Total Water Content System
SEA Model WCM-3000

OPERATING MANUAL

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WCM-3000

General Description:

The WCM-3000 system is comprised of four major components:

1. Sense Head
2. Power Box
3. Control Box
4. Cabling

Figure 1-1 depicts the relationship between the four major components.

The WCM-3000 system is a hot wire system designed to measure the Total-Water-Content (TWC) in clouds during flight. The system produces outputs that can be used to calculate the TWC. These outputs are passed to an SEA Model 300 to be analyzed or to a user supplied data acquisition system.

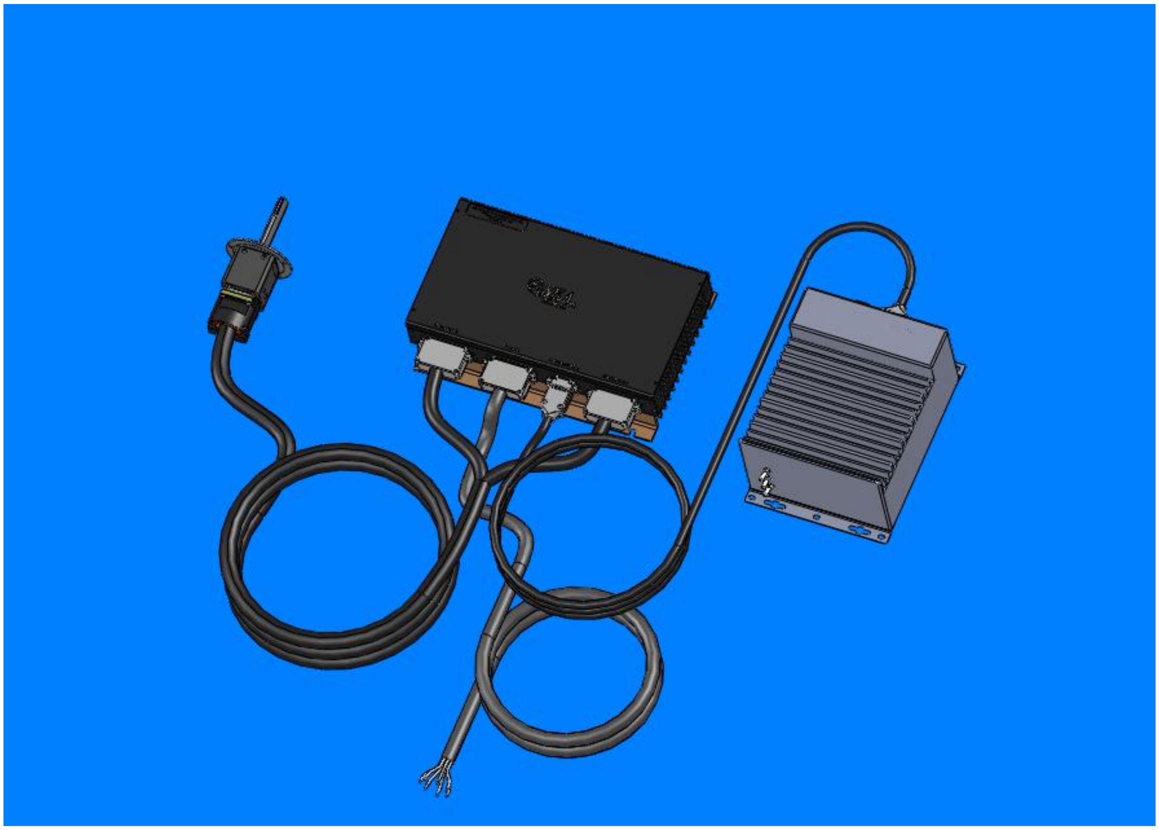


Figure 1-1

Sense Head:

The Sense Head is depicted in Figure 1-2. The Sense Head connector can have alternate orientations. Contact SEA for more information. shroud provides an anchor

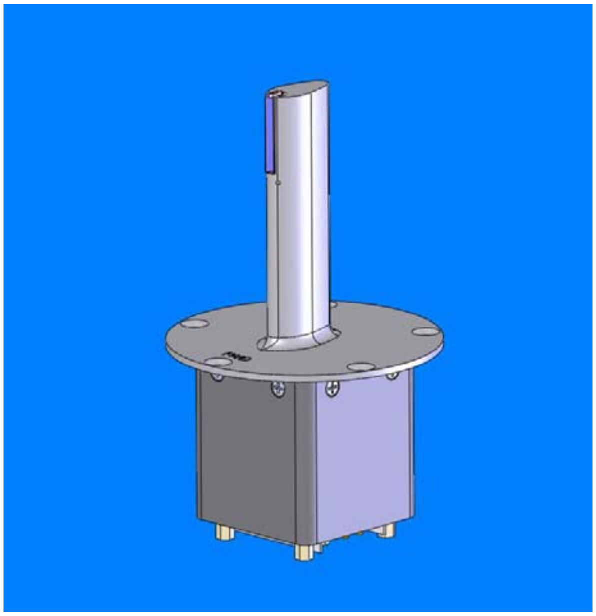


Figure 1-2 3000 series Sense Head

Power Box:

The power box for the WCM-3000 system interfaces with the sense head and the control system

Figure 1-3 Power Box

Control Box:

The WCM-2000 Control Box can come in many forms to include 19" rack enclosures, PC-104 formats or other smaller formats as depicted below. The same Control Box can be used for the SEA WCM-2000 (Multi-Element), WCM-3000 (Single Element - Robust), and the WCM-4000 (Ice Crystal Detection) systems

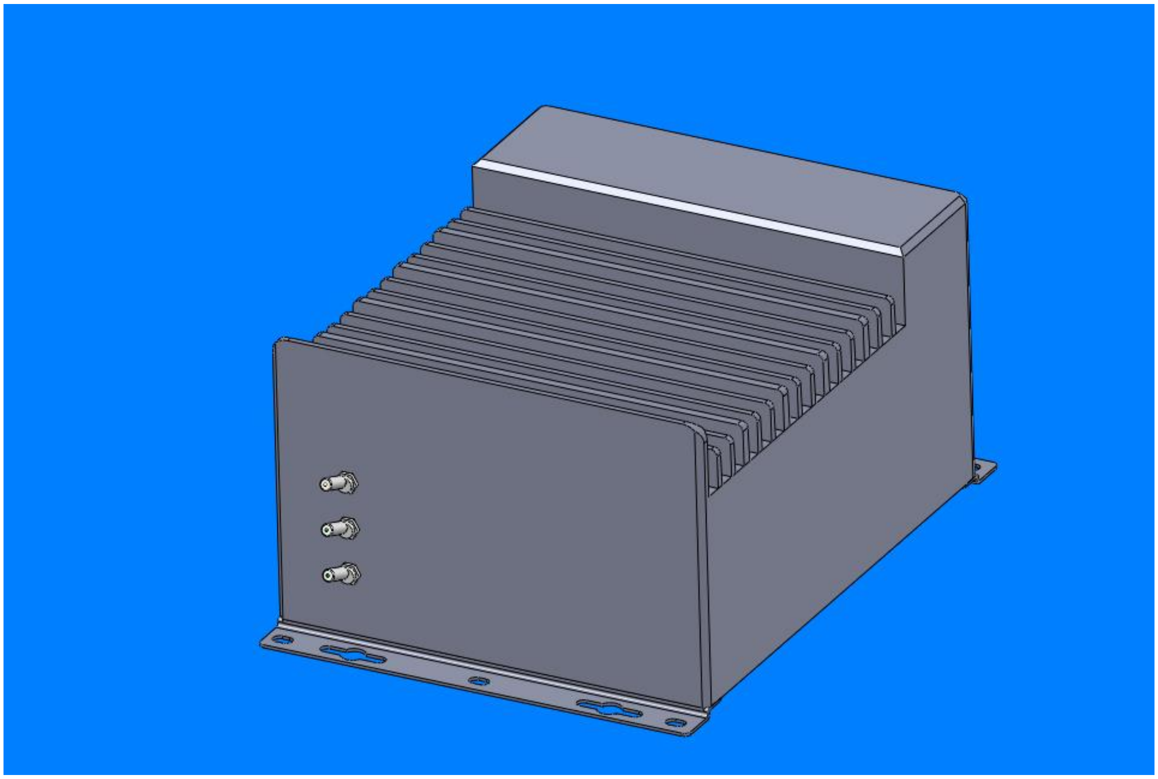


Figure 1-4 Control Box

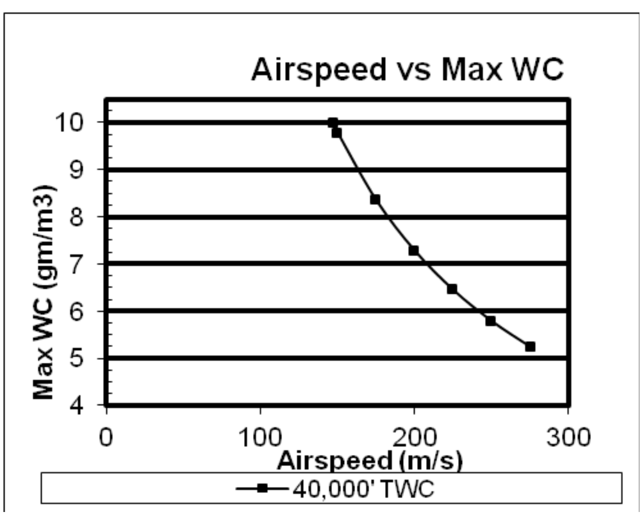
Cabling:

Cabling is required to connect the other three components. The required cables can be ordered with a system or manufactured by the user. The user must follow the manufacturing instructions found on the cable prints to ensure proper system function. The cable prints are found in Section 9.

Customization:

The equipment depicted above is typical of the equipment supplied by SEA, Inc. There are many options for customization that may include alternate power supplies to interface with existing supply power options and existing cable limitations, custom enclosures for the power box or control box to fit into existing physical constraints, and many other options as needed by individual installations.

LWC/TWC Range[1]	0 - 10 gms/m3 TAS < 150 m/s SL – 45,000 ft @ -40°F 0 - 6 gms/m3 TAS < 230 m/s SL - 45,000 ft @ -40°F
Airspeed Range	0 – 275 m/s (0 – 533 kt) (for Safe Operation)[2]
Measurement Range	10 – 275 m/s (20 – 533 kt)
Power Supply Range	18 – 32 volts dc, 28 volts dc nominal
Power Consumption[3]	3.5 amps minimum 11 amps typical 49 amps maximum
Dimensions:	Sensor Head 3.05 " x .46 " x .95" external 5.45 " x 3.25 " x 3.25" overall Power Control Box 15.2" x 7.8" x 3.5"* *can be made smaller if required
Weight	1.2 lb Sensor Head 12.0 lb Power Control Box 13.5 lb Total (excluding cables)
Data Output	R3-232/422 ASCII Serial Data. 9600 – 15,200 baud or Ethernet Network TCP/UDP
Data Update Rate	Selectable 1 to 20 updates/ second



[1] Refer to graph for details. Max possible LWC/TWC varies slightly with altitude and is about 10% greater at sea level compared to 40,000 ft at the same airspeed.

