All rights reserved. No part of this document shall be reproduced, stored in a retrieval system, or transmitted by any means, electronic, mechanical, photocopying, recording, or otherwise, without written permission from Droplet Measurement Technologies, Inc. Although every precaution has been taken in the preparation of this document, Droplet Measurement Technologies, Inc. assumes no responsibility for errors or omissions. Neither is any liability assumed for damages resulting from the use of the information contained herein.

Information in this document is subject to change without prior notice in order to improve accuracy, design, and function and does not represent a commitment on the part of the manufacturer. Information furnished in this manual is believed to be accurate and reliable. However, no responsibility is assumed for its use, or any infringements of patents or other rights of third parties, which may result from its use.

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.

Warranty

The seller warrants that the equipment supplied will be free from defects in material and workmanship for a period of one year from the confirmed date of purchase of the original buyer. Service procedures and repairs are warrantied for 90 days. The equipment owner will pay for shipping to DMT, while DMT covers the return shipping expense.

Consumable components, such as tubing, filters, pump diaphragms, and Nafion humidifiers and dehumidifiers are not covered by this warranty.
Laser Safety Information

The CIP contains a class IIIb laser. AVOID DIRECT EXPOSURE TO THE BEAM. Observe laser safety precautions and wear appropriate laser safety glasses. Avoid placing reflective materials in the beam that could redirect the beam, including watch bands, rings or tools.

STRICT OBSERVANCE OF THE FOLLOWING WARNING LABELS IS ADVISED.

The following label is located on the CIP arm:

![Danger Label](image-url)
# CONTENTS

1.0 Product Description .............................................................. 8
  1.1 Introduction .............................................................................. 8
  1.2 CIP Specifications ................................................................. 9
    1.2.1 General Specifications ...................................................... 9
    1.2.2 Electrical Specifications ................................................. 10
    1.2.3 Physical Specifications ................................................... 11
    1.2.4 Operating Limits ............................................................. 11
  1.3 Korolev Tips Specifications .................................................. 12

2.0 Theory of Operation ........................................................... 12
  2.1 CIP ..................................................................................... 12
  2.2 Korolev Tips ........................................................................... 13
  2.3 Data Transmission ............................................................... 14

3.0 Probe Unpacking and Handling .......................................... 15
  3.1 Inserting Probe in Canister .................................................... 17
  3.2 Bench Testing ........................................................................ 18
  3.3 Shipping Probe to DMT ........................................................ 19
  3.4 Configuring Software for Korolev Tip Upgrade ...................... 19

4.0 LWC-200 Sensor .................................................................... 22
  4.1 LWC Specifications ............................................................... 25
  4.2 Ground Testing ....................................................................... 25
  4.3 Replacement of the LWC-200 Sensing Element ...................... 26
  4.4 Data Interpretation ............................................................... 27

5.0 Other Instrument Components .......................................... 27
  5.1 Sensors for Environmental Measurements ......................... 28
  5.2 System Performance Sensors ............................................... 28

6.0 Particle Analysis and Display System (PADS) ..................... 29

7.0 Maintenance ........................................................................ 30
  7.1 Routine Maintenance ............................................................ 30
  7.2 Yearly Maintenance ............................................................... 30

8.0 Instrument Troubleshooting and Repair ............................ 30
  8.1 Troubleshooting with Housekeeping Channels ...................... 31
  8.2 Power Problems ................................................................. 33
  8.3 Image and Data Problems ..................................................... 35
    8.3.1 Varieties of Image Problems .......................................... 36
    8.3.2 Background Information on Diode Array Board .......... 36
  8.4 Heater Problems ................................................................. 37
8.5 Contacting DMT regarding CIP Problems ............................................. 39
9.0 Verifying CIP Calibration with the Spinning Disk Calibrator .......... 39
Appendix A: Revisions to Manual ............................................................... 40
Appendix B: Probe Air Speed Calculations .............................................. 41
Probe Air Speed (PAS) ............................................................................ 41
Options for Calculating Probe Air Speed .............................................. 41
Calculating Probe Air Speed On-Board the CIP ................................... 41
  Ambient Temperature ....................................................................... 41
  Mach Number ................................................................................. 42
  Probe Air Speed ............................................................................. 43
Appendix C: LWC-200 Calculations and Formulas ................................ 44
  Wire Temperature Estimation ............................................................ 46
Appendix D: LWC-200 References ........................................................... 49
Appendix E: Host Computer - CIP Communications for 1D Particle-Size Data
  Communications Parameters ............................................................. 50
  Initiating Communications ............................................................... 50
  List of Communications Commands ............................................... 51
  Setup Data Command ....................................................................... 51
    Definition of the Declared Parameters ......................................... 52
  CIP Response to Setup Data Command ............................................. 53
  Send Data Command ....................................................................... 53
    Definition of the Declared Parameters ......................................... 54
    Note on Probe Air Speed (PAS) Coefficient ................................ 54
  CIP Response to the Send Data Command ....................................... 55
    Definition of the Declared Parameters ......................................... 56
    CIP Housekeeping Channels .......................................................... 57
  Reset Command .............................................................................. 59
  Set Absolute Time Command ............................................................ 60
  CIP Response to Set Absolute Time Command .................................. 60
  Get Version Number Command ........................................................ 61
  CIP Response to Get Version Number Command ............................ 61
Appendix F: Host Computer - CIP Communications for 2D Image Data .... 62
Appendix G: DMT Instrument Locator—Operator Guide ....................... 62
  Purpose .......................................................................................... 62
  Installation ...................................................................................... 62
  Operation ........................................................................................ 63
Endnotes .............................................................................................. 64
List of Figures

Figure 1: Cloud Imaging Probe ........................................................... 8
Figure 2: CIP (shown here as a component of CAPS instrument) with 40 mm Korolev Tips ................................................................. 9
Figure 3: Particle Imaging with CIP Probe ............................................. 13
Figure 4: Korolev Tips Deflecting Particles ......................................... 14
Figure 5: Unscrewing CIP Socket-Head Screws .................................... 15
Figure 6: Handling the CIP (here shown as a component instrument on a CCP) ............................................................................ 16
Figure 7: CIP on Mounting Stand ...................................................... 17
Figure 8: Connectors in CIP Canister ................................................ 18
Figure 9: Attaching Test Cable ........................................................ 19
Figure 10: Configuring the PADS 3 Software for a Korolev Tip Upgrade .... 20
Figure 11: Configuring PADS 2 Software for a Korolev Tip Upgrade ....... 21
Figure 12: LWC-200 sensing element. The unit is constructed so that it can fit in the connector in either direction ..................................... 22
Figure 13: Circuitry Used to Control Master Coil Temperature .......... 24
Figure 14: Removing LWC-200 ......................................................... 26
Figure 15: CIP Data, Histogram, and Particle Images (shown during glass-beads test) ................................................................. 29
Figure 16: 28-Volt LED .................................................................. 34
Figure 17: LEDs for ±5 or ±15 Voltages .............................................. 34
Figure 18: CIP Backplane Board. Note that both the Array and DSP Board Connectors have pin one in the lower right corner. The AMP connectors on the top also have pin one on the right. ..................................... 35
Figure 19: Measuring Actual Resistance at the CIP Terminal Strip .... 38
Figure 20: Instrument Locator ......................................................... 63

List of Tables

Table 1: Acceptable Values for Diode Voltages 1, 32, and 64 when No Particles are Present ................................................................. 31
Table 2: Data Structures Used in CIP-Host Computer Communications .... 50
Table 3: Setup Data Command - Data Packet ...................................... 52
Table 4: CIP Response to Setup Data Command - Data Packet .......... 53
Table 5: Send Data Command - Data Packet ...................................... 53
Table 6: CIP Response to the Send Data Command - Data Packet .......... 56
Table 7: Definitions and Conversion Equations for CIP Housekeeping Channels ......................................................................................... 59
Table 8: Reset Command - Data Packet .............................................. 59
Table 9: Set Absolute Time Command - Data Packet .......................... 60
Table 10: CIP Response to Set Absolute Time Command - Data Packet ...... 60
Table 11: Get Version Number Command - Data Packet ...................... 61
Table 12: CIP Response to Get Version Number Command - Data Packet ... 61
1.0 Product Description

1.1 Introduction

The Cloud Imaging Probe (CIP) is a single-particle optical array probe complemented with sensors for air temperature, relative humidity, liquid water content, and air speed. Full specifications of the CIP are given in Section 1.2.

The Particle Analysis and Display System (PADS) offers a graphical user interface at the host computer. PADS provides control of CIP measurement parameters while simultaneously displaying real-time particle size distributions and derived parameters. Data interfaces are done via line drivers meeting the RS-422 or RS-232 electrical specifications. The former allows cable lengths of up to 100 meters, while RS-232 configurations require shorter cables.

Figure 1 displays a photograph of the CIP with its important components labeled. Figure 2 shows a CIP with Korolev tips, which are an optional accessory designed to minimize particle artifacts.

![Cloud Imaging Probe](image)

*Figure 1: Cloud Imaging Probe*
1.2 CIP Specifications

1.2.1 General Specifications

<table>
<thead>
<tr>
<th>Technique:</th>
<th>Single-particle optical imaging onto a linear array of 64 photodetectors</th>
</tr>
</thead>
</table>
| Measured Particle Size Range: | 12.5 µm – 1.55 mm (for 25-µm resolution CIP)\(^1\)  
7.5 µm - 9.3 mm (for 15-µm resolution CIP)\(^1\) |

\(^1\) The minimum size for detected particles varies based on where on the diode array the particle falls. For details, see the Data Analysis User’s Guide, Chapter II: Single Particle Imaging (DOC-0223).
| Sample Area: | 10 cm x 1.55 mm (for 25-µm resolution CIP)²  
|             | 10 cm x .93 mm (for 15-µm resolution CIP)²  |
| Air Speed Range: | 10 – 300 m/sec (for 25-µm resolution CIP)³  
|                 | 10 – 180 m/sec (for 15-µm resolution CIP)³  |
| Number of Size Bins: | 62  |
| Sampling Frequency: | 1D histogram data: selectable, 0.04 sec to 20 sec⁴  
|                   | 2D image data: asynchronous  |
| Laser: | 660 nm, 30-50 mW depending on configuration  |
| Data System Interface: | 1D: RS-232 or RS-422, 56.6 kb/sec Baud Rate  
|                   | 2D: RS-422, High Speed, 4 Mb/sec Baud Rate  |
| Auxiliary Parameters: | Ambient Temperature, Relative Humidity, Liquid Water Content (on standard CIPs), Static Pressure, Dynamic Pressure  |
| Calibration: | Spinning glass disk with opaque dots of known size  |
| Optional accessories: | Korolev tips (see section 1.3 for Korolev tip specifications)  |

### 1.2.2 Electrical Specifications

There are two circuits that are powered through the canister connections, where each circuit has its own pair of contacts. The circuits are called System Power and Anti-Ice Power. See the CIP Wiring Diagram for details. Standard CIPs also have a third circuit, the LWC power circuit.

*System Power* for the CIP must be specified at the time the probe is ordered. It can be either 28VDC or 115VAC.

---

² The sample area varies based on the size of detected particles. See the **Sample Volume** entry under *Appendix B: Calculations* in the *PADS Overview Manual (DOC-0300)*. For the CIP, sample volume = sample area • PAS.

