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Cloud Particle Imager

CPI V2.5

User’s Manual

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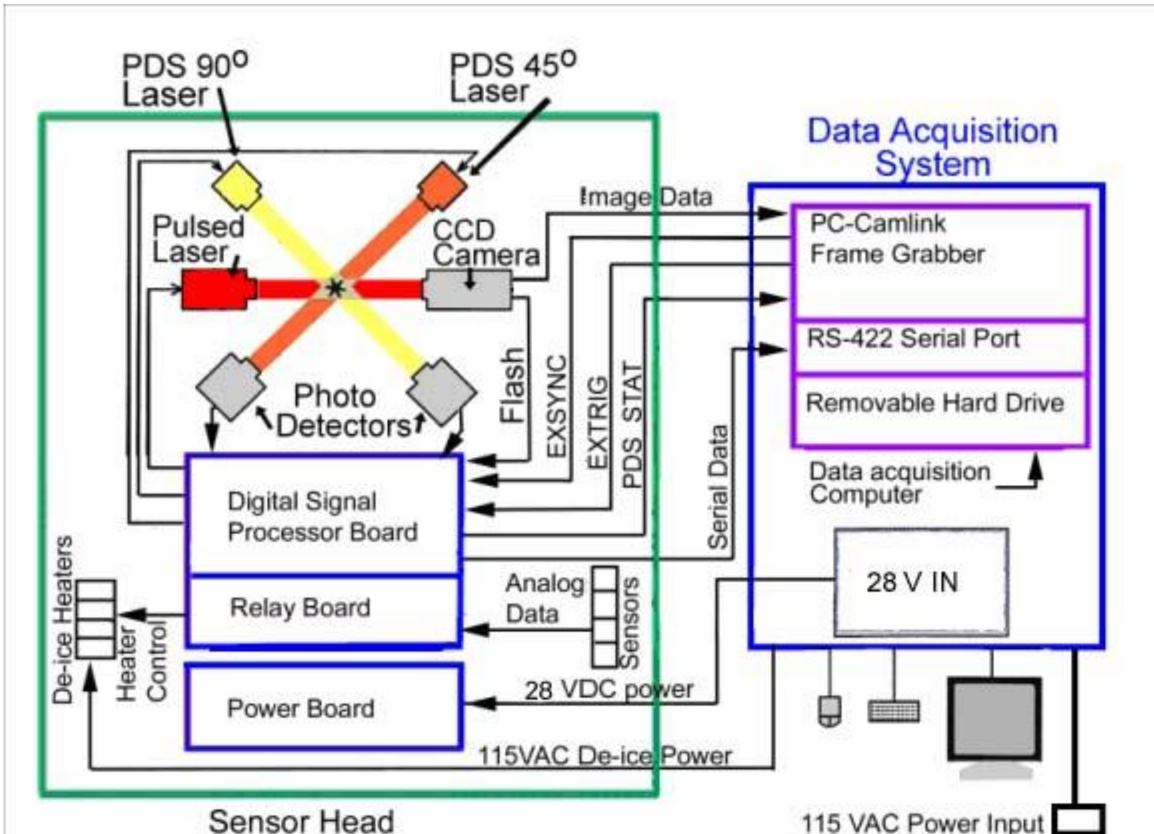
1.0 CPI OVERVIEW

1.1 CPI General Description

The UAV CPI is an airborne atmospheric research instrument that captures high-resolution images of particles as they pass through the instrument.

1.1.1 Main Parts of the CPI

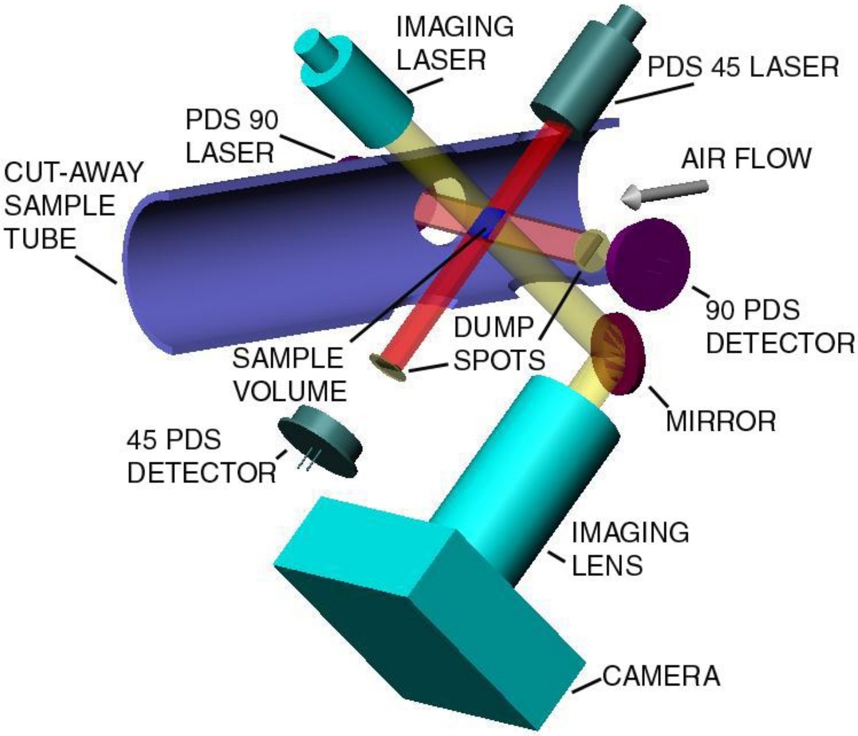
The UAV CPI can be subdivided into three basic parts, shown in the block diagram, **Figure 1.1.1.** The first part, the Data Acquisition System, is housed inside a rack-mount computer case. This is usually mounted inside the aircraft cabin. The second part is the Sensor Head, which is located outside the aircraft on the fuselage or wing. The third part, the power system, occupies space in both the rack-mount computer case and the sensor head.

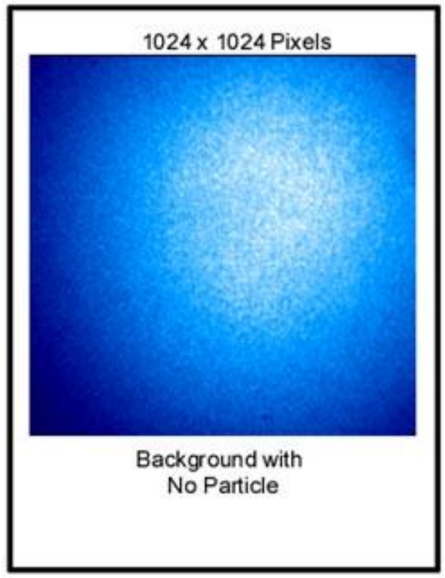


CPI Block Diagram

Figure 1.1.1 CPI Block Diagram

1.1.2 Functional Overview





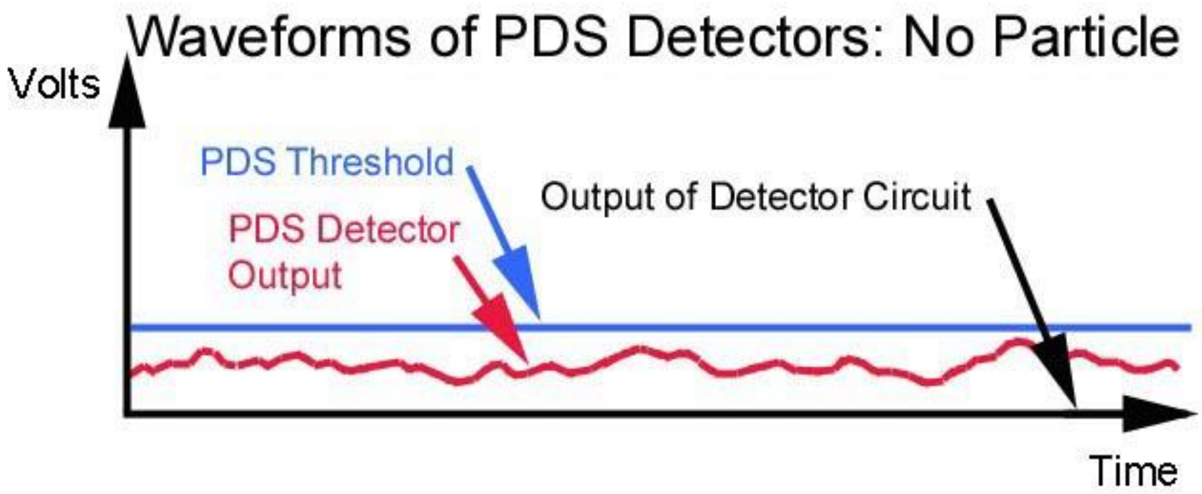


Figure 1.1.2 Optics, PDS detector waveforms, and exposed image of the CCD camera when no particle is present.

In the CPI, a two-beam particle detection system strobes a high-power laser to flash the instant a particle is in the imaging system object plane. A CCD camera records the particle image(s) and the frame containing the particle(s) is sent to an image processing system that locates the particle(s) in the image and cuts out these regions of interest (ROI) for display and recording. Electronics in the sensor monitor and control numerous parameters as dictated by the software in the Data Acquisition System. The imaging system utilizes a 1024 x 1024 pixel monochrome digital camera that has eight bits of resolution (256 levels) and has an effective pixel size of 2.3 microns. The camera can download approximately 72 frames per second, allowing the instrument to rapidly image small cloud particles.

1.1.2.1 Instrument Behavior With No Particle Present

Figure 1.1.2 shows the primary electro-optical components in the CPI. The upper left diagram shows a cut-away view of the CPI sample volume. Two ribbon-shaped intersecting laser beams form the particle detection system (PDS) sensitive area. Both PDSs are functionally identical. The PDSs use a continuous wave laser and beam shaping optics that produce laser beams with a rectangular cross-section. The two PDS laser beams are orthogonal to one another and form a volume of approximately 2.5 mm x 2.5 mm x 0.5 mm located in the center of the instrument sample tube, and tilted at an angle of 45 degrees to the particle trajectory. Each rectangular laser beam is dumped onto a dump spot before it reaches its PDS light detector, such that almost no light reaches the detector when no particle is present. The diagram in the upper left of **Figure 1.1.2** shows the laser beams being dumped, in the absence of a particle in the sample volume. The object plane for the imaging CCD camera is located on the trailing edge of the PDS beam intersection.

Upon instrument startup, the imaging system pulses the imaging laser and captures a full frame background CCD image in the absence of cloud particles. The background image is stored and used to process subsequent frames thought to contain a particle. The background CCD image is shown in **Figure 1.1.2**.

When there is no particle flying through the instrument and only a small amount of light from the PDS laser beams hits the PDS detectors, both detectors put out low voltage analog signals. A typical low voltage analog signal is shown in red on the voltage waveform graph in **Figure 1.1.2**. An electronic comparator circuit on each PDS detector compares the detector output voltage with a PDS Threshold voltage. The PDS threshold voltage is shown in blue. If the PDS Detector output voltage never rises above the PDS Threshold voltage then no particle is detected and no firing of the imaging laser occurs. The imaging CCD camera is constantly downloading images, but during this period of no particles, the camera's light sensitive surface is never exposed and the images are discarded by the data acquisition system.

1.1.2.2. Instrument Behavior With Particle(s) Present

When a particle flies through the instrument and passes through a PDS laser beam some light is scattered forward and around the dump spot by the particle as shown in the cutaway diagram in the upper left of **Figure 1.1.3**. This light is collected by the PDS photo-detector associated with that laser. The photo-detector converts the light pulse into an analog voltage pulse as shown in red in the PDS waveform diagram in **Figure 1.1.3**. A comparator

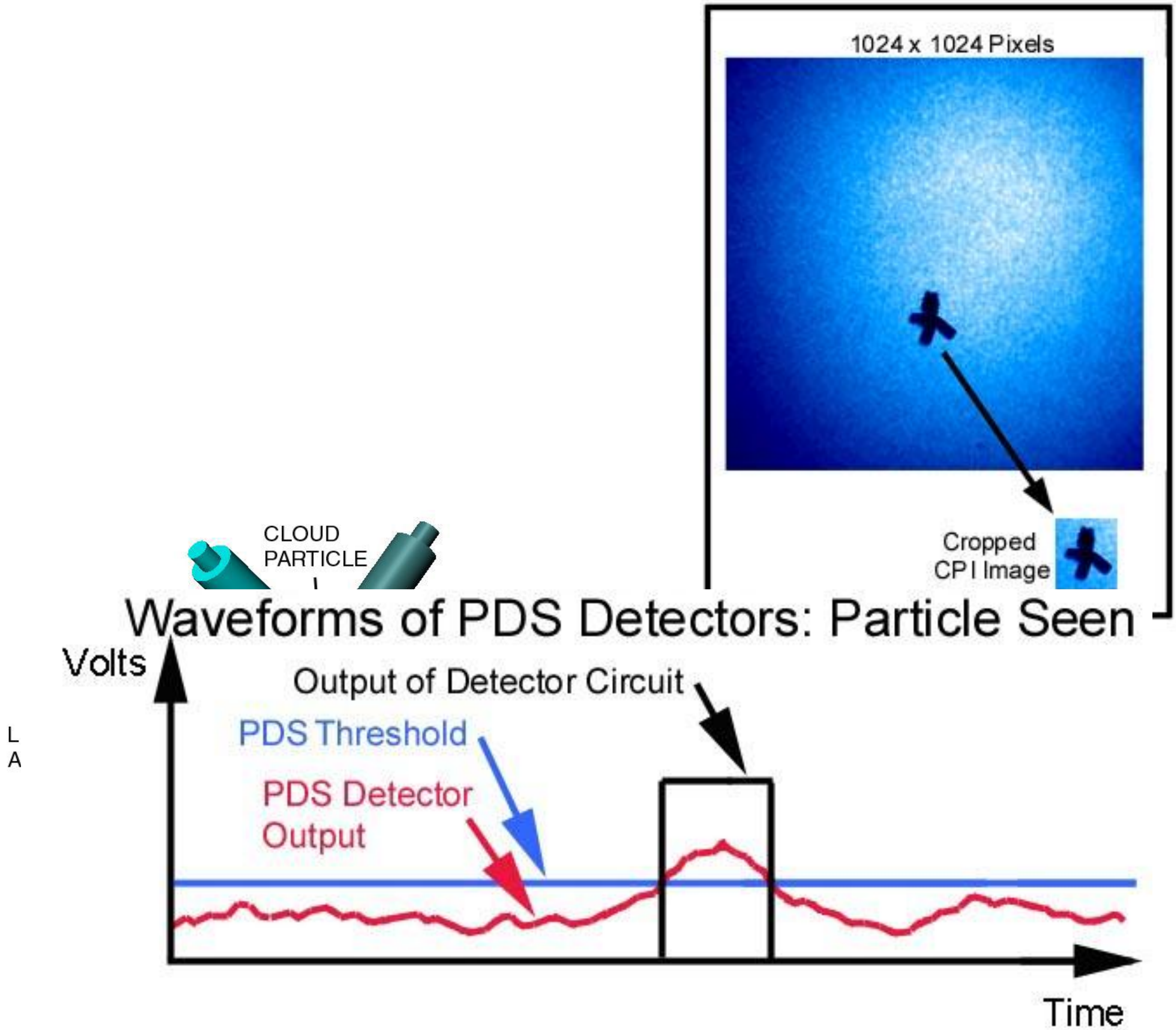


Figure 1.1.3. Optics, PDS detector waveforms, and exposure shot of the CCD camera when the CPI detects a particle.

in each PDS detector circuit compares the photo-detector output voltage with the PDS threshold voltage shown in blue in the waveform diagram in **Figure 1.1.3**. When the analog voltage pulse from the photo-detector exceeds the PDS threshold of the comparator circuit the comparator outputs a clean digital pulse. This digital pulse is shown in black in the PDS waveform diagram in **Figure 1.1.3**. It is passed to a digital logic circuit for processing.

When a particle passes through the intersection of both PDS laser beams, a pulse of light is observed on each of the scattered light detectors. In this case both PDS detectors output voltage pulses at the same time. If the pulses last longer than a minimum duration then the “Particle In Beam OK” (PIB_OK) signal goes high and a logical state machine located in the sensor head starts stepping through its 8-step cycle. This state machine orchestrates the imaging of the particle, the sending of data associated with that particle to the Data Acquisition Computer, and the resetting of the electronics in preparation for the next particle. The states of this state machine are as follows:

- State 0: Idle and wait for a particle. If a particle is present in both beams for a set minimum duration (the minimum transit time), as indicated by the PIB_OK signal going high, go to State 1.

- State 1: Start a timer that measures the time during which the particle is in the PDS beams. This is called the Transit Timer. Wait for the Particle In Beam OK (PIB_OK) signal to go low. (This signal goes high when both of the PDS pulses have been high for longer than a minimum duration. It goes low instantly when either one of the PDS pulses goes low. At the instant when PIB_OK goes low the particle is in the object plane of the camera.) When PIB_OK goes low jump to state 2.

- State 2: Fire the imaging laser. Notify the frame grabber in the Data Acquisition System that a particle was seen and this laser has fired by driving the PDS STATUS signal high. (The PDS STATUS signal is received by the frame grabber and is used by the data acquisition system to determine whether the next image frame it receives contains at least one particle or not.)

- State 3: The DSP is a microprocessor that resides in the sensor head of the CPI. Notify the digital signal processor (DSP) that a particle was seen so that it can send a PDS packet to the data acquisition system. (A PDS data packet accompanies each particle image with particle-specific information such as the voltage pulse height that was output from each of the PDS detectors.) Wait in this state and don’t allow any more particles to be imaged until an EXSYNC pulse is received from the frame grabber in the data acquisition system.

(The EXSYNC pulse causes the camera to download its current image to the data acquisition computer. It also tells the sensor head electronics that the camera and data acquisition computer are ready to take the next picture.)

- State 4: Perform some of the operations to reset the sensor head electronics in preparation for the next particle. Wait for the CLEAR HOLD signal from the DSP. (This signal tells the state machine that the DSP is ready for the next particle.)

- State 5: Go to state 6.

- State 6: Reset the pulse-shaping electronics in the PDS detectors to get ready for the next particle.

- State 7: Continue resetting the pulse-shaping electronics in the PDS detectors. If no particles are detected in the beam, go to state 0; otherwise, wait here.

The imaging laser will fire when the PIB_OK signal goes low. This causes the image of the particle to be captured by the CCD camera. The Camera downloads the captured image to the frame grabber which is located in the Data Acquisition System as soon as it receives the next EXSYNC pulse from the frame grabber.

Once the image download is complete the frame grabber interrupts the computer. Before the image was downloaded the frame grabber checked the PDS STATUS signal to see if the imaging laser was fired. If it was not fired, then the PDS STATUS bit will be a logic low. In this case the image frame is discarded. If it was fired, the PDS STATUS signal will be a logic high. In this case, the image frame is searched for regions of interest (ROIs) by the Data Acquisition System. These are locations in the image where particles are present. The image processing algorithm, subtracts the stored background image from the newly acquired frame. If the subtraction results in any areas of the CCD image greater than a predefined minimum pixel size with a shadow depth greater than the user selectable particle threshold, these areas are cropped from the full frame. **Figure 1.1.3** shows an example of an ROI that was cropped (cut out) from the image frame. The ROIs are cropped from the picture and stored into the current data file on the hard disk. This keep the data files as small and compact as possible. The data file has the file extension ".ROI ". A PDS data packet will be associated with each ROI in the data file. The PDS packet is sent from the DSP to the Data Acquisition System via the RS422 link. It contains information such as the particle's arrival time and the peak heights of the two PDS signals for the laser trigger event associated with this particle (see the data acquisition system section for full details of the PDS packet).

2.0 GETTING STARTED

2.1 Unpacking the CPI System

This procedure is to be followed when unpacking the CPI system after shipment or storage.

1. Open the container containing the CPI data system and other accessories (**Figure 2.1.1**).

2. Remove the flat panel monitor, manuals, mouse, keyboard, cleaning tool, alignment pin, and pulling fork from the case (**Figure 2.1.2**).

3. Remove the top layer of foam exposing the data system and accessories.

4. Remove the data system, AcquireNow hardware key, power cables, monitor stand, test stand, and atomizer from the case (**Figure 2.1.3**). The atomizer and alignment pin should be wrapped in bubble wrap.

5. Foam blocks have been inserted into the computer case for added protection during shipping. Remove the three screws for the computer cover (**Figure 2.1.4**) and remove the computer cover.

6. Remove the foam blocks from inside the computer (**Figure 2.1.5**). Taking proper ESD precautions, inspect the components inside the computer. Check that all the computer cards and chips are properly seated and that all cables are connected for disk drives, etc.

7. After a visual inspection that nothing was damaged in shipping, reinstall the computer cover.

8. The data system is shipped with the AcquireNow hardware key removed and the captive cabling unplugged (**Figure 2.1.6).**

9. Connect the AcquireNow hardware key and the captive connectors to the RS 422/232 converter card as shown in **Figure 2.1.7**.

10. Open the shipping case containing the CPI sensor head and cables (**Figure 2.1.8**).

11. Remove the cables from the top layer of foam, both the test cables and standard cables are contained in this box (**Figure 2.1.9**).

12. Remove the top layer of foam (**Figure 2.1.10**).

13. This foam insert has been designed to use as a cushion for the pylon cover and nose cone during disassembly of these components (**Figure 2.1.11**). Set this layer of foam aside for now.

14. Remove the CPI pylon from the shipping case (**Figure 2.1.12**).

15. Remove the foam insert in the bottom of the case (**Figure 2.1.13**).

16. This removable foam insert has been designed to serve as a cushion for the CPI pylon when the pylon is not operational (**Figure 2.1.14**).

17. Remove the pylon plug from the CPI sensor head before operating (**Figure 2.1.15**). The pylon plug is used to keep contamination out of the CPI sample tube during shipping. It should be reinstalled before the pylon is shipped.

18. Verify that the contents of both shipping containers match the contents on the included packing list.

19. The CPI can now be connected following the Connection Procedure, **Section 2.2**.

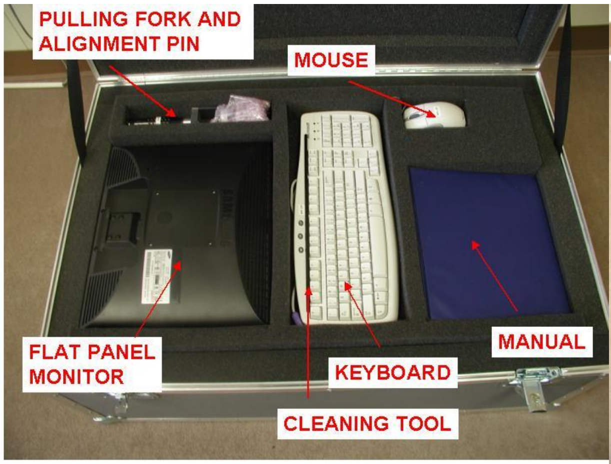


Figure 2.1.1.

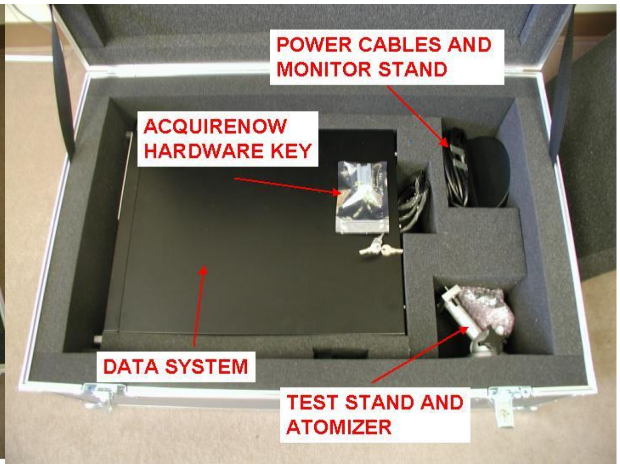


Figure 2.1.2.

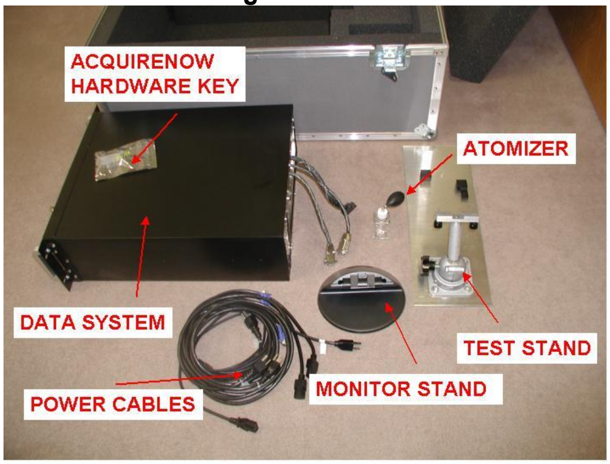


Figure 2.1.3.

Figure 2.1.4.

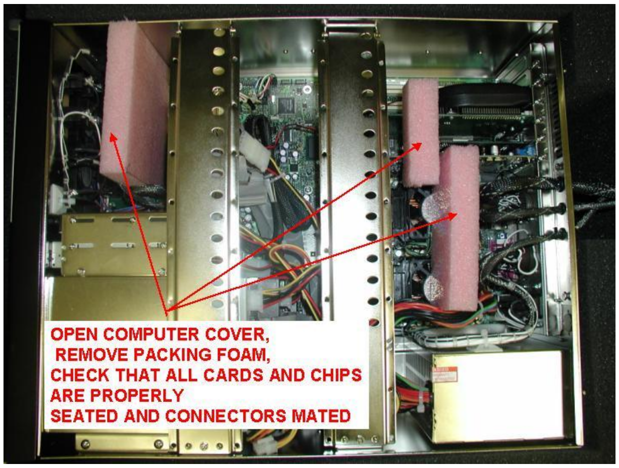


Figure 2.1.5.

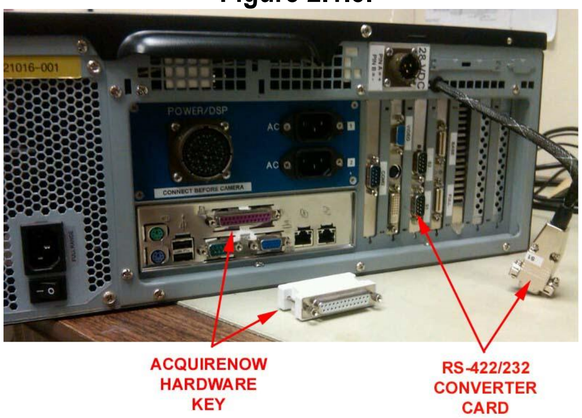


Figure 2.1.6.

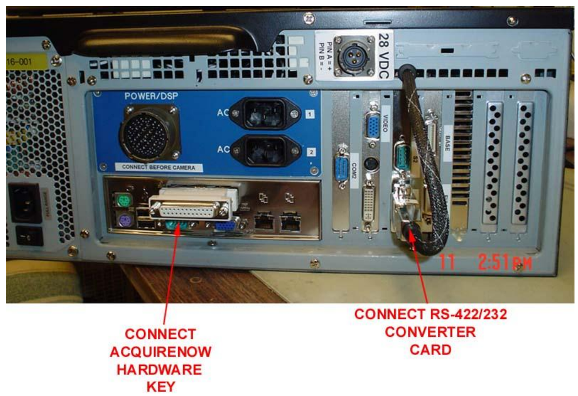


Figure 2.1.7.

Figure 2.1.8.

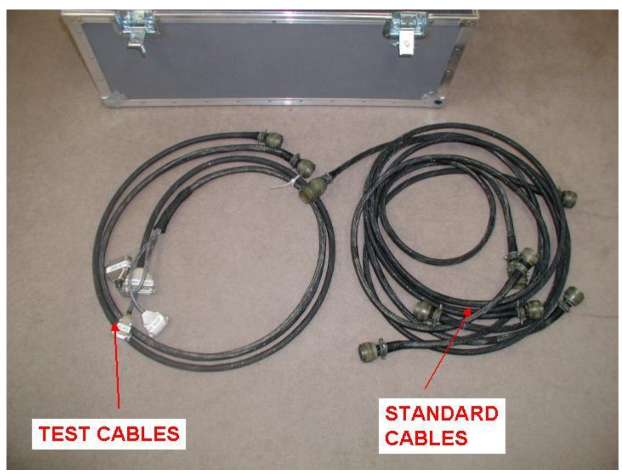


Figure 2.1.9.

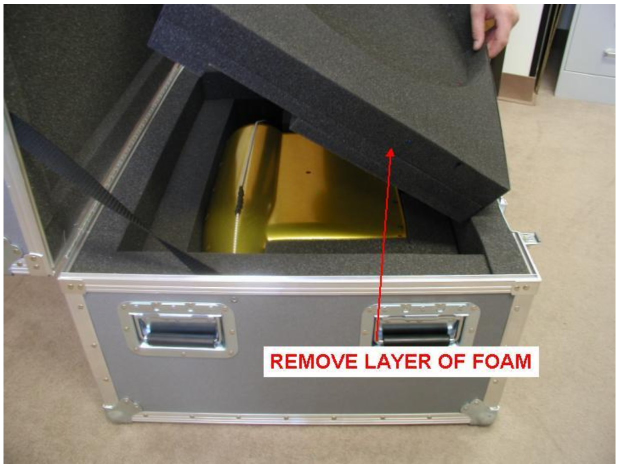


Figure 2.1.10.

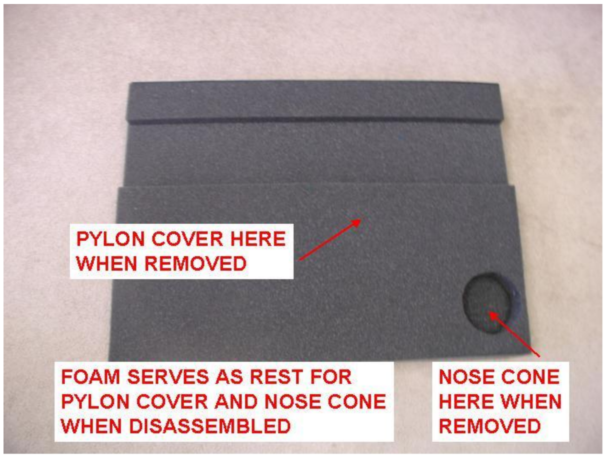


Figure 2.1.11.

Figure 2.1.12.

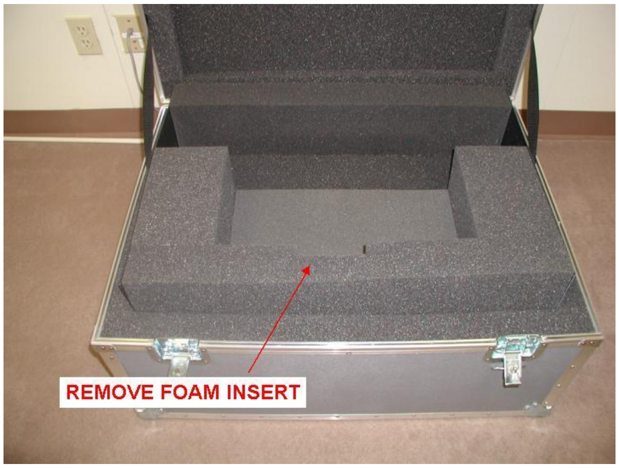


Figure 2.1.13.

Figure 2.1.14.

Figure 2.1.15.

2.2 Connecting the CPI Sensor Head to the Data Acquisition System

Warning! Cables **MUST** be connected in a certain sequence. If you do not follow this sequence, you may damage your CPI!

Warning! The Data acquisition system and Sensor Power switch **MUST** be turned off before any cables are connected or Disconnected. If you do not turn them off before connecting or disconnecting cables you may damage your CPI!

2.2.1 Connection Procedure for Operating the CPI in the Laboratory

1. Verify that the Sensor Power Switch on the front of the Data Acquisition System is turned off. Verify that the Data Acquisition System Computer is turned off.
   See **Figure 2.2.1**: Front of the Data Acquisition System.

2. Connect the Computer Power, AC1, and AC2 power cables to a 115 Volt AC source. The order of connection of the AC power cables is not important. See **Figure 2.2.2**: CPI Cable Connection Diagram and **Figure 2.2.3**: Back of the Data Acquisition System.

3. Connect the power/dsp cable from J2 on the Data Acquisition System to J2 on the Sensor Head. See **Figure 2.2.2**: CPI Cable Connection Diagram, **Figure 2.2.4**: Connecting the power/dsp to the Data Acquisition System, and **Figure 2.2.8**: Connecting the power/dsp cable to the Sensor Head.

4. Connect the framegrabber cable from J1 on the Data Acquisition System to J1 on the Sensor Head. See **Figure 2.2.5**: Connecting the framegrabber to the Data Acquisition System, and **Figure 2.2.9**: Connecting the sensor camera cable to the Sensor Head.

5. Connect the mouse, keyboard, monitor, Computer Power, AC1, and AC2 to the back of the Data Acquisition System. See **Figure 2.2.2**: CPI Cable Connection Diagram and **Figure 2.2.6**: Connecting the mouse, keyboard, power supply, screen, and sensor AC1 and AC2.

6. Connect the 28 VDC Power Cord to the back of the Data Acquisition System. See **Figure 2.2.7**: Connecting 28 VDC to back of Data Acquisition System.

7. The CPI is now ready to be powered up.

2.2.2 Connection Procedure for Installing the CPI on an Airplane

1. Verify that the Sensor Power switch on the front of the Data Acquisition System is turned off. Verify that the Data Acquisition System Computer is turned off. See **Figure 2.2.1**: Front of the Data Acquisition System.

2. Connect the Computer Power, AC1, and AC2 power cables to a 115 Volt AC source. The order of connection of the AC power cables is not important. See **Figure 2.2.2**: CPI Cable Connection Diagram and **Figure 2.2.3**: Back of the Data Acquisition System.

3. Connect the mouse, keyboard, and monitor to the back of the Data Acquisition System. Connect the AcquireNow Hardware Key to the parallel port. See **Figure 2.2.2**: CPI Cable Connection Diagram and **Figure 2.2.3**: Back of the Data Acquisition System.

4. Connect the power/dsp cable to J2 on the Data Acquisition System only. DO NOT connect the other end to the Sensor Head yet. See **Figure 2.2.3**: Back of the Data Acquisition System.

5. Connect the sensor camera cable to J1 on the Data Acquisition System only. DO NOT connect the other end to the Sensor Head yet.

6. Before making connections to the Sensor Head, electrostatic discharge (ESD) precautions should be taken. It is assumed that if the CPI Sensor Head is mounted on the aircraft, the CPI pylon is grounded to the aircraft frame. It is also assumed that if the Data Acquisition System is mounted in a metal frame inside the aircraft, that it is also grounded to the aircraft frame. In this case no extra ground wire is needed. However, if the CPI Sensor Head is lying outside and is not mounted, or if the Data Acquisition System is not mounted, then a temporary ground wire should be run between the CPI pylon and the Data Acquisition System Chassis. If the Data Acquisition System Chassis is grounded to the aircraft frame then the ground wire may alternatively be run from the pylon to the aircraft frame. This will ensure that the Sensor Head and the Data Acquisition System Chassis are at the same electrical potential when the cables are connected. The person making the cable connections should be grounded to the CPI pylon by using a ground strap or by touching a screw on the outside of the CPI pylon.

7. Connect the power/dsp cable that runs from J2 on the Data Acquisition System to J2 on the Sensor Head. See **Figure 2.2.4**: Connecting the power/dsp cable to the Sensor Head.

8. Connect the sensor camera cable that runs from J1 on the Data Acquisition System to J1 on the Sensor Head. See **Figure 2.2.5**: Connecting the sensor camera cable to the Sensor Head.