[2] Safe Operation means that the instrument can be left fully powered on continuously at zero airspeed without damage. However as the airspeed is reduced to zero, the effective sample volume decreases to zero and the measurement of LWC is not possible. Depending on the specifics, some minimum airspeed is required to establish a minimum acceptable sample volume. Please contact SEA for details about measurements at very low speeds.

[3] Power supply current varies with airspeed, altitude, ambient temperature and water content. Supply currents include deice power. Minimum current is for zero airspeed at 20 °C. Typical current is for 67 m/s, -9 °C, 1.5 gms/m3. Max current is for max possible LWC/TWC

***WARNING: As a general rule, m*ake sure power is off before installing any of the components and cables. The clients DC breakers must be off.**

On a new installation or modifications to the input power to the system, the user must verify with a meter that the correct power specifications is present for each component.

POWER BOX INSTALLATION

The power box needs to be installed near the sense head in order to minimize cable loss in distributing power to the sense elements. The standard cable between the sense head and power box is 10 ft. Other lengths possible, contact SEA.

All cables provided are labeled and uniquely keyed so they cannot be inserted in the wrong connector. The lid on the power box has labels for each of the four connecting ports.

Make sure you tighten all screws on the mounting cables assemblies, so each cable is secured properly and tight to the appropriate mounting connector on the power box.

The power box must be connected to the sense head with the sense head cable. The sense head cable splits into two sections where it connects to the power box. One connector connects to the Small LWC/Comp/Deice. The other connects to the TWC/Large LWC connector. If you are having trouble getting these pushed in, make sure that you have the right connector to the right port. New cables tend to be harder to push in, after they wear in a bit they are easier to push in.

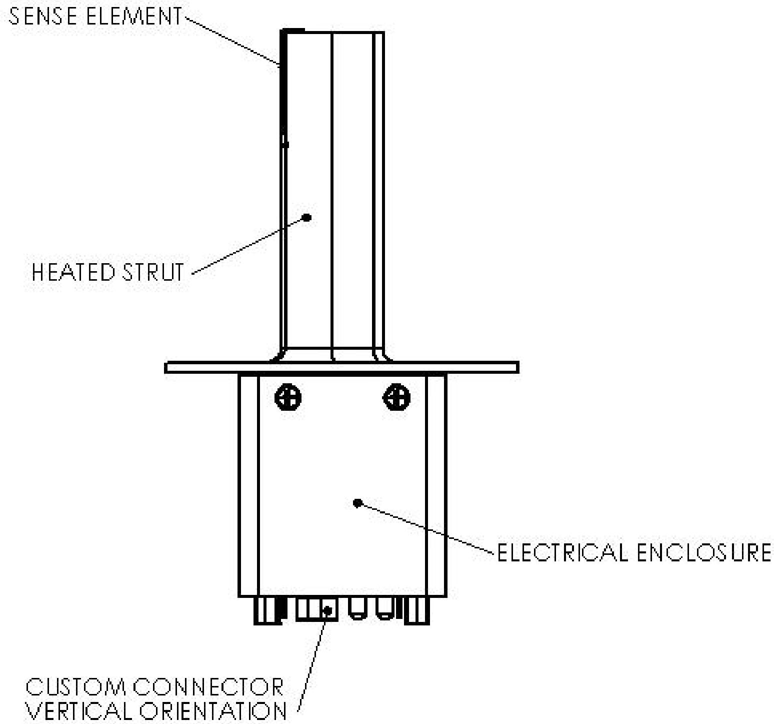
The power box must be connected to the control system with the communication cable on the communication port.

SEA provides a connector for the input power to the power box (Power In). Make sure the client DC breakers are off before connecting the power cable to the "Power In" connector.
The main power switch in the front of the control box powers up the power box. Before you provide power to the control box it is also a good idea to have that switch in the off position.

SENSE HEAD INSTALLATION

The sense head (probe) will operate in any orientation, including upside down. The sense head should be mounted in a location of undisturbed airflow. The sense element should be at a right angle to the airflow. The strut portion of the sense head positions the sense element away from the disturbed air near the connection point. The support strut contains a deicing heater. Additional mechanical details are provided in the schematics, diagrams and mechanical drawings. The sense head must be connected to the power box using the sense head cable. Align the pins on the cable with the connector on the sense head. Gently push in until fully inserted. Make sure to tighten screws in cable assembly.

Note: It is safe to remove and change sense heads with power to the power box and control system, as long as the element power and deice power switches are off. If the user is running SeaWcm, it also required to click on the stop button, so the SeaWcm stops trying to run and control the WCM-2000 system. The required parameters from the new head will automatically load when SeaWcm is restarted.



CONTROL SYSTEM INSTALLATION

The control system can be stand alone or integrated into the M300 system. The control system must be connected to the power box. This allows interface with the power box and sense head.

Usually you must provide power to the control system, this can be AC or DC, depending on user specifications. If the control system is in a PC104 enclosure the power is supplied in the control port from the power box.

Make sure the main power, element power and deice power switches in the front of the control system are in the off position prior to installation of the cables.

The installation of the control system should be pretty straight forward. This usually follows from the type of system being used and the application.

The standard cable between the Control Box and the control system is 40 ft. Other length possible, please contact SEA.

Typically, in the control system there is serial interface which usually supports up to 8 serial ports. There is a fan out cable with eight DB-9 connectors and one large connector. The large connector plugs into the serial card. Some of these are setup for RS-232 and some for RS-422.

Sometimes, depending on which control system is used there might be only a few serial ports labeled in the back of the system (like in the case of PC104 enclosures).

The import thing to keep in mind is that the WCM-2000 needs to use two RS-422 ports. One is the control port. The other is the 1-wire (eprom) port. These can be in the control system (stand alone or M300) or sometimes in network to serial boxes which are connected to the ethernet port. The SeaWcm application uses these port to control the WCM-3000.

Usually port "/dev/ser8" is the control port to the WCM-2000. You must connect the appropriate port to the control port on the back of the control system. Double check in the SeaWcm application in the "setup" tab to see which port is assigned to the control port.

Usually port "/dev/ser9" is the 1-wire (eprom) port to the WCM-2000. You must connect the appropriate port to the 1-wire (eprom) port on the back of the control system. Double check in the SeaWcm application in the "setup" tab to see which port is assigned to the 1-wire (eprom) port.

In the back of the control system there an ethernet connection port which sometimes also needs to be connected. This can be used to connect to other systems (M300 or user DAS) to transmit/receive the data. The SeaWcm uses this connection to transmit data to many different systems using UDP (if necessary). The SeaWcm can also use this connection to get static pressure, static temperature and true airspeed from one source (and only one). If the M300 and SeaWcm are running in the same system and there is no other use for the ethernet port, then you don't need to make a connection.

Cabling:

The interconnect cables can be purchased with the system or fabricated by the user. If the user does fabricate their own cables, strict adherence to the required components, wire size, and assembly methods is necessary. Information required for cable fabrication is included in Section 7.

The WCM-2000 control system uses QNX 4 RT OS. If your system is not setup to automatically start the Photon micro GUI, see these instructions.

Whenever we use the word QNX for it refers only to the QNX 4 RT OS system.

It is probably a good idea to look over the SeaWcm application documentation in the SEA Utilities documentation.

Login

In the QNX system there are users assigned to the system. Each user has a login name and password. To login into the QNX system.

1. Enter you username at the login prompt.
2. Enter you password at the password prompt.

Note: If you are going to run the SeaWcm during this session, you should NOT login as root/superuser. Rather, you should set-up a user account (if not already done so) with reasonable access rights and privileges.

Note: If you enter an incorrect or non-existent username/password, for security reasons, QNX will return to the login prompt without providing notification of the error.

For the WCM-2000 system the user name is usually 'operator' and there is not password setup initially.

Logout

To logout from the QNX system.

1. If Photon is running at this point, see "Exiting Photon" on page 18 first.
2. Type '`exit`' or '`logout`' at the QNX command prompt.

This will not make the system safe for shutdown. For that you need to look at the 'halt' section bellow.

Halt

QNX has a shutdown command that can be used. We have made a simple command called 'halt' that performs the QNX shutdown. Make sure you save any changes before using the halt. Power will have to be cycled manually.

1. Type '`halt`' from any command prompt window.

Reboot

QNX can also use the shutdown command to perform a system reboot (restart). We have made a simple command called 'reboot' that performs the restart. Make sure you save any changes before using the reboot.

1. Type '`reboot`' from any command prompt window.

STARTING PHOTON

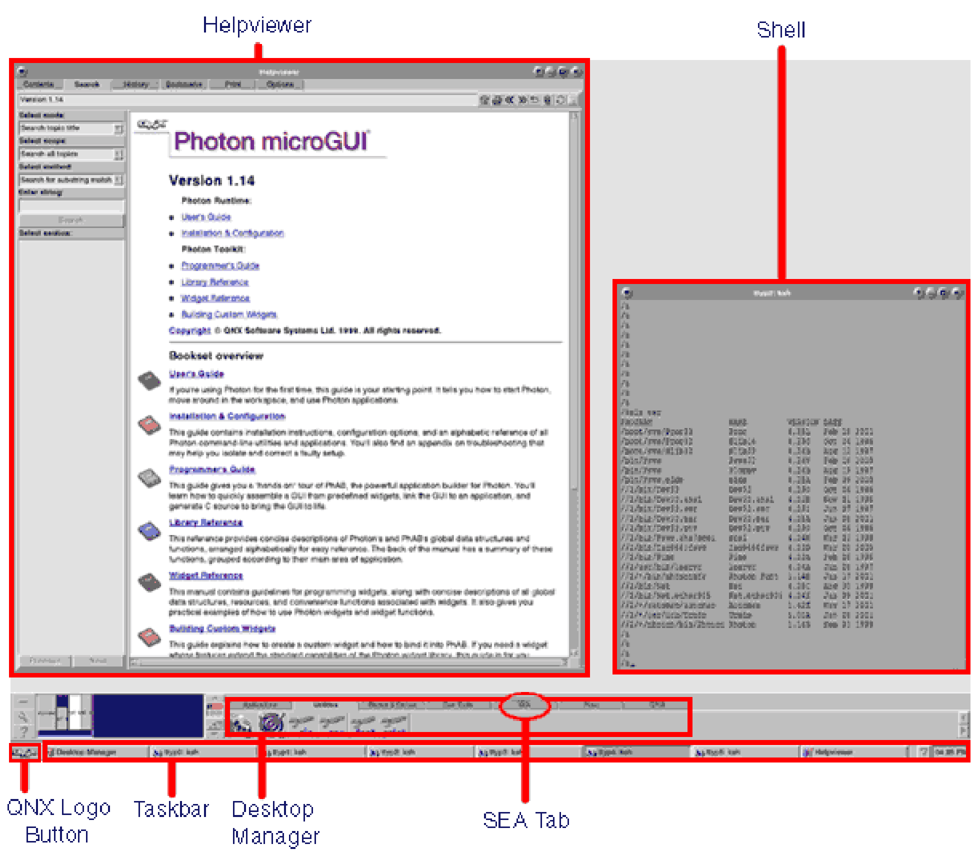
To start the QNX Photon GUI.

