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Universidad de Costa Rica

Atmospheric Boundary Layer Tunnel

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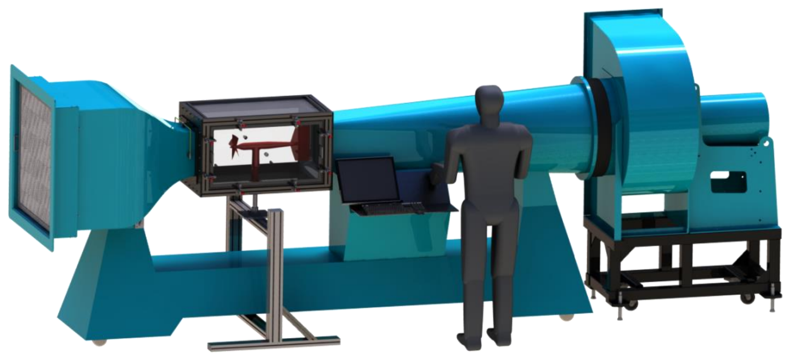

OPERATIONS MANUAL

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Team: Custom Design Division
Version: 1.0
Date: 8/3/2017

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Acronyms

Acronyms	Description
DAQ	Data Acquisition
in	Inch
MPS	Model Positioning System
NA	Not Applicable
NI	National Instruments
PC	Personal Computer
PTA	Pressure Transducer Array
V	Volt
VFD	Variable Frequency Drive
TBD	To Be Decided

Document Version Control

Version	Description	Date
1.0	Initial Release.	7/31/2017

Software Version Control

Version	Description	Date
1.0	Aero-Ware	03/20/2017

Reference Documents

Version	Document	Description	Date
1.1	AeroWare User Manual	Aerolab Software User Manual	Mar 2017
1.0	CPT6100 Data Sheet.pdf	CPT 6100 Transducer Documentation	Jan 2015
1.0	DS_CPT6100Barometer_en_um_33331.pdf	CPT 6100 Barometric Transducer	Mar 2015
1.0	ACS550-User Manual.pdf	VFD User Manual	Nov 2016
1.0	MDR-100-Series.pdf	100W Single Output Industrial DIN Rail Power Supply- MDR-100 series	Nov 2016
1.0	Centrifugal-Fans-ES-52.pdf	Centrifugal Fans -INSTALLATION, OPERATION & MAINTENANCE MANUAL	Aug 2014
1.0	HN2NSTA22 Data Sheet.pdf	Veris Industries HP/HN Digital RH and RH/T Transmitters	Nov 2016

1. Introduction

1.1. General Overview

The AEROLAB ~~12x12~~ 36x48 inch Atmospheric Boundary Layer Tunnel, designed for Universidad de Costa Rica is a Blow Down type Open Circuit tunnel.~~Open Jet Anemometer Tunnel is of the Eiffel, or suction, type with a 18x18x36 inch (45.72x45.72x91.44 cm) open wall test section.~~ A Single Width Single Inlet Belt driven Centrifugal fan blows air through a 30 inch (76.2 cm) long expansion duct into a 40 inch (101.6 cm) long screenbox section with 4 screens and a flow straightening honeycomb (0.25 inch cell size, 3.5 in thick) located upstream of the screens. The conditioned air stream then enters the fetch, which is comprised of three 68 in long constant cross section ducts. Gas shock supported acrylic windows are provided to set up the boundary layer generating surfaces (not included with tunnel). A tilting ceiling provides a means of compensating for the boundary layer growth along the ceiling, which helps in generating the Atmospheric Boundary Layer (ABL) in the test section. Lastly the air enters the test section where a 35 in (cm) turn table supports the models. Air exits the test section directly into the free stream, therefore the static pressure in the test section is equal to atmospheric pressure in the lab space.

~~12x12 in (30.48x30.48 cm) cross section forms the actual flow region, therefore providing a 3in (7.62 cm) buffer to any nearby walls.~~ Clean-tunnel (empty test section) top speeds ~~is in excess of 145.4 mph (65 m/s) are reachable with near-infinite adjustability above 0.45 mph (0.2 m/s).~~ of 44.7 mph (20 m/s) are achievable. Slightly faster speeds can be achieved with the removal of some or all of the turbulence reduction screens, but this leads to a drop in spatial uniformity and reduced turbulence level performance. This may or may not be desired based on the testing objectives, however, it is generally good practice to condition the non-uniform flow from the fan and then use the fetch region to develop the proper atmospheric boundary layer simulation.

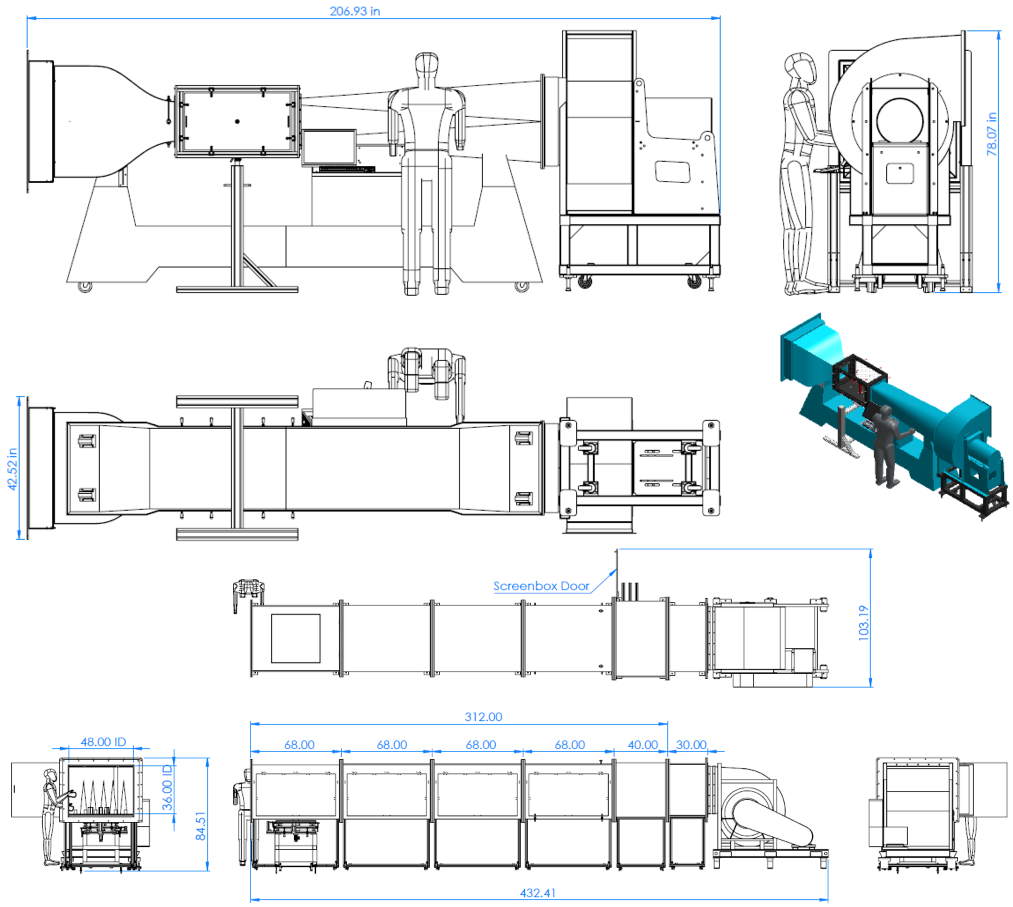


Figure 1: Tunnel Footprint (Dimensions in inches)

1.2. Tunnel Ducting

The four major duct components of the ~~Open Jet Anemometer~~ABL tunnel are ~~the contraction,~~ the test section, the ~~diffuser~~ fetch. The screenbox, and the fan housing. ~~A proprietary 9th-order polynomial defines the contraction contour. Its contraction ratio (inlet area to outlet area) of 9.5:1 is a major contributor to the tunnel's high performance and low turbulence levels.~~

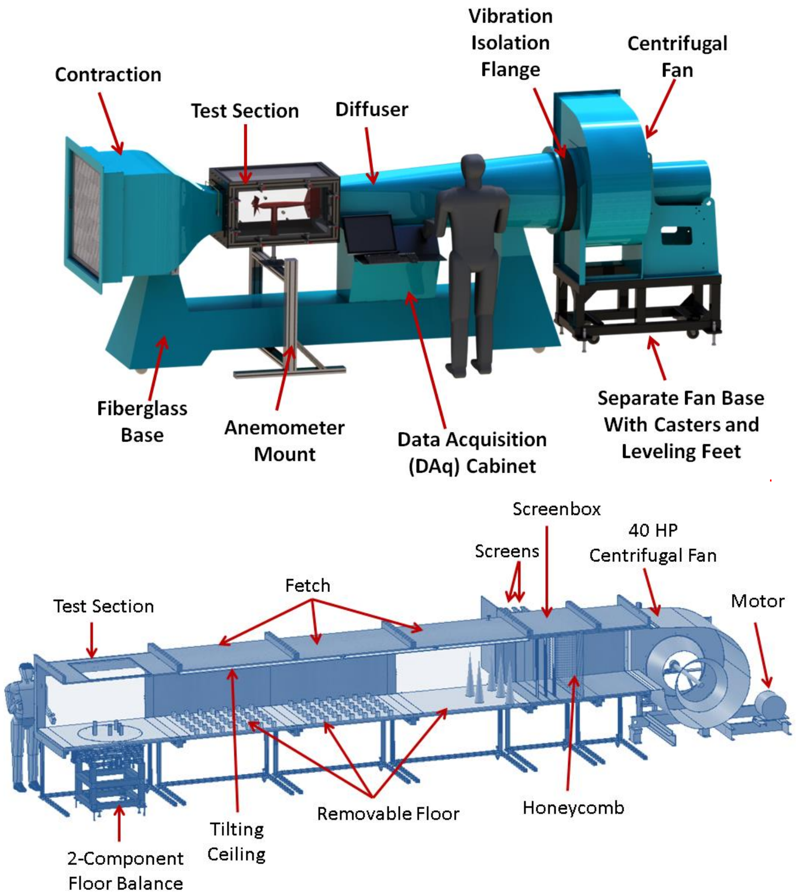
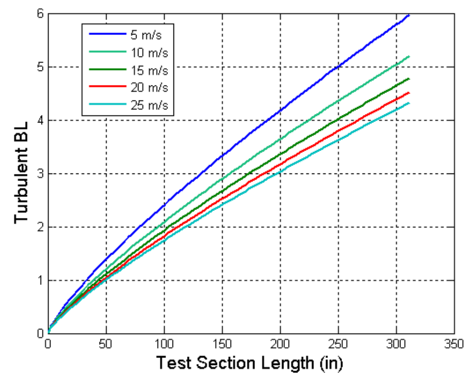


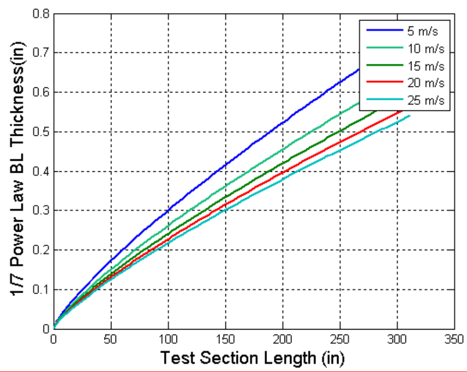
Figure 2: Tunnel Overview

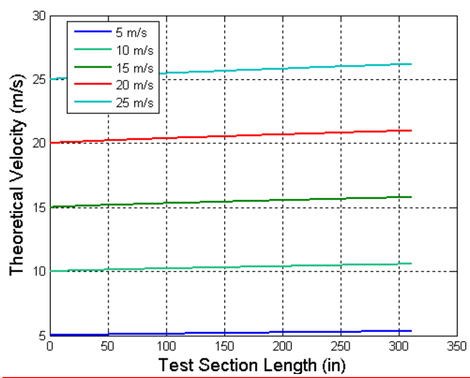
In order to mitigate test section buoyancy (a result of growing boundary layer thickness), the fetch ~~test section~~ is designed with a variable height ceiling ~~as a plenum to eliminate a solid wall boundary~~to eliminate too thick of a boundary layer near the ceiling. Boundary layer growth along the floor is desired, of course, to simulate the ABL. The tilting ceiling also provides a consistent velocity through the fetch and test section. Results from the boundary layer growth study, suggest the initial height of the ceiling to provide ample boundary layer growth compensation:

Tunnel Speed (m/s)	Ceiling Starting Height	Ceiling Final Height
5	33.75 in (85.725 cm)	36 in (91.44 cm)
10	34 in (86.36 cm)	36 in (91.44 cm)
15	34.2 in (86.87 cm)	36 in (91.44 cm)
20	34.3 in (87.12 cm)	36 in (91.44 cm)
25	34.36 in (87.27 cm)	36 in (91.44 cm)

This allows the flow to develop a natural shear layer which is captured and "collected" by the bell-mouth shaped collector at the rear of the test section. A secondary advantage to the Open Jet is that the removal of solid wall boundaries allows the flow to naturally expand over a model, whereas a closed wall test section would accelerate air via the venturi effect. In a closed wall test section, blockage ratios more than 5% typically require blockage corrections. With the Open Jet Anemometer tunnel, blockage ratios can be as high as 10% before requiring corrections. This allows much larger models to be tested than would otherwise be possible before flow quality becomes a concern.