9. Remove the temporary ground wire that was installed in step 5.

10. The CPI is now ready to be powered up.

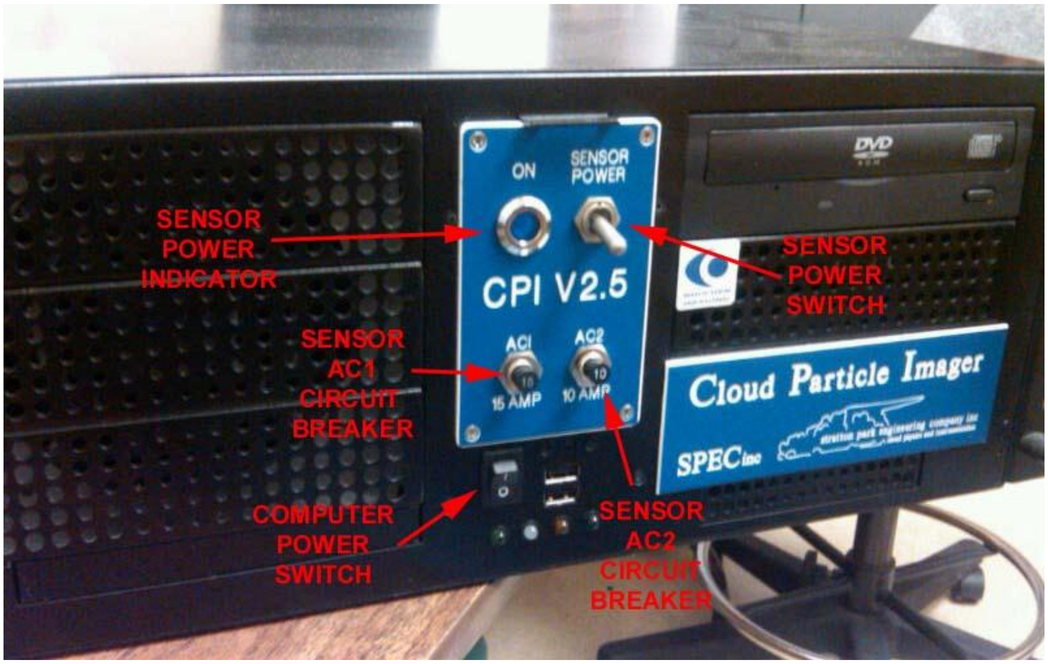


Figure 2.2.1: Front of the Data Acquisition System

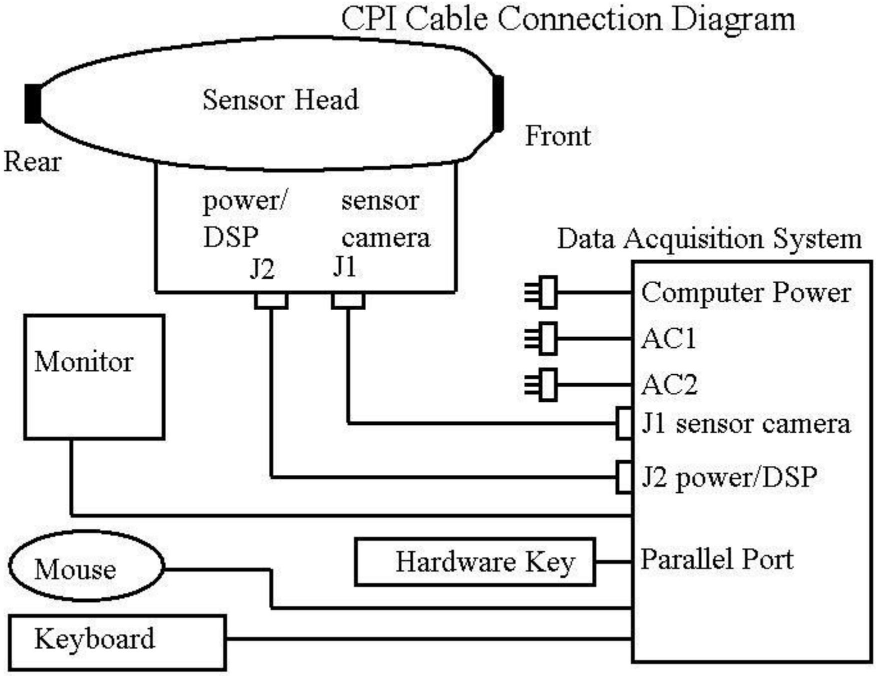


Figure 2.2.2: CPI Cable Connection Diagram

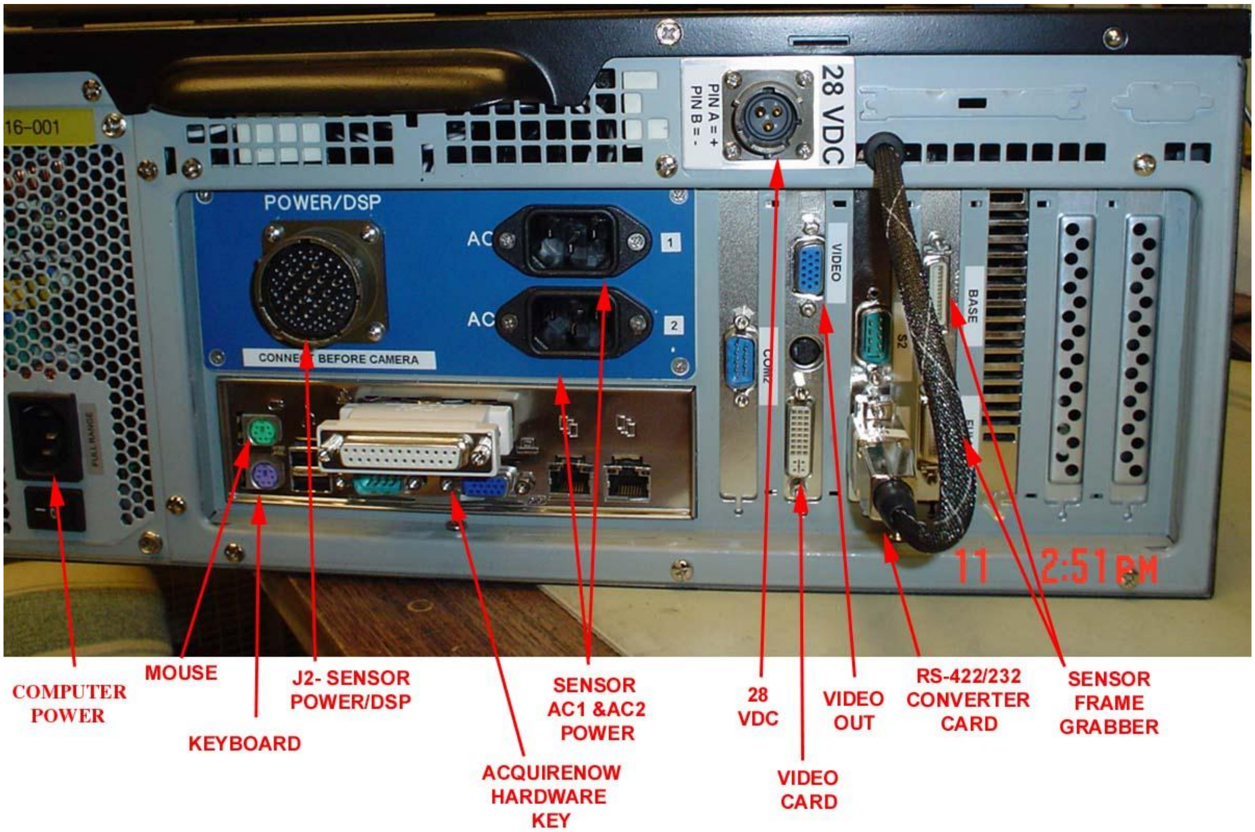


Figure 2.2.3: Back of the Data Acquisition System

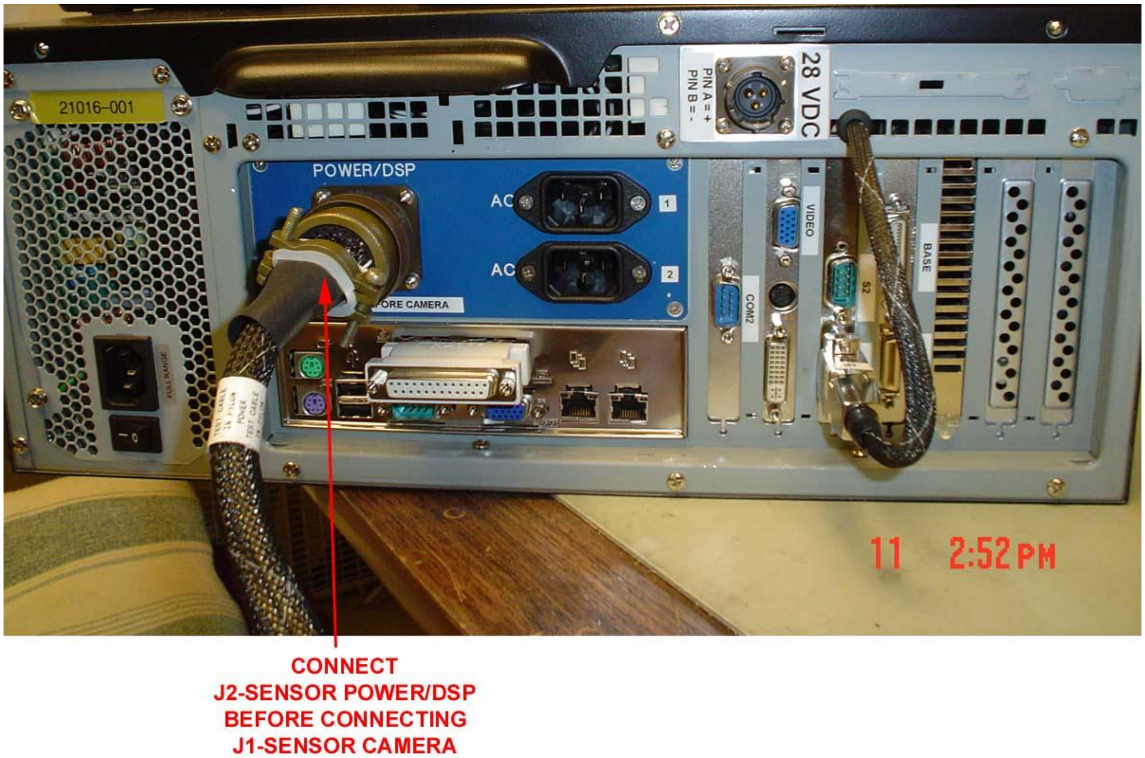


Figure 2.2.4: Connecting the power/dsp to the Data Acquisition System

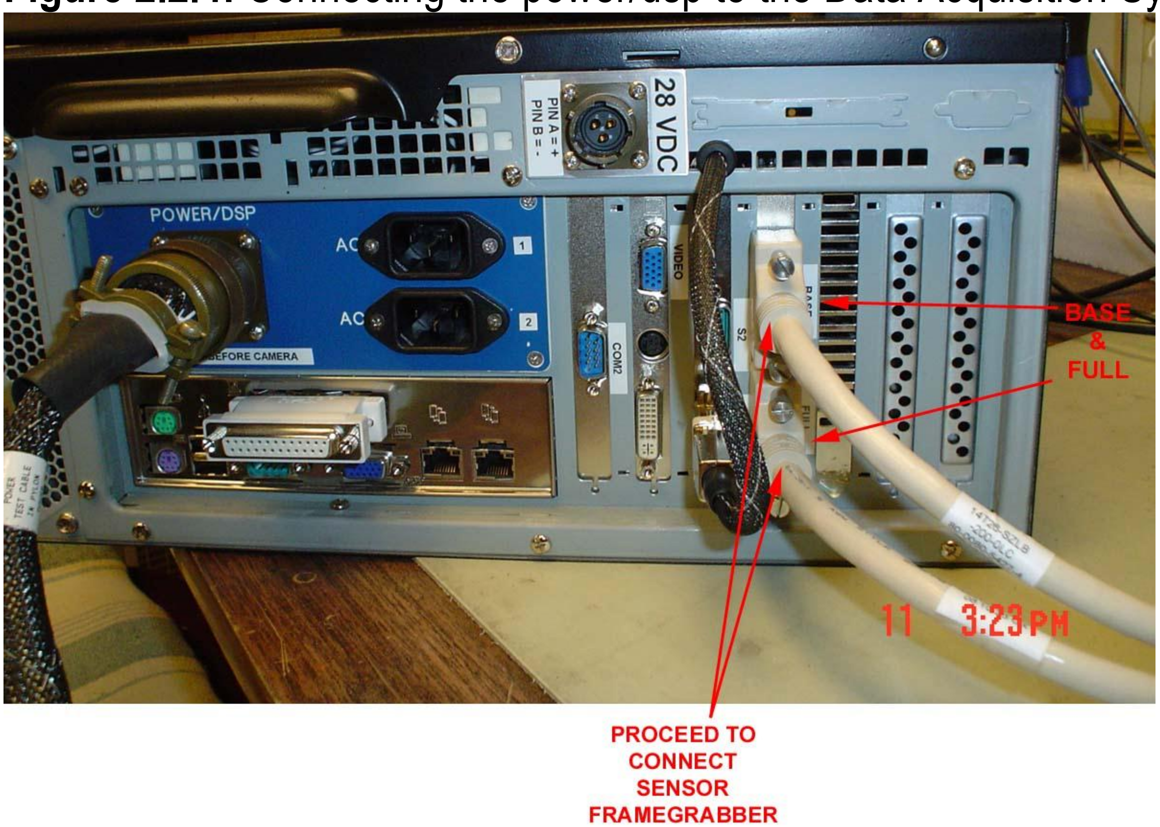


Figure 2.2.5: Connecting the framegrabber to the Data Acquisition System

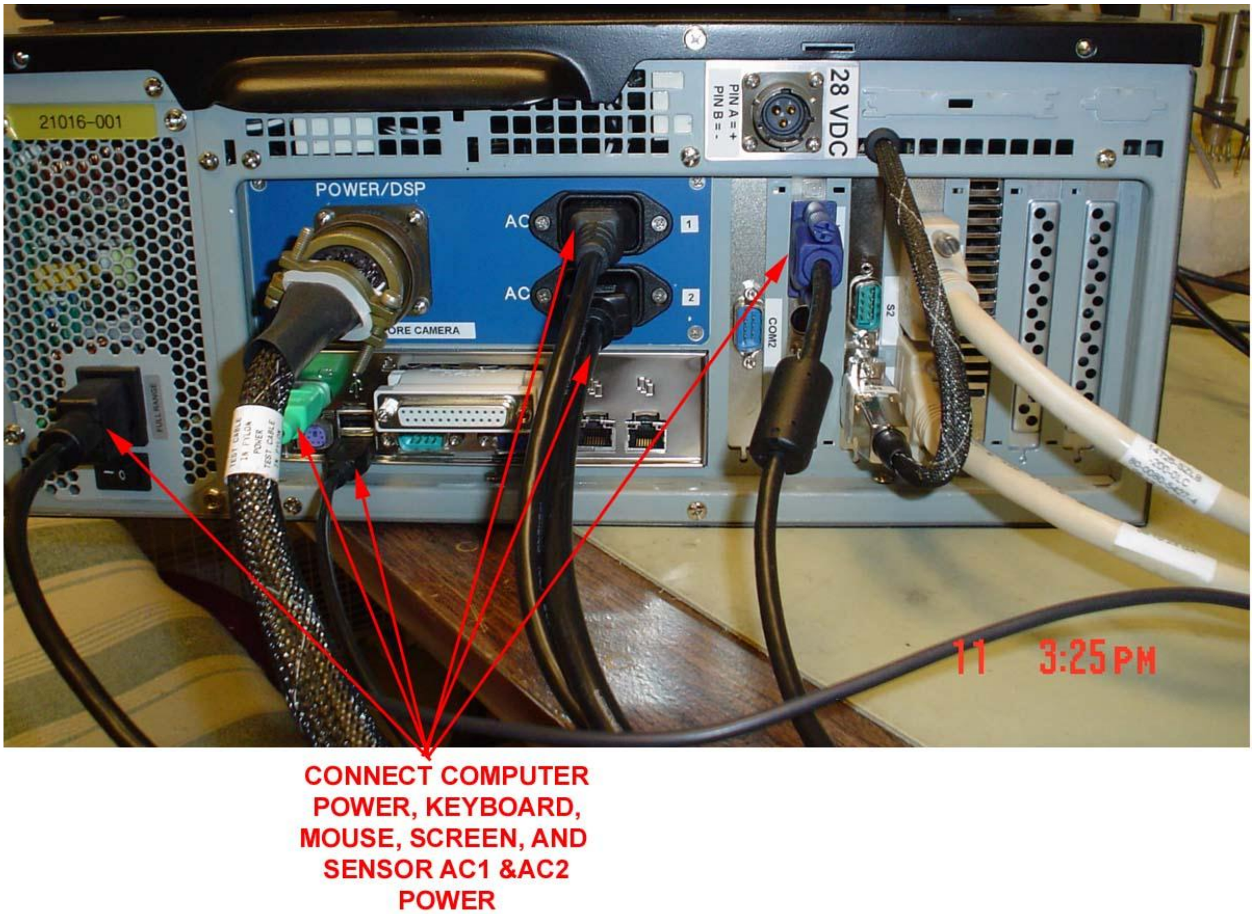


Figure 2.2.6: Connecting the mouse, keyboard, power supply, screen, and sensor AC1 and AC2

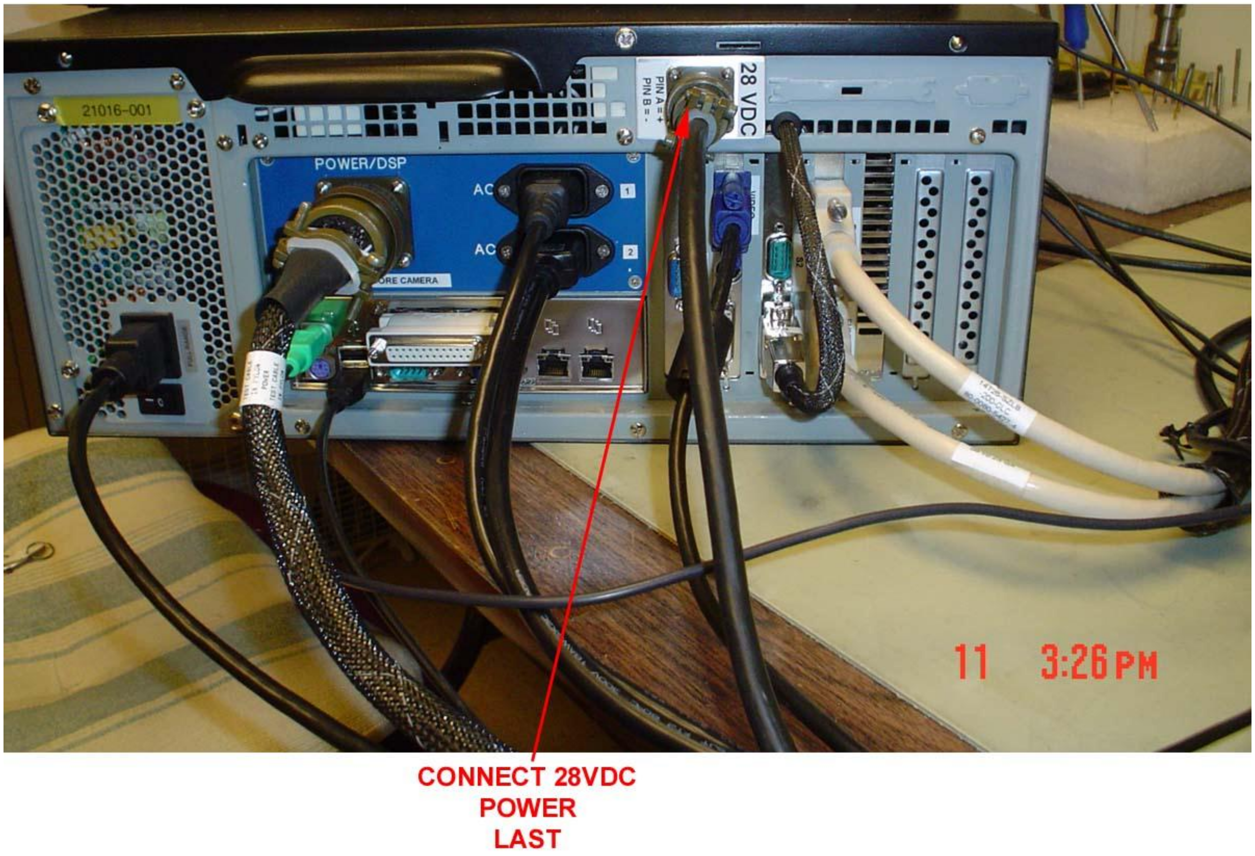


Figure 2.2.7: Connecting 28 VDC to back of Data Acquisition System

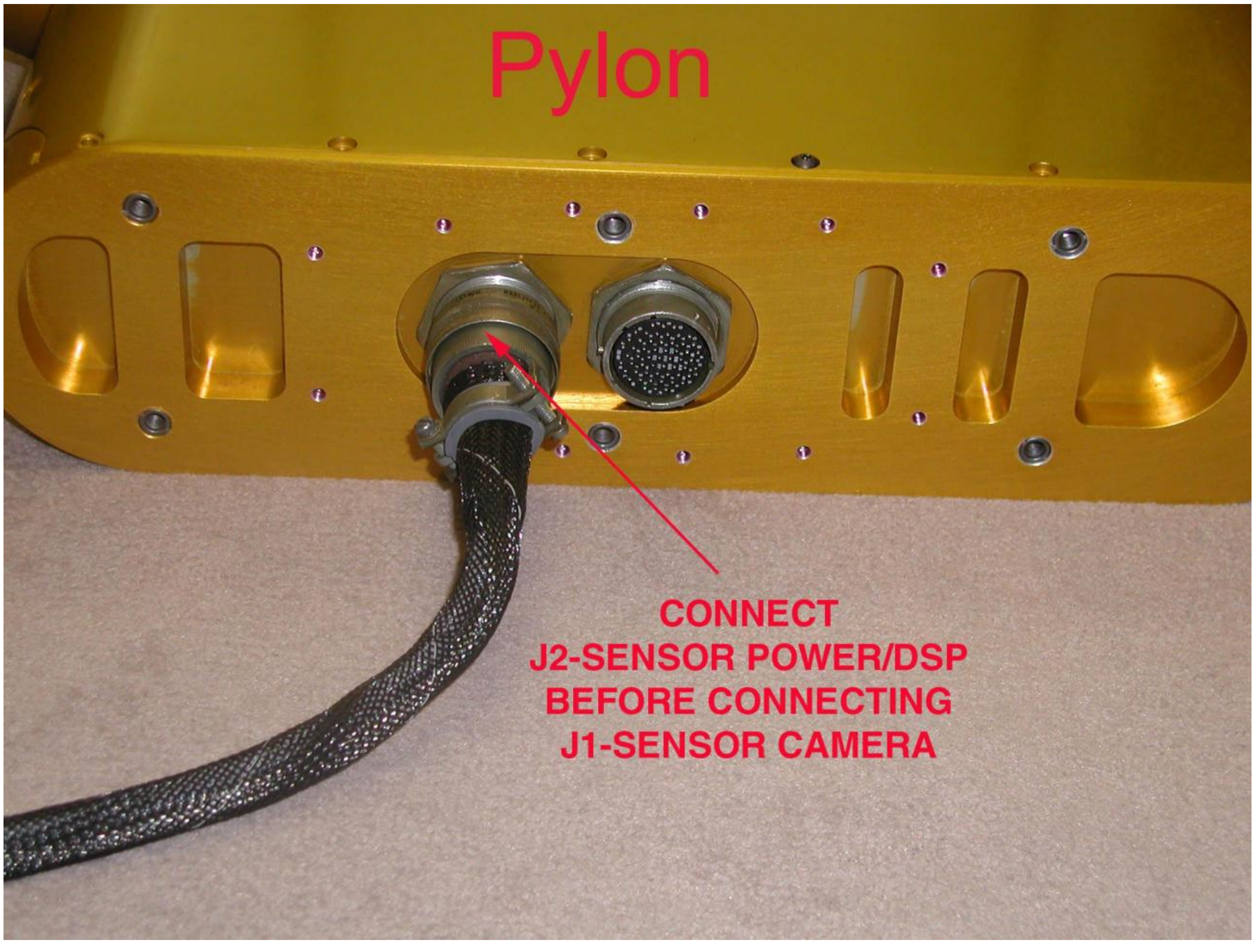


Figure 2.2.8: Connecting the power/dsp cable to the Sensor Head.

Figure 2.2.9: Connecting the sensor camera cable to the Sensor Head.

2.3 CPI Atomizer Setup for Laboratory Testing

1. Verify CPI has been connected to the Data Acquisition System unit following the connection procedure.

2. Place CPI on stable riser blocks (**Figure 2.3.1**). Height of blocks should be sufficient for bottom connector clearance, but low enough to keep instrument stable (**Figure 2.3.2**).

3. Plug in vacuum hose adapter to CPI exhaust tube (**Figure 2.3.3**). Vacuum hose adapter may have to be custom fit to mate with CPI exhaust tube (**Figure 2.3.4**).

4. Setup droplet atomizer in front of CPI (**Figure 2.3.5**). The atomizer should spray drops in a direction perpendicular to the direction of airflow into the CPI. **DO NOT** spray drops directly into CPI along flow direction. **(See Figure 2.3.6)** Water drops will contaminate the windows and the windows will need to be cleaned.

5. Power on the data system and probe per the CPI startup procedure, **Section 2.4**, and run CPI.exe program.

6. After the CPI program has successfully started and obtained a background, turn on vacuum cleaner and spray water drops by squeezing atomizer bulb. The CPI program should show water drops appearing in real time. If the vacuum is turned on before the CPI has obtained a background, it may take longer for the CPI to obtain a background due to particles passing through the sample volume.

Figure 2.3.1

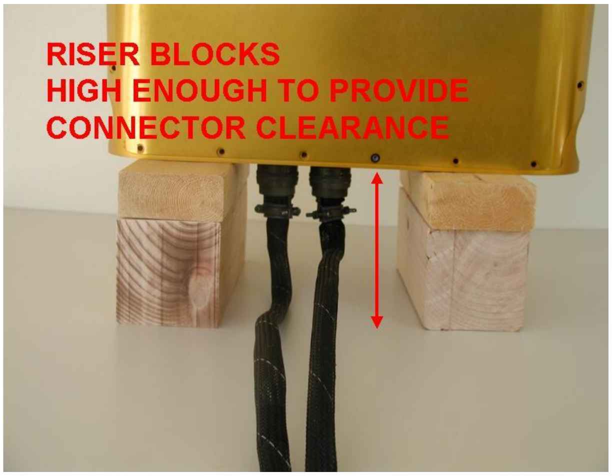


Figure 2.3.2

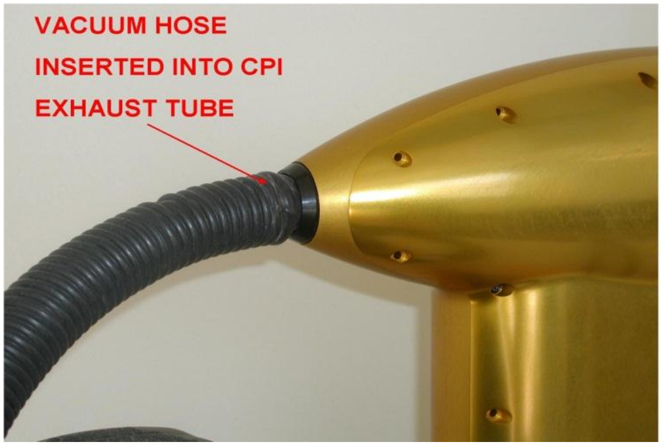


Figure 2.3.3

Figure 2.3.4

Figure 2.3.5

Figure 2.3.6

2.4 CPI Startup Procedure

1. Verify that all cables are connected according to the "Connecting CPI Sensor Head to Data Acquisition System" **Section 2.2**. See **Figure 2.4.1**.

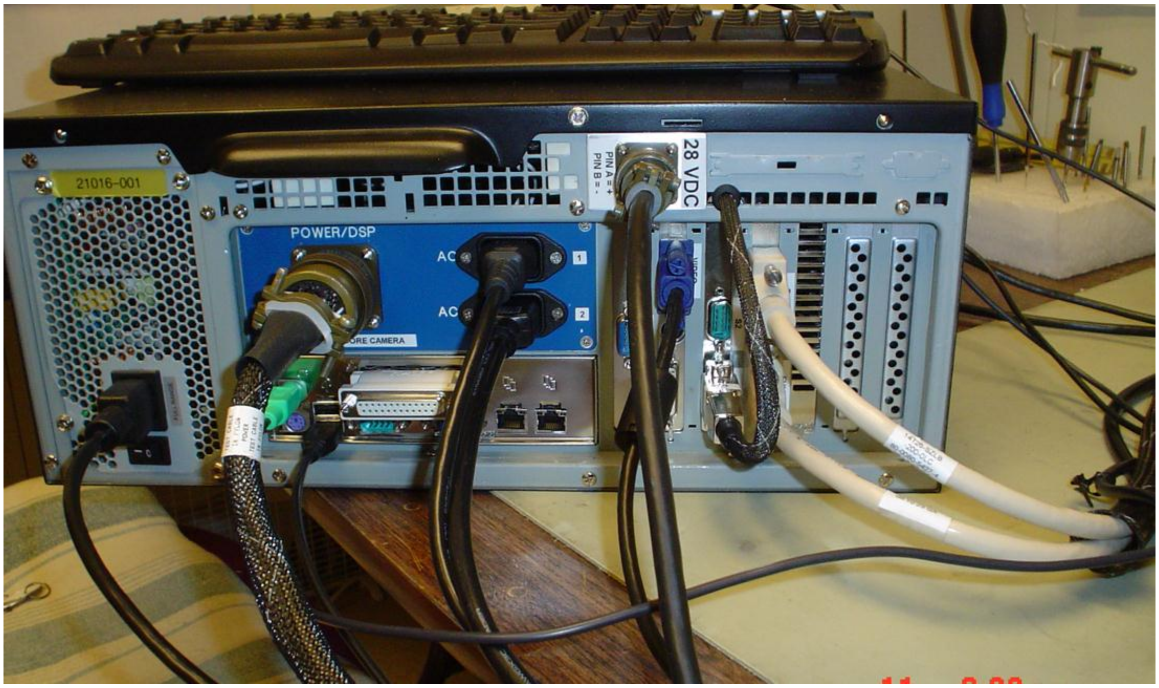


Figure 2.4.1: Rear of Data Acquisition System with all cables connected.

2. Unlock & open the disk drive bay door.

3. Start the Data Acquisition System computer by pressing the "Computer Power" switch on the lower left side of the disk drive bay by the red "RESET" button. See **Figure 2.4.2**. Allow the computer to boot up.

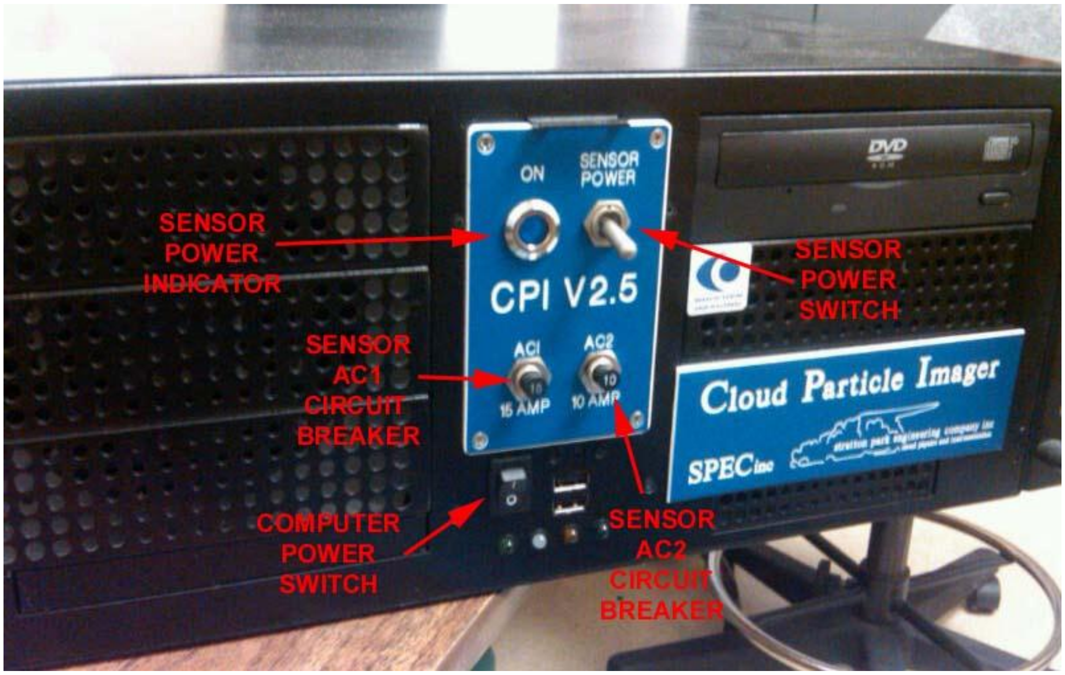


Figure 2.4.2: Front panel of the CPI Data Acquisition System.

4. Double click the CPI icon on the desktop to start the CPI.exe program.

5. After the CPI program has started, switch on the "Sensor Power" switch on the front panel of the Data Acquisition System. See **Figure 2.4.2**.

6. Single click the "Start Probe" button on the left side on the CPI program window. See **Figure 2.4.3**.

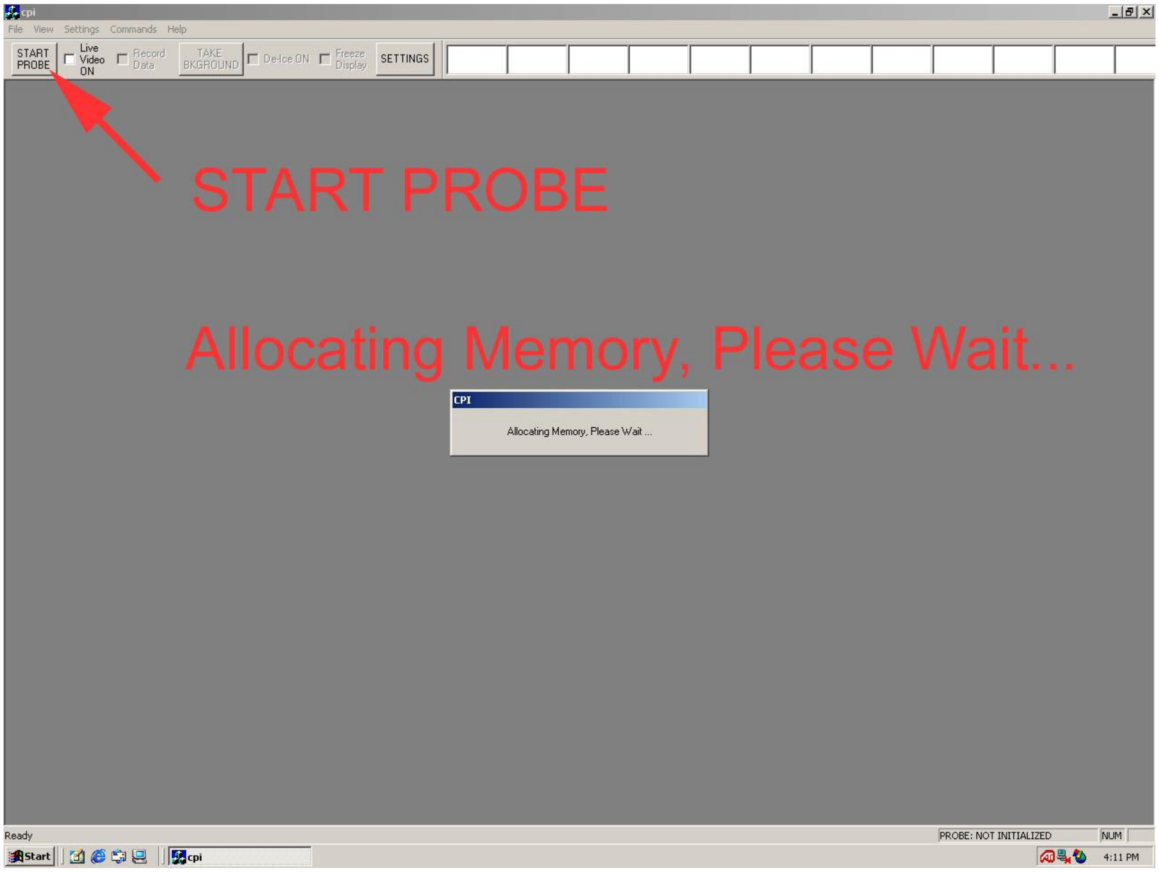


Figure 2.4.3: CPI Program Screen While It Is Allocating Memory.

7. You should see an “Allocating Memory” message as shown in **Figure 2.4.3**. This message indicates that the CPI program is allocating memory locally in the Data Acquisition Computer. It is not yet trying to communicate with the probe (Sensor Head). Wait about forty seconds.

8. After about forty seconds the message window should change to “Initializing the Probe…” as shown in **Figure 2.4.4**. In this step the CPI program tries to communicate with the probe. If it is successful, it sets up probe operating values, receives data packets from the probe, directs the CCD camera to take two background images, and processes those images to establish a background reference for the probe’s imaging system. After about ten more seconds you should see the CPI startup screen, as described in step 9 below.

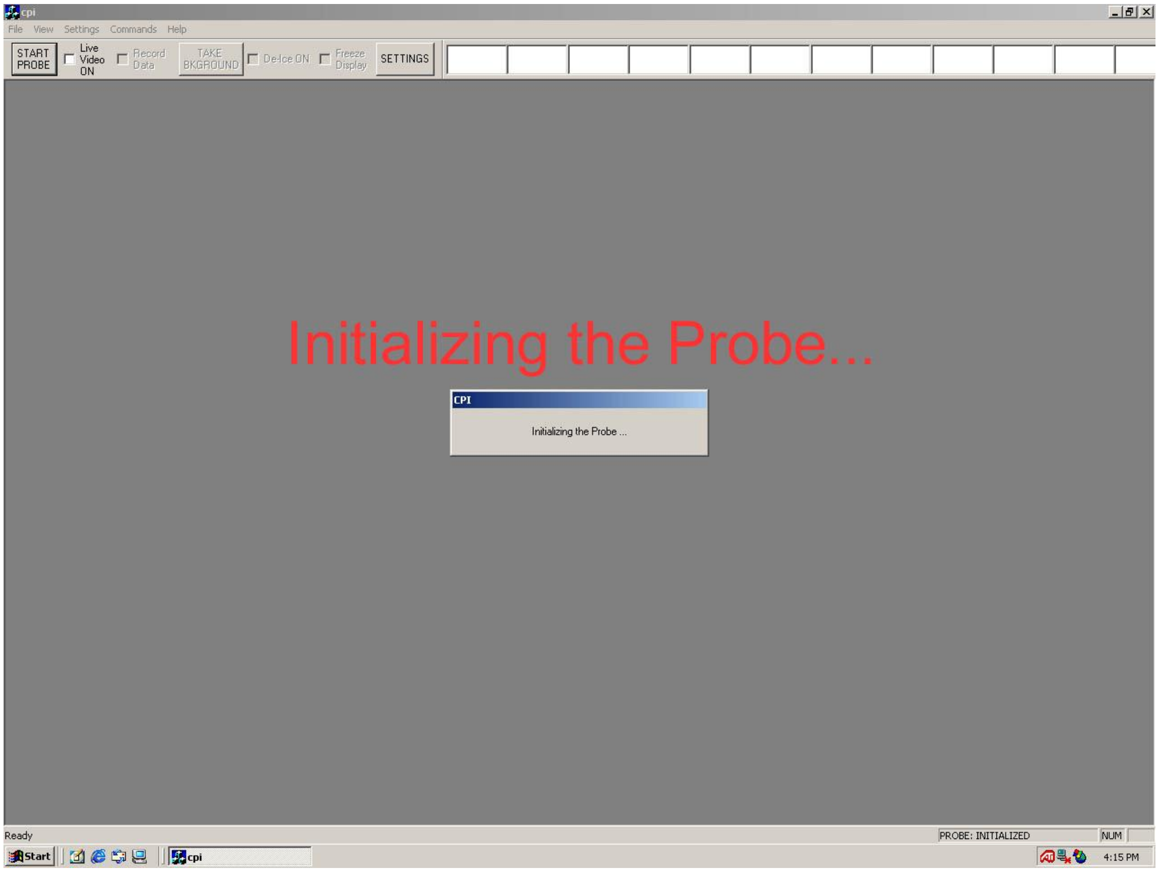


Figure 2.4.4: CPI Program Screen While It Is Initializing the Probe.

9. Once the Probe is initialized you should see the CPI startup screen which contains a particle image display window with at least one background image. Also you should see a “Statistics” window on the right-hand side of the screen, as shown in **Figure 2.4.5**. If you see a screen like **Figure 2.4.5** then your CPI has been started correctly and is running. See the “Software Description and Real Time Operation, **Section 5**) for further instructions on fine-tuning and running your CPI.

   If you DO NOT see a screen like **Figure 2.4.5** then the software or probe has a problem. Review the CPI cable connection procedure and CPI startup procedure to make sure that they were done correctly. If these procedures were followed correctly, then please see the “Real Time Operation and Troubleshooting, **Section 5.2**).

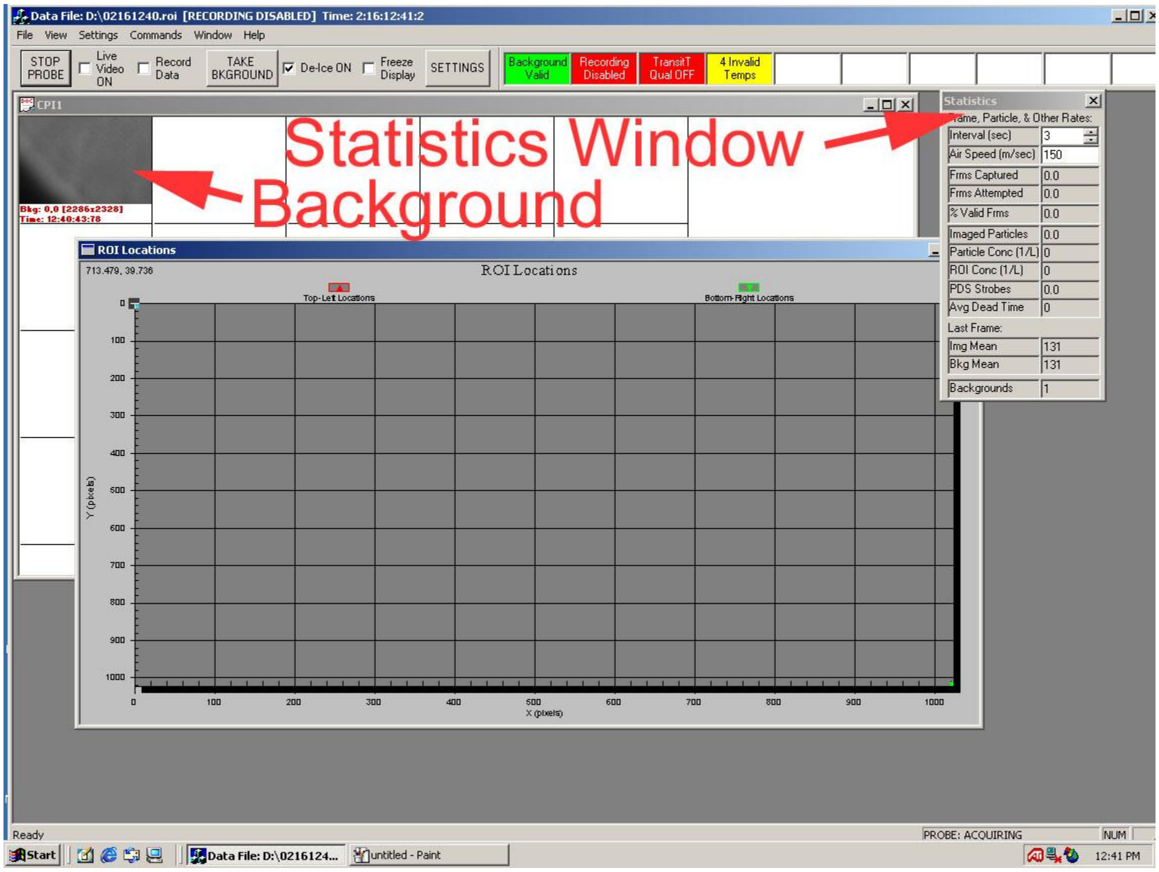


Figure 2.4.5: Startup screen of CPI Program**.**

2.5 Disconnecting the CPI Cables

Warning! The sensor camera cable must be disconnected before the power/dsp cable. If you do not disconnect the sensor camera cable first you may damage your CPI!

CPI cables must be disconnected in the reverse of the sequence in which they were connected, as follows:

1. Verify that the Sensor Power switch on the front of the data acquisition system is switched off. Verify that the Data Acquisition System Computer is switched off.

2. Disconnect the sensor camera cable from J1 on the Data Acquisition Computer.

3. Disconnect the sensor camera cable from J1 on the Sensor Head.

4. Disconnect the power/dsp cable from J2 on the Data Acquisition Computer.

5. Disconnect the power/dsp cable from J2 on the Sensor Head.

6. Disconnect mouse, keyboard, and monitor from the back of the Data Acquisition Computer.

7. Disconnect the three AC power cables: Computer Power, AC1, AC2.

2.6 Packing CPI System

This procedure is to be followed when packing the CPI system for shipment or storage.

20. Place the foam insert into the shipping case for the CPI pylon (**Figure 2.6.1**).

21. Place the pylon plug over the inlet and outlet of the CPI pylon to keep dust out during shipping (**Figure 2.6.2**).

22. Place the CPI pylon in the shipping container and cover with the foam insert with the circular cutout as shown in **Figure 2.6. 3**. Be sure the CPI pylon is in the same orientation as **Figure 2.6.2**.

23. Place the CPI cables into the circular cutout as shown in **Figure 2.6.4**. Close and latch this shipping case.

24. Remove the AcquireNow Hardware key and then disconnect the captive cables from the back of the data system (**Figure 2.6.5**).

25. This step is optional, but provides more protection during shipping of the computer. Remove the three screws for the computer cover as shown in **Figure 2.6.6** and remove the computer cover.

26. Insert the foam blocks included in the original shipment into the computer case for added protection during shipping. Place the foam blocks in the location shown in **Figure 2.6.7**. Replace the three screws for the computer cover. Replace the computer cover.

27. Place the data system and other accessories in the shipping case as shown in **Figure 2.6.8**. The atomizer should be wrapped in bubble wrap.

28. Place the foam insert shown in **Figure 2.6.9** on top of the data system.

29. Place the flat panel monitor, keyboard, mouse, cleaning tool, manual, pulling fork and alignment pin into the foam insert as shown in **Figure 2.6.10**. The alignment pin should be wrapped in bubble wrap.

30. Close and latch the lid to the shipping container.

31. The system is now ready for shipping.

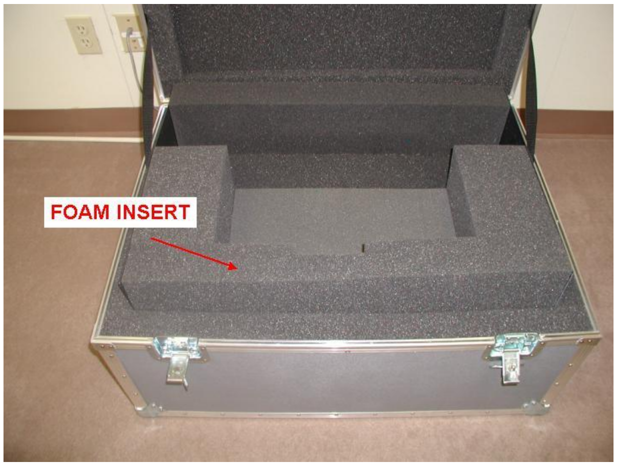


Figure 2.6.1.

Figure 2.6.2.

Figure 2.6.3.

Figure 2.6.4.

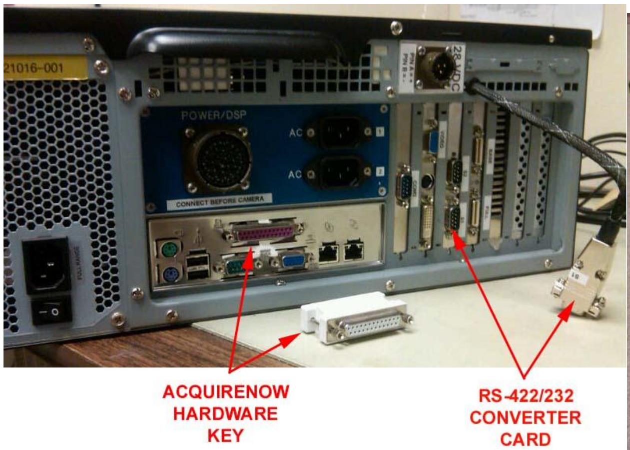


Figure 2.6.5.

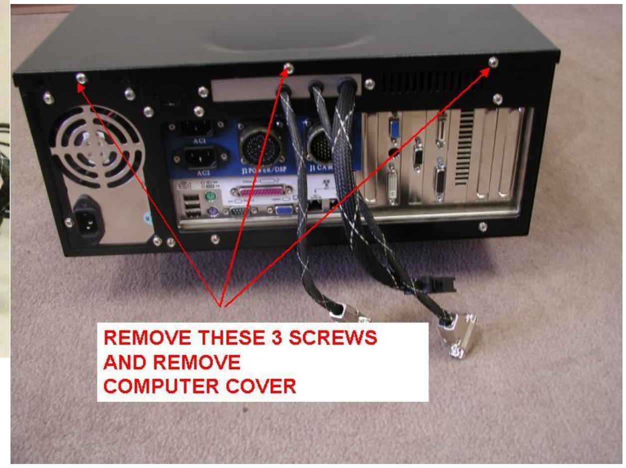


Figure 2.6.6.

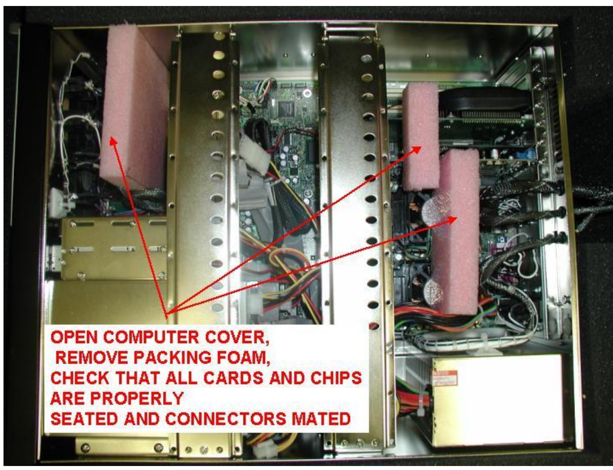


Figure 2.6.7.

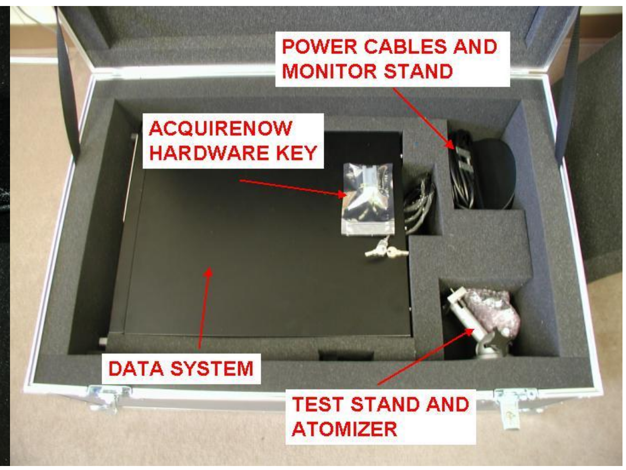


Figure 2.6.8.

Figure 2.6.9.

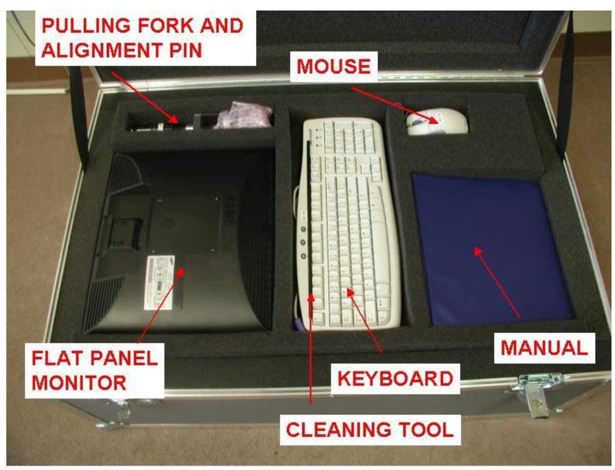


Figure 2.6.10.