1. Type ‘ph’ at the QNX command prompt.

Note: The system can be configured to start Photon automatically after boot up as opposed to the traditional login through the QNX shell. If you wish to have this, just contact SEA for help on getting it done.

GETTING FAMILIAR WITH PHOTON

The QNX Photon GUI (Graphical User Interface) has a similar interface much like any GUI you might be familiar with already, with the exception that it is designed for a real-time operating system. It is because of this real-time requirement that some of the special features of modern day GUI are not available in the Photon GUI. With that said, Photon still provides scalable graphics support, multimedia capability, and a fully customized interface. Below is a snapshot of the Photon desktop along with the highlighting of its main features.



Note: This section will provide you with an overall description of main Photon GUI features, to get more help on the Photon GUI, please see the Photon documentation in the QNX Helpviewer (See “Getting Help for QNX 4 and Photon” on page 18).

Helpviewer

This is the application you will use to view any electronic QNX Documentation.

QNX Logo Button

This is similar to the 'start' button on Windows XP. However this button will only give you access to system configuration dialogs and the **shutdown** command.

Desktop Manager

This is where any Photon applications can be launched from. By default, QNX has a handful of different tabs for various applications on this menu bar. This is where you will find the **SEA Tab**.

Task Bar

This is where any running application's buttons will displayed. For SEA applications, each window will have a corresponding button on this taskbar. To bring a particular window into focus, click on its task button.

In the task bar you switch between running applications. In the SEA tab you start the program.

SEA Tab

This is where you will find the program icons for any SEA software you have purchased.

This includes the SeaWcm application, which is responsible for running the WCM-2000 system.

The user clicks here to start a new instance of the Program, such as SeaWcm.

Shell

This is a QNX shell (pterm window, command/terminal window) that will provide you with an interface to enter commands directly into the QNX system.

Screen saver

It's not recommend to use a screen saver with the system. You don't want the screen saver to come up while you are passively looking at the data. If you set a screen saver, stay away from the blank screen saver. Many novice users confuse this with a system shutting down or crash (not realizing the screen saver has engaged a blank screen).

Exiting Photon

You can exit Photon using a couple of different commands. Before you exit Photon you should terminate any applications you have running first.

Click on the QNX logo in the bottom left corner of the screen, and select **shutdown**.

Don't use the **CTL** + **ALT + SHIFT + BACKSPACE** key combination to shutdown photon.

Note: We had to disable this option on WCM-2000 installed systems. The key combination exit is not the same as mouse exit on the QNX button. As a result applications don't get shutdown the way they should and cause problems with bad values on files, etc.

Note: Once you exit Photon, you will return to the QNX 4 command prompt or to the Photon login screen if your system is configured to start Photon automatically.

GETTING HELP FOR QNX 4 AND PHOTON

The QNX 4 system does not provide `man` pages like in traditional UNIX systems. To get help on a command, type '`use cmd`' where '*cmd*' is the command in question. For example, for help with the '`ls`' command, type '`use ls`' at the command prompt from a 'pterm' window). Help is also available using the Helpviewer Photon application. To get help on any QNX 4, TCP/IP 5 and Photon 1.14 issues consult the Helpviewer using one of the following methods.

1. In the **Desktop Manager**, select the **Applications** tab in the application groups panel. Click on the **Helpviewer**  icon. Or from a QNX shell, type '`helpviewer &`'.

POWER UP THE WCM-2000

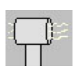
To power up the WCM-2000 control system.

***WARNING:* This assumes all components of the WCM-2000 system are connected properly to avoid damage to the sense head or power box.**

1. Turn on the clients DC power supplies (circuit breakers).
2. Turn on the control system or M300. Wait for it to power up. Login and start photon.
3. Turn on the main power to the WCM-2000 system (this provides power to the power box).

STARTING THE WCM-2000 Control System

To start SeaWcm application.

1. In the **Desktop Manager**, select the **SEA** tab in the application groups panel. Click on the **SeaWcm**  icon. Or from a QNX shell, type '`SeaWcm &`'.

2. Click on the start button (a window with the loading message should appear for a few seconds). The SeaWcm will load all settings from the eproms and start to control the WCM-2000 system. Consequently you should be in the TWC/LWC tab with data updating at 1 hz. To see all the detailed information about the WCM-2000, click on the data tab. You can switch back and forth between the TWC/LWC and the data tabs at time.

***WARNING:* If for some odd reason the SeaWcm doesn't load all the data properly and goes immediately to the TWC/LWC tab when you click on the start button, then you should not proceed to the next step. You should instead troubleshoot your connection cables and make sure that you have actually power all the components in the system.**

3. Turn on the element power (leave your fingers on the switch). Make sure you look at the values on the data tab. The temperature of the elements should increase to the set point (usually 140 °C). Make sure no text values are in red color (indicating warnings or error conditions) in any of the text boxes for the elements. If you suspect a problem you should turn off the element power immediately and troubleshoot this before proceeding any further.
4. Turn on the deice power (leave your fingers on the switch). Again make sure you look at the values for the deice element. The temperature of the deice element should increase until is reaches the set point (usually 50 °C). Make sure no text values are in red color (indicating warnings or error

conditions) in any of the text for the deice element. If you suspect a problem, you should turn off the power to the deice element immediately and troubleshoot this.

HOW TO EXIT WCM-2000 Control System

Exit the SeaWcm by using on of the following methods.
1. To be extra safe and precautions you can click on the stop button on the SeaWcm (before exit).
2. It is recommended that you turn off the power to the deice and element power to sense head.
3. From the **File** menu, select **Exit**. (Shortcut: **Alt + F, X**). Or click on the close symbol (**"X"**) in the upper right corner of the main interface window.

Note: If the SeaWcm system freezes for any reason, you can close the program by typing `'slay SeaWcm'` ***from a QNX shell. However, this will not allow you to save any changes you have made. Use only a last resort to close the program.***

SHUTTING DOWN THE WCM-2000 Control System

Shutdown the WCM-2000 system by performing the following.

1. If running the WCM-2000 system it is recommended that you turn off the power to the deice and element power to sense head.
2. Exit all applications, including SeaWcm and Photon if they're running.
3. Turn the main power off to WCM-2000 control box (this powers off the power box).
4. Wait at 3 three seconds before turning power off to the control box or M300 system (this allows the cache to empty to the hard drive). Additionally you can type `'halt'`. This is the preferred way to shutdown QNX 4 and ensures proper and safe termination.
5. Turn off the clients DC power supplies (circuit breakers).

CHANGE SENSE HEAD

To change the Sense Head you can follow the following steps.

1. Turn off the power to the deice and element power to sense head.
2. Exit SeaWcm application. See how to exit WCM-2000 about.
3. Turn the main power off to WCM-2000 control box (this powers off the power box).
4. Then it's safe to change the Sense Head. This might be different depending on the user installation. If necessary remove the mounting screws for Sense Head first. Then, remove the four captive screws that hold the cable to the Sense Head.
5. Install new Sense Head. See Installation instructions for Sense Head. 6. Turn the main power on to WCM-2000 control box (this powers on the power box). 7. Then follow instructions in starting the WCM-2000 system.

THEORY OF OPERATION

CALCULATION OF WATER CONTENT

The following section describes the theory of how the LWC/TWC sensor responds to liquid/ice water.

The theory portion provides a basic understanding of the physical process that occurs when liquid/ice water is intercepted by the heated element in the sensor.

The data reduction section gives methods and techniques required to process the data output from the controller into liquid water content. We will describe three basic approaches that have been proven to work well in actual conditions.

Note: For users who are using the companion SEA Model 300 data acquisition system, the data reduction algorithms described in the data reduction portion of this section are already available for your system.

LWC MEASUREMENT THEORY

Note: This section is written primarily for encounters with liquid water. When actual encounters include water in the form of ice and a TWC Sense Element is being used, considerations must be made for the amount of power required to convert the ice to liquid water (Heat of Fusion).

The sense element is exposed to cooling from two sources, airflow and intercepted liquid water. The control system outputs the total amount of power required to maintain the element's temperature in the presence of these two cooling influences.

The total power is made up of two components, dry power and wet power. The dry power is the amount of power required to overcome all cooling influences except the interception and evaporation of water. Wet power is the extra, incremental power required above the dry power requirement to warm and evaporate liquid water intercepted by the heated element. The wet power is directly related to the amount of liquid water present.

Therefore in general.

$$P_{total} = P_{wet} + P_{dry}$$

Or restated in terms of the wet power.

$$P_{wet} = P_{total} - P_{dry}$$

The actual magnitudes of the wet and dry terms depend on airspeed, air density, ambient temperature and sense element geometry.

DATA INTERPRETATION

The first step in measuring the liquid water content is to determine the magnitude of the dry power (P_{dry}) and subtract it from the total power measured by the sense elements. There are several methods to do this.

If the sense head has multiple elements that include a compensation element, the primary method used to subtract the dry power is based on the fact that the probe contains two types of heated elements, the sense elements, which are exposed to both liquid water and to the general airflow and the compensation element, which is exposed to only the general airflow. This is accomplished through the mounting arraignment of the two elements. The sense elements are located perpendicular to the airflow and receive the full impact of the impinging water. The compensation element is mounted behind the sense elements and is parallel to the airflow.

Given that the sense elements and compensation element differ in size and location, plus the fact that the compensation element is not sensitive to water content ($P_{comp,wet} = 0$), we can write the following.

$$P_{sense,wet} = P_{sense,total} - P_{sense,dry}$$

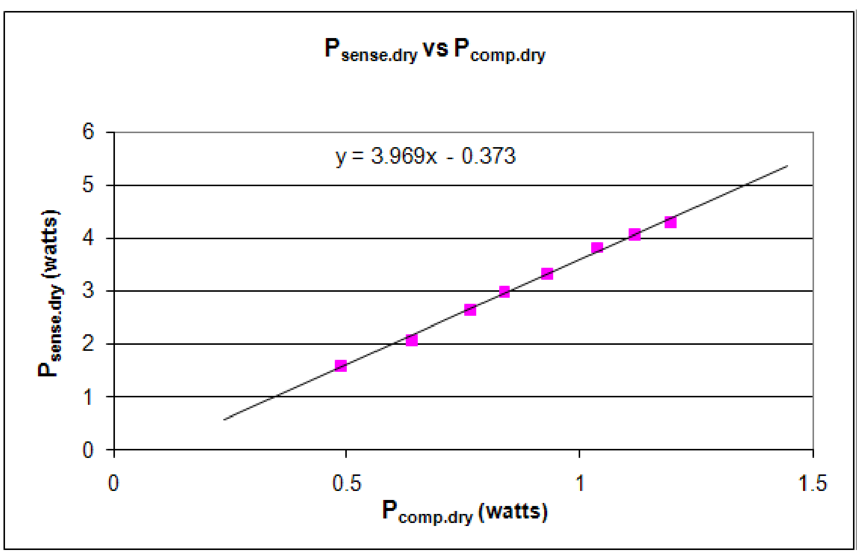
$$P_{comp,total} = P_{comp,dry} = P_{comp}$$

The power measured by the compensation element is highly correlated to the dry power term for the sense elements. Therefore we can write.

