Particle Analysis and Display System (PADS):

Hotwire LWC Module

Operator Manual

DOC-0174 Rev A-1

PADS 2.5.6

Hotwire LWC Module 2.5.3

DROPLET MEASUREMENT TECHNOLOGIES

2545 Central Avenue
Boulder, CO 80301 USA

Copyright © 2010 Droplet Measurement Technologies, Inc.

2545 CENTRAL AVENUE
BOULDER, COLORADO, USA 80301-5727
TEL: +1 (303) 440-5576
FAX: +1 (303) 440-1965
WWW.DROPLETMEASUREMENT.COM

Trademark Information

All Droplet Measurement Technologies, Inc. product names and the Droplet Measurement Technologies, Inc. logo are trademarks of Droplet Measurement Technologies, Inc.

All other brands and product names are trademarks or registered trademarks of their respective owners.

Risks of Installing Additional Software

Instrument computers from DMT are configured to acquire data in a reliable, robust manner. Typically, such instruments are either not connected to a network or are connected to a small, local network that is isolated from the internet, reducing the risk of viruses. Since anti-virus programs can cause erratic behavior when run in the background on data acquisition computers, DMT does not install anti-virus, anti-spam, or anti-malware programs. If you choose to install these programs, you accept the risk associated with them in terms of potential performance degradation of the software installed by DMT.

For similar reasons, DMT recommends that you do not install or run other software on the dedicated instrument computer. Although the installation of some software may be unavoidable, it is particularly important not to run other software while the computer is acquiring data.

C O N T E N T S

L i s t   o f   F i g u r e s

1.0 Introduction

The Particle Analysis and Display System (PADS) is a software package that interfaces with all the instruments produced by Droplet Measurement Technologies (DMT) and other leading instruments used in the atmospheric sciences. This manual describes the PADS module for the Hotwire LWC.

For an explanation of the basic PADS setup and instructions on how to acquire data using PADS, consult the *PADS Operator Manual*. Definitions and calculations used in the Hotwire LWC module are also described in the *PADS Operator Manual*.

2.0 Configuration

Your Hotwire LWC should arrive preconfigured from DMT. In some cases, however, you may want to configure the instrument yourself. The following section describes in detail how to do this. The next section explains how to configure the Hotwire LWC Display in PADS so that it shows you data in the desired formats.

Configuring the Hotwire LWC

To configure the probe itself, follow the steps below. *Note: Droplet Measurement Technologies STRONGLY recommends customers contact our office prior to changing any of the parameters in the instrument configuration. Improper changes can result in communication failure and/or changes in PADS computation algorithms, which can compromise data validity.*

1. Click on the "Hotwire LWC" tab.

2. From the **Configure** menu, select **Configure Instrument.** You will see the following window.
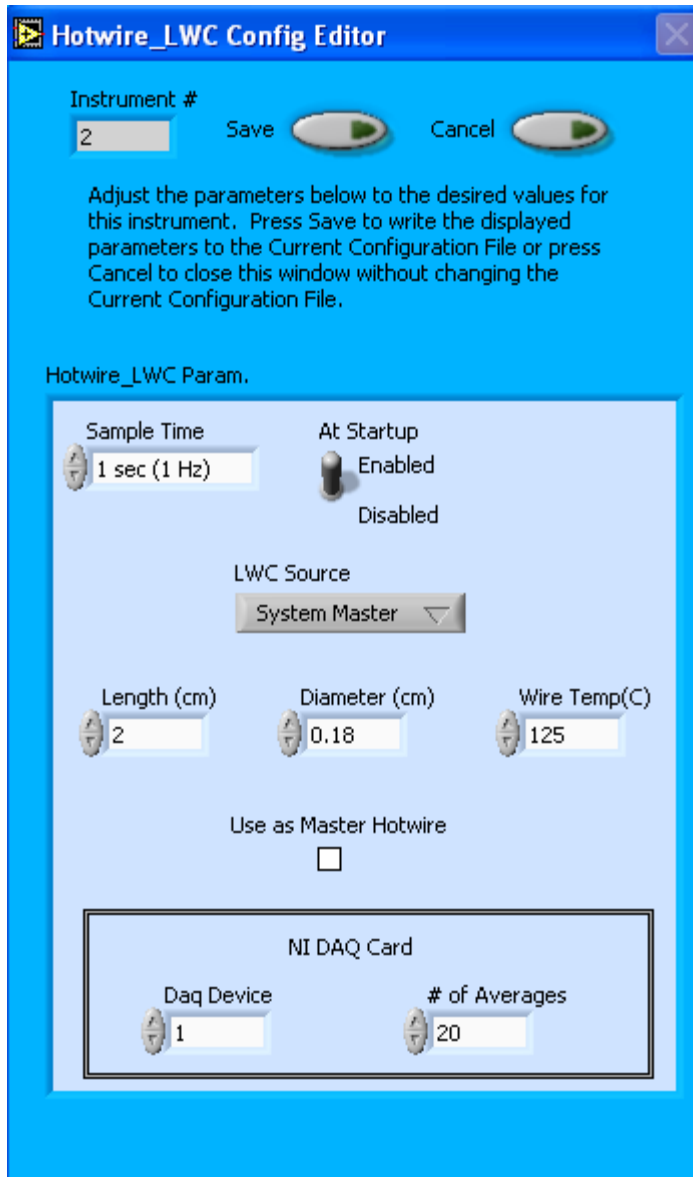
Figure 1: Hotwire LWC Configuration Editor Window

3. Now you can configure the instrument parameters to your desired specifications. You will find a list of the parameters you may want to reconfigure in the two sections below, "More Commonly Reconfigured Hotwire LWC Parameters" and "Rarely Reconfigured Hotwire LWC Parameters." If at any time you would like to revert to the previously saved values for the Hotwire LWC parameters, press **Cancel** to exit the window without saving changes.