3.0 CPI PHYSICAL DESCRIPTION

3.1 CPI Sensor Head – Physical Description

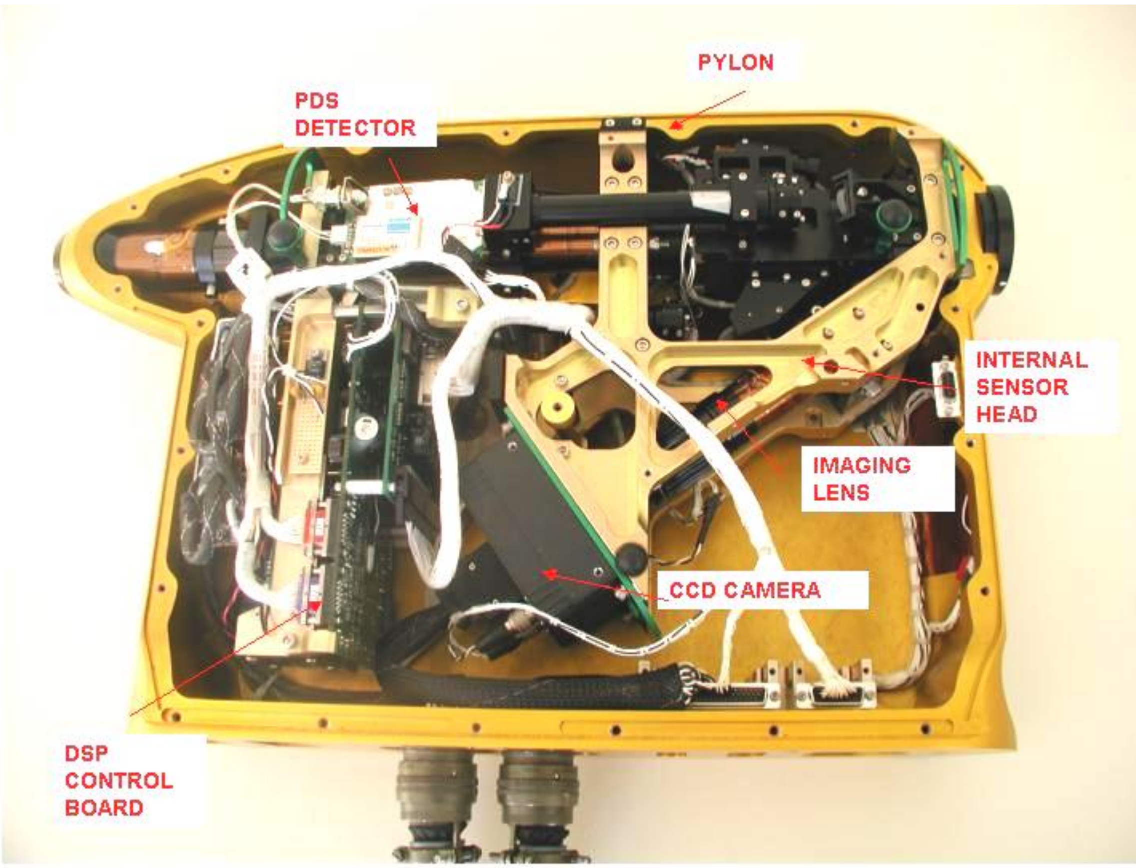


Figure 3.1.1. Photograph of CPI sensor head with pylon cover removed.

Figure 3.1.1 is a photograph of the CPI sensor head with the pylon cover removed. (See **Section 6.1** Pylon Cover Removal) The sensor head consists of the pylon and internal sensor. The internal sensor contains all of the electro-optical components and electronics and the pylon serves as a protective housing for the internal sensor. For laboratory operation or troubleshooting, the internal sensor can be removed from the pylon and operated independently.

Figure 3.1.2 shows the various components of the CPI sensor head sample tube. The direction of airflow is from right to left in **Figure 3.1.2**. The sample volume is located in the optical block, just downstream of the forward sample tube. A detailed drawing of the flow geometry is included in **Appendix 7.2**. Each of the sample tube components has an associated heat zone that is controlled from the "advanced control and settings window" in the real time software. **Figure 3.1.3** is a photograph of the CPI sensor head showing the physical location of the various components of the sample tube.

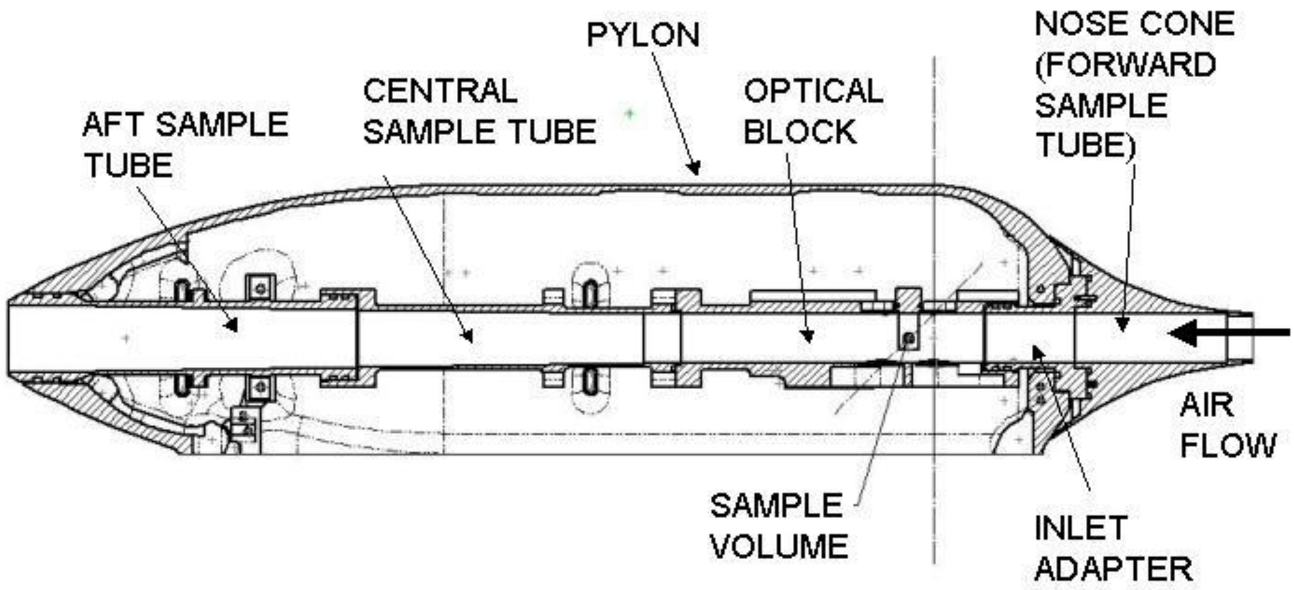


Figure 3.1.2. Cutaway view of CPI Sample Tube showing relevant components.

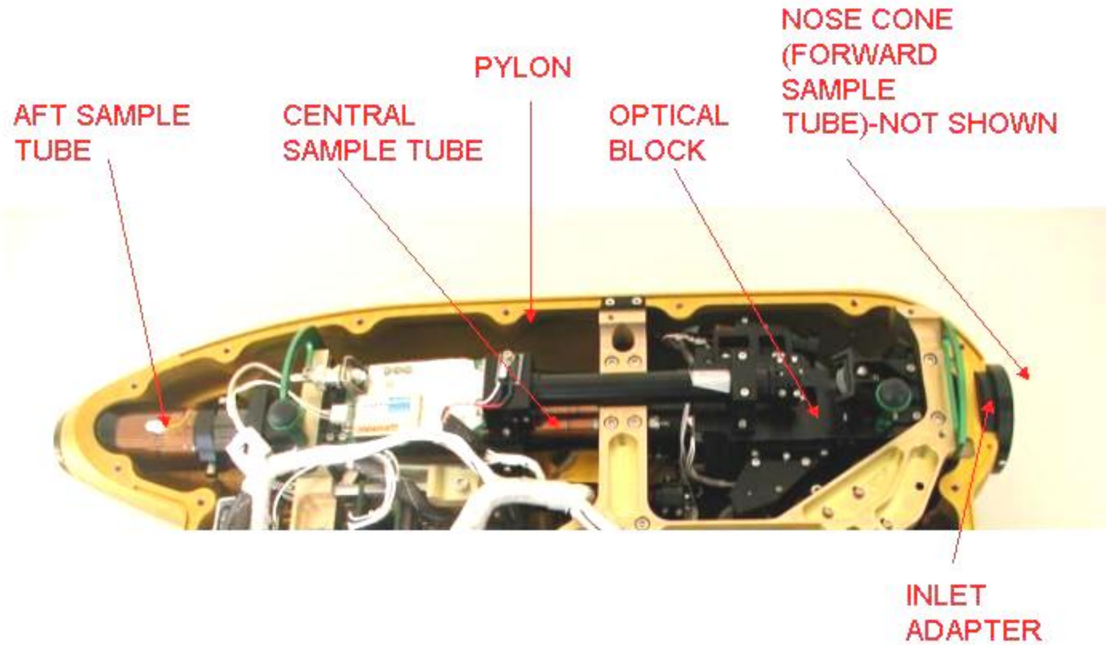


Figure 3.1.3. Photograph showing the physical location of the various sample tube components.

Figure 3.1.4 is a cutaway view of the optical block showing the locations of the three laser beam paths through the sample volume. The location of the six windows is also shown. Knowledge of the window locations is important for cleaning of the windows. Contamination on the PDS output windows has the largest effect on the PDS DC detector levels. During cleaning, the real time software should be running to provide feedback for the cleaning process. If the PDS DC level increases after a particular PDS window is cleaned, that window needs to be cleaned again. Removal of contamination from the windows should result in a decrease in the baseline stray light hitting the PDS detectors.

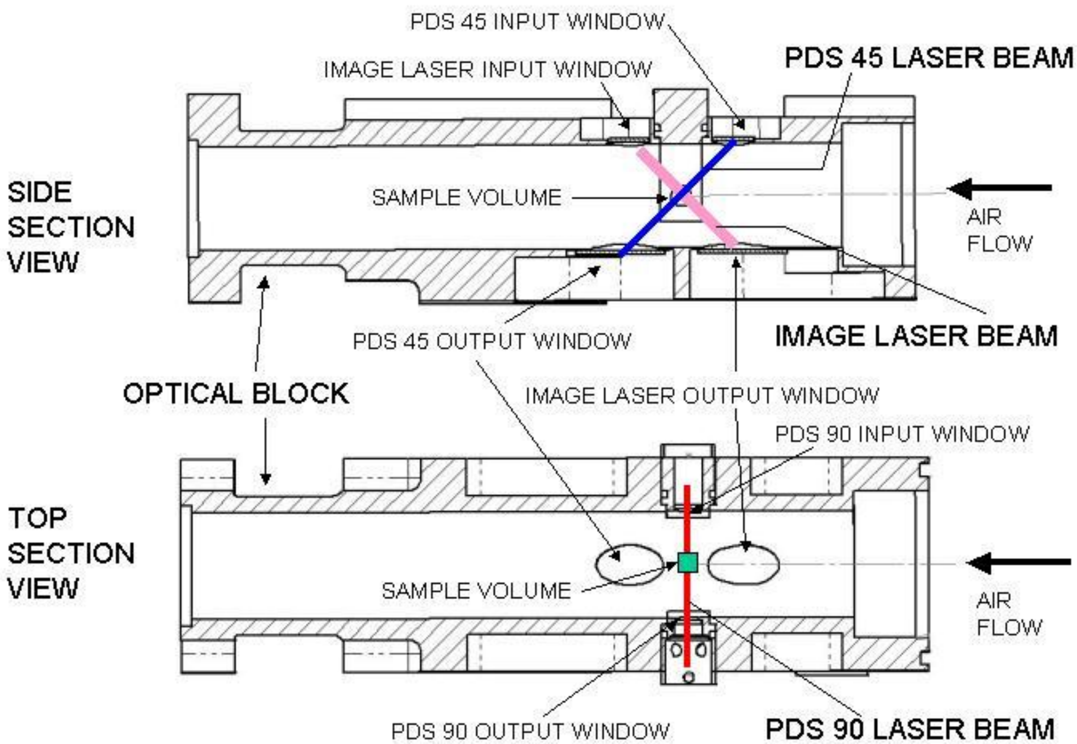


Figure 3.1.4. Cutaway of optical block showing laser beam locations and window locations.

Figure 3.1.5 is a photograph showing the location of the electronics printed circuit boards in the CPI sensor head. The power supply board and Digital Signal Processor (DSP) control board are equipped with temperature sensors that monitor the temperature of these boards. This information is displayed in the housekeeping window. These temperatures are monitored, but do not have a corresponding temperature setpoint in the advanced control and settings window, as there are no heaters associated with these circuit boards.

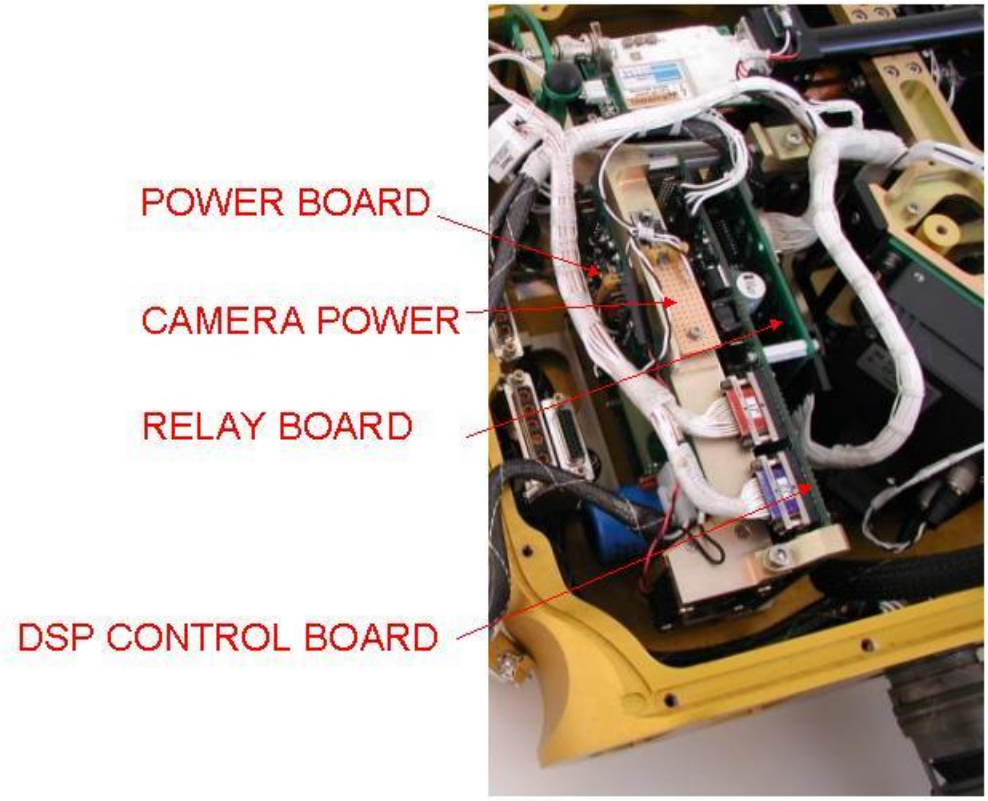


Figure 3.1.5. Photograph showing location of the CPI printed circuit boards.

Figure 3.1.6 is a photograph of the pylon cover and pylon main body showing the location of the different heat zones. The heat zones in the pylon are broken into three different areas for control: the pylon slugs, pylon base patch, and pylon cover patch. Physically, there are four pylon slug heaters, two in the pylon cover and two in the pylon base. They are all controlled together by one temperature sensor mounted in the base near one of the slug heaters. The pylon base patch heater and pylon cover patch heater are shown in **Figure 3.1.6**. Each of these heaters has its own temperature sensor and they are individually controlled in the software. The main purpose of the pylon heaters is to de-ice the pylon when flown in icing conditions. During normal operation, **these temperature zones should not fall below freezing in icing conditions**. In very cold temperatures, such as –60C, these temperatures may fall below freezing, but icing is not a concern at these temperatures.

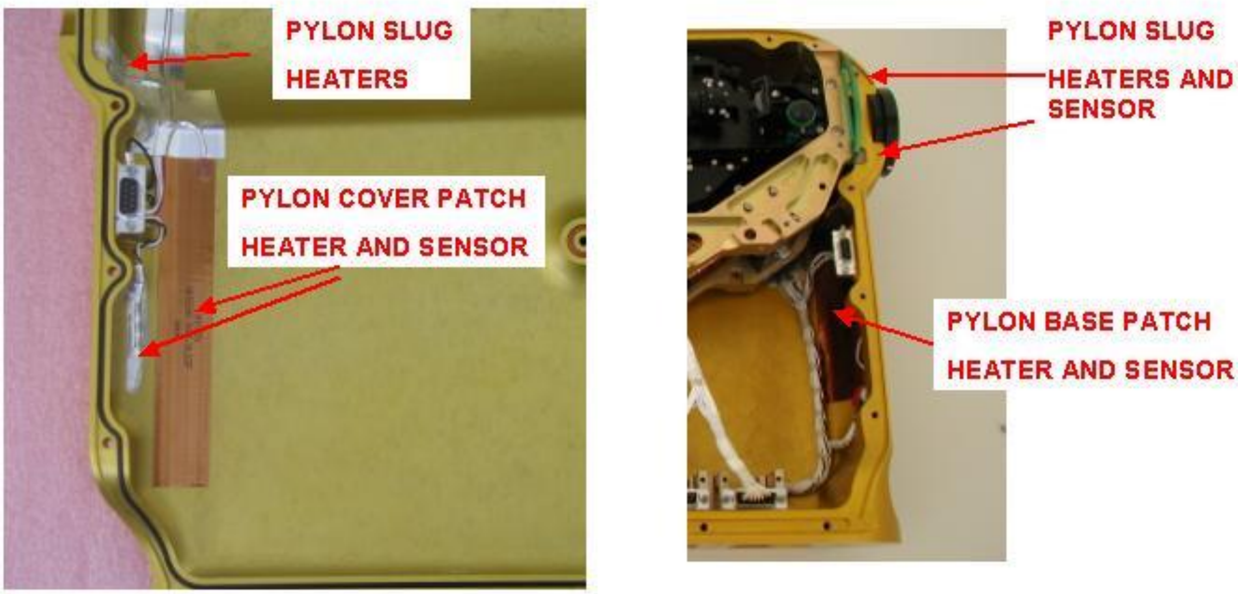


Figure 3.1.6. Photograph showing location of pylon heaters.

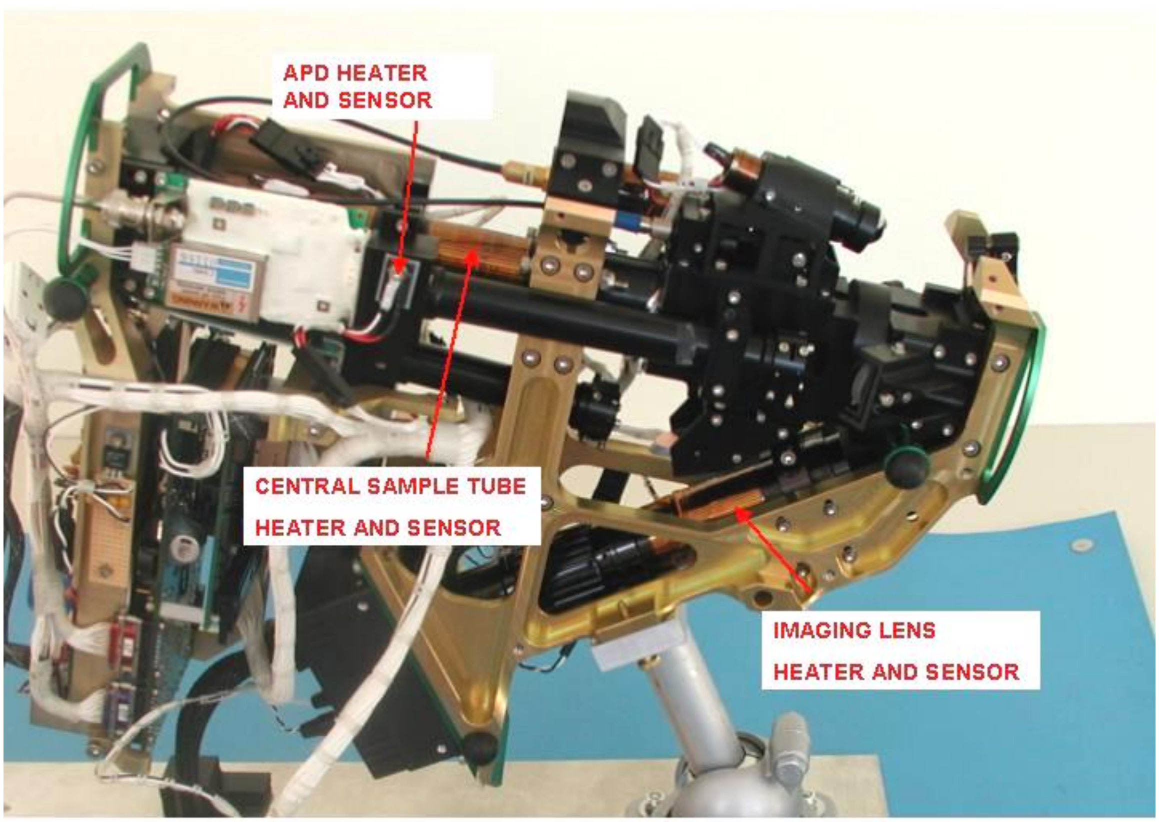


Figure 3.1.7. Photograph of heat zone locations on front side of internal sensor.

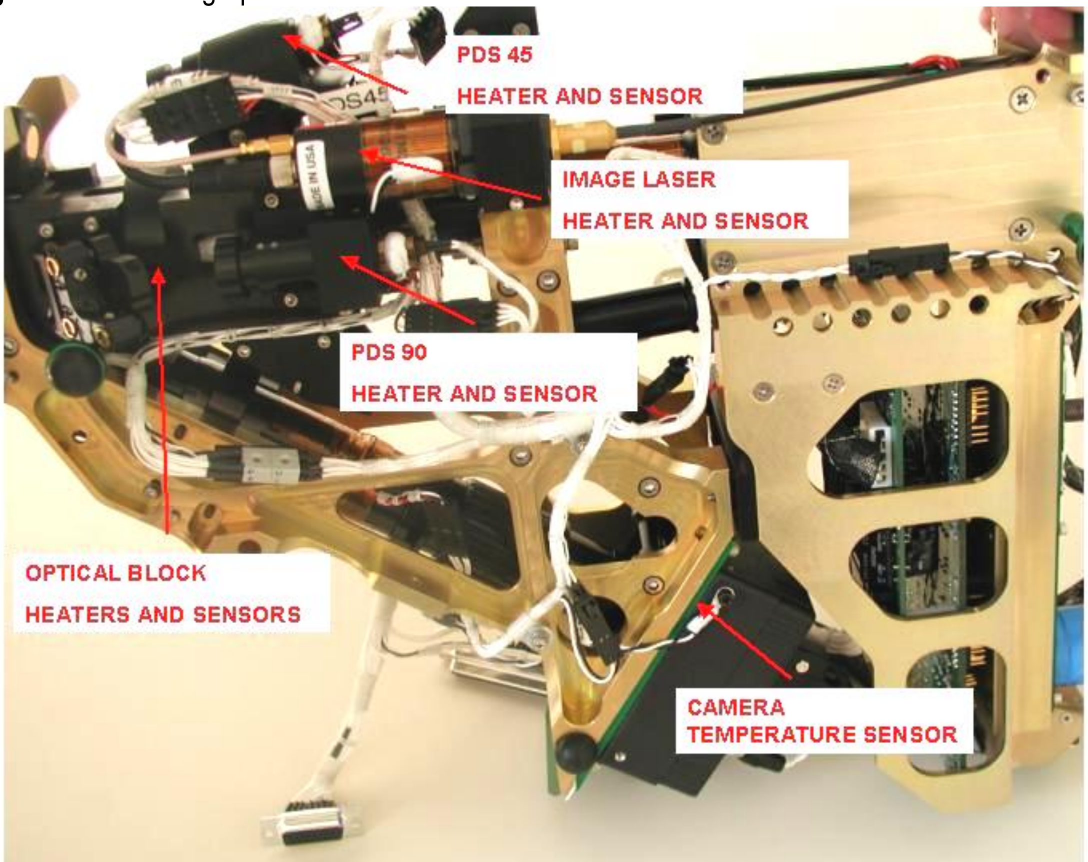


Figure 3.1.8. Photograph of heat zone locations on rear side of internal sensor.

Figures 3.1.7 and **3.1.8** show various heat zone locations for the CPI internal sensor. There are two Avalanche Photodiode Detectors (APDs) in the system (PDS 45 and PDS 90) but only one heat zone is used for control of the APDs. A sensor is on the PDS 90 APD and heaters are on both the PDS90 and PDS 45 APD. Each of the three laser assemblies has its own heat zone. The camera temperature sensor monitors the camera temperature but does not have a heater associated with it.

4.0 THEORY OF OPERATION

4.1 Optical System Description

The overall optical system consists of three separate subsystems: the 45 Particle Detection System (PDS), the 90 PDS system, and the imaging system. **Figure 1.1.2** is a functional schematic for the CPI optical system. For the sake of clarity, only the major components of each system are shown in the figure. The PDS system is used to detect the presence of a particle in the sample volume. The CPI DSP electronics process the particle information. If certain triggering criteria are satisfied (pulse height, minimum transit time, etc.), the DSP electronics send a signal to pulse a high power imaging laser and capture an image of the particle on a CCD camera**.**

Both PDS systems are functionally identical. The PDS systems use a continuous wave laser and beam shaping optics that produce a laser beam with a rectangular cross-section. The two PDS laser beams are orthogonal to one another forming a volume of approximately 2.5 mm x 2.5 mm x 0.5 mm thick. This volume is located in the center of the instrument sample tube, tilted at an angle of 45 degrees. The rectangular laser beams are "dumped" onto a dump spot upstream of the PDS detectors. **Figure 1.1.2** shows the laser beams being dumped, in the absence of a particle in the sample volume.

Figure 1.1.3 is a schematic of the optical system as a particle passes through the sample volume. As the particle traverses the PDS laser beams, it begins to scatter light around the dump spots and onto the PDS detectors. Avalanche photodiodes (APDs) are used for the PDS detectors due to their ability to detect low light levels. The output of the PDS detectors is monitored by the DSP control board.

The imaging system consists of a CCD camera with an imaging lens, and a high power pulsed laser. When the DSP electronics receive simultaneous signals from the 45 PDS and 90 PDS detectors, to indicate the presence of a particle in the sample volume, the CCD camera is exposed with a 20-40 ns laser flash. The image of the particle is then captured by the camera. The imaging system is configured such that the object plane is coplanar with the backside of the rectangular volume formed by the PDS laser beams. The effective imaging area is a square that is 2.5 mm x 2.5 mm.

4.1.1 PDS System

Figure 1.1.3 is a simplified representation of the overall optical system. The actual PDS systems and imaging system consist of many optical components used to achieve the desired optical performance. The 90 PDS system has a beam path that makes an angle of 90° with the axis of the sample tube. The 45 PDS system has a beam path that makes an angle of 45° with the axis of the sample tube. **Figure 4.1.1** is a solid model the 90 PDS system showing all of the individual system components. **Figure 4.1.1** also shows a simplified laser beam path through the 90 PDS system. The actual laser beam shape as the light propagates through each optical element in the system is described using ray tracing diagrams.

Figure 4.1.2 is a ray trace for the PDS laser beam shaping optics. The laser diodes and beam shaping optics are identical for both the 90 degree and 45 degree PDS systems. The beam shaping optics are used to produce an output beam with a rectangular cross-section of the appropriate dimensions and a relatively uniform energy distribution**.**

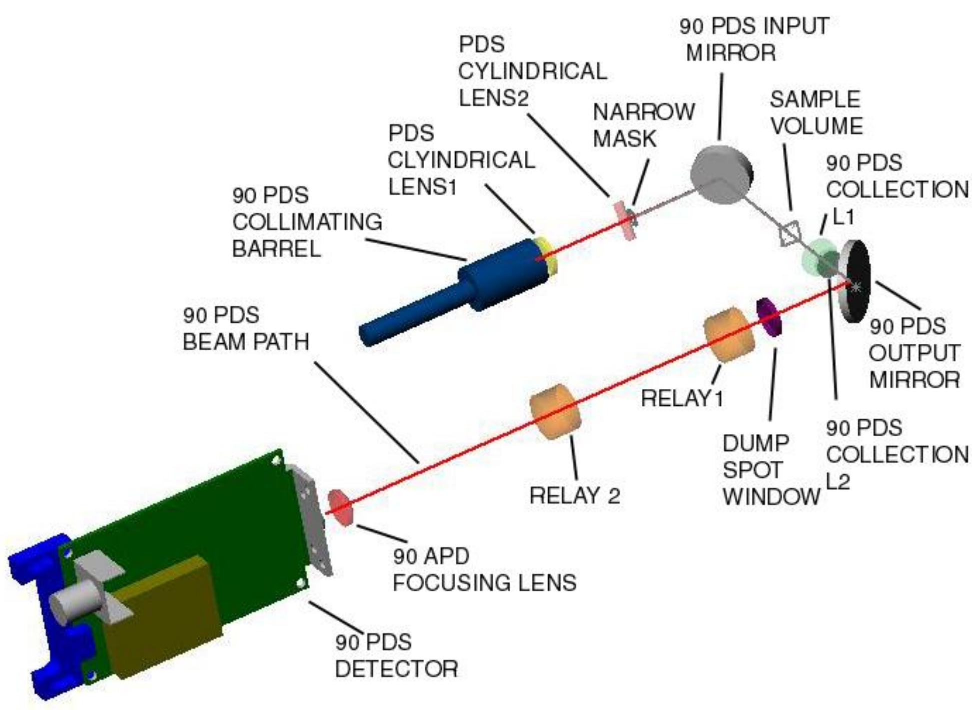


Figure 4.1.1. 90 PDS system optical component layout.

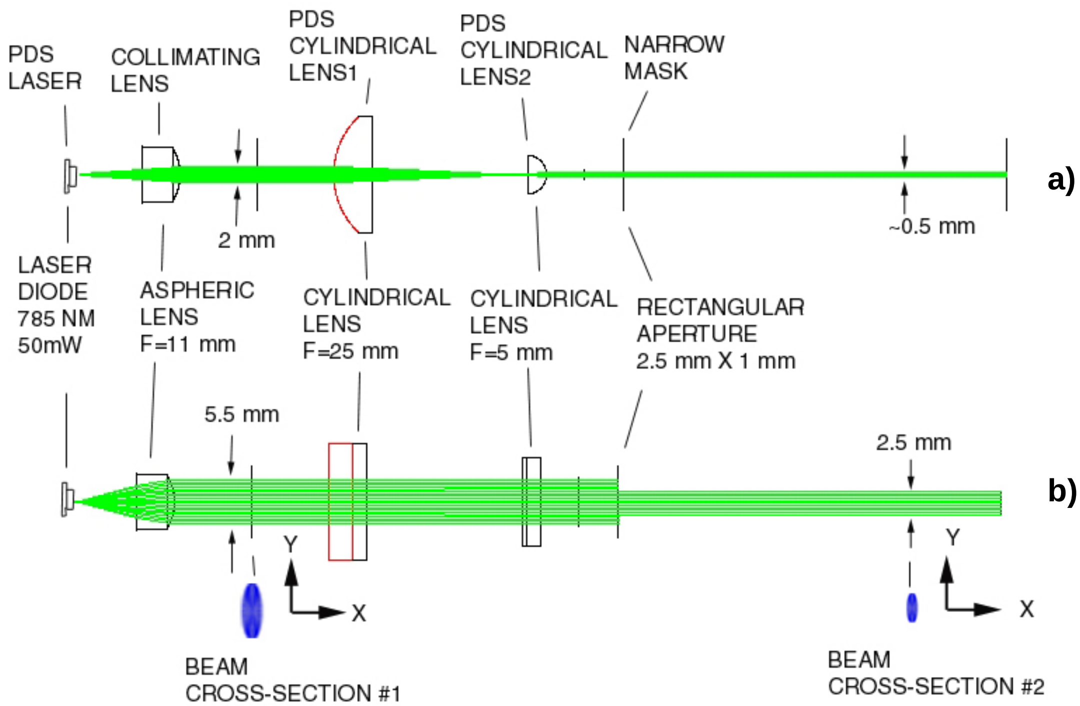


Figure 4.2.2. Ray trace for PDS laser beam shaping optics with **a)** view of compressed axis and **b)** view of uncompressed axis.

The lasers used for the PDS system are Hitachi HL7851 laser diodes. The lasers operate at a wavelength of 785 nm with a maximum output power of 40 mW. The output from the laser diode has an elliptically divergent beam with a parallel divergence angle of 9.5° and a perpendicular divergence angle of 23°. An aspheric lens is used to produce a collimated beam with an elliptical cross-section. As shown in **Figure 4.2.2**, the dimensions of the collimated beam are approximately 5.5 mm x ~2 mm.

The minor axis of the elliptical beam is then compressed using a pair of cylindrical lenses. In **Figure 4.2.2**, the minor axis is referred to as the x-axis and the major axis is referred to as the y-axis. The beam is compressed by the ratio of the focal lengths of the cylindrical lenses. In this case the compression is 5/25 or 0.2X. This reduces the minor axis of the ellipse to approximately 0.4 - 0.5 mm. The beam shape is now closer to rectangular than elliptical. Since the cylindrical lenses do not affect the y-dimension of the beam, a rectangular aperture is used to reduce the beam to the desired 2.5 mm dimension. The width of the aperture is 1 mm to allow the laser beam to cleanly pass through in the x-dimension.

The PDS lasers and the beam shaping optics are contained in the PDS tube assembly. This assembly is an integral unit that allows the shaped laser beam to be pointed and steered without affecting the beam shape and collimation. As shown in **Figure 4.1.1**, the shaped beam intersects the 90 PDS input mirror, which directs it through the 90 PDS input window and into the sample volume. The windows and mirrors mount on the optical block, a key mechanical component of the instrument. The optical block defines the physical location of the sample volume and serves as an interface between air and cloud particles flowing through the sample tube and the internal structure of the CPI.

The sample volume is located in the center of the sample tube, running through the optical block. This relationship is depicted in **Figure 1.1.2.** After the PDS laser beam traverses the sample volume and exits the optical block, it intersects the PDS collection optics.

The PDS collection optics are designed to collect light scattered by particles in the sample volume and focus it onto the APD which acts as the PDS detector. The PDS collection optics and dump spot define the collection angle for the PDS system. In this case both PDS systems have been designed to collect light scattered into an angle of approximately 2.5° - 8.2°.

Figure 4.1.3 is a ray trace for the 90 PDS collection optical system. In this figure, the sample volume is on the left side and the PDS detector is located on the right side. Four separate ray traces are shown. **Figure(s) 4.1.3a** and **4.1.3b** show the PDS laser beam as it is blocked by the dump spot when no particle is present in the sample volume. **Figure 4.1.3a** shows the beam in the X-Z plane (~0.5 mm dimension) and **Figure 4.1.3b** shows the beam shape for the Y-Z plane (2.5 mm dimension). The beam size on the dump spot is relatively the same size as that in the sample volume, even though it has passed through 90 PDS Collection Lens1 and 90 PDS Collection Lens2. The spacing between the various optical elements is shown in **Figure 4.1.3b**.

Figures 4.1.3c and **4.1.3d** are ray traces for the scattered light path propagating through the 90 PDS collection optics. A particle must be present in the 90 PDS beam to scatter light around the dump spot. **Figure 4.1.3c** shows the scattered light path for the X-Z plane and **Figure 4.1.3d** shows the scattered light path for the Y-Z plane. The effect of the dump spot can be seen in both these ray traces by noticing the shadowed area just to the right of the dump spot. The minimum collection angle of 2.5° is defined by the rays that just pass around the dump spot in **Figure 4.1.3c**. The maximum angle of 8.2° is defined by the maximum clear aperture of 90 PDS Collection Lens2. The relay lenses are used to accommodate the mechanical packaging of the collection optics by increasing the total path length. The APD Focusing Lens is used to focus the scattered light rays onto the 1.5 mm diameter active area of the detector.

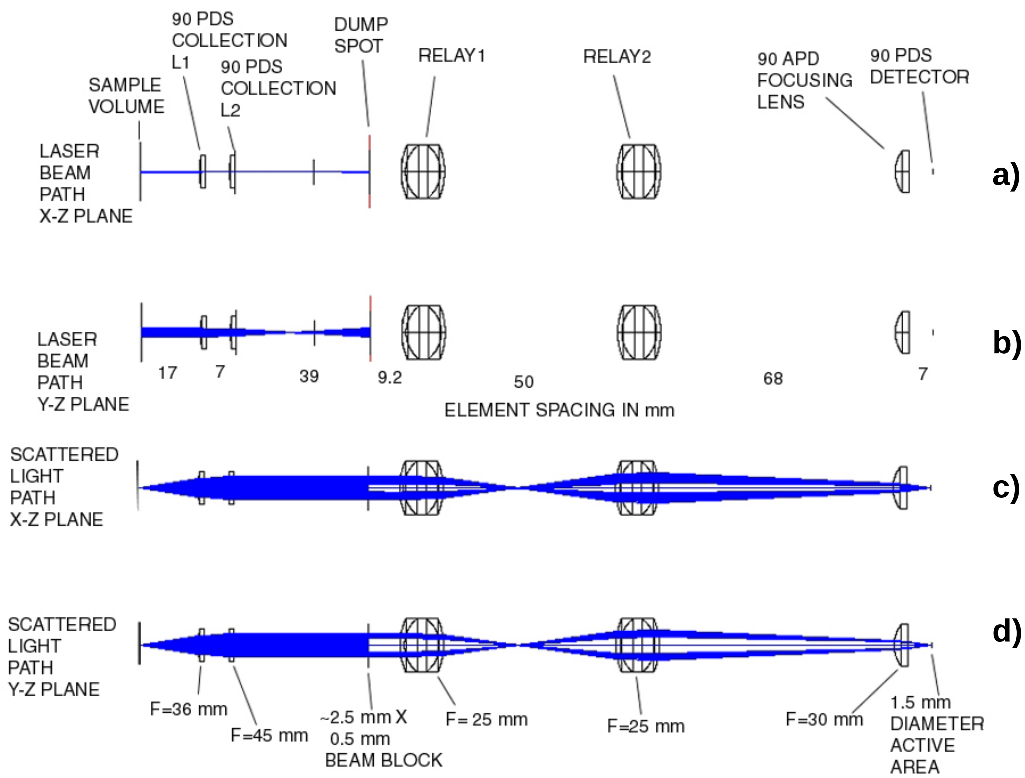


Figure 4.1.3. Ray trace for 90 PDS collection optics: **(a)** beam in X-Z plane, **(b)** beam in Y-Z plane (c) scattered light path X-Z plane **(d)** scattered light path Y-Z plane.

Figure 4.1.4 is a solid model showing all of the components for the 45 PDS collection system. The 45 PDS laser and beam shaping optics are identical to the 90 PDS laser and beam shaping optics described above. The primary difference between the 90 PDS and 45 PDS optical systems are found in the collection optics. The collection lenses must have longer focal lengths because the distance from the first collection lens to the sample volume is longer due to the beam crossing the sample tube at a 45° angle.

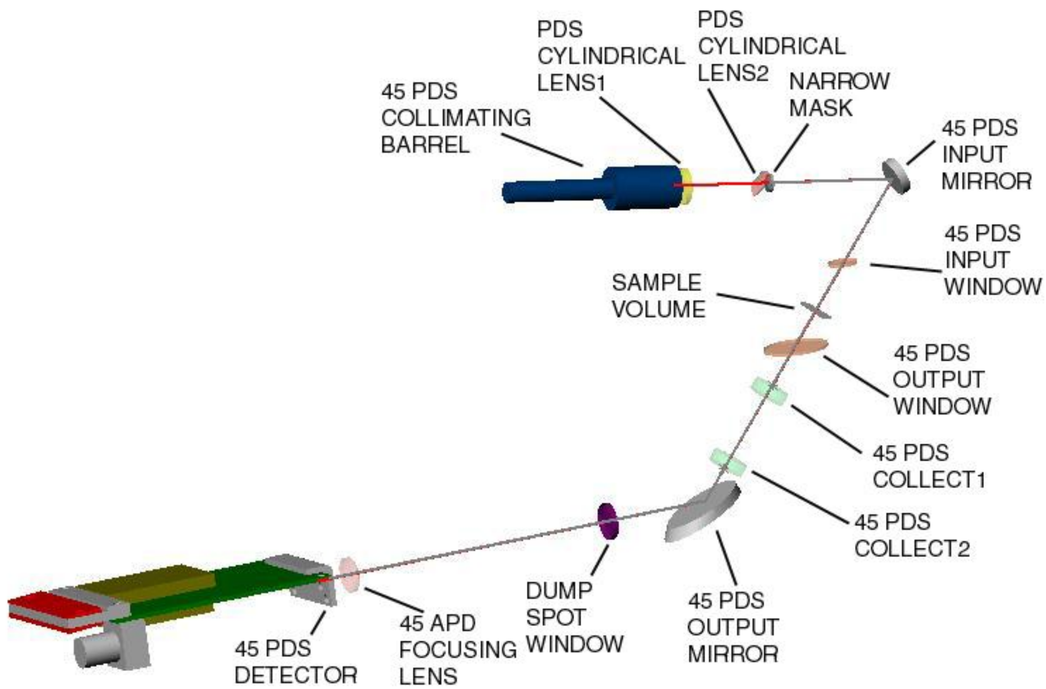


Figure 4.1.4. 45 PDS system optical component layout.

Figures 4.1.5a-d are ray traces for the 45 PDS collection optics. The lenses labeled 45 Collection Lens1 and 45 Collection Lens2 have longer focal lengths than the corresponding lenses in the 90 PDS collection optics. Relay lenses are not necessary due to the shorter path length to accommodate the mechanical packaging. As in the case of the 90 PDS collection optics, 45 PDS Collection Lens2 is the limiting aperture that defines the maximum collection angle of 8.2°.

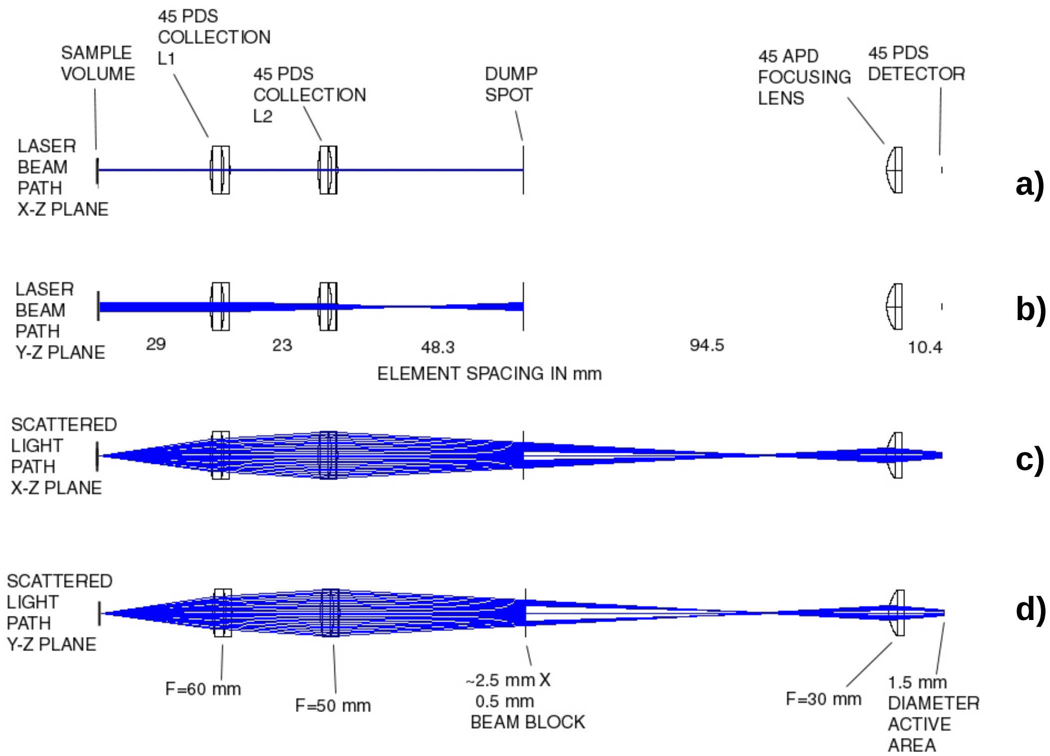


Figure 4.1.5. Ray trace for 45 PDS collection optics.

