix B. 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 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.[6]

Structural Instrumentation

The structural response of the turbine is measured with a variety of gauges, primarily strain gauges. A schematic of the structural gauges and their placement is shown in Fig. 7.

Most of the strain gauge circuits are placed on the rotor. Each blade is instrumented at its root and at the 40 percent span station with strain gauge sets that measure flap and edgewise bending. The tower is instrumented with bending gauge sets located approximately 3.9 m (154 in) above the turbine base. These gauge sets measure tower bending fore-and-aft (along the prevailing wind direction) and side-to-side bending (across the prevailing wind direction). The main shaft is instrumented with gauges that measure vertical and horizontal bending and torque. In addition two accelerometers are mounted in the nacelle to measure motion along and across the primary axis of the nacelle.

All strain gauges were calibrated using static loading.

Strain Gauge Circuits

A total of 17 strain gauge circuits are used here, see Fig. 7. A complete list of these circuits is given in Table IV. All circuits used here are full-bridges.

Blade Strain Gauges

The strain gauges are dual element encapsulated 1000-ohm gauges (Micro Measurements WK-06-250PD-10C)[7] located at 40% of span on each blade, see Fig. 7 and Appendix B.

Hub Strain Gauges

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

Main Shaft Strain Gauges

The strain gauges on the main shaft are single element 350 ohm encapsulated weldable gauges. The bending circuits use Micro Measurements LWK-06-250B-350 and the torque circuit use LWK-06-250D-350.[7] The bending gauges were orientated on the main shaft to provide vertical and horizontal bending with-respect-to Blade 1 in the vertical position, see Fig. 7, see Appendix B.

A problem was encountered with the main shaft gauges. When the three turbines were modified to their current configurations, the diameter of the main shaft was increased using a sleeve. When strain gauges were placed on the sleeve, they did not provide consistent readings because the sleeve has some motion relative to the underlying (original) main shaft. Thus, accurate measurements of shaft bending are not provided by this instrumentation. However, these gauges are in place and are being monitored to demonstrate capabilities and to ascertain if useful data may be obtained from them.

Table IV. Strain Gauge Circuits.

Type	Active Elements	Position	Gauge Type	Resistance (ohms)	Gage Factor	Name	Direction
Bending	2	Tower	WK-06-250TM-350	350	1.96 ± 4.5%	BTBFA	Fore-Aft
						BTBSS	Side-to-Side
	4	Root 1	WK-06-250PD-350	350	2.03 ± 1%	BTB1RFB	Flap
						BTB1REB	Edge
		Blade 1	WK-06-250PD-10C	1000	2.055 ± 0.5%	BTB1SFB	Flap
						BTB1SEB	Edge
		Root 2	WK-06-250PD-350	350	2.03 ± 1%	BTB2RFB	Flap
						BTB2REB	Edge
		Blade 2	WK-06-250PD-10C	1000	2.055 ± 0.5%	BTB2SFB	Flap
						BTB2SEB	Edge
		Root 3	WK-06-250PD-350	350	2.03 ± 1%	BTB3RFB	Flap
						BTB3REB	Edge
		Blade 3	WK-06-250PD-10C	1000	2.055 ± 0.5%	BTB3SFB	Flap
						BTB3SEB	Edge
		Main Shaft	LWK-06-250B-350	350	2.02 ± 1%	BTMSVB	Vertical
						BTMSHB	Horizontal
Torque			LWK-06-250D-350	350	2.02 ± 1%	BTMST	

Tower Strain Gauges

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

Nacelle Acceleration

The nacelle is instrumented with two semiconductor strain gauge type accelerometers. They are single axis accelerometers attached to the nacelle frame. They measure horizontal acceleration parallel and perpendicular to the current yaw position of the turbine. The accelerometers are Endevco, model number 2262A-25,[8] and are located on the nacelle frame next to the gearbox, see Fig. 7 and Appendix B.

Additional Instrumentation

In addition to the instrumentation cited above, several other turbine parameters are measured, see Table II. These include yaw position, rotor position, rotor speed, turbine monitor (on-off switch) and power production. The yaw and rotor positions are measured directly with 360° angle encoders. The rotor speed is derived from the rotor position using a dedicated, differentiating analogue circuit. The turbine monitor indicates the state of the grid/turbine connection, i.e., whether or not the turbine is connected to the gird. The power production for each of the three turbines is monitored using 3-phase power transducers.

Yaw Position

Nacelle yaw position is measured using a brushless rotary encoder, Computer Conversions Corporation, model HSTDCC-PB16S-SE.[9] The encoder is located on the yaw drive gear box inside the nacelle, see Fig. 12. The encoder shaft is connected to the yaw drive 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 yaw position, see Appendix B. The unit was calibrated to yield yaw measurements with respect 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).[9] The encoder is located by the main shaft inside the nacelle, see Fig. 12. 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 when Blade 1 is vertically up. The blade sequence for this turbine is 1-3-2 clockwise from up wind.

The rotor speed is derived from the rotor position using a dedicated, differentiating analogue circuit, designed specifically by Computer Conversions Corp. to be used with the EVSTDCC-PB16VIC-SIRPS unit.

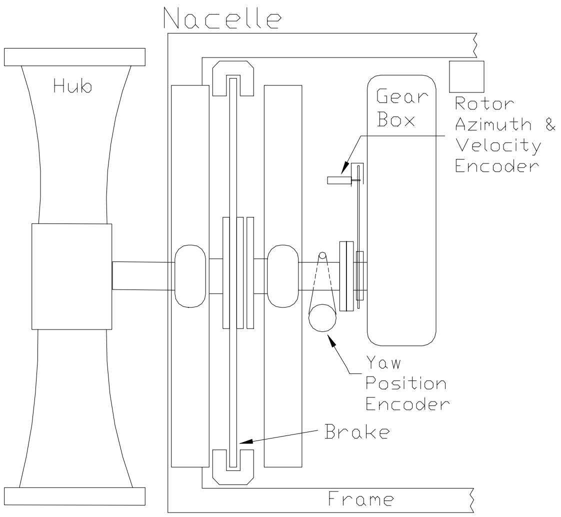

Fig. 12. Rotor Azimuth, Velocity and Nacelle Yaw Position.

Turbine Monitor

The turbine monitor circuit is an on/off signal that indicates when the turbine is connected to the grid; i.e., the turbine is up to speed, producing power and 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 supply an on/off voltage signal to the data system. The relay is located in the turbine control junction box at the base of the turbine tower.

Power Production

The power produced by each of the three turbines is monitored using precision self-powered voltage, watt VAR, and current tranducers from Ohio Semitronics.[10] For this installation, only the total power (3-phase) is being recorded. However, current instrumentation also permits measurement of the power and voltage on the individual phases, the current and the VARS. As warranted, additional measurements may or may not be added to the data record. One each of these instruments is located in the turbine control junction boxes at the base of each turbine tower, see Appendix B.

DATA ACQUISITION SYSTEM

Berg, Rumsey and Zayas[11] have developed the unique data acquisition and analysis system used on these turbines. The hardware system, called ATLAS, (Accurate, Time-Linked Data Acquisition System), is designed to acquire long-term, continuous, time synchronized, multi-channel time series data from an operating wind turbine. The 16-bit data stream from the ATLAS hardware system is acquired and recorded using the Advanced Data Acquisition System (ADAS) II software. ADAS II segments the data into 10-minute blocks, converts the data to engineering units, and stores them for future processing. The final step in the acquisition of continuous data is handled by the Smart Data Acquisition System (SDAS) which automatically archives the data and provides the researcher with the tools needed to organize and process the data.

For this series of experiments, the data rate was chosen to be 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

For this experiment, 3 data acquisition units are used in the ATLAS. The first two are ground-based units (GBU's) that are hard-wired together. These units are located in the Instrument Enclosure near the base of Turbine B, see Fig. 2. The third is a rotor-based unit (RBU) that is mounted to the rotor.

The GBU's are mounted to the top of the "Instrumentation Rack" inside the Instrument Enclosure, see Appendix C. These two units are wired in a master/slave combination. They monitor the instrument circuits cited in Tables I and II; i.e., all instruments except the strain gauge circuits on the rotor. For this test series, the slave unit is sampling all of the analog data and the master unit is sampling the strain gauge and accelerometer data. The former is filled to capacity with five 8-channel analog cards, and the latter contains a single 8-channel bridge circuit 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 III. These cards are identical to the one used in the master GBU. Data from the RBU are 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 ADAS II software).

All three units are timed using GPS synchronized clocks. This timing technique insures that the clocks in the RBU and the GBU's are maintained within 1 microsecond of each other.

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

All of these units are programmed using ATLAS software package developed by Berg, Rumsey and Zayas.[11] The ATLAS program is run on the main PC that downloads the data acquisition program to the ATLAS units over a fiber optic connection. The RBU has an additional capability that permits it to be programmed via a telemetry link.

ADAS II

The data stream from ATLAS is acquired by the ADAS II data acquisition system. This system is run on a dedicated PC using a specialized version of the original code developed for NREL. The current version is designed to acquire and store continuous time-series data from the ATLAS hardware.

The PC is located in the Control Building, see Fig. 2. It was originally hard wired to the master GBU. However, to provide additional lightening protection, the hard-wired connection has been replaced with a fiber optic link.

ADAS II acquires the data from the ATLAS system in a PCM format. It then decodes these data, converts them into engineering units via a user-defined calibration table, and records the data to hard disk. Each data file is assigned a unique name based upon the date and time the data was acquired. All data files are stored in a collimated ASCII format. A header file is included with each data file and contains all of the pertinent information, including the calibration table that belongs to that specific data file.

The ADAS II system is takes a continuous stream that is divided into 10-minute blocks for convenience. All data acquisition and data archival activities are accomplished with no loss of data between the data blocks.

Data Archival

The ADAS PC is networked to a data archival PC, also located in the Control Building. This PC automatically reads each 10-minute ADAS II data file, after it has been stored to disk. It then “zips” the file and stores it on a large hard disk. When the process is completed, the original file is removed from the ADAS PC to free space for forthcoming data files.

Approximately once a week the site engineer downloads the zipped data files to C-DR’s for permanent storage and analysis. When complete, the archived files are removed from the hard disk to free space for the next set of data files.

WIRING DIAGRAMS

The 60 instrument channels that are monitored in this measurement campaign are hardwired to one of the three ATLAS units. The myriad of cables and function 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 and junction box.

Instrument Enclosure

The confluence of the wires, “black boxes,” power supplies, lightening protection, terminal strips and telemetry signals takes place in the Instrument Enclosure, see Fig. 13. To insure maximum protection of the instrumentation, this enclosure is sealed to protect the instruments from rain, dust, rodents, etc. Most of the hard-wired circuits into and out of the enclosure are protected with lightening 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 and environment seals around its doors.

The enclosure is located in a small metal shed near the base of Turbine B, see Fig. 2. The shed is heated and cooled by a wall-mounted heat pump.

The enclosure is divided into two primary sections. The left side contains a slide-out instrument rack for mounting the data system and associated black boxes (converters) 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 right side contains connection boards and the lightening 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 all are grounded through a grounding grid that is connected to the turbine towers, meteorological towers, guy wires, and test site buildings, see Appendix D.

Fig. 13. Instrument Enclosure.

Lightening Protection

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

Almost all of the electrical leads into and out of the enclosure are protected with commercial high-speed gas tube/diode lightning protection circuits (Citel Inc.).[12] 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 system.

The data acquisition system (located in the Instrument Enclosure) was originally connected to its controlling computer (located in the Control Building, see Fig. 2) via a hard wire connection. However, this link proved susceptible to lightning. To alleviate this problem and to gain added electrical isolation for the instruments inside the enclosure and for the computers in the control room, the hard wire connection was replaced with a fiber optic link (Fiberplex).[13]

All circuits in the data acquisition system on the rotor are protected using commercial high-speed gas tube/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 that range over the site, see Appendix D. All of the instrumentation cables are 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 V, VI and VII. Wiring diagrams for these cables is 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 VIII. Wiring diagrams and specifications are provided in Appendix D.