4. When you are done configuring the Hotwire LWC parameters, press **Save** at the top of the Config editor window. (If you would instead like to revert to the previously saved values, click **Cancel**.) Then press the green **Reset Program** button for the new configuration to take effect. Note that pressing the **Reset Program** button will clear any data currently being displayed.

More Commonly Reconfigured Hotwire LWC Parameters

Sample Time: This parameter shows the time interval you'd like between samples. You can have the probe sample at intervals of .1, .2, .5, 1, 2, 5, or 10 seconds (10, 5, 2, 1, 0.5 or 0.1 Hz).

At Startup Enabled / Disabled: If you want the Hotwire LWC to acquire data when PADS begins sampling, make sure this parameter is in the "Enabled" mode. In some cases, such as if the Hotwire LWC is inoperative, you may want to use this control to disable the probe. Disabling the Hotwire LWC allows data to transmit from other instruments without interference.

LWC Source: This parameter tells PADS how the master and slave hotwire voltages are being measured. If the Hotwire LWC is mounted on another instrument rather than acting as a stand-alone device, LWC Source should be set to "System Master" and the appropriate instrument then specified in the Setup screen's **Hotwire Source** parameter. If the LWC is a stand-alone instrument, LWC Source should be set to either Labjack U12 or NI DAQ Card, depending on the hardware being used.

At the bottom of Config Editor screen are two parameters that are only relevant if the LWC source is an NI DAQ card:

Daq Device: This parameter identifies which NI DAQ card is measuring Hotwire LWC data. It helps PADS distinguish the Hotwire inputs in the event that the system uses more than one NI DAQ card.

# of Averages: This parameter instructs the Hotwire LWC to take *n* readings during one sample period, where *n* is the number specified in the parameter field. During each reading, the instrument reports values for both LWC Hotwire (V) and LWC Slave (V). PADS then averages hotwire and slave readings to come up with the appropriate values for the sample period. This results in less noise than using one instantaneous reading.

Note on timing: the time elapsed in Hz between readings is [2 • # of Averages] • [Hotwire Cycle Rate]. For example, if the Hotwire Cycle Time is 1 sec (1 Hz), and the # of Averages is 20, the Hotwire voltage will be measured at a rate of 40 Hz. The device uses this rate rather than 20 Hz to ensure that one set of samples is completed before the allotted Hotwire Cycle Time is over.

You will notice that there are other parameters listed on the **Hotwire LWC Config Editor** window. Most of these you should not need to change, and changing them inadvertently may compromise your data. If you are curious about these parameters or think you do need to modify them, see the section titled "Rarely Reconfigured Hotwire LWC Parameters" below or consult with a DMT technical representative.

Rarely Reconfigured Hotwire LWC Parameters

The Hotwire LWC configuration editor displays several parameters that you will rarely need to modify. The following is a list of these parameters and an explanation of what they do.

Instrument #:   This lists the number corresponding to the instrument you are viewing, in this case the Hotwire LWC. So if your Hotwire LWC has been assigned instrument number one, you will see "1" in this field. You should not need to modify the instrument number field, and in fact you are unable to do so from within PADS.

Length: The length of the hotwire sensor in cm. DMT determines the sensor length at time of manufacture, and this value should not change. Since the formula for LWC (g/m^3) uses sensor length as a variable, changing this parameter may compromise your data.

Diameter: The diameter of the hotwire sensor's master coil in cm. DMT determines the coil's diameter at time of manufacture, and this value should not change. Since the formula for LWC (g/m^3) uses diameter as a variable, changing this parameter may compromise your data.

Wire Temp (C):   The wire temperature of the hotwire sensor's master coil. The electronics keep the coil at this fixed temperature, so the Wire Temp value should not change. Since the formula for LWC (g/m^3) uses this temperature as a variable, changing the Wire Temp may compromise your data.

Use as Master Hotwire: This parameter does not have any functionality on the Hotwire LWC Config Editor Screen and should be ignored.

After making changes in the instrument configuration window, you will need to press the **Save** button and then click the green **Reset Program** to activate these changes. Clicking **Reset Program** will clear any data PADS is currently displaying.

Configuring the Hotwire LWC Display

To configure the Hotwire LWC display, go to the **Configure** menu from the Hotwire LWC tab and select **Configure Display.** This will bring up the following window.
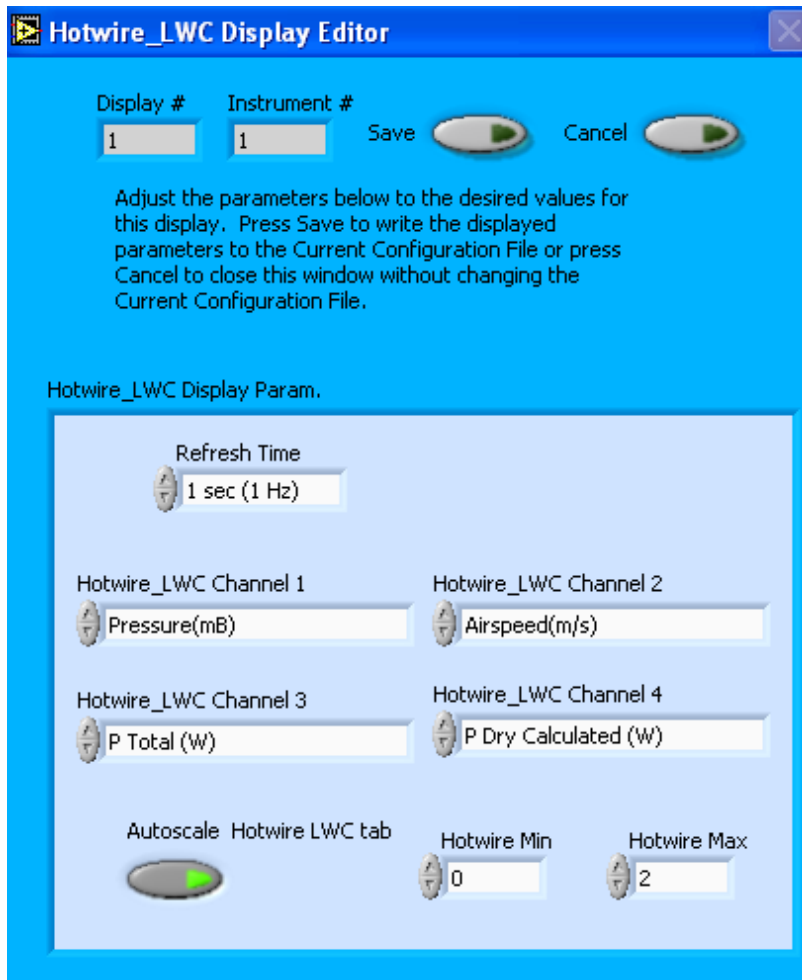