$$P_{sense,wet} = P_{sense,total} - (offset + slope \bullet P_{comp})$$

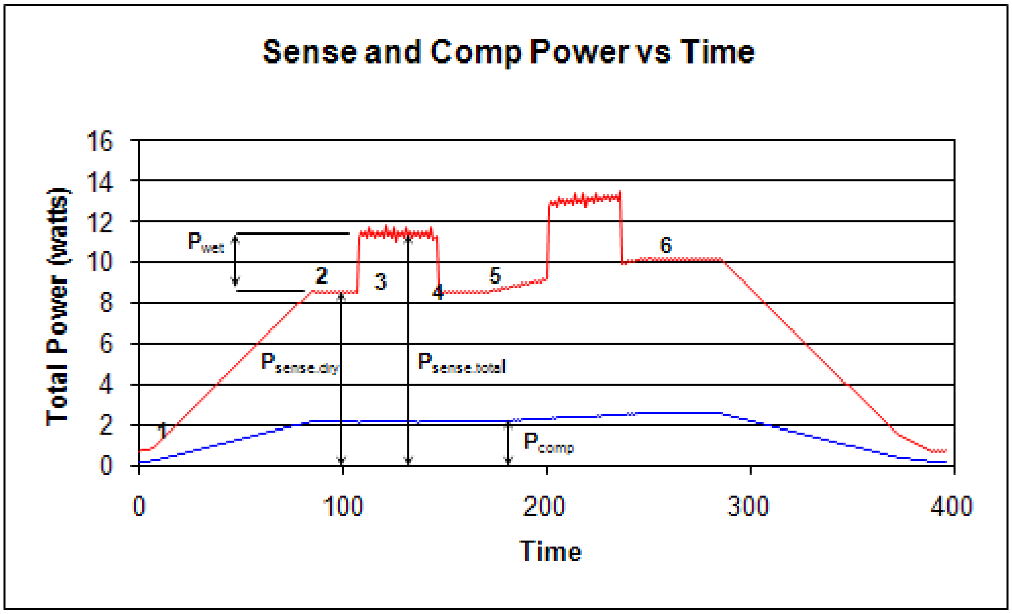
The values for *offset* and *slope* are determined by examination of data at varying airspeeds and altitudes in clear air.

This shows sample data taken with the system over a range of airspeeds. It illustrates one method of determining the correlation between the sense power and the compensation power.



Sense vs. Compensation Power (LWC)

This shows the values of Psense,total and Pcomp during a typical operational cycle. The upper trace shows the total sense power, Psense,total. The lower trace shows the compensation element power, Pcomp.



Sense and Compensation Power vs. Time

At point 1, the airspeed is zero and both elements are drawing minimum power. Between points 1 and 2 the airspeed is increasing and both the sense and compensation powers rise in a correlated manner. Between points 2 and 3 the airflow is stable. Points 3 and 4 bracket the first encounter with liquid water. The sense total power is seen to increase by the amount Pwet. At point 4, Psense,total returns to its pre-encounter value. This scenario is representative of wind tunnel operation or an aircraft encounter where the atmosphere is stable and the aircraft does not change altitude, airspeed, attitude, etc.

Points 4, 5 and 6 are a more typical aircraft encounter, where both the dry and wet terms for the sense element and the dry term for the compensation element are changing. In this case the changing ambient conditions are corrected for by changes in the compensation element power.

The first encounter, points 2 to 5, illustrate a situation where a net and tare approach can be used to remove Psense,dry from Psense,total. When the ambient conditions are stable before and after encountering liquid water, it is possible to store the value of Psense,total, which equals Psense,dry when there is no liquid water present, and subtract it from the value of Psense,total during the encounter. This method has the advantage of not requiring any other data than the value of Psense,total. It works particularly well in wind tunnel applications where the pre and post spray conditions are identical.

The net and tare method of dry power removal has the advantage of simplicity but it cannot compensate for any changes in airflow that occur during the encounter.

A third possible method is the direct calculation of Psense,dry from theory. In general a good approximation is:

$$P_{sense,dry} = K_1 \bullet (T_{sense} - T_{ambient}) \bullet (P_{ambient} \bullet TAS)^{K_2}$$

Where:

Tsense = Sense element operating temperature (typically 140°C)
Tambient = Ambient temperature of the air stream
Pambient = Ambient (static) air pressure
TAS = True Air Speed
K_1 = Constant
K_2 = Constant generally in the range of 0.5

The values of K_1 and K_2 can be determined experimentally for a particular installation by recording data in clear air and finding the values for K_1 and K_2 that give the minimum difference between the predicted total sense power and the actual measured sense power.

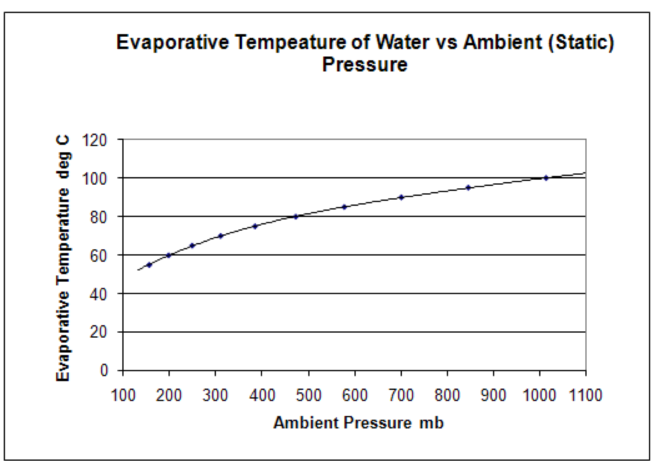
A more correct approach from a units standpoint is to use ambient air density instead of ambient air pressure in the above equation. However, experience has shown that a more usable prediction is achieved using ambient pressure rather than ambient density, in spite of the mixed units.

The direct calculation method for dry term prediction can be quite accurate, but has the disadvantage of requiring additional information to use in the calculations.

Once the dry power has been removed from the sense element's total power, the next step is to convert the calculated wet power into liquid water content.

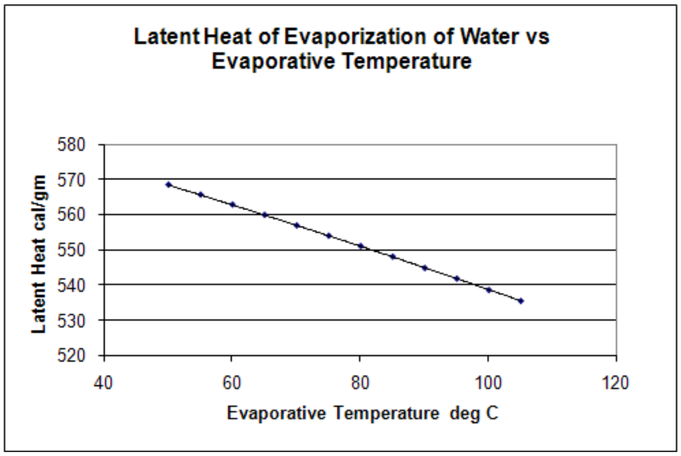
When a droplet of liquid water impacts the sense element, two steps are necessary to evaporate the droplet. First the droplet must be heated from its initial temperature to its evaporative temperature at which time it begins to rapidly evaporate. In general it is assumed that the initial temperature of the droplet is the same as the ambient air temperature. By definition it requires one calorie/gm for each degree Celsius rise in temperature.

The temperature at which a droplet begins to rapidly evaporate, Tevap, depends on ambient pressure. This shows the dependency of Tevap on ambient pressure. A method for calculating the evaporative temperature given the ambient pressure is given later in this section.



Tevap vs. Pressure

Once evaporation begins, it takes an extra quantity of heat, the latent heat of evaporation Levap, to evaporate the droplet. The lower the evaporative temperature, the larger the amount of heat required to evaporate the drop. This shows the relationship between the latent heat of evaporation and the evaporative temperature. A method for calculating the latent heat of evaporation given the evaporative temperature is given later in the data analysis portion of this section.



Levap vs. Temperature

The calculation of warming the incoming water to the evaporative temperature plus the latent heat of evaporation allows for the conversion of the wet power in watts to the number of grams of water currently being evaporated per second.

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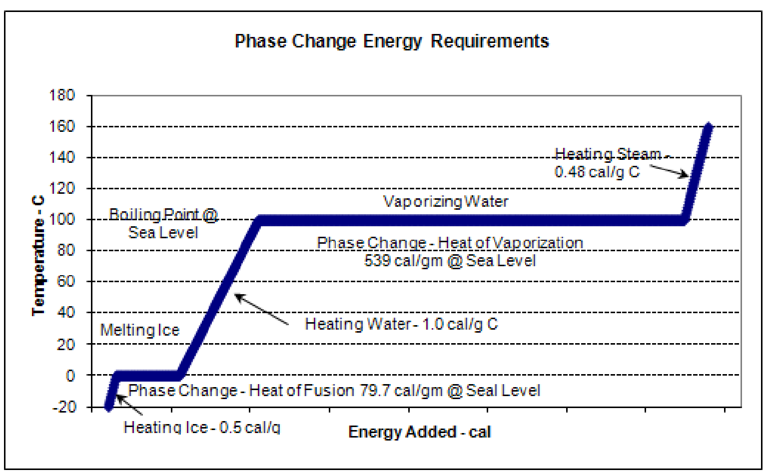


Phase Change Energy Requirements

The second step in the conversion of $P_{sense,wet}$ to LWC is to take the number of grams of water currently being evaporated and convert it to grams per cubic meter. This conversion is done by calculating the volume of air being sampled by the sense element and then dividing the grams per second by the volume sampled per second. The sample volume is given by.

$$Svol = L_{sense} \cdot W_{sense} \cdot TAS$$

Where:

$Svol$ = Volume of air sampled per unit time
L_{sense} = Length of the sense element
W_{sense} = Width of the sense element
TAS = True Airspeed.

Putting all the terms together using metric units, the conversion of wet power to LWC is given by.

$$LWC\ (g/m^3) = \frac{P_{sense,wet}(watts) \cdot 2.389x10^5}{\left[L_{evap}(cal/g) + 1.0(cal/g \cdot °C) \cdot (T_{evap} - T_{ambient})\right] \cdot TAS(m/s) \cdot L_{sense}(mm).W_{sense}(mm)}$$

Where:

$P_{sense,wet}$ = Wet power measured by the sense element watts
L_{evap} = Latent heat of evaporation cal/gm
T_{evap} = Evaporative temperature in °C
$T_{ambient}$ = Ambient (SAT) temperature in °C
L_{sense} = Length of the sense element in mm
W_{sense} = Width of the sense element in mm
TAS = True airspeed in m/s

CONVERSION OF OUTPUT DATA

1. Calculation and Subtraction of $P_{sense,dry}$ from $P_{sense,total}$
2. Calculation of T_{evap} and L_{evap}
3. Calculation of LWC

$$P_{sense,wet}(watts) = I_{sense} \cdot V_{sense}$$
$$P_{comp}(watts) = I_{comp} \cdot V_{comp}$$
$$P_{deice}(watts) = I_{deice} \cdot V_{deice}$$

If possible, slightly less variability in the power levels for the Sense and Compensation elements can be achieved by multiplying the individual samples of voltage and amperage together and then averaging the resulting power levels to produce a one second average.