Appendix D also provides conduit schedules for the cable system.

Table V. Turbine Instrument Cables.

Turbine Instrument Cables			
Turbine	Name	Description	Routing
Turbine A	ATI1	15 Pair cable	Turbine A to Instrument Enclosure
	ATI2	15 Pair cable (spare)	Turbine A to Instrument Enclosure
	ATI3	15 Pair cable (spare)	Turbine A to Instrument Enclosure
Turbine B	BTI1	15 Pair cable	Turbine B to Instrument Enclosure
	BTI2	15 Pair cable (spare)	Turbine B to Instrument Enclosure
	BTI3	15 Pair cable (spare)	Turbine B to Instrument Enclosure
Turbine C	CTI1	15 Pair cable	Turbine C to Instrument Enclosure
	CTI2	15 Pair cable (spare)	Turbine C to Instrument Enclosure
	CTI3	15 Pair cable (spare)	Turbine C to Instrument Enclosure

Table VI. 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
North Met Tower	BANI	9 Pair cable	North Met Tower to Center Met. Tower
South Met Tower	BASI	9 Pair cable	South Met Tower to Center Met. Tower
Far North Met Tower	AANI	9 Pair cable	Far North Met Tower to Instrument Enclosure
Far South Met Tower	CASI	9 Pair cable	Far South Met Tower to Instrument Enclosure
Off Axis Met Tower	OANI	9 Pair cable	Off Axis Met Tower to Instrument Enclosure

Table VII. 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 VIII. AC Power Cables.

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

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. The location of these boxes is outlined in Appendix D and a wiring diagram for each is provided in Appendix C.

Ground Grid

An extensive ground grid was placed about the 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 LIST & BMI turbines and their inflow at the Bushland test site. It also provides a detailed reference manual for those who choose to use these data in their studies of wind turbine behavior.

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8. Endevco, Endevco Corporation, San Juan Capistrano, Ca.

9. Computer Conversions, Computer Conversions Corporation, East Northport, NY.

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

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13. Fiberplex, Fiberplex Inc,. Annapolis, Md.

14. Tower Systems, Watertown, South Dakota.

APPENDIX A

DETAILED DIAGRAMS OF THE METEOROLOGICAL TOWERS

As noted above, there are a total of six meteorological towers used in this experiment. Their locations at the site are described in Fig. 3. Tower nomenclature is presented in Fig. 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.

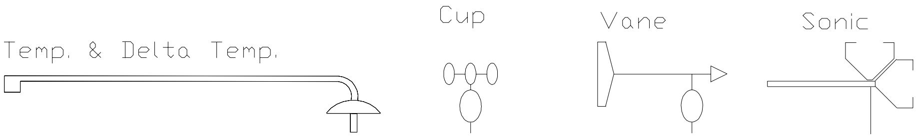


Fig. A-1. Symbols used on the Diagrams of the Meteorological Towers.

Center Meteorological Tower

A significant portion of instrumentation that characterizes the inflow is mounted on the center meteorological (met) tower. This tower is located directly in front, with-respect-to the prevailing wind of the LIST turbine, see Fig. 3. The instrumentation includes 3 sonic anemometers, 4 cup anemometers, one wind vane, temperature and differential temperature. The position of all of these instruments is summarized in Fig. A-2.

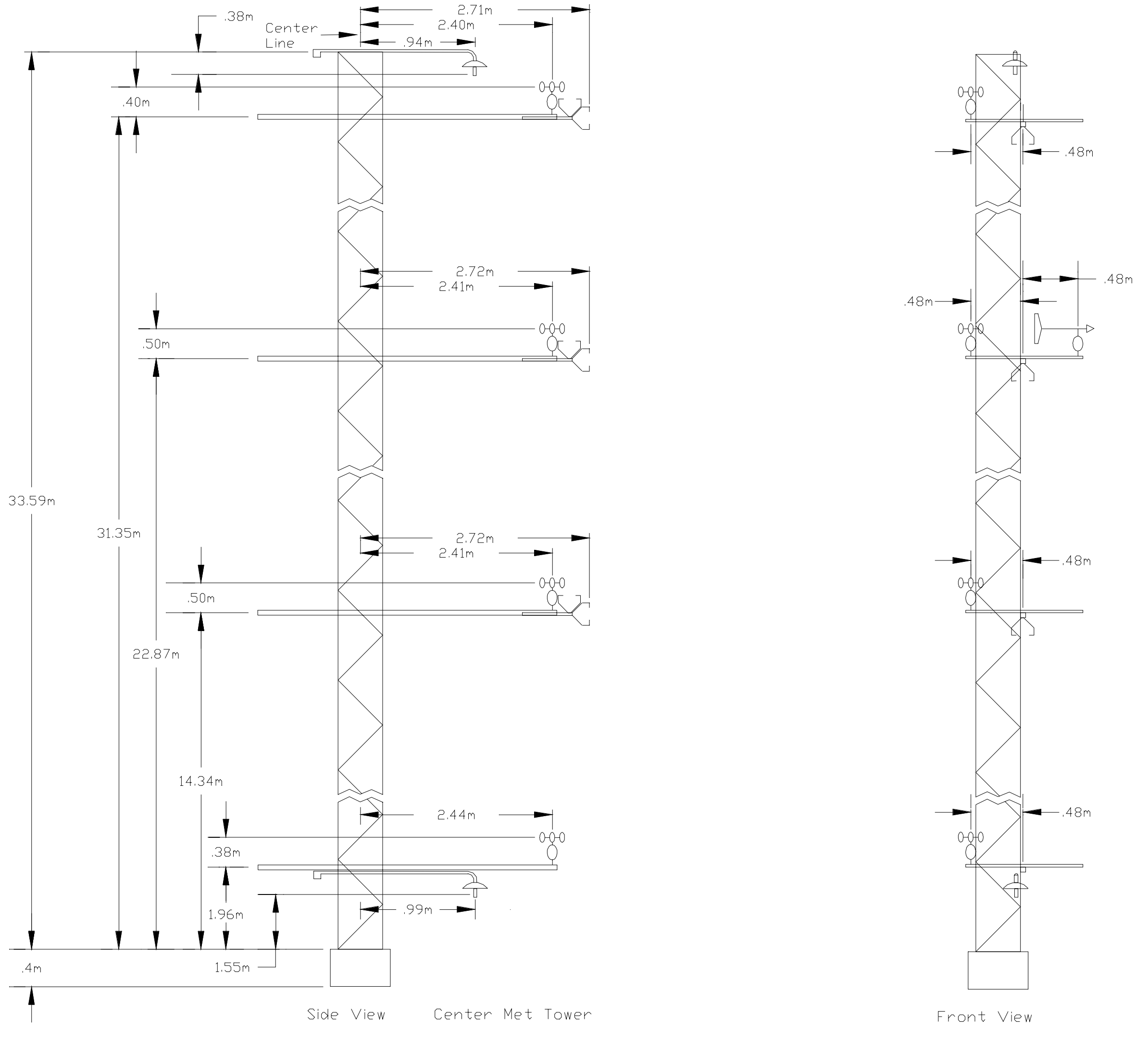


Fig. A-2. Center Meteorological Tower.

North & South Meteorological Towers

The North and South Meteorological Towers are the two meteorological towers located closest to the Center Meteorological Tower, see Fig. 3. They are orientated across the prevailing wind and are approximately one blade radius to either side of the Center Meteorological Tower. Each has a sonic anemometer mounted on its top. The position of these instruments is summarized in Fig. A-3

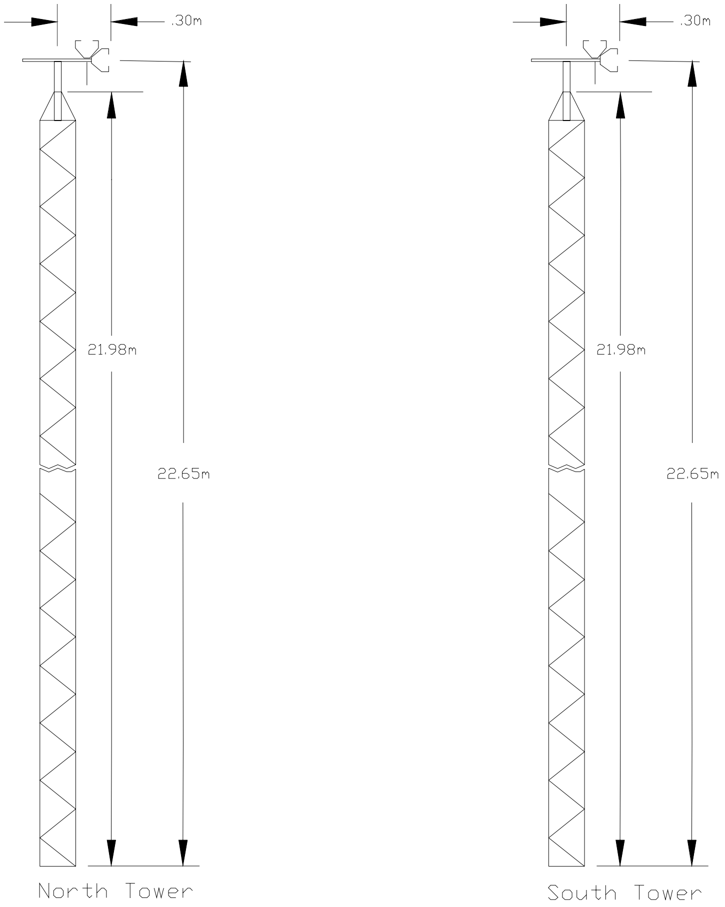


Fig. A-3. North and South Meteorological Towers.

Far-North, Far-South and Off-Axis Meteorological Towers

The remaining three towers, see Fig. 3, have a cup anemometer and a wind vane mounted on their top. The position of these instruments is summarized in Fig. A-4.

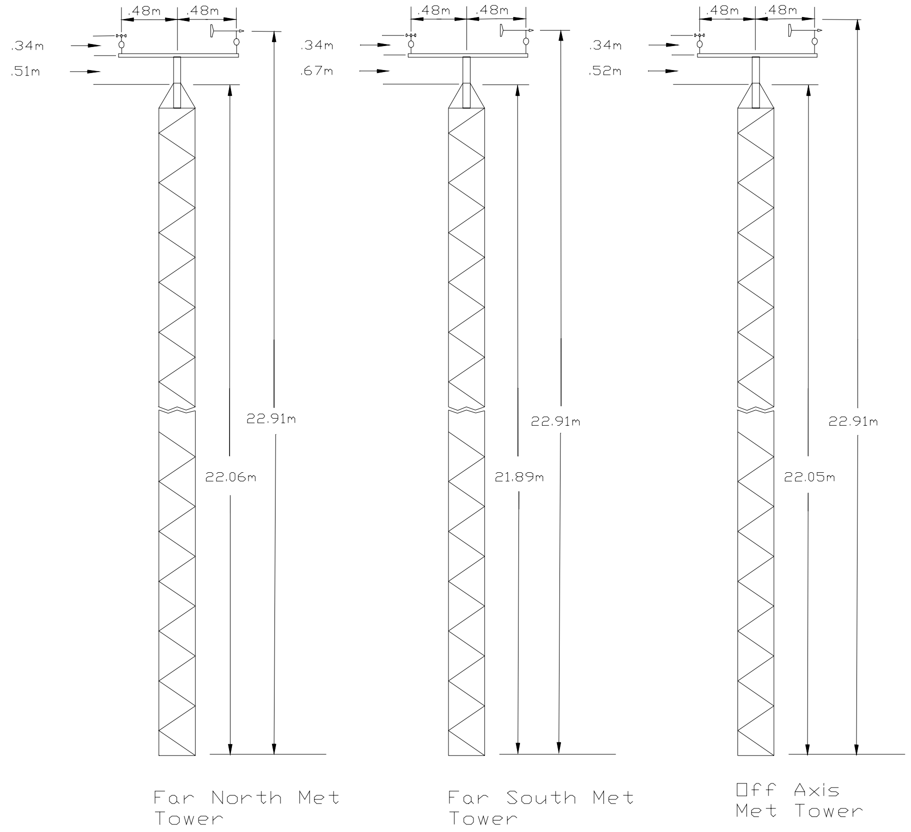


Fig. A-4. Far-North, Far-South and Off-Axis Meteorological Towers.