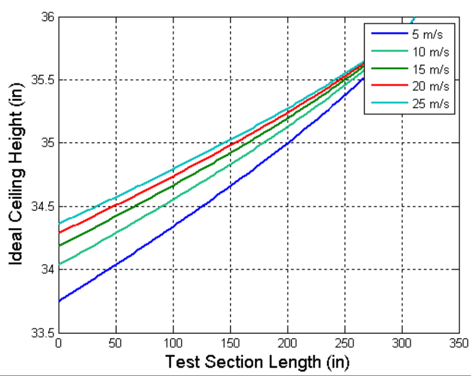


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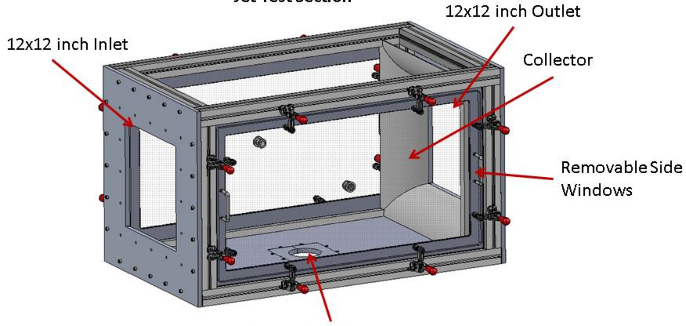
Figure 3: (Top Left): Theoretical Turbulent Boundary Layer, (Top Right): Theoretical Boundary Layer Thickness, (Bottom Left): Theoretical Velocity Profile Without Variable Height Ceiling, (Bottom Right): Theoretical Ceiling Height To Achieve Boundary Layer Compensation

In a closed wall test section, blockage ratios more than 5% typically require blockage corrections. It is Aerolab's recommendation that the frontal area blockage of the models be kept below 36x48x0.05 = 86.4 in^2 (557.42 cm^2). By opening the 2 side windows and removing the top window of the test section, the model blockage ration can be technically doubled by removal of the immediate boundaries. This only works because the flow in the test section is atmospheric (no diffuser downstream of the test section to re-capture static pressure). This comes at a cost of higher power to run the tunnel than would otherwise be needed, but the benefits of an easily accessible working section from 3 sides far out weigh these energy concerns.



~~Figure 3: Test Section Design~~

~~Diffuser design is also critical to test section flow quality. AEROLAB's shallow-angle diffuser (6º total included divergence angle based on cross sectional area) helps eliminate diffuser effects especially when large models are being tested. The fan housing is more than a simple straight duct. It is a double-walled structure – the inner wall is made of perforated steel and the outer wall is made of structural fiberglass. Between these two walls is a layer of sound-absorbing fiberglass batons (similar to household fiberglass insulation).~~

1.3. Flow Conditioning

Being an open-circuit design, the tunnel draws air from the surrounding environment (laboratory, classroom, etc.) This entering air first passes through the centrifugal fan inlet on both sides of the fan. Air exits the fan in a non-uniform pattern and therefore it is vital to provide some room for the flow to naturally develop and then immediately enter a screenbox to further condition the flow using a grid of hexagonal narrow passages, which removing lateral movement of the flow. Because the passages are hexagonal in shape, this matrix is referred to as honeycomb. The honeycomb cells are 3.5 inches (8.89 cm) long and serve to straighten the flow – to eliminate most flow angularity. Because the honeycomb does little to eliminate small eddies, the screenbox is equipped ~~two~~ with four turbulence-reducing screens immediately downstream of the honeycomb. They are made of 0.009 inch (0.23mm) stainless steel wire spaced at 20 wires per inch (2.54cm). Small eddies in the air are broken into yet smaller eddies by the screens, which ~~. Comparatively speaking, smaller eddies~~ dissipate faster than larger eddies. Eddies passing through the test section are termed "turbulence". The screens also serve to reduce axial velocity variation. Together, the honeycomb and screens smooth the air before it enters the ~~contraction~~fetch. The ~~honeycomb and~~ screens can be removed from the tunnel entrance for cleaning via an access door on the side of the screenbox.

1.4. Electric Motor and Fan

A heavy duty centrifugal airfoil blade Single Width Single Inlet (SWSI) centrifugal fan outfitted with a 40 HP (29.8 KW) motor powers the tunnel. The fan is constructed of sheet metal and an aluminum cast wheel designed for a maximum rotational speed of 1770 rpm (rotations per minute). The fan operates at a maximum speed of 1770 rpm. The fan is belt driven by a 40 HP (29.8 KW) 230/460 Vac 60 Hz 3-Phase motor. This motor is readily available to operate with 380 Vac 50 Hz 3-Phase power. Please note, appropriate programming of the VFD is required for international voltages.

Table 1: Motor Nameplate Data

Parameters	Motor Ratings 230/460 VAC	Motor Ratings 190/380 VAC
Power	40 HP	40 HP
Frequency	60 Hz	50 Hz
Amps	92.6/46 A	112/56 A
RPM	1770	1470
Service Factor	1.15	1.0

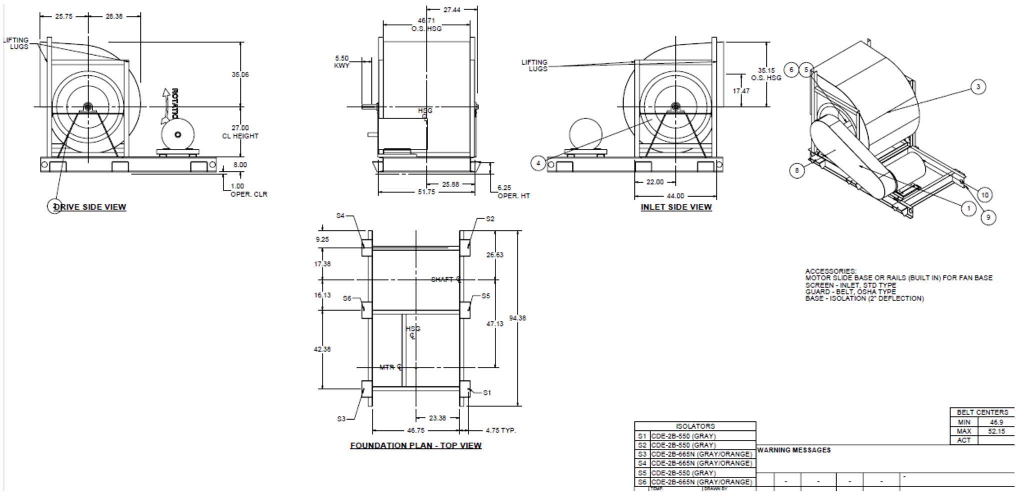


Figure 4: Fan Dimensional Overview

Description	
Quantity	1
Model	BAE-DW
Size	330
Width	DWDI
Arrangement	3
Class	II
Rotation	CCW
Discharge	THD
Wheel Diameter (in)	33.0
Drive method	Belt
Percentage width	100%
Percentage diameter	100%
Motor position	W

Performance	
Volumetric Flow CFM	47,520
Operating SP (in WC)	1.200
Standard SP (in WC)	1.200
RPM	1423
Tip Speed (FPM)	12294
Oper. Power BHP	35.00
Standard Power BHP	35.00
Outlet Area (sq.ft)	11.27
Outlet Velocity (FPM)	4217
Max RPM for Class	1644
Static Efficiency	25.61%
Total Efficiency	49.22%
FEI	0.86
FEP (KW)	29.22
System FEI	N/A
System FEP (KW)	N/A

Air/Gas Properties	
Altitude above sea level (ft)	0
Inlet Pressure (in WC)	0.000
Inlet Temperature(°F)	70
Design Temperature (°F)	70
Gas Type	Standard air
Estimated Density (lb/ft³)	0.075

Motor Data	
Power (HP)	40
Enclosure	TEFC
Speed (RPM)	1800
Voltage	230/460V
Phase	3
Frequency	60Hz
Frame Size	324T

Figure 5: Fan Specifications

1.5. Speed Control Data Acquisition System

The motor speed is controlled by a heavy-duty 40 HP 480 Vac @ 59A ABB Variable Frequency Drive (VFD). The VFD accepts both 50 Hz and 60 Hz incoming power with 3-Phase voltages between 380 and 480 V. The Drive converts the incoming 3-Phase signal to DC Voltage and regenerates the appropriate frequency signal to drive the fan at different rpms. The VFD is commissioned at AEROLAB by an authorized factory technician. Further information regarding the electrical installation and operation can be found in the manufacturer's manual. A quick reference is provided in Appendix E – VFD Electrical Installation. The drive can be controlled locally, via a keypad on the drive or via Ethernet from the provided tunnel control software. A special Modbus TCP Adapter has been included and pre-installed on the drive to enable Ethernet communication.

Figure 6: ACS355 Variable Frequency Drive

Table 2: VFD Parameters

VFD Parameter	Setting		VFD Parameter	Setting
1001 EXT1 Commands	Comm		3415 SIGNAL 3 PARAM	POWER
1002 EXT2 Commands	Comm		5101 FBA TYPE	Ethernet
1102 EXT1/EXT2 Sel	Comm		5102 FB PAR 2 (PROTOCOL/PROFILE)	1
1103 REF1 Select	Comm		5103 FB PAR 3 (COMMRATE)	0

1105 REF1 MAX	1800 RPM		5104 FB PAR 4 (IP CONFIGURATION)	0
1106 REF2 SELECT	Comm		5105 FB PAR 5 (IP ADDRESS 1)	192
1202 CONST SPEED 1	0 RPM		5106 FB PAR 6 (IP ADDRESS 2)	168
1203 CONST SPEED 2	0 RPM		5107 FB PAR 7 (IP ADDRESS 3)	1
1601 RUN ENABLE	Comm		5108 FB PAR 8 (IP ADDRESS 4)	1
1604 FAULT RESET SEL	Comm		5109 FB PAR 9 (SUBNET CIDR)	24
2001 MINIMUM SPEED	0 RPM		5120 FB PAR 20 (MODBUS/TCP TIMEOUT)	10
2002 MAXIMUM SPEED	1800 RPM		5121 FB PAR 21 (TIMEOUT MODE)	2
2003 MAX CURRENT	82.8 A		5401 FBA DATA IN 1	106
2008 MAXIMUM FREQUENCY	60 Hz		5402 FBA DATA IN 2	107
2015 MIN TORQUE 1	-150%		5501 FBA DATA OUT 1	1202
2016 MIN TORQUE 2	-150%		5502 FBA DATA OUT 2	1203
2017 MAX TORQUE 1	150%		9802 COMM PROT SEL	EXT FBA
2018 MAX TORQUE 2	150%		9904 MOTOR CTRL MODE	VECTOR:SPEED
2109 EMERGENCY STOP SEL	DI1 (INV)		9905 NOM VOLTAGE	460 V
3018 COMM FAULT FUNC	1		9906 MOTOR NOM CURR	46 A
3019 COMM FAULT TIME	3		9907 NOM FREQUENCY	60 Hz
3401 SIGNAL 1 PARAM	SPEED		9908 MOTOR NOM SPEED	1770
3408 SIGNAL 2 PARAM	CURRENT		9909 MOTOR NOM POWER	40 HP

Note: The parameters in **RED** may have to be updated based on the facility power available for the tunnel. Consult with your facility Electrician and Aerolab if you have any questions.

Note: If the fan spins backwards for some reason, then the user will need to disconnect power, wait 5 minutes, check phases for voltage differential, then carefully flip 2 of the phases going to the motor.