It is a good idea, but not necessary to calculate the following resistance values. They can be used to verify correct operation of the system.

$$R_{sense}(m\Omega) = 1x10^3\ V_{sense}/I_{sense}$$

$$R_{comp}(m\Omega) = 1x10^3\ V_{comp}/I_{comp}$$

$$R_{deice}(\Omega) = 1x10^3\ V_{deice}/I_{deice}$$

Protection in the reduction software should be taken to avoid division by zero when the amperage values are very low or zero.

Once the resistances of the sense and compensation elements are calculated, the sense and compensation element temperatures can be calculated by using the following formula.

$$T_{element}(°C) = 100 + (R_{element} - R_{100}) \bullet (dT/dR)$$

Where R@100 and dT/dR are taken from the calibration data for the Sense Head. During normal operation the calculated element temperature should be close to the set point temperature indicated on the controller.

Continuous operation significantly above or below (5°C) the set point temperature indicates a problem with either the controller or the data acquisition system. During an WC encounter, temperature fluctuations are normal due to fluctuations in the amount of water striking the sense element, however the average temperature should not change.

If the element temperature drops and remains below the set point during an WC encounter, it indicates that the sense element is saturated and the calculated WC values are lower than the actual values.

For the deicing circuit, the calculated resistance should range between 1.3 and 2.2 ohms. The nominal value is 1.7 ohms, but this value depends on the length and size of wire used in the deice supply circuit. Values lower than 1.0 ohms indicate a short in the deicing circuit. Values above 3.0 ohms are indicative of a poor connection or a failed heater element in the probe itself. (These values are for the standard Multi-Element Sense Head and will be different for the Robust Head and the Ice Crystal Detector)

CALCULATION AND SUBTRACTION OF *PSENSE,DRY* FROM *PSENSE,TOTAL*

As mentioned in the previous part of this section, there are several ways to determine Psense,dry and subtract it from Psense,total.

Once one method has been chosen, Psense,wet can be determined by subtracting the Psense,dry estimate/measurement/calculation from Psense,total.

No method of subtracting the dry term to produce the wet term is completely accurate under all conditions. In general it is advisable to provide the user with some software mechanism to trim calculated LWC to zero.

For example, when using the scaled compensation element power to determine the dry term, slightly adjusting either the slope or offset term will allow the user to perform a final zero adjustment.

Calculation Of *Tevap* And *Levap*

The Evaporative Temperature Tevap varies with ambient pressure, further, the Latent Heat of Evaporation, Levap, varies with Evaporative Temperature.

For operations at fixed ambient pressures, fixed values for these values can be taken from the following tables.

Evaporative Temp(°C)	Latent Heat (cal/gm)
45	571.3
50	568.4
55	565.6
60	562.8
65	559.9
70	556.9
75	554.0
80	551.1
85	548.1
90	544.9
95	541.9
100	538.7
105	535.6

Tevap to *Levap*

Static Pressure (mb)	Evaporative Temp (°C)
1100	102.56
1000	99.76
900	96.65
800	93.35
700	89.84
600	85.97
500	81.50
400	76.04
300	69.07
200	59.96
100	47.95

Static Pressure to *Tevap*

For operations where the ambient pressure varies, the following polynomial functions can be used to calculate Tevap and Levap. These equations are of sufficient accuracy over the range of 100 to 1050 mb. Given the ambient pressure in millibars as Pmb.

$$T_{evap}(C) = 32.16 + 0.1801 \cdot P_{mb} - 2.391x10^{-4} \cdot (P_{mb})^2 + 1.785x10^{-7} \cdot (P_{mb})^3 - 5.19x10^{-11} \cdot (P_{mb})^4$$

Once the evaporative temperature has been determined. The latent heat of evaporation can be calculated from.

$$L_{evap}(cal/gm) = 594.4 - 0.484 \bullet T_{evap} - 7.0x10^{-4} \bullet (T_{evap})^2$$

CALCULATION OF LWC/TWC

The calculation of LWC/TWC is now straight forward. It is important to include software protection if the true airspeed becomes near zero in value. Near zero airspeed, the calculated LWC/ TWC becomes very erratic. At zero airspeed the LWC/TWC becomes infinite or undefined.

In addition to Psense,wet, Tevap, and Levap, the calculation of LWC requires knowledge of the true airspeed and the ambient temperature.

Given that the true airspeed is not zero.

$$LWC\ (g/m^3) = \frac{P_{sense,wet}(watts) \bullet 2.389x10^5}{\left[L_{evap}(cal/g) + 1.0(cal/g \bullet {}^\circ C) \bullet (T_{evap} - T_{ambient})\right] \bullet TAS(m/s) \bullet L_{sense}(mm).W_{sense}(mm)}$$

Where:
Psense,wet = Wet power measured by the sense element watts
Levap = Latent heat of evaporation cal/gm
Tevap = Evaporative temperature in °C
Tambient = Ambient (SAT) temperature in °C
Lsense = Length of the sense element in mm
Wsense = Width of the sense element in mm
TAS = True airspeed in m/s

PSENSE VS. PCOMP CALIBRATION PROCEDURE

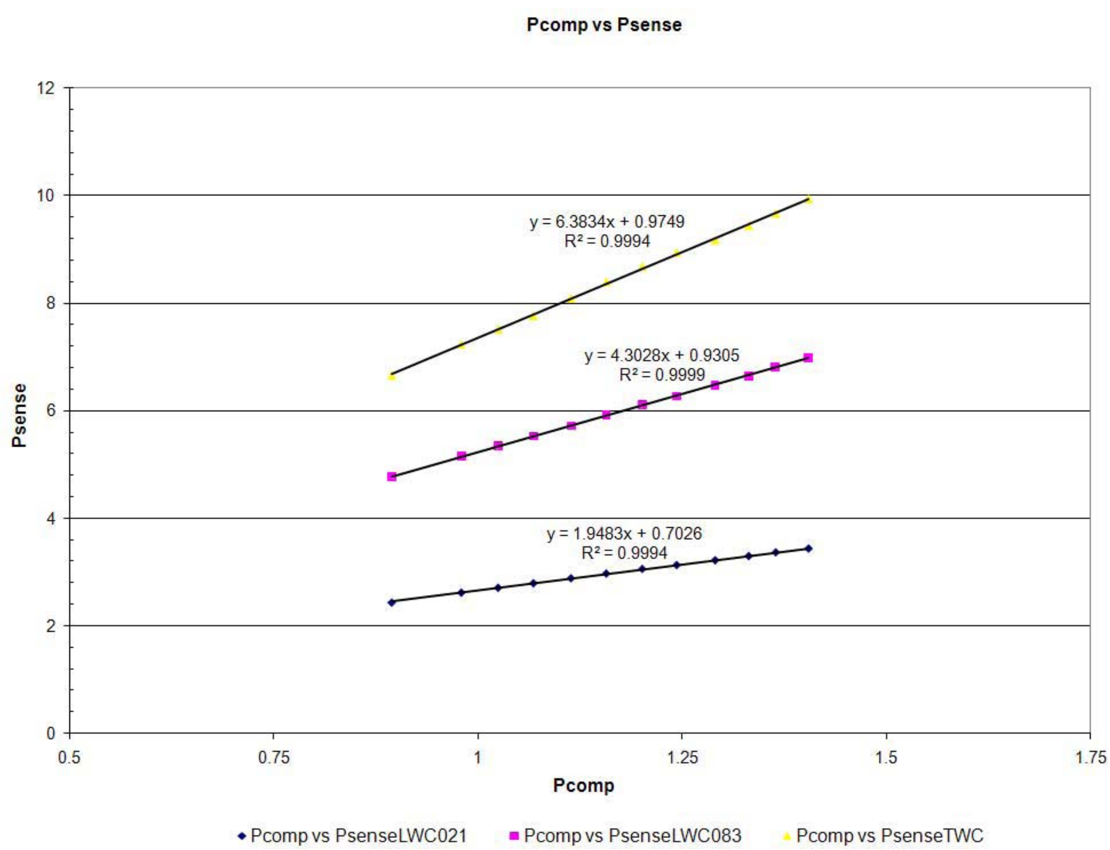
The goal is to acquire twelve or more data points covering a range of airspeeds that will be observed during the flight testing. A second way of acquiring this data is to perform the entire test, recording data during dry and wet conditions. After flight in playback the slope and offset can be generated by using all or some of the dry data.

From the data acquisition system (this could be an M300 or other DAS), at the desired airspeed point, pause the data on the screen and write down the values or capture the data to file. Collect the power for each element including the Compensation element. The following table shows an example of data points for Psense vs. Pcomp.

TWC(w)	083(w)	021(w)	COMP(w)
6.665	4.778	2.429	0.895
7.238	5.152	2.613	0.980
7.514	5.345	2.704	1.025
7.769	5.524	2.787	1.068
8.096	5.719	2.879	1.114
8.396	5.914	2.967	1.157
8.680	6.107	3.052	1.201
8.940	6.271	3.124	1.243
9.176	6.472	3.213	1.290
9.444	6.645	3.290	1.331
9.670	6.809	3.359	1.364
9.939	6.979	3.430	1.404

Psense vs. Pcomp Calibration Data

Once you got these data points plot the data into a spreadsheet application. Find the slope and offset for each element. The following illustrates a chart for the previous data points.



Once you have collected the data and come up with new values for slope and offset you need to use the SeaWcm application to burn the new values into the sense head eprom.

Make sure the new values seem reasonable. They should be fairly similar to existing values for slope and offset. Otherwise there is probably a problem with the data or computation. Double check your data and computations. If the values seem to be off by quite a bit you might need to contact SEA.

Note: Before proceeding to the next steps make sure your are using reasonable values for slope and offset. Use caution. If you make a mistake, exit SeaWcm and don't perform the burn operation.

1. Make sure all cables are connected properly and connect the correct sense head to the WCM- 2000 system.
2. Power the WCM-2000 system (main power on only). Element power and deice power switches must be in the off position.
3. Run SeaWcm application.
4. If in play mode, click on the stop button.
5. Click on the probe tab.
6. Click on the read from eprom button (this loads current values from sense head eprom). Wait until cycle completes. This might take several seconds.
7. Modify the *slope* and *offset* fields with the appropriate new values. Double check for correctness.
8. Burn the new values by clicking on the burn button. Wait until cycle completes. This might take several seconds.
9. Save new values to configuration file for sense probe by clicking the save button.
10. Press play button to run the WCM-2000 system.
11. Check to make sure new *slope* and *offset* values are correct. Both on the SeaWcm and also on the data acquisition system side (M300 or other DAS).
12. The next step should be to follow normal run procedure for the WCM-2000 system. Make sure to take caution and check all values to be in safe range. The slope and offset will give incorrect results for TWC and LWC, if programmed incorrectly. This will not damage the WCM-2000 system. The fear is making a change on a critical variable, by accident. This is why we advise caution when doing these types of operations with the WCM-2000 system.

CALIBRATION

There is no calibration to be performed by the user for the WCM-3000 system.

CALIBRATION PROCEDURE

The calibration procedure establishes a baseline unique to each sense head. The sense head is suspended in a constant temperature bath. The bath is heated from 85 °C to 145 °C. The resistance for each element is measured at multiple temperatures during the heating. The resistances are plotted verses the temperature and the required calibration constants are computed.