APPENDIX B

INSTRUMENTATION SPECIFICATIONS

A complete list of the instrumentation circuits is given in Tables I, II and III. This appendix describes the instruments, their specification and their placement.

Met One Instrumentation

Met One Instruments Incorporated[4] 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[4] (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 hard wired 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[4] (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 probe.

The vanes are hard wired 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 cups and vanes are mounted on cross arms that rotate 360° horizontally and adjust 0.52 m (1.5 ft.) vertically. The cross arms are mounted at the end extendable boom arms made of aluminum tubing 5.08 cm (2 inches)square by 0.635 cm (0.25 inch) wall by 3.048 m (10 ft.) long. The boom arms are mounted on the tower end in a roller housing (Tower Systems Inc.)[14] 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 Fig. 8.

On the other towers (Far-North, Far-South and Off-Axis), the cup and vane cross-arms are mounted directly to the top of the tower, see Fig. 10.

Temperature Measurements

Absolute Temperature

The temperature is measured at approximately 1.6 m (5.1 ft) above ground level by a 4-wire platinum resistance temperature detector (PRT), Met One Model No. 063-1.[4] 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 hard wired 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 temperature [1.6 m (5.1 ft.)], with two 4 wire platinum resistance temperature detectors (PRT), Met One Model No. 063-1,[4] 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 hard wired 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 Fig. 11. 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 hard wired 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 Instrument Inc. Model 2014-75/1050.[6] The instrument range is 74.5 to 105 kPa with an accuracy of ± 0.125% of full scale.

The sensor is hard wired directly to the instrument enclosure. A Met One[4] signal processor is used to monitor this gauge. The processor is mounted in the bottom section of the instrumentation rack in the instrument enclosure inside the instrumentation building, see Appendix C.

Sonic Anemometer

Five each Applied Technologies Incorporated Sonic Anemometer/thermometers[5] model SATI/3K, are used here for the "detailed" inflow measurements. Each of these units measures three velocity components (two horizontal, U and V, and one vertical, W) and the sonic temperature. Their 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 analogue 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 anemometers are hard wired through junction boxes at the base of the met towers to the instrument enclosure. The signal processors for the sonic anemometers are mounted in the middle of the instrumentation rack, see Appendix C.

The sonic anemometers on the Center Tower are mounted on extendable boom arms made of aluminum tubing 5.08 cm (2 inches) square by 0.635 cm (0.25 inch) wall by 3.048 m (10 ft.) long. The boom arms are mounted at the tower in a roller housing (Tower Systems Inc.)[14] allowing for the arm to freely roll in and out. The arm is braced with 5.08 cm (2-inch) 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 Fig. 8. The sonic anemometers on the North and South Towers are mounted on the top of the tower on 2-inch steel angle and held in place with "U" bolts, see Fig. 9.

Strain Gauges

A total of 17 strain gauge circuits and two accelerometers are used here to monitor the structural performance of the LIST turbine, see Fig. 7. A complete list of the strain gauge circuits is given in Table IX. All of these circuits use full bridges built from strain gauges manufactured by Micro Measurements (Measurements Group).[7] The accelerometers, Endevco model number 2262A-25,[8] use bridge circuits to monitor the acceleration of the nacelle.

The strain gauge circuits use internal bridge card circuitry in the ATLAS units.[11] 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.

All strain-gauge circuits were calibrated using static pull tests with ATLAS reading the circuit output. Back-up calibrations were conducted using a Micro Measurements Digital Strain Indicator, Model P-3500.[7]

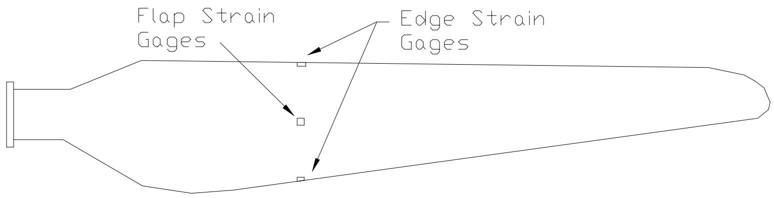
The strain-gauge circuits that are mounted to components of the rotor were hard wired to WINDY, the rotor-based unit of ATLAS.[11] Wire runs for gauges on the hub and the main shaft were approximately one meter long. For the blade gauges, the runs were approximately of 4.5 m (14.76 ft). As these distances are relatively short, the excitation voltage was monitored at WINDY, rather than at the bridge. The gauges mounted to the tower are hard-wired to one of the GBU's in the Instrument Enclosure. As this run is approximately of 35 m (114.84 ft), the excitation voltage to each bridge was monitored at the "completion tabs" for the bridge, using the "6-wire" bridge circuit capabilities of the ATLAS bridge circuit cards.

The accelerometers are also strain-gauge circuitry. The two used here are hard-wired to one of the GBU's in the Instrument Enclosure. As this run is approximately 45 m (147.65 ft), the excitation voltage was monitored using the “6-wire” bridge circuit configuration. An excitation voltage of 2.5 VDC with a 500 multiplier was used for these instruments.

Blade Gauges

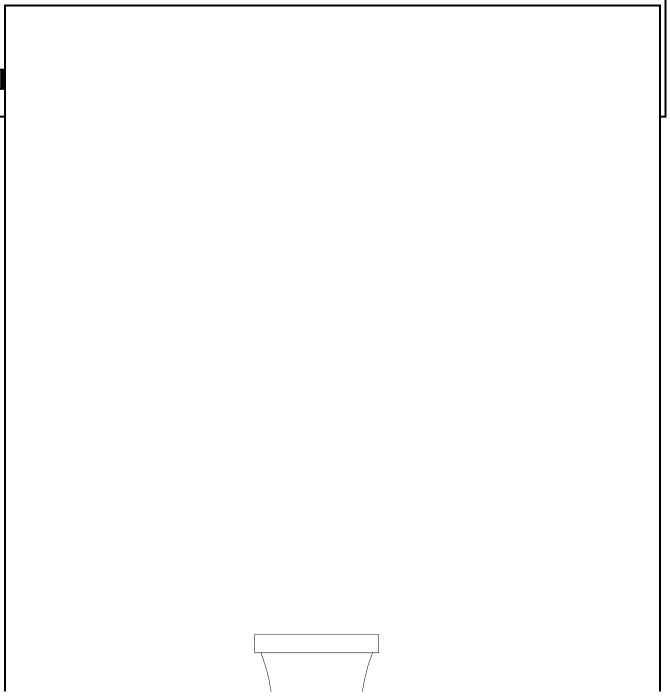
Each turbine blade on the LIST turbine was instrumented with two bending strain circuits wired to measure bending stresses, one each in the primary flap and edge directions of the blade. The gauges used for these installations are dual element, encapsulated 1000 ohm gauges (WK-06-250PD-10C). The gauges are located on each blade at the 40 percent span station [3.4 m (station 134 in)], see Fig. B-1. The flap gauges are mounted at the position of maximum thickness of the airfoil; namely, at the 30 percent of chord position, 0.3 m (11.8 in) from the leading edge. The edge gauges are mounted to the leading and trailing edges. The strain gauge circuit for each set is wired as a full bridge with 4 active elements.

Wiring between the gauges and WINDY is routed through the interior of the blades.



Hub Gauges

The hub on the LIST 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 Fig. 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 435 m (17.1 in) from the centerline of the main shaft.



Main Shaft

The main shaft is instrumented with 3 strain gauge circuits: one to measure vertical bending, one to measure horizontal bending and the third to measure torque. The two sets of bending gauges are orientated with Blade 1 vertically up. The gauges are located on the main shaft mid way between the main bearing and the hub, see Fig. B-3. Single element 350 ohm encapsulated weldable gauges (LWK-06-250B-350) are used for the bending circuits. They are located at 0° and 180° for vertical bending and at 90° and 270° for horizontal bending, see Fig. B-4. Dual element bi-axial encapsulated weldable 350 ohm gauges (LWK-06-250D-350) are used for the torque measurement. They are located at 45° and 225° , see Fig. B-4.

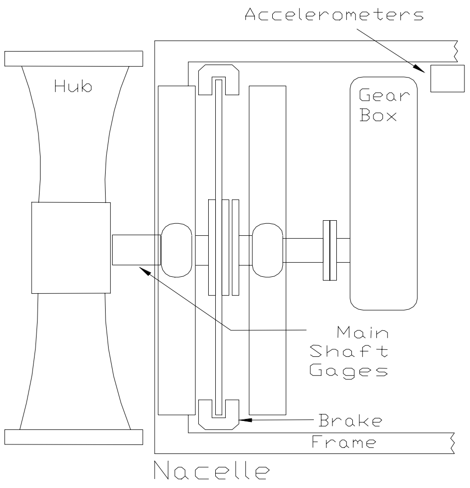


Fig. B-3. Accelerometers & Main Shaft Strain Gauges.

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 3.9m (154 in) above the turbine base, see Fig. B-5.

Accelerometers

The nacelle is instrumented with two accelerometers, Endevco model number 2262A-25.[8] They are piezoresistive, fluid dampened, semiconductor strain gauge elements. One instrument is aligned along the rotational axis to the turbine and the second is aligned across the rotation axis. These units have a 25g full scale range. At the 2.5 VDC excitation used here, full-scale output is 83.33 millivolts. They have an operating range of - 18°C to + 93°C (0°F to 200°F).

The accelerometers are located in a small junction box on the nacelle frame next to the gear box on the turbine, see Fig. B-3. The units are hard wired through a junction box located in the base of the turbine to the instrument enclosure.

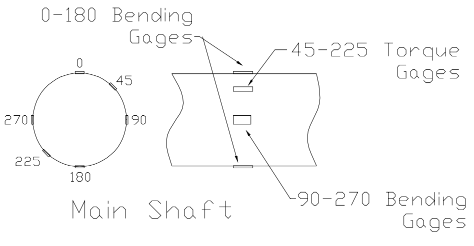


Fig. B-4. Strain Gauges Main Shaft.

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.[9] 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 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 attached the encoder to the yaw drive, see Fig. 12. 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 hard wired 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, rotor azimuth, and velocity are measured by a brushless rotary encoder, model EVSTDCC-PB16VIC-SIRPS, Computer Conversions Corporation.[9] 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 a 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 Fig. 12. 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 hard wired 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 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.

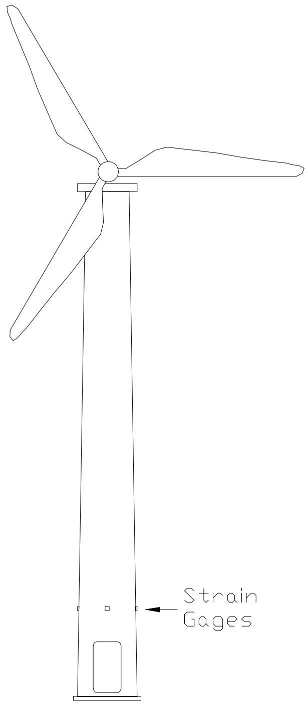


Fig. B-5. Tower Strain Gauges.