³ Maximum probe air speed (PAS) depends on the CIP’s resolution and maximum clock rate, as follows: Maximum PAS = resolution (µm) • clock rate (MHz) • 10⁶ (MHz/sec) • 10⁸ (m/µm). The maximum CIP clock rate is 12 MHz. Note that the 300 m/sec air speed maximum is largely theoretical and reflects only the constraints imposed by the CIP, not those of other instruments or the aircraft itself.

⁴ Versions of the Particle Analysis and Display System (PADS) earlier than 3.5 assume a sampling frequency of 1 sec / 1 Hz. As a result, this frequency is recommended if you are using PADS 2.7 or earlier.
Anti-Ice Power is either 28VDC (standard) or 115VAC, and should be controlled such that the heaters will only be powered when the aircraft is airborne. DMT recommends routing the anti-ice circuit through a weight-on-wheels switch, with an override installed at the customer’s discretion. Anti-ice heaters can be ground-tested, but for no longer than 10 seconds. This is enough time to feel for warming at the CIP tips, Pitot tube and cross-arm. Beyond this time, operation without significant airflow over the heated area will cause damage.

Power Requirements for CIP Circuits are given below.

<table>
<thead>
<tr>
<th>SYSTEM POWER CIRCUIT</th>
<th>Electronics</th>
<th>LWC only</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>28VDC CIP</td>
<td>2.0A</td>
<td>9.0A</td>
<td>11.0A</td>
</tr>
<tr>
<td>115VAC CIP</td>
<td>1.0</td>
<td>4.5A</td>
<td>5.5A</td>
</tr>
</tbody>
</table>

Note: The above electronics currents are nominal maximums that the device may use during startup or at times when temperatures cause the heaters to turn on. Similarly, the LWC current shown is the absolute maximum that can occur under extremely high water loading conditions. Normal operating current is significantly lower.

<table>
<thead>
<tr>
<th>ANTI-ICE POWER CIRCUIT</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>28VDC CIP</td>
<td>Standard Tips</td>
<td>--</td>
<td>13A</td>
</tr>
<tr>
<td></td>
<td>Korolev Tips</td>
<td>--</td>
<td>17A</td>
</tr>
<tr>
<td>115VAC CIP</td>
<td>Standard Tips</td>
<td>--</td>
<td>3A</td>
</tr>
<tr>
<td></td>
<td>Korolev Tips</td>
<td>--</td>
<td>4.5A</td>
</tr>
</tbody>
</table>

1.2.3 Physical Specifications

1. CIP probe outside of canister: 10.5 lbs / 4.8 kg.
2. CIP probe in DMT canister: 21 lbs / 9.5 kg.
3. CIP probe in generic canister: 25 lbs / 11.4 kg

1.2.4 Operating Limits

1. Temperature: -40° to +40° C
2. Altitude: 50,000 feet / 15,000 m
3. Humidity: 0 - 100%
1.3 Korolev Tips Specifications

<table>
<thead>
<tr>
<th>Technique</th>
<th>Pointed tips on CIP arm windows to deflect particle fragments away from the sample space</th>
</tr>
</thead>
</table>
| Sample Volume Length | Two separate arm lengths available to optimize measurement under different cloud optical densities:  
  • Short arm-width length (40 mm) best for optically dense clouds  
  • Long arm-width length (70 mm) best for optically thin clouds |
| Anti-Ice Heaters | Heaters embedded in tips to avoid ice-build-up  
  Specify voltage when ordering: 115 VAC or 28VDC |
| Construction Material | Tips constructed of aluminum with titanium nitride (TiN) coating for surface protection and electrical conductivity |
| Windows | • Prevent water and moisture from entering the probe arms  
  • Are removable for easy cleaning  
  • Contain water removal features that direct water away from the windows |
| Tip covers | Covers are included for user safety and to protect tips from damage; remove before use |

2.0 Theory of Operation

2.1 CIP

The CIP design is based on established optical imaging techniques whereby images of particles passing through a collimated laser beam are projected onto a linear array of 64 photodetectors. The presence of a particle is registered by a change in the light level on each diode. The CIP registers the change as either “On” or “Off,” where “On” is when the light level decreases below 50%. The registered changes in the photodetectors are stored in a buffer at a rate consistent with probe velocity of particles passing through the beam and the size resolution. Particle images are reconstructed from individual “slices,” where a slice is the state of the 64-element linear array at a given moment in time. A slice must be stored each time interval that the particle advances through the beam a distance equal to the resolution of the probe. For example, a 25-µm resolution CIP must store the state of the photodetectors every \((25 \times 10^{-6}/V)\) seconds for a particle velocity, \(V\). This means at 100 ms\(^{-1}\) the array is stored every 250 nanoseconds.
The laser produces an oval 50 mW beam illuminating the diode array. Whenever a particle passes through the laser beam, its shadow is optically magnified onto a 200-µm pitch, 64-element photo-diode array. The CIP determines the particle's size based on how many diodes in the array its shadow obscures. Particles shadowing an end diode (i.e., diode number one or sixty-four) are rejected from the sizing routine but will generate a 2D image. The size range for CIP-detected particles ranges from 12.5 to 1550 µm for a 25-µm resolution CIP and 7.5 to 930 µm for a 15-µm resolution CIP.

On-board digital electronics begin storing photo-diode information at a clock rate associated with the probe air speed (PAS) frequency. Specifically, the clock rate is set to PAS / [probe resolution]. PAS is determined using an on-board Pitot-static system that provides information about air speed at the probe itself. Each time the aircraft moves forward by the CIP’s resolution—i.e., 25 or 15 µm—a clock pulse occurs. As stated earlier, the distance the aircraft travels between slices must match the CIP’s resolution so that particle images are not artificially elongated or truncated. When a particle no longer obstructs the laser for two PAS clock periods, the electronics stop sampling the diode array.

### 2.2 Korolev Tips

Korolev tips are an optional accessory designed to minimize particle artifacts. Atmospheric ice and liquid particles that strike a solid surface on a traditional CIP may shatter, bounce, and/or splash, creating many small particles. When this occurs forward of the probe sample area, the fragments can cause errors in the measured

---

5 “Pitch” refers to the distance from one diode’s center to the next diode’s center on a photodiode array. The array’s pitch is constant regardless of the CIP’s resolution, so the optical magnification factor varies accordingly.

6 In practice, the minimum size for detected particles varies based on where on the diode array the particle falls. For details, see the Data Analysis User’s Guide, Chapter II: Single Particle Imaging (DOC-0223).
particle number and size distribution. The design principle behind the Korolev Tips, pictured in Figure 2, insures that trajectories of the modified particles do not intersect the probe sample area and cause a sampling artifact.

The Korolev-tip design does not prevent shattering and splashing from occurring, but it deflects shattered fragments away from the sample volume. This tip modification further reduces the artifact by eliminating probe protrusions upstream from the sample area.

![Image: Korolev Tips Deflecting Particles](image)

**Figure 4: Korolev Tips Deflecting Particles**

### 2.3 Data Transmission

For one-dimensional (1D) sizing data, the digital signal processor monitors the transition of the particle shadow over the diode array, and uses the maximum detected width to determine the correct size bin for the particle. The processor also stores the cumulative number of particles of each size during the sample period (a frequency distribution) as well as the number of end-diode rejected particles. The 1D statistical data, when polled, is sent to the host processor. PADS or similar software then stores and displays this information. 1D data transmission is synchronous, meaning that information between the CIP and the host computer is sent at regular, synchronized intervals.

2D image data are compressed using run-length encoding and transmitted to the host computer. 2D data transmission is asynchronous, meaning that data are sent intermittently. Along with the image data, the host computer receives particle header information that contains the precise beginning and end location of every particle, the time the particle was measured relative to instrument start-up, and the total number of particles received. Whenever the image and header data fill a 4096-byte buffer, these data are sent to the host, and the host software de-compresses a portion of this data for image display to the screen and stores the entire compressed information to disk.

For more information on data transmission, see Appendixes E and F.
3.0  Probe Unpacking and Handling

The CIP will normally be shipped inside the mounting canister. To remove the probe from the canister, loosen the 8 recessed socket-head cap screws that are on the leading edge at the radius of the canister. These are #8 screws and are best removed with a 9/64” long stem ball-end hex driver (Figure 5). Once the screws are loose, the probe can be pulled straight out of the canister.

To pull the probe out of the canister, pull on the CIP arms. Once the probe has been removed, it is best handled at the crown and the rear bulkhead (Figure 6).

Figure 5: Unscrewing CIP Socket-Head Screws
Figure 6: Handling the CIP (here shown as a component instrument on a CCP)

All probes are shipped with a stand. To avoid damage to the probe it is recommended that the probe be placed in the stand, as shown in Figure 7.
3.1 Inserting Probe in Canister

When mounting the probe on an aircraft, the optical windows should be kept vertical so that no water will pool in the window spaces if take-off is conducted in rain. To make this orientation possible, the CIP canister contains two connectors at 90-degree orientations on the back plate. These are wired in parallel so the probe can be inserted into either connector. Select the connector that will best position the CIP windows.
When inserting the probe in the canister, note the orientation of the securing screws and attempt to align them with the recessed screw holes in the canister. The connectors have locating pins on them and the probe should seat easily with the crown of the probe tight against the front of the canister. If the probe does not seat, withdraw the probe slightly and attempt to seat it.

### 3.2 Bench Testing

Before bench-testing the CIP, ensure that the anti-ice heaters are off; see section 1.2.2.

The CIP is shipped with a bench test cable. Depending on the computer configuration, the test cable will either connect to a rack or bench computer with D connectors or to the Airborne Power Distribution System (see the APDS Operator Manual, DOC-0208) with a Bendix-type locking connector.
The connector (Figure 9) that mates to the CIP is polarized with locating pins of different sizes. If the test cable connector does not easily fit on the mating CIP connector, reverse the connector 180 degrees. Always insure that the test cable does not have power on it when connecting to the CIP.

The CIP is not reverse polarity protected, and if using the bench test cable with the open power leads and connecting to any type of external power supply, make sure the polarity is correct.

3.3 Shipping Probe to DMT

In the event that the probe needs to be shipped to DMT for service, it is not necessary to ship the canister unless the problem involves the canister itself.

3.4 Configuring Software for Korolev Tip Upgrade

If you have received Korolev tips on a new CIP, you will not need to configure the Particle Analysis and Display System (PADS) software. Likewise, PADS arrives pre-configured for customers who do not have Korolev tips on their probes. However, if you upgraded an older CIP so that it now has Korolev tips, you will need to reconfigure the software. The procedure is the same for PADS versions 2.X and 3.X:

1.) Open PADS.

Figure 9: Attaching Test Cable
2.) Click on the CIP tab.

3.) On the Configure menu, select Configure Instrument.

4.) You will see a window like that in either Figure 10 (for PADS 3) or Figure 11 (for PADS 2). In the Arm Width field, identified by the black arrow, type the size of your Korolev tips. This should be either 40 mm or 70 mm, and will be printed on the side of the tips.

Figure 10: Configuring the PADS 3 Software for a Korolev Tip Upgrade
5.) Click on **Save**.

6.) On the main PADS screen, click on the green **Reset Program** button.
4.0 LWC-200 Sensor

Standard CIPs come equipped with an LWC-200 hot wire liquid water sensor. The LWC-200 is the DMT implementation of an instrument originally developed by Warren King (see Appendix D) for the measurement of cloud liquid water content. This sensor, often referred to as the “King” probe, is used primarily for the study of cloud micro-physical processes and for icing studies.