Figure 2: Hotwire LWC Display Editor Window

You do not need to modify the **Display #** or **Instrument #**. Changing the **Refresh Time** allows you to set the time intervals for data display during acquisition mode; you can choose any time that is equal to or greater than the sample time. (Choosing a time less

than the sample time is not useful, since the same data will be displayed multiple times.) The box at the bottom of the window allows you to configure the channels on the Hotwire LWC's two selectable graphs, which are located in the "Selectable Charts" tab. For information on specific channels and their definitions, consult *Appendix A: Hotwire LWC Channels* and the *PADS Operator Manual's Appendix A: Definitions*.

In the Hotwire LWC Display Parameter box, you can click on the arrow buttons to scroll between available options for the channels. You can also click on the white fields to bring up a list of all the available options, from which you can then choose the channel you want.

When you are done, click on **Save** to update the configurations or **Cancel** to revert to the previous configurations. After you reset PADS, you will be able to see any changes by clicking on the **Hotwire LWC Selectable Charts** tab. Note that clicking **Reset Program** will clear out any data currently being displayed.

Configuring channels in the Configuration Display Editor will change the display upon start-up. Once PADS has started, you can select any channels to be displayed. See the "Selectable Charts" heading under the "Chart Displays" section for more information.

PADS graphs the channels listed as selectable Channels 1 and 2 together in the Dual Selectable Charts tab. It graphs Channels 3 and 4 separately in the Selectable Charts tab.

If the **Autoscale Hotwire LWC Button** is on, the data for the Hotwire LWC tab will be autoscaled. To disable autoscaling, press the button so it turns off. PADS autoscales data for the remaining four time-series tabs regardless of whether this button is on or off.

The **Hotwire Min** and **Hotwire Max** buttons currently do not have functionality.

3.0 The Hotwire LWC Window

At the top of the window, you will see the **Enable** button, **COM Port** indicator, and **Fault/No Fault** button. For explanations of these features, see the "Instrument Tabs" section of the *PADS Operator Manual*.

To the right of the **Enable** button and status indicator, you will see the **Save Config** and **Get DAT Observed** Buttons, as depicted in Figure 3.

Figure 3: **Save Config** and **Get DAT Observed Buttons**

The **Save Config** button saves the current display set-up to the configuration file. Unlike the **Save Configuration** option on the **Configuration** menu, this button allows you to save the configuration during data acquisition.

The **Get DAT Observed** button should be used when there are no clouds present. The acronym DAT stands for "Dry Air Term" referring to the LWC equation that consists of a heat loss term due to dry air convection. (See Appendices for more detail.) When you press this button, the power currently being measured from the sensor is captured and stored. In a no-cloud "Dry" air environment, most to all of this power is due to convective heat losses. (See "dry air term" in *Appendix A: Definitions* of the *PADS Operator Manual* for more details.) PADS displays the measured power in the Dry Air Term (W) indicator, and it records this value in the DAT Observed (W) channel. The Dry Air Term is also given in units of equivalent liquid water content (g/m^3) that shows the amount of LWC that would produce the same amount of cooling through vaporization. PADS records this amount of liquid water content in the DAT Observed (g/m^3) channel. See *Appendix B* of this document for information on how PADS uses DAT Observed (g/m^3) to calculate LWC.

When the **Get DAT Observed** button is on, PADS will average the DAT Observed values measured since the button was pressed. When the button is off, DAT indicators will remain at the values they were when the button was last on. When the button is turned off and then turned back on, PADS clears out the previously recorded DAT Observed data and begins averaging these values from the time when the button was last turned on.

Warning: PADS currently clears out DAT Observed values when you specify new channels for the Hotwire LWC's selectable charts. This is a known bug that will be fixed in an upcoming version of the program.

The other parts of the Hotwire LWC Window are discussed below.

Channel Data

PADS displays Hotwire LWC channel data on the left side of the Hotwire LWC window. The channel data window is shown in Figure 4.
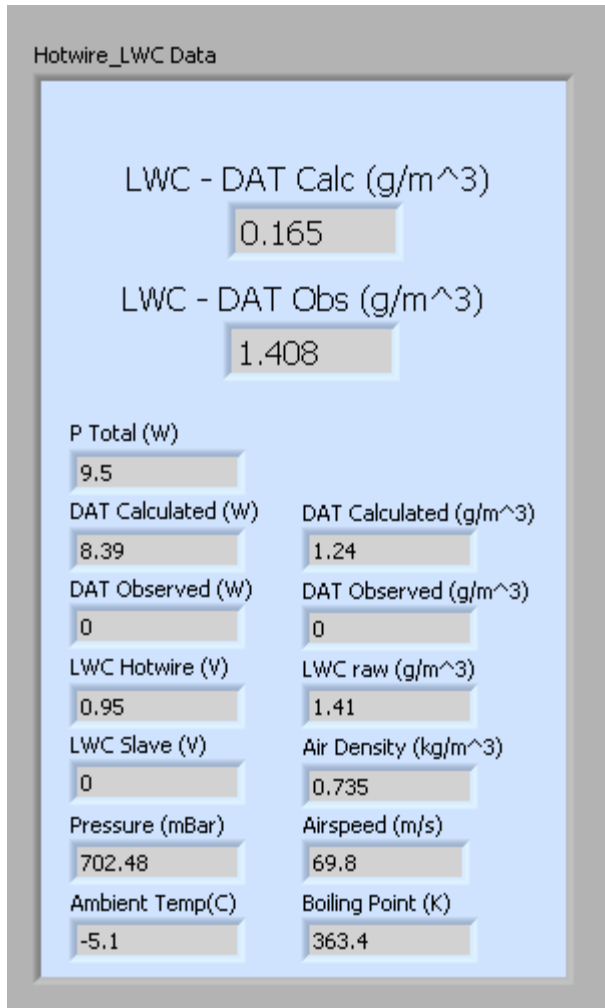
Figure 4: Hotwire LWC Channel Data Window