Power

The power produced by the turbines is monitored using a model GWV5-006AY precision WATT/VAR transducer by Ohio Semitronics Inc.[10] 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 and current and total power and VAR (Volts Amps Reactive). 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 3-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 hard wired through the junction box in the base 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 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.

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 Fig. 13.

AC Power Supply

AC power is provided to all instrumentation via a UPS (uninterruptable power supply). The unit used here is a Model BC Pro 1400 manufactured by Tripp Lite. It supplies 940 watts or 1400VA.

DC Power Supplies

The ATLAS power and the ATIs' power are provided by two ± 12 volt power supplies. The yaw position, rotor velocity, rotor position encoders and their electronics boards are powered by a ± 15 volt power supply, see Fig. C-1 and Fig. C-2.

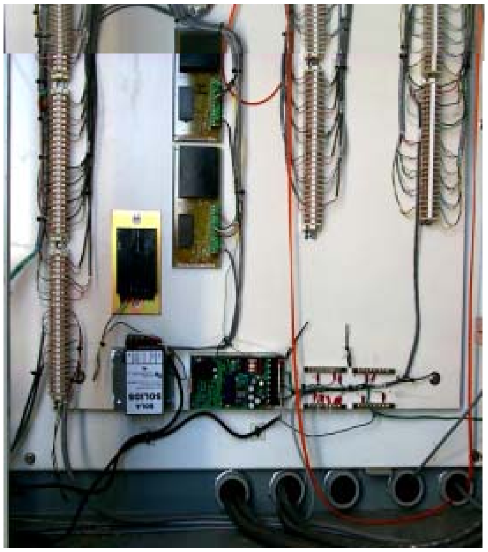


Fig. C-1. Power Supplies & Back Panel of the Instrument Enclosure.

Fig. 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 due to the extreme weather. The majority of the lightning protection is mounted in the instrument enclosure, see Fig. C-3 and Fig. 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.[12] manufactured the lightning protection units. Each unit consists of a base circuit board that can hold up to 8 plug-in modules. Each module protects two pairs of wires. The circuitry incorporates high-speed gas tube/diodes 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.

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

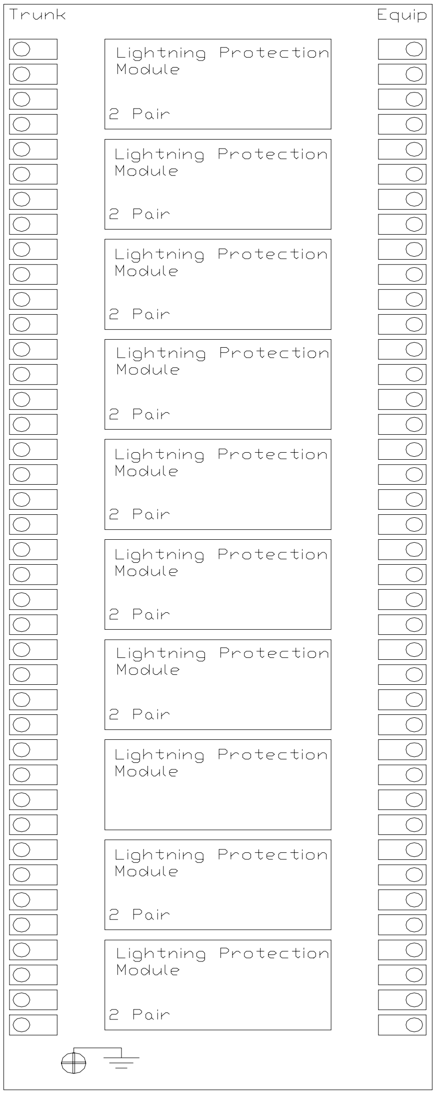


Fig. C-4. Typical Lightning Protection Circuit Board.

Instrument Rack

The slide out rack (see Fig. C-5 and Fig. C-6) houses the DAS/ATLAS system, the Met One[4] signal processing and power supply racks,

Fig. C-6. Rear view of the Instrument Rack.

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.

Turbine Junction Boxes and Wiring

A-Turbine JB

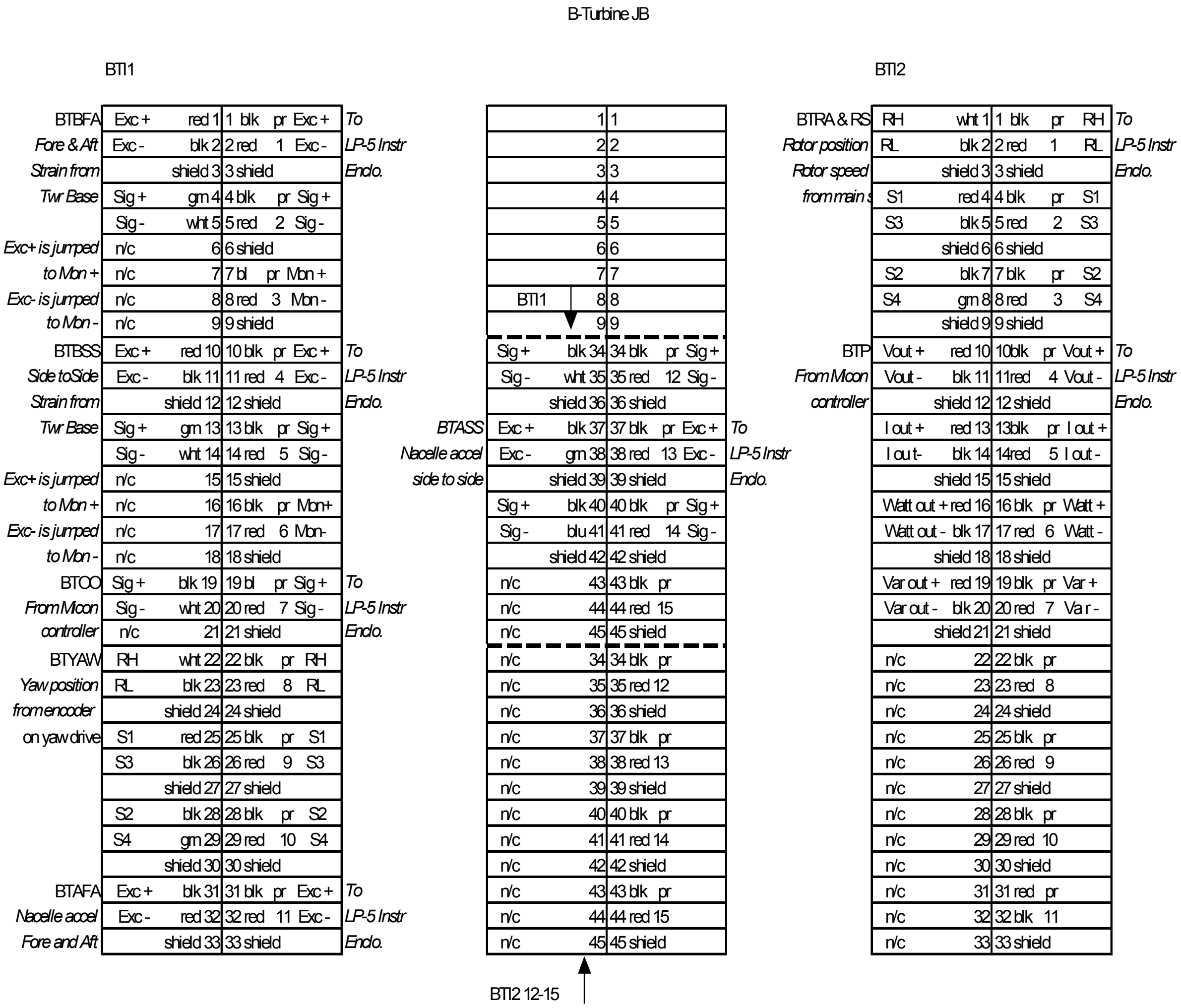
	Cable ATP1		Cable ATI1		
	n/c	1	1 blk pr		
	n/c	2	2 red 1		
	n/c	3	3 blk pr		
	n/c	4	4 red 2		
	n/c	5	5 blk pr		
	n/c	6	6 red 3		
ATP	V out +	red 7	7 blk pr	Vout+	*To*
From Micon	V out-	blk 8	8 red 4	Vout-	*LP-6 Inst.*
controller	I out +	red 9	9 blk pr	Iout+	*Enclo.*
	I out -	blk 10	10 red 5	Iout-	
	Watt out +	red 11	11 blk pr	Watt+	
	Watt out -	blk 12	12 red 6	Watt -	
	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		

Turbine A Junction Box

The junction box at the base of Turbine A 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 Fig. C-7. Spare wires in the cables are terminated on the terminal strips.

Turbine B Junction Box

The junction box for Turbine B contains the turbine power monitoring wiring, yaw nacelle position, rotor velocity & position, nacelle accelerations fore-and-aft and side-to-side, tower strain fore-and-aft and side-to-side, and turbine-state (on/off), see Fig. C-8. Cables BTI1 and BTI2 connect this junction box to the lightning protection in the Instrument Enclosure.



B-Turbine JB

BTI1

BTBFA	Exc + red 1	1 blk pr Exc +	*To*
Fore & Aft	Exc - blk 2	2 red 1 Exc -	*LP-5 Instr*
Strain from	shield 3	3 shield	*Enclo.*
Twr Base	Sig + grn 4	4 blk pr Sig +	
	Sig - wht 5	5 red 2 Sig -	
Exc+ is jumped	n/c 6	6 shield	
to Mon +	n/c 7	7 bl pr Mon +	
Exc- is jumped	n/c 8	8 red 3 Mon -	
to Mon -	n/c 9	9 shield	
BTBSS	Exc + red 10	10 blk pr Exc +	*To*
Side toSide	Exc - blk 11	11 red 4 Exc -	*LP-5 Instr*
Strain from	shield 12	12 shield	*Enclo.*
Twr Base	Sig + grn 13	13 blk pr Sig +	
	Sig - wht 14	14 red 5 Sig -	
Exc+ is jumped	n/c 15	15 shield	
to Mon +	n/c 16	16 blk pr Mon+	
Exc- is jumped	n/c 17	17 red 6 Mon-	
to Mon -	n/c 18	18 shield	
BTOO	Sig + blk 19	19 bl pr Sig +	*To*
From Micon	Sig - wht 20	20 red 7 Sig -	*LP-5 Instr*
controller	n/c 21	21 shield	*Enclo.*
BTYAW	RH wht 22	22 blk pr RH	
Yaw position	RL blk 23	23 red 8 RL	
from encoder	shield 24	24 shield	
on yaw drive	S1 red 25	25 blk pr S1	
	S3 blk 26	26 red 9 S3	
	shield 27	27 shield	
	S2 blk 28	28 blk pr S2	
	S4 grn 29	29 red 10 S4	
	shield 30	30 shield	
BTAFA	Exc + blk 31	31 blk pr Exc +	*To*
Nacelle accel	Exc - red 32	32 red 11 Exc -	*LP-5 Instr*
Fore and Aft	shield 33	33 shield	*Enclo.*