Note: Configuration for International (380 VAC) Power: (9905 – 380V, 9906 – 59 A, 9907-50 Hz, 9908-1470 RPM)

Note: It is recommended before changing any settings on the drive to upload the parameters to the keypad. This will permit the user to safely revert to the original parameters by downloading the settings if needed. Set the steps below for uploading and downloading the VFD parameters.

- Upload Parameters to Keypad: Menu=>Par Backup=>Upload to Panel
- Download Parameters from Keypad to the Drive: Menu=>Par Backup=>Download Full Set

1.6. Speed Control Data Acquisition System

The Complete tunnel system is provided with research grade electronics for monitoring system environmentals including dynamic pressure, barometric pressure, Temperature, Humidity, and motor signals. The electronics for the Tunnel Power System and Data Acquisition (DAC) System are listed in the table below.

Table 3: Tunnel and Balance Electronics

Quantity	Part Number	Company	Description
1	Dell - Inspiron 3650 Desktop	Dell	Data Acquistion Computer Intel Core i3, 8GB Memory, 1TB Hard Drive
1	ACS550-U1-059A-4+K466	ABB	40 HP 380-480 VAC ACS550 VFD + RETA-01 Module
1	RETA-01 KIT	ABB	Ethernet IP/Modbus TCP Adapter
1	NA	TECO Westinghouse	40 HP Motor 1770RPM, 3PH, 60HZ, 324T TEFC
1	BAE-DW-330	Twin Cities	40 HP Centrifugal Fan 324T TEFC 1800 RPM, 230/460V, 3-PH, 60 Hz
1	MDR-100-12	Mean Well USA	Din Rail 12 V@7.5A Power Supply
1	MDR-100-24	Mean Well USA	Din Rail 24 V@4A Power Supply
1	CPT6100 (8-17 psia Total Pressure)	Mensor	Digital Barometer (0.01% FS Accuracy)
1	CPT6100 (0-1 psig Differential Pressure)	Mensor	Digital Differential Pressure Transducer (0.01% FS Accuracy)
1	HN2NSTA2	Veris Industries	NIST Calibrated 2% Temperature & Humidity Probe
1	NI cRIO-9064	National Instruments	4-Slot Integrated 667 MHz Dual-Core Controller and Artix-7 FPGA
1	NI 9215	National Instruments	±10 V, Simultaneous Analog Input, 100 kS/s, 4 Ch Module

1	**NI 9237**	**National Instruments**	**4-Ch 50 kS/s per Channel, 24-Bit Bridge Analog Input Module**
1	**Static-Pitot Probe**	**Aerolab**	**24 Inch Long, 1/4 Inch Diameter Pitot Probe**

1.7. Emergency Stop

The tunnel is equipped with an emergency stop button located on the data acquisition panel. Pressing this button while the tunnel is operating forces a hard stop to the tunnel motor in case of emergency. Please only use the emergency stop in emergency situations since the abrupt stop is hard on the motor. To resume operation after an emergency stop, return the button to its normal state and restart the VFD from the tunnel control GUI. Parameter 2109- EMERG STOP SEL is programmed to receive a 24 V Input on Digital Input 1 (DI1) of the VFD. See the wiring diagram for the Emergency stop in the Appendix of the manual.

Figure 7: Emergency Stop

2. Tunnel Performance

The purpose of this chapter is to provide an overview of the tunnel performance in terms of achievable flow speeds and flow quality. To understand how speed is measured by the tunnel, a brief overview of the airspeed derivation algorithm, used by Aerolab's Aeroware software will be presented.

Note: All flow performance data was taken with the vertical tilting ceiling in its up most position. It will be up to the responsibility of the user to qualify what tilt angles, if any, should be set for the specific experiments in mind.

2.1. Airspeed Derivation

The speed of an airstream is typically determined with a calibrated Pitot-static probe. A Probe Factor

(PF) is determined by calibrating the Pitot Probe with respect to a Gold Standard Pitot Probe, which is conducted at Aerolab.

$$PF = \left(\frac{q_{gold\ standard}}{q_{pitot\ probe}}\right)$$

$$q_{test\ section} = q_{gold\ standard} = (PF)q_{pitot\ probe}$$

For airspeed calculations, atmospheric (barometric) pressure of the lab is assumed to equal the wind tunnel static pressure, p. The actual difference between atmospheric pressure of the lab and the test section static pressure is negligible, however the user is welcome to pipe the static pressure tubing from the Pitot-Probe to the input side of the Barometric pressure transducer (T-Fitting required) from the Pitot Probe to the Barometer for improved accuracy. Assuming incompressible flow (M<<0.3), airspeed is calculated from Incompressible Bernoulli's equation.

Recall:

$$p_o = p + q$$

$$q = \frac{1}{2}\rho V^2$$

$$\boldsymbol{V} = \sqrt{\frac{\boldsymbol{2q}}{\boldsymbol{\rho}}}$$

Where,

- p_o is total pressure (assumed to be atmospheric pressure for airspeed calculation)
- p is static pressure (test section static pressure)
- q is dynamic pressure
- ρ is air density

The local air density, ρ, is determined using the following equation:

$$\rho = \frac{1}{T}\left[\frac{B}{R_0} - \emptyset P_w\left(\frac{1}{R_0} - \frac{1}{R_w}\right)\right]$$

Where,

- B is the barometric Pressure [Pa]
- T is the absolute temperature [K]
- Ø is the relative humidity [range 0 to 1]

- R_0 is the gas constant of dry air [287.05 J/kgK]
- R_w is the gas constant of water vapor [461.5 J/kgK]
- P_w is the vapor pressure [Pa]

Vapor Pressure is calculated by the following

$$P_w = 2.05 \times 10^{-5} e^{0.0631846T}$$

2.2. Tunnel Velocity

The figure below illustrates the Velocity as a function of RPM . Please note, this study is very dependent on local environmental conditions and is meant to provide a quick reference for approximating empty tunnel speeds that can be expected at specific RPMs. With a model installed, the increase in system resistance will cause a shift in the fan curve and therefore higher RPMS will be required to reach the same airspeeds. Similarly, tilting of the ceiling for boundary layer compensation will impact the test section velocity by a small but noticeable amount.

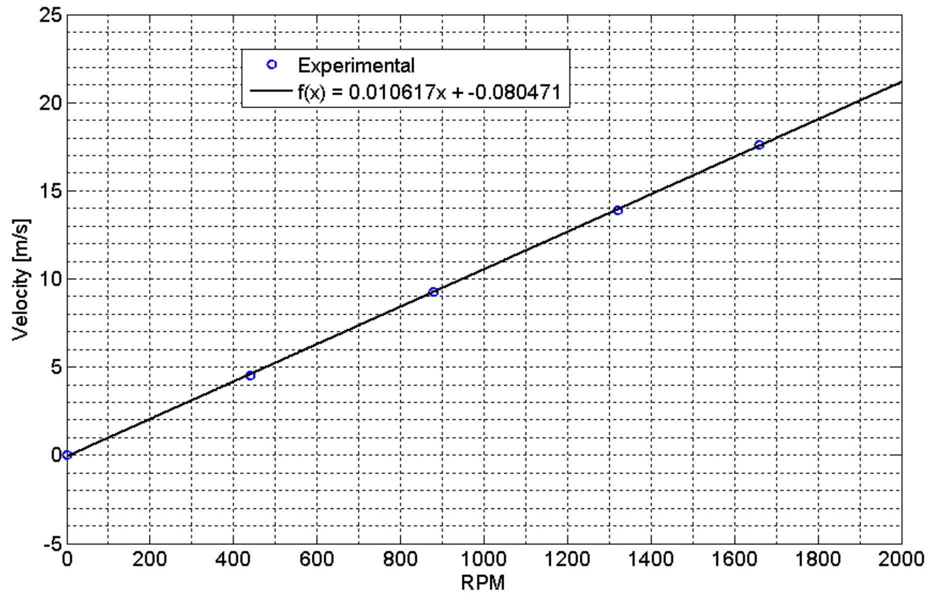


Figure 8: Test Section Velocity Versus RPM

2.3. Tunnel Power

The nominal RPM of the fan motor included with the tunnel is 1770 RPM. A 40 HP (29.8 kW) Variable Frequency Drive can drive the 40 HP (29.8 kW) fan motor up to 1770 RPM safely. A study was conducted that demonstrates the increase in power with RPM. It is not recommended to run the motor beyond the nominal Power for extended periods of time in order to conserve motor life, however, permanent damage will not occur as long as the motor is not driven beyond the 1.15 service factor, 46 HP (34.3 kW).

Note: For 380 V power supply, the service factor drops to 1.0 and therefore the motor should not be run above 40 HP (29.83 kW).

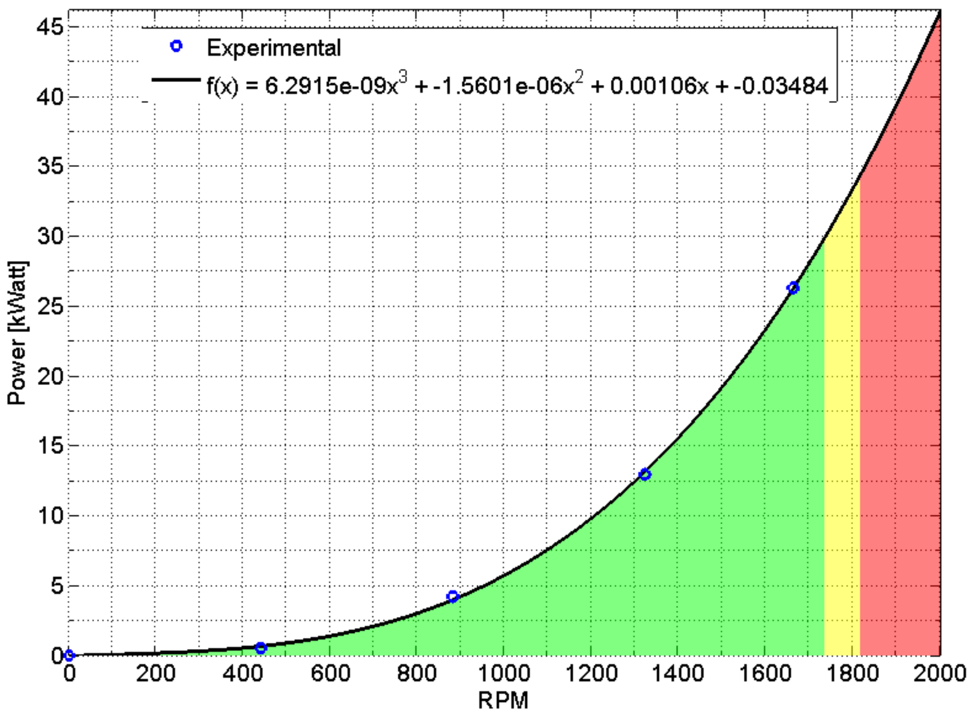


Figure 9: Power Versus RPM

- Continuous operation between 0- 40 HP (0-29.83 kW) is considered safe. GREEN
- 40 HP to 46 HP (29.83-34.3 kW) is running in the Service Factor range YELLOW and can be run periodically with caution as long as the voltage supply is 410-480. For 380 Voltage, the Service Factor is 1.0 and so the fan should not be run within this range.
- Running the fan beyond the 1.15 Service Factor, beyond 46 HP, (34.3 kW) should be minimized and only allowed for short durations to prevent motor overheating or damage to the fan and the tunnel ducting. Aerolab is not responsible for any damage caused by misuse of the fan. RED

2.4. Tunnel Current and Torque

Below are plots representing the Torque and Current draw across the range of Fan RPMs.

Note: This study was conducted with the VFD configured for US power (3-Phase 480 VAC 60 Hz). Results overseas will vary.