CALIBRATION RESULTS

The calibration procedure results in two constants, two for each of the elements.

- Element resistance at 100°C (R@100)
- Element change in temperature vs. change in resistance (dT/dR)

These values will be unique to an individual sense head. It is desired that each sense head respond identically to any given set of controlled conditions but actual testing indicates that variations do occur. Variations in component dimensions or physical properties combined with manufacturing tolerances can result in variations that may be noticeable in the final calculations. For this reason it is imperative to utilize the calibration constants provided with each sense head.

Note: The user should not change any of the values unless advised by an SEA engineer.

The calibration parameters are programmed in each sense head into the 1-wire eproms with the SeaWcm application. Each head is test in the SEA wind tunnel before shipping to the client.

Unused sense heads should theoretically have a very long shelf life.

Sense heads in active service should be re-calibrated on an annual basis.

Sense heads that have been subject to overheating or other physical damage should be re-calibrated before using.

The SeaWcm will display the calibration date and the calibration due date in the probe tab.

Sense heads need to be returned to SEA for calibration due to the specialized equipment required.

Overall Description

There are many unique characteristics of your WCM-3000 system that were needed to fit the system to the following requirements for use on the Safire Falcon 20:

1. The system must utilize 28V DC as the primary voltage sourced from the Falcon 20.
2. The system must utilize the existing wing wiring that runs to the designated pylon.
3. The sense head must mount to the nose cone of DMT's CDP canister.
4. The power box must be reshaped to fit within the existing space of the DMT canister not used by the CDP components.

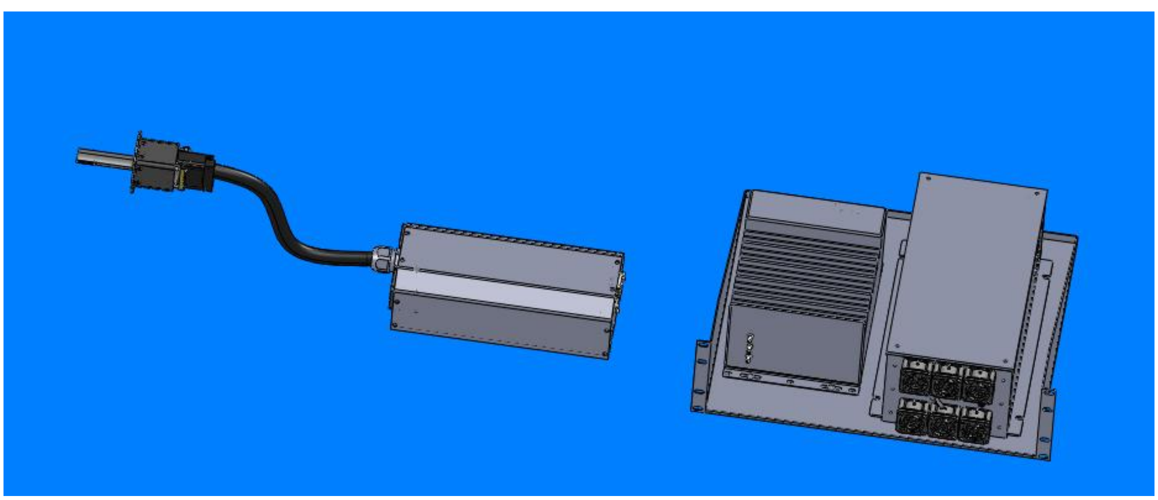
These requirements led to the system requiring a High Voltage power supply to convert the 28V DC to +/- 144V DC. The higher voltage allowed the required power to be transmitted through the Falcon 20 within the current caring capability of the existing wing wiring.

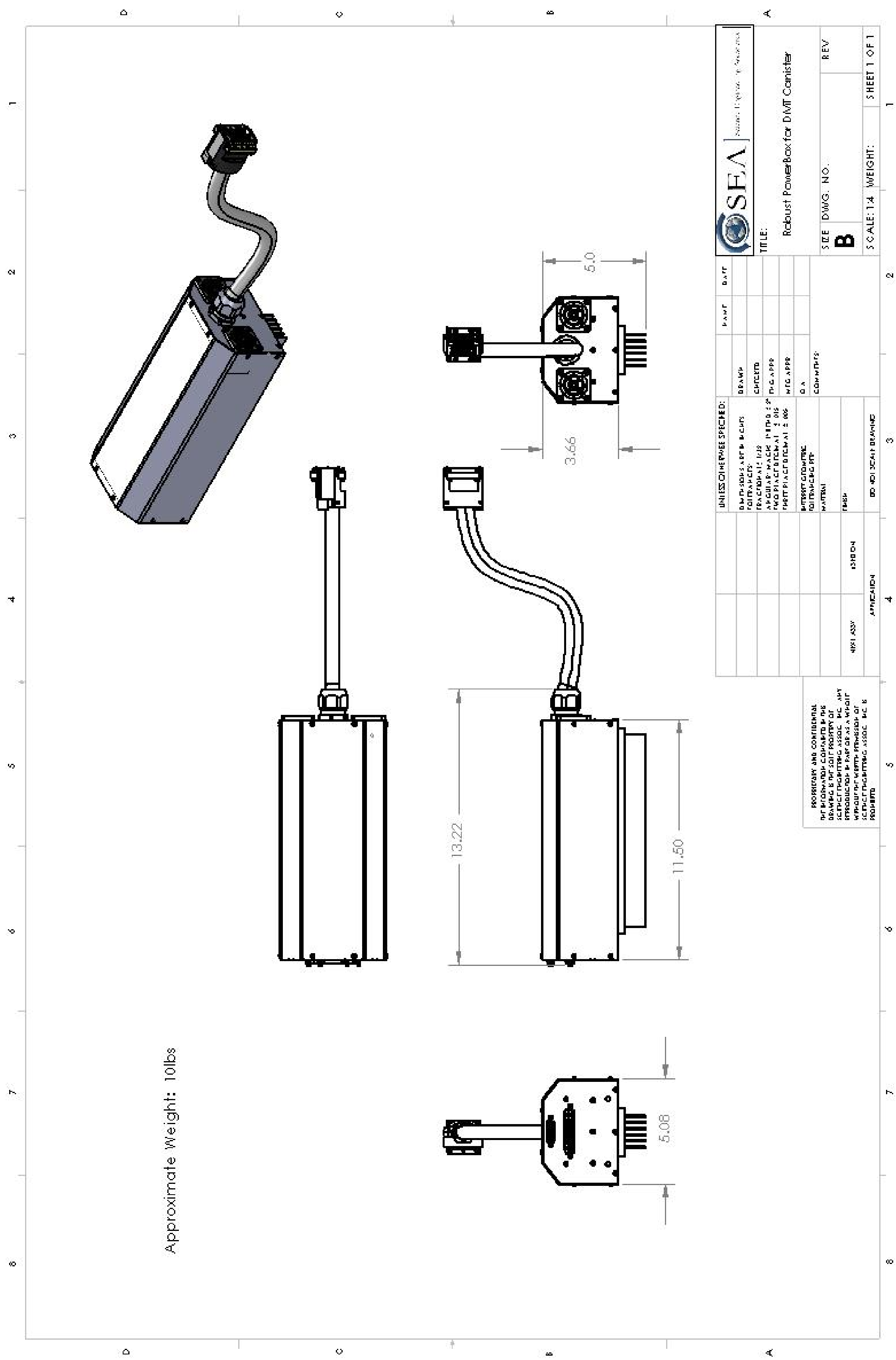
The power box was also redesigned to utilize the higher voltage input, fit within the DMT canister, and have an integral sense head cable.

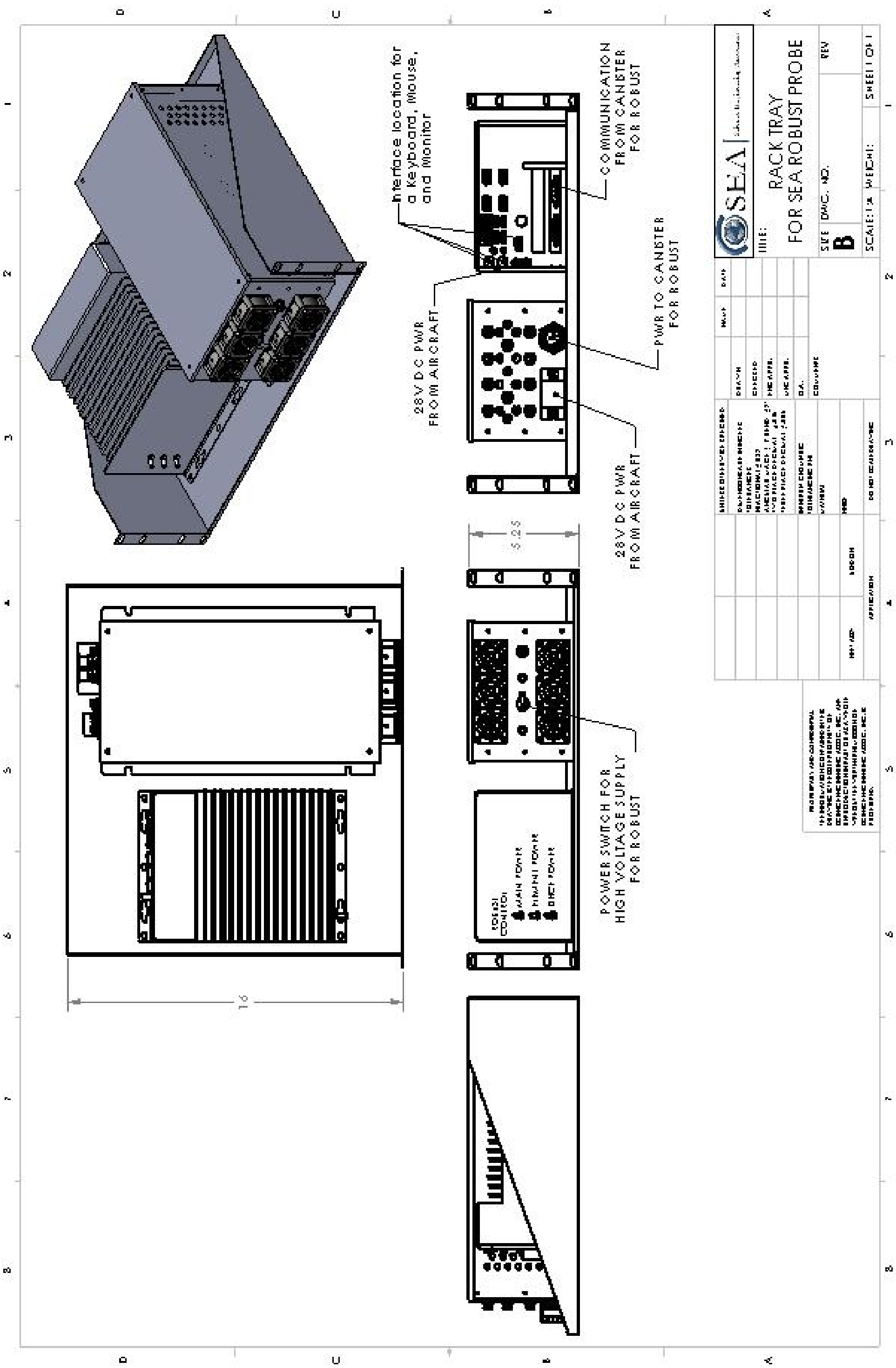
No modifications were made to the Robust Sense Head .