	1	1	
	2	2	
	3	3	
	4	4	
	5	5	
	6	6	
	7	7	
	BTI1 8	8	
	9	9	
	Sig + blk 34	34 blk pr Sig +	
	Sig - wht 35	35 red 12 Sig -	
	shield 36	36 shield	
BTASS	Exc + blk 37	37 blk pr Exc +	*To*
Nacelle accel	Exc - grn 38	38 red 13 Exc -	*LP-5 Instr*
side to side	shield 39	39 shield	*Enclo.*
	Sig + blk 40	40 blk pr Sig +	
	Sig - blu 41	41 red 14 Sig -	
	shield 42	42 shield	
	n/c 43	43 blk pr	
	n/c 44	44 red 15	
	n/c 45	45 shield	
	n/c 34	34 blk pr	
	n/c 35	35 red 12	
	n/c 36	36 shield	
	n/c 37	37 blk pr	
	n/c 38	38 red 13	
	n/c 39	39 shield	
	n/c 40	40 blk pr	
	n/c 41	41 red 14	
	n/c 42	42 shield	
	n/c 43	43 blk pr	
	n/c 44	44 red 15	
	n/c 45	45 shield	

BTI2 12-15

BTI2

BTRA & RS	RH wht 1	1 blk pr RH	*To*
Rotor position	RL blk 2	2 red 1 RL	*LP-5 Instr*
Rotor speed	shield 3	3 shield	*Enclo.*
from main s	S1 red 4	4 blk pr S1	
	S3 blk 5	5 red 2 S3	
	shield 6	6 shield	
	S2 blk 7	7 blk pr S2	
	S4 grn 8	8 red 3 S4	
	shield 9	9 shield	
BTP	Vout + red 10	10blk pr Vout +	*To*
From Micon	Vout - blk 11	11red 4 Vout -	*LP-5 Instr*
controller	shield 12	12 shield	*Enclo.*
	I out + red 13	13blk pr I out +	
	I ou t- blk 14	14red 5 I out -	
	shield 15	15 shield	
	Watt out + red 16	16 blk pr Watt +	
	Watt out - blk 17	17 red 6 Watt -	
	shield 18	18 shield	
	Var out + red 19	19 blk pr Var +	
	Var out - blk 20	20 red 7 Va r -	
	shield 21	21 shield	
	n/c 22	22 blk pr	
	n/c 23	23 red 8	
	n/c 24	24 shield	
	n/c 25	25 blk pr	
	n/c 26	26 red 9	
	n/c 27	27 shield	
	n/c 28	28 blk pr	
	n/c 29	29 red 10	
	n/c 30	30 shield	
	n/c 31	31 red pr	
	n/c 32	32 blk 11	
	n/c 33	33 shield	

Fig. C-9. Junction Box for Turbine B

Turbine C Junction Box

C-Turbine JB

	Cable CTP1	Cable CTI1	
	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	
CTP	/ out + red 7	7 blk pr Vout +	*To*
From Micon	V out - blk 8	8 red 4 Vout -	*LP-6 Inst.*
controller	I out + red 9	9 blk pr I out +	*Enclo.*
	I out - blk 10	10 red 5 I out-	
	Watt- out red 11	11 blk pr Watt +	
	Watt- out blk 12	12 red 6 Watt -	
	Var - out red 13	13 bl 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	

The junction box at the base of Turbine C 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 Fig, C-9.

Met Tower Junction Boxes and Wiring

Center Met Tower Junction Box

The junction box at the base of the center meteorological (called met for short) tower contains the wiring from the sonic anemometers on the north, south and 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 Fig. 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	

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

North Met Tower Junction Box

The junction box at the base of the north meteorological tower contains the wiring from the sonic anemometer on the north met tower to the center met tower junction box. Cable BANI in this junction box is connected to the center met tower junction box, see Fig. C-11.

North Met Tower JB

Cable BANI TB-1

BANATI	12 volt	blk	1	1	red	12 volts	BANATI
cable	gnd	red	2	2	blk	gnd	*Instrument*
To Cntr Met		shield	3	3			*From ATI*
Twr JB	receive	blk	4	4	blk	receive	*Top of Twr*
	transmit	wht	5	5	wht	transmit	
		shield	6	6			
	sig gnd	blk	7	7	gr	sig gnd	
	n/c	grn	8	8	blk	n/c	
		shield	9	9			
		blk	10	10			
		blu	11	11			
		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

Fig. C-11. North Met Tower Junction Box.

South Met Tower Junction Box

The junction box at the base of the south meteorological tower contains the wiring from the sonic anemometer on the south met tower to the Center Met Tower Junction Box. Cable BASI in this junction is connected to the center met tower junction box, see Fig. C-12.

South Met Tower JB

	Cable BASI			TB-1			
BASATI	12 volts	blk	1	1	red	12 volts	BASATI
cable	gnd	red	2	2	blk	gnd	*Instrument*
To Cntr Met		shield	3	3			*From ATI*
Twr JB	receive	blk	4	4	blk	receive	*Top of Twr*
	transmit	wht	5	5	wht	transmit	
		shield	6	6			
	sig gnd	blk	7	7	gr	sig gnd	
	n/c	grn	8	8	blk	n/c	
		shield	9	9			
		blk	10	10			
		blu	11	11			
		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

Fig. C-12. South Met Tower Junction Box.

Far South Met Tower Junction Box

The junction box at the base Far South meteorological tower contains the wiring from a cup anemometer, and a wind direction vane on the Far South met tower. Cable CASI in this junction box is connected to the lightning protection in the Instrument Enclosure, see Fig. C-13.

Far 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

Fig. C-13. Far South Met Tower Junction Box.

Far North Met Tower Junction Box

The junction box at the base Far North meteorological tower contains the wiring from a cup anemometer and wind direction vane on the Far North met tower. Cable AANI in this junction box is connected to the lightning protection in the Instrument Enclosure, see Fig. C-14.

Far 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

Fig. C-14. Far North Met Tower Junction Box.

Off Axis Met Tower Junction Box

The junction box at the base Off-Axis meteorological 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 Fig. C-15.

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

Fig. C-15. Off Axis Met Tower Junction Box.

Wiring Diagram for the Accelerometers

This wire list covers the wiring from the accelerometers to the DAS in the Instrument Enclosure, see Fig. C-16.

lame	B Turbine Accelerometer Fore-Aft						2262-25G SN KL03									
TAFA	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	
C + 5	Red		Red		Red	A	Black	31	Black	pair 1	Black	Exc +	Black	Exc +	Black	Exc +
C -5	Black		Black		Black	B	Red	32	Red	pair 1	Red	Exc-	Red	Exc-	Red	Exc-
nd	Gnd		Gnd		Gnd	E	Gnd	33	Gnd		Black	Sig +	Gnd	shield	Gnd	shield
ig (+)	Green		White		White	C	Black	34	Black	pair2	Wht	Sig -	Black	Sig +	Black	Sig +
ig (-)	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
lame	B Turbine Accelerometer Side-Side						2262-25G SN TJ45									
TASS	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	
C + 5	Red		Brn		Green	F	Black	37	Black	pair 1	Black	Exc +	Black	Exc +	Black	Exc +
C -5	Black		Black		Black	G	Green	38	Red	pair 1	Red	Exc-	Red	Exc-	Red	Exc-
nd	Gnd		Gnd		Gnd	K	Gnd	39	Gnd		Black	Sig +	Gnd	shield	Gnd	shield
ig (+)	Green		Blue		Blue	H	Black	40	Black	pair2	Wht	Sig -	Black	Sig +	Black	Sig +
ig (-)	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

Fig. C-16. 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 temperature, and barometric pressure, see Fig. C-17.

Met One Racks

Top Rack Cup Anemometers	*Bottom Rack Vanes, Temps, Pressure*
Slot 1 Blank	Slot 1 Blank
Slot 2 OC Off Axis Met Tower Cup	Slot 2 EPR Barometric Pressure
Slot 3 CASC South Met Tower Cup	Slot 3 BACDTP Delta Temp.
Slot 4 BAC2C Center Met Tower 2 Meter Cup	Slot 4 BACTP Temp.
Slot 5 BACBC Center Met Tower Bottom of Rotor Cup	Slot 5 OV Off Axis Met Tower Vane
Slot 6 BACCC Center Met Tower Center Of Rotor Cup	Slot 6 CASV South Met Tower Vane
Slot 7 BACTC Center Met Tower Top of Rotor Cup	Slot 7 BACCV Center Met Tower Vane
Slot 8 AANC North Met Tower Cup	Slot 8 AANV North Met Tower Vane

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

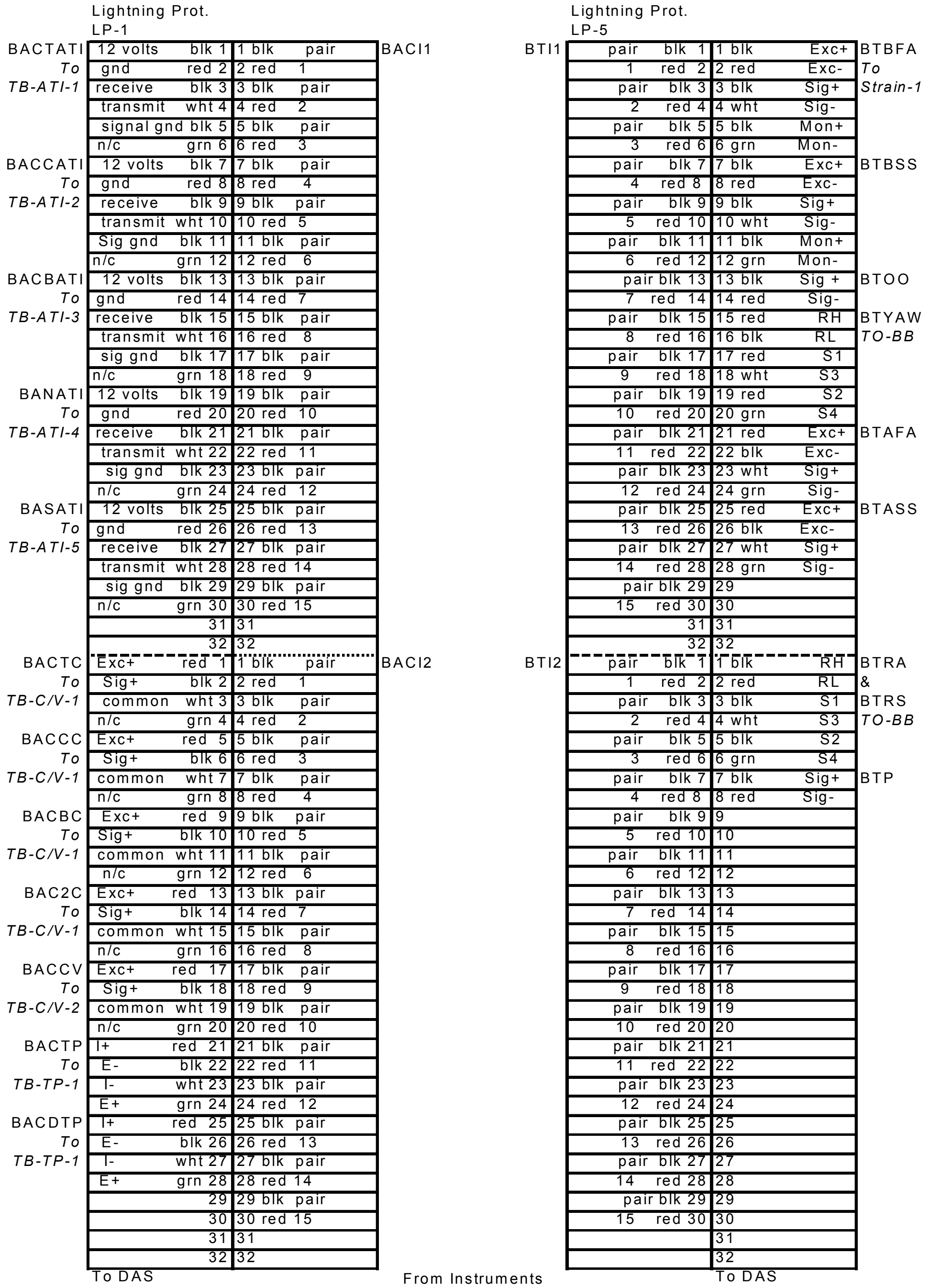
EPR	BACDTP	BACTP	OV	CASV	BACCV	AANV
From TB-CV-3	*From TB-CV-3*	*From TB-CV-3*	*From TB-CV-2*	*From TB-CV-2*	*From TB-CV-2*	*From TB-CV-2*
1 blk sig In	1 jmp to temp 4	1 n/c	1 blk ref	1 blk ref	1 blk ref	1 blk ref
2 blk ga com	2 blk gage E-	2 blk gage E-	2 n/c	2 n/c	2 n/c	2 n/c
3 n/c	3 grn gage E+	3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

Fig. C-17. 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 data acquisition system (DAS), see Fig. C-18a, C-18b and C-18c.