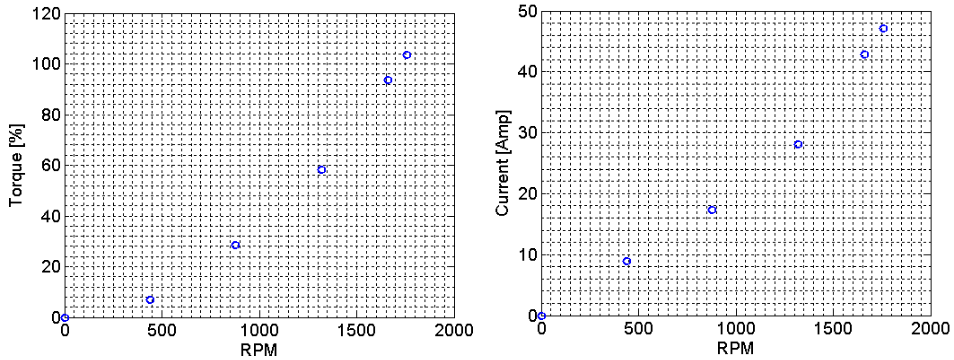


Figure 10: Torque Versus RPM (left) Current Versus RPM (Right)

2.5. Flow Uniformity

Figure 11: Flow Uniformity Traverse System W/ Pitot Static Probe and CTA

An assessment of the velocity spatial uniformity was performed by Aerolab using a wall mounted 2-axis traverse sweep with the tunnel velocity set to a constant fan RPM (Open Loop control). Data was collected at the center of the test section, right above the Yaw Turntable. Due to limitations in travel, the area of study was reduced down to +/- 16 inches in the Y-axis (wall-to-wall direction) and 17.75 inches in the Z-axis (Ceiling-to-Floor). The center of the Jet is designated at Y = 0 in, Z = 0 in. The step size was set to 1.0 inch resulting in velocity data being collected at 1,221 discrete Y-Z data points. A 0.01% Full Scale accuracy 1 psig Mensor Transducer was used with a calibrated Pitot Probe. 3 seconds of data collected at 10 Hz (30 samples) were collected and averaged at each Y-Z point. Four different rpms were studied: 440, 880, 1320 and 1660 RPM. The results of each run are shown below.

Note: Flow statistics are computed using only the free stream of the flow. This is because outside this area, influences of the boundary layer artificially influence on the flow statistics. Aerolab uses a proprietary Mixture of Gaussian Clustering Routine to analyze and characterize the data as free stream or boundary layer.

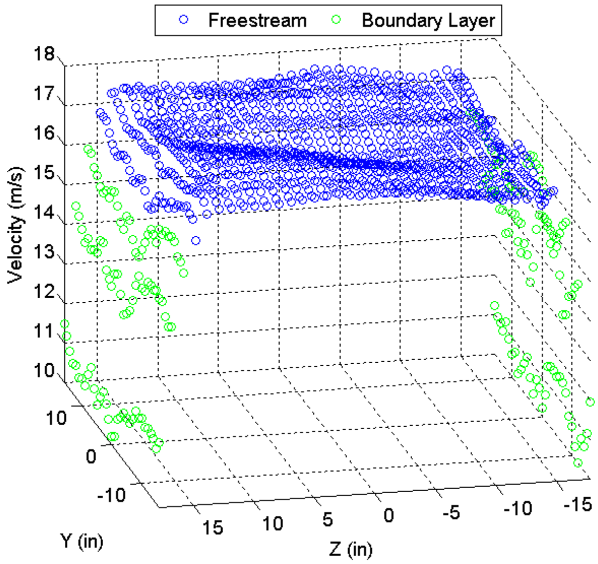


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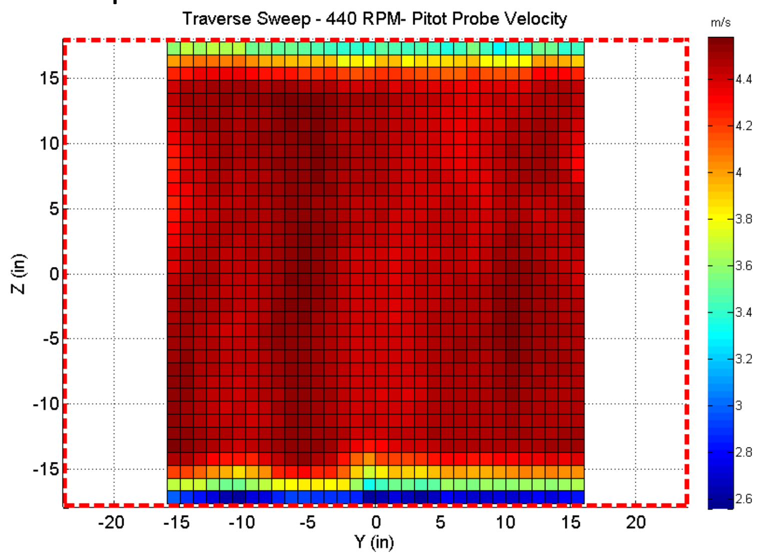
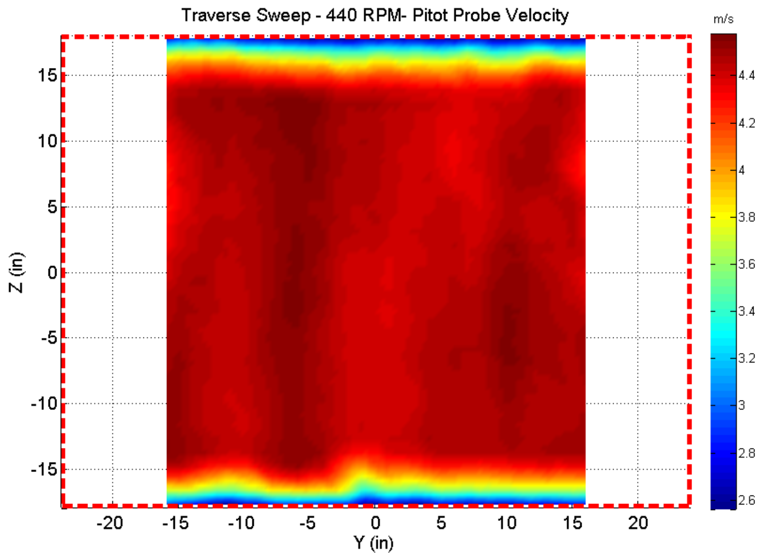
Figure 12: Boundary Layer Vs Free Stream Clustering

Table 4: Velocity Profile Statistics

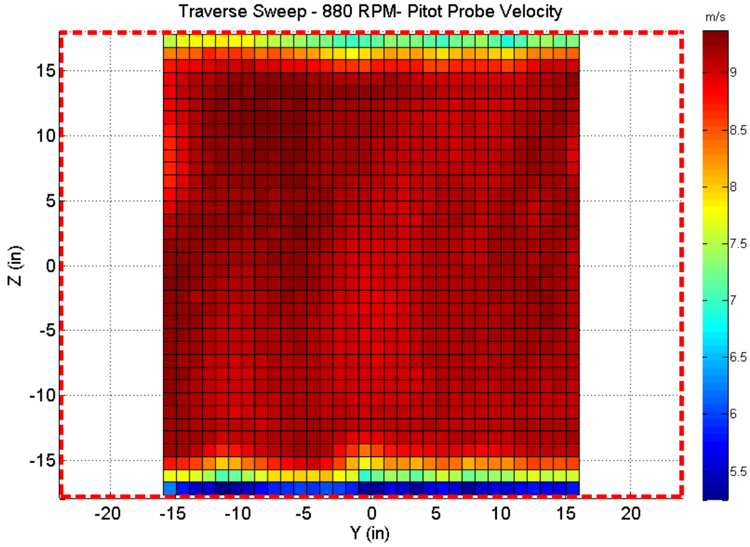
RPM	Power kW	Mean Velocity (m/s)	Standard Deviation (m/s)	Flow Uniformity (%)
440	0.51	4.45	0.0642	1.44
880	4.20	9.12	0.126	1.38
1320	12.91	13.70	0.2109	1.53
1660	26.2	17.25	0.267	1.55