The LWC-200 operates under the principle that liquid water content is calculated from measuring the heat released when water droplets are vaporized. A heated cylinder is exposed to the airstream and intercepts oncoming droplets. The electronics maintain this sensor at a constant temperature (approximately 125° C) and monitor the power required to regulate the temperature as droplets vaporize. This power is directly related to the amount of heat taken away by convection plus the heat of vaporization. The convective heat losses are known empirically and vary with airspeed, temperature and pressure. The liquid water content is calculated from power loss measured from the difference between total and convective power losses.

Figure 12 shows the LWC-200 sensing element. Fine copper wire is wound on a mandrel. An electrical current passes through it and heats the wire. The overall length of the coil is 4 cm, and it is divided into three sections. On each end, there is a 1 cm long coil called the “slave” coil, and the sensing element is the 2 cm center section. The purpose of the slave coils is to keep the temperature uniform across the sensing coil and avoid cooler end sections.

![Figure 12: LWC-200 sensing element. The unit is constructed so that it can fit in the connector in either direction.](image-url)
The hot-wire liquid water sensor coil is maintained at 125°C, and acts as a variable resistance in one arm of a Wheatstone Bridge circuit. The resistance of the sensor wire decreases as the wire temperature decreases. Temperature decreases can be caused by vaporization of water droplets or convective heat losses to air that flows past the sensor. Heat losses by conduction from the ends of the master coil are minimized by slave coils that are maintained at the same temperature as the master coil and are located at each end of the master. The master coil has a resistance of approximately 2Ω at room temperature. Each of the slave coils are half the resistance of the master coil and are connected in series through the connector in the strut to form a coil with the same resistance as the master.

The resistance of the sensing coil is directly proportional to its temperature; therefore, the control circuit maintains the sensor at constant temperature by maintaining it at constant resistance. A Wheatstone bridge is formed of four resistances, of which the master coil sensor is one. Three fixed resistors form the other three legs (see Figure 13). A 1Ω resistor is in series with the sensor and the two resistance values are selected so that the ratio of their resistances is the same as the ratio of the sensor resistance when it is heated to 125°C.

Example: In Figure 13, the potentiometer has a maximum resistance of 200 Ω and a nominal resistance of 100 Ω. The total resistance on this side of the bridge is thus 100 Ω + 432 Ω = 532 Ω. The ratio of the resistances on the right side of the bridge is then 1580/532, which forces the coil resistance to be maintained at 3 Ω in order for the bridge to remain balanced. The voltage difference between the resistors on the right side of the bridge and between the sensor and 1Ω resistor is monitored. When the bridge is balanced, this difference is zero. When it is greater or less than zero, either more or less current is flowing through the sensor, and therefore the sensor resistance has changed from its nominal value. The voltage difference is used to modulate the duty cycle of the square wave voltage used to heat the sensor. If the voltage drop increases, it indicates that the current through sensor of the bridge is decreasing, i.e. the temperature is increasing. The control electronics decrease the duty cycle of the square wave. This cools the sensor and the resistance decreases to once again balance the bridge.
This “Pulse Width Modulated” system of heating and cooling the coil is preferable over the original design by King in that much less heat is dissipated in the power FET’s that heat the master and slave coils. The original design used a DC voltage to heat the sensor and overheating of the power transistor was a habitual cause of failure.

The power dissipated by the sensor is the product of the current through the sensor and the voltage drop across it. The current is measured by measuring the voltage drop across the 1Ω resistor (I = E/R) and the voltage drop is measured directly across the sensor itself. These two signals are sent to individual amplifiers and then multiplied together in an analog multiplier. The output of this multiplier is scaled so that 1V = 10 watts.

![Figure 13: Circuitry Used to Control Master Coil Temperature](image)
4.1 LWC Specifications

<table>
<thead>
<tr>
<th>Technique:</th>
<th>Hot-wire Liquid Water Content sensor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measured Liquid Water Content Range:</td>
<td>0 – 3 g/m²</td>
</tr>
<tr>
<td>Air Speed Range:</td>
<td>10 – 200 m/sec</td>
</tr>
<tr>
<td>Sampling Frequency:</td>
<td>Up to 25 Hz⁸</td>
</tr>
<tr>
<td>Calibration:</td>
<td>None required</td>
</tr>
</tbody>
</table>

4.2 Ground Testing

The LWC system should be tested on the ground (1) after initial installation, (2) if a sensor has been replaced, or (3) if a problem with the system is suspected. If the LWC-200 is powered up with no air flow over the sensor, it will burn out in 1-2 seconds. Before activating the system, be sure that a constant air flow is supplied. The exhaust output of a typical vacuum cleaner Shop-Vac, directed on the sensing and slave coils, will supply an adequate air flow. As an alternative, a large blower or flow from a compressed air hose can be directed over the sensing and slave coils. At system power up, the analog signal will peak at about 4 volts, and immediately decrease to about 0.6 volts, as the sensor reaches operating temperature. A water-sprayer can then be used to add mist to the air flow. The analog output will increase to a higher level as the spray cools the sensor or if air velocity is increased.

The LWC-200 measurement units typically last for 100 or more flight hours. Flights in ice crystals will remove the insulation from the wire and will result in shorter lifetimes. Failure of the coil is indicated by a near-zero analog output voltage level. View this signal level at the end of each flight to ensure that the sensing coil has survived the flight.

---

⁷ Measured range depends on airspeed, temperature, and pressure. 0 – 3 g/m² is typical.
⁸ 25 Hz is the maximum LWC-200 sampling frequency. If you are using a version of the Particle Analysis and Display System (PADS) earlier than 3.5, however, the maximum frequency is 10 Hz. In addition, versions of PADS earlier than 3.5 assume a sampling frequency of 1 sec / 1 Hz. As a result, this frequency is recommended for users of PADS 2.7 and earlier.
Failure of the slave coil is monitored in the electronics. In normal operation, the PADS data system will report a value of <0.5 V for an operational slave coil. If the slave coil has failed, the voltage given will be > 4.5 V.

If there is uncertainty if the LWC-200 card has failed, a resistance check can be performed on the coils. Each slave coil will nominally be 1.0 Ω and the sensing element 2.0 Ω. Resistance values that vary by more than 10% of these values should be considered as defective. For measurement of the slave coils view the card with the measurement element at the top, make a resistance measurement between pin number 1 which will be on the left side, and then pin number 2 on the opposite side. To measure the other slave coil flip the card over and repeat the measurement. To measure the resistance of the sensing coil, make a measurement between pin 4 as counted from the top left and pin 7 as counted from the left on the reverse side.

If the sensor or slave coils have failed, replace the sensor with a fresh sensor card.

4.3 Replacement of the LWC-200 Sensing Element

To replace the LWC-200 card, remove the 5 screws that hold the card and retainer on the crown of the probe (Figure 14). This requires a 3/32 hex driver. Once the screws have been removed, the card can be pulled straight out. The retainer may also come out at the same time. If available, a thin film of silicone grease should be applied across the width of the card just above the center hole in the new LWC-200.
Insert the new card into the connector. The card is not orientation sensitive and can be inserted in either direction. If the card is inserted until it bottoms in the connector, the large center hole where one of the mounting screws passes will not line up. The card will need to be pulled out about 2 mm for this hole to line up. This can be accomplished by viewing the alignment with a flashlight.

The card retainer must be pushed in firmly to properly seat the gaskets and retain the LWC card. The retainer should fit flush with the fixed part of the mounting boss. If necessary, press on the retainer with a hard plastic tool like the handle of a screwdriver. When the retainer is properly seated and the LWC card aligned, the screws can be inserted without difficulty.

4.4 Data Interpretation

The King probe sensor is limited by collection efficiency considerations on the small droplet end of the spectrum and by vaporization time on the large end. The sensor has a diameter of approximately 2 mm and small water droplets, less than 10 µm, will not impact with 100% efficiency as they follow the airflow around the sensor. These losses are typically about 5% for 10 µm droplets but increase to greater than 20% for diameters less than 5 µm. This is normally not a major problem, since the largest fraction of the water mass is typically carried in droplets greater than 10 µm. In developing clouds, however, near cloud base where droplets are still quite small, or in cloud edges where entrainment and evaporation is occurring, the underestimation of liquid water content can be significant.

On the large droplet side, the King probe begins to underestimate the liquid water contained in drops larger than 30-40 µm as a result of incomplete evaporation as these larger droplets impact and are carried away by the airstream before sufficient heat has been transferred to vaporize them.

For information on LWC calculations, formulas, and wire-temperature estimation, see Appendix C.

5.0 Other Instrument Components

In addition to the CIP’s optical components with associated detectors and signal conditioning electronics, the instrument includes numerous other elements. These components are dedicated to measuring the ambient environmental conditions,
monitoring system performance, and providing heat to prevent icing or fogging of the optics while optimizing performance of the probe.

For information on the CIP heaters, see Appendix G. Other instrument components are explained below.

### 5.1 Sensors for Environmental Measurements

The CIP contains sensors to measure ambient temperature, relative humidity, and static and dynamic pressures. These measurements allow a computation of air speed at the point where the CIP samples air. This is referred to as Probe Air Speed (PAS), and may differ significantly from the aircraft’s True Air Speed (TAS) that is measured at a different location. The CIP’s PAS is a parameter needed to calculate statistics such as number and mass concentrations from the particle measurements.

Ambient temperature and relative humidity are read at a location at the base of the lower CIP arm. The sensors are placed at this location to minimize wetting in cloud environments. Ambient temperature is typically measured with an AD-590, while relative humidity is measured with a Honeywell HIH-3610 sensor. See analog.com and honeywell.com respectively for data sheets on these two sensors.

The Pitot tube supplies static and dynamic pressures, which are used in calculating air speed. The pressure transducers are located on the power supply board of the CIP. The static and dynamic pressure transducers are calibrated at DMT with a pressure standard. These derived calibration coefficients are entered into the PADS program under the “Configure Instrument” pull-down menu.

### 5.2 System Performance Sensors

The CIP measures several system performance variables. These are stored in the following housekeeping channels:

- Diode 1
- Diode 64
- Diode 32
- DSP Board Temp
- Ambient Temp
- Laser Current
- Laser Power

For more information on troubleshooting with housekeeping channels, see Section 8.1.
6.0 Particle Analysis and Display System (PADS)

PADS is a Windows-based, LabVIEW software package that is the default interface system for the CIP. It offers attractive display and analysis features, and data acquired with PADS can be stored to a file for later analysis. The program also stores all configuration information as a file header, so users can easily determine the system settings at the time of data acquisition.

The PADS display allows users to see particle images (Figure 15) and time-series charts of important variables. It also provides instantaneous readings for number concentration, liquid water content (LWC), and effective diameter.

![Figure 15: CIP Data, Histogram, and Particle Images (shown during glass-beads test)](image)

In addition, PADS is used to configure the set-up for the CIP. For instance, the program allows users to specify how many and what sizes of particles should get imaged, whether CIP measurements for channels like ambient temperature and probe air speed
(PAS) should be used as the global settings, and whether particles that hit end diodes should be rejected for sizing. See the *PADS Overview Manual (DOC-0300)* and the *PADS CIP Module Manual (DOC-0280)* for configuration and display details.  