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		

From Instruments

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	

Fig. C-18a. 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

Fig. C-18b. 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	

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	

To DAS

From Instruments

To DAS

Fig. C-18c. Panel 3: Lightning Protection Wiring Diagram.

Sonic Anemometers

The sonic anemometers 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 data acquisition system, see Fig. C-19.

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	

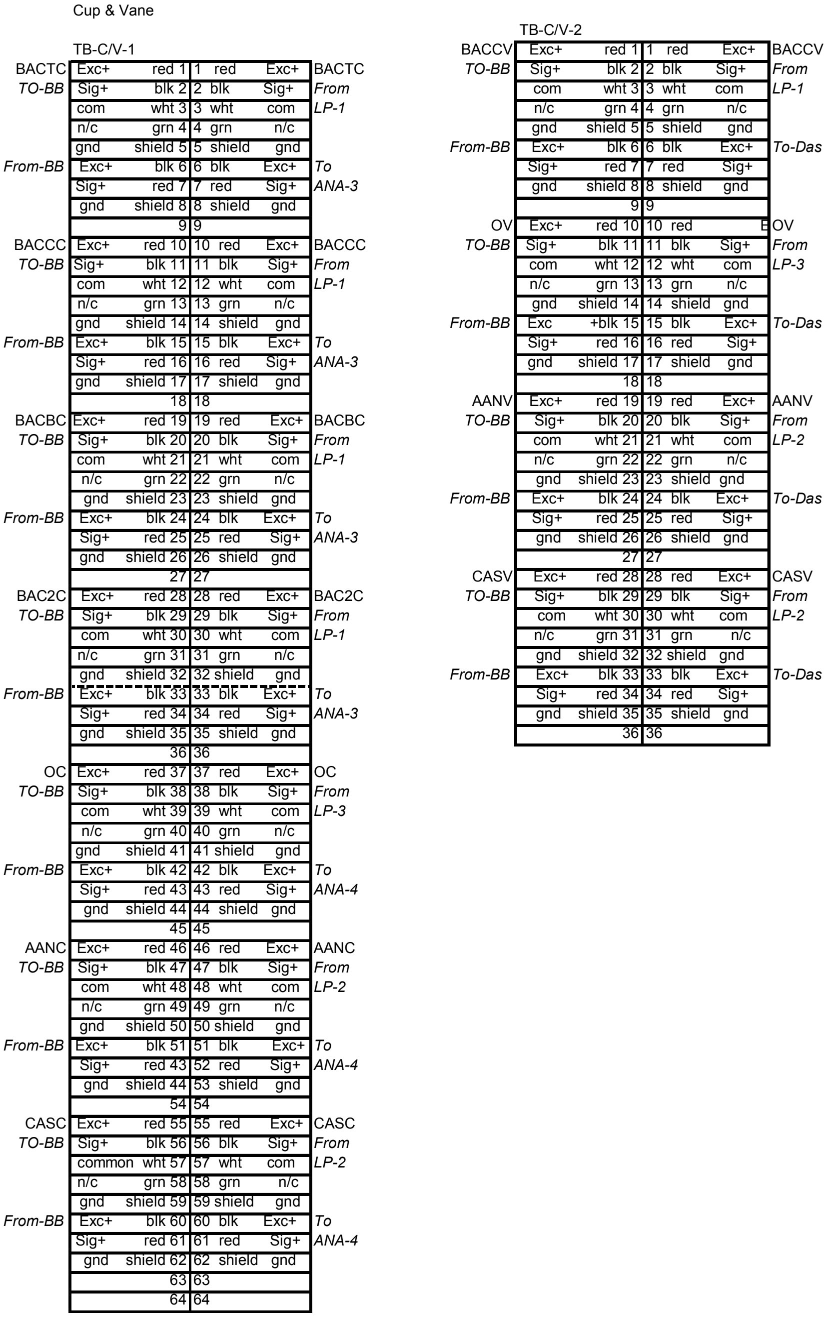
TB-ATI-5

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	

Fig. C-19. Sonic Anemometers Wiring Diagram.

Cups & 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 data acquisition system, see Fig. C-20.



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		

Fig. C-20. 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 data acquisition system, see Fig. C-21.

Strain-1

	Exc+	red	1	1	blk	Exc+	BTBFA
Cable-1	Exc-	blk	2	2	red	Exc-	*From*
		shield	3	3	gnd	shield	*LP-5*
	Sig+	wht	4	4	blk	Sig+	
	Sig-	blk	5	5	wht	Sig-	
		shield	6	6	gnd	shield	
	Mon+	grn	7	7	blk	Mon+	
	Mon-	blk	8	8	grn	Mon-	
		shield	9	9	gnd	shield	
	Exc+	blu	10	10	blk	Exc+	BTBSS
	Exc-	blk	11	11	red	Exc-	*From*
		shield	12	12	gnd	shield	*LP-5*
	Sig+	yel	13	13	blk	Sig+	
	Sig-	blk	14	14	wht	Sig-	
		shield	15	15	gnd	shield	
	Mon+	brn	16	16	blk	Mon+	
	Mon-	blk	17	17	grn	Mon-	
		shield	18	18	gnd	shield	
	Exc+	org	19	19	red	Exc+	BTAFA
	Exc-	blk	20	20	blk	Exc-	*From*
		shield	21	21	gnd	shield	*LP-5*
Cable-6	Sig+	blu	22	22	wht	Sig+	
	Sig-	blk	23	23	grn	Sig-	
Cable-1		shield	24	24	gnd	shield	
	Exc+	wht	25	25	red	Exc+	BTASS
	Exc-	red	26	26	blk	Exc-	*From*
		shield	27	27	gnd	shield	*LP-5*
Cable-6	Sig+	yel	28	28	wht	Sig+	
	Sig-	blk	29	29	grn	Sig-	
	gnd	red	30	30	gnd	shield	
			31	31		n/c	
			32	32		n/c	
BTRA	RH	blk	1	1	blk	RH	BTRA
&	RL	red	2	2	red	RL	&
BTRS	Gnd	shield	3	3	shield	Gnd	BTRS
TO-BB	S1	blk	4	4	blk	S1	*From*
	S3	wht	5	5	wht	S3	*LP-5*
	Gnd	hield	6	6	shield	Gnd	
	S2	blk	7	7	blk	S2	
	S4	grn	8	8	grn	S4	
	Gnd	shield	9	9	shield	Gnd	
From-BB	Azimuth	blk	10	10	blk	Azimuth	*To-Das*
	Speed	wht	11	11	wht	Speed	
	Com	red	12	12	red	Com	
	Gnd	shield	13	13	shield	Gnd	
			14	14			
			15	15			
			16	16			
			17	17			
			18	18			
			19	19			
			20	20			
			21	21			
BTYAW	RH	blk	1	1	blk	RH	BTYAW
TO-BB	RL	red	2	2	red	RL	*From*
	Gnd	shield	3	3	shield	Gnd	*LP-5*
	S1	blk	4	4	blk	S1	
	S3	wht	5	5	wht	S3	
	Gnd	shield	6	6	shield	Gnd	
	S2	blk	7	7	blk	S2	
	S4	grn	8	8	grn	S4	
	Gnd	shield	9	9	shield	Gnd	
From-BB	Azimuth	blk	10	10	blk	Azimuth	*To-Das*
	Com	red	11	11	red	Com	
	Gnd	shield	12	12	shield	Gnd	
			13	13			
			14	14			
			15	15			
			16	16			
			17	17			
			18	18			

TB-C/V-3

BACTP	Exc+	red	1	1	red	Exc+	BACTP
TO-BB	Sig+	blk	2	2	blk	Sig+	*From*
	common	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			
BACDPT	Exc+	red	10	10	red	Exc+	BACDPT
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-Das*
	Sig+	red	16	16	red	Sig+	
	gnd	shield	17	17	shield	gnd	
			18	18			
EPR	Exc+	red	19	19	red	Exc+	EPR
	Sig+	blk	20	20	blk	Sig+	
	com	wht	21	21	wht	com	
	n/c	grn	22	22	grn	n/c	
	gnd	shield	23	23	shield	gnd	
	Exc+	blk	24	24	blk	Exc+	
	Sig+	red	25	25	red	Sig+	
	gnd	shield	26	26	shield	gnd	
			27	27			

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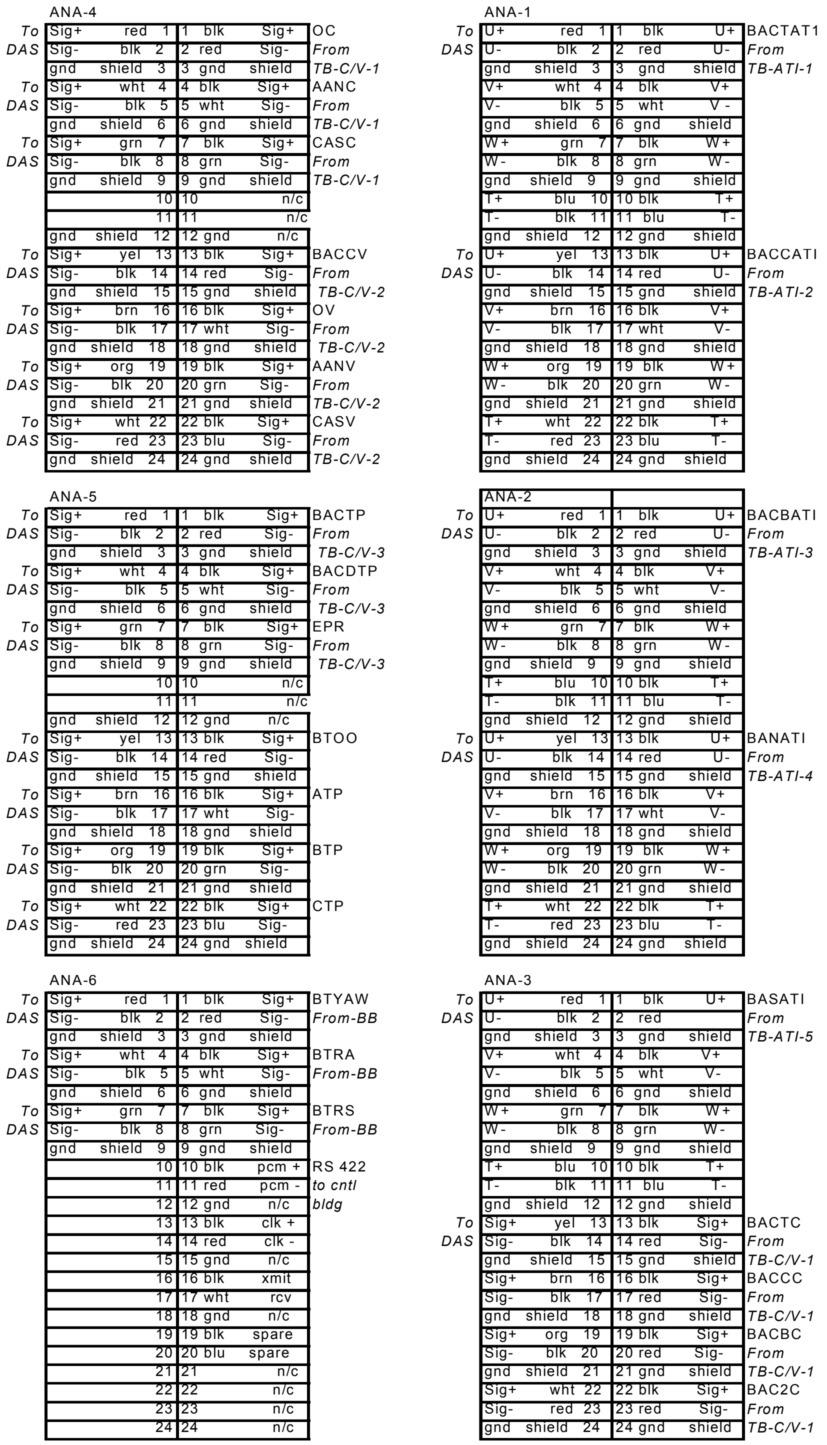
Fig. C-21. Accelerometer, Strain Gauge Wiring Diagram.