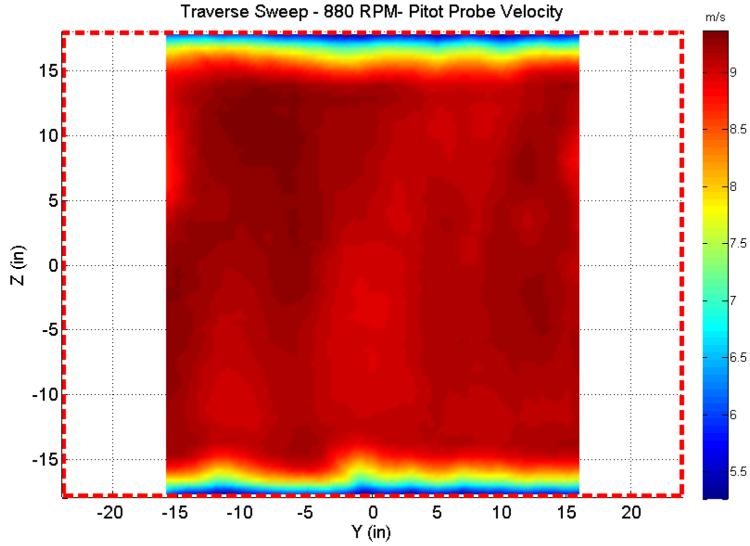
2.5.1. Traverse Sweep -440 RPM



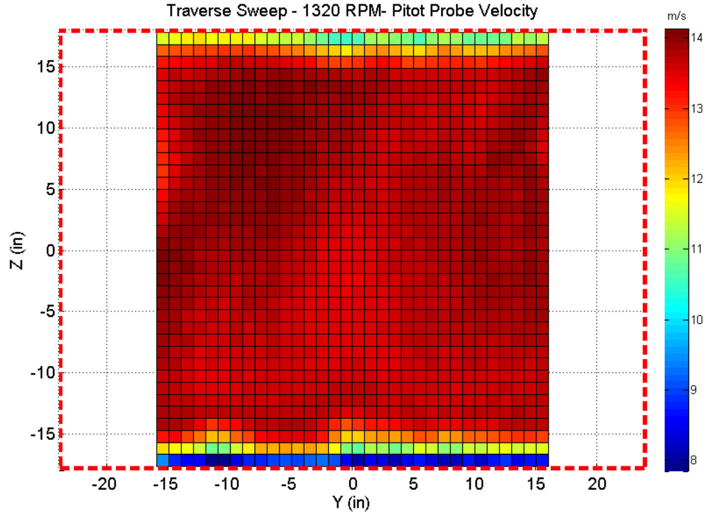


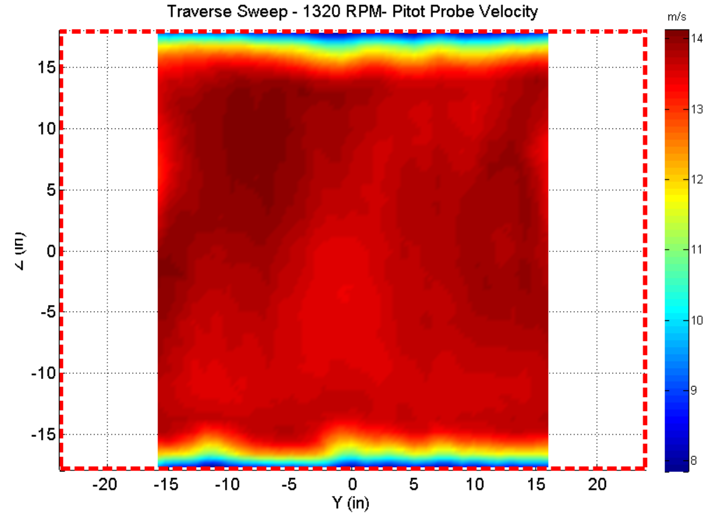
2.5.2. Traverse Sweep -880 RPM



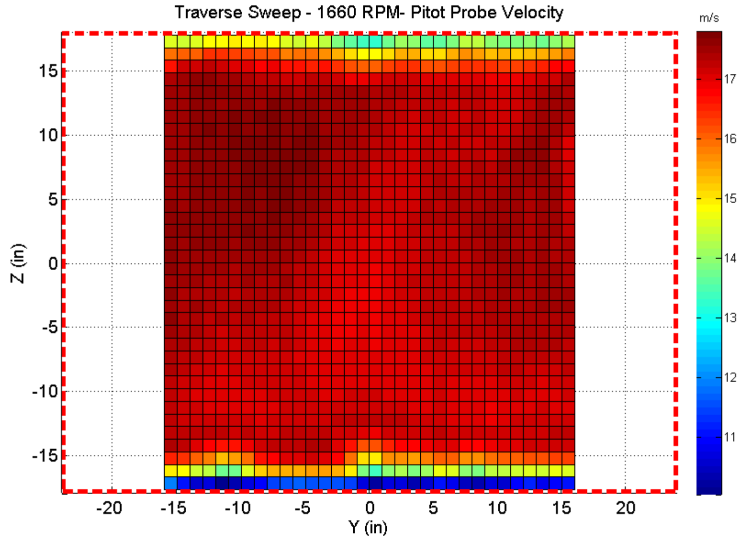


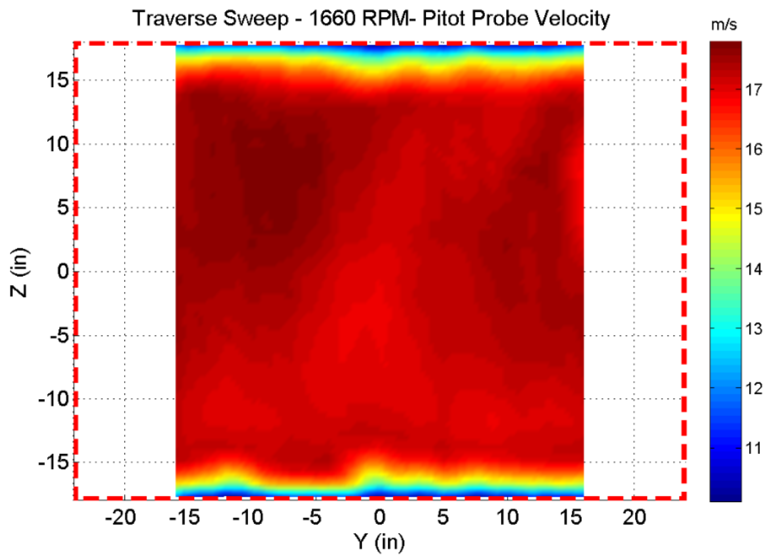
2.5.3. Traverse Sweep -1320 RPM





2.5.4. Traverse Sweep -1660 RPM





2.6. Turbulence

The turbulence levels were characterized at the center of the test section from top (ceiling) to bottom (floor) at different RPMs. This permits some insight into the natural turbulence levels within and out of the tunnel boundary layer prior to the addition of spires and other turbulence inducing devices in the fetch.

2.6.1. 440 RPM

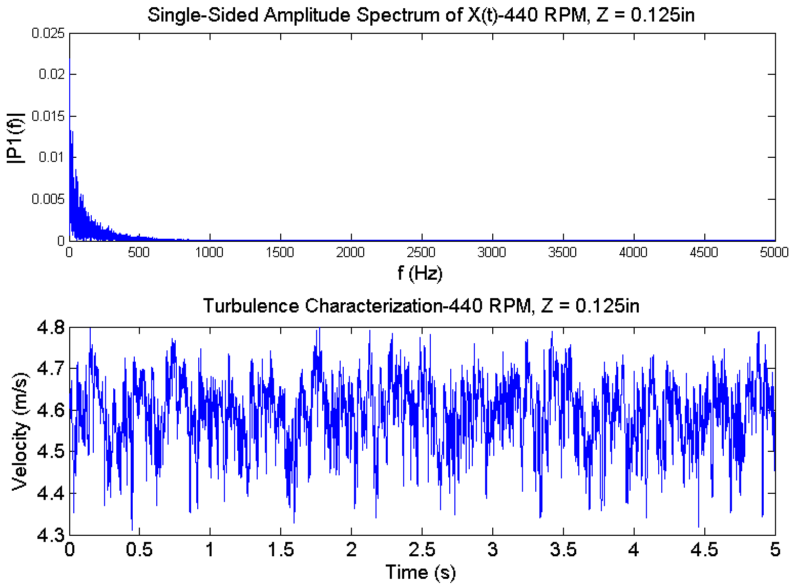


Figure 13: Turbulence at 440 RPM at Z = 0.125 inch Above Floor (Boundary Layer)

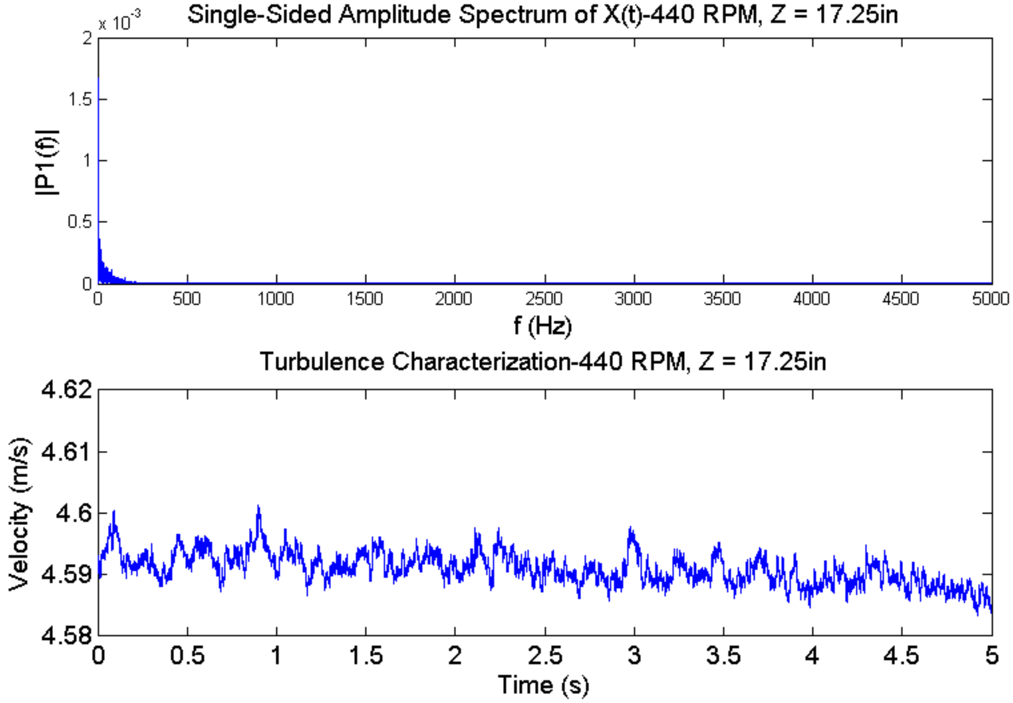


Figure 14: Turbulence at 440 RPM at Z = 17.25 inch Above Floor (Free Stream)

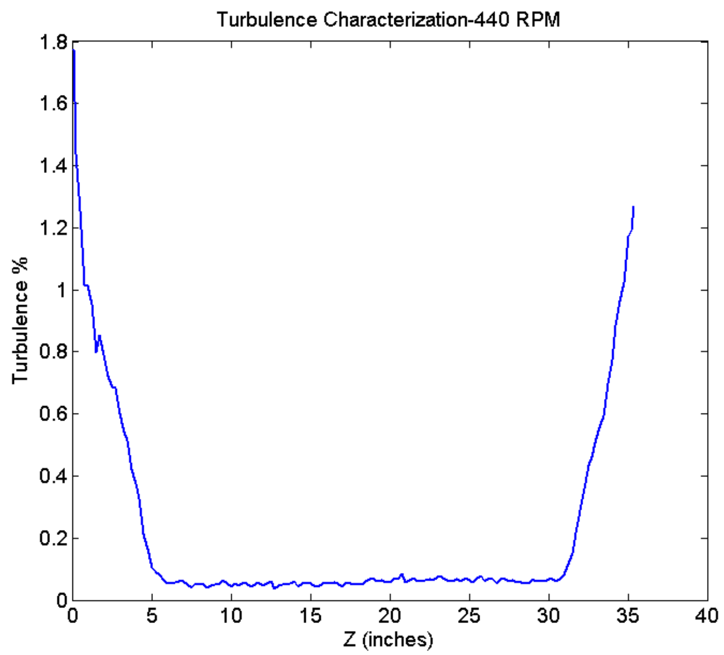


Figure 15: Turbulence Relationship with Z axis at 440 RPM (Z=0 in=floor)

2.6.2. 1660 RPM

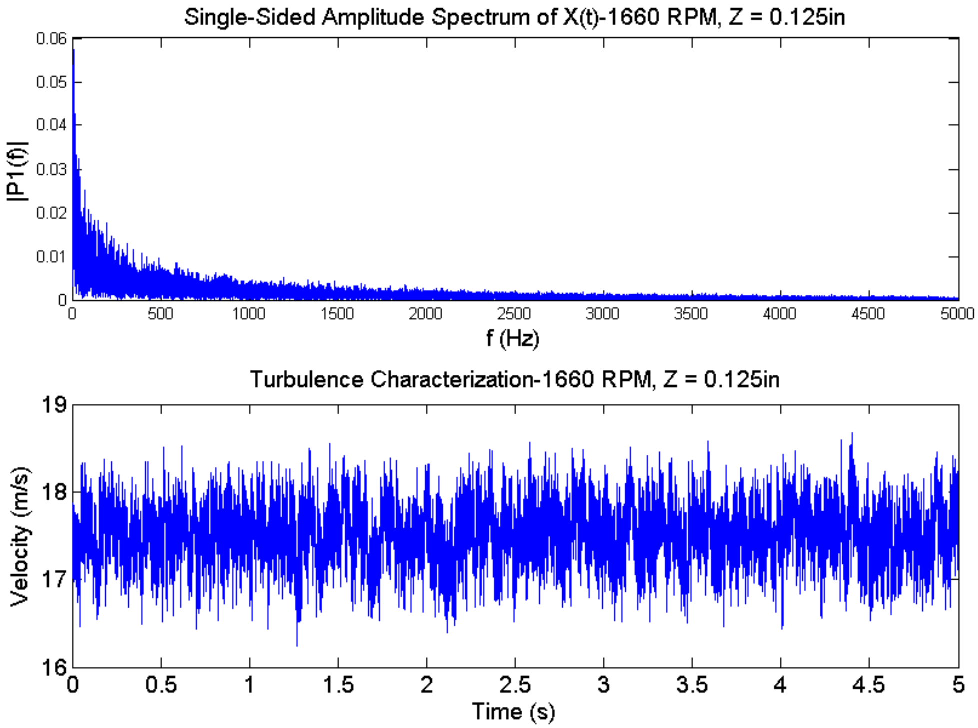


Figure 16: Turbulence at 1660 RPM at Z =0.125 inch Above Floor (Boundary Layer)

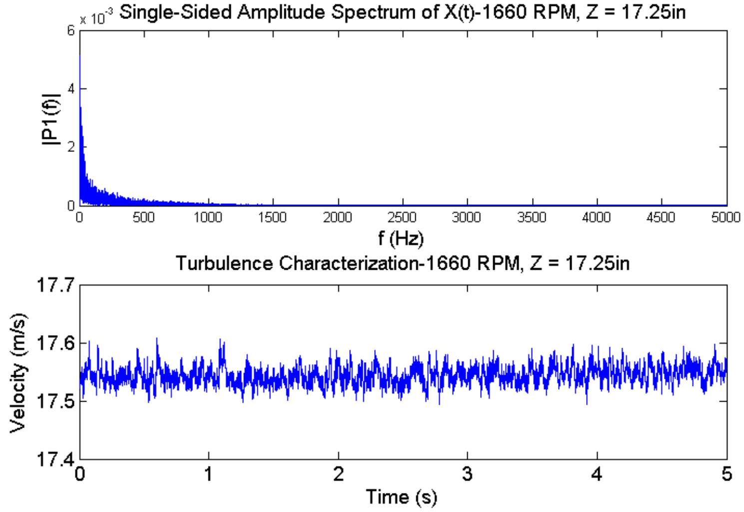


Figure 17: Turbulence at 1660 RPM at Z =17.25 inch Above Floor(Free Stream)

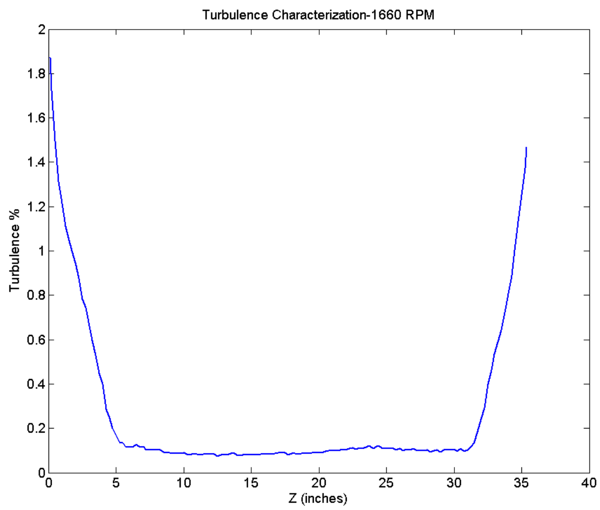


Figure 18: Turbulence Relationship with Z axis at 16600 RPM (Z=0 in=floor)