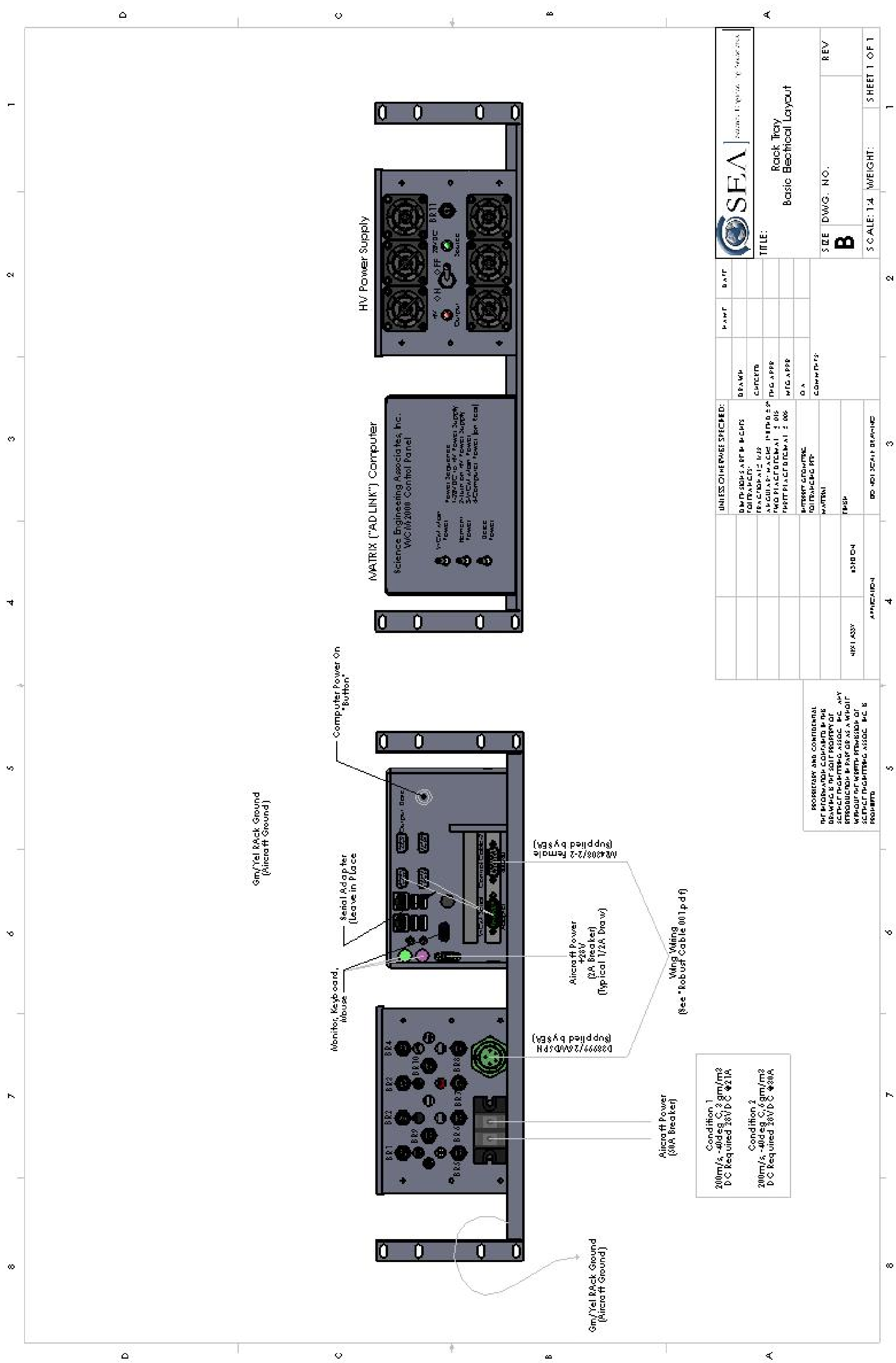
The Control Box was mounted along with the High Voltage Power Supply on a 19" Rack mountable tray.

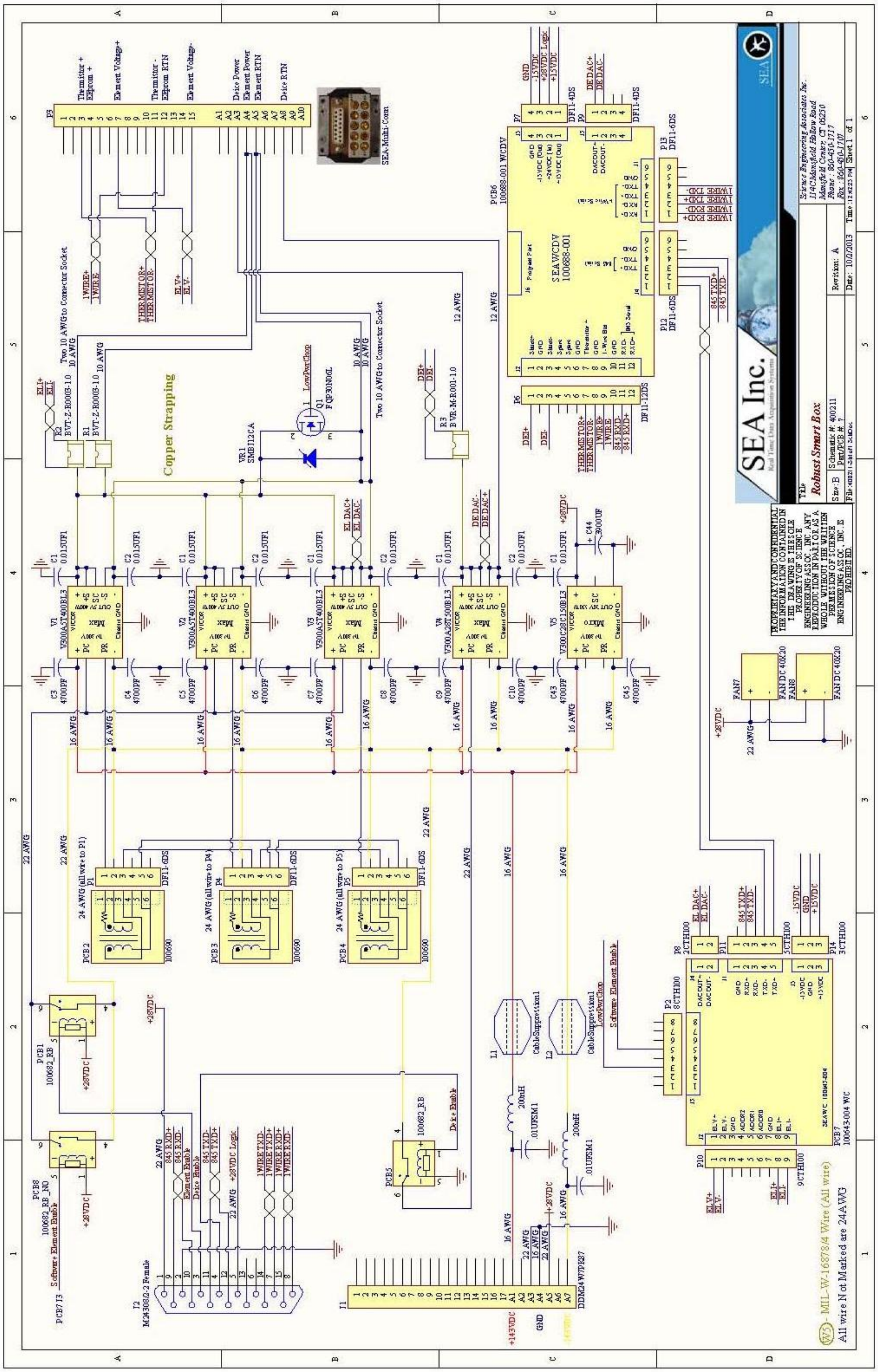
Note: This system is capable of controlling only a Robust Sense Head. Multi-Element and Ice Crystal Detector heads cannot be controlled without modifications to the Power Box mounted within the DMT canister.

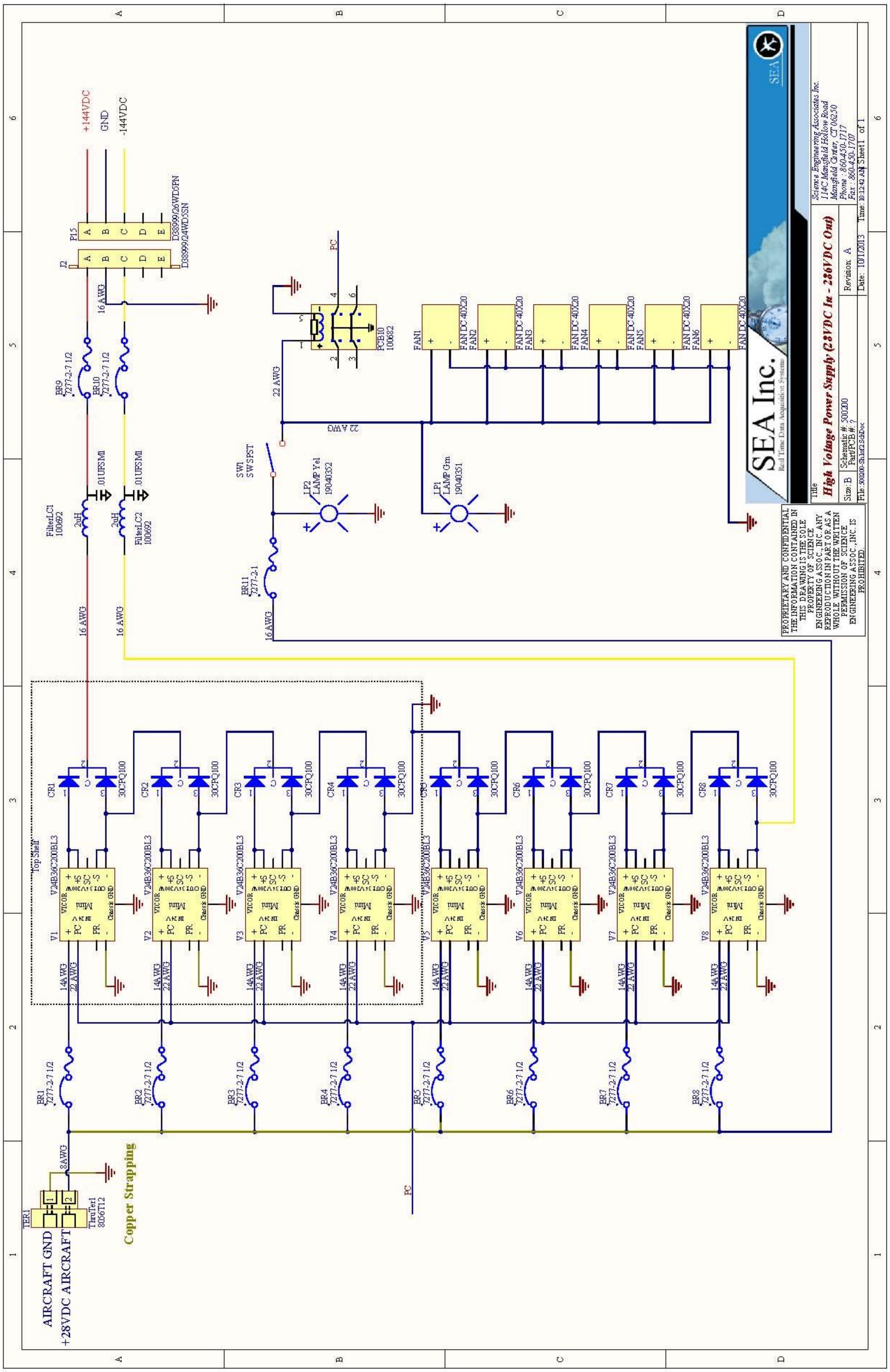



Approximate Weight: 10lbs
5.0
3.66
13.22
11.50
5.08
SEA
TITLE:
Robust PowerBox for DMT Canister
SIZE
B
DWG. NO.
REV
SCALE: 1:4
WEIGHT:
SHEET 1 OF 1