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 data acquisition system, see Fig. C-22.



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-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-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-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-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-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*

Fig. C-22. Data Acquisition Wiring Diagram.

APPENDIX D

INFRASTRUCTURE

The 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 Fig. 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 power wiring. A grounding grid is connected to all of the buildings, turbines, and meteorological towers for lightning protection and power ground.

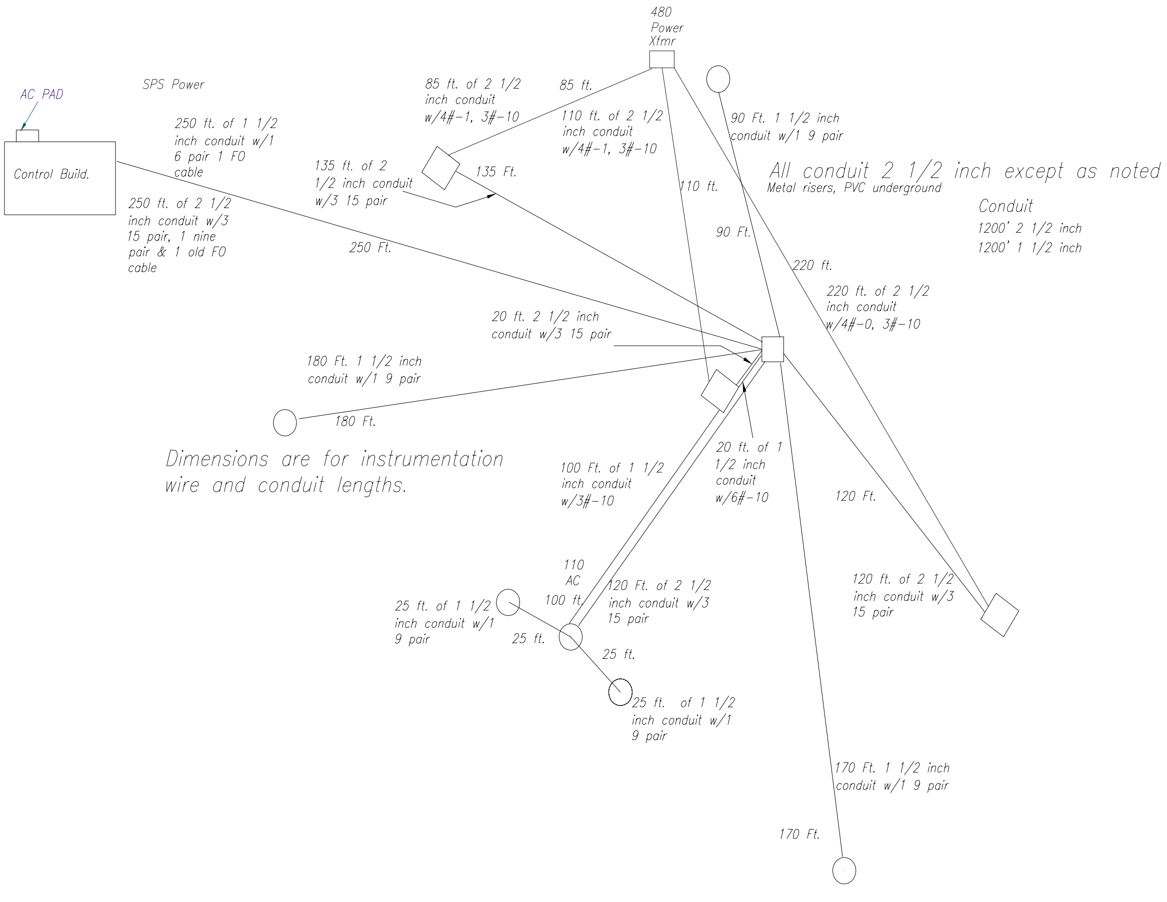
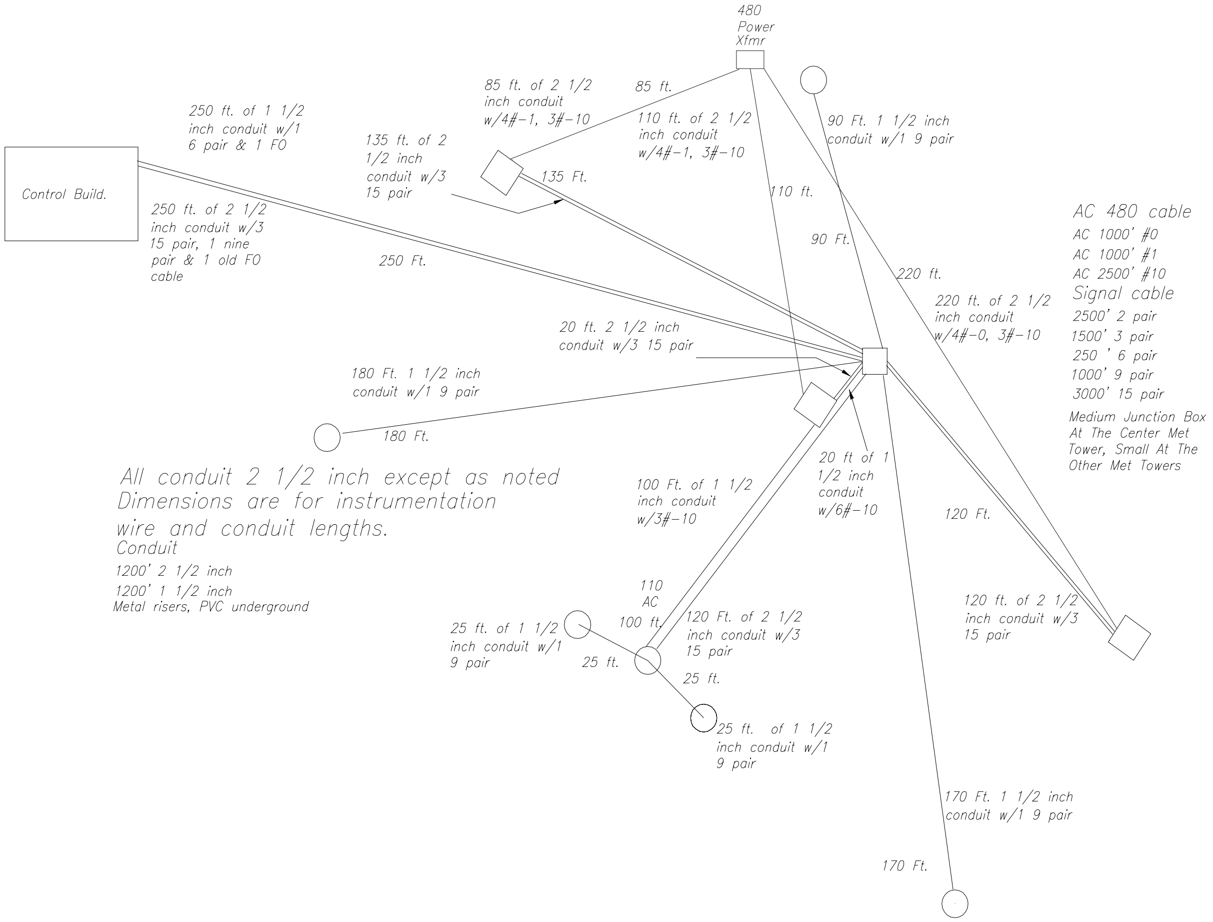


Fig. D-1. Conduit Schedule for the Site.

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. Wire in the cable is 18 gauge wire with an overall shield and a bare copper ground wire. The junction boxes are utilized for interconnections on terminal strips located in the junction boxes, see Fig. D-2.



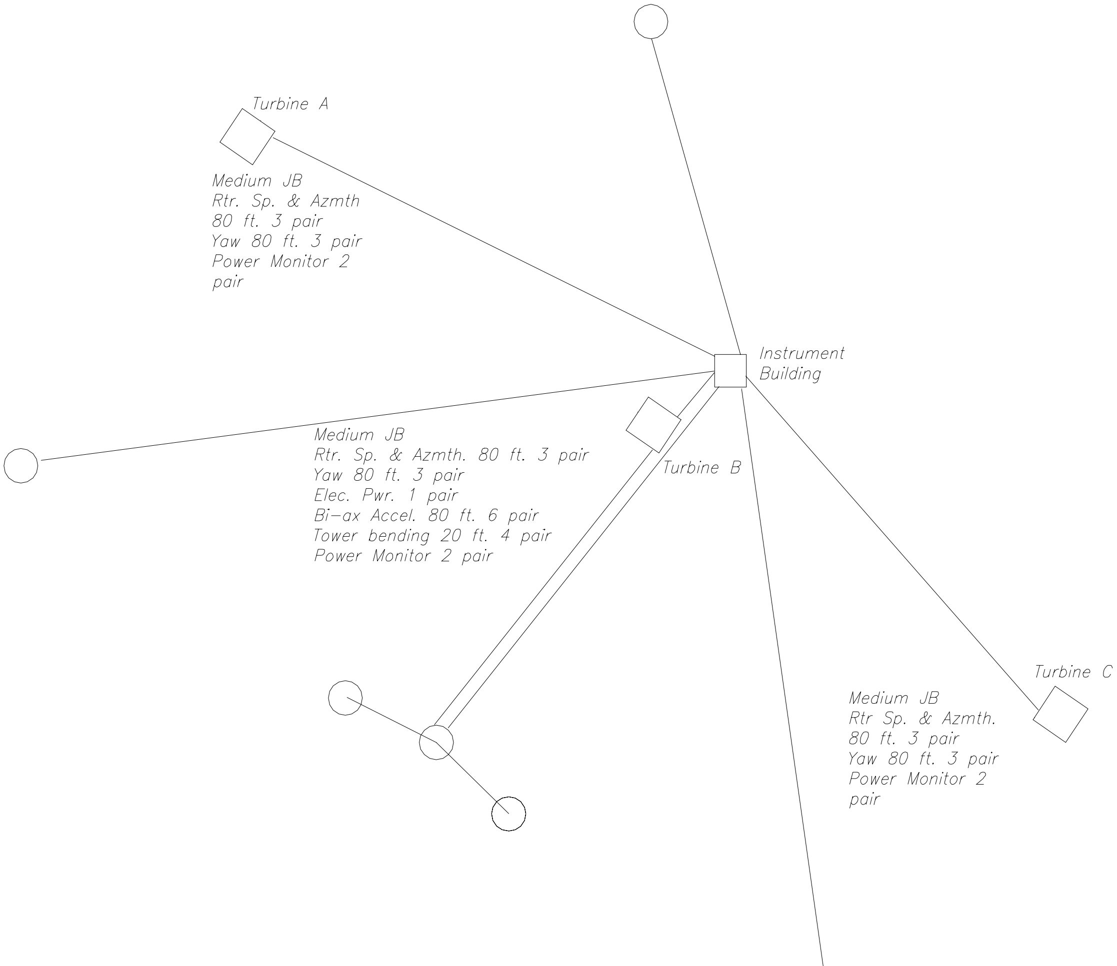
All conduit 2 1/2 inch except as noted
Dimensions are for instrumentation
wire and conduit lengths.
Conduit
1200' 2 1/2 inch
1200' 1 1/2 inch
Metal risers, PVC underground