2.7. Cleaning and maintenance

- Follow the maintenance schedule for the provided fan and motor. The motor includes grease fittings and may require grease to be added once a year to ensure appropriate lubrication.
- The wind tunnel exterior can be cleaned with mild soap and a soft cloth. DO NOT use abrasive items such as powdered cleanser or abrasive pads. These will permanently scratch the surface finish!!
- The test section windows are made of Acrylic. Use only suitable cleaners and a soft cloth.
- Every 6 months, dust and lint should be removed from the screens to keep the tunnel operating nominally.
- This tunnel came with NIST calibrated pressure transducers. The transducers *can* be calibrated every 6 months to ensure the calibration accuracy remains true, but this is generally only required if trying to maintain NIST traceability for the purposes of sensor calibration

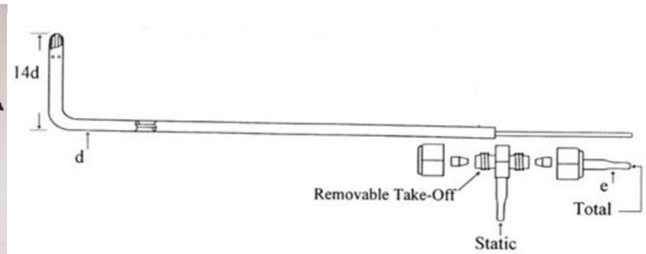
2.8. Aerolab Pitot-Static Probe Installation

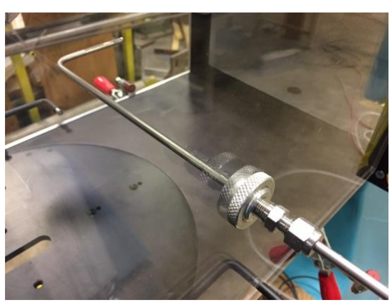
The supplied Pitot-static tube mounts into the aluminum threaded test section window insert. This Pitot-Probe is used to read the tunnel Free Stream airspeeds. It needs to be installed at all times in order to have Velocity feedback in the software.

To use the transducer, simply attach pneumatic lines to the connectors. Pneumatic lines were provided with the system and so hooking up the Pitot Probe is all that should be necessary.

Notes:

- When used with the provided pitot probe, the Total pressure port should hook up to 'P' on the Transducer and the static port should hook up to 'R'. If hooked up backwards, the data may not make any sense as the Mensor CPT6100 differential transducers are calibrated only in 1 direction for highest accuracy levels to be achieved. Flip the two lines if the software is reading 'NAN' for airspeed.
- The safe differential pressure range is 0-1 psig (0 to 6894 Pa)





Aerolab LLC
8291 Patuxent Range Rd
Jessup, MD 20794
Phone: (301) 658-3570
Email: contact@aerolab.com
Website: www.aerolab.com

3. AeroWare Software

Please refer to the AeroWare Software Manual for a detailed overview of the Aeroware system. This specific User Manual will focus on customizations provided for this specific project. The specific customizations for this project are:

- Tunnel Signals Broadcasting

3.1. Tunnel Signals Broadcasting

This section contains important information for connecting to AeroWare via TCP/IP connection to be able to retrieve that data over a high throughput network line. Aerolab has provided sample broadcaster receiver Labview code for the user to use and integrate into their own development software. Please contact Aerolab if additional support is required in this regard.

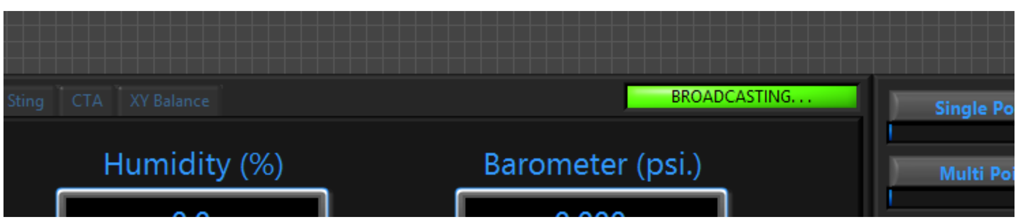
All signal data is transmitted from the following IP address and port:

IP Address: 192.168.1.100

Subnet mask: 255.255.255.0

Port: 55555

When AeroWare is properly connected and transmitting, the indicator in the upper right-hand corner of the GUI will illuminate and display a transmission confirmation. This indicator looks like this:

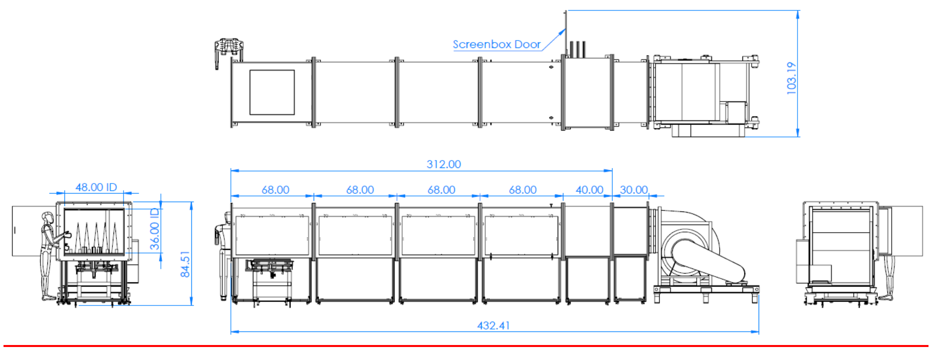


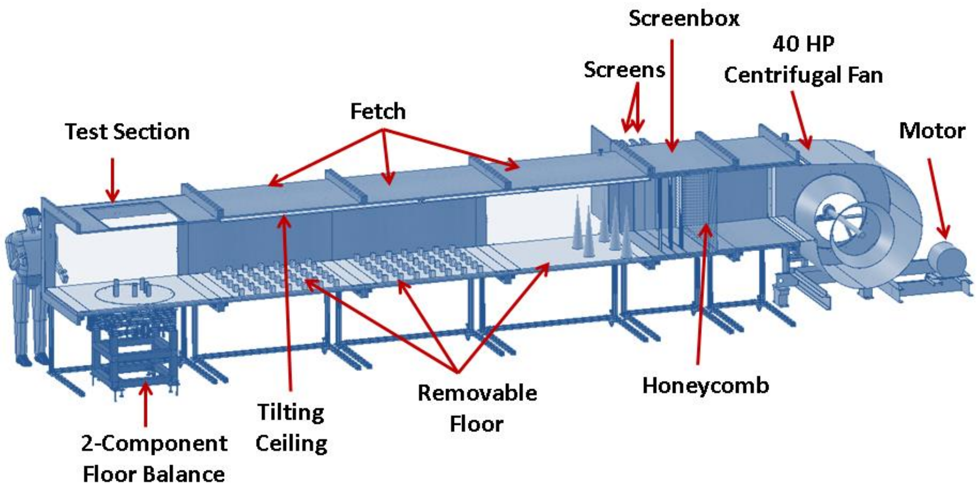
When the indicator is light and you can read the “BROADCASTING. . .” text, you are connected and should be receiving data.

Data is being transmitted at 10 Hz. To avoid memory issues, it is in your best interest to pull data from the TCP connection at a frequency of at least twice this speed (20 Hz). This eliminates the possibility that data you are receiving is stale and assures that the buffer for the connection never fills beyond capacity.

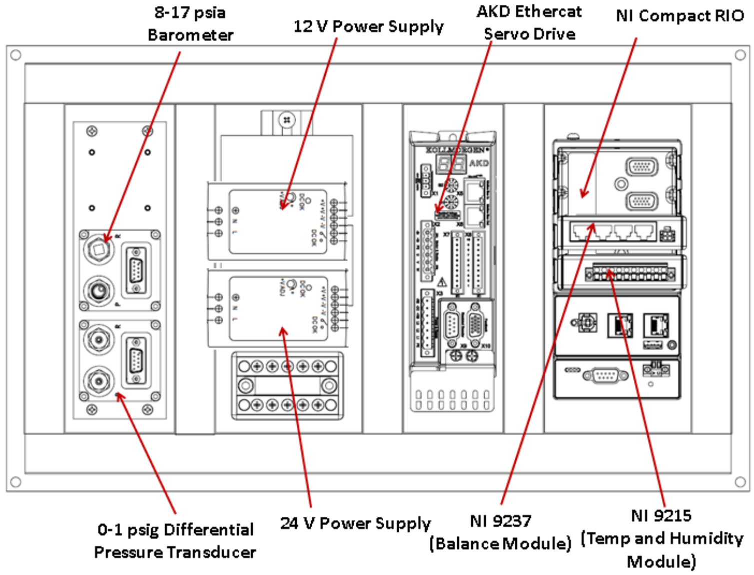
This transmission protocol is built upon National Instruments Simple TCP/IP Messenger and follows all industry standards for TCP/IP communication. Any device on the same subnet should be able to receive data from AeroWare.

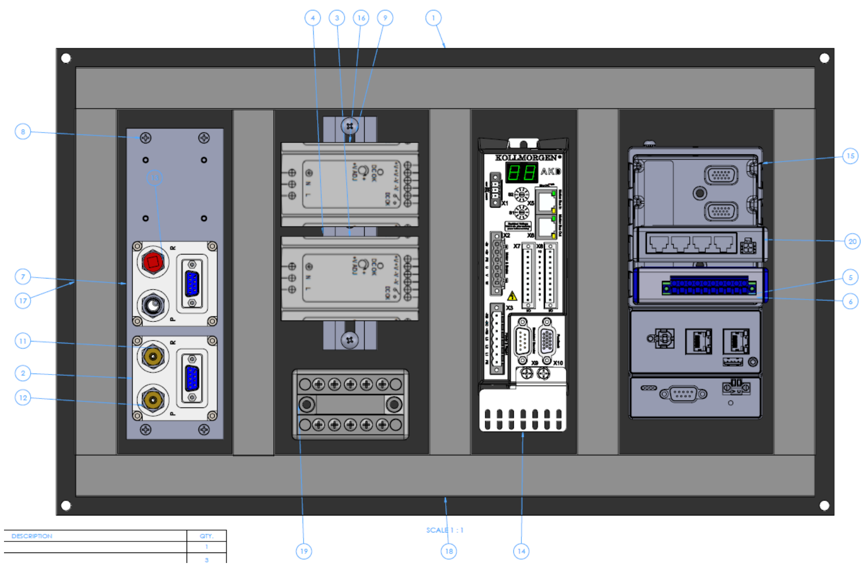
4. Appendix A – Basic Tunnel Layout





5. Appendix B – General DAC Layout

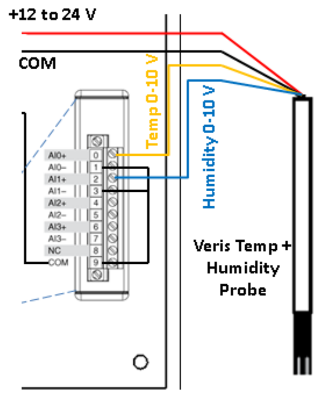




ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	16-78 Mounting Plate		1
2	CPT6100, UNIVERSAL MOUNTING		3
3	MDR-100-24 Power Supply	Mean Well USA 12 Volt DC @ 5A Power Supply; 100-264 V In	1
4	8961K15 DIN3 Rail	DIN Rail, Steel, DIN 3,.25" Mount Hole Diameter, 35mm HX7.5mm Dx1m L	1
5	cu_conn_crio_10_pos_weid		1
6	cu_mod_crio_10_pos_cmbcn		1
7	16-78 Mensor Base Plate	Mcmaster: 8975K532, For Mounting Mensor Transducers	1
8	91099A210	18-8 Stainless Steel Flat Undercut Head Phillips Machine Screw, 6-32 Thread, 5/16" Length	16
9	91770A825	18-8 Stainless Steel Truss Head Phillips Machine Screw, 10-32 Thread, 1/4" Length	2
10	95495K716 Adhesive-Back Bumper	Adhesive-Back Bumper Square, Polyurethane, 3/4" Wide, 1/4" High	4
11	5346K61	Brass Barbed Hose Fitting, 1/8" Hose ID, 1/8 NPTF Male End	4
12	50925K172	Straight Adapter, 1/8 NPTF Female x 7/16"-20 UNF Male	6
13	5481K14	Threaded Round Plug with Raised Head Square, Fits 1/8 NPT	1
14	Danaher-AKD-P00306-NAEC-0000		1
15	cu_crio-9064_5		1
16	MDR-100-12 Power Supply	Mean Well USA 12 Volt DC @ 5A Power Supply; 100-264 V In	1
17	7578K221		5
18	7578K221		2
19	9290T120_HARSH ENVIRONMENT HIGH-AMP DISTRIBUTION BAR (2)		1
20	cu_ni-9237_rj50		1