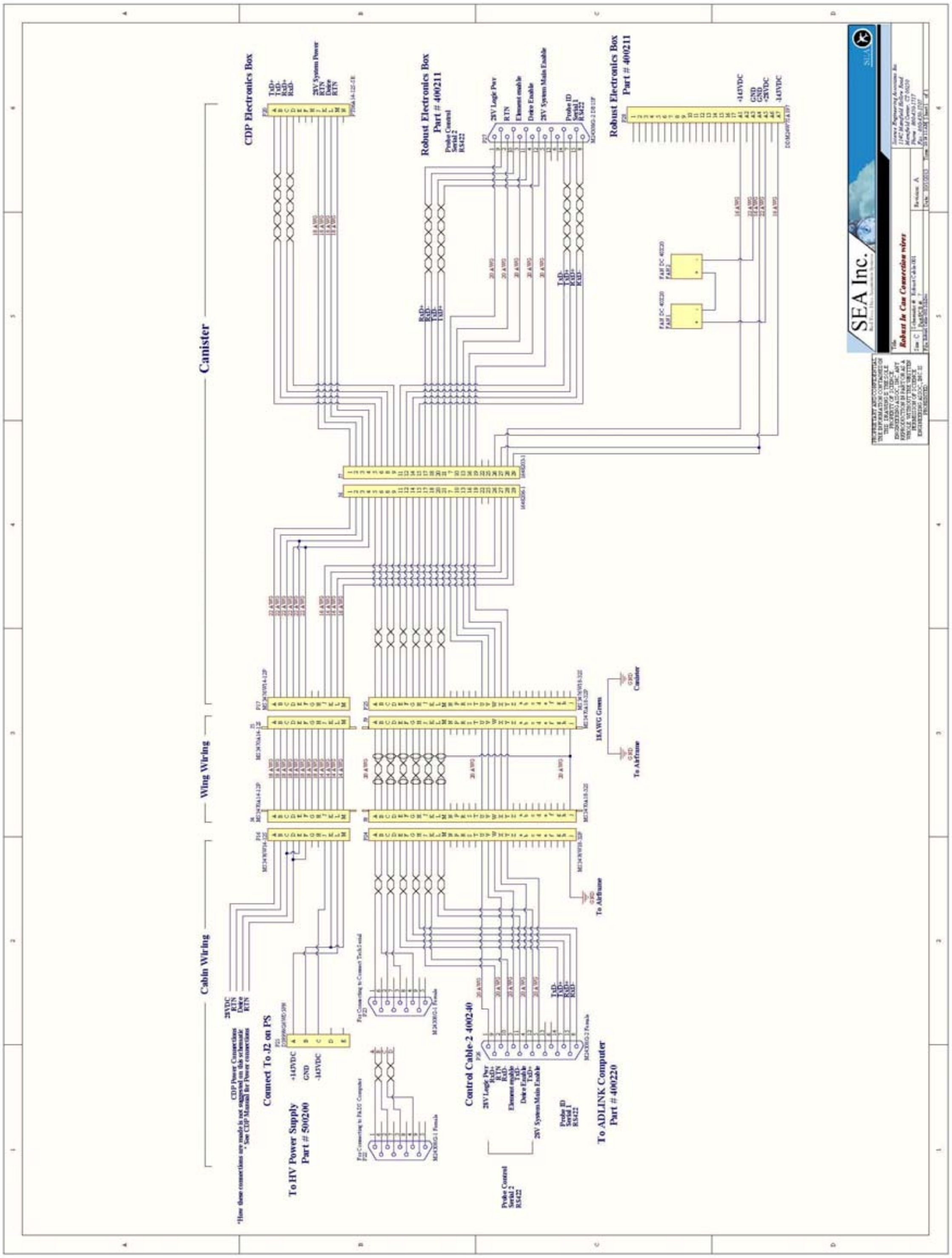

Interface location for a keyboard, mouse, and Monitor
COMMUNICATION FROM CANISTER FOR ROBUST
PWR TO CANISTER FOR ROBUST
28V DC PWR FROM AIRCRAFT
28V DC PWR FROM AIRCRAFT
5.25
POWER SWITCH FOR HIGH VOLTAGE SUPPLY FOR ROBUST
16
RACK TRAY
FOR SEA ROBUST PROBE
B

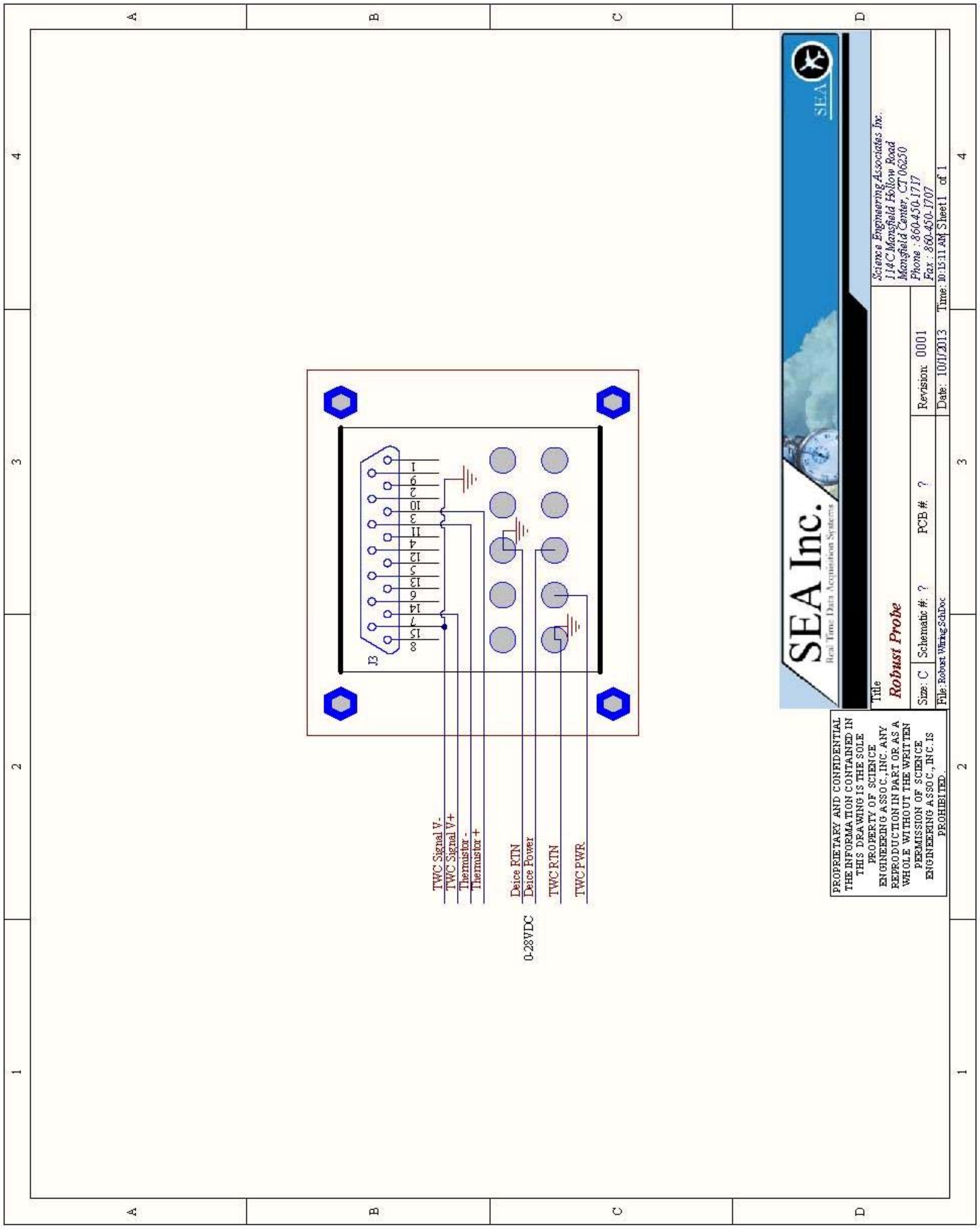

HV Power Supply
MATRIX ("ADLINK") Computer
Science Engineering Associates, Inc.
WCM-3000 Control Panel
Computer Power On "Button"
Serial Adapter (Leave in Place)
Monitor, Keyboard, Mouse
Aircraft Power +28V (2A Breaker) (Typical 1/2A Draw)
Wing Wiring (See "Robust Cable 001.pdf")
Aircraft Power (50A Breaker)
Condition 1
Condition 2
Grn/Yel RAck Ground (Aircraft Ground)
SEA
TITLE:
Rack Tray
Basic Electrical Layout
SIZE
B
DWG. NO.
REV
SCALE: 1:4
WEIGHT:
SHEET 1 OF 1


SEA Inc.
Robust Smart Box
Copper Strapping
SEA-Multi-Conn



+144VDC
GND
-144VDC
High Voltage Power Supply (28VDC In - 286VDC Out)
SEA Inc.
AIRCRAFT GND
+28VDC AIRCRAFT
Copper Strapping


Canister
Wing Wiring
Cabin Wiring
CDP Electronics Box
Robust Electronics Box Part # 400211
Robust Electronics Box Part # 400211
Connect To J2 on PS
To HV Power Supply Part # 500200
Control Cable-2 400240
To ADLINK Computer Part # 400220
SEA Inc.


J3
TWC Signal V-
TWC Signal V+
Thermistor -
Thermistor +
Deice RTN
Deice Power
TWC RTN
TWC PWR
0-28VDC
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SEA Inc.
Real Time Data Acquisition Systems
Title
Robust Probe
Size: C
Schematic #: ?
PCB #: ?
Revision: 0001
Science Engineering Associates Inc.
114C Mansfield Hollow Road
Mansfield Center, CT 06250
Phone : 860.450.1717
Fax : 860.450.1707
Date: 10/1/2013
Time: 10:15:11 AM
Sheet 1 of 1