For information on specific channels, their definitions, and their acceptable ranges, consult *Appendix A: Hotwire LWC Channels* and the PADS Operator Manual's *Appendix A: Definitions*.

Chart Displays

The Hotwire LWC chart displays consist of two time-series windows, a real-time image display, and a real-time particle-size histogram. You can access any of these charts by selecting the tabs in the upper part of the chart display window, as shown in the following figure.
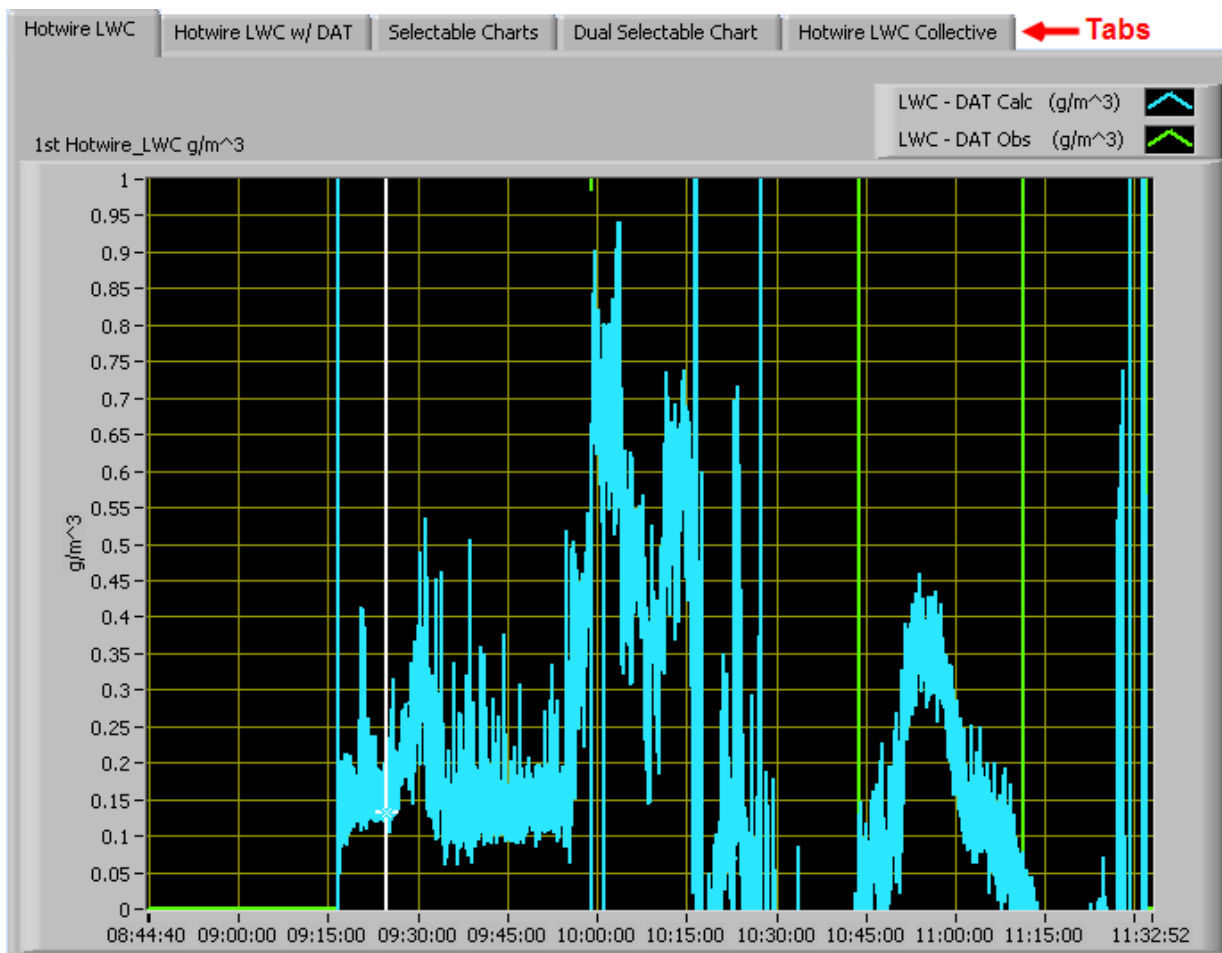
Figure 5: Hotwire LWC Time-Series Charts

When you access time-series charts in playback mode, the currently selected moment in time is indicated by a white cursor, as shown above. The y-axis value for this time is indicated by cross (+) on this cursor. Note that when you display a large range of time-series data, the chart display does not have sufficient resolution to display each individual time point. To increase resolution, zoom in on the data by changing the time interval to a smaller range.

On all the charts with x and y axes, you can change the scale by typing a different number into the starting and ending values on each axis. For instance, if you want to change the time period in the graphs above to end at 09:00:00, you simply type this time into the fields that currently say 11:32:52. In acquisition mode, you should disable autoscaling (see below) before you can type new values into fields this way.