Note that existing PADS users who receive a Korolev tip upgrade will have to update their software. See section 3.4 for details.

### 7.0 Maintenance

#### 7.1 Routine Maintenance

DMT recommends that you perform the following routine checks before each flight:

- Verify CIP calibration with the spinning disk (see the *Spinning Disk Calibrator Manual (DOC-0012)*).

- Do a visual check to ensure the CIP windows are clean; if they look dirty, clean them with a Q-tip and acetone or alcohol.

- Check that diode voltages 1, 32 and 64 are within acceptable levels. See Table 1 for acceptable values.

#### 7.2 Yearly Maintenance

DMT recommends returning your CIP to the factory for an annual cleaning and calibration. This will ensure your instrument is working properly and prolong its lifetime.

### 8.0 Instrument Troubleshooting and Repair

If the CIP does not seem to be functioning properly, it is advisable to begin troubleshooting by analyzing the instrument’s housekeeping data (see section 8.1). You can also examine various components of the instrument itself. The CIP electronics are modular in design, which allows for in-field troubleshooting and repair. There are four printed circuit boards (PCBs) that make up the CIP probe: the backplane, power module, DSP module, and diode array. The CIP backplane and power module are useful

---

9 PADS 2.X users should consult the *PADS Overview Manual (DOC-0300)* and the *PADS CIP Manual (DOC-0180)*, which describe the earlier version of PADS.
in identifying power problems; see section 8.2. The diode array board is the most likely cause of image problems, which are described in section 8.3. Finally, the instrument’s terminal strip can be used to determine if the CIP’s heaters are functioning properly. Section 8.4 describes how to attach an ohmmeter to the terminal strip to test the heaters.

Note that schematics for each of the CIP’s PCBs are shipped with the probe. See the CIP Block Diagram (in the Schematics) for a functional diagram of the CIP modules.

8.1 Troubleshooting with Housekeeping Channels

Several of the CIP’s housekeeping channels offer information that helps diagnose instrument health. These are described below. For information on how to convert the housekeeping analog-digital values returned by the CIP into the units given below, see Appendix E. If you have PADS, the program will have already performed these conversions.

**Diode Voltages 1, 32, and 64** store the representative power level of the laser light illuminating the corresponding diode on the CIP’s photodetector array. These indicators are used as a diagnostic. A very low or high voltage indicates a problem with the instrument, as does the appearance of one diode voltage being much higher or lower than the others. See the table below for acceptable values when no particles are present.

<table>
<thead>
<tr>
<th>Diode #</th>
<th>(1)</th>
<th>(32)</th>
<th>(64)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum Measured</td>
<td>1.5</td>
<td>2</td>
<td>1.5</td>
</tr>
<tr>
<td>Mean Measured</td>
<td>2.1</td>
<td>2.9</td>
<td>2.1</td>
</tr>
<tr>
<td>Maximum Measured</td>
<td>3.2</td>
<td>3.6</td>
<td>3.2</td>
</tr>
</tbody>
</table>

*Table 1: Acceptable Values for Diode Voltages 1, 32, and 64 when No Particles are Present*

A chronic low voltage may indicate a blockage of photodetector array. Although much less likely, a low voltage may also indicate the laser is nearing end of its life. In this case, the laser current reading will likely be higher than usual. A misalignment of the laser on the array will be seen as an imbalance in the #1 and #64 diode voltages with respect to one another.

**LWC Hotwire (V)** measures the voltage that is proportional to the power required to maintain the fixed temperature of the Hotwire Liquid Water Content sensor. This field
is only used in the event your CIP is wired to accept data from a hotwire. If your instrument system does not have a hotwire LWC, or if you have a combination system such as the CAPS where the CAS reads hotwire data, this field on the CIP will not store meaningful data.

On CIPs that do read hotwire LWC data, LWC hotwire voltage will vary depending on the water content in the air and the air density and velocity. In general, LWC Hotwire (V) readings fall between 0.0 - 1.5 V when no clouds are present and increase in clouds. A constant LWC Hotwire reading of 10 (the maximum value) indicates a potential problem with the LWC hotwire element, which is a consumable product that occasionally needs replacement.

**LWC Slave (V) / LWC_Slave_Monitor (V)** measures a voltage proportional to the power used by the end sections or “slaves” of the LWC Hotwire, which are used as active insulators. The slave voltage is not used in calculating LWC; rather, the slaves maintain a constant temperature for the measurement section of the LWC hotwire, which makes the device more accurate. An LWC Slave reading of more than five volts reflects a problem with the device. However, as with the LWC Hotwire (V) reading, this field will not store meaningful data unless the instrument system has a hotwire LWC sensor and the CIP is wired to read the sensor’s data.

**DSP Board Temp (C)** stores the temperature at the digital signal processing board. In flight situations, the DSP Board Temperature will typically be considerably higher than the ambient temperature. This is because the power consumption of the electronics raises the board’s temperature and because the board is encased in an insulating canister. A DSP Board temperature that is routinely above 50ºC will shorten the life of the laser.

**Laser Current** stores the electrical current flowing through the CIP’s laser diode. A reading of 60 - 120 mA indicates the instrument is functioning properly. A sudden change in current can reflect a problem with the instrument; however, a temporary drop in laser current is normal when anti-icing heaters are initially turned on. If the laser current is weak and the laser begins pulsing, the laser has become overheated. A current reading of zero indicates a failure. A high laser current can indicate the laser is nearing the end of its life.

**Laser Power** indicates the relative laser power as measured by the laser onboard power monitor. This reading is obtained by converting a digital count to volts, which correlates to the optical power produced by the laser diode. This channel is useful for observing general trends, but currently it does not accurately indicate absolute laser
power. However, the channel is still useful in diagnosing laser health. Laser power should stay stable ±20%; vacillation beyond this boundary indicates a problem with the laser.

Note that the CIP’s laser will most likely be the first instrument component that needs replacement. The laser has a lifetime of approximately 8,000 hours in ideal conditions, but this figure is reduced considerably if there are dramatic thermal variations and electrical oscillations.

### 8.2 Power Problems

The Power Module and the Backplane should be checked first in the event of power problems. The Backplane routes all signals including the power signal between boards, and its connectors must be properly mated and its voltages within required levels. To make sure the Power Module and Backplane are functioning properly, do the following with the probe on:

*Ensure the five voltage LEDs are lit on the Power Module. This board is mounted on the bottom in the CIP PCB area.*

1. Figure 16 shows the 28-V LED, while Figure 17 shows the four LEDs for ±5 V and ±15 V. If the 28V LED is unlit, there is no power to the CIP. It will be necessary to trace the power back through the canister and the aircraft. If any of the ±5 V and ±15 V LEDs is unlit, there is a DC-to-DC power supply problem. With the probe power disconnected, reseat the Backplane. If all the LEDs are lit, proceed with the rest of the tests.
Figure 16: 28-Volt LED

Figure 17: LEDs for ±5 or ±15 Voltages
2. Check for +5 Volts on pin one of both the DSP Board and Array connectors (ground is on pin 4 of the DSP Board connector, and 5 of the Array connector). See Figure 18 for details on Backplane pin locations.

![CIP Backplane Board](image)

*Figure 18: CIP Backplane Board. Note that both the Array and DSP Board Connectors have pin one in the lower right corner. The AMP connectors on the top also have pin one on the right.*

3. Check for +15 Volts on pin two of the DSP Board and pin three of the Array connectors.

4. Check for -15 Volts on pin 34 of the DSP Board connector.

5. If any of the voltage levels is bad, check the power connector for the correct levels (+5V on pin 1, ground on 2, -5V on 3, 15V on 5, -15V on 7).

**8.3 Image and Data Problems**

If the probe is producing no images, the size histogram is empty, or the images consistently have one diode that is always light or dark, there may be a failure on the diode array board. Section 8.3.1 discusses different causes of image problems. Section 8.3.2 provides background information about the diode array that is useful in understanding these issues.
8.3.1 Varieties of Image Problems

If the problem occurring is a pixel that is always “on” in the images, the voltage at the test point (see section 8.3.2) is probably stuck high. Monitor the test point and block the laser from hitting the diode array. If the test point voltage doesn’t drop, there is a problem with the first or second stage amplifier, or the potentiometer has failed. If the test point voltage does drop when the laser is obscured, then the 3rd-stage op amp or the comparator has failed.

If there are no images and/or no sizing histogram data, then a photodiode has probably failed at a low voltage. First check the -Particle signal, which is pin 30 on the Array Connector of the CIP Backplane board. If it is greater than 3V when the laser is not blocked, but falls to less than 2V if the laser is blocked briefly, then the diode array board is not the problem. If the test shows the array board is not working, check the diode test points (see section 8.3.2) with full laser illumination on the diode array. A single test point voltage well below 1V indicates an electrical problem. Contact DMT for further assistance.

8.3.2 Background Information on Diode Array Board

This section provides background information on the diode array board’s signal processing chains. To follow the explanation below, first locate the CIP Diode Array schematic and turn to the page labeled Diode Array Amplifiers 1, 3, 5, 7. (Labels are in the bottom right.) The following discussion pertains to the signal processing chain for diode 7, which is shown at the bottom of the page.

On the array board, there are 64 analog signal-processing circuits just like the one depicted in this signal processing chain. (The PCB is a high-density, 12-layer board, with multiple ground and power planes.) The input marker labeled IN-D is the input from a reverse-biased photodiode. When a particle is imaged, causing a decrease in light on the array, a shadowed photodiode produces a current that flows through R155, the 10KΩ resistor, generating a positive voltage swing on pin 14 of U16 on the order of 1 mV. Amplifier U17D inverts and amplifies this signal, producing a negative swing at its output, viewable at the TP7 test point. Normally, the signal at TP7, with the laser incident on the array, is between 2 and 2.5 Volts; a voltage below 1 under these conditions indicates a problem. When the diode is fully shadowed, the voltage drops to approximately 100 mV. Amplifier U18D DC couples this signal and divides it by ½. Thus comparator U61C will switch from high to low at its output, pin 8 (labeled Diode-D), when shadowing of the laser drops the voltage at TP7 to half its full laser incidence voltage. Note that as the laser is shadowed, the charge stored on capacitor C32 begins to drain off, and the Output of U18D will begin to decay.
The last thing to note on this chain is R129, a potentiometer. This adjusts the DC voltage of TP7. When there is no light on the diode array, the test point is set to approximately 100 mV.

Looking now at the NAND/NOR page of the schematic, note that all 64 of the comparator outputs are ANDed, then ORed together, so that if any one comparator goes low, the \(-\text{PARTICLE}\) signal goes low. The digital electronics on the DSP board watch this signal to determine when there is a particle and when to begin storing image data. If the signal stays low for more than 100 sample clocks, the electronics stop storing the image until this signal again goes high. If any one signal chain fails such that its comparator output is stuck low, the CIP will stop measuring particles.

The DOF comparators perform the same function, but require the DC test point outputs to drop to 1/3 their nominal voltage before triggering. The digital electronics only use this signal to determine whether the particle should be based on depth of field. The signal does not affect particle image acquisition.