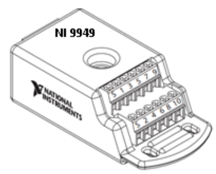

30.00
18.00
4.00
30.00

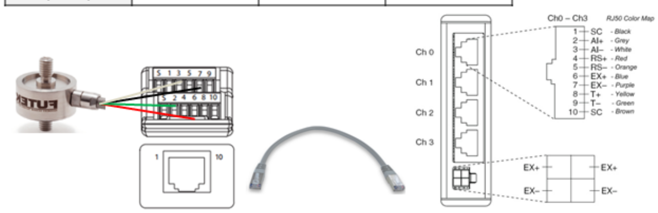
6. Appendix C – Temperature/Humidity Wiring



7. Appendix D – Load Cell Wiring

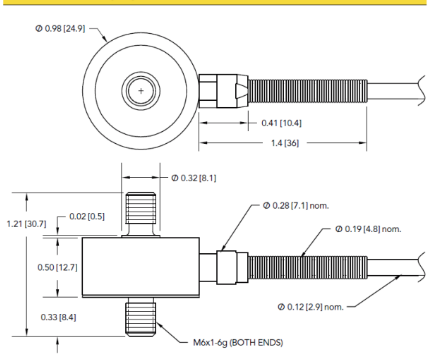
LCM 300	NI 9949 RJ-50 to Screw-Terminal Accessory	RJ-50 Cable Color Map	NI 9237
+Excitation (red)	6	Blue	EX+
-Excitation (black)	7	Purple	EX-
+Signal (green)	2	Grey	AI+
-Signal (white)	3	White	AI-
Floating Shield (silver)	-	-	-





Model LCM300 2

DIMENSIONS inches [mm]

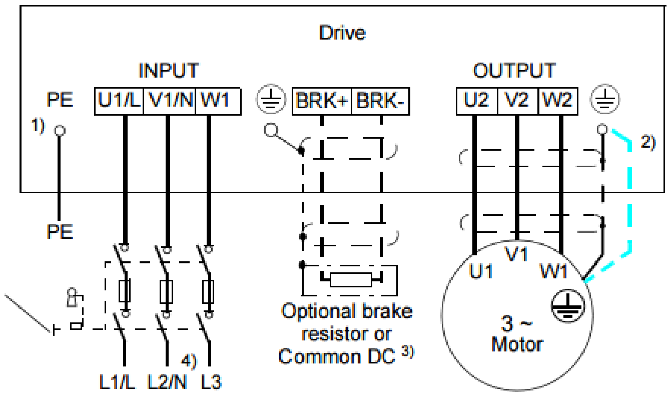


WIRING CODE (WC1)	
RED	+ EXCITATION
BLACK	– EXCITATION
GREEN	+ SIGNAL
WHITE	– SIGNAL
SHIELD	FLOATING

CAPACITIES

ITEM #	lb	N	Natural Frequency (kHz)
FSH03884	50	223	7.5
FSH03885	100	445	10.2
FSH03886	250	1112	16.2
FSH03887	500	2224	22.9
FSH03888	1000	4448	30.1

8. Appendix E – VFD Electrical Installation



For alternatives, see section *Selecting the supply disconnecting device (disconnecting means)* on page *40*.

1) Ground the other end of the PE conductor at the distribution board.

2) Use a separate grounding cable if the conductivity of the cable shield is insufficient (smaller than the conductivity of the phase conductor) and there is no symmetrically constructed grounding conductor in the cable. See section *Selecting the power cables* on page *41*.

3) For more information on Common DC, see *ACS355 Common DC application guide* (3AUA0000070130 [EN]).

4) In one-phase installations, connect the neutral cable here.

Note:

Do not use an asymmetrically constructed motor cable.

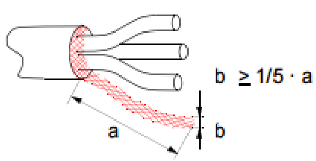
If there is a symmetrically constructed grounding conductor in the motor cable in addition to the conductive shield, connect the grounding conductor to the grounding terminal at the drive and motor ends.

Route the motor cable, input power cable and control cables separately. For more information, see section *Routing the cables* on page *45*.

Grounding of the motor cable shield at the motor end

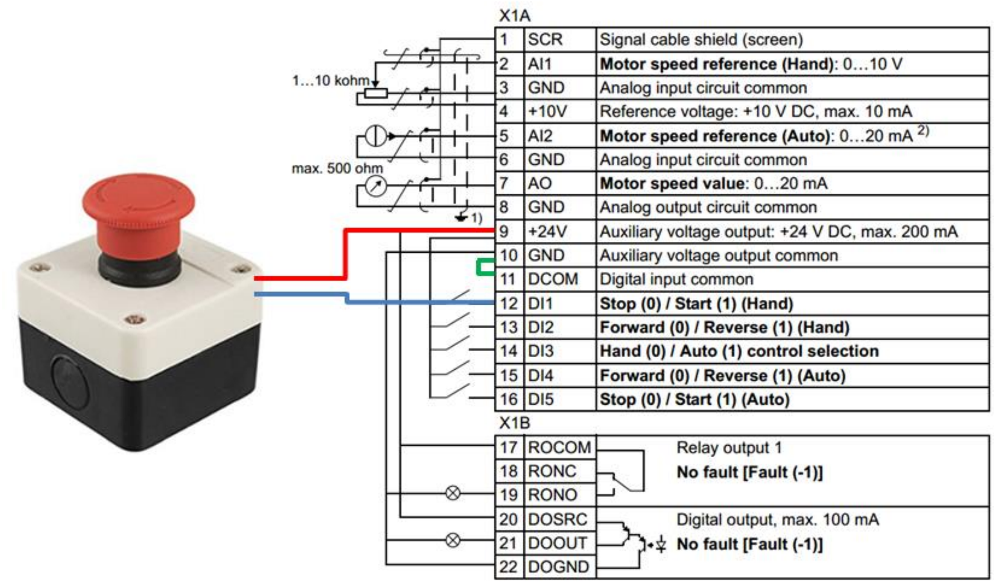
For minimum radio frequency interference:

- ground the cable by twisting the shield as follows: flattened width ≥ 1/5 · length
- or ground the cable shield 360 degrees at the lead-through of the motor terminal box.

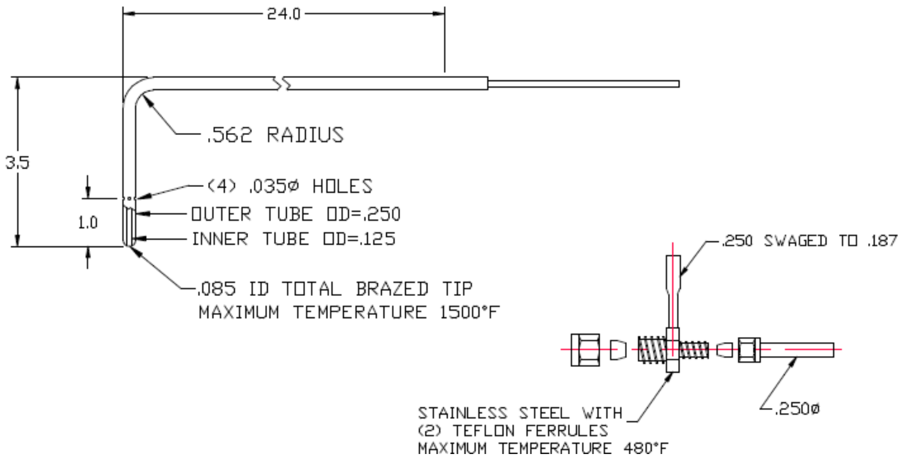


9. Appendix F – Emergency Stop Wiring

ACS 355 VFD



10. Appendix G – Pitot Probe Drawing



11. Appendix H – DAC Power Supplies

■ Features :

- Universal AC input / Full range
- Protections: Short circuit / Overload / Over voltage / Over temperature
- ZCS/ZVS technology to reduce power dissipation
- Cooling by free air convection
- Can be installed on DIN rail TS-35/7.5 or 15
- DC OK relay contact
- No load power consumption<1W
- LED indicator for power on
- 100% full load burn-in test
- 3 years warranty

MODEL		MDR-100-12	MDR-100-24	MDR-100-48
OUTPUT	DC VOLTAGE	12V	24V	48V
	RATED CURRENT	7.5A	4A	2A
	CURRENT RANGE	0 ~ 7.5A	0 ~ 4A	0 ~ 2A
	RATED POWER	90W	96W	96W
	RIPPLE & NOISE (max.) Note.2	120mVp-p	150mVp-p	200mVp-p
	VOLTAGE ADJ. RANGE	12 ~ 15V	24 ~ 30V	48 ~ 56V
	VOLTAGE TOLERANCE Note.3	±1.0%	±1.0%	±1.0%
	LINE REGULATION	±1.0%	±1.0%	±1.0%
	LOAD REGULATION	±1.0%	±1.0%	±1.0%
	SETUP, RISE TIME Note.5	3000ms, 50ms/230VAC 3000ms, 50ms/115VAC at full load		
	HOLD UP TIME (Typ.)	50ms/230VAC 20ms/115VAC at full load		
INPUT	VOLTAGE RANGE Note.6	85 ~ 264VAC 120 ~ 370VDC		
	FREQUENCY RANGE	47 ~ 63Hz		
	POWER FACTOR (Typ.)	PF≧0.95/230VAC PF≧0.98/115VAC at full load		
	EFFICIENCY (Typ.)	85%	86%	88%
	AC CURRENT (Typ.)	1.3A/115VAC 0.8A/230VAC		
	INRUSH CURRENT (Typ.)	COLD START 30A/115VAC 60A/230VAC		
	LEAKAGE CURRENT	<1mA / 240VAC		
PROTECTION	OVERLOAD	105 ~ 150% rated output power		
		Protection type : Constant current limiting, recovers automatically after fault condition is removed		
	OVER VOLTAGE	15.6 ~ 18V	31.2 ~ 36V	57.6 ~ 64.8V
		Protection type : Shut down o/p voltage, re-power on to recover		
	OVER TEMPERATURE	Shut down o/p voltage, auto-recovery or re-power on to recover		
FUNCTION	DC OK SIGNAL	Relay contact rating(max.): 30V/1A resistive		
ENVIRONMENT	WORKING TEMP.	-10 ~ +60℃ (Refer to "Derating Curve")		
	WORKING HUMIDITY	20 ~ 90% RH non-condensing		
	STORAGE TEMP., HUMIDITY	-40 ~ +85℃, 10 ~ 95% RH		
	TEMP. COEFFICIENT	±0.03%/℃ (0 ~ 50℃)		
	VIBRATION	Component : 10 ~ 500Hz, 2G 10min./1cycle, period for 60min. each along X, Y, Z axes ; Mounting : Compliance to IEC60068-2-6		
SAFETY & EMC (Note 4)	SAFETY STANDARDS	UL508, TUV EN60950-1 approved		
	WITHSTAND VOLTAGE	I/P-O/P:3KVAC I/P-FG:2KVAC O/P-FG:0.5KVAC		
	ISOLATION RESISTANCE	I/P-O/P, I/P-FG, O/P-FG:>100M Ohms / 500VDC / 25℃/ 70% RH		
	EMC EMISSION	Compliance to EN55011, EN55022 (CISPR22), EN61204-3 Class B, EN61000-3-2,-3		
	EMC IMMUNITY	Compliance to EN61000-4-2,3,4,5,6,8,11, EN55024, EN61000-6-2, EN61204-3, heavy industry level, criteria A		
OTHERS	MTBF	346K hrs min. MIL-HDBK-217F (25℃)		
	DIMENSION	55*90*100mm (W*H*D)		
	PACKING	0.42Kg; 30pcs/13.6Kg/0.82CUFT		
NOTE	1. All parameters NOT specially mentioned are measured at 230VAC input, rated load and 25℃ of ambient temperature. 2. Ripple & noise are measured at 20MHz of bandwidth by using a 12" twisted pair-wire terminated with a 0.1uf & 47uf parallel capacitor. 3. Tolerance : includes set up tolerance, line regulation and load regulation. 4. The power supply is considered a component which will be installed into a final equipment. The final equipment must be re-confirmed that it still meets EMC directives. For guidance on how to perform these EMC tests, please refer to "EMI testing of component power supplies." (as available on http://www.meanwell.com) 5. Length of set up time is measured at first cold start. Turning ON/OFF the power supply may lead to increase of the set up time. 6. Deating maybe needed under low input voltages, please check the derating curve for more detail.			