4.1.2 Imaging System

Figure 4.1.6 is a solid model of the CPI imaging optical system showing all of the components. The two primary components of the system are the imaging laser and the imaging system lens. The primary function of the imaging system is to capture images of cloud particles as they move through sample volume at aircraft speeds. This is accomplished by flashing a laser at pulse widths up to 40 ns while a particle is present in the object plane. A 1024 x 1024 pixel CCD camera captures the image of the particle and transfers the frame to the data system. A previously stored background image is subtracted from the newly acquired image and the result is a region of interest (ROI) that contains an image of the cloud particle. The camera runs at approximately 74 frames per second

The laser used for the imaging system is a stacked array consisting of three emitters. A 600 µm core multimode fiber is butt-coupled to the face of the stacked array. The fiber is used to provide an output beam that is circularized and has a relatively uniform energy distribution. The output from each of the laser segments is blended together as the beam propagates through the fiber, resulting in a much more uniform energy distribution than would be otherwise achievable. The laser operates at a wavelength of 810 nm and has an output power greater than 120 W. The fiber is terminated with an SMA style fiber connector. The connector screws into a collimating barrel that uses an aspheric lens to collimate the output of the fiber.

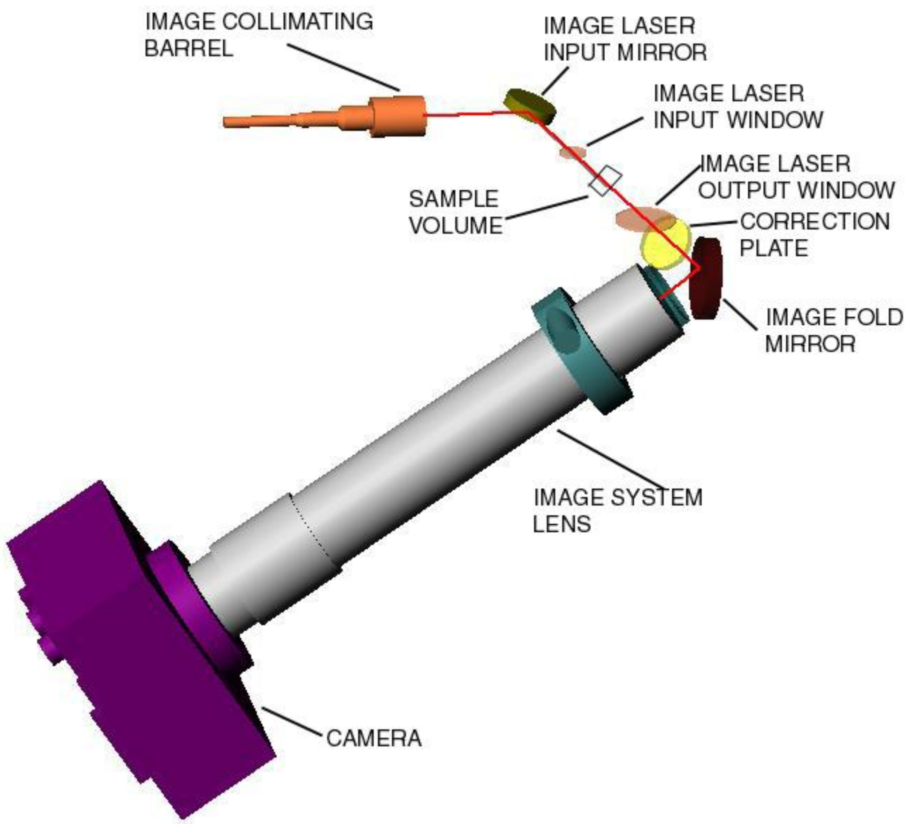


Figure 4.1.6. Imaging system optical component layout.

The collimated beam is directed into the sample volume using the image laser input mirror. After passing through the sample volume, the beam passes through a correction plate before being folded into the imaging system lens. The laser provides the illumination to image particles as they pass through the sample volume. In the absence of a particle, the imaging laser must provide a uniform and repeatable background on the CCD camera. The imaging system lens expands the incoming laser beam by 5X magnification to uniformly illuminate the CCD chip.

The CPI uses an imaging lens with a primary magnification of 5X. A feature of the imaging lens is the ability to maintain a constant magnification over its focus adjustment range. The focus of the imaging system is adjusted with an adjustment barrel on the body of the lens. This lens system greatly simplifies the optical alignment of the imaging system.

The correction plate is necessary to correct the astigmatism produced in the imaging system. This astigmatism is the result of the image output window being tilted at an angle of 45° to the imaging system optical axis. The rays are refracted at different angles depending on where they intersect the window. The result is an astigmatism that makes a spherical water drop look elliptical. The correction plate is a plane parallel element that is tilted at a specific angle to nullify the astigmatism.

Table 4.1.1 is a summary of the optical specifications for the CPI.

Table 4.1.1. CPI optical specifications.

PARAMETER	***VALUE***	***UNITS***
Sample area	2.5 X 2.5	mm x mm
Pixel resolution	~2.4	μm/pixel
camera array size	1024 x 1280	pixels x pixels
camera pixel size	12 x 12	μm
Max. Frame Rate	74 at 1024 x 1024	frames per second at pixels x pixels
Image system primary magnification	~5X	Linear magnification

Image laser wavelength	810	Nm
Image laser power	120	W
Image laser pulse max. pulse width	40	ns
Image laser max. pulse frequency	74 (currently)	Hz
PDS laser wavelength	785	nm
PDS laser max. power	40	mW (cw)
PDS beam size	~0.5 x 2.5	mm x mm
PDS collection angle	2.5 - 8.2	Degrees

4.1.3 Physical Location of Optical Components

Figures 4.1.7, **4.1.8** and **4.1.9** show the location of each of the optical components described above. The figures should be used as a reference when trying to locate various optical components in the internal sensor head.

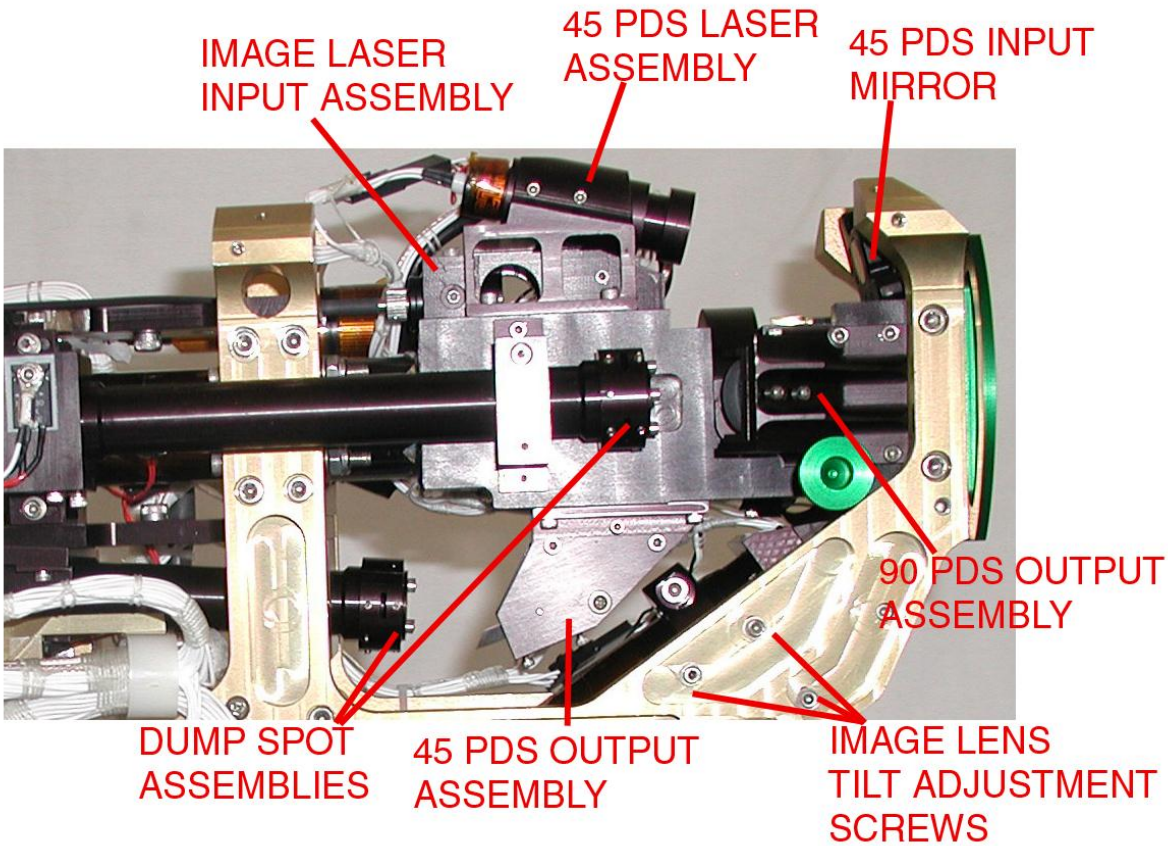


Figure 4.1.7. Location of optical components visible from top side of internal sensor.

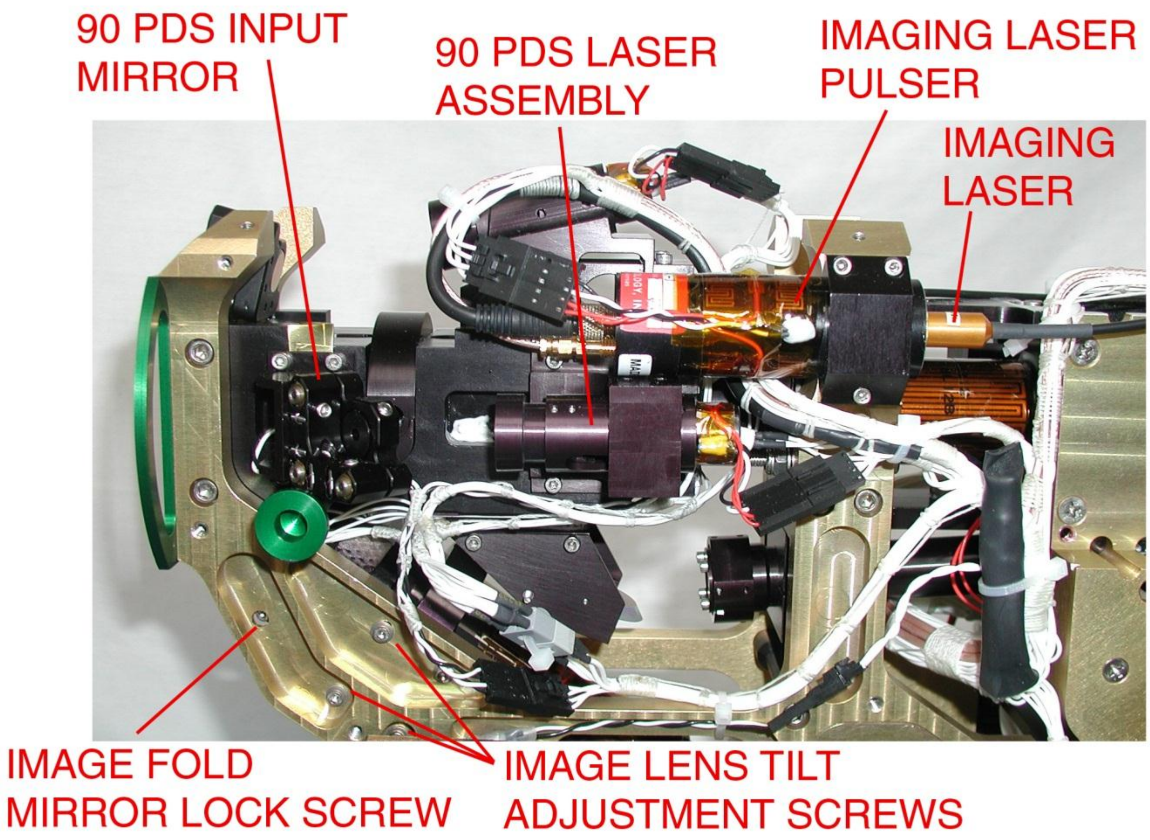


Figure 4.1.8. Location of optical components visible from bottom side of internal sensor.

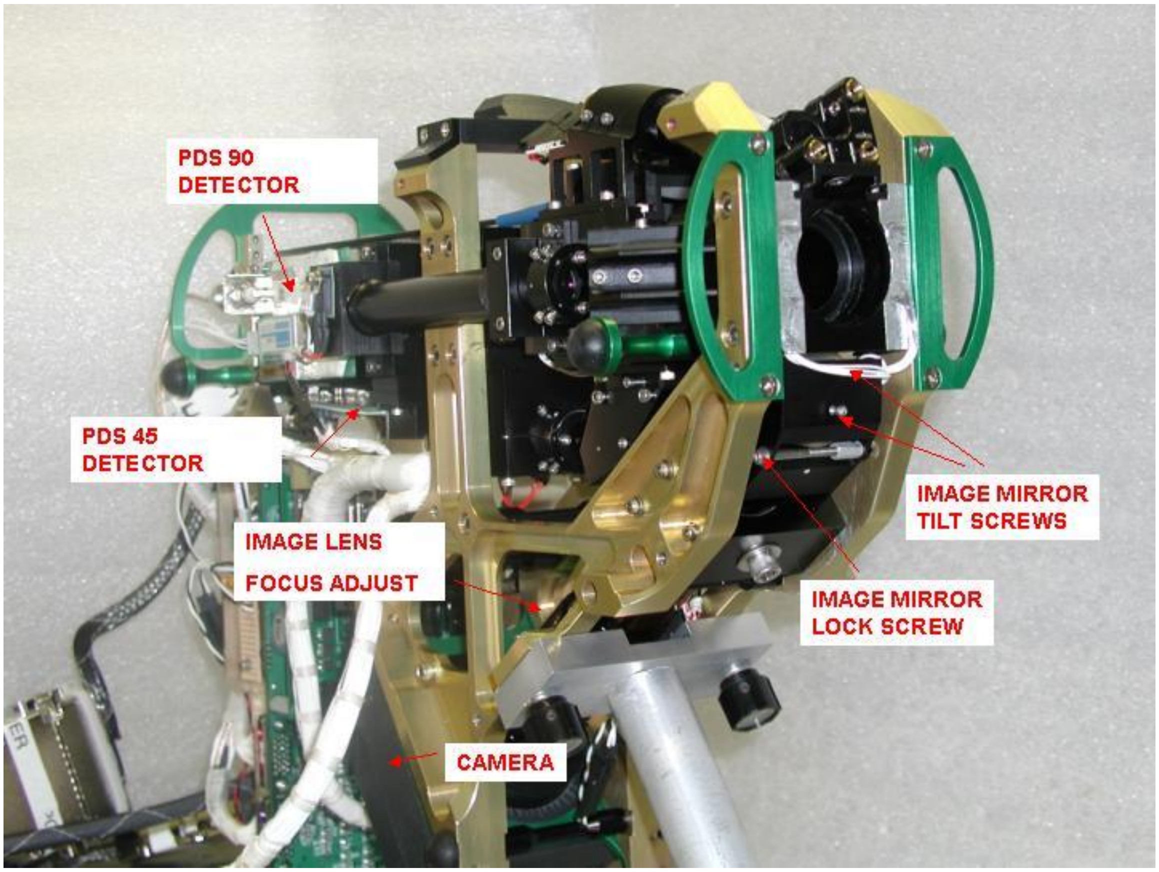


Figure 4.1.9. Location of optical components visible from front side of internal sensor.

4.2 Detailed Description of Electronics

The electronic assembly is comprised of three printed circuit boards. They are the Digital Signal Processor (DSP) board, the Relay board, and the Power board (not to be confused with the sensor head power supply, which is located in the Data Acquisition System Box). The DSP board is the main control center of the Sensor Head. It contains the ADSP 2191 digital signal processor microcomputer and logic chips. Together these circuits manage particle detection, laser drive power, heater control, and the collection and reporting of housekeeping data to the Data Acquisition System. These processes are described in the following sections.

4.2.1 Particle Detection System (PDS)

The particle detection system consists of two particle detection lasers and two Avalanche Photodiode Detectors (APDs). Please refer to the Optical Assembly description for the laser-related part of the PDS. The two APDs are designated PDS 45 detector and PDS 90 detector to indicate from which laser they receive light. Only the PDS 45 detector circuitry is described here but the PDS 90 circuitry is identical. See

Figure 4.2.1, the block diagram of the PDS 45 analog electronics found in the schematics of **Appendix 7.1**. The analog-processing electronics in the PDS 45 detector circuit high-pass filters the APD output pulse and then feeds it to a comparator which generates a clean digital logic pulse, as shown in **Figure 4.2.2**.

A Hamamatsu Avalanche Photo Diode (APD) based detector with an on-board thermoelectric cooler, part number C5460, is used to sense scattered light due to particles passing through the PDS 45 laser beam. The output is fed into a resistor divider, R54 and R17, which scales the voltage down by a factor of 0.755. This voltage is buffered through U15A, and the output fed to a low pass and to a high-pass filter. The low pass filter scales the voltage down again, permitting DC monitoring of the PDS signal at the output of U16, pin 1 with a limit of 3V max at the output. This signal goes to an analog to digital (A/D) converter and the DSP sends the corresponding digital value to the data Acquisition system in the housekeeping packet. The high pass filter blocks the DC component with capacitor C22, whose output is baseline restored by transistor Q4. The baseline restored signal is input to U17, where the gain brings the AC signal amplitude back up to 0.95 times the APD detector output.

The output of U17 is, due to the described circuitry, a baseline restored, AC coupled analog signal which should go positive when a particle passes through the PDS 45 laser beam, with an amplitude determined by the particle's scattering cross sectional area, the PDS 45 laser intensity, and the APD sensitivity. This signal is compared with a PDS 45 threshold voltage, which is user programmable, at comparator U18. The AC coupled signal, the comparator threshold and the comparator output are shown in **Figure 4.2.2**. The comparator output, which is a clean digital pulse, is then sent to the digital logic IC U20.

The output of U17 described above also goes to the pulse peak detector, U19, as shown in the block diagram in **Figure 4.2.1**. The output of U19 goes to an A/D converter and the corresponding analog to digital converted (ADC) value is sent to the Data Acquisition System in the PDS packet. The PDS packet is stored in the .roi file along with the image(s) of the particle(s) that triggered the PDS event. This allows data analysts to correlate the size and shape of the particle with the amount of light it scattered past the dump spot and into the APD detector.

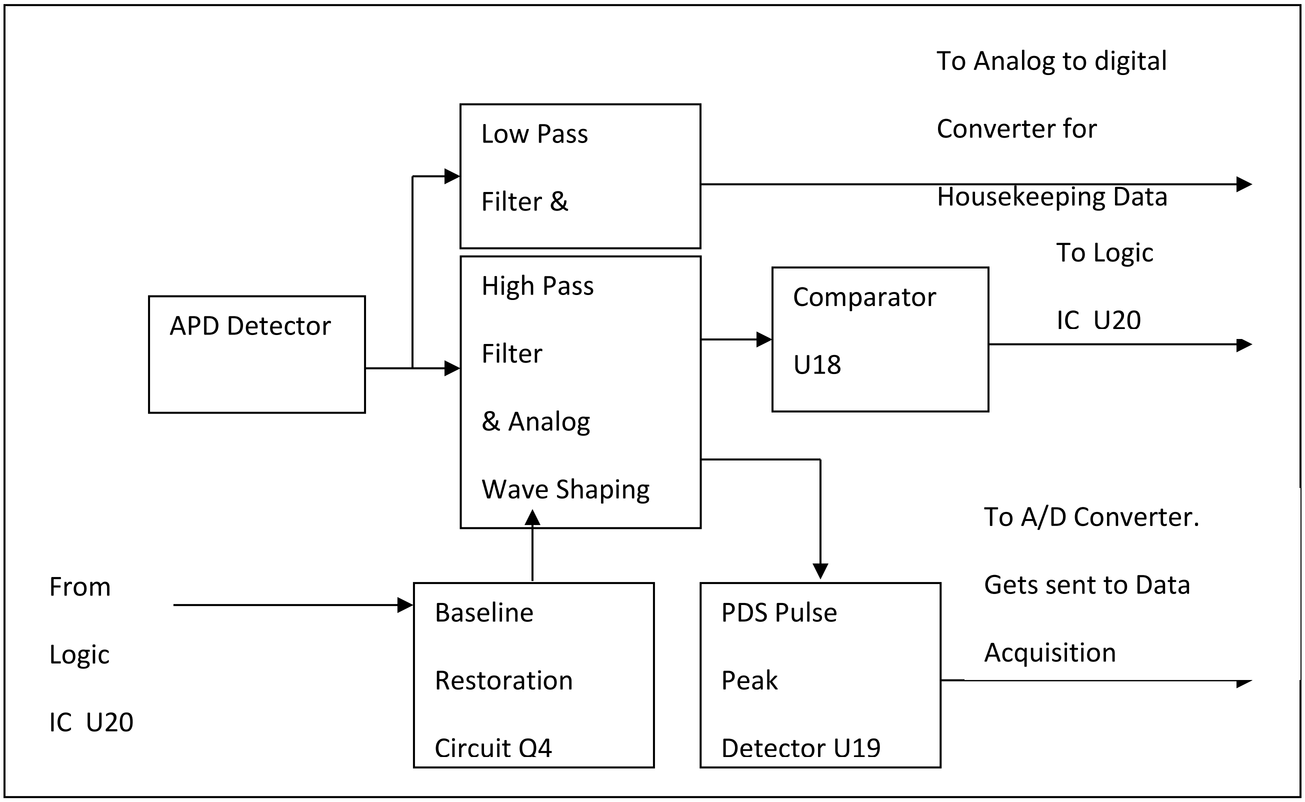


Figure 4.2.1: Block Diagram of PDS 45 Analog Electronics.

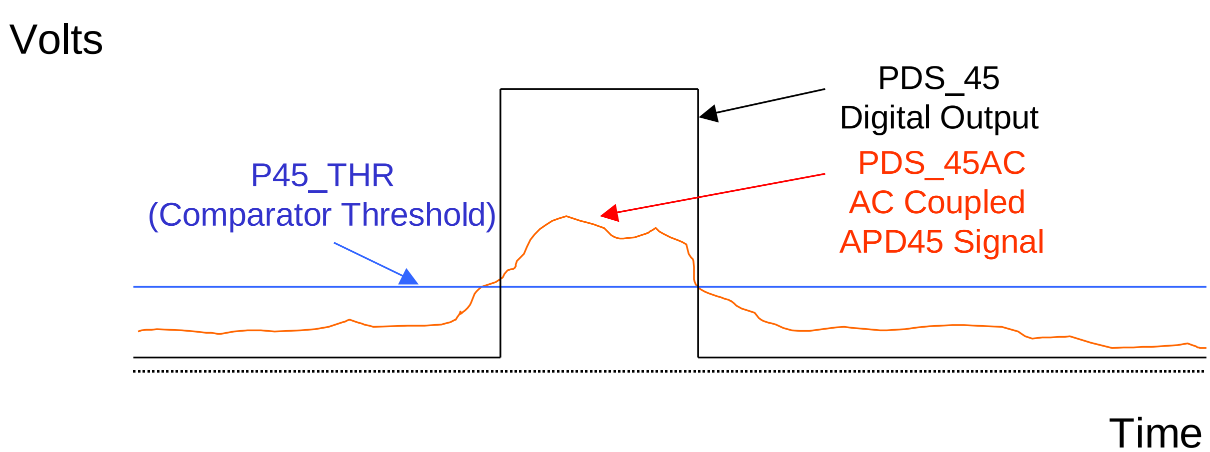
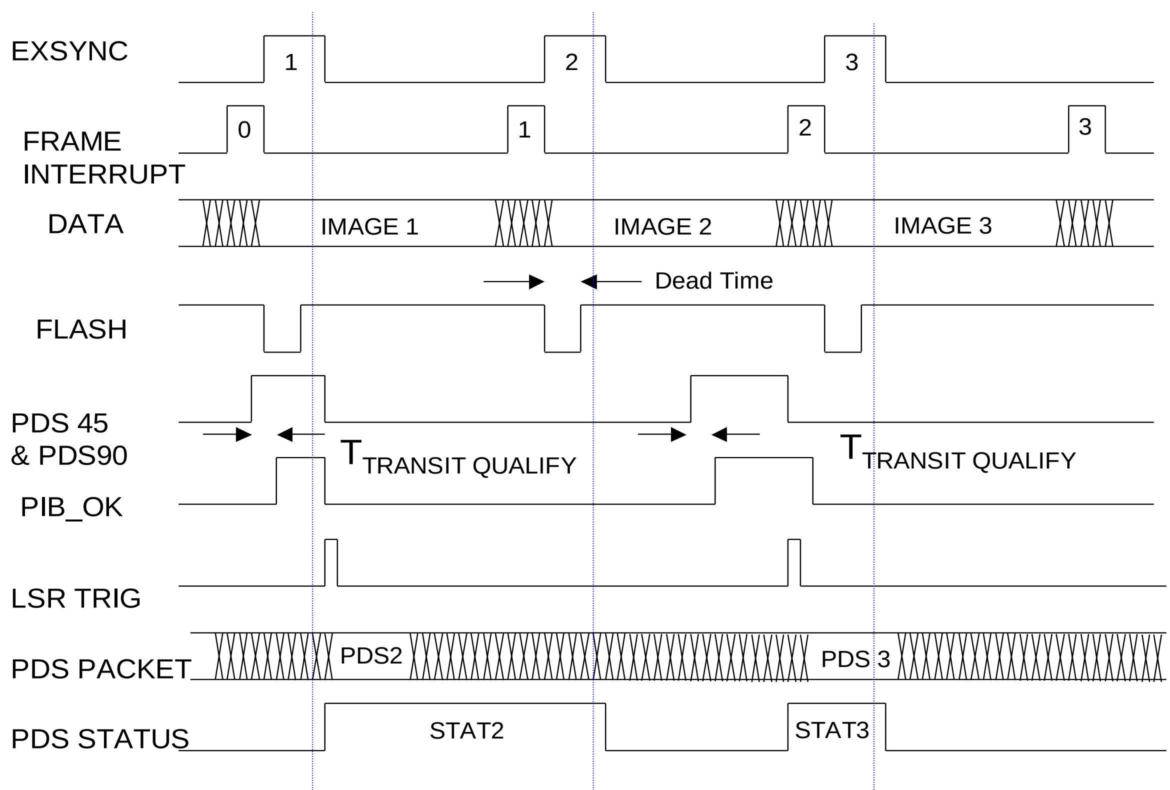


Figure 4.2.2: AC coupled APD (PDS_45) signal, comparator threshold, and resultant digital output.

4.2.2 PDS Logic and Camera Image Processing

A digital logic state machine inside U20 processes the PDS 45 pulse from U18 and the PDS 90 pulse from U26 and decides when an imaging laser strobe can occur.

The PDS 45and PDS 90 pulses are digital logic 3.3V CMOS compatible signals. They are fed into U20, a CPLD logic chip that controls the firing of the imaging laser. U20 also provides interrupts and data to the DSP, U35, and an output signal providing status of the current image being sampled by the Basler A501 camera. A timing diagram of the relevant signals for particle imaging is shown in **Figure 4.2.3**.



BASLER A501B UAV CPI Camera Timing With PDS STATUS
(EXSYNC, EDGE CONTROLLED – SEE A500 MANUAL SECTION 3.3.1.1)

Figure 4.2.3: Particle imaging timing diagram.

4.2.2.1 Logical State Machine

The PDS detection system is managed by a logical state machine located inside the Programmable Logic Device (PLD) U20. A diagram of the state machine is shown in **Figure 4.2.4**.

The state machine idles in state 0 (S0). As long as there is no particle seen by the PDS 45 and PDS 90 detectors it idles in S0 and S8. The EXSYNCIN pulses from the frame grabber have no effect on it other than to drive it to S8 and back to S0.

Recall that if the PDS 45 avalanche photodiode detector (APD) sees a particle then the output of comparator U18 will go high. Likewise, if the PDS 90 APD sees a particle then the output of comparator U26 will go high. The PDS digital processing electronics looks to see that both the PDS 45 and PDS 90 signals go high, then starts a “minimum transit time” counter. Once a minimum transit time, user set, is exceeded, the PIB_OK signal goes high (internal to U20). The minimum transit time is shown as “T Transit Qualify” in **Figure 4.2.3**. This causes the state machine to advance from S0 to S1.

When either the PDS 45 or PDS 90 signal goes low the PIB_OK signal goes low which causes the state machine to go from S1 to S2. S2 forces the imaging laser to immediately fire a short (~20 nanosecond) pulse of high intensity laser light, illuminating the detected particle onto the BASLER A501 CCD camera. At the same time, the PDS STATUS signal goes high. The PDS STATUS signal tells the Data Acquisition System that the next image downloaded from the CCD camera contains at least one particle and therefore should not be discarded.

The state machine then advances from S2 to S3. In S3 the state machine outputs an interrupt signal to the digital signal processor (DSP). This Notifies the DSP that a particle was seen so that it can send a PDS packet to the data acquisition system. A PDS data packet accompanies each particle image with particle-specific information such as the voltage pulse height that was output from each of the PDS detectors. The PDS packet is shown in the timing diagram in **Figure 4.2.3**. The state machine waits in S3 and doesn’t advance to S4 until an EXSYNC pulse is received from the frame grabber in the data acquisition system. This means no more particles will be imaged until the next EXSYNC pulse is received.

When the EXSYNC pulse is received from the frame grabber the state machine advances from S3 to S4. In S4 the state machine outputs a CLRX signal which clears the latch that captured the last EXSYNC pulse. This is done in preparation for the next particle. In S4 it waits for the CLEAR HOLD signal from the DSP before advancing to S5. This signal tells the state machine that the DSP is ready for the next particle.

The EXSYNC pulse causes the CCD camera to download its current image to the frame grabber in the data acquisition computer. EXSYNC also tells the sensor head electronics that the camera and data acquisition computer are ready to take the next picture. The Basler A501 CCD camera is always taking images and downloading them to the frame grabber asynchronously to the DSP and state machine clock. This occurs at the rate of 72 frames per second. Each EXSYNC pulse corresponds to a single image sent from the CCD camera. The EXSYNC signal is generated by the frame grabber card in the data system computer and goes to two places: the Basler A501 CCD camera and the DSP board. If the state machine did not have to wait for the EXSYNC pulse from the frame grabber in S3 or the CLEAR HOLD signal from the DSP in S4 it could run through its eight-step cycle many thousands of times in the time between EXSYNC pulses, which is the same time that it takes the camera to download one image to the data acquisition system. Forcing it to wait in S3 for EXSYNC from the frame grabber and to wait in S4 for CLEAR HOLD from the DSP slows it down and synchronizes it somewhat with the entire image capturing process.

When the state machine receives a CLEAR HOLD signal from the DSP it advances from S4 to S5.

It immediately moves from S5 to S6. In S6 it puts out a CLR_SMPL signal. This signal discharges the peak-hold capacitors in the PDS 45 pulse peak detector U19 and the PDS 90 pulse peak detector U27, see Block Diagram in **Figure 4.2.1** and schematic diagrams in **Appendix 7.1**.

The state machine immediately moves from S6 to S7. In S7 it continues to put out a CLR_SMPL signal. If no particles are detected in the PDS laser beams, it will go to S0; otherwise, it will wait here.

In S0 it idles and waits for the next particle. When the PDS detectors see the next particle the cycle repeats itself.

EXSYNC causes the CCD camera to download its current image to the data system computer. Referring to **Figure 4.2.3.** Once the image download is complete, the frame grabber interrupts the computer with a FRAME INTERRUPT signal, and the CPI software checks the PDS STATUS bit to see if the imaging laser was fired. If it was not, then the PDS STATUS bit is a logic zero and the image frame is discarded. If it was, then the PDS STATUS bit is a logic one and the image frame is searched for regions of interest (ROIs): locations in the image where particles are present. The ROIs are effectively cut out of the picture and stored into the current data file, the name of which is based on the data system computer time when the file was started, with the file extension .ROI. Also associated with each ROI in this file will be a PDS packet containing information such as arrival time and peak heights of the PDS 45 and PDS 90 signals for the laser trigger event that captured the particle image. The PDS packet is sent from the DSP to the data acquisition system via the RS422 link.

Returning to the timing diagram of **Figure 4.2.3**, the 1st EXSYNC pulse (from the frame grabber to the Basler camera and the DSP board) starts the camera downloading IMAGE 1 to the frame grabber. When the data transfer completes, the data system computer gets a FRAME INTERRUPT from the frame grabber associated with IMAGE 1 and sees there are no PDS packets to look for because PDS STATUS was low during EXSYNC1. IMAGE 1 is discarded. The laser has been triggered during the transfer of IMAGE 1, and the computer should therefore look at IMAGE 2, which is transferred due to EXSYNC2. The computer will, during EXSYNC2, look at the new PDS STATUS signal. The blue timing line represents when the computer looks at this signal. It is sent from U20 on the DSP board to the frame grabber. It tells the data acquisition system to process the next image received. During FRAME INTERRUPT 2 the data acquisition system will therefore process the next image received.

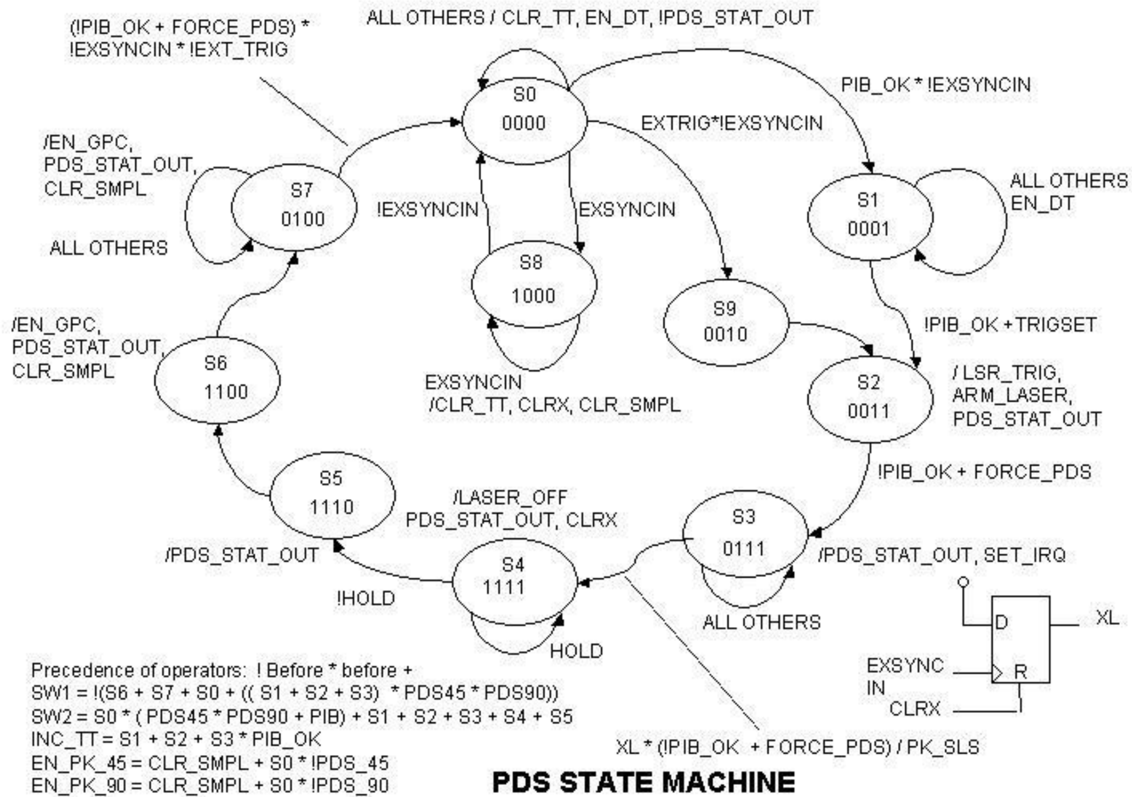


Figure 4.2.4: PDS State Machine

4.2.3 PDS 45, PDS 90, & Imaging Laser Drivers

These analog-processing electronics consist of variable-power laser drivers for the PDS continuous lasers and bias supplies for the high-power imaging laser driver. The PDS continuous laser drivers servo the current through the PDS laser diode to force the monitor current to match a level that the digital signal processor (DSP) sets. The maximum current through the laser diodes is limited by a series resistor to the maximum specified for each diode. The power level of each laser diode is sensed with the internal monitor diode whose current is converted to a voltage with an instrumentation amplifier (U7, U11). This voltage provides negative feedback to the integrator circuit that drives the current drivers (driver transistor Q13 or Q14, and driver transistor Q7 or Q10). Each current driver can be configured to source, by populating Q10 and Q13, or sink, by populating Q7 and Q14, current for their respective lasers, allowing for common anode and common cathode devices. The default laser is currently a common cathode device from Hitachi, the HL7851G, a 50 mW, 785 nm diode laser.

The imaging laser flasher, a Power Technologies IP40C/20/40-10V is controlled with two supply voltages: one sets the forward current, the other sets the pulse width. These bias voltages are generated with two linear voltage drivers from an on board 60V DC source. These drivers (U44) integrate until the output voltage equals the control voltage times a constant. The feedback is set on these drivers so the output voltage will never overdrive the pulse driver. All of the laser controllers' operating points, for the imaging laser current and pulse width values, and for the PDS 45 and PDS 90 lasers, are set utilizing a quad 12-bit digital to analog converter (DAC), U40, controlled by the user through the data system graphical user interface (GUI).

4.2.4 DSP Data Acquisition and Control

The sensor electronics are based on a digital signal processor (DSP) control board that monitors system temperature, pressure and voltage and controls 18 heat zones. The monitoring and controlling of heat zones are implemented using the relay board piggy backed on the DSP control board. Additionally, the control board communicates using standard asynchronous serial data protocol using a pair of RS-422 differential signals (RS-232 optional by board jumpers) with the Data Acquisition System, and implements a particle detection system using analog and digital electronics.

When the data system initially establishes communications with the DSP board, it sends a set time (**Table 4.2.4**) packet and a set mode packet (**Table 4.2.5**). The DSP board will subsequently track the time and observe the commanded temperature set points for turning on heaters, as well as other commanded parameters, such as minimum transit time limits. See **Table 4.2 5** for a full list of set mode parameters.

The DSP board utilizes an Analog Devices ADSP2191 Digital Signal Processor to control and monitor the probe hardware. This DSP has a bi-directional, high-speed, universal asynchronous receiver transmitter serial port interfaced to either RS-422 or RS-232 level drivers and receivers, user selected using jumpers J3, J4, J5, J6 and J7. The jumpers should short pins 1 and 2 (pin one is identified by a square solder pad on the bottom of the board) for RS-422 interfaces (recommended), or short pins 2 and 3 for RS-232 interfaces. The asynchronous communications lines interface directly to a serial port on the host computer, receiving commands from the host and transmitting data to it as described below.

Three types of data packets are currently output from the sensor head (probe) and four types are received. The transmitted packets are the PDS or PDS with SLS packet that is transmitted when a particle is detected, and the housekeeping packet (**Table 4.2.3**) which is transmitted once per second. The format of the PDS packet is given in **Table 4.2 1**. The PDS with SLS packet is found in **Table 4.2.2**.

Table 4.2.1. PDS packet format.

Word	Description
1	Packet Sync Word (0x4450)
2	Packet Length (12)
3	Packet Type (0x5050)
4	UTC Seconds of Year (LSW)
5	UTC Seconds of Year (MSW)
6	Arrival time - # of 62.5 ms periods into

	sec
7	Arrival time - # of 1.3333 us periods into 16th
8	Transit time
9	Particles detected since last PDS packet
10	PDS_45 pulse height
11	PDS_90 pulse height
12	Checksum

Table 4.2.2. PDS with SLS packet format.

Word	Description
1	Packet Sync Word (0x4450)
2	Packet Length (10)
3	Packet Type (0x5051)
4	UTC Seconds of Year (LSW)
5	UTC Seconds of Year (MSW)
6	Arrival time - # of 62.5 ms periods into sec
7	Arrival time - # of 1.3333 us periods into 16th
8	Transit time
9	Particles detected since last PDS packet
10	PDS_45 pulse height
11	PDS_90 pulse height
12-27	SLS pulse heights [16]
28	Checksum

The PDS packet fields are described below:

1. **Packet Sync Word**: Used by the data system to detect the beginning of a packet.
2. **Packet Length**: The number of words in this packet (12).
3. **Packet Type**: PDS packet with no SLS system is defined 0x5050
4. **UTC LSW**: Universal Time Code least significant word. This and word 5, the most significant word, combine to give the number of seconds since the beginning of the current year.
5. **UTC MSW**: Defined in 4.
6. **Arrival Time 16ths**: Number of 62.5 millisecond periods elapsed into the current second (see 4 and 5) at which the particle was detected.

7. **Arrival Time 1.333uS periods**: Number of 1.333uS periods into the current 16th second (see 6) at which the particle was detected.
8. **Transit Time**: The number of 20.8333 uS periods during which the particle was detected by the APD45 and APD90 sensors.
9. **Particles Detected Since Last PDS Packet**: This number includes the current imaged particle for which this packet is sent.
10. **PDS_45 Pulse Heigh**t: 16 bit number representing the maximum detected voltage for the imaged particle(s) on the APD45: V_{PK} = 5V x (PDS_45 Pulse Height) x 4096.
11. **PDS_90 Pulse Heigh**t: 16 bit number representing the maximum detected voltage for the imaged particle(s) on the APD90: V_{PK} = 5V x (PDS_45 Pulse Height) x 4096.
12. **Checksum**: Word by word checksum over the previous 10 words.

A housekeeping packet is built and sent to the data system once per second. **Table 4.2.3** lists the format of this packet.

Table 4.2.3. Housekeeping packet format.