### 8.4 Heater Problems

To test for shorts or burnt-out connections on the CIP heaters, measure the actual resistance of the anti-ice heaters and compare this to the calculated value. To measure the actual resistance, hook one of the ohmmeter’s probes up to a connector with white wires and the other probe to a connector with black wires, as shown in Figure 19. Measure the resistance.
Next, derive the calculated resistance for all the CIP heaters—the Pitot heater, the two parallel CIP cross-arm heaters, and the two in-series arm-tip heaters. The total voltage, \( V \), and current in Amps, \( I \), for your system should be printed on the metal specifications tag on the side of the probe. These are labeled \textit{HTR Volts} and \textit{HTR Current}, respectively.

Resistance in Ohms, \( R_{\text{Calc}} \), is calculated using the following derivation of Ohm’s Law:

\[
R_{\text{Calc}} = \frac{V}{I}
\]

where
\[
\begin{align*}
V &= \text{Voltage} \\
I &= \text{Amperes}
\end{align*}
\]
Example: A CIP has a heater voltage of 28 VDC and a heater current of 2.14 A. The calculated or expected resistance is 28 VDC/2.14A = 13.08 Ohms.

8.5 Contacting DMT regarding CIP Problems

If none of the above trouble-shooting actions resolves the problem with the CIP, contact DMT for assistance. Please be prepared to send a data set that illustrates the problem. If you are using PADS, data files should be in the following format:

- All data files from the sampling session should be included with their original names and in their original directory. This includes instrument data files, configuration files, and log files. Image files are optional.
- Data files should be the originals that PADS created or unmodified copies of these originals.

9.0 Verifying CIP Calibration with the Spinning Disk Calibrator

The DMT spinning disk calibrator allows users to validate the CIP’s size resolution. The calibrator does not fix a faulty optical magnification that sets the size resolution; rather, it is intended solely as a diagnostic.

See Spinning Disk Calibrator Manual (DOC-0012) for information on mounting, calibrating, using, and cleaning the spinning disk.
# Appendix A: Revisions to Manual

<table>
<thead>
<tr>
<th>Rev. Date</th>
<th>Rev No.</th>
<th>Summary</th>
<th>Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-9-10</td>
<td>G</td>
<td>Moved Heater and Data Communication sections to Appendices</td>
<td>Appendices A, B, and C</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Added laser safety sheet</td>
<td>Front matter</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Added probe unpacking and handling section</td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Incorporated LWC section from LWC manual</td>
<td>4.0</td>
</tr>
<tr>
<td>10-26-10</td>
<td>H</td>
<td>Removed packing list</td>
<td>Appendices</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Inserted mounting instructions</td>
<td></td>
</tr>
<tr>
<td>1-13-11</td>
<td>I</td>
<td>Inserted information about Korolev tips</td>
<td>1.1, 1.3, 2.2, 3.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Updated PADS screen shot to PADS CIP version 3</td>
<td>6.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Changed True Air Speed (TAS) references to Probe Air Speed (PAS), to follow PADS naming change</td>
<td>Throughout</td>
</tr>
<tr>
<td>1-14-11</td>
<td>J</td>
<td>Added routine maintenance section</td>
<td>7.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Updated diode 1, 32, and 64 voltages</td>
<td>Table 1</td>
</tr>
<tr>
<td>3-31-11</td>
<td>K</td>
<td>Deleted section on 2D data communication and referred readers to DOC-201.</td>
<td>Appendix F</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Updated electrical specifications to include information for 115VAC option and Korolev-tips option</td>
<td>1.2.2</td>
</tr>
<tr>
<td>4-25-11</td>
<td>K-1</td>
<td>Corrected anti-ice power requirement for 115VAC with Korolev tips</td>
<td>1.2.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Corrected voltage reading for case where photodiode is fully shadowed</td>
<td>8.3.2</td>
</tr>
<tr>
<td>7-18-11</td>
<td>K-2</td>
<td>Removed outdated schematics</td>
<td>Appendix I</td>
</tr>
<tr>
<td>4-19-12</td>
<td>L</td>
<td>Removed schematics in accordance with new policy</td>
<td>Appendix I</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Added information on the DMT Instrument Locator</td>
<td>Appendix I</td>
</tr>
<tr>
<td>7-30-12</td>
<td>L-1</td>
<td>Added recommendation to return CIP to factory for annual cleaning and calibration</td>
<td>7.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Updated 1D data sampling frequency</td>
<td>1.2.1</td>
</tr>
<tr>
<td>6-26-13</td>
<td>L-2</td>
<td>Updated LWC-100 references and specs to LWC-200</td>
<td>Throughout</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Removed information on heaters</td>
<td>Appendix G</td>
</tr>
<tr>
<td>7-10-12</td>
<td>L-3</td>
<td>Updated electronic specifications</td>
<td>1.2.2</td>
</tr>
</tbody>
</table>
Appendix B: Probe Air Speed Calculations

Probe Air Speed (PAS)

The CIP’s PAS is the velocity of the air at the point where it is measured by the CIP’s Pitot-static system, which may differ from the speed of the aircraft by up to 20%.

Options for Calculating Probe Air Speed

The CIP allows two options for calculating probe air speed. The CIP can calculate PAS internally using an on-board Pitot sensor, or the host computer can perform the calculation and relay information about the PAS clock rate to the CIP. The Setup Data Command sets the source for the probe air speed. If the command parameter Probe Air Speed Source = 1, the host computer acts as the source. If Probe Air Speed Source = 0, air speed is calculated on-board the CIP as described below.

The host computer is the default PAS source and is preferable to using the CIP’s on-board Pitot sensor for several reasons. The host computer can store the results of PAS calculations, which the CIP does not. Moreover, the host computer is likely to generate more accurate results, as a data system such as PADS uses sensor calibrations that are specific to individual probes. The CIP, in contrast, uses default factory calibrations.

If you are using a host computer and external data system as the PAS Source, see the software manual for details on how the program performs air speed calculations.

Calculating Probe Air Speed On-Board the CIP

If the CIP is selected as the Probe Air Speed Source (see Options for Calculating Probe Air Speed, above), it uses the following equations to calculate probe air speed. It executes these equations once per second using the most recently updated housekeeping parameters. Note that onboard CIP calculations are executed using the default factory calibrations for sensors.

Ambient Temperature

Ambient Temperature is a variable in calculated air speed, so this temperature must be known before air speed calculations can proceed. The CIP actually stores the measured temperature rather than the ambient temperature. The measured
temperature is higher than the ambient temperature because the air warms by compressional heating near the temperature sensor.

This additional heating is a function of the air density and velocity and can be calculated using Bernoulli’s equation. To convert measured temperature to ambient temperature, the instrument uses the following standard formula derived from Bernoulli’s equation:

\[
T_a = \frac{T_m}{1 + M^2 \cdot r \cdot \frac{\gamma - 1}{2}}
\]

where

\[T_a\] = Ambient Temperature
\[T_m\] = Measured Temperature
\[M\] = Mach number (see Mach Number entry below for calculations)
\[r\] = Recovery coefficient, which is currently set to 1. In theory, this number is a constant that depends on the probe. It is equal to \((1 - f^2)\), where \(f\) is fraction of probe air speed, PAS, at which the air around the sensor is flowing. The host computer sends the CIP the recovery coefficient during the Setup Data command.
\[\gamma\] = 1.403509, the ratio of specific heat for dry air at a constant pressure (0.24 cal/gK) to specific heat for dry air at constant volume (0.171 cal/gK)

This formula is taken from Appendix B, Section 7 of Bulletin #9 from the National Center for Atmospheric Research’s Research Aviation Facility (RAF). The bulletin is available online at [http://www.eol.ucar.edu/raf/Bulletins/b9appdx_B.html#THERMO](http://www.eol.ucar.edu/raf/Bulletins/b9appdx_B.html#THERMO)

Mach Number

Mach number is also a variable in air speed calculations. The CIP uses the following formula to calculate Mach Number:

\[
M = \sqrt{\frac{2 \cdot C_r \cdot \left(\frac{Q_c}{P_c} + 1\right)^{\frac{R}{C_r} - 1}}{R}}
\]

where
\[ S = \left[ \frac{\gamma \cdot B \cdot T_a}{m} \right]^{0.5} = 20.06 \cdot T_a^{0.5} \]

where
\[ m = \text{mass of one molecule of air, } 4.8 \times 10^{-26} \text{ kg} \]
\[ B = \text{Boltzmann’s Constant (gas constant per molecule) } = 1.38 \times 10^{-23} \text{ joule molecule}^{-1} \text{ K}^{-1} \]

**Probe Air Speed**

The CIP calculates air speed according to the formula below:

\[ U_a = M \sqrt{T_a \cdot \gamma \cdot R} \]

where
\[ U_a = \text{Air speed at the probe in m/sec} \]
\[ \gamma = 1.403509, \text{ the ratio of specific heat for dry air at a constant pressure (0.24 cal/gK) to specific heat for dry air at constant volume (0.171 cal/gK)} \]
\[ R = \text{Gas constant for dry air, 286.9 J/kgK} \]
\[ T_a = \text{Ambient temperature (K)} \]
\[ M = \text{Mach number} \]
Appendix C: LWC-200 Calculations and Formulas

The power dissipated by the sensing wire is the total of the convective, radiative and latent heat of vaporization losses, i.e.

\[ P_t = P_d + P_r + P_w \]

The convective heat losses, \( P_d \), result from the air that flows past the heated sensor. The radiative heat losses are negligible compared to the convective losses and are not included in the overall heat balance equation. The latent heat losses are a result of water droplets that strike or pass near the sensor and are vaporized. The convective heat loss term has been empirically derived (Zukauskas and Ziugzda, 1985) and is related to the Reynolds number and Prandtl number by

\[ P_d = A_0 \pi k(T_s - T_a)Re^xPr^y \]

where \( k \) is the thermal conductivity of the air, \( T_s \) is the sensor temperature, \( T_a \) is the air temperature, \( Re \) is the Reynold's number, \( Pr \) is the Prandtl number and \( A_0 \), \( x \) and \( y \) are constants for a heated cylinder at high Reynold's number. The Reynold's number is expressed as

\[ Re = \frac{\rho VP}{v} \]

where \( \rho \), \( V \), \( P \) and \( \nu \) are the air density, velocity, pressure and viscosity, respectively, and \( d \) is the diameter of the sensor. The Prandtl number is the thermal conductivity divided by the viscosity. The density, viscosity, and thermal conductivity are all functions of temperature. The temperature used to calculate these quantities is referred to as the film temperature and is normally computed as the arithmetic average between the sensor temperature and the environmental air temperature.

The heat loss that results from vaporizing droplets is computed as follows:

\[ P_w = ldvw [L_v + c(T_b - T_a)] \]

where \( l \) is the sensor length, \( w \) is the liquid water content, \( L_v \) is the latent heat of vaporization, \( c \) is the specific heat of water, and \( T_b \) is the boiling point of water. When the total power is measured, the liquid water content is calculated as

\[ w = \frac{P - P_d}{ldv[L_v + c(T_b - T_a)]]} \]
The following FORTRAN code computes the liquid water content.