AC 480 cable
AC 1000' #0
AC 1000' #1
AC 2500' #10
Signal cable
2500' 2 pair
1500' 3 pair
250 ' 6 pair
1000' 9 pair
3000' 15 pair

Medium Junction Box
At The Center Met
Tower, Small At The
Other Met Towers

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

Turbine instrument wires and junction boxes


Turbine A
Medium JB
Rtr. Sp. & Azmth
80 ft. 3 pair
Yaw 80 ft. 3 pair
Power Monitor 2
pair
Instrument
Building
Medium JB
Rtr. Sp. & Azmth. 80 ft. 3 pair
Yaw 80 ft. 3 pair
Elec. Pwr. 1 pair
Bi-ax Accel. 80 ft. 6 pair
Tower bending 20 ft. 4 pair
Power Monitor 2 pair
Turbine B
Turbine C
Medium JB
Rtr Sp. & Azmth.
80 ft. 3 pair
Yaw 80 ft. 3 pair
Power Monitor 2
pair

A variety of cables are used to connect the Turbine instrumentation to the data acquisition system. Wire in the cable is 18 gauge wire with an overall shield and a bare copper ground wire. The junction boxes are utilized for interconnections on terminal strips located in the junction boxes, see Fig. D-3.

AC Transformer Power

AC power is brought onto the site from the local utility, Southwest Public Service (SPS) and fed into the main three-phase 480 volt transformer. Power from the 480 volt transformer to the turbine transformers, and the instrument enclosure is run in PVC conduit underground. Each turbine has a separate 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 turbine B are on another transformer. Turbine A and turbine C are on their own separate transformers. Power generated by each of the turbines is sent through the turbine control junction box and then to its respective transformer and out to the SPS power grid, see Fig. D-4.

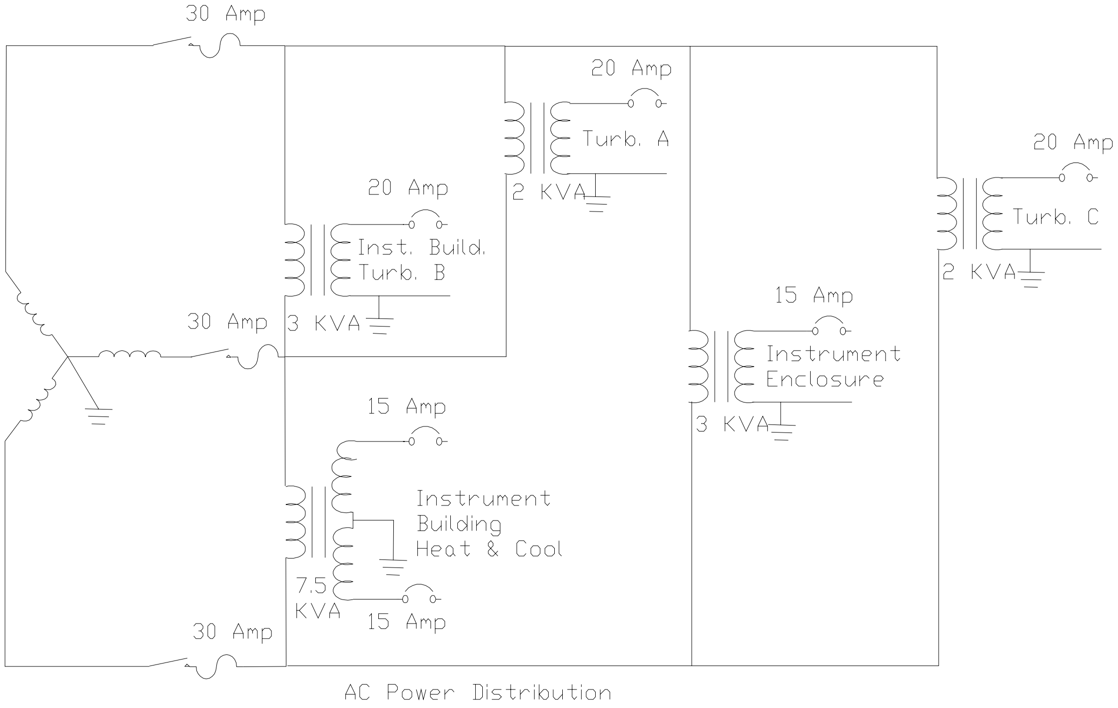


Fig. D-4. Grid Connections and Auxillary AC Power.

Grounding Grid

The grounding grid is made up of bare braided # 00 copper cable cad-welded at each connection, 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 shows the met tower guy wires and the ground grid, see Fig. D-5.

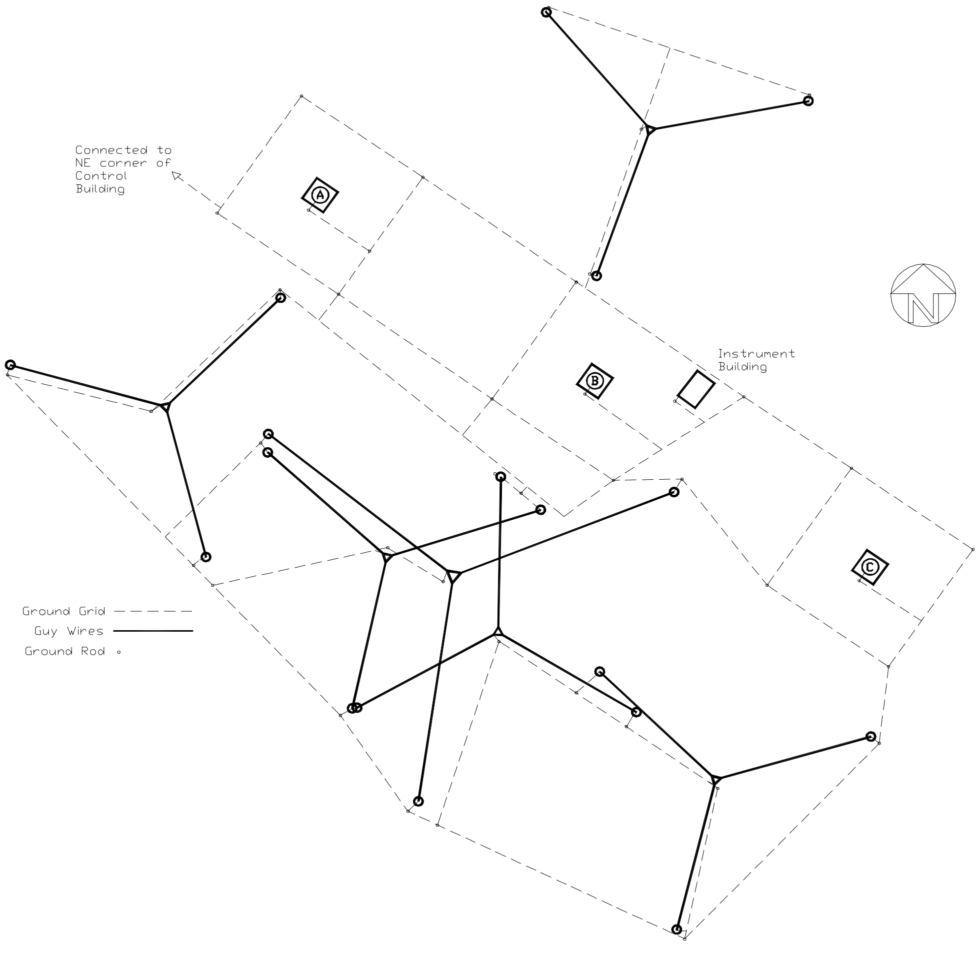


Fig. D-5. Ground Grid.

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 Fig. 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 uninterruptable power supply (UPS) which is used for the instrumentation power for the Micon turbine. The 220 volt transformer is for the instrument building heating and air conditioning.

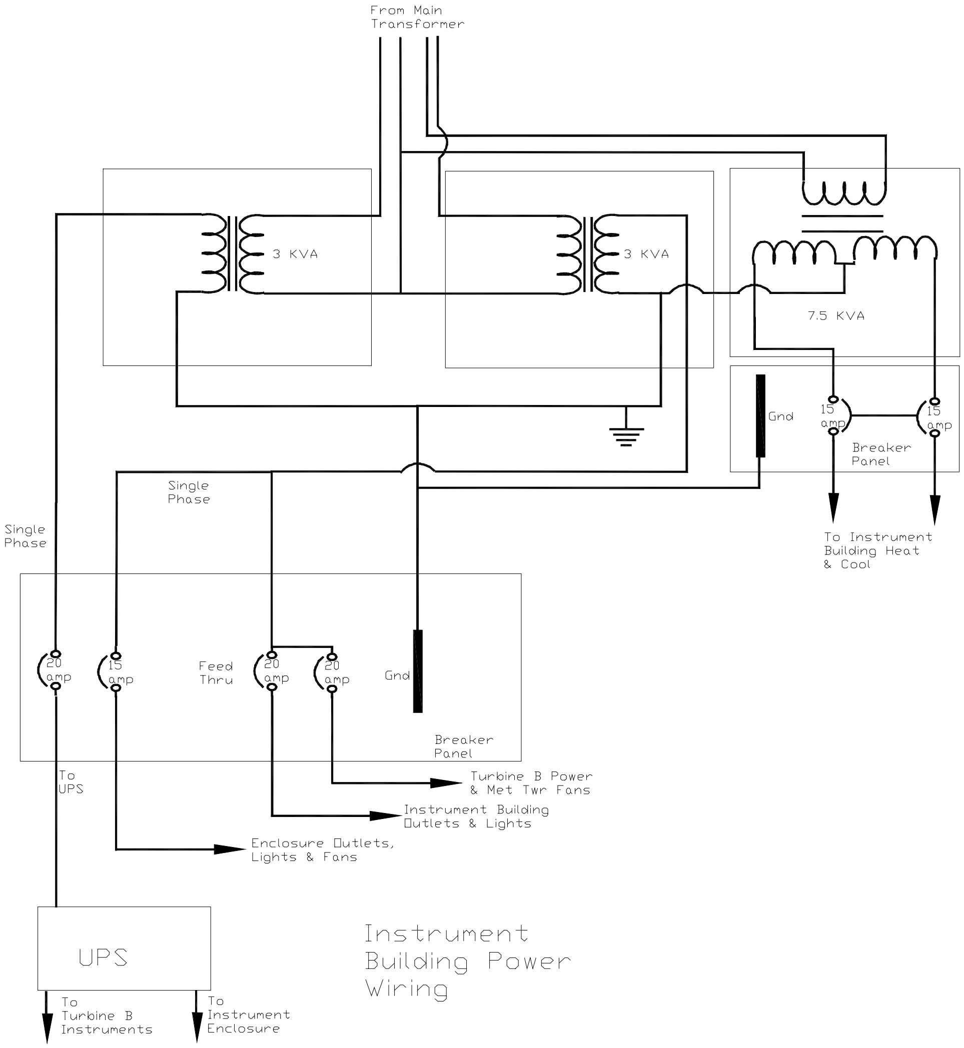


Fig. D-6. AC-Power Wiring Diagram for the Instrument Building and Enclosure.