Word	Description	C_0	C_1
1	Packet Sync (0x4450)	0	1
2	Packet Length (51)	0	1
3	Packet Type (0x484b)	0	1
4	UTC Seconds of Year (LSW)	0	1
5	UTC Seconds of Year (MSW)	0	1
6	Forward Sample Tube Temp. - °C	1.8775	0.02935559
7	Optics Block A Temp. - °C	1.8775	0.02935559
8	Optics Block B Temp. - °C	1.8775	0.02935559
9	Central Sample Tube Temp. - °C	1.8775	0.02935559
10	Aft Sample Tube Temp. - °C	1.8775	0.02935559
11	Pylon Slug Temp. - °C	1.8775	0.02935559
12	Pylon Base Patch Temp. - °C	1.8775	0.02935559
13	Porex Drain Tube Temp. - °C	1.8775	0.02935559
14	45 APD Amplifier Temp. - °C	1.8775	0.02935559
15	Power Supply Temp. - °C	1.8775	0.02935559
16	DSP Card Temp. - °C	23.958	.0146484 *
17	PMT Temp - °C	23.958	.0146484 *
18	SLS Laser Temp - °C		.0146484 *

		23.958	
19	Inside Air Temp. - °C	1.8775	0.02935559
20	CCD Camera Temp - °C	23.958	.0146484 *
21	Imaging Laser Temp. - °C	23.958	.0146484 *
22	PDS_45 Laser Temp. - °C	23.958	.0146484 *
23	PDS_90 Laser Temp. - °C	23.958	.0146484 *
24	PDS_45 Laser Power - mW	0	0.0177557
25	PDS_45 Detector DC level	0	.00439451
26	PDS_90 Laser Power - mW	0	0.0177557
27	PDS_90 Detector DC level	0	.00439451
28	Imaging Laser Current - Volts	35.0	0.02050781
29	Imaging Laser Pulse Width – Volts	35.0	0.02050781
30	-5 Volt Supply - Volts	0	.00292969
31	+ 5 Volt Supply - Volts	0	.00292969
32	+ 12 Volt Supply - Volts	0	.00735352
33	- 12 Volt Supply - Volts	0	.00735352
34	Probe Mode (Bit Mapped) Bit 0 set -> De-ice Heat on Bit 1 set -> Unused Bits 2 -> Probe Reset Bit 3 -> 1 equals enable the imaging laser trigger timer threshold feature (see word 35) Bit 4 -> 1 equals enable diagnostic mode (for diagnostics only—should be hard to set). Bits 5 - 7 -> unused Bits 8 - 15 = Command #		1
35	Heater Status (Bit Mapped, 1 = on) Bit 0 -> Forward Sample Tube Bit 1 -> Upper Optics Block Bit 2 -> Lower Optics Block	0	1

	Bit 3 -> Central Sample Tube Bit 4 -> Aft Sample Tube Bit 5 -> Imaging Lens Bit 6 -> APD_45 Amplifier Bit 7 -> APD_90 Amplifier Bit 8 -> Pylon Cover Patch Bit 9 -> Pylon Slug Bit 10 -> Pylon Base Patch Bit 11 -> Imaging Laser Bit 12 -> PDS 45 Laser Bit 13 -> PDS 90 Laser Bit 14 -> Spare_DC1 Bit 15 -> Camera		
36	Number of detected particles	0	1
37	Dead Time - Seconds	0	0.000341333
38	PDS45 Laser Power Setpoint – Mw	0	0.0073982
39	PDS45 Threshold Setpoint -V	0	0.000610352
41	PDS90 Laser power Setpoint – mW	0	0.0073982
41	PDS90 Threshold Setpoint -V	0	0.000610352
42	Imaging laser current control voltage Setpoint – V	0	0.00642700
43	Imaging laser pulse width control voltage Setpoint - V	0	0.007995605
44	Minimum transit time – sec^{-1}	0	20.83e-9
45	90 APD Amplifier Temp. - °C	1.8775	0.02935559
46	-REF10/2 (Vref10) - Volts	0	.001464843
47	Pressure Sensor – psi	-3.7594	.011014
48	Heater Status 2 (Bit Mapped, 1 = on) Bit 0 -> PMT Bit 1 -> SLS Laser Bit2 -> Unused Bit3 -> Unused	0	1
49	SLS Laser power Setpoint - mW		
50	PMT Voltage		
51	Pylon Cover Patch	.013736	21.7308
52	Imaging Lens	1.8775	0.02935559
53	Laser Trigger Time Threshold	0	20.83e-9
54	Checksum	0	1

* This equation is only valid for temperatures between 0C and 50C.

Housekeeping values are signed 16 bit integers, and the values of each parameter are solved from:

Housekeeping Value = C0 + C1 x Raw

where Raw is the 16 bit signed value sent in the housekeeping packet.

The CPI accepts four control packets that allow the data system to set various parameters and to control the data flow. **Table 4.2.4** lists the format of the set time packet, and **Table 4.2.5** lists the format of the set mode packet.

Table 4.2.4. Set Time Packet Format.

Word	Description	Value
1	Packet Sync Word	0x4450
2	Packet Length	6
3	Packet Type	0x544d
4	Time (MSW)	
5	Time (LSW)	
6	Checksum	

Table 4.2.5. Set Mode Packet Format.

Word #	Description	C_0	C_1
1	Packet Sync Word (0x4450**)**	NA	NA
2	Packet Length (26)	NA	NA
3	Packet Type	0x4d44	NA
4	Probe Mode (Bit Mapped) Bit 0 set -> De-ice Heat on Bit 1 set -> Unused Bit 2 -> Reset probe Bit 3 -> 1 equals enable the imaging laser trigger timer threshold feature (see word 35) Bit 4 -> 1 equals enable diagnostic mode (for diagnostics only—should be hard to set). Bits 5 - 7 -> Unused	0	1

	Bits 8 - 15 = Command #		
5	Heater Status (Bit Mapped, 1 = on) Bit 0 -> Forward Sample Tube Bit 1 -> Upper Optics Block Bit 2 -> Lower Optics Block Bit 3 -> Central Sample Tube Bit 4 -> Aft Sample Tube Bit 5 -> Imaging Lens Bit 6 -> APD_45 Amplifier Bit 7 -> APD_90 Amplifier Bit 8 -> Pylon Cover Patch Bit 9 -> Pylon Slug Bit 10 -> Pylon Base Patch Bit 11 -> Imaging Laser Bit 12 -> PDS 45 Laser Bit 13 -> PDS 90 Laser Bit 14 -> Spare_DC1 Bit 15 -> Camera	0	1
6	Forward Sample Tube Temperature Set point	1.8775	0.02935559
7	Upper Optics Block Temperature Set Point	1.8775	0.02935559
8	Lower Optics Block Temperature Set Point	1.8775	0.02935559
9	Central Sample Tube Temperature Set Point	1.8775	0.02935559
10	Aft Sample Tube Temperature Set Point	1.8775	0.02935559
11	Pylon Slug Temperature Set Point	1.8775	0.02935559
12	Pylon Base Patch Temperature Set Point	1.8775	0.02935559
13	Porex Drain Tube Temperature Set Point	1.8775	0.02935559
14	45 APD Amplifier Temperature Set Point	1.8775	0.02935559
15	Electronics Temperature Set Point	23.958	.0146484 *
16	Imaging Laser Temperature Set Point	23.958	.0146484 *
17	PDS_45 Laser Temperature Set Point	23.958	.0146484 *
18	PDS_90 Laser Temperature Set Point	23.958	.0146484 *
19	PDS_45 Laser Power Set Point	0	0.0073982
20	PDS_90 Laser Power Set Point	0	0.0073982
21	PDS_45 Threshold Set Point	0	0.00061035
22	PDS_90 Threshold Set Point	0	0.00061035
23	Imaging Laser Current Voltage	0	0.00642700
24	Imaging Laser Pulse Width Voltage	0	0.007995605
25	Minimum Transit Time	0	20.83e-9
26	Heater Status 2 (Bit Mapped, 1 = on) Bit 0 -> PMT Bit 1 -> SLS Laser	0	1
27	90 APD Amplifier Temperature Set Point (Unused)	1.8775	0.02935559

28	Camera Temperature Set Point	23.958	.0146484 *
29	PMT Temperature Set Point	23.958	.0146484 *
30	SLS Laser Temperature Set Point	23.958	.0146484 *
31	SLS Laser Power Set Point	Tbd	tbd
32	PMT Voltage	Tbd	tbd
33	Pylon Cover Patch Set Point	1.8775	0.02935559
34	Imaging Lens Set Point	1.8775	0.02935559
35	Laser Trigger Time Threshold Bits 0:10 -> Count at which to fire (needs to be greater than the minimum transit time (above)	0	20.83e-9
36	Checksum	NA	NA

The temperature set points are integers in the range of -2048 to 2047. The power and voltage set points are in the range of 0 to 4095. In either case, the engineering unit (EU) for a particular parameter is calculated with the following equation.

$$EU = C_0 + C_1 * \text{Set Point}$$

The probe mode is returned in the housekeeping so that bits 8 – 15 of word 4, which contain the command number, can be used to hold a unique number thereby providing the mechanism for verifying that a set mode packet has been accepted.

4.2.5 Power Supply Board

See the schematic in **Appendix 7.1**. This board generates four DC voltages using +28V DC that comes from the Data Acquisition System. The generated DC Voltages are: +15V, -15V, +7V, and -7V. Many of these are converted using linear regulators at the DSP board to create the most noise free DC supplies possible. The DSP board also has an on-board DC/DC converter to generate a 60V signal used in the bias circuits for the imaging laser, discussed previously.

5.0 SOFTWARE DESCRIPTION AND REAL-TIME OPERATION

5.1 Data System Overview

The SPEC CPI data acquisition system (DAS) and its settings are as important to the collection of high quality data as is the correct operation of the electronics. Were the electronics working perfectly but the DAS settings adjusted incorrectly, the instrument could go an entire flight collecting no useful images. Thus, a thorough understanding of the user adjustable operating parameters is a prerequisite to successful use of the CPI.

The parameters under user control fall into the following categories:

1. Particle detection system (PDS).
2. Image collection.
3. Probe thermal control.
4. Data acquisition system (DAS) display.

The first two categories affect how particle images are collected. These include items such as PDS laser power settings and image mean minimums (to be discussed in the next section). The third category includes the temperature set points of various locations in the probe, as well as whether or not heaters should be turned on if the temperature is below the set points in those regions. The fourth category doesn't affect the operation of the probe; the DAS display parameters only affect how information is presented to the user.

Each time the CPI DAS program is started, the program retrieves information from the CPI.ini file. This file contains set points, set point limits, and warning limits for parameters in the first three categories, as well as other information of use to the program. This file is discussed in the next section.

Figure 5.1.1 shows the DAS running with an active probe. The very top line tells the user that the program is running with recording disabled, so no data is written to file. The file name of the current file that would be written to if recording were active is also displayed here, along with the DAS time. On the right side of this line are the standard window controls: Hide, Minimize / Maximize, and Close.

The next line contains the menu items: File, View, Settings, Commands, Window and Help.

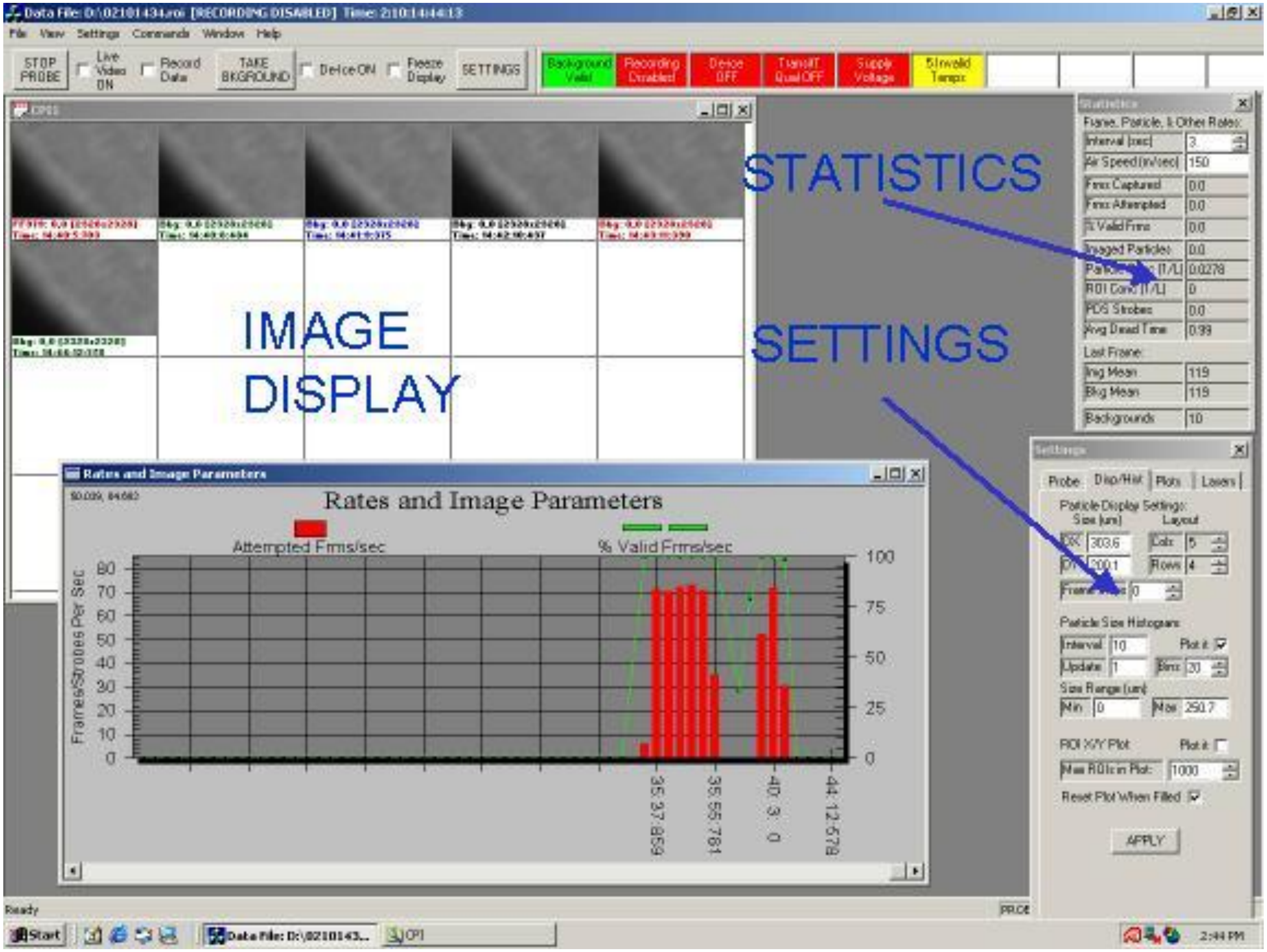


Figure 5.1.1. Screen shot of data system GUI.

Next come the control buttons, check boxes, radio buttons and enunciator window items on a quick access line. From here the user may easily perform operations such as turn on and off the heaters (De-ice ON check box) or take a background. Users will find all of these commands in various sub-menus as well, but their location here provides easy access to these commonly accessed selections. The enunciator window indicates to the user that probe parameters are out of range (such as temperature readings) or other items that the user should be aware of and possibly take action on.

The image display section shown in **Figure 5.1.1** contains regions of interest (ROIs) cut outs. This is where particles will be displayed as they are processed by the DAS. The statistics and settings windows are another set of quick observation and control windows in which the user can view and control various parameters that are also available in other menus, but are easily accessed here. The settings window can be opened, (if not currently open), by clicking the "Settings" button on the quick access line discussed in the previous paragraph. The "Rates and Image Parameters" window plots various real time parameters to inform the user of probe performance, such as the displayed frames per second plotted in red, the percent of valid frames in green.

Detailed descriptions of all the data system menus and displays, including the above items, are given in the following sections. System menu windows will first be generally described, then the operation of the probe and DAS using the categories of parameters under user control will be detailed: PDS system, image collection system, probe thermal control and DAS display.

5.1.1 View Menu

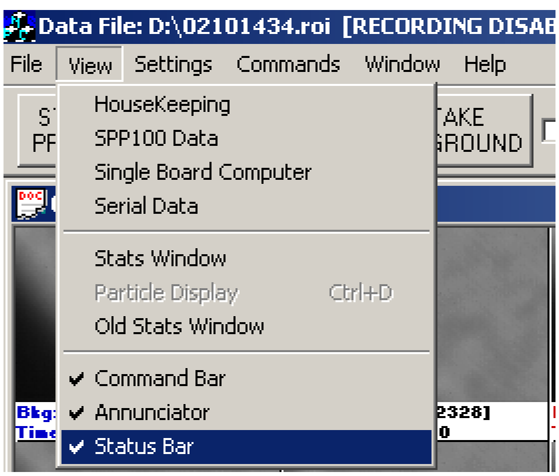


Figure 5.1.2. The View drop down menu used for selecting the Housekeeping window.

Figure 5.1.2 shows a screen shot of the View menu. The "Housekeeping" and "Stats Window" selection items will be discussed in the following sections. The "SPP100 Data", "Single Board Computer" and "Serial Data" selections are for customized use and not described in this manual.

The other 5 items display or remove windows that will not be described but which the user may wish to experiment with by selecting and deselecting from this menu.

5.1.1.1 Housekeeping Window

Selecting the first item in the "View" menu opens the housekeeping window shown in **Figure 5.1.3**. Here, the user may observe all the measured parameters of the operating probe in one window. The housekeeping data is used to evaluate the status or "health" of the probe by monitoring such engineering parameters as internal temperatures, power supply voltages, pylon internal pressure, etc. Real-time values for laser powers and actively controlled temperature zones are also contained in the housekeeping data. The right side of the window shows housekeeping parameters measured in the last second by the probe, e.g. the PDS 45 Laser Power Actual, as well as current set points used by the probe, e.g. the PDS 45 Laser Power Set (point). The column labeled "RAW" contains analog to digital (ADC) and digital to analog (DAC) converter values currently measured or set by the probe and DAS. Using the PDS 45 laser again as an example, the PDS 45 Laser Power Actual value of 876 seen in **Figure 5.1.3** (19^{th} item down) is the result of an ADC conversion taken in the last second; the PDS 45 Laser Power Set (point) value of 2123 (29^{th} item down) is the current DAC setting, generating a Voltage in an electronic servo loop that forces the PDS 45 laser to 20.154 mW, as seen in the column labeled "Corrected".

The "Corrected" column values have units, such as mW and degrees C, and use coefficients from the cpi.INI file described in **Section 5.1.7**. Noting that the set and measured raw values for the PDS 45 laser power are quite different—876 and 2123—but that the corrected values are quite close—19.938 mW and 20.154 mW respectively—one observes that the set point and observed coefficients are often different for the same parameter (in this case, the laser power).

On the left side of the housekeeping window is a set of radio buttons labeled "Heater Status". The button at the bottom of this section labeled "De-Ice Heat" would be enabled (black) if the heaters are currently chosen active by the user. If so, the CPI sensor head will turn on heaters if any region (that is individually enabled—see **Section 5.1.2.1**) has a measured temperature less than its set point. If a heater was on during the last second, the sensor head reports that this is the case and the corresponding radio button will be active (black). In **Figure 5.1.2**, the De-Ice Heat is off and thus, correctly, there are no heaters displayed as currently on.

The other reported values on the top left side of the window Include the update rate (set to once per second in the window); the time reported by the probe when it sent its most recent housekeeping information, which it does once per second; the command number, which should increment every time probe operating commands are sent from the DAS to the sensor head (see **Section 5.1.2.1**); the laser strobes count, which is the number of times the imaging laser was flashed in the last second because a particle was detected; and the dead time, which is the sum of the small windows of time during which the probe was processing a particle and therefore could not acquire a subsequent particle, if there was one. This sum is taken over a period of one second.

The two radio buttons at the bottom left of the housekeeping window indicate current sensor head settings for parameters that may be used in the future, but currently should always be off (white), as shown in the **Figure 5.1.3.** Parameters that do not display any corrected units in the housekeeping window are not used for that particular version of CPI. Any references to PMT or SLS powers or set points are only used with CPIs containing a Scattered Light System (SLS).

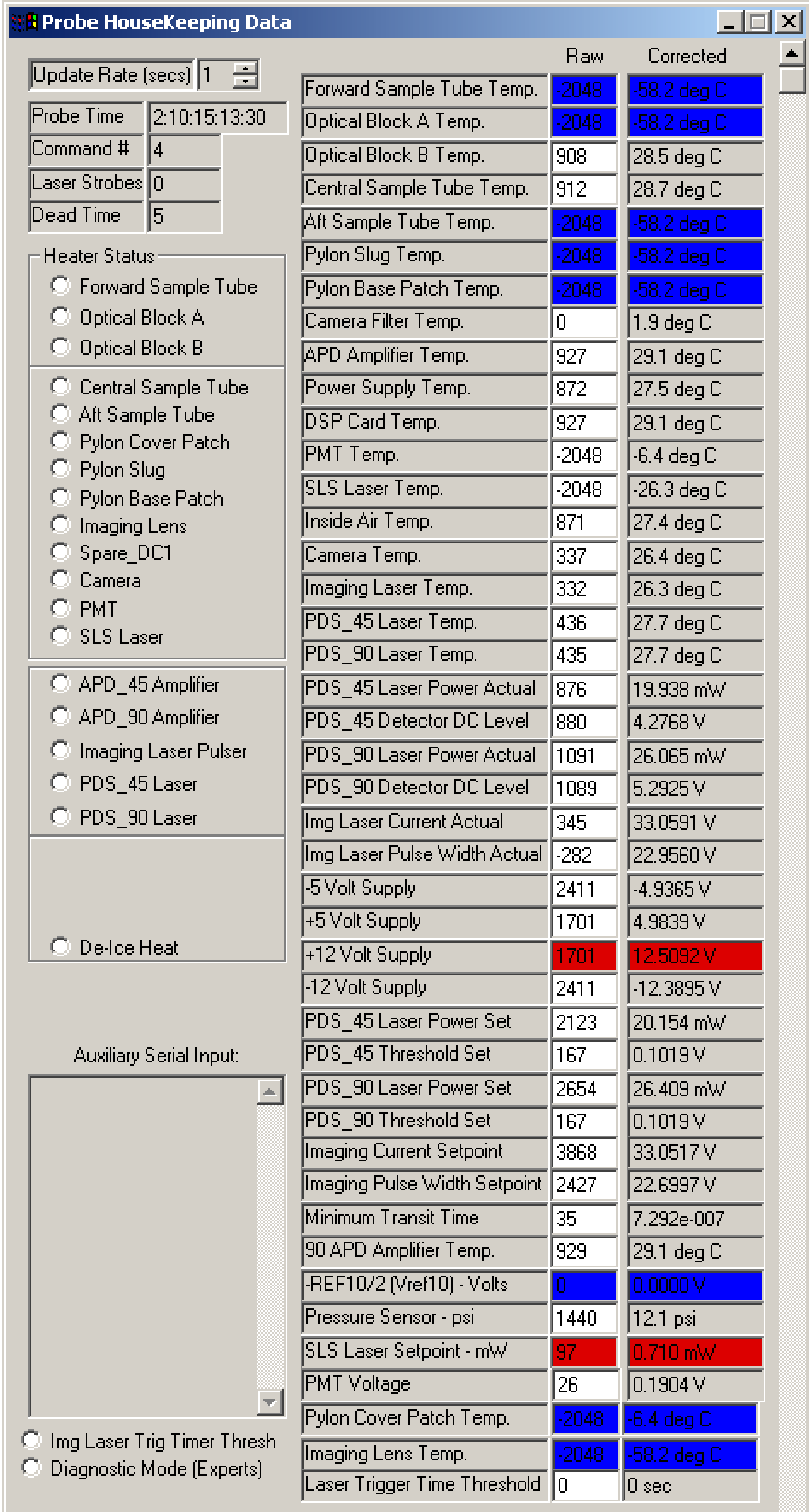

Probe HouseKeeping Data
Update Rate (secs) 1
Probe Time 2:10:15:13:30
Command # 4
Laser Strobes 0
Dead Time 5
Heater Status
Forward Sample Tube
Optical Block A
Optical Block B
Central Sample Tube
Aft Sample Tube
Pylon Cover Patch
Pylon Slug
Pylon Base Patch
Imaging Lens
Spare_DC1
Camera
PMT
SLS Laser
APD_45 Amplifier
APD_90 Amplifier
Imaging Laser Pulser
PDS_45 Laser
PDS_90 Laser
De-Ice Heat
Auxiliary Serial Input:
Img Laser Trig Timer Thresh
Diagnostic Mode (Experts)
Raw
Corrected
Forward Sample Tube Temp. -2048 -58.2 deg C
Optical Block A Temp. -2048 -58.2 deg C
Optical Block B Temp. 908 28.5 deg C
Central Sample Tube Temp. 912 28.7 deg C
Aft Sample Tube Temp. -2048 -58.2 deg C
Pylon Slug Temp. -2048 -58.2 deg C
Pylon Base Patch Temp. -2048 -58.2 deg C
Camera Filter Temp. 0 1.9 deg C
APD Amplifier Temp. 927 29.1 deg C
Power Supply Temp. 872 27.5 deg C
DSP Card Temp. 927 29.1 deg C
PMT Temp. -2048 -6.4 deg C
SLS Laser Temp. -2048 -26.3 deg C
Inside Air Temp. 871 27.4 deg C
Camera Temp. 337 26.4 deg C
Imaging Laser Temp. 332 26.3 deg C
PDS_45 Laser Temp. 436 27.7 deg C
PDS_90 Laser Temp. 435 27.7 deg C
PDS_45 Laser Power Actual 876 19.938 mW
PDS_45 Detector DC Level 880 4.2768 V
PDS_90 Laser Power Actual 1091 26.065 mW
PDS_90 Detector DC Level 1089 5.2925 V
Img Laser Current Actual 345 33.0591 V
Img Laser Pulse Width Actual -282 22.9560 V
-5 Volt Supply 2411 -4.9365 V
+5 Volt Supply 1701 4.9839 V
+12 Volt Supply 1701 12.5092 V
-12 Volt Supply 2411 -12.3895 V
PDS_45 Laser Power Set 2123 20.154 mW
PDS_45 Threshold Set 167 0.1019 V
PDS_90 Laser Power Set 2654 26.409 mW
PDS_90 Threshold Set 167 0.1019 V
Imaging Current Setpoint 3868 33.0517 V
Imaging Pulse Width Setpoint 2427 22.6997 V
Minimum Transit Time 35 7.292e-007
90 APD Amplifier Temp. 929 29.1 deg C
-REF10/2 (Vref10) - Volts 0 0.0000 V
Pressure Sensor - psi 1440 12.1 psi
SLS Laser Setpoint - mW 97 0.710 mW
PMT Voltage 26 0.1904 V
Pylon Cover Patch Temp. -2048 -6.4 deg C
Imaging Lens Temp. -2048 -58.2 deg C
Laser Trigger Time Threshold 0 0 sec

Figure 5.1.3. Housekeeping window.

5.1.1.2 Stats Window

Selecting “Stats Window” in the “View” menu opens the statistics window shown in **Figure 5.1.4**. This window contains a set of parameters of interest to the user.

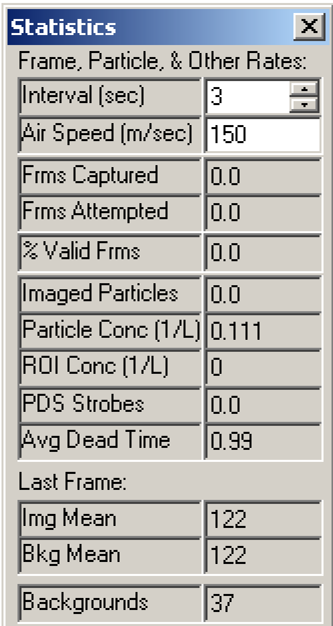


Figure 5.1.4. Statistics window.

Items in the section of the statistics window labeled “Last Frame” are discussed in **Section 5.1.4** covering image collection control and monitoring.

The items in the upper portion of the window are updated at the user selected interval, in seconds which is the first item in the “Frame, Particle, and Other Rates” section. The user also enters air speed here in meters per second, for use in deriving parameters such as particle concentrations. The true air speed has no other function and entering values that do not match the speed of the craft on which the CPI is located will not affect its operation.

The “Frms Captured”, “Frms Attempted” and “% Valid Frms” fields refer to the number of frames the DAS has received in the last “Interval” period in which a valid ROI was found, the number of frames total received in the same period (with and without ROIs), and the percentage of valid frames, equal to (frames captured / frames attempted) x 100%, respectively. Imaged particles are the number of ROIs found during the interval. “Particle Conc” is the derived particle concentration and “ROI Conc” is the derived number of ROIs in the last interval period, given in units of number per liter. “PDS strobes” is the number of times the PDS system has seen a qualified particle pass through the sample volume during the interval, and “Average Dead Time” is the time, in seconds, summed over the interval that the sensor head was busy processing a current particle and thus unable to image subsequent particles.

5.1.2 Settings Menu

The settings menu is shown in **Figure 5.1.5** below. The "Probe and Display" selection brings up the window labeled "Settings" in **Figure 5.1.1**. The "Settings" window provides easy access to many parameters that are also found, but with more searching required, in the "housekeeping" and "advanced control and settings" windows discussed elsewhere.

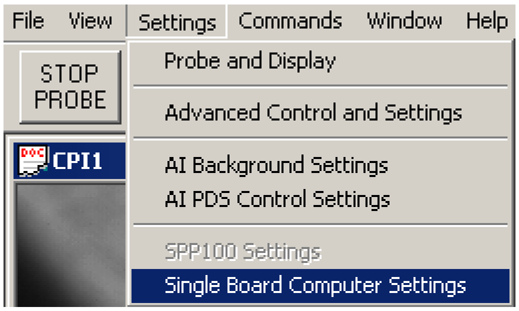


Figure 5.1.5. The Settings Menu

The "AI Background Settings" and "AI PDS Control Settings" are discussed in **Section 5.3**. The "Advanced Control and Settings" selection is discussed next.

5.1.2.1 Advanced Control and Settings Window

Selecting the "Advanced Control and Settings" item in the settings menu of **Figure 5.1.5** brings up the window shown in **Figure 5.1.6**. The upper section of the window is much like that of the "housekeeping" window. The set points for various probe parameters are defined in this window by the user and sent to the probe by hitting the "Apply" button. The left side contains heater enable radio buttons (instead of status indicators), and the right side has parameter set points (instead of observed values). For most of the parameters in this window, such as temperature zone set points and laser powers when the user enters a new value and then hits the "apply" button, a corresponding change in the housekeeping data will occur as the CPI sensor Digital Signal Processor (DSP) responds to the new set point values.

Disabling the "De-Ice Heat" radio button (black means it is enabled—as shown, white means it is disabled) disables temperature controlling at the sensor head. If disabled, no heaters will be turned on, regardless of the monitored temperature values. If "De-Ice Heat" is enabled, the sensor head DSP control board (**Section 3.1 Figure 3.1.5**) will monitor the measured temperatures of the selectively enabled heat zones—enabled by selecting them with the radio buttons on the left side of **Figure 5.1.6**—and if the temperature is below the set point value, turn on a heater in the appropriate sensor head zone. The set points for heaters (and other parameters) are located on the right side of the "Advanced Control and Settings" window, with the "Corrected" and "Raw" column labels having the same meaning as previously described for the housekeeping window. By selecting one of the displayed values, such as the "Forward Sample Tube Temp" on the first line, right side, a user can adjust the set point in two ways. First, one can type in a new number (either raw or corrected—the corresponding value in the other field will change). Second, once a field is highlighted, one may use the slider bar located immediately right of the "Raw" column to adjust the values.

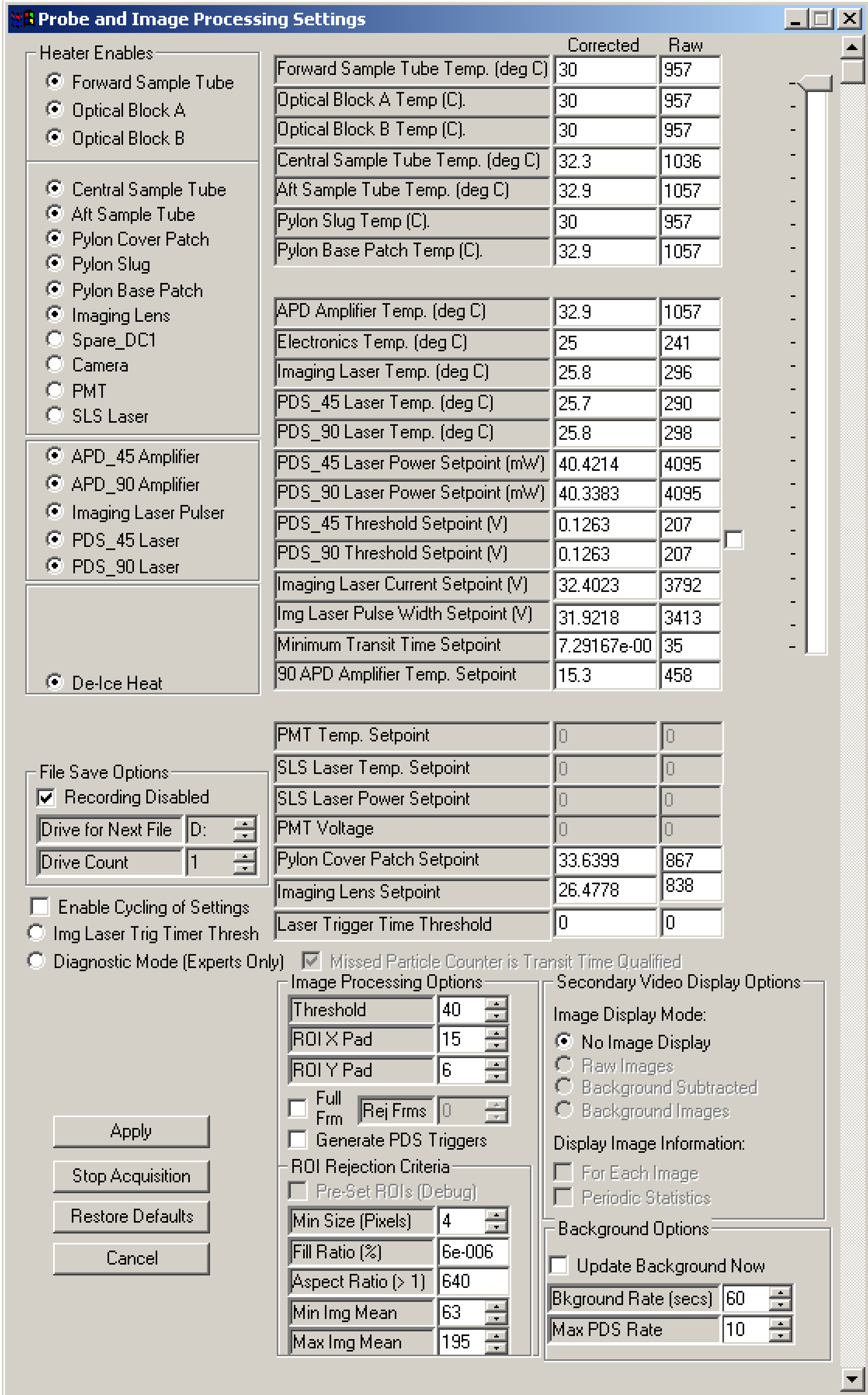

Probe and Image Processing Settings
Heater Enables
Forward Sample Tube
Optical Block A
Optical Block B
Central Sample Tube
Aft Sample Tube
Pylon Cover Patch
Pylon Slug
Pylon Base Patch
Imaging Lens
Spare_DC1
Camera
PMT
SLS Laser
APD_45 Amplifier
APD_90 Amplifier
Imaging Laser Pulser
PDS_45 Laser
PDS_90 Laser
De-Ice Heat
Corrected
Raw
Forward Sample Tube Temp. (deg C) 30 957
Optical Block A Temp (C). 30 957
Optical Block B Temp (C). 30 957
Central Sample Tube Temp. (deg C) 32.3 1036
Aft Sample Tube Temp. (deg C) 32.9 1057
Pylon Slug Temp (C). 30 957
Pylon Base Patch Temp (C). 32.9 1057
APD Amplifier Temp. (deg C) 32.9 1057
Electronics Temp. (deg C) 25 241
Imaging Laser Temp. (deg C) 25.8 296
PDS_45 Laser Temp. (deg C) 25.7 290
PDS_90 Laser Temp. (deg C) 25.8 298
PDS_45 Laser Power Setpoint (mW) 40.4214 4095
PDS_90 Laser Power Setpoint (mW) 40.3383 4095
PDS_45 Threshold Setpoint (V) 0.1263 207
PDS_90 Threshold Setpoint (V) 0.1263 207
Imaging Laser Current Setpoint (V) 32.4023 3792
Img Laser Pulse Width Setpoint (V) 31.9218 3413
Minimum Transit Time Setpoint 7.29167e-00 35
90 APD Amplifier Temp. Setpoint 15.3 458
PMT Temp. Setpoint 0 0
SLS Laser Temp. Setpoint 0 0
SLS Laser Power Setpoint 0 0
PMT Voltage 0 0
Pylon Cover Patch Setpoint 33.6399 867
Imaging Lens Setpoint 26.4778 838
Laser Trigger Time Threshold 0 0
File Save Options
Recording Disabled
Drive for Next File D:
Drive Count 1
Enable Cycling of Settings
Img Laser Trig Timer Thresh
Diagnostic Mode (Experts Only)
Missed Particle Counter is Transit Time Qualified
Image Processing Options
Threshold 40
ROI X Pad 15
ROI Y Pad 6
Full Frm
Rej Frms 0
Generate PDS Triggers
ROI Rejection Criteria
Pre-Set ROIs (Debug)
Min Size (Pixels) 4
Fill Ratio (%) 6e-006
Aspect Ratio (> 1) 640
Min Img Mean 63
Max Img Mean 195
Secondary Video Display Options
Image Display Mode:
No Image Display
Raw Images
Background Subtracted
Background Images
Display Image Information:
For Each Image
Periodic Statistics
Background Options
Update Background Now
Bkground Rate (secs) 60
Max PDS Rate 10
Apply
Stop Acquisition
Restore Defaults
Cancel

Figure 5.1.6. The Advanced Control and Settings Window.

Adjusting the slider bar has the benefit of only allowing the user to choose set point values that are within the allowed limits as set in the cpi.INI file, discussed in **section 5.1.7**. If manually entering values via the first option, a user-entered number may exceed the allowed limits, generating an error window and requiring the user to try another value.

Focusing again on the left side of the window, a check box labeled “Recording Disabled” is visible, checked in the **Figure 5.1.6**. **If checked, the data system will not record any activity. All housekeeping, image and PDS information received by the DAS will be visible to the user via the GUI, but no data will be recorded**. If recording is disabled, the user is warned via a red enunciator in the main window, as seen in **Figure 5.1.1**.

The “Drive For Next File” selection tool, located mid to lower left in the window, allows the user to choose to which storage drive the data files should go on the DAS computer. The “Drive Count” selection tool allows multiple drives to be used for data recording after the initial drive is full.

The “Enable Cycling of Settings”, “Image Laser Trig Timer Thresh” and “Diagnostic Mode” radio buttons, located in the lower left of the window, are under development and should always be left disabled, as shown.

The “Apply” button is context sensitive: if the probe and DAS are not communicating, it will read, “Apply and Acquire”. Regardless of what is displayed on the button, **if a change is made to any of the settings in this window, the “Apply” button must be clicked to make the changes active**.

Clicking on the “Stop Acquisition” button is the same as clicking the “Stop Probe” button located in the main screen; both will stop communications with the sensor head. However, if power is maintained to the sensor head, the last commanded settings will continue to be observed and the probe will continue operating. The DAS will ignore any communications and the GUI will not update with housekeeping or image data.

The “Restore Defaults” button retrieves all the saved settings from a default file called cpi_restore_defaults.INI, located in the same directory as the cpi.INI file. The cpi_restore_defaults.INI file matches the cpi.INI file when the CPI is originally configured. Users should customize the cpi.INI file to have temperature set-points and alarm limits appropriate for the operating environment of that particular instrument (see **Section 5.1.7**) Users are encouraged to store a copy of the customized cpi.INI file with safe settings (such as a large PDS threshold value, described later) as the cpi_restore_defaults.INI file for quick restoration of safe operating parameters for the CPI system.

The rest of the parameters in the window will be discussed in the sections covering the PDS and Image Control systems. Parameters that are greyed out or do not display any corrected units in this window are not used for this particular version of CPI. Any references to PMT or SLS powers or set points are only used with CPIs containing a Scattered Light System (SLS).

5.1.3 Particle Detection System Control and Monitoring

The upper left section of **Figure 1.1.2** of the "General Description" **section 1.1** of this manual shows the major components of the PDS system: lasers, dump spots and detectors. The user adjustable parameters for the PDS system are as follows:

1. PDS 45 laser power.
2. PDS 90 laser power.
3. PDS 45 detector DC level (feedback -dependent on PDS 45 laser power).
4. PDS 90 detector DC level (feedback –dependent on PDS 90 laser power).
5. PDS 45 threshold Voltage.
6. PDS 90 threshold Voltage.
7. PDS minimum transit time.

These items are easily accessed via the Settings window, labeled and displayed in the full DAS image, **Figure 5.1.1**. To observe and change items 1 through 4 click on the "Lasers" tab on the upper right of the Settings window, shown in **Figure 5.1.7**. Items 5 through 7 are easily accessed via the "Probe" tab of the "Settings" window shown in **Figure 5.1.8.**

5.1.3.1 PDS Laser Power and DC Level

The PDS settings and monitors are contained within the boxes labeled PDS 45 and PDS 90. The PDS 45 laser power set point is controlled using the slider bar shown in **Figure 5.1.7** with value 2123. As the slider is adjusted, the raw number is incremented and decremented. This value is a set point sent to the sensor head DSP board (**See Section 3, Figure 3.1.5**) which applies this value to a digital to analog converter (DAC), with its output setting the desired PDS 45 laser power. The laser power set point is given in units of milliWatts (mW) and is updated as the slider is moved.

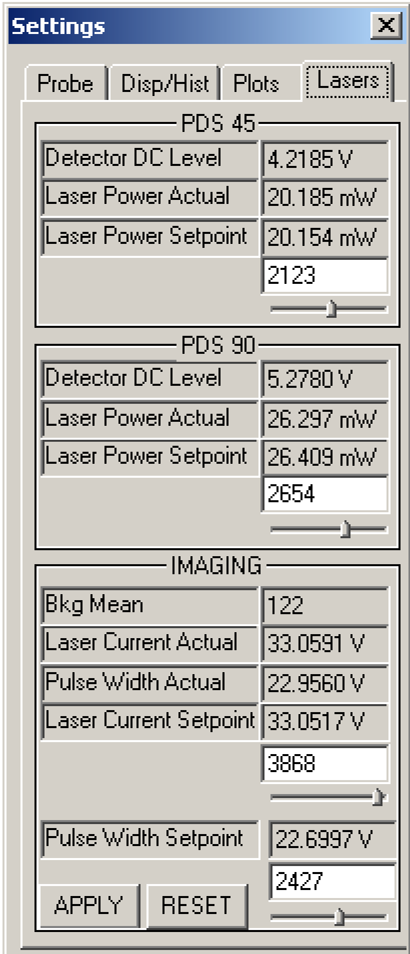


Figure 5.1.7. Lasers tab of the Settings window.

Once the desired set point is chosen with the slider, the user must click the "APPLY" button for the new setting to be sent to the sensor head. **If "APPLY" is not clicked, any changes to the settings in this window will not be implemented on the sensor head**.

The detector DC level has units of Voltage. It indicates the steady state average of the PDS detector outputs. The PDS detector has an output voltage maximum of approximately 9.6V, and the DC level must be below this to provide dynamic range for the detector to respond to incoming particles. The DC level, during periods when no particles are being detected for a second or more, is an indication of how much light from the laser is making its way past the dump spot and on to the PDS detector. **If the detector DC level goes above 8.8V, there is not enough dynamic range for the PDS system to sense a particle and the system may not record particle images, even though particles may be present**. In this case, the enunciator indicators will flash red and indicate that the PDS 45 or PDS 90 detector DC level is out of range. The user should decrease the associated laser power to get the DC level to below 8.8V.

5.1.3.2 PDS Threshold Control

The PDS 45 and PDS 90 thresholds are easily monitored in the "Probe" tab of the Settings window, shown in **Figure 5.1.8**.

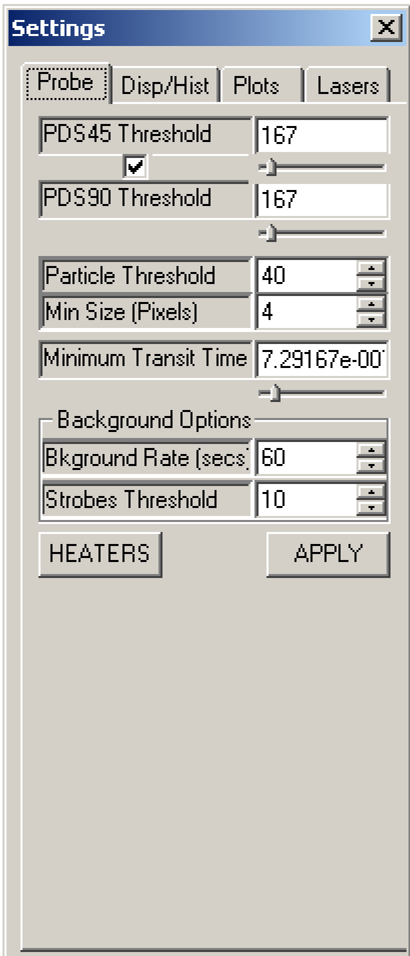


Figure 5.1.8. Probe tab of the Settings window.

To understand the threshold setting, refer back to **Figure 1.1.2** of the general overview section of this manual. In that figure the waveforms of the PDS detector are shown. The PDS threshold, shown in blue, is a DC Voltage applied to a comparator whose other input is an AC coupled version of the PDS detector output (either the PDS 45 or PDS 90 detector). **The threshold Voltage must be set greater than the highest value of the AC coupled signal, which has a varying value due to a random noise component. During airborne operation, the lowest practical threshold value is approximately 200-400 digital counts, depending on the noise environment**. If the threshold is set such that the AC coupled signal may exceed it due to the noise, and if both the PDS 45 and PDS 90 channels experience such a threshold exceeding event at the same time, a false PDS event will occur and the imaging laser will be fired, even though no particle is present. Another possibility is that of setting the threshold so low that the AC coupled PDS signal always exceeds the threshold, in which case the probe will never respond to particles and the imaging laser will never fire.