Many charts also show you options for scaling and copying the data when you right-click on the graph. These options are as follows:

Autoscale Y This autoscales the y-axis. Note that on charts that have autoscale buttons, like the large histogram chart, the buttons override the Autoscale Y option in the drop-down menu.

Copy Data This copies the histogram chart to the clipboard using a screen capture.

Export Simplified Image This copies a simplified image of the data to the clipboard or an output file. You can choose the format you desire—bitmap (.bmp), encapsulated postscript (.eps), or enhanced metafile (.emf). Note that when you select the .eps option, you must copy the data to a file. Unless you specify otherwise, output files will be saved in the time-and-date-specific output file directory for the current session.

Clear Graph This lets you clear the graph of the currently displayed data points.

More information about each of the tabs on the chart displays section is given below.

PADS displays a legend in the upper right corner of all graphs with more than one charted channel. You can change the appearance of the chart by clicking on the legend and selecting the desired options.

1. Hotwire LWC

The **Hotwire LWC tab** shows time-series charts for LWC (g/m^3) – DAT (g/m^3), or LWC corrected for the influence of dry air convective heat losses. PADS displays two such charts overlaid on each other; one uses the calculated DAT and one the observed DAT. See *Appendix B* of this document for details on how PADS estimates actual LWC using DAT calculated and DAT observed.

2. Hotwire LWC w/DAT

The **Hotwire LWC w/DAT tab** shows the same time-series charts for LWC (g/m^3) as the Hotwire LWC Tab, along with three additional channels: LWC Raw (i.e., without DAT subtracted), and the calculated and observed DAT (g/m^3) values.

3. Selectable Charts

The **Selectable Charts** tab displays two charts with user-specified channels plotted against time. PADS displays selectable channel three in the upper graph, and channel

four in the lower graph. To change the channels plotted in the selectable charts, you have two options:

1.) To change the display before PADS begins sampling data, go to the **Configure** menu, select **Configure Display**, and choose the desired channel(s). Then press the **Reset Changes** button to apply this configuration. PADS will use this new configuration whenever the program starts.

2.) While PADS is sampling, click on the **Selectable Charts** tab and use the control in the upper left of the chart to select the channel you desire. You can either click on the text control to the right, which brings up a selectable list of channels, or you can use the button on the left to scroll between channels. Changes made on the **Selectable Charts** tab affect the current session only. However, you can press **Save Config** to make these changes permanent for future sessions.

4. Dual Selectable Chart

The **Dual Selectable Chart** tab shows two additional user-specified channels graphed against time. Unlike the charts in the previous tab, PADS overlays these graphs on top of one another. The Dual Selectable Chart window displays the channels selected as Channel One and Two. Again, to change the channels plotted in the selectable charts, you have two options:

1.) To change the display before PADS begins sampling data, go to the **Configure** menu, select **Configure Display**, and choose the desired channel(s). Then press the **Reset Changes** button to apply this configuration. PADS will use this new configuration whenever the program starts.

2.) While PADS is sampling, click on the **Selectable Charts** tab and use the control in the upper left of the chart to select the channel you desire. You can either click on the text control to the right, which brings up a selectable list of channels, or you can use the button on the left to scroll between channels. Changes made on the **Selectable Charts** tab affect the current session only. However, you can press **Save Config** to make these changes permanent for future sessions.

5. Hotwire LWC Collective

The **Hotwire LWC Collective** displays a multivariable plot that graphs the following channels against time:

     a. LWC – DAT Calc (g/m^3)
     b. Air speed (m/sec)
     c. Ambient temperature (C)[1]
     d. Pressure (mBar)

Note that air speed, ambient temperature and pressure are used to calculate LWC. See *Appendix B: Calculations* in the *PADS Operator Manual* for details.

---

[1] Ambient temperature is really the measured temperature; see Ambient Temperature in the PADS Operator Manual's Appendix A.

Appendix A: Hotwire LWC Channels

A complete list of Hotwire LWC data channels appears below. The Hotwire LWC output file will contain data values for each channel for each sampling period. You can also plot each of these channels against time using the Hotwire LWC Selectable Charts tab.

Appendix A in the *PADS Operator Manual* provides definitions and relevant formulas for PADS channels. Channels specific to the LWC are also defined in this manual in *Appendix B*.

Time	Viscosity Wet(g/sec-cm)
LWC hotwire(V)	Thermal Cond Dry(cal/sec-cm-K)
LWC Slave(V)	Thermal Cond Wet(cal/sec-cm-K)
LWC raw (g/m^3)	Reynolds Number
DAT Calculated (g/m^3)	Prandtl Numb Dry
DAT Observed (g/m^3)	Prandtl Numb Wet
LWC-DAT Calc (g/m^3)	Boiling Point Water (K)
LWC-DAT Observed(g/m^3)	P Total (W)
Ambient Temp(C)	P Dry Calculated (W)
Pressure(mB)	DAT Observed (W)
Airspeed(m/s)	Status
Density(kg/m^3)	GPS Time
Viscosity Dry(g/sec-cm)	

Hotwire LWC channels fall into several broad categories:

Time Channels: The time channels store time data. Time is generated by the PADS computer clock and is the time when the program receives the Hotwire LWC data. It is given in seconds after midnight on the day the program was started. GPS Time is included in every instrument's list of channels whenever a GPS is included as one of the PADS instruments. GPS Time may be collected from an instrument other than the Hotwire LWC, even though it appears as a channel in the Hotwire LWC output file.

Hotwire Channels: LWC Hotwire (V) and LWC Slave (V) store voltages collected from the hotwire sensor. LWC Slave (V) can also be considered a housekeeping channel, as it reflects instrument health.