C DMT Probe Liquid Water Content Code
C
C Definitions:
C T  = Air Temperature in Celsius
C PMB = Pressure in millibars
C PAS = Air speed in meters/second
C V  = Voltage output from lwc probe (0-10 V)
C TW = Wire temperature in Celsius sensor (125°C)
C L  = length of sensor (2.0 cm)
C D  = diameter of sensor (0.18 cm)
C
C Start of Code
C
data tw/125. /
data l,d/2.0,0.18 /
TK=T+273.16
TWK=TW+273.16
TFLM=(TWK+TK)/2.
C Convert volts to watts
P = 10*V
C
C CALCULATE THE THERMAL CONDUCTIVITY
CND=5.8E-5*(398./(125.+TFLM))*(TFLM/273.)**1.5
CNDW=5.8E-5*(398./(125.+TWK))*(TWK/273.)**1.5
C
C CALCULATE THE VISCOSITY
VISC=1.718E-4*(393./(120.+TFLM))*(TFLM/273.)**1.5
VSCW=1.718E-4*(393./(120.+TWK))*(TWK/273.)**1.5
C
C CALCULATE THE DENSITY
DENS=PMB/(2870.5*TFLM)
FCT=3.14159*L*CND*(TWK-TK)
C The Reynold's Number
RE=100.*DENS*PAS*D/VISC
C Prandtl Numbers
PRF=0.24*VISC/CND
PRW=0.24*VSCW)/CNDW
C Calculate the dry air loss
DRYP=0.26*RE**0.6*PRF**0.37*(PRF/PRW)**0.25*FCT/0.239
FACT=1.238E6*0.239/(L*D*PAS*100.*(597.3+373.16-TK))
C Calculate the liquid water content
LWC=(P-DRYP)*FACT

C

C End of liquid water code

Wire Temperature Estimation

The temperature of the sensor is difficult to measure directly. The temperature of the sensor is set at the factory to be approximately 125° C. This is determined by using a wax material that melts at a specific temperature. Each sensor has a slightly different resistance, however, causing a slightly different set temperature. The wire temperature is more accurately determined from actual flight data. In principle, if the wire temperature is correctly selected, then the derived liquid water content will be equal to zero when out of cloud, regardless of the environmental conditions or air speed. This is because the measured power loss from the sensor should match the calculated dry air losses if the dry air loss equation is correct. Assuming that air speed, pressure, and temperature are accurately known, the only remaining unknown is the sensor temperature, which affects the Reynold’s number and the Prandtl number in the dry air term, as well as the thermal conductivity. If the assumed sensor temperature is too low, the calculated dry air loss will be too low and the calculated liquid water content will be greater than zero in clear air. Likewise, assuming too hot a temperature will cause an overestimate of the dry air term leading to negative liquid water contents in clear air.

The best technique is to fly the sensor in clear air over the range of air speeds and temperature that the sensor is expected to encounter during normal operation. Try a number of different wire temperature until one is found that causes the smallest possible zero offset under all conditions.

The FORTRAN code below performs this function automatically.

C:::::::::::::::DMT LWC Probe Wire Temperature Estimation Routine:::::::::::::::
C   This program determines the wire temperature of the LWC probe
C   This program requires an ASCII file with the following variables
C   In this order:
C   Time, Temperature, Pressure, Airspeed, FSSP Concentration, DMT LWC Probe Power
C
The physical principle is that the relationship between Nusselt number
and Reynold’s number and Prandtl number has been relatively well
estdablished in many laboratory experiments. The only factor that would
cpossibly vary will be the so called film temperature which is usually
taken to be the average between the wire and environmental temperature.
This program leaves the Nu, Re, and Pr relationships fixed while
determining the film temperature.
C
character*50 filenm
integer istart(3,20),istop(3,20)
real zero(10,90),std(10,90)
data zero/900*0.0/,std/900*0.0/
c Sensor length (cm)
data xlen/2.0/
c Sensor Diameter (cm)
data diam/0.18/
data npts/0/
C FUNCTION TO CALCULATE THE CONDUCTIVITY
CNDCT(T)=5.8E-5*(398./(125.+T))*(T/273.)**1.5
C FUNCTION TO CALCULATE THE VISCOSITY
VISC(T)=1.718E-4*(393./(120.+T))*(T/273.)**1.5
C FUNCTION TO CALCULATE THE DENSITY
DENS(P,T)=P/(2870.5*T)
490 write(6,7001)
7001 FORMAT("Enter Data Filename "$)
READ(5,7105) filenm
7105 format(a50)
open(20,file=filenm)
122 twire0=120.
twire1=180.
twired=1.
tsfct0=.9
tsfct1=.9
tsfctd=.1
npas=1+(tsfct1-tsfct0)/tsfctd
ntmp=(twire1-twire0)/twired
C ............ENTER IN THE DESIRED TIME SEGMENTS
80 ITMS=0
85 ITMS=ITMS+1
write(6,7032)ITMS
7032 format("Enter Time interval #",i2,"(-1=end)"/
$ "HHMMSS HHMMSS")
READ(5,7033)(ISTART(J,ITMS),J=1,3),(ISTOP(J,ITMS),J=1,3)
7033 FORMAT(3I2,X,3I2)
IF (istart(1,ITMS).ge.0)goto 85
ITMS=ITMS-1
c write(6,8444)
8444 format("PAS Factor = '$")
c read(5,*pasfct
do 9000 it=1,ITMS
startm=istart(1,it)*3600.+istart(2,it)*60.+istart(3,it)
start=startm
stoptm=istop(1,it)*3600.+istop(2,it)*60.+istop(3,it)
startx=xtim(startm)
stoptx=xtim(stoptm+npts)
100 read(20,8000,end=9000,err=9000)ihr,imin,isec,t,pmb,pas,
$ concf,pwr$
c   write(6,8000)ihr,imin,isec,t,pmb,pas,concf,pwr
8000 format(1x,3i2,f12.2,f8.2,f8.2,f8.2,f6.2)
206 TIME=IHR*3600.+IMIN*60.+ISEC
   if (amod(time,600).eq.0)print *,ihr,imin,isec,t,pmb,pas,
$ concf,pwr$
   IF (TIME .LT. startm)GOTO 100
   if (time .gt. stoptm)goto 9000
   if ((concf .gt. 1.0).or.(pwr .lt. 10).or.(pas .lt. 50))goto 100
   c   write(6,9696)T,PMB,P,pas,concf
9696 FORMAT(" T,PMB,P,pas,concf=",5F10.3)
   TK=T+273.16
   do 250 I=1,npas
   pasfct=tsfct0+(I-1)*tsfctd
   do 200 j=1,ntmp
   twire=twire0+(j-1)*twired+273.16
   tf=(twire+tk)/2.0
   DNS=DENS(PMB,TF)
   CND=CNDCT(TF)
   VSC=VISC(TF)
      fct=3.14159*xlen*cnd*(twire-tk)
   RE=100.*DNS*PAS*pasfct*diam/VSC
      prf=0.24*vsc/cnd
      prw=0.24*visc(twire)/cndct(twire)
      dryp=0.26*re**0.6*prf**0.37*(prf/prw)**0.25*fct/0.239
      diff=abs(dryp-pwr)
      zero(i,j)=zero(i,j)+diff
      std(i,j)=std(i,j)+diff*diff
   200   continue
   250   continue
   if (amod(time,600).eq.0)print *,twire,tf,re,dryp,diff
   npts=npts+1
   goto 100
9000 continue
   do 9020 I=1,npas
   pasfct=tsfct0+(I-1)*tsfctd
   twrmin=0.0
   stdmin=0.0
   avgmin=1.0e6
   do 9010 j=1,ntmp
   zero(i,j)=zero(i,j)/npts
   std(i,j)=std(i,j)/npts-zero(i,j)*zero(i,j)
   if (std(i,j).lt.0)std(i,j)=sqrt(std(i,j))
   twire=twire0+(j-1)*twired
   if (zero(i,j) .lt. avgmin)then
      twrmin = twire
      stdmin = std(i,j)
      avgmin = zero(i,j)
      if (end if
write(33,8257)twire,zero(i,j),std(i,j)

8257  format('Wire Temp. =',f6.1,
$    ' Avg. Offset# =',f6.3,' +-',f6.3)
9010  continue
   write(33,8258)twrmin,avgmin,stdmin
8258  format('******Wire Temperature@minimum offset=',f6.1,
$    ' Avg. Offset# =',f6.3,' +-',f6.3)
9020  continue
END

function xtim(secs)
ihr=int(secs/3600)
imin=int((secs-ihr*3600)/60)
isec=secs-ihr*3600-imin*60
xtim=ihr*10000 + imin*100 +isec
return
end

Appendix D: LWC-200 References


Appendix E: Host Computer - CIP
Communications for 1D Particle-Size Data

Communications Parameters

Any computer with an RS-232 or RS-422 port should be capable of sending and receiving 1D particle-size data to and from the CIP. The port parameters for communications should be set as follows:

- 56K baud
- 8-N-1 data format:
  - 8-bit data bytes
  - One start bit
  - One stop bit
  - No parity checking

The CIP and host computer send data to each other in data packets. Within these packets, data are stored in two types of structures: unsigned characters and unsigned integers. More information about these structures appears in Table 2 below.

<table>
<thead>
<tr>
<th>Data Structure</th>
<th>Abbreviation</th>
<th>Number of Bits</th>
<th>Order of Bytes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unsigned Character</td>
<td>U8</td>
<td>8</td>
<td>N/A (only one byte)</td>
</tr>
<tr>
<td>Unsigned Integer</td>
<td>U16</td>
<td>16</td>
<td>1.) Least significant byte</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2.) Most significant byte</td>
</tr>
<tr>
<td>Unsigned Long</td>
<td>U32</td>
<td>32</td>
<td>1.) Least significant byte</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2.) 2\textsuperscript{nd}-least significant byte</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3.) 3\textsupernum{-least significant byte}</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4.) Most significant byte</td>
</tr>
</tbody>
</table>

Table 2: Data Structures Used in CIP-Host Computer Communications

Initiating Communications

The host computer initiates all communications with the CIP. Since the CIP only responds with data after it has received a request for data, all of the timing for data acquisition needs to be performed in the host processor. To increase the rate data are relayed from the CIP, the host only needs to increase the rate at which it makes
requests for data. After completing a data request, the CIP clears all of its summation registers and starts taking a new set of data.

Note that the first packet of particle information the CIP sends cannot be easily compared to subsequent packets. This is because the time interval between instrument start-up and the first data packet being sent likely differs from the standard sampling interval.

List of Communications Commands

There are several commands that host computer can send to the CIP:

- Setup Data Acquisition Parameters command (Command = 1)
- Send Data command (Command = 2)
- Reset command (Command = 3)
- Set Absolute Time command (Command = 5)
- Get Version Number command (Command = 6)

The function, data format, and response of each of these commands are discussed in the following sections.

Setup Data Command

The host computer sends the CIP a Setup Data command to set up the data acquisition parameters. The command follows the format shown below. Full definitions of these parameters appear after the table.

<table>
<thead>
<tr>
<th>Byte</th>
<th>Parameter Description</th>
<th>Data Type</th>
<th>Ex. Hex</th>
<th>Parameter Setting as Indicated by Hex Value in Previous Column</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Start Byte</td>
<td>U8</td>
<td>1B</td>
<td>1B h = ASCII 27 = Esc Character</td>
</tr>
<tr>
<td>1</td>
<td>Command Number</td>
<td>U8</td>
<td>01</td>
<td>01 h = Setup Data Command</td>
</tr>
<tr>
<td>2</td>
<td>Probe Airspeed Source</td>
<td>U16</td>
<td>01</td>
<td>0001 h = Host Computer</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td>00</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>DOF Reject</td>
<td>U16</td>
<td>01</td>
<td>0001 h = True</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td>00</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Particle Sizing Dimension</td>
<td>U8</td>
<td>01</td>
<td>01 h = 1 = Width</td>
</tr>
<tr>
<td>7</td>
<td>Recovery Coefficient</td>
<td>U8</td>
<td>FF</td>
<td>FF h = 255 dec = .11111111 bin</td>
</tr>
</tbody>
</table>
Definition of the Declared Parameters

The definitions and possible values for the parameters the host computer sends to the CIP are explained below.