From the above paragraph's description of the PDS threshold, it is apparent that setting the threshold too low can cause the probe to operate incorrectly. Setting the threshold too high can also have negative effects on probe functionality. The higher the threshold is set, the more light a particle must scatter in order to exceed the PDS threshold. For example, if the PDS threshold—the blue line—in **Figure 1.1.3** of the General Description **Section 1** of this manual were set greater than the peak that occurs in the figure's red line—the AC coupled PDS output—the probe would not recognize that a particle had passed through the sample volume, and no image of the particle would be produced.

Because the user is not able to see a waveform of the AC coupled signal and threshold Voltage applied to the detector circuit comparator, such as those shown in **Figure 1.1.3,** the user must become familiar with the effects on the probe of changing the PDS laser power and the PDS thresholds. Some other monitored values provide useful information in assessing these effects, such as the percentage of valid frames, which is shown in the histogram window of **Figure 5.1.1**. A high percent valid is an indicator that a large percentage of the images captured by the sensor head camera contain in-focus particles. The possible problem with a high percentage valid, however, is that the threshold may be set so high that only large particles scatter enough light to cause the PDS threshold to be exceeded, thus discriminating against small particles**. Again, this points to the necessity of users familiarizing themselves with the operation of their probe in a laboratory environment prior to engaging in flight operations.** Monitoring the threshold Voltage and the AC coupled PDS signal to the comparator is possible in a laboratory environment using an oscilloscope and reading the Detailed Description of Electronics, **Section 4.2**.

Another option during flight (and in the lab) is to use the artificial intelligence (AI) PDS DC level and threshold adjustment algorithms discussed in **Section 5.3**. The AI algorithm has been successfully used during flights of the original CPI (not the one for which this manual was written, but which has very similar operational parameters) in which there was no user control of the CPI. The AI code successfully optimized the settings of the PDS system on every flight and is an option users may prefer even during flights in which an operator is present. Reading how the AI control works will also provide insight into how to optimize the PDS settings.

5.1.3.3 PDS Minimum Transit Time Control

The minimum transit time is programmable and is the amount of time a particle passing through the sample volume must cause both the PDS 45 and PDS 90 comparators to go high for the PDS logic to recognize the particle as valid. See the electronics description in **Section 4.2** and **Figure 5.1.8** for more information. The "Raw" value for the transit time is entered in the "Advanced Control and Settings" window of **Figure 5.1.6** in the "Minimum Transit Time Setpoint" field. Alternatively, the corrected time may be entered in the "Settings" window, choosing the "Probe" tab, shown in **Figure**

5.1.8. The time is in units of 20.833 x 10^{-9} seconds (1 / 48 MHz) times the raw value. The display of the corrected values attempts to display the value in scientific notation; however the exponent is often not viewable. In the Advanced control and settings window (Figure 5.1.6), **a raw value of about 35 counts is a practical value for operation. Setting this value too high will prevent the CPI from triggering on smaller particles.**

5.1.4 Image Collection Control and Monitoring

The image processing performed by the DAS is critical in achieving maximum probe performance. Just as poor settings in the PDS system can cause the probe to receive no images, so can poor settings in the image processing setup parameters cause the probe to process no images, even in the presence of high concentrations of particles.

The DAS takes several steps in order to process images. First it takes a background image: a frame from the CCD camera with no particles present. Then, when received camera frames arrive—which happens approximately 72 times per second—the DAS checks the PDS Status bit to see if the imaging laser was fired during this frame's exposure period. If it was, the DAS subtracts the frame from the stored background image (pixel by pixel subtraction), and performs a search algorithm to determine if a particle or particles is/are present in the frame and cutting it/them out into ROIs.

The parameters affecting this process are discussed in the next sections.

5.1.4.1 Background Images and Parameters

Two parameters define the recognition of a particle within a frame: particle threshold and minimum size (pixels). The role of these parameters will first be discussed in explaining how a background image is taken.

115	115	120	120	120	115	115
115	120	120	120	120	120	115
120	120	120	120	120	120	120
120	120	120	120	120	120	120
120	120	120	120	120	120	120
115	120	120	120	120	120	115
115	115	120	120	120	115	115

IMAGE 1

110	110	120	120	120	110	110
110	120	120	120	120	120	110
120	120	120	120	120	120	120
120	120	120	120	120	120	120
120	120	120	120	120	120	120
110	120	120	120	120	120	110
110	110	120	120	120	110	110

IMAGE 2

Figure 5.1.9. Representation of two 7 x 7 CCD camera images.

When the DAS is ready to take a background, it waits until there are fewer than “Strobes Threshold” image frames per second that have an associated PDS STATUS bit high (See **Section 1.1**). The PDS STATUS bit indicates the presence of sensed particles. When there are fewer than “Strobes Threshold” image frames per second that have an associated PDS STATUS bit high a signal called EXTRIG from the frame grabber, under DAS control, is pulsed once per image frame period, forcing the digital logic system on the sensor head to fire the imaging laser. Two frames are thus generated, a depiction of which is shown in **Figure 5.1.9**. The two image examples are only 7 x 7 pixels, but the actual CCD camera sends over 1024 x 1024 pixel images—though the camera is capable of 1280 x 1024. To check for a valid background image (the camera will use IMAGE 1 as the background if the process qualifies it), the DAS performs a bit by bit subtraction of the two images. The result is shown in **Figure 5.1.10**.

5	5	0	0	0	5	5
5	0	0	0	0	0	5
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
5	0	0	0	0	0	5
5	5	0	0	0	5	5

SUBTRACTION RESULT

Figure 5.1.10. Result of background subtraction applied to images of **Figure 5.1.9.**

The DAS now checks each pixel value in the subtracted image to see if it is greater than the current "Particle Threshold" value divided by three (backgrounds are more strictly tested than when testing for particles, described later). Thus, if the particle threshold were set to 15 by the user, the corner pixels, with value of 5, would meet or exceed the 15 / 3 = 5 threshold used for backgrounds. In that case the DAS would check to see if there are equal to or greater than the "Minimum Pixel Size" number of pixels collocated that meet or exceed the pixel threshold just described. If the minimum pixel size were set to three, then the above attempt at a background would fail. In that case, the DAS would generate two more EXTRIG signals and perform the background test algorithm just described on two new images. However, if either the particle threshold were raised to 16 or greater, or the minimum pixel size were raised to 4 or greater, the above two images would be considered a valid background. Two realistic values for these parameters are 36 for the particle threshold and 4 for the minimum pixel size. Using these values, IMAGE 1 would possibly be accepted as a valid background.

Once it is determined there are no particles in the potential background image, the average of the pixel values is taken. For IMAGE 1, the value would be 118.8. This value is then compared with an acceptable range entered by the user: "Min Img Mean" and "Max Img Mean". **Figure 5.1.11** shows these parameters entered in the "Advanced Control and Settings Panel". The values 2 and 255 shown in the figure are not a normal range, as it allows almost any image to be accepted since each pixel has a value range of 0 to 255; usually the minimum value is on the order of 70 and the maximum value on the order of 180. If such were the range, our IMAGE 1 mean of 118.8 would be acceptable, and IMAGE 1 would be stored as the current background.

Background images are taken almost immediately after the probe is started. No particle images are processed until a valid background is acquired, apparent to the user via a green enunciator declaring "Background Valid" as seen in **Figure 5.1.1**. The probe also takes backgrounds at regular intervals, the period of which is set by the user. If the DAS fails to get a valid background in a reasonable amount of time, the enunciator panel displays a red warning of "Background Failed". If the DAS has just started communicating with the sensor head, too many repeated failed attempts to acquire a background will cause the program to stop communications with the sensor head. These failures and others, and their solutions, will be explained in "Real Time Operation and Troubleshooting", **Section 5.2**.

Changing Particle Threshold, Minimum Pixel Size, Strobes Threshold, Minimum and Maximum Image Mean, and Background Rate

All of these parameters except Minimum and Maximum Image Mean are readily changed in the "Probe" tab of the "Settings" window, shown in **Figure 5.1.8**. All of these parameters are located in the "Advanced Control and Settings" window, located at bottom center. A cut out of the image control section of the "Advanced Control and Settings" window is shown in **Figure 5.1.11**. Note that the "Strobes Threshold" of **Figure 5.1.8** is labeled "Max PDS Rate" in the "Advanced Control and Settings" window; they are the same parameter.

Remember that changes to the parameters are not active until the "Apply" button is clicked, whether in the "Settings" or the "Advanced Control and Settings" windows.

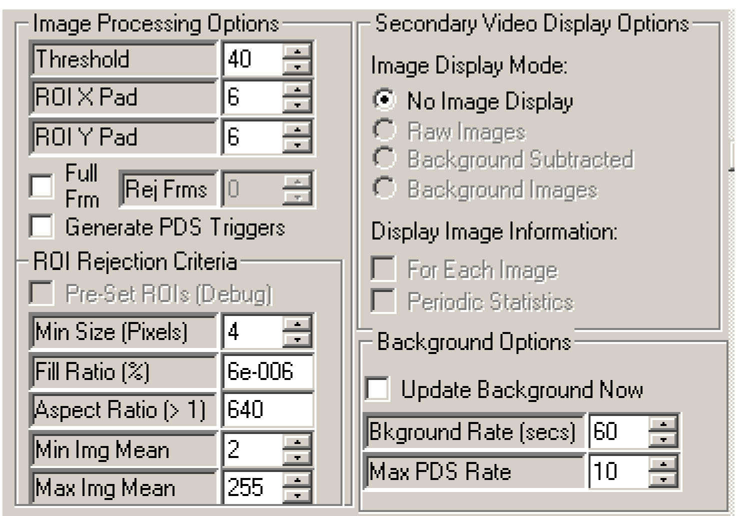


Figure 5.1.11. Image processing control section of the Advanced Control and Settings window.

5.1.4.2 Particle Collection and Associated Controls

The process of searching for particles in an image frame that arrives with a concurrent PDS STATUS bit value of one, indicating the imaging laser was fired due to the presence of a particle, is much like the process for acquiring a background image. The new image is subtracted from the background image and the difference image, referred to as a background subtracted image, is searched for pixels below the particle threshold. An example of the background image (IMAGE 1 taken from **Figure 5.1.9**), and an image with a potential particle are shown in **Figure 5.1.12**. **Figure 5.1.13** shows the background subtracted image.

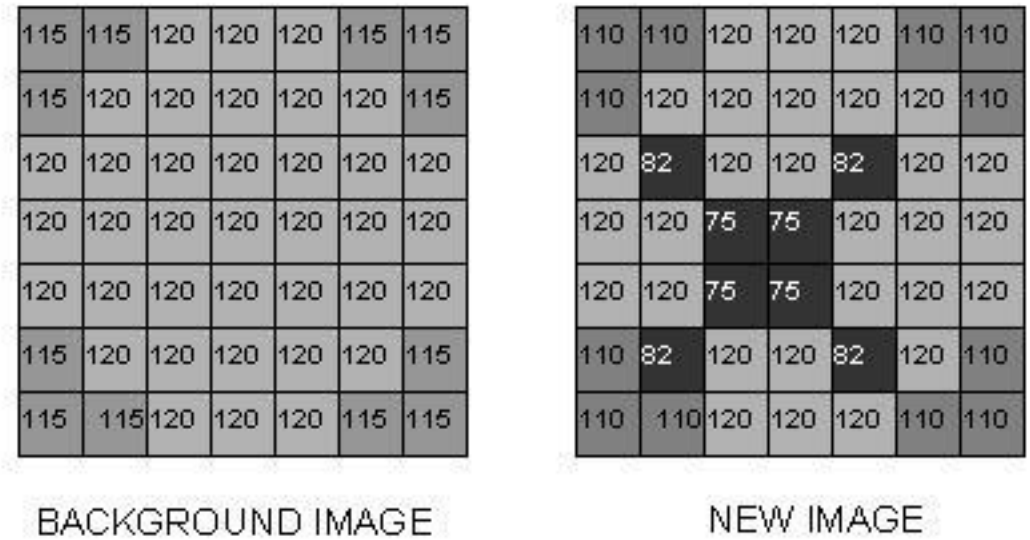


Figure 5.1.12. Background image and new CCD camera image for particle extraction example.

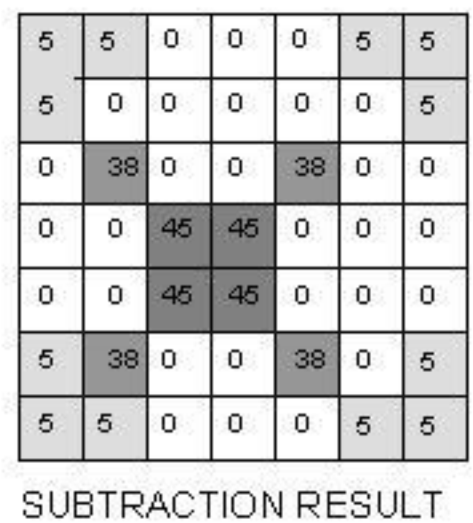


Figure 5.1.13. Result of background subtraction on images of **Figure 5.1.12.**

The DAS looks through the background subtracted image and compares the values, such as those shown in **Figure 5.1.13**, with the particle threshold parameter. With the particle threshold at 40, only four pixels in the image are considered as shadowed due to a particle. If the particle threshold were lowered to 38, the DAS would recognize eight shadowed pixels. The number of collocated pixels is then compared to the minimum pixel size parameter. The value of four for this parameter means that this particle is accepted as an ROI and stored (if recording is enabled) to the current data file.

Other parameters under user control affect how a recognized ROI is stored. The “ROI X Pad” and “ROI Y Pad” fields, both set to 6 in **Figure 5.1.11**, tell the DAS to include six pixels to the left and right and six pixels above and below a rectangle that encompasses all recognized shadow pixels (as described in the previous paragraph) when saving the ROI image to file.

5.1.4.3 Image and Background Mean Settings

Because the CCD camera’s active area is unlit, except by the flash of the imaging laser, it is the total incident light energy of this pulse that must be adjusted to change the image brightness and mean. This is important, because if an image is too bright or too dark, it may not respond linearly to the occultation of the laser by passing particles, and sensed particles may not be correctly imaged.

How many Joules of light energy reach the camera are set by changing two imaging laser parameters: “Laser Current Setpoint” and “Pulse Width Setpoint”, as accessed via the “Laser” tab of the “Settings” window shown in **Figure 5.1.7**. These parameters are also accessed in the “Advanced Control and Settings” window on the right side, found in **Figure 5.1.6**. **Generally, the DAS is set to run the imaging laser current at a safe maximum when the CPI is manufactured, and users should need change only the laser pulse width**. The laser power is approximately constant, but for a duration controlled by the “Pulse Width Set Point” parameter. The parameter is given in Voltage units, but the maximum Voltage corresponds to approximately 40 nS (this varies slightly from instrument to instrument). Setting a lower applied Voltage decreases the time the laser is on when it pulses, thus lowering the amount of light energy to the CCD camera, and lowering the image mean.

5.1.4.4 LIVE VIDEO MODE

To adjust the image mean in real time, the user can check the “Live Video On” check box shown in the upper left of **Figure 5.1.1**, in the main screen. **It is best to run live video with recording disabled, as approximately 72 full images of approximately 1 Megabyte size each per second will be saved to hard disk if recording is active**. Live Video Mode is very useful for troubleshooting any image system problems. Once live video is turned on, the image display will look like **Figure 5.1.13.** A full frame (1024 x 1024) image of the entire CCD camera (though for most CRT and LCD computer monitors, only a fraction of the total image may be seen; move the scroll bars for the image display area to view different portions of the CCD image) will be displayed. A red “Live Video On” message will display in the enunciator panel to indicate live video has been selected. The Rates and Image Parameters window (see **Section 5.1.1**) will show the attempted frames per second at 72 and the % valid images at 100%. The values in the rates and image parameters window will update at the selected update interval. The setting of this interval is discussed in **Section 5.1.6.2.**

The image mean will be updated in real time in the "Img Mean" field of the "Statistics" window of **Figure 5.1.13**. While running live video, adjustment of the imaging laser current pulse width remember to click the "Apply" button) will change the image brightness displayed and reported. Once the image mean is at a desirable value—e.g. somewhere between 100 and 150, though this is different for each probe—turn off live video by unchecking the "Live Video" box. **A new background should be taken immediately after any changes are made to the imaging laser set points**. If not, the background subtraction will now have a large offset due to the changed image mean, causing the particle processing algorithm to work poorly or not at all.

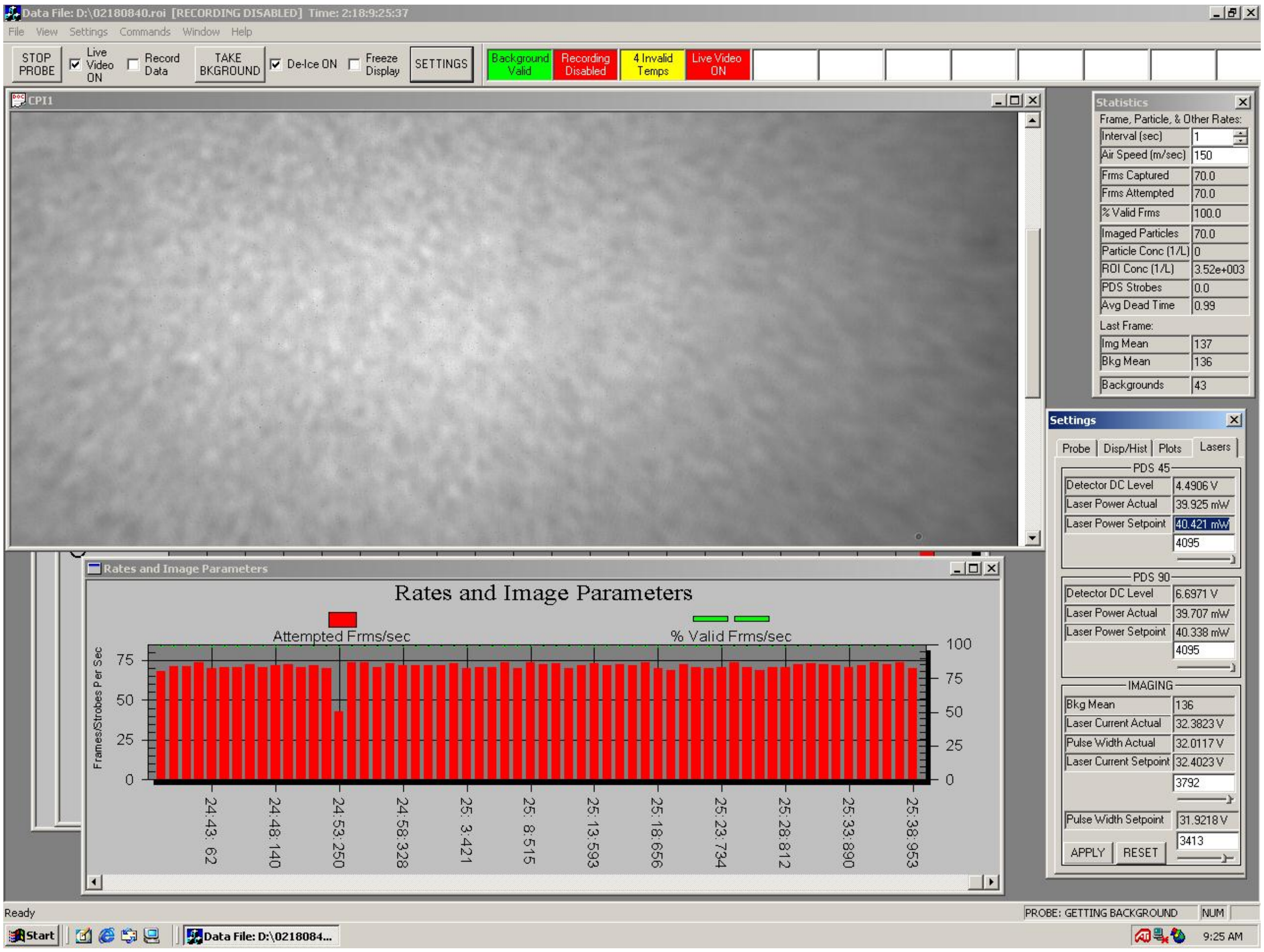


Figure 5.1.13. Main GUI window and Rates and Image parameters window in Live Video mode.

5.1.5 Probe Sensor Head Thermal Control

The probe sensor head has 12 temperature zones it controls, all with set point controls in the "Advanced Control and Settings" window of **Figure 5.1.6**. The name for the 12 heat zones is given here for reference:

1. Forward Sample Tube
2. Optical Block A
3. Optical Block B
4. Central Sample Tube
5. Aft Sample Tube
6. Pylon Slug
7. Pylon Base Patch
8. APD Amplifiers
9. Electronics – monitor only, no control
10. Imaging Laser
11. PDS 45 laser
12. PDS 90 laser

Currently there is no heater for the electronics (item 9), but all the others are controlled as described in **Sections 5.1.1.1 Housekeeping Window and 5.1.2.1 Advanced Control and Settings Window**. The physical description of the heat zones is given in the SPI Sensor Head – Physical Description **Section 3.1**. Pictures, diagrams and descriptions in that section provide an understanding of where the 12 controlled heat zones in this list exist on the sensor head. Other temperatures are also monitored, but not controlled, such as at the CCD camera. Here, no associated heater is used to maintain a minimum temperature.

Warning! Running the instrument in the pylon for extended periods at room temperature (20C) or above results in excessive self- heating. With De-ice heat off, it is still possible for the internal temperature of the sensor head to become overly warm. Shut down the instrument, including instrument power, if the Power supply board or DSP temperature exceed 45C.

5.1.6 Display Options

Aside from the displays previously discussed, some derived parameters, size histograms, and ways of looking at and storing particle images are available to the user.

5.1.6.1 Rates and Image Parameters

Some of these were discussed in **Section 1** and seen in **Figure 5.1.1**. More are available to the user via the "Settings" window in the "Plots" tab, shown in **Figure 5.1.14**.

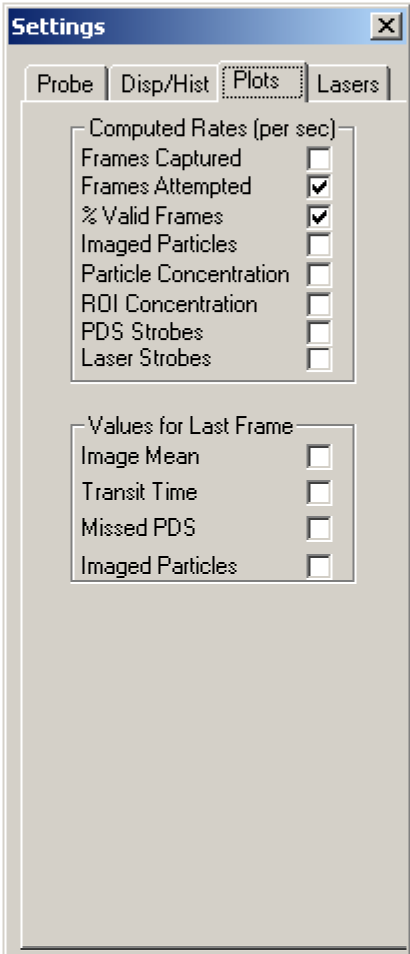


Figure 5.1.14. Plots tab of the Settings window for selecting items to display in the Rates and Image Parameters plot.

A short description of each item available for plotting follows:

1. Frames Captured: The number of frames in which the DAS found particles and cut out ROIs.
2. Frames Attempted: The number of frames the DAS searched for particles due to correlated PDS STATUS having value of one.
3. %Valid Frames: Frames Captured / Frames Attempted x 100%
4. Imaged Particles: The number of ROIs cut out from searched image frames.
5. Particle Concentration: An estimate of the number of particles per liter based on the air speed ROI Concentration: TBD
6. PDS Strobes: Total number of transit time qualified particles sensed.
7. Laser Strobes: The number of times the imaging laser was fired in an attempt to image a sensed particle.
8. Image Mean: The mean of the last processed frame.
9. Transit Time: Interval during which the particle was in both PDS beams.

10. Missed PDS: TBD
11. Imaged Particles: The number of ROIs found in the last processed frame.

5.1.6.2 Displays, Histograms and ROI X/Y Plots

The last tab available in the "Settings Window" is the "Disp/Hist" tab shown in **Figure 5.1.15**. Under the label "Layout", the number of columns and rows for displaying particle images is selected. Shown in **Figure 5.1.15** is Cols = 5 and Rows = 4. This corresponds to the number of available ROI display boxes in the "Image Display" section of **Figure 5.1.1**. Each box will display a single ROI when particles are successfully imaged. When changing the number of columns and rows, the size of the ROI display boxes is changed in the "DX" and "DY" fields, corresponding to the size of an image (in microns) that will fit in the ROI box. Not all DX and DY values will work for a given set of column and row numbers, so experimentation is required.

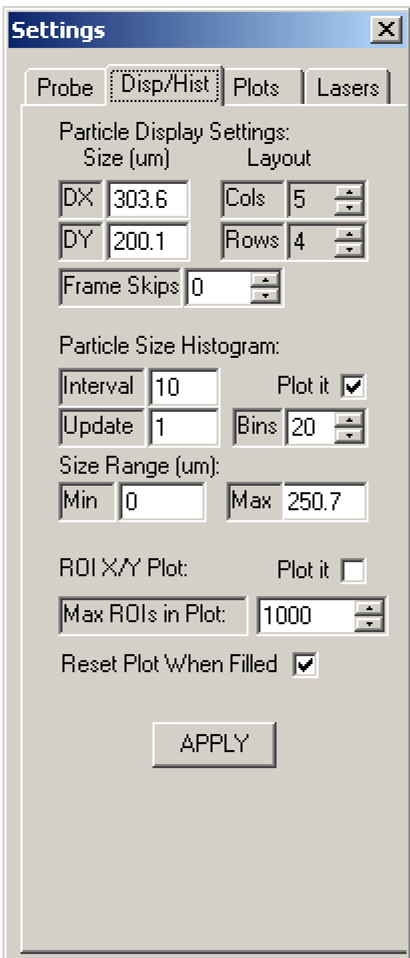


Figure 5.1.15. Disp/Hist tab of the Settings window.

A close up of eight ROI display boxes is shown in **Figure 5.1.16**. Beneath each ROI box is the x and y location on the CCD in pixels of the ROI, the total size of the ROI in the box in microns, including the pad (not the total size displayed, which is DX and DY above), and the time the ROI was captured. If more than one ROI is captured in a single frame, ROI display boxes will be plotted one after the other with the x and y location, total size of the ROI, and the time displayed in the same color descriptions to give the user a visual cue that this has occurred. The color of each sequential frame alternates. In the example of **Figure 5.1.16**, some displayed ROIs are portions of a background, as identified by the reported "Bkg:" information, otherwise the frame number is displayed. Skips in the frame number are a result of no ROI's found in the frames skipped.

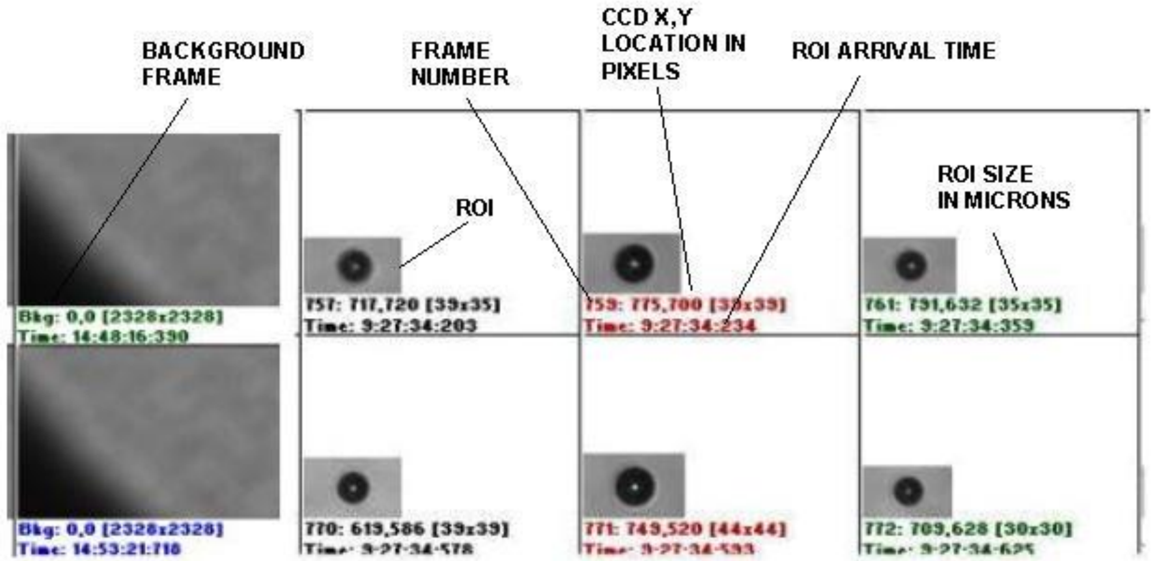


Figure 5.1.16. Close up of ROI display boxes.

The second set of controls in **Figure 5.1.15** are for the "Particle Size Histogram" display. The histogram plots the number of particles in a given size bin against a number of size bins chosen by the user, as seen in **Figure 5.1.17**. If the "Plot it" box is checked, the histogram will activate the first time a ROI is found. The particle size range and the number of bins are entered in the "Settings" "Disp/Hist" window in the "Min" and "Max" size bin text boxes and in the "Bins" selection box.

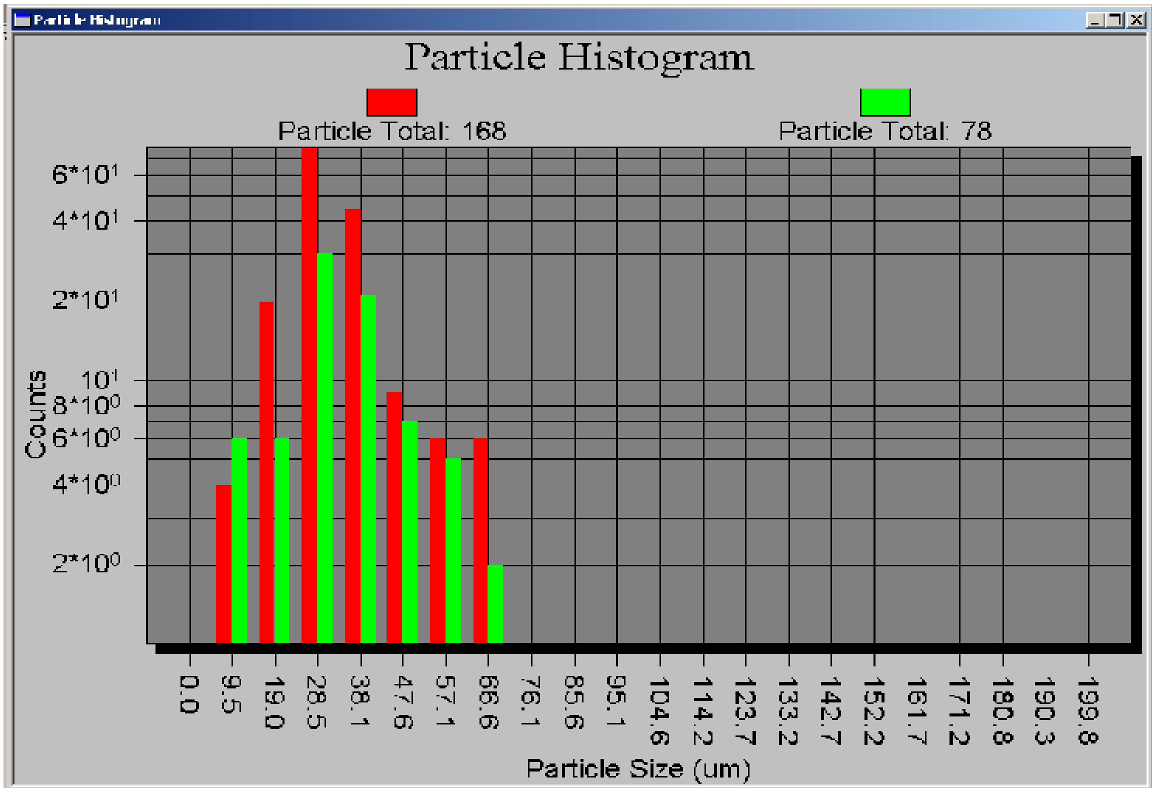


Figure 5.1.17. The particle histogram plot used to size particles in real time.

The histogram plot uses two colors, red and green, in plotting. The two are plotted alternately in order to contrast current measurements with past measurements. Two other parameters in **Figure 5.1.15**, "Interval" and "Update", affect how often the current color is updated (update) and for how long each color is plotted (interval). For example, if update is 1 sec, and interval is 5 sec, every 1 sec the histogram will update and every 5 sec the counting will alternate between green and red. If update is 5 sec and interval is 20, there will be 4 updates between red and green changing.

To remove the histogram display, either click on the minimize button in the upper right of the histogram window, or uncheck the "Plot it" box in the "Settings" window.

The last plot of interest shows the location of detected particle ROI locations, shown in **Figure 5.1.18**. Each ROI's top left corner and lower right corner are plotted, in red and green, respectively, against x and y pixel coordinates of the CCD camera. Thus each axis range is 1 to1024. This plot provides a visual means of identifying how uniformly the PDS system detects particles in the sample volume. If the ROI locations become biased to one side of this plot, there is likely a problem with the PDS electro-optical system.

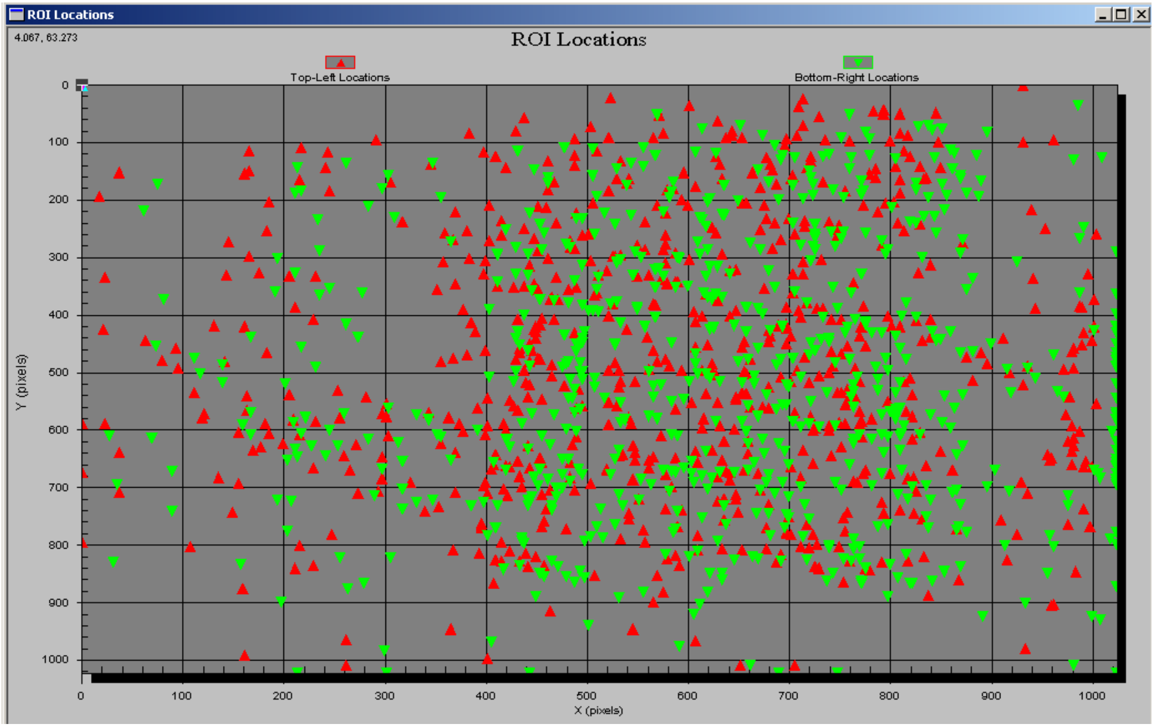


Figure 5.1.18. ROI x, y location plot.

To enable the ROI x, y plot, check the "Plot it" box in the "ROI X/Y Plot" section of the "Disp/Hist" tab of the "Settings" window of **Figure 5.1.15**. The plot will open when the first ROI is found in an image after checking the "Plot it" box. The plot will continue adding red and green markers with each ROI until the "Max ROIs in Plot" number of ROIs is displayed. If "Reset Plot When Filled" box is checked, the plot will be cleared and begin updating again as if just opened. If not checked, the plot will stop updating once the maximum number of ROIs is plotted.

5.1.7 cpi.INI File Description

The cpi.INI file is opened and its information used each time the CPI.exe program is started. Additionally, information is recorded into this file each time the CPI.exe program is stopped by the user, reflecting changes in operation parameters since the program was started.

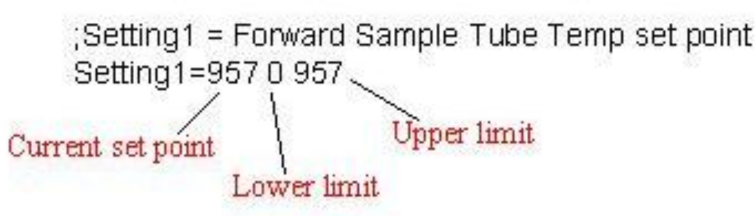
WARNING! The format of the cpi.INI file is critical. Manipulation of the file manually, though sometimes necessary, must be performed carefully. Incorrect format of the cpi.INI file can cause the DAS program to fail to communicate correctly with the probe or even to start. Therefore, always back up the cpi.INI file before making changes.

The cpi.INI file is located in the c:\winnt\ directory. Editing may be done using the Windows Notepad program. A copy of a sample cpi.INI file is included in appendix **Section 7.3**, and **has line numbers added for reference that are not in the standard cpi.INI file. These are for reference only and should not be added to the actual file!** The cpi.INI file records the set point value of all parameters accessed from the CPI.exe program. Most changes to the cpi.INI file occur when the user adjusts a parameter (eg, in Advanced control and settings window) during real time operation and then stops data acquisition by hitting the “stop probe” button and exits the program. Some parameters in the cpi.INI file, however, must be changed within the file directly, and will be carefully discussed below.

The cpi.INI file is separated into sections, each delimited by brackets. For example, on line 1, [System] indicates to the DAS program that it will find information related to the current system here. **The parameters under [System] come factory configured and should not be changed by the user.**

Likewise, the parameters under the next heading, [ROI Parameters], should not be changed directly using a text editor such as Notepad. Some of these parameters are manipulated by the user from within the CPI.exe program, but will be explained in following sections that describe the DAS graphical user interface (GUI).

Next comes the [Probe Settings] heading. This section contains the first parameters a user may need to change directly. For example, on lines 26 and 27 the cpi.INI file contains the following:



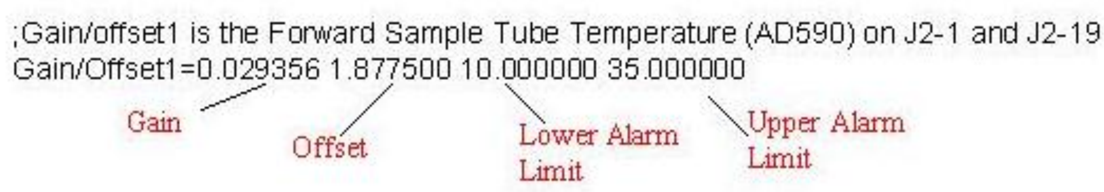
Note that the semicolon indicates that the information on line 26 is for the user’s information only; the DAS does not do anything with it. Line 26 tells the user that the next line contains the temperature set point for the Forward Sample Tube. The three numbers, from left to right are:

1. The current set point.
2. The lower limit of the set point.
3. The upper limit of the set point.

The current set point value is written to the file every time the CPI.exe program is shutdown by the user. The lower and upper limits set the acceptable set point range for the particular parameter. These limits serve as the slider limits in the “advanced control and settings” window. If a value is manually typed in that is not within range, an error message will appear “Probe set point out of range”. The only numbers the user may need to change from within a text editor are items 2 and 3.

Item 1 is automatically changed from within the CPI.exe program, so should not be manipulated here. **The value of these three items is given in analog to digital conversion (ADC) raw numbers; they are not actual engineering units**. Understanding how to interpret and set these numbers requires looking further into the file.

The next section of the file, with heading [Gains/Offsets for Readings], contains on lines 116 and 117:



Again note that the semicolon indicates that the information on line 116 is for the users information only; the DAS does not do anything with it. The next line contains values described from left to right:

1. Gain
2. Offset
3. Lower Alarm Limit
4. Upper Alarm Limit

The gain and offset are applied to measured Analog to Digital Converter (ADC) values. For example, if the ADC is read for the Forward Sample Tube and is determined to be 800, the temperature in degrees Centigrade would be found:

Forward Sample Tube Temp = ADC x Gain + Offset
Forward Sample Tube Temp = 800 x 0.029356 + 1.8775
Forward Sample Tube Temp = 25.36 C.

The alarm limits are given in engineering units (degrees Centigrade in this case) and tell the DAS that if the derived temperature is less than 10 or greater than 35 degrees Centigrade for the Forward Sample Tube, flash a blue (if less than lower limit) or red (if greater than upper limit) alarm in the housekeeping window. A yellow “invalid temperature” light will also appear in the enunciator panel (see red enunciator windows near the top of **Figure 5.1.1**).

Returning to lines 26 and 27 of the cp.INI file, note that items 2 and 3 are limits given in ADC values. For the given values of 0 and 957, the Forward Sample Tube temperature set point has the range:

Upper = 957 x 0.029356 + 1.8775 = 29.97 C.
Lower = 0 x 0.029356 + 1.8775 = 1.8775 C.

The effect of these settings is such that, from within the CPI.exe program, users may change the Forward Sample Tube set point to be any value from 1.8775 to 29.97 degrees centigrade. If the probe reports back any temperature below 10 degrees C or above 35 degrees C, the DAS should display warning enunciator indicators to the user.

Other parameters may be changed that have different units, such as Volts or milliWatts, but the procedure is the same. To determine the units, find the parameter in the housekeeping window. For example the PDS45 Laser Power is reported with units of mW (milliWatts). The settings for this, on line 66 of the cpi.INI file, are again given in ADC values:

Setting14=4095 0 4095

And the reported limits on line 171—

Gain/Offset19= 0.0246752 -1.6774 15.000000 41.000000

–are 15 and 41 mW, upper and lower, respectively.

The settings and gains/offsets all have a descriptive line of text above them indicating which physical parameter the values correspond to. Other than the settings limits and alarm limits, the user should not manipulate anything in the cpi.INI file. The limits are set to reasonable values by SPEC before shipping the CPI and data system; however some changes to these values may be appropriate depending on operating conditions (**See Section 5.1.7.1)**

Finally, a few setting limits and gain/offset limit values are set at the factory and should not be changed: They are:

1. Imaging laser current set voltage.
2. Imaging laser pulse width set voltage.
3. Imaging Laser Current Set Point.
4. Imaging Laser Pulse Width Set Point.

5.1.7.1 Enunciator Panel

The purpose of the enunciator panel is to alert CPI operators to potential instrument problems. **Figure 5.1.19** shows the enunciator panel that is located at the top of main real time operation window in **Figure 5.1.1**. Ideally, the user sees a “clean” panel during normal operation. That is, only a green “background valid” light is present. The other lights alert the user to some problem conditions for normal operation. “Recording Disabled” tells the user that no data is currently being recorded. “Live Video On” tells the user that the probe is in Live Video Mode. “4 Invalid Temperatures” tells the user that four different temperatures are beyond their alarm limits.

Figure 5.1.19. Enunciator Panel lights

Any light other than “Background Valid” should prompt the user to further investigate the problem or take corrective action. “Live Video On” can be corrected by clicking off the Live Video checkbox in the main Real Time Operation Window **Figure 5.1.1**. “Recording Disabled” can be corrected by clicking on the Record Data Checkbox in the main operators window. Messages such as “invalid temperature”, “power supply out of range”, “PDS detector invalid” require the user to look at the housekeeping window to further diagnose the problem. **Figure 5.1.20** shows a portion of the housekeeping window with two parameters out of range. One parameter is turned blue because it is below the lower alarm limit and another parameter is red because it is above the upper alarm limit.