Channels for Other Statistical Data: Ambient Temp(C), Pressure (mBar), Airspeed (m/sec), and DAT Observed (W) store information about the flight environment. Status stores statistical data the Hotwire LWC has gathered on the communication between PADS and the probe.

Calculated Channels: The remaining Hotwire LWC channels store the results of PADS calculations.

Appendix B: Explanations and Usage of Dry Air Term (DAT)

The Hotwire LWC instrument estimates liquid water content (LWC) by using a heated, wire-wound cylinder. The system maintains the sensor coil at a constant temperature, usually 125 °C, and measures the power necessary to maintain the sensor at this temperature. More power is needed to maintain the temperature constant as droplets evaporate on the cylinder surface and cool the surface and surrounding air. Hence, this power reading can be used to estimate LWC.

However, the power required to maintain the sensor wire temperature constant also reflects variables unrelated to LWC. In general, the total power is the sum of three terms, the dry air term, the radiation term and the wet term (LWC).

In practice, radiative heat losses are negligible, and PADS ignores them when calculating the LWC from the total power measured. However, heat losses due to convective heat losses, those included in the dry air term (DAT), are significant. PADS estimates DAT in two ways. First, it allows users to measure the actual DAT by taking readings of the power necessary to maintain the sensor wire in negligible LWC (low moisture) conditions. Users can press the "Get DAT Observed" button in cases where there are no visual clouds to obtain these readings. Presumably, the data obtained when the "Get DAT Observed" button is on accurately indicate DAT, since there should be no heat losses due to vaporization.

The second way PADS estimates heat loss due to DAT is by calculating it from the true air speed, temperature, pressure and the geometry of the sensor wire. For a complete list of these variables and the relevant calculations, see below or see *Appendix B* in the *PADS Operator Manual*.

Once PADS has observed or calculated the power devoted to the DAT, it converts this reading to a g/m^3 term that reflects the amount of liquid water content that would cause a comparable heat loss from the wire sensor. PADS then subtracts this term from LWC raw (g/m^3), or the LWC that would be present if the power flowing to the sensor were all devoted to offsetting LWC. The result gives an estimate actual LWC (g/m^3). When DAT Calculated is used, PADS labels the result LWC – DAT Calc (g/m^3); when DAT Observed is used, the result is LWC – DAT Obs (g/m^3).

The theoretical basis for the formulas PADS uses are derived largely from Zukauskas, A. and Ziugzda, J., 1985, *Heat Transfer of a Cylinder in Crossflow*, Hemisphere Publishing Corporation.

Air density (kg/m³): A channel in the Hotwire LWC output file. PADS calculates air density, ρ_a , according to the formula below.

$$\rho_a \quad = \quad \frac{P}{T_a} \bullet 0.348388$$

where

P = Static pressure (mBar)

T_a = Ambient temperature[2] (K)

This air density reading, which depends on ambient temperature, differs from the air density used in calculating the Hotwire LWC's Reynolds number. The latter air density, ρ_d , depends on film temperature and is calculated as follows:

$$\rho_d \quad = \quad \frac{P}{T_{flm}} \bullet 0.348388$$

where

P = Static pressure (mBar)

T_{flm} = Film temperature (K) = $(T_{wire} + T_a)/2$

T_{wire} = Wire temperature

---

[2] PADS currently use the measured temperature rather than the ambient temperature in this calculation. This is a known bug that will be fixed in an upcoming version of the program.

Dry Air Term (DAT): The amount of heat loss due to convection. The heat that is removed from the heated cylinder by the air flowing past the sensor is dependent on the ambient temperature, the wire temperature, the ambient pressure, the air velocity and the cross sectional area of the sensor. These losses have been parameterized from wind tunnel studies and depend on the Reynolds and Prandtl numbers (see **P Dry Calculated** below).

Dry Air Term Calculated (g/m^3): A channel on the Hotwire LWC output file. This channel is identical to **P Dry Calculated (W)** *except the units are converted to g/m^3*. Dry Air Term Calculated (g/m^3) is the amount of cooling that is caused by air passing the sensor. In cloud-free air, this cooling is measured by the amount of power required to keep the sensor at a constant temperature. The power is normally given in units of watts but is also converted into units of g/m^3 of equivalent water content, i.e. the water concentration that would cause the equivalent amount of cooling by evaporation. When in clouds, the dry air term cannot be directly measured due to the presence of water, but it can be calculated using an empirical equation that has been derived from wind tunnel studies. See Zukauskas and Ziugzda, 1985, and the **LWC** and **P Dry Calculated (W)** entries.

Dry Air Term Observed (g/m^3): A channel on the Hotwire LWC output file. Dry Air Term Observed (g/m^3) gives the amount of liquid water content that would cause the same amount of latent heat loss as the heat loss currently being caused by convection (i.e., dry air term). PADS uses this channel in calculating actual liquid water content, because subtracting the dry air term from the raw liquid water content gives an estimate of actual LWC (In the *PADS Operator Manual DOC-0116*, see **LWC** in *Appendix B: Calculations for Derived Variables*). In contrast to the Dry Air Term Calculated channel, which calculates dry air term from other variables, PADS derives the Dry Air Term Observed directly from the measured power in Watts (**Dry Air Term Observed (W)**) by averaging dry air term readings when the **Get DAT Observed** button is pressed. Presumably, this button is pressed when no clouds are present, yielding accurate readings of heat dissipation due entirely to convection.

Dry Air Term Observed (W): This is identical to **Dry Air Term Observed (g/m^3)** but reports the DAT in units of watts, not g/m^3.

Film Temperature: On a hotwire sensor instrument, the arithmetic average of the sensor temperature and the ambient air temperature. PADS thus calculates film temperature, T_{flm}, as follows:

$$T_{flm} = \frac{T_a + T_w}{2}$$

where

$$T_a = \text{Ambient temperature}[3] \text{ (K)}$$

$$T_w = \text{Sensor temperature}$$

PADS uses film temperature in calculating air density, viscosity, and thermal conductivity. The film temperature is also used when calculating Reynolds number because of the air density and viscosity that are temperature-dependent.