- **Start Byte**
  A byte indicating the start of the packet. This parameter is always ASCII 27, HEX = 1B, the escape character.

- **Command Number**
  The command number, in this case 01h (setup data).

- **Probe Airspeed Source**
  An indicator that selects the probe air speed (PAS) source, either an external source or an on-board Pitot sensor. *Default:* On startup, the CIP defaults to using an external PAS clock. If this option is selected, CIP data may still supply the parameters used to calculate PAS, but the host computer will perform these calculations. If the on-board Pitot sensor option is selected, the CIP performs all PAS calculations internally (see Appendix B) but does not relay PAS to the host computer.

- **DOF Reject**
  A parameter that commands the CIP to either reject or not reject particles for statistical processing based on the depth of field signal. 0000h = include particles outside the DOF, 0001h = reject them. *Default:* On startup, the CIP defaults to rejecting particles that fall outside the depth of field.

- **Particle Sizing Dimension**
  The dimension for measuring particles. This can be either width (recommended) or slice count. 01 h = width, 00 h = slice count.

- **Recovery Coefficient**
  The recovery coefficient to be used in calculating probe air speed (see Appendix B). This is a binary value with the radix point assumed to be the left of the most significant character of the byte. Thus, to send the default value, 1, the closest number would be 255 decimal, FF hex. In binary, this looks like 0.11111111, with a corresponding value 0.9960.

- **Checksum**
  The 16-bit sum of all the 8-bit characters in the packet.
CIP Response to Setup Data Command

After the CIP receives a setup data command, it responds with two ACK characters (ASCII character 6, HEX = 06), as follows.

<table>
<thead>
<tr>
<th>Byte</th>
<th>Parameter Description</th>
<th>Data Type</th>
<th>Ex. Hex Value</th>
<th>Parameter Setting as Indicated by Hex Value in Previous Column</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Response</td>
<td>U8</td>
<td>06</td>
<td>06 h = ACK</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>U8</td>
<td>06</td>
<td>06 h = ACK</td>
</tr>
</tbody>
</table>

Table 4: CIP Response to Setup Data Command – Data Packet

Send Data Command

The second type of command the host computer sends to the CIP probe is the Send Data Command, command 2. This command instructs the probe to send back all the data it has acquired since it last relayed data to the host computer. Table 5 shows the packet that the computer sends to the CIP probe to request a data packet. Full definitions for the parameters appear in the following section.

<table>
<thead>
<tr>
<th>Byte</th>
<th>Parameter Description</th>
<th>Data Type</th>
<th>Ex. Hex Value</th>
<th>Parameter Setting as Indicated by Hex Value in Previous Column</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Start Byte</td>
<td>U8</td>
<td>1B</td>
<td>1B h = ASCII 27 = Esc Character</td>
</tr>
<tr>
<td>1</td>
<td>Command Number</td>
<td>U8</td>
<td>02</td>
<td>02 = Send Data Command</td>
</tr>
<tr>
<td>2</td>
<td>Host Sync Counter</td>
<td>U16</td>
<td>01</td>
<td>0001 h = 1</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td>00</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>PAS Coefficient N</td>
<td>U32</td>
<td>00</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td>08</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td>34</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Relay Control</td>
<td>U16</td>
<td>00</td>
<td>N/A</td>
</tr>
<tr>
<td>9</td>
<td></td>
<td></td>
<td>00</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Checksum</td>
<td>U16</td>
<td>9A</td>
<td>009A h = 154</td>
</tr>
<tr>
<td>11</td>
<td></td>
<td></td>
<td>00</td>
<td></td>
</tr>
</tbody>
</table>

Table 5: Send Data Command – Data Packet
Definition of the Declared Parameters

The following table provides definitions and possible values for the parameters the host computer sends to the CIP during the Send Data command.

- **Start Byte**: A byte indicating the start of the packet. This parameter is always ASCII 27, HEX = 1B, the escape character.
- **Command Number**: The command number, in this case 02h (send data).
- **Host Sync Counter**: A 16-bit communications check. The host sync counter is sent back to the host computer in the response data packet. No processing needs to be done with the Host Sync Counter.
- **PAS Coefficient N**: A coefficient used in the default circumstance that the host computer, not the CIP, is calculating PAS. If CIP is calculating PAS on-board these values are ignored.
- **Relay Control**: A parameter that is not used on a standard CIP.
- **Checksum**: The 16-bit sum of all the 8-bit characters in the packet.

Note on Probe Air Speed (PAS) Coefficient

The PAS Coefficient is used to calibrate the clock rate generator in the event the computer tells the probe how fast to sample, i.e. if the PAS Source is the host computer. (The probe can also set the PAS clock independently, without instruction from the host computer, in which case the PAS coefficient is ignored.) The PAS Coefficient \( N \) is calculated as follows:

\[
N = \frac{\text{PAS in m/sec}}{\text{probe resolution in m}} \times 34.415
\]

For a 25-µm resolution CIP, this equates to:

\[
N = \frac{\text{PAS in m/sec}}{25 \times 10^{-6}} \times 34.415 = \frac{\text{PAS in m/sec}}{1.37659208 \times 10^6} \times 34.415
\]

For a 15-µm resolution CIP, it equates to:

\[
N = \frac{\text{PAS in m/sec}}{15 \times 10^{-6}} \times 34.415 = \frac{\text{PAS in m/sec}}{2.29432014 \times 10^6} \times 34.415
\]

**Example:**

Say PAS is 100 m/s and the CIP has a resolution of 25 µm. Using Equation 1 above, PAS \( N \) is 137659208. In a 32-bit binary format, this equates to
CIP Response to the Send Data Command

When the CIP receives a Send Data command, it replies with the data packet shown in Table 6. Full definitions of the parameters appear in the following section.

<table>
<thead>
<tr>
<th>Byte</th>
<th>Parameter Description</th>
<th>Data Type</th>
<th>Ex. Hex Value</th>
<th>Parameter Setting as Indicated by Hex Value in Previous Column</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Header Part I</td>
<td>U8</td>
<td>BE</td>
<td>BE h = 190</td>
</tr>
<tr>
<td>1</td>
<td>Header Part II</td>
<td>U8</td>
<td>EF</td>
<td>EF h = 239</td>
</tr>
<tr>
<td>2</td>
<td>Packet Byte Count</td>
<td>U16</td>
<td>B0</td>
<td>00B0 h = 176</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Oversize Reject</td>
<td>U16</td>
<td>00</td>
<td>0000 h = 0</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td>00</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Bin 1 Count</td>
<td>U16</td>
<td>00</td>
<td>0020 h = 32</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Bin 2 Count</td>
<td>U16</td>
<td>00</td>
<td>000A h = 10</td>
</tr>
<tr>
<td>9</td>
<td></td>
<td></td>
<td>0A</td>
<td></td>
</tr>
<tr>
<td>128</td>
<td>Bin 62 Count</td>
<td>U16</td>
<td>00</td>
<td>0000 h = 0</td>
</tr>
<tr>
<td>129</td>
<td></td>
<td></td>
<td>00</td>
<td></td>
</tr>
<tr>
<td>130</td>
<td>DOF Reject Count</td>
<td>U16</td>
<td>00</td>
<td>0000 h = 00</td>
</tr>
<tr>
<td>131</td>
<td></td>
<td></td>
<td>00</td>
<td></td>
</tr>
<tr>
<td>132</td>
<td>End Reject Count</td>
<td>U16</td>
<td>12</td>
<td>0012 h = 18</td>
</tr>
<tr>
<td>133</td>
<td></td>
<td></td>
<td>00</td>
<td></td>
</tr>
<tr>
<td>134</td>
<td>Housekeeping 0 / Diode 1 Voltage</td>
<td>U16</td>
<td>33</td>
<td>0333 h = 819 ADC counts</td>
</tr>
<tr>
<td>135</td>
<td></td>
<td></td>
<td>03</td>
<td></td>
</tr>
<tr>
<td>136</td>
<td>Housekeeping 1 / Diode 64 Voltage</td>
<td>U16</td>
<td>3E</td>
<td>033E h = 830 ADC counts</td>
</tr>
<tr>
<td>137</td>
<td></td>
<td></td>
<td>03</td>
<td></td>
</tr>
<tr>
<td>…</td>
<td>Counts for Bins 3 – 61</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>164</td>
<td>Housekeeping 15 /</td>
<td>U16</td>
<td>00</td>
<td>0000 h = 0</td>
</tr>
</tbody>
</table>

(See Table 7 for Housekeeping Channels)
### Definition of the Declared Parameters

The following table provides definitions and possible values for the parameters the CIP sends to the host computer as a response to the Send Data command.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laser Power</td>
<td>00</td>
</tr>
<tr>
<td>Particle Counter</td>
<td>U16, FA 00, 00FA h = 250</td>
</tr>
<tr>
<td>Seconds/Milliseconds</td>
<td>U16, E7, 00EF, EFE7h = 59 seconds and 999 msec</td>
</tr>
<tr>
<td>Hours/Minutes</td>
<td>U16, FB 05, 05FBh = 23 hours 59 minutes</td>
</tr>
<tr>
<td>Host Sync Counter</td>
<td>U16, 00 00, 0000 h = 0</td>
</tr>
<tr>
<td>Reset Flag</td>
<td>U16, 00 00, 0000 h = 0</td>
</tr>
<tr>
<td>Checksum</td>
<td>U16, 0C 0A, 0A0C h = 2572</td>
</tr>
<tr>
<td>Trailer Part I</td>
<td>U8, FA, FA h = 250</td>
</tr>
<tr>
<td>Trailer Part II</td>
<td>U8, DE, DE h = 222</td>
</tr>
</tbody>
</table>

Table 6: CIP Response to the Send Data Command – Data Packet
end diodes.

- **Housekeeping Channels**
  Housekeeping data measured during the sample period. See “CIP Housekeeping Channels” for more information.

- **Particle Counter**
  A 16-bit count of the number of particles sampled. This counter includes both sized particles and those rejected because they hit one or more end diodes or fell outside the depth of field.

- **Seconds / Milliseconds**
  The seconds and milliseconds given by the CIP absolute time clock at the time the data packet was sent. Note that these parameters do not conform to byte boundaries: bits 15-10 store the seconds and bits 9-0 the milliseconds. So a hex value of EFE7h indicates a binary value of:

  $\begin{array}{c|c}
  \text{Seconds} & \text{Milliseconds} \\
  11101111110011 & \\
  \end{array}$

  which translates into 59 seconds (dec) and 999 msec.

- **Hours / Minutes**
  The hours and minutes given by the CIP absolute time clock at the time the data packet was sent. Note that these parameters do not conform to byte boundaries: bits 10-6 store the hours and bits 5-0 store the minutes. So a hex value of 05FBh indicates a binary value of:

  $\begin{array}{c|c}
  \text{Hours} & \text{Minutes} \\
  1011111101 & \\
  \end{array}$

  which translates to 23 hours and 59 minutes. (The on-board clock counts to 24 hours.)

- **Host Sync Counter**
  A copy of the sync count sent over in the data request.