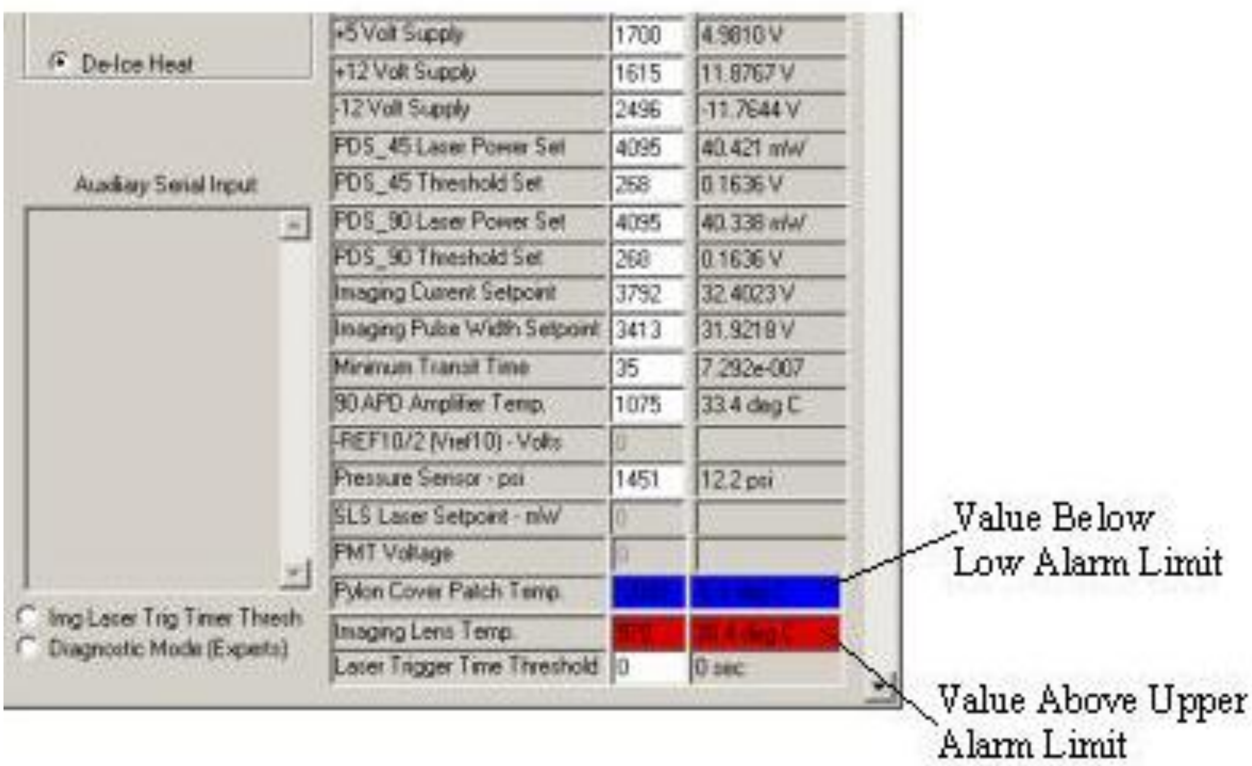


Figure 5.1.20. Section of HouseKeeping window showing out of range parameters.

Provided the alarm limits have been set to reasonable values, these out of range parameters indicate a problem. The "pylon cover patch" heater may not be selected on, for instance, in the advanced control and settings window. If the user enables this heater, the pylon cover patch temperature should increase and the blue alarm should go away. If the heater is already enabled, perhaps the AC2 circuit breaker is off, and there is no AC heater power present (there would be many blue temperatures in this case). For the over range parameter, in **Figure 5.1.20**, the "Imaging Lens Temp.", the heater may be experiencing normal thermal overshoot. In this case the upper alarm limit should be increased, because this is a "false alarm". The set point may be 25 C, and the actual temperature overshoots to 27 C as the heater pulses on for one second. A problematic over temperature condition could occur, for example, if a temperature sensor became unattached from its particular heat zone.

Another example of an incorrect alarm range could be the pylon temperature alarm limits of 5 C and 35C, shown on line 135 of the cpi.INI file. This heat zone may have a lower limit that is often exceeded during flights in extremely cold ambient conditions. In this case, the user should decrease the lower limit to below –10 C: a temperature that the pylon may often reach and that does not require a warning to be issued to the user**. For the user to have any confidence that the flashing enunciator lights should be taken seriously, the limits must be customized in the cpi.INI file for a particular CPI in a particular operating environment.**

Other enunciator messages such as "PDS Detector Invalid" alert the user to a problem with the PDS system. If the PDS detector DC level is too high, that particular PDS laser power needs to be decreased, to allow dynamic range on the detector for triggering (see **Section 5.1.3.1**). This may also indicate a larger problem, such as contamination on the windows of the PDS system. This condition may indicate it is time for the windows to be cleaned.

5.2 CPI Real-Time Operation and Troubleshooting

The real time operation and troubleshooting section will outline the process of operating the CPI in real time. The flowchart in **Figure 5.2.1** should be used as a step-by-step guide to enable the user to operate the CPI in the most efficient manner. At certain points in the flow chart, depending on the branch taken, the user will be referred to troubleshooting information for specific operational problems. By using the information in this section, the operator will optimize the data collected by the CPI.

5.2.1 Operation and Troubleshooting In Flight

This section assumes the user has set up the probe per the instructions in the "Getting Started" **Section 2** and is attempting to run the probe. The flowchart in **Figure 5.2.1** assumes the user has started the CPI.exe real time program and is attempting to communicate with the probe by having clicked “Start Probe” in the main window or “Apply and Acquire” in the “Advanced Control and Settings” window.

If the probe is not working, the flowchart will lead to one of four sections:

1. RTIA Log Troubleshooting.
2. Background Troubleshooting.
3. PDS System Troubleshooting.
4. Enunciator Troubleshooting.

If the flowchart does not list an observed problem, reading the troubleshooting sections may provide insight and is still suggested. Problems with displaying data such as rates and image parameters are not handled here. The user is referred to **Section 5.1.6.1, “**Rates and Image Parameters” for information on this topic.

AT THIS TIME, THE USER SHOULD BEGIN OPERATING THE PROBE, FOLLOWING THE FIGURE 5.2.1 FLOW CHART STEP-BY-STEP UNTIL THE “PROBE IS WORKING” BOX IS ARRIVED AT.

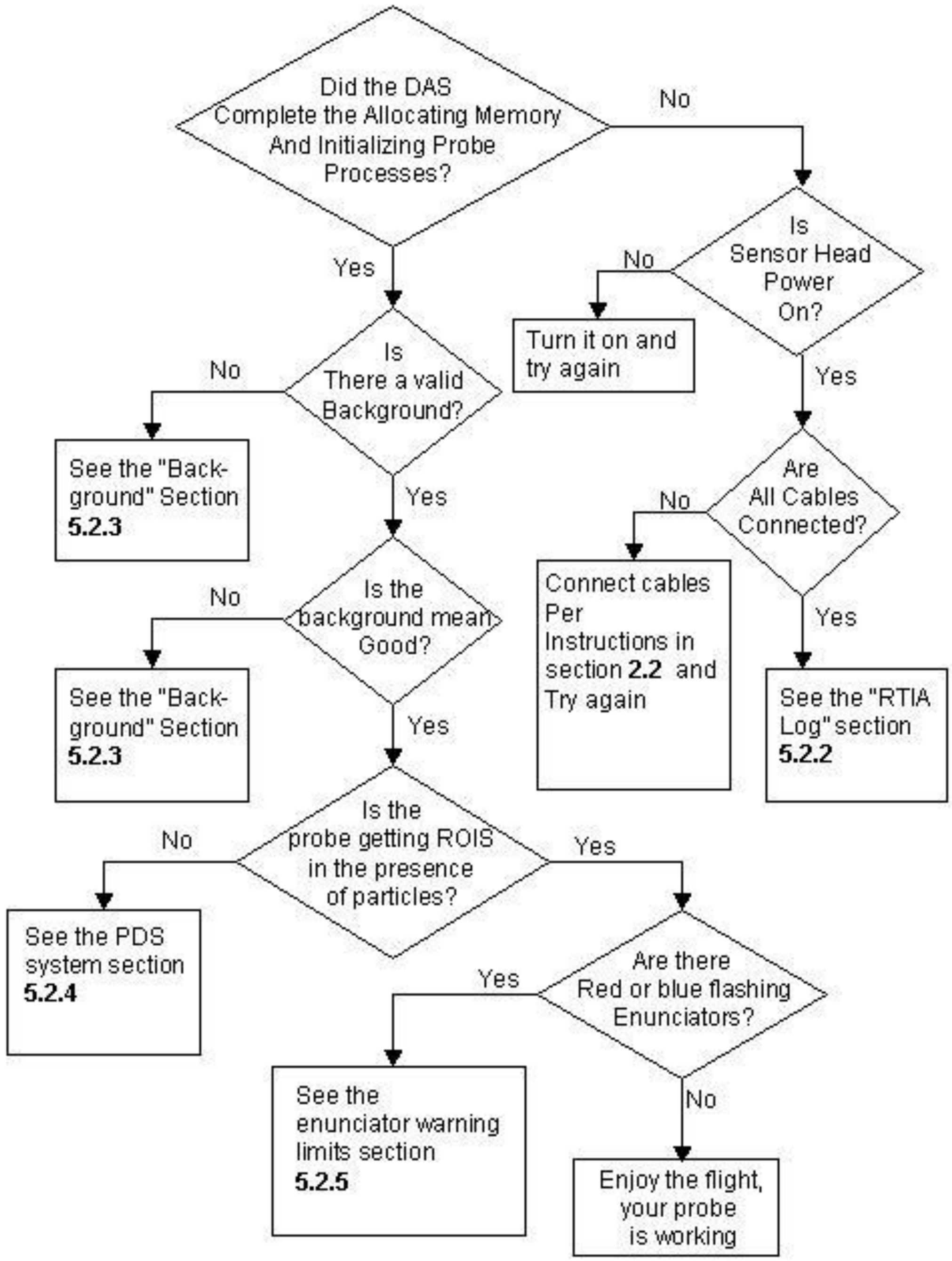


Figure 5.2.1. Troubleshooting flow chart (data system access only).

5.2.2 RTIA Log Troubleshooting

The rtialog.txt file is found in the following directory:
C:\Program Files\boulderimaginginc\acquirenow\cpi\ directory. This file is produced every time the probe is run and is written with information that is useful for troubleshooting many different problems, some of which are described here. The following RTIA subsection headings describe the problem (such as sensor head powered off) and the information in that section includes lines copied from a rtialog.txt file taken when that error occurred.

5.2.2.1 Sensor Head Powered Off / Camera Connector Disconnected

Trying to start communicating with the probe while the sensor head is powered off is a common mistake. Fortunately it is easy to diagnose. See **Figure 2.2.1** of the "Connecting the CPI Sensor Head to the Data Acquisition System" **Section 2.2**. Locate the sensor power indicator and see that it is lit; if not, turn on the sensor power switch.

If the sensor power is off, the rtialog.txt file will have lines in it that match the following:

[0]PCLNKCapture: m_CaptureStartingEvent.Set()
PCLNKCapture::PCD_SWTRIG1_32 SENT - Frame TIMEOUT.
PCLNKCapture::PCD_SWTRIG1_32 SENT - Frame TIMEOUT.
PCLNKCapture::PCD_SWTRIG1_32 SENT - Frame TIMEOUT.

If these repeating lines are found in the log file, check the sensor head power is on as described. If the power is on, another cause of these lines in the log file is the data acquisition system (DAS) computer to sensor head camera connector being disconnected. See **Figures 2.2.3 and 2.2.5** for the J1 sensor camera connector locations on the DAS and sensor head in the "Connecting the CPI Sensor Head to the Data Acquisition System" **Section 2.2**.

5.2.2.2 No Hardware Key Connected

The CPI software requires that a hardware key be connected to the parallel port of the computer. If there is nothing plugged into the parallel port, the rtialog.txt file will produce the following:

CTracer::FinalConstruct - Enabled = 1; Level = 9
ThrowError:: CUserConfigCamera::FinalConstruct - No cameras are specified in the registry.
CMemoryOperator::FinalConstruct
CMemoryOperator::FinalConstruct- m_bDontLockLargeMem=0
ThrowError:: CBlobOperator::FinalConstruct - Operator is NOT licensed.

The final line indicates, "Operator is NOT licensed", meaning the software could not find the hardware key. See **Figure 2.2.3** of the "Connecting the CPI Sensor Head to the Data Acquisition System" **Section 2.2**. Locate and plug in the hardware key.

5.2.2.3 Imaging Laser Power Too Low or Too High

The probe won't acquire a background if the image mean is too low (or too high). A possibility is that the imaging laser power has been turned down or up in the controls such that the incident light energy is not within operating range on the CCD camera. If this is the case, the rtialog.txt file will have text like the following in it:

CSerialComm::ReadDataPacket - a PDS packet received, Cnt=2764.
PCLNKCapture: [0]Frm #2831 (1, 0, 2, 2): 0 0 2 (XFer 0.0086 s, Period 0.0136 s)
CCorecoPCLNKDevice::CompleteAcquire: !m_bFrameCycleComplete
CBlobOperator::PerformOperation *Mean* = 0.000336sec/frame (Mean= 9.75).
CBlobOperator::PerformOperation BAD Mean: 9, (Valid: 63, 195).

The last line tells the user that the mean of the CCD camera image was 9, but the acceptable range is 63 to 195. In this case, the imaging laser power might have been turned down and needs to be adjusted back up. If the line read "…BAD Mean: 220", the imaging laser would need to be turned down. See **Section 5.2.3.2** " What To Do If Probe Is Communicating With DAS, but No Background Taken" which describes how to adjust the image mean.

5.2.3 Background Troubleshooting

The background collection process and the parameters affecting it are described in detail in **Section 5.1.4.1** "Background Images and Parameters". The first thing the DAS must do on start up is acquire a background from the sensor head CCD camera. The various problems that can occur in taking a background are described in the following sections. The flowchart of **Figure 5.2.2** provides a guide to steps for correcting background problems.

5.2.3.1 What To Do If No Background Is Acquired At Startup

See flowcharts of **Figure 5.2.1** and **Figure 5.2.2.**

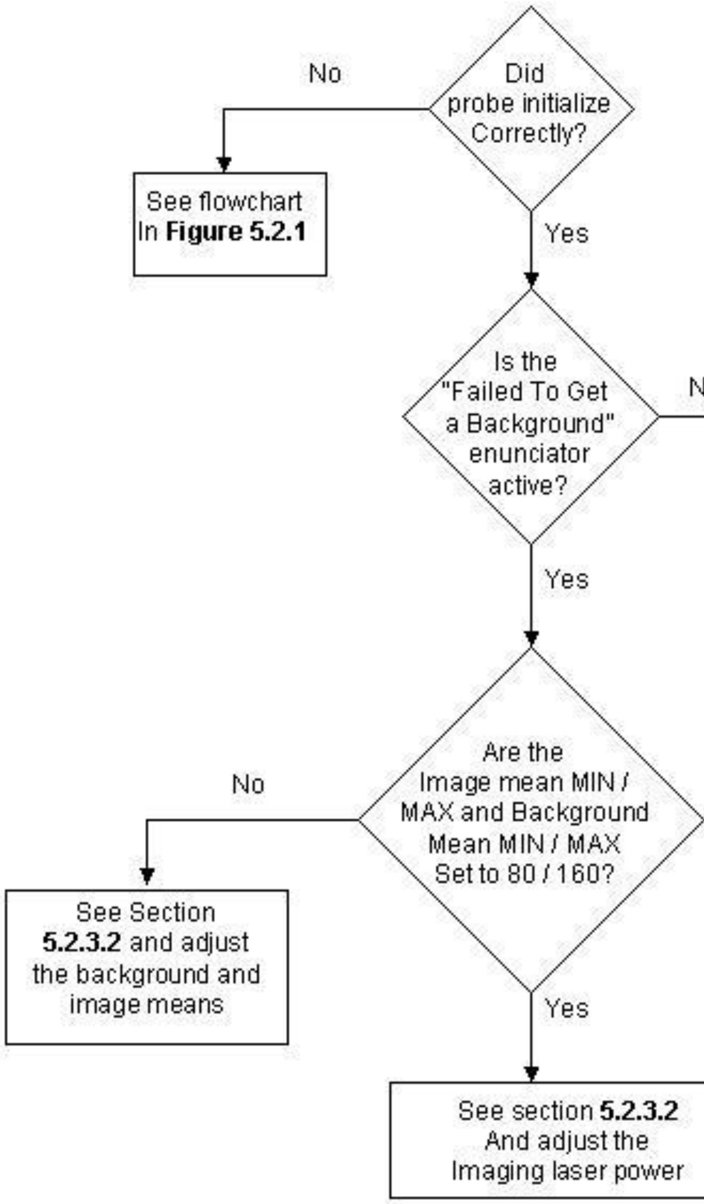


Figure 5.2.2. Background image troubleshooting flowchart.

5.2.3.2 What To Do If Probe Is Communicating With DAS, but No Background Taken

If the “Background Invalid” enunciator is flashing, or if the background image has a very low or high image mean, which varies from probe to probe, steps can be taken to improve the background.

High Particle Concentration

The first type of problem that can occur is the DAS attempting to get a background while in the presence of high particle concentrations. The DAS waits until there are less than “Strobes Threshold” number of PDS events per second before attempting to get a background (see **Figure 5.2.3**).

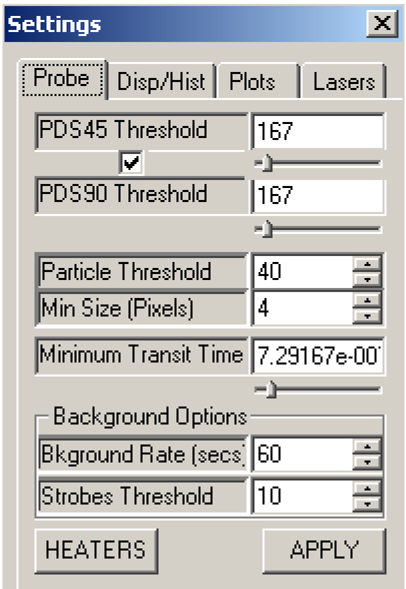


Figure 5.2.3. The probe tab of the settings window.

Raising the Strobes Threshold value does not improve the likelihood of getting a valid background while in high particle concentrations because the background validation process will reject images that have a particle present in the image. If the probe is repeatedly trying to take a background and is in high concentrations, the solution is to exit the cloud for a brief period to allow the probe to take a background image in clear air.

Particle Threshold Too Low, Minimum Size (Pixels) Too Low

The “Particle Threshold” and “Min Size (Pixels)” fields in **Figure 5.2.3** greatly affect whether or not the DAS detects particles (real or not) in image frames. If the probe is failing to get a background, try changing these values to the more conservative values of 50 for the “Particle Threshold” and “6” for the ”Min Size (Pixels)”. **If this is not the problem, the user should go back to the previous settings (somewhere around 40 and 4), as raising these values raises the minimum size particle the probe will measure.** See **Section 5.1.4.2** “Particle Collection and Associated Controls” for more information on the “Particle Threshold” and “Min Size (Pixels)” settings.

Image Mean Too High / Too Low

Each CPI has a different range of image means with which it performs well. A reasonable range for most probes, however, is 80 to 160. These limits are entered by the user in the “Advanced Control and

Settings" window, a portion of which is shown in **Figure 5.2.4**, and which comes from the bottom center of the full window.

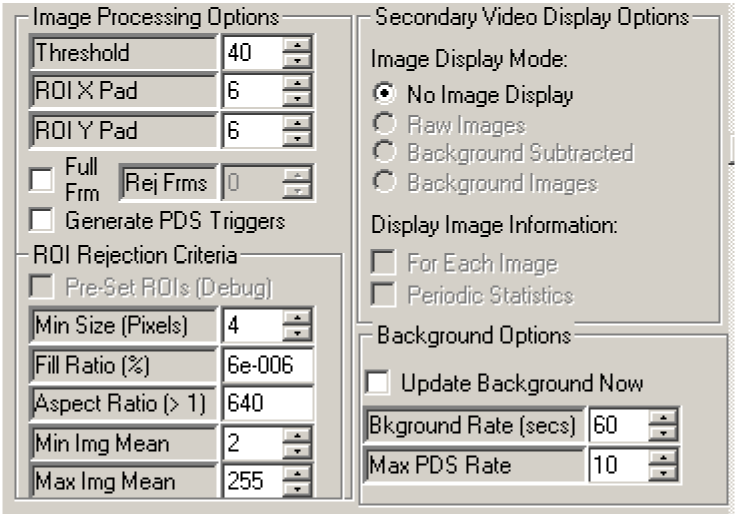


Figure 5.2.4. Background acquisition parameters in the Advanced Control and Settings window.

In **Figure 5.2.4**, the minimum and maximum image mean are set to 2 and 255, respectively, which is so large a range as to allow image means below and above desired operating limits. This is useful for diagnosing the image mean when the probe is failing to take a background, or for running live video. If these limits are tighter than the current image mean of received CCD frames, both live video and background acquisitions will fail, so a wide range is useful for troubleshooting; however, once the retrieved image mean has been adjusted to desired levels, the user should set the limits to 80 and 160 for the "Min Img Mean" and "Max Img Mean" fields, respectively. **Once changed, as with all fields in the "Advanced Control and Settings Menu", the user must click the "Apply" button (which may also say "Apply and Acquire"), else the DAS won't use the new values.**

Note that also the background mean limits must be changed in the AI background control window, shown here in **Figure 5.2.5**, and discussed in detail in the "Laser Pulse Width Control" **Section 5.3.5**. These limits must be tighter (the minimum mean greater than or equal, the maximum mean less than or equal to, respectively) than the image mean settings in **Figure 5.2.4**. To open the limits of the image mean for live video, only the "Min Img Mean" and "Max Img Mean" values in **Figure 5.2.4** need to be changed.

If the image mean needs to be raised or lowered, the imaging laser is adjusted to bring the image mean to a desired level. The adjustment is easily made in the "Lasers" tab of the "Settings" window, shown in **Figure 5.2.6**. Make sure the "Laser Current Set Point" is at or near its maximum (4095), then adjust the "Pulse Width Set Point" up to get a higher image mean or down for a lower image mean.

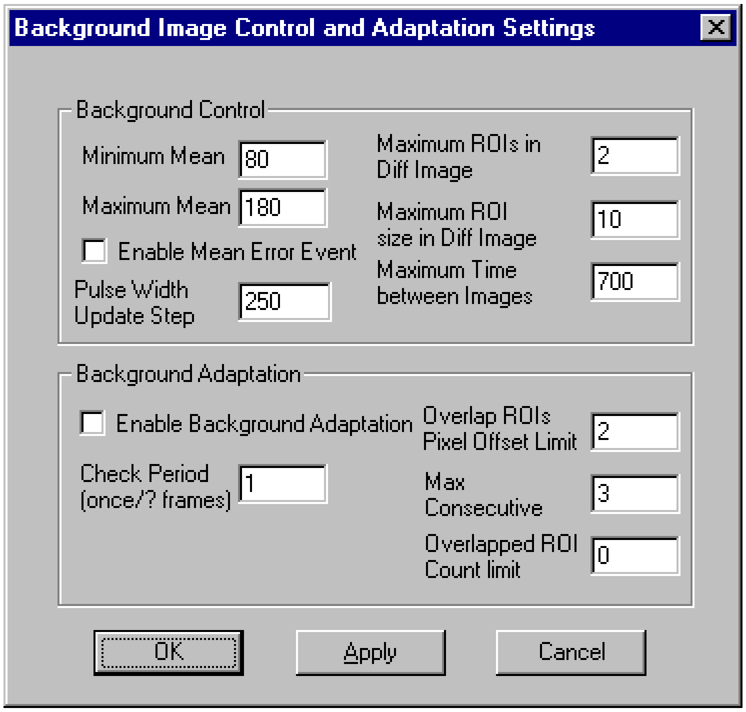


Figure 5.2.5. AI Background control chosen from the Settings menu.

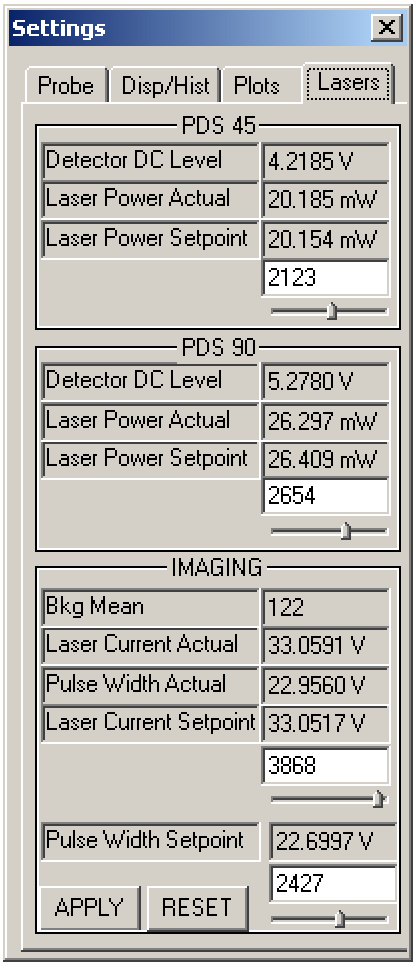


Figure 5.2.6. Lasers tab of the Settings window.

To adjust the image mean in real time, the user can check the "Live Video On" check box in the main screen. **It is best to run live video with recording disabled, as about 72 full images of approximately 1 Megabyte size each will be saved to hard disk every second if recording is active**. Once live video is turned on, the image display area will show the entire CCD camera image (though for most CRT and LCD computer monitors, only a fraction of the total image may be seen; move the scroll bars for the image display area to view different portions of the CCD image). The image mean will be updated in real time in the "Img Mean" field of the "Statistics" window (see "Live Video mode" **Section 5.1.4.4**). While running live video, adjustment of the imaging laser current (remember to click the "Apply" button) will change the image brightness displayed and reported. Once the image mean is at a desirable value—e.g. somewhere between 80 and 160, though this is different for each probe—turn off live video by unchecking the "Live Video" box. **A new background should be taken immediately after any changes are made to the imaging laser set points**. If not, the background subtraction will now have a large offset due to the changed image mean, causing the particle processing algorithm to work poorly or not at all.

Warning! If the image mean is outside the limits set in the "Advanced Control and Settings" window, shown in **Figure 5.2.4**, live video will fail to update the "Display" window and the probe will fail to take a background. To prevent the image mean from falling outside the limits, set "Min Img Mean" equal to 1 and the "Max Img Mean" equal to 255 when troubleshooting image mean problems. Be sure to return the limits to a proper operating range when you are finished diagnosing and correcting the image mean problem.

5.2.4 PDS Operation and Troubleshooting

The PDS system is described in detail in **Section 5.1.3** "Particle Detection System Control and Monitoring".

The flowchart of **Figure 5.2.7** is a guide to troubleshooting any problems with this system.
The user adjustable parameters for the PDS system are as follows:

8. PDS 45 laser power.
9. PDS 90 laser power.
10. PDS 45 detector DC level.
11. PDS 90 detector DC level.
12. PDS 45 threshold Voltage.
13. PDS 90 threshold Voltage.
14. PDS minimum transit time.

Items 1 through 4 are easily accessed via the "Lasers" tab of the "Settings" window of **Figure 5.2.6**

Items 5 through 7 are easily accessed via the "Probe" tab of the "Settings" window shown in **Figure 5.2.3**

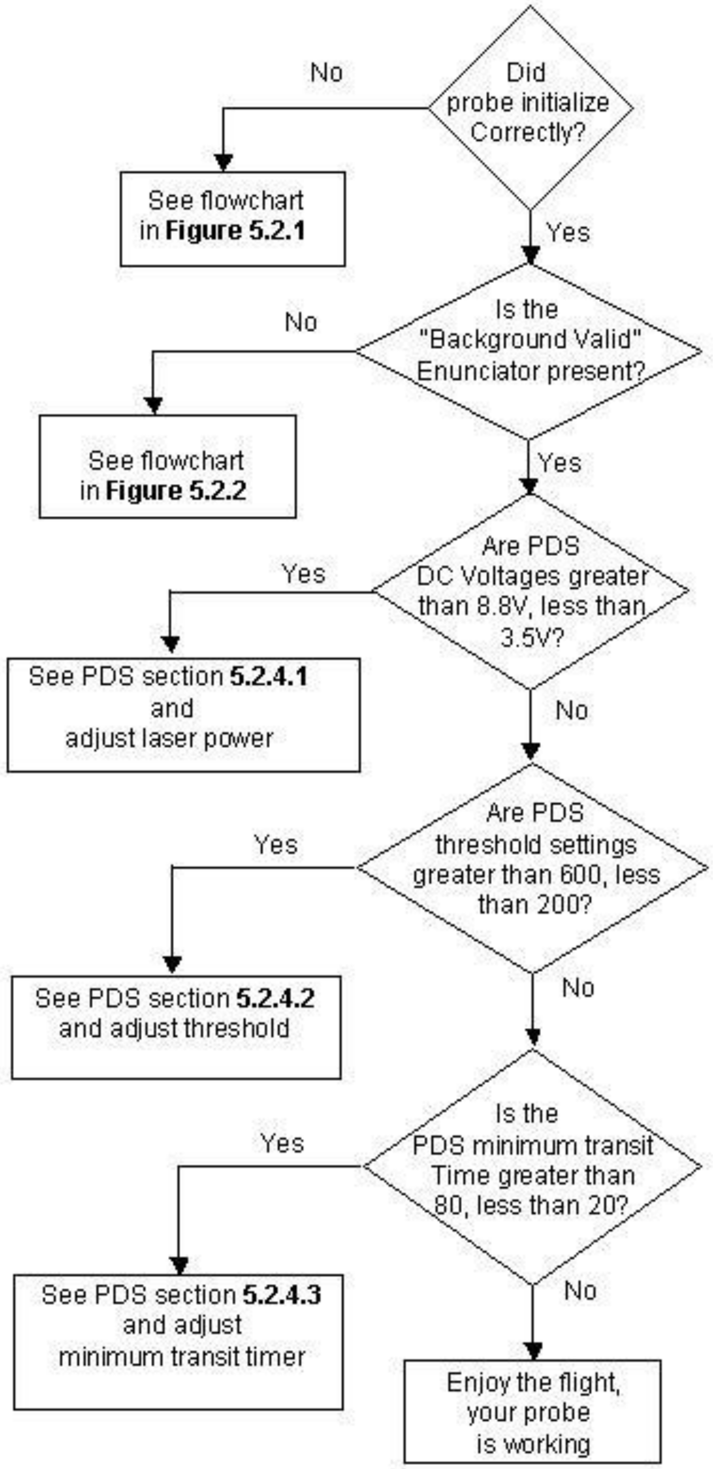


Figure 5.2.7. PDS troubleshooting flowchart.

5.2.4.1 What To Do If PDS Laser Power Needs Adjustment

The indicator for laser power out of range is that the "Detector DC Level" for either the PDS 45 or PDS 90 system, is above 8.8V or below 3.5V, as reported in the Lasers tab of the Settings window, **Figure 5.2.6**. These limits are different for every probe, but a well-aligned probe with clean optics will have an operating range of approximately 3.5V to 8.8V. If not within this range (or a normal range for a given probe), adjust the laser power up or down by moving the slider in the PDS 45 or PDS 90 box in the lasers tab of the Settings window. This window is shown in **Figure 5.2.6.** Move the slider right for more power, raising the DC level, or left, lowering the DC level. Slide the adjuster to a new value and click the "Apply" button. Monitor the DC values and the reported "Laser Power Setpoint" to see that the change was accepted and the DC Voltage levels are at an acceptable level. Repeat the steps if necessary until the DC levels are within the above stated range.

If the DC Voltage remains very high, even though the "Laser Power Setpoint" and "Laser Power Actual" values are low—less than 18 mW—then either the PDS laser is not correctly focused on the dump spot (see diagram in the upper left of **Figure 1.1.2** of the "General Description" **Section 1.1**), or the PDS optics are dirty and scattering laser light around the dump spot. Both problems require access to the sensor head. A knowledgeable person must work on the optics of the PDS system (see procedure in "Cleaning Windows **Section 6.7**).

5.2.4.2 What To Do If the PDS Threshold Needs Adjustment

The PDS threshold settings are adjusted in the "Probe" tab of the "Settings" window, shown in **Figure 5.2.3.** 200 is a normal lower limit, though some probes can be operated at even lower values while running in a laboratory (such as the 167 value, shown in **Figure 5.2.3**). As described in the "Particle Detection System Control and Monitoring" **Section 5.1.3**, the higher the threshold is set, the fewer small particles are seen. 600 is a nominal upper limit, however, like the lower limit, this is not a hard and fast number.

If the probe is not collecting particles and the PDS laser power levels are acceptable, adjust the PDS threshold to a safe value, 350, and click the "Apply" button. At this setting, particles of the smallest size may not be seen, but if in the presence of an ensemble of cloud particles that includes some medium (50 to 100 μm) to larger particles, this setting should be safely above the noise and allow the PDS system to detect particles. However, if particles are still not collected, lower values should be attempted.

5.2.4.3 What To Do If the PDS Minimum Transit Time Needs Adjusting

As described in the optics section of the manual, the PDS sample volume is 0.5mm thick and tilted at an angle of 45° to the direction of particle travel. The time required for a particle to enter, then exit the sample volume is, ignoring the particle size, approximately:

$$T_{TRANSIT} = 0.5 \times 10^{-3} \text{ meters} / (V \times \sin 45°)$$

$$T_{TRANSIT} = 0.707 \times 10^{-3} \text{ meters} / V$$

Where V is the velocity in meters per second. To a first approximation, the transit time including the particle size is given by:

$$T_{TRANSIT} = (0.707 + D) \times 10^{-3} \text{ meters} / V$$

Where D is the particle diameter in millimeters. From this equation, the transit time of a 10 micron particle traveling at 200 m/S is 3.585 x 10^{-6} seconds. The transit time counter operates at 48 MHz, so this particle would have a total transit time count of approximately 172 counts. A 200 micron particle at the same speed would have a transit time of 4.535 x 10^{-6} seconds and transit time count of approximately 218. In actuality, the particle spends time in the beam during which the particle threshold is not exceeded, so the transit time count is smaller than those given. From this analysis it is apparent that a “Minimum Transit Time” setting of 200, when flying at 200 meters per second, is going to limit the smallest sizes seen; in some cloud droplet distributions, no particles might be imaged at all due to failing the minimum transit time criterion.

If the probe is not imaging particles, adjust the raw value of the “Minimum Transit Time Setpoint” to 30 and click “Apply” in the “Advanced Control and Settings” window shown in **Figure 5.1.6** in the Software Description **Section 5.1**.

5.2.5 Enunciator Warnings

When operating with no limits exceeded, such as heat zone measured temperatures, laser powers, etc., the DAS enunciator panel (see the upper part of the window shown in **Figure 5.1.1** in the Software Description **Section 5.1**) should have one green background alert stating “Background Valid”. Any other alert, given in red, yellow or blue, indicates a parameter is out of the assigned operating range. Users assign these limits in the cpi.INI file, described in **Section 5.1.7** The enunciator panel is further described there as well. If any alerts other than “Background Valid” or short alerts titled “Getting Background” are in the enunciator panel, read **Section 5.1.7** and address the problem.

5.3 Artificial Intelligence (AI) DAS Controls

Incorporated into the software are control algorithms that automate the PDS threshold settings, the PDS laser power settings, and the imaging laser power. Also available for use is an algorithm to take a new background any time a particle is seen in nearly the same position in multiple frames. All of these algorithms were designed to remove the need for an operator to monitor and control the system settings. However, this should not preclude operator oversight and we encourage users to turn the control algorithms off until they have spent significant lab time familiarizing themselves with them.

5.3.1 Settings Menu AI Items

Figure 5.3.1 shows the Settings menu options. The Settings/SPP100 Settings and Settings/Single Board Computer Settings options should be ignored, as they are features of a purely stand-alone data system, or a system incorporating an SPP100 instrument. The two menu options that change the control algorithm behaviors, including turning them on and off, are Settings/AI Background Setting and Settings/AI PDS Control Settings. These will be discussed in the following sections.

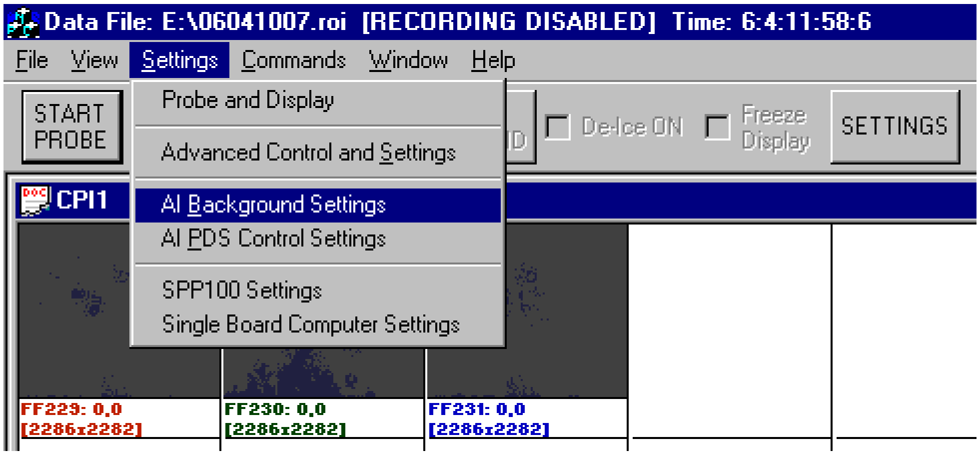


Figure 5.3.1. The New Settings Menu.

5.3.2 PDS Laser Control

The CPI, due to changes in temperature affecting optical paths and laser power fluctuations, requires monitoring and control of the PDS laser settings. Users typically set the laser power monitoring the PDS DC voltage on both the PDS45 and PDS 90 lasers, attempting to set the PDS laser power as high as possible without going over 8.8V on the monitor. The artificial intelligence (AI) code added to the real time software attempts to do the same thing using the following algorithm:

1. Start with the set point stored in the CPI.ini file.
2. Wait X (start with 5) seconds.
3. Look at error between desired PDS DC level—the upper limit for the DC Voltage measured found in the cpi.INI file—and the measured value.
4. Implement proportional/integral control based on error in 3.
5. Record new set point
6. Go to 2.

Figure 5.3.2 shows the window used to change the parameters that affect this algorithm. The lower two thirds of the form are for PDS laser setting control, which this section discusses, while the upper third is for controlling the PDS threshold, to be discussed in the next section.

To turn off the DC level control algorithm so that the real time software lets the user maintain control, leave the Algorithm Enabled checkboxes unchecked.

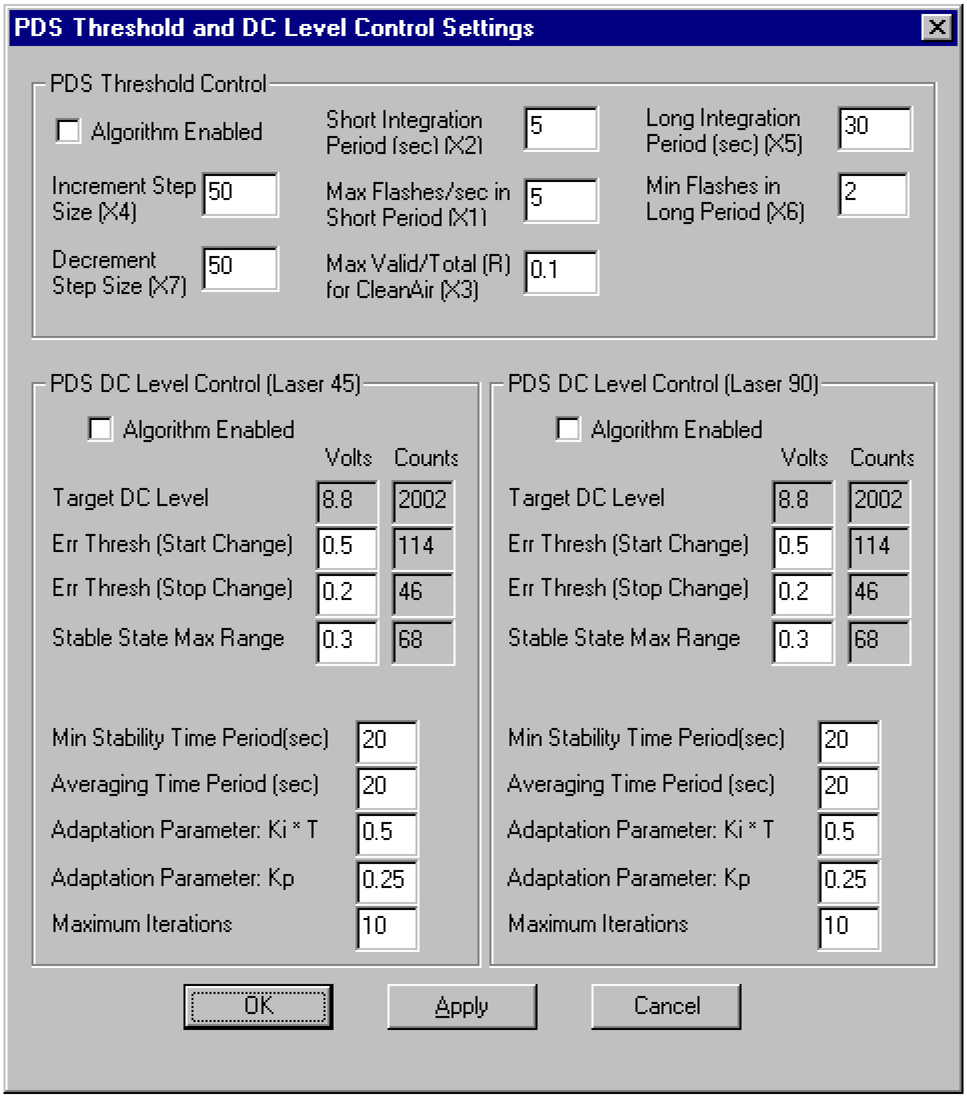


Figure 5.3.2. PDS threshold and DC level control form.

The following is a description of the parameters affecting the PDS laser DC level control. Note that both the PDS45 and PDS90 lasers have settings that need entered, but should usually be the same. One possible difference is the target DC level.

Target DC Level: This comes from the cpi.ini file in the C:\Winnt directory -- Gain/Offset 20 (line 173 of the example .ini file in the appendix) and Gain/Offset 22 (line 179 of the example .ini file in the appendix); the max value entered in the file is used as the target DC level. This value is not editable in the form shown in **Figure 5.3.2**.

Err Thresh (Start Change): Volts away from the target for the algorithm to go active. The control algorithm will do nothing until the target DC value differs from the actual DC value by more than this value.

Err Thresh (Stop Change): Volts away from the target to stop the algorithm. Once the difference between the desired DC value and the actual DC value is less than this value, the control algorithm will end. This value should be smaller than the Err Thresh (Start Change) value just discussed.

Stable State Max Range: For min. stability time period (which will be the next field that we discuss), all the values need to be within the Stable State Max Range Volts to be considered good. If the Voltage samples of the laser DC level within a window of time equal to Min. Stability Time Period vary by more than this setting, the control will not be implemented. This feature keeps the algorithm from becoming unstable if the measurements are varying too erratically.

Min Stability Time Period: How long the PDS DC levels must be within “Stable State Max Range” Volts of each other before the proportional—integral (PI) control will begin. See “Stable State Max Range” parameter explanation.

Averaging time period: How long to average PDS DC levels for comparison with set point. This is time T in the difference equation discussed below.

Adaptation Parameter Ki*T: For the PI algorithm the difference equation implemented is uk = uk-1 + (Kp + Ki*T)*ek + (Ki*T - Kp)ek-1. In this equation, uk is the applied DC laser setting (as the user would enter in the Settings/Advanced Control and Settings form); uk-1 is the previously applied value; ek-1 is the error between the desired laser DC voltage and the previously measured DC voltage. The larger this number, Ki*T, the faster things change, but you get less stability. Ki*T should be greater than Kp--twice Kp is a good start.

Adaptation Parameter Kp: See above.

Maximum Iterations: After this number of iterations, if the set level isn't within “Err Thresh (Stop Change)” Volts of the DC set point, the algorithm looks for a stable state again and starts over.