Latent Heat of Vaporization: A variable used in Hotwire LWC calculations for LWC. PADS calculates the latent heat of vaporization, L_v, as a function of the boiling temperature of water, T_b, as follows:

$$L_v = 597.3 \bullet \left[\frac{273.16}{T_b} \right]^{T_b \bullet 0.000367 \, + \, 0.167}$$

LWC Slave (V): The power used by the end sections or "slave coils" of the LWC Hotwire, which are used as active insulators. The slave voltage is not used in calculating LWC; rather, the slaves prevent temperature gradients across the measurement section of the LWC hotwire. An LWC Slave reading of more than one volt reflects a problem with the device. If the slave coils are not functioning properly, the master coil will lose heat transversely out of its ends and the subsequent derived LWC will be an underestimate of the actual LWC.

---

[3] PADS currently uses the measured temperature rather than the ambient temperature in this calculation. This is a known bug that will be fixed in an upcoming version of the program.

LWC Hotwire (V): The voltage that is proportional to the power required to maintain the fixed temperature of the Hotwire Liquid Water Content Sensor. This voltage will vary depending on the water content in the air and the air density, viscosity and velocity. In theory, the LWC Hotwire (V) reading reflects power needed to offset convective, radiative, and latent heat of vaporization losses. In practice, radiative losses are negligible, and the LWC Hotwire (V) reading reflects only convective losses and those due to vaporization. By calculating the power required to offset convective losses and subtracting this from the LWC Hotwire (V) total, PADS can determine the amount of power necessary to offset heat losses due solely to vaporization, and then derive an estimate of LWC (g/m^3).

The LWC reading for some probes, such as the CIP, is in fact calculated using another method (see **LWC** entry in *Appendix B* in the *PADS Operator Manual DOC-0116*). However, the LWC Hotwire's reading can also be useful, as the hotwire measures LWC for a different range of particle sizes using a different mechanism. To see the LWC derived from the hotwire, click on the "Hotwire_LWC" tab and look at the "LWC raw" indicator. (If no Hotwire_LWC tab exists, then your instrument does not have a hotwire.)

The LWC Hotwire (V) reading for individual instruments may stay set to zero in the following circumstances:

- No hotwire is present
- The hotwire is wired to a different instrument (see **Hotwire Source** on the Setup tab to see your hotwire reading source)

For example, say you have a CIP and a CAS, and your instrument is configured so that the hotwire data are sent to the CAS. The CAS tab will show the voltage reading for the LWC hotwire, and the Hotwire_LWC tab will give specifics on hotwire data. However, the LWC Hotwire (V) indicator on the CIP screens may be zero, since the CIP is not reporting hotwire data.

Note that if a CIP and CAS are both present, the CAS's version of LWC Hotwire should take precedence. This preference should be indicated on the Setup tab.

LWC raw (g/m^3): The liquid water content that would be present if all of the LWC Hotwire (V) power were dedicated to offsetting latent heat loss due to vaporization. In practice, some of this power is dedicated to offsetting convective heat losses as well. However, by calculating LWC raw (g/m^3) and then subtracting either the calculated or the observed LWC DAT (g/m^3), PADS derives an accurate estimate of actual LWC (g/m^3).

PADS calculates LWC raw (g/m^3) as follows:

$$\text{LWC raw} \quad = \quad \frac{P_t \bullet 238850}{l \bullet d \bullet TAS \bullet 100 \bullet (L_v + T_b - T_a)}$$

where

P_t =   P Total (W), the total the total power required to keep the hotwire sensor coil at the target temperature

l =   Length of sensor (cm)

d =   Diameter of sensor (cm)

TAS =   True air speed (m/sec)

L_v =   Latent heat of vaporization

T_b =   Boiling temperature of water (K)

T_a =   Ambient air temperature[4] (K)

LWC – DAT Calc (g/m^3): The liquid water content estimate that PADS derives by subtracting the DAT Calc (g/m^3) estimate for dry air term from raw LWC (g/m^3). This channel gives an accurate estimate of the actual LWC in the air.

$$\text{DAT Calc} \quad = \quad \frac{(P_t - P_d) \bullet 238850}{l \bullet d \bullet TAS \bullet 100 \bullet (L_v + T_b - T_a)}$$

where

P_t =   P Total (W), the total power dissipated by the hotwire sensor coil

P_d =   P Dry Calculated (W), the power that the hotwire sensor dissipates due to calculated dry air term

l =   Length of sensor (cm)

d =   Diameter of sensor (cm)

TAS =   True air speed (m/sec)

---

[4] PADS currently uses the measured temperature rather than the ambient temperature in this calculation. This is a known bug that will be fixed in an upcoming version of the program.

L_v = Latent heat of vaporization

T_b = Boiling temperature of water (K)

T_a = Ambient air temperature[5] (K)

LWC – DAT Observed (g/m³): The liquid water content estimate that PADS derives by subtracting the DAT Observed (g/m³) estimate for dry air term from raw LWC (g/m³). This channel gives an accurate estimate of the actual LWC in the air. This is identical to the **LWC – DAT Calc (g/m³)** except P_d is taken from the averaged, observed power measured when out of cloud and when the button is depressed to average these values.

P Total (W): A channel in the Hotwire LWC output file. P Total is the total power required to keep the hotwire sensor coil at the target temperature specified on the instrument configuration editor screen. This power is the sum of the power the sensing wire dissipates through losses of convective heat (i.e., dry air term) and latent heat of vaporization. In theory, radiative heat losses also contribute to P Total, but these are so negligible that PADS ignores them.