- **Reset Flag**
  An indication of whether the probe has reset. A value of one indicates a reset has occurred and the host computer should send a setup command, command 1.

- **Checksum**
  A byte-by-byte sum over all the data from Packet Byte Count to Reset Flag, including both of these parameters.

- **Trailer**
  A two-byte data sequence used to find a data packet in case of a communications error. The header is set to FADEh.

### CIP Housekeeping Channels

A list of CIP housekeeping channels appears in Table 7, along with the equations used to convert analog housekeeping values to meaningful digital values. The following conventions are assumed:
• “ad” is the analog-to-digital converter value sent over the serial channel in the housekeeping slots.
• All temperatures are in degrees Celsius.
• The analog-to-digital converter on the CIP has a 12-bit output and an input voltage range of 0 to 10 volts. Therefore, the solution of the input voltage, given a conversion value, (ad), is

\[ V = 10(\text{ad}/4095) \]

<table>
<thead>
<tr>
<th>#</th>
<th>Name</th>
<th>Definition</th>
<th>Equation to Convert Analog-Digital Counts to Meaningful Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Diode 1</td>
<td>The DC voltages of the corresponding diodes on the CIP 64-element array(^{10})</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Diode 64</td>
<td></td>
<td>[ V = 20(\text{ad}/4095) ]</td>
</tr>
<tr>
<td>2</td>
<td>Diode 32</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Pitot pressure</td>
<td>Pitot or Differential Pressure</td>
<td>[ \text{mBar} = 70.786 \times 5(\text{ad}/4095) ]</td>
</tr>
<tr>
<td>4</td>
<td>Static Pressure</td>
<td>Static Pressure</td>
<td>[ \text{mBar} = 206.88 \times 5(\text{ad}/4095) ]</td>
</tr>
<tr>
<td>5</td>
<td>LWC(^{11})</td>
<td>The voltage required to maintain the LWC hotwire’s fixed temperature</td>
<td>[ V = 10(\text{ad}/4095) ]</td>
</tr>
<tr>
<td>6</td>
<td>LWC Slave(^{11})</td>
<td>A voltage representation of the voltage used by the end sections or “slaves” of the LWC hotwire</td>
<td>[ V = 10(\text{ad}/4095) ]</td>
</tr>
<tr>
<td>7</td>
<td>DSP Board Temp</td>
<td>Temperature at the Digital Signal Processing Board</td>
<td>[ T = (\text{ad}-599) \times 20/4095 ]</td>
</tr>
<tr>
<td>8</td>
<td>Relative Humidity</td>
<td>Relative Humidity</td>
<td>[ \text{RH%} = 32.258 \times 10(\text{ad}/4095) - 25.81 ]</td>
</tr>
<tr>
<td>9</td>
<td>Optional Input 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Optional Input 2</td>
<td>Varies depending upon input</td>
<td>Varies depending upon input</td>
</tr>
<tr>
<td>11</td>
<td>Optional Input 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Optional Input 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Temperature(^{12})</td>
<td>Temperature uncorrected for</td>
<td>[ T = 100/4095 \times \text{ad} - 50 ]</td>
</tr>
</tbody>
</table>

\(^{10}\) Voltages at the sensing point are half the true DC voltages, which is why a multiplication factor of 20 rather than 10 is used.

\(^{11}\) If the CIP is part of a CAPS probe, the LWC Hotwire Signal and Slave Monitor are sampled through the CAS housekeeping data, not the CIP.
### Laser Current

The electrical current flowing through the CIP’s laser diode. 

\[ I = \frac{(ad)}{4095} \times 100 \text{ mA} \times 5 = 0.122 \text{ ad} \]

### Laser Power

The relative laser power as measured by the onboard laser power monitor.

(Arbitrary Units) \[ = \frac{ad \times 10}{4095} \]

<table>
<thead>
<tr>
<th>Byte</th>
<th>Parameter Description</th>
<th>Data Type</th>
<th>Ex. Hex Value</th>
<th>Parameter Setting as Indicated by Hex Value in Previous Column</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Start Byte</td>
<td>U8</td>
<td>1B</td>
<td>1B h = ASCII 27 = Esc Character</td>
</tr>
<tr>
<td>1</td>
<td>Command Number</td>
<td>U8</td>
<td>03</td>
<td>03 = Reset Command</td>
</tr>
<tr>
<td>2</td>
<td>Checksum</td>
<td>U16</td>
<td>1E 00</td>
<td>001E h = 30</td>
</tr>
</tbody>
</table>

### Table 7: Definitions and Conversion Equations for CIP Housekeeping Channels

Note that several of these channels can be used to diagnose the CIP’s health. See section 8.1 for details.

### Reset Command

The Reset command, command 3, resets the CIP. Table 8 shows the data packet the host computer sends to the CIP when executing the reset command.

Note that this parameter is recovery or measured temperature rather than ambient temperature. See Appendix G for information on calculating ambient temperature from measured temperature.

Laser Power is currently not well calibrated and units are arbitrary. However, the channel can still be used to diagnose instrument health. See section 8.1.
Set Absolute Time Command

The Set Absolute Time Command, command 5, sets the CIP absolute time on the on-board clock. Note that it takes approximately 1.5 milliseconds to send this command, so data systems may want to add between 1 and 2 milliseconds to the absolute time before sending it. This command should be sent before the first data request command to ensure the correct time has been established on the probe.

<table>
<thead>
<tr>
<th>Byte</th>
<th>Parameter Description</th>
<th>Data Type</th>
<th>Ex. Hex Value</th>
<th>Parameter Setting as Indicated by Hex Value in Previous Column</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Start Byte</td>
<td>U8</td>
<td>1B</td>
<td>1B h = ASCI 27 = Esc Character</td>
</tr>
<tr>
<td>1</td>
<td>Command Number</td>
<td>U8</td>
<td>05</td>
<td>05 = Set Absolute Time Command</td>
</tr>
<tr>
<td>2</td>
<td>Seconds and Milliseconds</td>
<td>U16</td>
<td>E7 EF</td>
<td>59 seconds and 999 milliseconds</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Hours and Minutes</td>
<td>U16</td>
<td>FB</td>
<td>23 hours and 59 minutes</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td>05</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Checksum</td>
<td>U16</td>
<td>F6</td>
<td>02F6 h = 758</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
<td>02</td>
<td></td>
</tr>
</tbody>
</table>

*Table 9: Set Absolute Time Command – Data Packet*

Start Byte, Command Number and Checksum operate as described in the “Setup Data Command” section. The time parameters store the time to which the CIP on-board clock should be set.

CIP Response to Set Absolute Time Command

After the CIP receives a Set Absolute Time Command, responds with two ACK characters, as shown below.

<table>
<thead>
<tr>
<th>Byte</th>
<th>Parameter Description</th>
<th>Data Type</th>
<th>Ex. Hex Value</th>
<th>Parameter Setting as Indicated by Hex Value in Previous Column</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Response</td>
<td>U8</td>
<td>06</td>
<td>06 h = ACK</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>U8</td>
<td>06</td>
<td>06 h = ACK</td>
</tr>
</tbody>
</table>

*Table 10: CIP Response to Set Absolute Time Command – Data Packet*

---

14 Time parameters are stored the same way as in the CIP Response to the Send Data Command.
Get Version Number Command

The Get Version Number Command, command 6, requests that the CIP send the instrument version number. The version number of the CIP described in this document will always be 4. Previous versions of the CIP sent and received different data packets, so the parameter was originally designed to instruct the host computer on what data structures it should send to and expect from the probe.

<table>
<thead>
<tr>
<th>Byte</th>
<th>Parameter Description</th>
<th>Data Type</th>
<th>Ex. Hex Value</th>
<th>Parameter Setting as Indicated by Hex Value in Previous Column</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Start Byte</td>
<td>U8</td>
<td>1B</td>
<td>1B h = ASCI 27 = Esc Character</td>
</tr>
<tr>
<td>1</td>
<td>Command Number</td>
<td>U8</td>
<td>06</td>
<td>06 = Get Version Number Command</td>
</tr>
<tr>
<td>2</td>
<td>Checksum</td>
<td>U16</td>
<td>21</td>
<td>0021 h = 33</td>
</tr>
</tbody>
</table>

Table 11: Get Version Number Command – Data Packet

CIP Response to Get Version Number Command

The CIP responds to the Get Version Number Command with the following data packet.

<table>
<thead>
<tr>
<th>Byte</th>
<th>Parameter Description</th>
<th>Data Type</th>
<th>Ex. Hex Value</th>
<th>Parameter Setting as Indicated by Hex Value in Previous Column</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Version Number</td>
<td>U8</td>
<td>04</td>
<td>0004 h = Version 4</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>U8</td>
<td>00</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Checksum</td>
<td>U16</td>
<td>04</td>
<td>0004 h = 4</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td>00</td>
<td></td>
</tr>
</tbody>
</table>

Table 12: CIP Response to Get Version Number Command – Data Packet
Appendix F: Host Computer - CIP
Communications for 2D Image Data

For information on the 2D image data communication between the host computer and the CIP, see DOC-201, the Image Probe Data Reference Manual. This document describes the communications protocol, the data-compression algorithm, and the format of uncompressed data. It also gives example code for decompressing and parsing data.

Appendix G: DMT Instrument Locator—Operator Guide

Purpose

The Droplet Measurement Technologies (DMT) Instrument Locator tests whether a DMT instrument is responsive to an initialization command. This can be useful in determining if an instrument is powered on and has functional communications lines, or in verifying the serial port number that each instrument is connected to. Beyond this, the software does not ensure that the instrument is functioning properly.

This document describes version 1.0.1 of the Instrument Locator. This version of the program supports the following DMT instruments:

- APSD
- BCP
- CAS and CAS-DPOL
- CDP and CDP-PBP
- CIP and CIP-GS
- CPSD
- FM-100
- FSSP
- MPS
- PCASP-100X
- PCASP-X2
- PIP

Installation

The DMT Instrument Locator is on a USB stick included in a sealed plastic bag. To install the software, follow the instructions on the small card also included in the bag.
Operation

1. To open the Instrument Locator, navigate to C:\Program Files\PADS 3 and double-click on DMT Instrument Locator.exe. You will see the window in Figure 1.

   ![Figure 20: Instrument Locator](image)

   Note: Several DMT instruments—the CDP, CDP-PbP, BCP, FSSP, and FM-100—all respond to the same initialization string. The instrument locator simply sends this string to the instrument. The program has no way of knowing if the instrument connected to the COM port is actually of the correct type. Thus, if you have multiple instruments in your system, it is important to specify the correct COM port for the instrument you wish to test.

   © 2013 DROPLET MEASUREMENT TECHNOLOGIES, INC.
Endnotes

i Appendix B, Section 7 of Bulletin #9 from the National Center for Atmospheric Research’s Research Aviation Facility (RAF). www.eol.ucar.edu/raf/Bulletins/b9appdx_B.html#THERMO.

ii Appendix B, Section 7 of Bulletin #9 from the National Center for Atmospheric Research’s Research Aviation Facility (RAF). www.eol.ucar.edu/raf/Bulletins/b9appdx_B.html#THERMO.

iii Appendix B, Section 7 of Bulletin #9 from the National Center for Atmospheric Research’s Research Aviation Facility (RAF). www.eol.ucar.edu/raf/Bulletins/b9appdx_B.html#THERMO.