12. Appendix I– Mensor Transducer Calibrations

mensor CALIBRATION
Date: 12/17/2016 SN: 41000DHH
Due: By: CK

mensor

Calibration Certificate

Accredited Calibration

A2LA ACCREDITED
Calibration Lab Cert 2066.01

Cal Cert ID: 131635

Cust. Name: AEROLAB LLC
Address: 8291 PATUXENT RANGE RD
SUITE 1200
City: JESSUP
State/Zip: MD 20794 US

Page 1 of 2

Instr SN:	41000DHH	**Out1 Min Range:**	0.00000 PSI	**Cal Date:**	12/17/2016
Instr Descr:	6100	**Out1 Max Range:**	1.00000 PSI	**Cal Time:**	10:19 am
Sensor SN:	41000DHH	**Limit of Error:**	0.010 %F.S.	**Cal Tech:**	CRISK
Procedure ID:	WI02058	**Pressure Type:**	Gauge	**Order Nbr:**	14875

Test Points Values and Readings

Test Point #	Reference Value PSI	Measured Values PSI	Error % F.S.	Uncertainty PSI
1	-0.000162	-0.00016	0.000	.000002
2	0.190238	0.19026	0.002	.000003
3	0.401738	0.40177	0.003	.000006
4	0.592084	0.59212	0.004	.000009
5	0.803584	0.80361	0.003	.000012
6	0.993841	0.99385	0.001	.000014
7	0.803584	0.80362	0.004	.000012
8	0.592084	0.59213	0.005	.000009
9	0.401738	0.40177	0.003	.000006
10	0.190238	0.19026	0.002	.000003
11	-0.000162	-0.00016	0.000	.000002

Measurement Standards Used in Calibration

Std Type	Serial Number	Description	Assoc. Test Reports	Recal Date
14500	290222	Mensor Barometer	CAL ID: 126262	07/01/2017
HMT	H3450112	Vaisala HMT 331 Temp and RH transmit	2020644-160329-HMT331-H3 450112	09/29/2018
HP MULTIMETER	MY47024628	34410A	CAL ID: 109885	02/02/2017
Mass Set	13788	Ruska mass set	CAL ID: 1500128222	01/15/2017
Mass Set	13788-A	Ruska Mass	CAL ID: 1500128222	01/15/2017
Mass Set	20400	Troemner Trim Mass Set	CAL ID: 20400-MAR102016	03/09/2021
Mass Set	45981	Ruska Mass Set	CAL ID: 45981-MAR172016	03/16/2021
Piston	TL-1279	Ruska low range pneumatic piston	CAL ID: 1500164026	04/27/2019
Piston	TL1333	Ruska low range pneumatic piston	CAL ID: 1500181024	05/01/2020
PRT	PRT3	Platinum Resistance Thermometer	CAL ID: 114228	06/18/2017
PRT	PRT5	Platinum Resistance Thermometer	CAL ID: 113613	05/22/2017

The combined and expanded uncertainty is reported at K=2 providing an approximate 95% confidence level.

Remarks and Notes

As Left Calibration.
An asterisk (*) denotes a measured condition where the error exceeds the maximum permissible error.
Dash numbers preceded by the sensor SN reference a primary (-1) or turndown (-2) range as applicable.

MENSOR · THE PRECISION PRESSURE COMPANY
201 BARNES DR. · SAN MARCOS, TEXAS 78666 · 512.396.4200 · FAX 512.396.1820 · WWW.MENSOR.COM

Cal Cert ID: 131635 Page 2 of 2

The standards and calibration program at Mensor complies with the requirements of ISO/IEC 17025:2005, ANSI/NCSL Z540-1 and Mensor Quality Manual 2.0, Revision R, dated March 10, 2015.
Standards used in this calibration are traceable to SI units of measurements through N.I.S.T. or recognized national metrology institutes. All calibrations are performed in ambient conditions of 23 +/- 4 deg C and 20-80% relative humidity.
This calibration certificate shall not be reproduced, except in full, without the written approval of Mensor.

I, Christina Kloesel, certify the accuracy of this Calibration Certificate: Christina Kloesel

Calibration Lab Technician

Mensor Calibration Certificates and Stickers

Mensor calibration certificates and stickers do not contain calibration intervals unless specified by the customer, as Mensor will not dictate to our customers when they should re-calibrate their instruments.
The Calibration Sticker that is with this product is for your records. Due to the various location requirements of our customers, we do not affix the Calibration Sticker to the product.
For Mensor products, refer to the Calibration Section of your operation manual for the recommended calibration interval.

mensor CALIBRATION
Date: 12/17/2016 SN: 41000D7R
Due: By: PR

Calibration Certificate
Accredited Calibration

ACCREDITED
Calibration Lab
Cert 2066.01

Cal Cert ID: 131648

Cust. Name: AEROLAB LLC
Address: 8291 PATUXENT RANGE RD
SUITE 1200
City: JESSUP
State/Zip: MD 20794 US

Instr SN: 41000D7R
Instr Descr: 6100
Sensor SN: 41000D7R
Procedure ID: WI02058

Out1 Min Range: 8.0000 PSI
Out1 Max Range: 17.0000 PSI
Limit of Error: 0.000 %F.S.+ 0.010 % R
Pressure Type: Absolute

Cal Date: 12/17/2016
Cal Time: 1:13 pm
Cal Tech: PHILIPR
Order Nbr: 14875

Test Points Values and Readings

Test Point #	Reference Value PSI	Measured Values PSI	Error % R	Uncertainty PSI
1	8.00754	8.0076	0.001	.00018
2	9.80707	9.8072	0.001	.00022
3	11.60661	11.6068	0.002	.00026
4	13.40625	13.4065	0.002	.00029
5	15.20591	15.2062	0.002	.00033
6	17.00563	17.0058	0.001	.00037
7	15.20604	15.2063	0.002	.00033
8	13.40629	13.4065	0.002	.00029
9	11.60668	11.6069	0.002	.00026
10	9.80712	9.8073	0.002	.00022
11	8.00757	8.0077	0.002	.00018

Measurement Standards Used in Calibration

Std Type	Serial Number	Description	Assoc. Test Reports	Recal Date
CPD 8000	10017/10016/9994	DH CPD 8000	CAL ID: 119787	12/10/2018

The combined and expanded uncertainty is reported at K=2 providing an approximate 95% confidence level.

Remarks and Notes

As Left Calibration.
An asterisk (*) denotes a measured condition where the error exceeds the maximum permissible error.
Dash numbers preceded by the sensor SN reference a primary (-1) or turndown (-2) range as applicable.
The standards and calibration program at Mensor complies with the requirements of ISO/IEC 17025:2005, ANSI/NCSL Z540-1 and Mensor Quality Manual 2.0, Revision R, dated March 10, 2015.
Standards used in this calibration are traceable to SI units of measurements through N.I.S.T. or recognized national metrology institutes. All calibrations are performed in ambient conditions of 23 +/- 4 deg C and 20-80% relative humidity.
This calibration certificate shall not be reproduced, except in full, without the written approval of Mensor.

I, Philip Romero, certify the accuracy of this Calibration Certificate:

Calibration Lab Coordinator

Cal Cert ID: 131648

Mensor Calibration Certificates and Stickers

Mensor calibration certificates and stickers do not contain calibration intervals unless specified by the customer, as Mensor will not dictate to our customers when they should re-calibrate their instruments.
The Calibration Sticker that is with this product is for your records. Due to the various location requirements of our customers, we do not affix the Calibration Sticker to the product.
For Mensor products, refer to the Calibration Section of your operation manual for the recommended calibration interval.

13. Warranty & Contact Information

(a) Equipment and Services Warranty. Aerolab warrants that Equipment (excluding Software, which is warranted as specified in paragraph (d) below) shall be delivered free of defects in material and workmanship and that Services shall be free of defects in workmanship. The Warranty Remedy Period for Equipment (excluding Software, Spare Parts and Refurbished or Repaired Parts) shall end twelve (12) months after installation or eighteen (18) months after date of shipment, whichever first occurs. The Warranty Remedy Period for new spare parts shall end twelve (12) months after date of shipment. The Warranty Remedy Period for refurbished or repaired parts shall end ninety (90) days after date of shipment. The Warranty Remedy Period for Services shall end ninety (90) days after the date of completion of Services.

(b) Equipment and Services Remedy. If a nonconformity to the foregoing warranty is discovered in the Equipment or Services during the applicable Warranty Remedy Period, as specified above, under normal and proper use and provided the Equipment has been properly stored, installed, operated and maintained and written notice of such nonconformity is provided to Aerolab promptly after such discovery and within the applicable Warranty Remedy Period, Aerolab shall, at its option, either (i) repair or replace the nonconforming portion of the Equipment or re-perform the nonconforming Services or (ii) refund the portion of the price applicable to the nonconforming portion of Equipment or Services. If any portion of the Equipment or Services so repaired, replaced or re-performed fails to conform to the foregoing warranty, and written notice of such nonconformity is provided to Aerolab promptly after discovery and within the original Warranty Remedy Period applicable to such Equipment or Services or 30 days from completion of such repair, replacement or re-performance, whichever is later, Aerolab will repair or replace such nonconforming Equipment or re-perform the nonconforming Services. The original Warranty Remedy Period shall not otherwise be extended.

(c) Exceptions. Aerolab shall not be responsible for providing working access to the nonconforming Equipment, including disassembly and re-assembly of non-Aerolab supplied equipment, or for providing transportation to or from any repair facility, all of which shall be at Purchaser’s risk and expense. Aerolab shall have no obligation hereunder with respect to any Equipment which (i) has been improperly repaired or altered;

(ii) has been subjected to misuse, negligence or accident; (iii) has been used in a manner contrary to Aerolab’s instructions; (iv) is comprised of materials provided by or a design specified by Purchaser; or (v) has failed as a result of ordinary wear and tear. Equipment supplied by Aerolab but manufactured by others is warranted only to the extent of the manufacturer’s warranty, and only the remedies, if any, provided by the manufacturer will be allowed.

(d) Software Warranty and Remedies. Aerolab warrants that, except as specified below, the Software will, when properly installed, execute in accordance with Aerolab’s published specification. If a nonconformity to the foregoing warranty is discovered during the period ending one (1) year after the date of shipment and written notice of such nonconformity is provided to Aerolab promptly after such discovery and within that period, including a description of the nonconformity and complete information about the manner of its discovery, Aerolab shall correct the nonconformity by, at its option, either (i) modifying or making available to the Purchaser instructions for modifying the Software; or (ii) making available at Aerolab's facility necessary corrected or replacement programs. Aerolab shall have no obligation with respect to any nonconformities resulting from (i) unauthorized modification of the Software or (ii) Purchaser-supplied software or interfacing. Aerolab does not warrant that the functions contained in the software will operate in combinations which may be selected for use by the Purchaser, or that the software products are free from errors in the nature of what is commonly categorized by the computer industry as "bugs".

(e) THE FOREGOING WARRANTIES ARE EXCLUSIVE AND IN LIEU OF ALL OTHER WARRANTIES OF QUALITY AND PERFORMANCE, WHETHER WRITTEN, ORAL OR IMPLIED, AND ALL OTHER WARRANTIES INCLUDING ANY IMPLIED WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE OR USAGE OF TRADE ARE HEREBY DISCLAIMED. THE REMEDIES STATED HEREIN CONSTITUTE PURCHASER'S EXCLUSIVE REMEDIES AND AEROLAB'S ENTIRE LIABILITY FOR ANY BREACH OF WARRANTY.

14. References

- Barlow, J.B., Rae, W.H. Jr. and Pope, A. (1999) Low-Speed Wind Tunnel Testing, 3rd edn, John Wiley and Sons, New York

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