P Dry Calculated (W): A channel in the Hotwire LWC output file that tracks the power that the hotwire sensor dissipates due to calculated dry air term. This channel is identical to **Dry Air Term Calculated (g/m³)** *except the units are kept in Watts.* **P Dry Calculated** is the amount of cooling that is caused by air passing the sensor. In cloud-free air, this cooling is measured by the amount of power required to keep the sensor at a constant temperature. When in clouds, the dry air term cannot be directly measured due to the presence of water, but it can be calculated using an empirical equation that has been derived from wind tunnel studies (see Zukauskas and Ziugzda, 1985). Specifically, the heat loss P_d, the dry air term, is expressed by the equation

$$P_d \quad = \quad A_0 \bullet \pi \bullet k \bullet (T_s - T_a) \bullet Re^x \bullet Pr^y$$

where

---

[5] PADS currently uses the measured temperature rather than the ambient temperature in this calculation. This is a known bug that will be fixed in an upcoming version of the program.

k = Thermal conductivity of the air (g/sec-cm-K)

T_s = Sensor temperature (K)

T_a = Ambient air temperature (K)

Re = Reynolds number

Pr = Prandtl number

$\left.\begin{array}{l} A_0 \\ x \\ y \end{array}\right\}$ = constants for a heated cylinder at a high Reynolds number

Using this formula, PADS calculates **P Dry Calculated (W)**, P_d, as follows:

$$P_d = \frac{0.26 \bullet \pi \bullet k_d \bullet (T_s - T_a) \bullet Re^{0.6} \bullet Pr_d^{0.37} \bullet \left(\dfrac{Pr_d}{Pr_w}\right)^{0.25} \bullet l}{0.23885}$$

where

Re = Reynolds number

Pr_d = Prandtl number dry

Pr_w = Prandtl number wet

k_d = Thermal Cond Dry (cal/sec-cm-K), the thermal conductivity of the air

T_s = Sensor temperature (K)

T_a = Ambient air temperature[6] (K)

l = sensor wire length (cm)

---

[6] PADS currently uses the measured temperature rather than the ambient temperature in this calculation. This is a known bug that will be fixed in an upcoming version of the program.

Prandtl Num Dry: A channel on the Hotwire LWC output file. The Prandtl number is the viscosity divided by the thermal conductivity. PADS calculates **Prandtl Num Dry,** Pr_d, as follows:

$$Pr_d \quad = \quad \frac{v_d}{k_d}$$

where

$$v_d \quad = \quad \text{Viscosity Dry (g/sec-cm)} = f(T_{flm})$$

$$k_d \quad = \quad \text{Thermal Cond Dry (sec-cm-K)} = f(T_{flm})$$

Prandtl Num Wet: A channel on the Hotwire LWC output file. The Prandtl number is the viscosity divided by the thermal conductivity. PADS calculates **Prandtl Num Wet,** Pr_w, as follows:

$$Pr_w \quad = \quad \frac{v_w}{k_w}$$

where

$$v_w \quad = \quad \text{Viscosity Wet (g/sec-cm)}$$

$$k_w \quad = \quad \text{Thermal Cond Wet (sec-cm-K)}$$

Reynolds Number: A channel on the Hotwire LWC output file. A Reynolds number measures the ratio of inertial forces to viscous forces and thus indicates the relative importance of these two forces under given flow conditions (wikipedia.org). The Reynolds number, Re, is generally expressed as

$$Re = \frac{\rho \bullet V \bullet d}{v}$$

where

ρ	=	Air density (kg/m^3) for the film temperature
V	=	Velocity (m/sec)
v	=	Viscosity (g/sec-cm) = $f(T_{flm})$
d	=	Diameter (mm)

PADS calculates the Reynolds number for the LWC hotwire sensor as follows:

$$Re = \frac{\rho_d \bullet TAS \bullet d \bullet 100}{v}$$

where

ρ_d	=	Air density (kg/m^3) for the film temperature
TAS	=	True air speed (m/sec)
v_d	=	Viscosity Dry (g/sec-cm)= $f(T_{flm})$
d	=	Diameter of sensor (cm)

Thermal Cond Dry (cal/sec-cm-K): A channel on the Hotwire LWC output file. It indicates the thermal conductivity of the air as a function of film temperature, T_{flm}. PADS calculates the Thermal Cond Dry, k_d, as follows:

$$k_d = \frac{T_{flm}^{1.5} \bullet 0.00264638}{418.68 \bullet \left(T_{flm} + 245.4 \bullet 10^{-12/T_{flm}} \right)}$$

Thermal Cond Wet (cal/sec-cm-K): A channel on the Hotwire LWC output file. It indicates the thermal conductivity as a function of sensor temperature, T_s. PADS calculates the Thermal Cond Wet, k_w, as follows:

$$k_w \quad = \quad \frac{T_s^{1.5} \bullet 0.00264638}{418.68 \bullet \left(T_s + 245.4 \bullet 10^{-12/T_s} \right)}$$

Viscosity Dry (g/sec-cm): A channel on the Hotwire LWC output file that is used in calculating the Prandtl and Reynolds number and ultimately the LWC. Viscosity measures a fluid's resistance when the fluid is being subjected to shear stress or extensional stress. Viscosity Dry (g/sec-cm), v_d, is a function of the film temperature, T_{flm}. PADS calculates it as follows:

$$v_d \quad = \quad 0.0001718 \bullet \frac{393.16}{120 + T_{flm}} \bullet \left[\frac{T_{flm}}{273.16} \right]^{1.5}$$

Viscosity Wet (g/sec-cm): A channel on the Hotwire LWC output file that is used in calculating the Prandtl and Reynolds number and ultimately the LWC. Viscosity measures a fluid's resistance when the fluid is being subjected to shear stress or extensional stress. Viscosity Wet (g/sec-cm), v_w, is a function of the sensor wire temperature, T_w. PADS calculates it as follows:

$$v_w \quad = \quad 0.0001718 \bullet \frac{393.16}{120 + T_w} \bullet \left[\frac{T_w}{273.16} \right]^{1.5}$$