5.3.3 PDS Threshold Control

PDS thresholds affect the sensitivity of the CPI. Users balance the desire to see the smallest particles, corresponding to lowest threshold settings, with getting empty images caused by the probe interpreting electronic or optical noise as a particle event. The artificial intelligence (AI) code added to the real time software attempts to do the same thing using the following algorithm:

1. Raise PDS threshold by X4 (start with X4 = 50). If the following two conditions are met:

    a) The number of laser flashes per second is > X1 for X2 seconds (start with X1 = 5, and X2 = 5).
    b) R < X3 (0.1 to start) for the same period of X2 seconds, where R = number of valid frames / number of strobes.

2. If the sum of the laser flashes per second over the duration of X5 seconds is < X6 (start with X5 = 30, X6 = 2), then lower the PDS threshold by X7 (start with X7 = 50).

Figure 5.3.2 shows the form used to change the parameters that affect this algorithm, with the upper third of the form controlling the PDS threshold control parameters.

To turn off the PDS Threshold Level control algorithm so that the real time software lets the user maintain control, leave the Algorithm Enabled checkbox unchecked.

The parameters in the form are all described in the description of the control algorithm above. Note that item number 1 in the algorithm raises the threshold if a number of particles have been detected (via imaging laser flashes) over a given time period, but the percentage of valid frames (frames containing valid particles, or regions of interest denoted as ROI's) is low. The assumption is increasing the PDS thresholds will increase the valid frames.

Item 2 in the algorithm decreases the PDS threshold if, over a long period of time, very few (X6) laser flashes occur. In clear air, with no particles present, this algorithm will decrease the PDS thresholds enough to cause light and optical noise to just begin triggering the PDS system. This is the optimum sensitivity setting of the probe's PDS system.

5.3.4 Background Control

Currently users set a time period, in seconds, after which the probe should take a background. This is done so that variations in the image intensity over time can be removed when looking for particles in a captured frame. An added feature that may be user enabled looks, in every captured frame, to see if multiple frames have captured a detectable ROI in the same area of the image. So if, for example, a piece of dust on a lens were to remain in one spot, this algorithm would then take a background, thus removing the effect of the dust spot. Otherwise, every time a particle was detected by the PDS system, causing the image processing software to look for ROI's, the image processing would find the dust spot and count it as a particle.

Choosing the "Settings/AI Background Settings" menu option brings up the form shown in **Figure 5.3.3**. The background adaptation just described is controlled in the lower half of the form, and to cause the real time software not to perform the algorithm, leave the Algorithm Enabled checkbox unchecked.

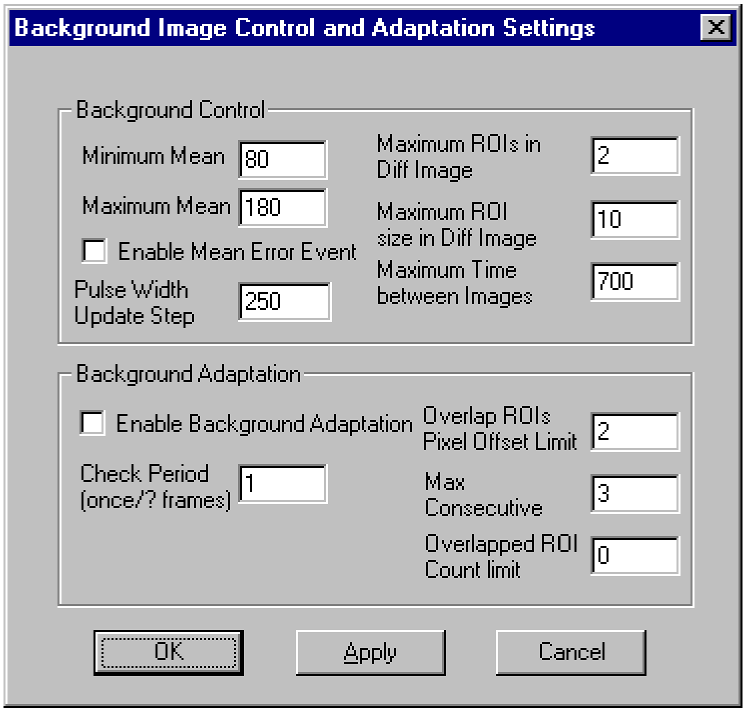


Figure 5.3.3. Background and image laser setting control form.

The parameters that affect the background algorithm are described below:

Check Period: Once every Check Period frames, the image processing algorithm will look for ROI's that overlap. If this value is 1, the data system will monitor every frame. If value is 2, the data system will monitor every other frame. Choosing bigger numbers makes the system faster.

Overlap ROIs Pixel Offset Limit: See **Figure 5.4.3.** Two corners of possible overlapping ROIs are compared. The comparison calculation for the upper left corner (points P) is explained here, but the calculation for the lower right corner is similar. For the points P1 and P2:

If |X1 – X2| < "Overlap ROIs Pixel Offset Limit"
AND
|Y1 – Y2| < "Overlap ROIs Pixel Offset Limit"

then the upper left corners overlap. If upper left corners P1 and P2 overlap AND lower right corners Q1 and Q2 overlap then the two ROI's are considered overlapping.

Due to very small changes in the optical and electronic systems the image of even a fixed dust particle stuck on a lens will move around by a few pixels from frame to frame. "Overlap ROIs Pixel Offset Limit" allows the AI algorithm to identify a dust particle stuck to the lens even if its image moves around a little from frame to frame. An "Overlap ROIs pixel offset" value of 1 means EXACT overlap.

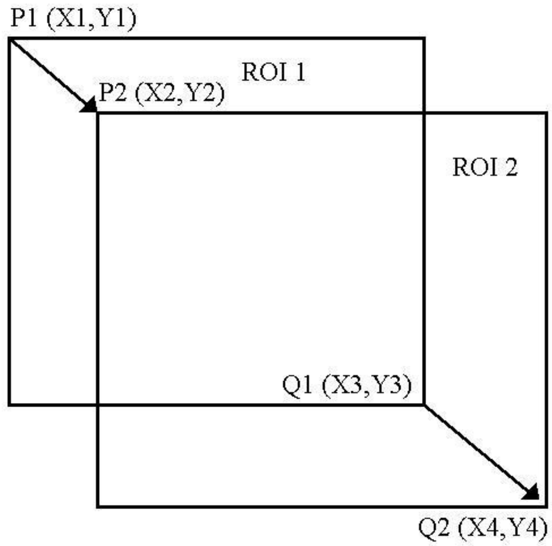


Figure 5.3.4. Calculation of Overlap ROIs Pixel Offsets.

Max Consecutive Frames Checked: Number of frames that must have overlapping particles to execute new background.

Overlapped ROI count limit: Need more than this value to execute background. Leave at 0 to remove all stuck images.

5.3.5 Laser Pulse Width Control

The imaging laser energy incident on the CPI's digital camera sensor is proportional to the image mean, or how light the exposed image appears. If the energy is too low, then the exposure is too dark to see particles; too high and saturation nets the same effect. Users can set this incident energy by changing the imaging laser current setting and the imaging laser pulse width setting. It is standard practice with the CPI to set the imaging laser current to its maximum (4095 counts), then adjust the pulse width to achieve an optimum image. A new AI control does the same thing, changing the imaging laser pulse width to maintain an optimal image mean.

The upper half of the form shown in **Figure 5.3.3** controls this new AI feature.

To turn off the imaging laser level control algorithm so that the real time software lets the user maintain control, leave the Enable Mean Error Event checkbox unchecked.

Even if the checkbox is left unchecked, the background minimum and maximum values, for acceptable background image means, is entered in this form and must be set correctly.

Under user control the image mean min and max, set in the “Settings/Advanced Control and Settings” window (see **Section 5.2.3.2**), defined the acceptable range of the background mean. However, under AI algorithm control the background mean’s range must also be entered in the form shown in **Figure 5.3.3**, and the background mean’s range should be tighter than the image mean’s range. In other words, the Minimum Mean in the AI form (**Figure 5.3.3)** should be larger than the minimum image mean in the “Advanced Control and Settings” Window. Also the Maximum Mean in the AI form (**Figure 5.3.3)** should be smaller than the maximum image mean in the “Advanced Control and Settings Window”. A good starting point for the AI algorithm settings is: Minimum Mean = 130 and Maximum Mean = 150.

Pulse Width Update Step: how many counts to adjust the laser pulse width setting. “100” is a good value here.

Maximum ROIs in Diff image: If there are more than this number of ROI’s detected in an image, then the background algorithm will not use the current frame for image mean calculation. “2” is a good value to use.

Max ROI size in Diff image: If any ROI in the image is over this number of pixels, the image is rejected for background. A value of “10” will work OK here.

Max time between images: If frames get thrown out, the time between the first and last accepted frame for performing ROI subtraction must be less than this number in milliseconds. “700” is a good value here.

All these values are set in the form shown in **Figure 5.3.3.**

6.0 PROCEDURES

6.1 Pylon Cover Removal

The CPI sensor head pylon cover must be removed to gain access to the internal sensor head. This step is necessary if the internal sensor head is to be completely removed from the pylon, or to perform electronics troubleshooting of the internal sensor head while in the pylon. The photographs show the sensor head lying flat on a table. The pylon should always be placed on a soft material, such as foam, to avoid scratching the outer surface. This procedure can also be followed when the sensor head is mounted on an aircraft.

The pylon internal pressure is monitored in the Housekeeping data. If the internal pressure drops during flight, a leak in the pylon cover's seal is indicated. If the instrument was being flown in a wet environment when the pressure dropped, the pylon cover should be removed after the flight. The internal sensor should be inspected for moisture. If moisture is found, allow the pylon internal sensor to dry out before putting the pylon cover back on. **The AR coatings on the optical block windows are sensitive to high humidity environments. Do not allow moisture to reside in the closed pylon, it will damage the AR coatings.**

Warning! The CPI pylon is a high performance assembly that serves as a protective housing for the internal sensor head components and as the structural interface to the aircraft. It is hermetically sealed up to approximately 65,000 ft altitude. O-rings and precision-machined surfaces are used to achieve this seal. **Improper disassembly/assembly of the pylon or mishandling of the components can result in damage that will compromise the pressure integrity of the pylon. This may result in malfunctioning of the instrument during flight. Disassembly/Assembly of the pylon should only be performed by personnel who have read and become familiar with this procedure.**

1. Verify CPI sensor head power is turned off.

2. **Figure 6.1.1** shows the primary external components of the pylon assembly; the pylon body, pylon cover, and nose cone

3. The nose cone is fastened to the pylon using 4X - #6-32 socket head cap screws (SHCS) (**Figure 6.1.2**).

4. In order to remove the pylon cover, it is first necessary to remove the nose cone. Using a 7/64" ball driver or hex wrench, remove the four screws mounting the nose cone to the pylon (**Figure 6.1.3**).

5. Do not twist the nose cone during removal. After the four screws are completely loose, remove the nose cone from the pylon by pulling away from the pylon. Do not twist the nose cone as you pull. This procedure is shown in **Figure 6.1.4**. Put the nose cone in a safe place, taking care not to damage any sharp edges. The nose cone contains two de-ice slug heaters, a temperature sensor,

and connector (**Figure 6.1.5**). Dowel pins are used to properly align the connector to mate correctly.

6. Torx plus fasteners are used to fasten the pylon lid to the pylon body. This type of fastener uses a special type of drive to minimize stripping of the drive head over repeated use. Special T15 Torx Plus drivers (**Figure 6.1.6**) are necessary to work on the pylon. These drivers have been provided with the CPI.

7. 21X - #8-32 Torx plus fasteners are used to fasten the pylon cover to the pylon body. 19 of the fasteners are ¾" long while 2 of the fasteners are only ½" long (**Figure 6.1.7**). The locations of the ½" fasteners are important during reassembly of the pylon cover.

8. Using the Torx plus driver, gradually loosen all the pylon fasteners approximately ¼ to ½ turn, saving the center fastener for last (**Figure 6.1.8**). This will gradually decrease the compression on the O-ring, and uniformly decrease the stress on the pylon cover. Once all the fasteners have been initially loosened, proceed to remove them until all 21 fasteners are removed. Place the fasteners in a safe place, as they will be reused during reassembly.

9. Two pry points are located on the pylon cover to facilitate removal (**Figure 6.1.9**). The pylon cover mates onto the pylon body with a tongue and groove design.

10. Verify that all 21 fasteners have been removed form the pylon cover. Insert a small flat-blade screwdriver into one of the pry grooves (**Figure 6.1.10**), and gradually pry upward on the pylon cover. Take care not to damage the tongue or O-ring on the pylon cover. Very little force should be required to lift the tongue on the pylon cover from the groove on the pylon body.

11. After the cover has been freed from groove, grasp the cover with two hands as shown in **Figure 6.1.11**.

12. Lift the cover directly upward to until it clears the internal sensor head assembly (**Figure 6.1.12**).

13. Place the cover in a safe location such as a soft foam surface (**Figure 6.1.13**).

14. **Figures 6.1.14** and **6.1.15** show the parts of the pylon cover and pylon body that mate together. Inspect the O-rings for wear that may occur over time. If the O-rings appear damaged, they should be replaced.

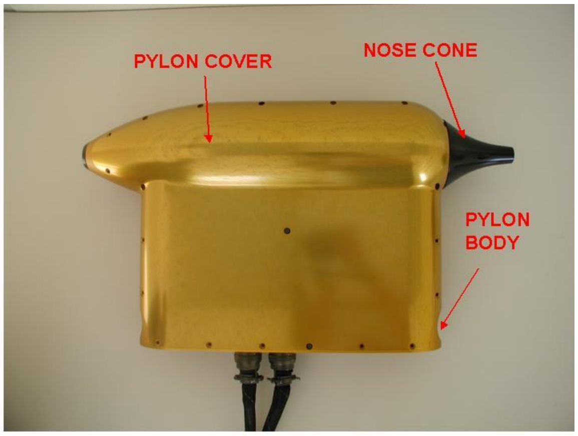


Figure 6.1.1.

Figure 6.1.2.

Figure 6.1.3.

Figure 6.1.4.

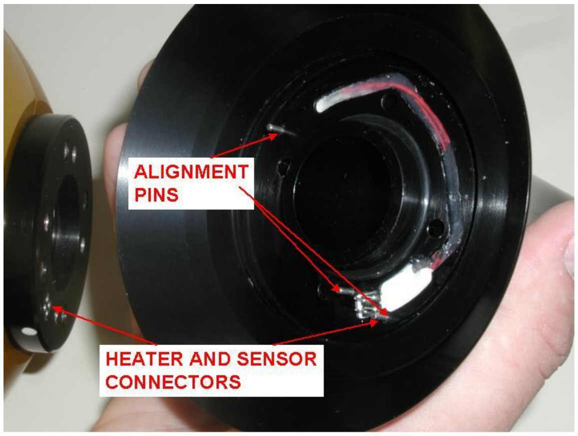


Figure 6.1.5.

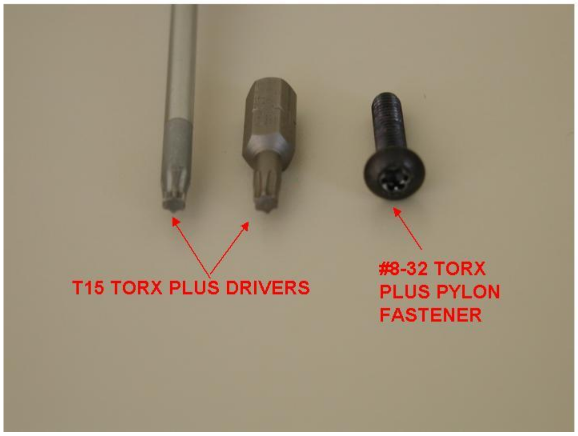


Figure 6.1.6.

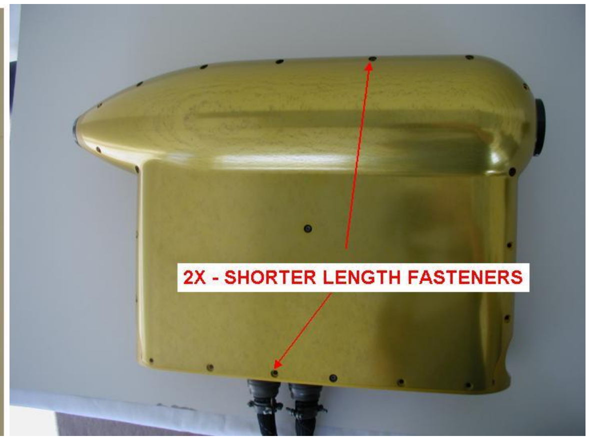


Figure 6.1.7.

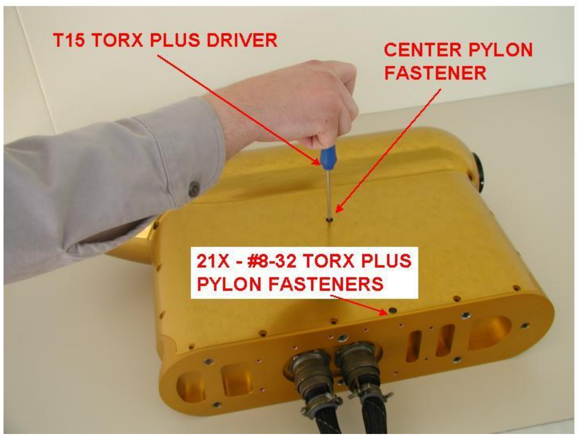


Figure 6.1.8.

Figure 6.1.9.

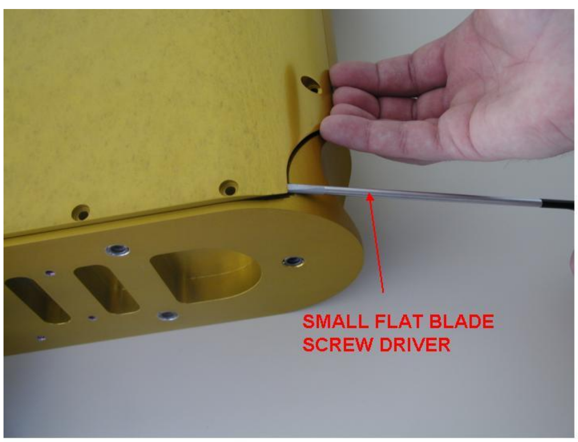


Figure 6.1.10.

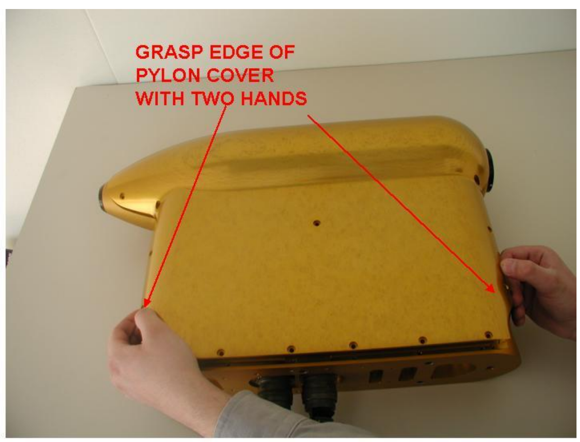


Figure 6.1.11.

Figure 6.1.12.

Figure 6.1.13.

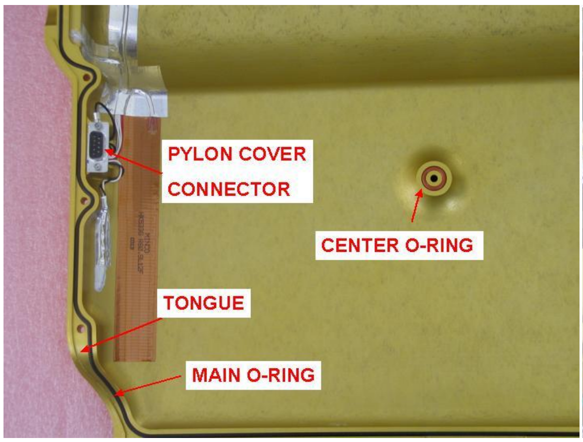


Figure 6.1.14.

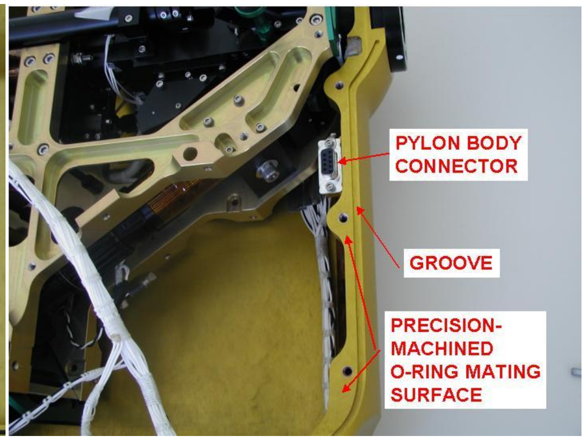


Figure 6.1.15.

6.2 CPI DSP Control Board Access When Internal Sensor Head Is Mounted in the Pylon

The following steps describe how to access the DSP control board (also called printed circuit board (PCB)) for troubleshooting when the instrument in mounted in the pylon. The ability to access the PCB in the pylon can be particularly useful when the instrument is mounted to an aircraft, as it does not require removal of the entire internal sensor head.

1. Before rotating the PCB, verify CPI power is switched off.

2. Using a 5/32" ball driver of hex wrench, loosen the PCB retaining screw that holds the PCB retaining clip (**Figure 6.2.1**).

3. Rotate the PCB retaining screw away from the PCB (**Figure 6.2.2**).

4. Before accessing the PCB to perform any troubleshooting, make sure proper precautions to avoid electrostatic discharge (ESD) are followed (**Figure 6.2.3**).

5. Rotate the PCB outward to gain access for troubleshooting (**Figure 6.2.4**).

6. When the PCB is in a stable position, sensor head power can be switched on.

7. When troubleshooting is complete, turn off sensor head power. Rotate the PCB back into position verifying the PCB aligns with the machined slots in the instrument frame located at the rear of the PCB mounting location (**Figure 6.2.5**).

8. Rotate the retaining clip back into position and tighten the clip retaining screw.

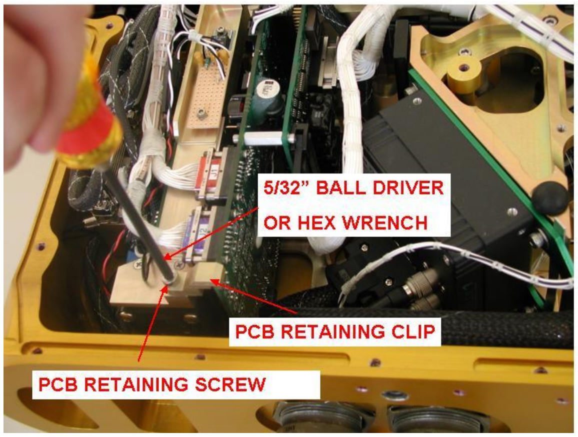


Figure 6.2.1

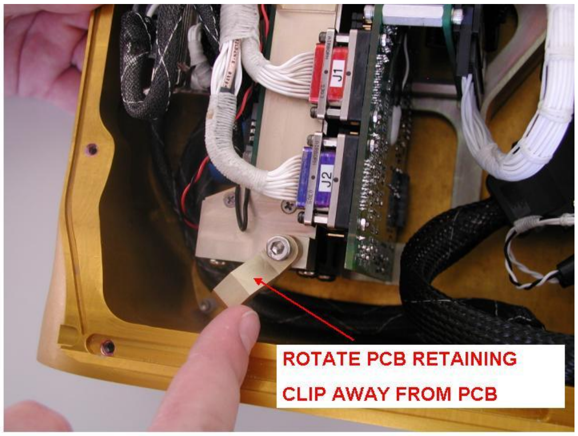


Figure 6.2.2

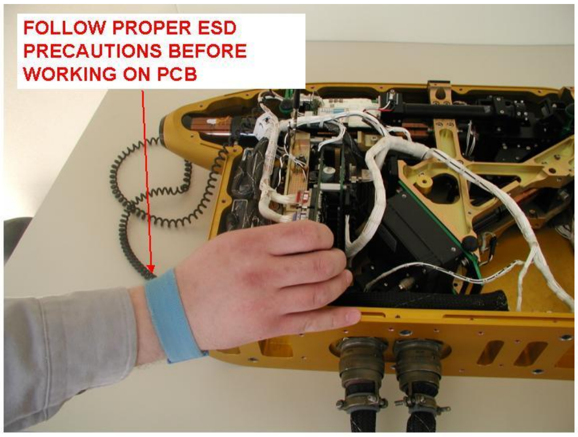


Figure 6.2.3

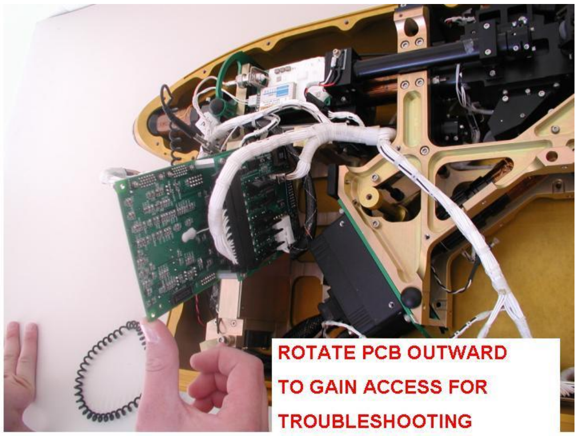


Figure 6.2.4

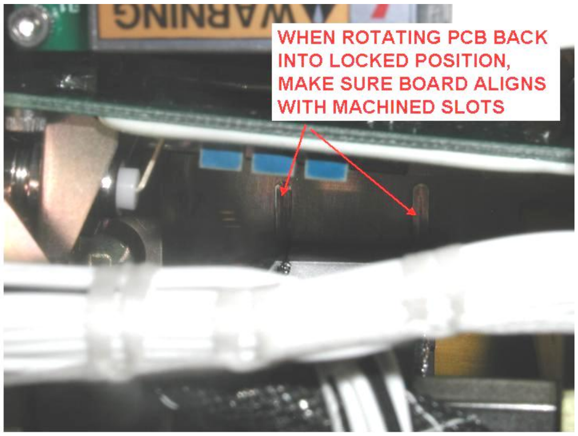


Figure 6.2.5

6.3 CPI Internal Sensor Removal

The CPI internal sensor must be removed from the pylon to perform various optical adjustments that cannot be performed in the pylon, or to perform troubleshooting that cannot be accomplished with the internal sensor mounted in the pylon. If the CPI is mounted to an aircraft, removal of the internal sensor head does not require removal of the pylon from the aircraft. The photographs show the sensor head lying flat on a table, but the same procedure is followed if it is mounted on an aircraft. The pylon should always be placed on a soft material, such as foam, to avoid scratching the outer surface.

Warning! The CPI internal sensor head is a high performance assembly that consists of many optical components, electro-optics assemblies, and ESD sensitive electronics. The pylon serves as a protective housing for the internal sensor head. When the internal sensor head is removed from the pylon, the optics are no longer protected from contamination. The internal sensor head should be worked on in a dust free, ESD protected environment after removal. **Removal of the internal sensor from the pylon should only be performed by personnel who have read and become familiar with this procedure. If this procedure is not followed correctly, the optical alignment of the CPI may be compromised or damage to components of the CPI may result.**

1. Verify CPI sensor head power and computer power are turned off.

2. Verify the pylon cover removal procedure has been followed correctly.

3. Verify the PCB retaining clip is locking the PCB into place (see Pylon Cover Removal Procedure).

4. **Figure 6.3.1** shows the primary mount points for the internal sensor in the pylon, with the internal sensor removed for clarity. In the installed position, the internal sensor is mounted to two O-rings on the inlet adapter, two O-rings on the aft sample tube, and a robber grommet on the pylon

spreader. The O-rings and grommet serve to vibration isolate the internal sensor from the pylon, as it is free to float a small amount on these points. The O-rings also serve as a hermetic seal between the sample tube and internal pylon.

5. **Figure 6.3.2** shows the general location of the connectors that need to be de-mated.

6. De-mate both base and full cables from the camera (**Figure 6.3.3**).

7. De-mate the J23S-internal pylon connector from the connectors captive to the pylon. (**Figure 6.3.4**). If the pylon is connected to the data system (as is the case when installed on an aircraft), make sure that both the base and full cables are removed before J20S, J21S, or J22S.

8. Using a small flat-blade screwdriver, loosen the screws for connector J20S-AC power and J21S-DC power (**Figure 6.3.5**). These screws are captive to the connectors. Using the 3/32" ball driver, remove the screws and lock washers for connector J22S-DSP data.

9. De-mate connectors J20S, J21S, and J22S from each of their mating connectors captive to the pylon. Verify that five connectors have been completely de-mated at this point.

10. 2X - #8-32 Torx plus fasteners are used to lock the aft sample tube into the correct position (**Figure 6.3.7**). Using the T15 Torx plus driver, remove the two fasteners for the aft sample tube (**Figure 6.3 8**).

11. The CPI pulling fork tool is required to assist in the internal sensor removal. **Figure 6.3.9** shows the CPI pulling fork tool and the pry points on the aft sample tube and pylon.

12. Study **Figure 6.3.9** thru **Figure 6.3.22** before proceeding any further.

13. Slide the slots in the pulling fork over the aft sample tube pry bosses and the pylon pry bosses (**Figure 6.3.10**).

14. Gradually pull back on the pulling fork in the direction shown in **Figure 6.3.11** to begin removal of the aft sample tube. As the aft sample tube begins to slide, the internal sensor head will also begin to slide off the inlet adapter and pylon spreader. Assist the sliding of the internal sensor by pulling on the green handle (**Figure 6.3.11**) with your available hand in the same direction as you are pulling with the fork. If the pylon is not mounted on an aircraft, have another person steady the pylon if it begins to move.

15. **Figure 6.3.12** shows the direction the components will begin to move.

16. **Figure 6.3.13** shows the aft sample tube O-rings that will be exposed as the aft sample tube slides back.

17. **Figure 6.3.14** shows the inlet adapter O-ring that will be exposed as the internal sensor slides back.

18. **Figure 6.3.15** shows the gap that will develop between the internal sensor and pylon spreader grommet as the internal sensor slides back.

19. Continue pulling back on the CPI pulling fork until the maximum pulling point is reached (**Figure 6.3.11**). Both O-rings on the inboard end of the aft sample tube should be almost completely exposed by this time (**Figure 6.3.16**). By hand, slide the aft sample tube into the farthest back position shown in **Figure 6.3.16**.

20. **Figure 6.3.17** shows the PDS 45 laser and Delrin laser guard on the internal sensor. The Delrin laser guard protects the PDS 45 laser from colliding with the pylon screw boss. If the PDS 45 laser collides with the pylon screw boss, damage to the laser can occur.

21. **S**tudy **Figures 6.3.18** through **Figure 6.3.22** before proceeding further.

22. Place your hands in the position shown in **Figure 6.3.18**, with the left hand on the green handle, and the right hand as shown. Continue to slide the internal sensor in the direction shown in **Figure 6.3.18**.

23. Eventually the internal sensor will be completely freed from the pylon spreader grommet (**Figure 6.3.19**) and the inlet adapter (**Figure 6.3.20**).

24. As shown in **Figure 6.3.20,** rotate the bottom of the internal sensor upward, pivoting around the laser guard, and taking great care to safeguard the PDS 45 laser**.**

25. After the PDS 45 laser and pylon spreader are cleared (**Figure 6.3.21**), lift the internal sensor upward, out of the pylon.

26. Place the internal sensor on the side shown on an ESD safe surface (**Figure 6.3.22**).

27. The internal sensor should rest on the support feet (**Figure 6.3.23**) to protect sensitive components from misalignment or damage.

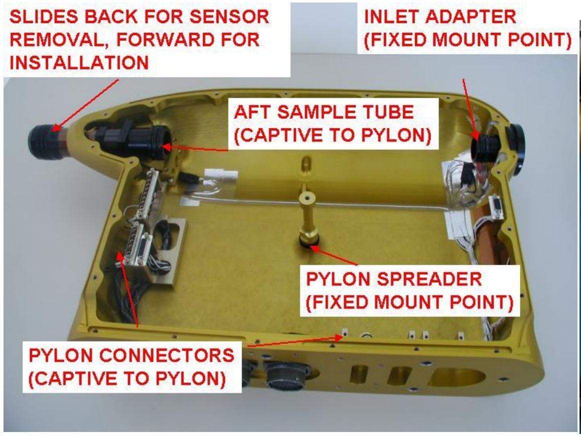


Figure 6.3.1.

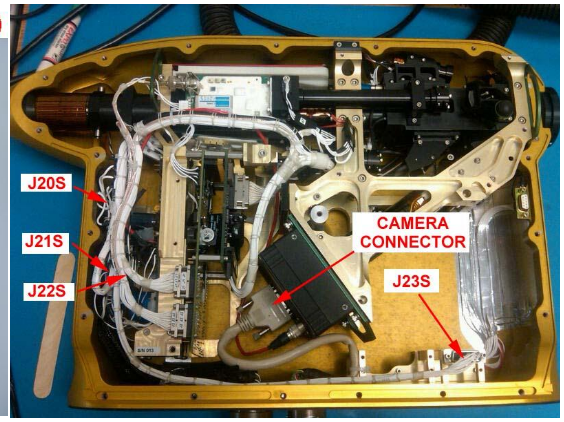


Figure 6.3.2.

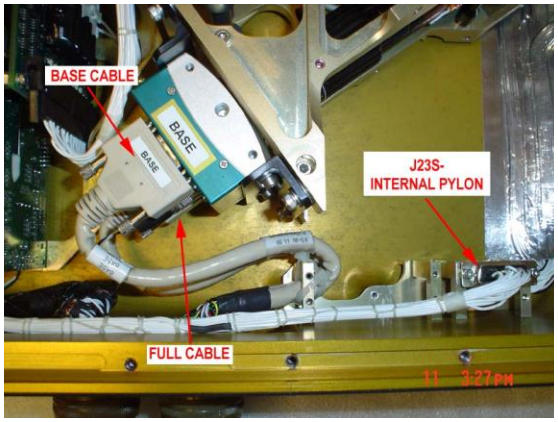


Figure 6.3.3.

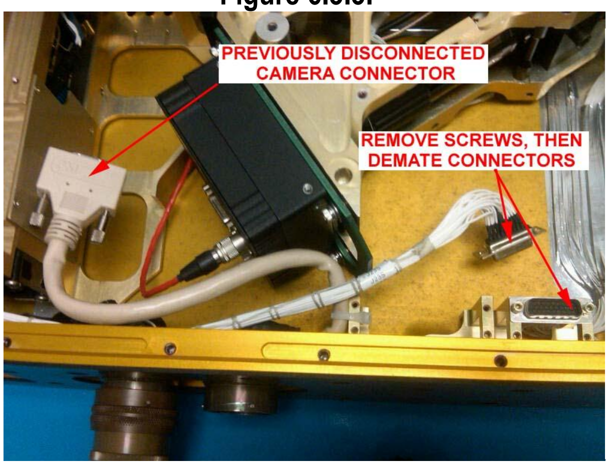


Figure 6.3.4.

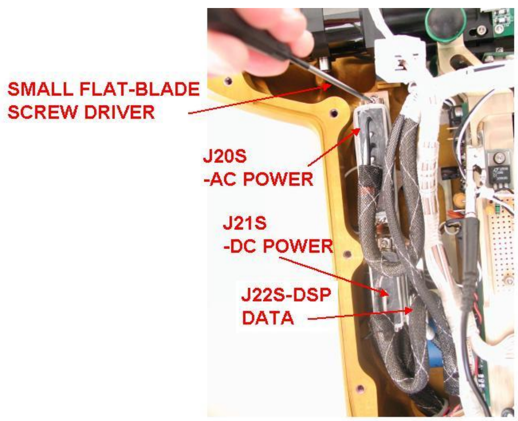


Figure 6.3.5.

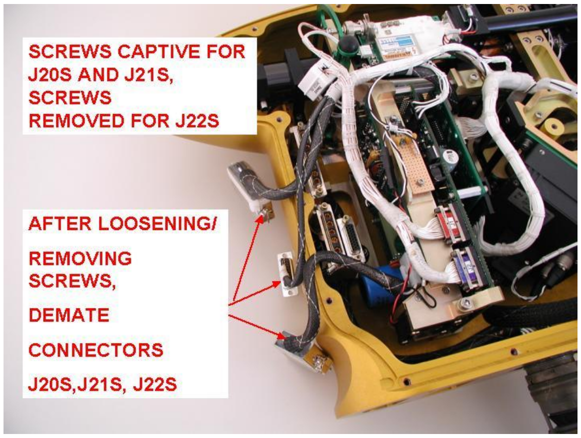


Figure 6.3.6.

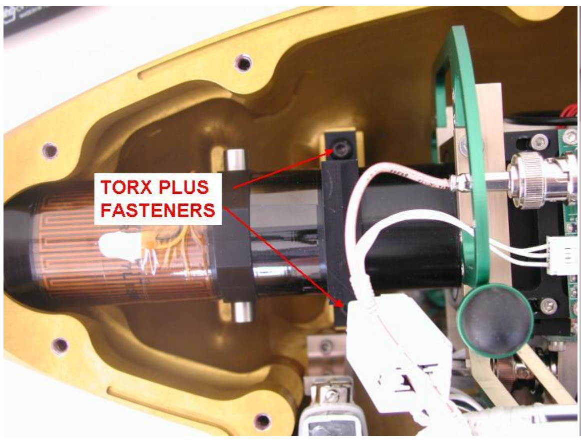


Figure 6.3.7.

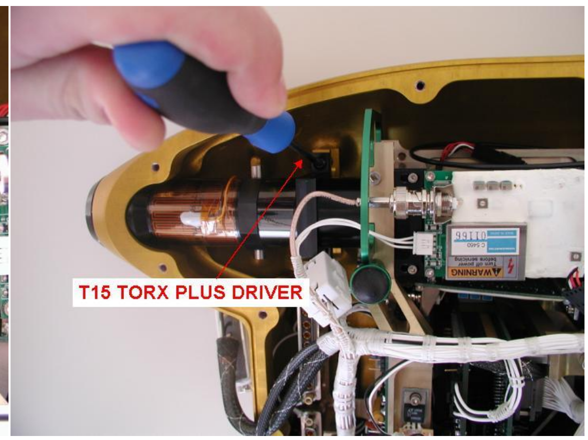


Figure 6.3.8.

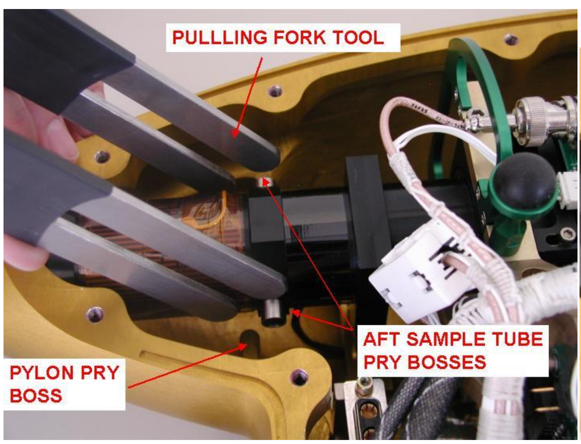


Figure 6.3.9.

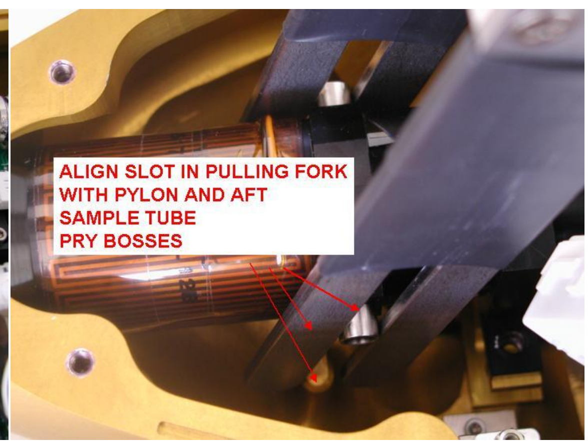


Figure 6.3.10.

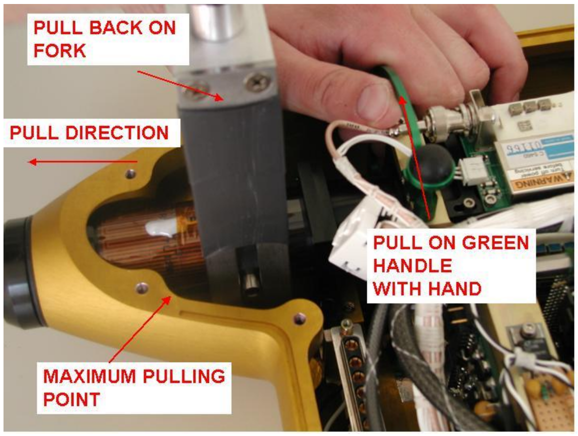


Figure 6.3.11.

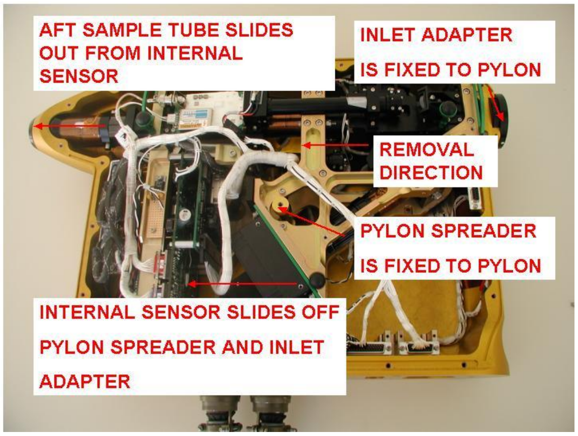


Figure 6.3.12.

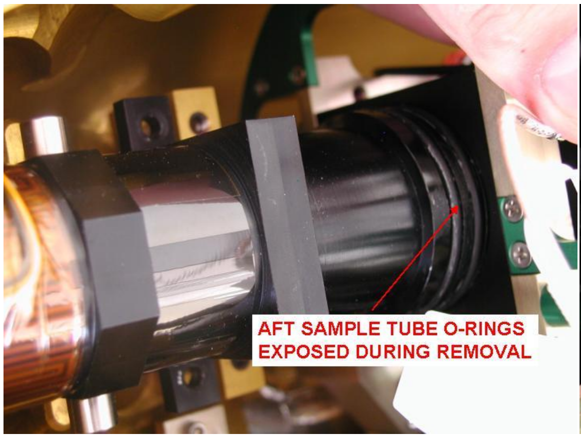


Figure 6.3.13.

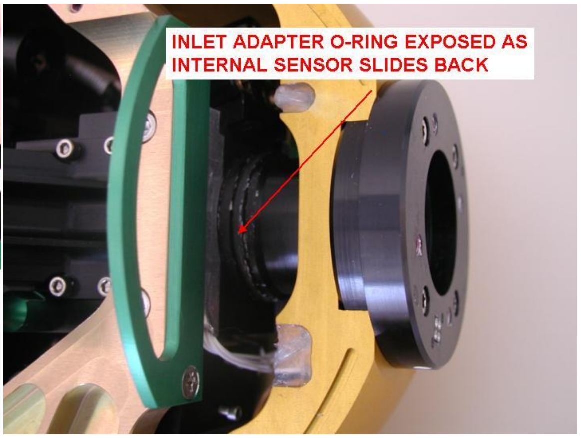


Figure 6.3.14.

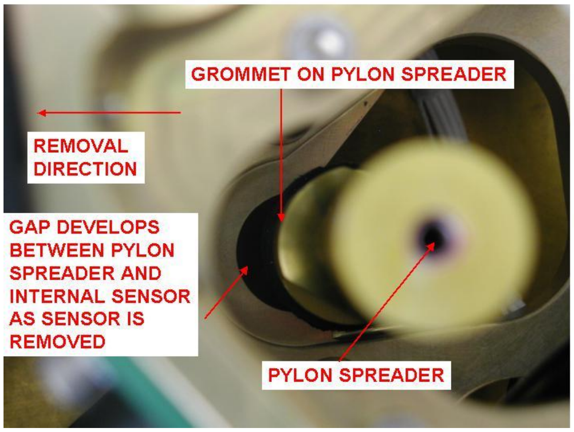


Figure 6.3.15.

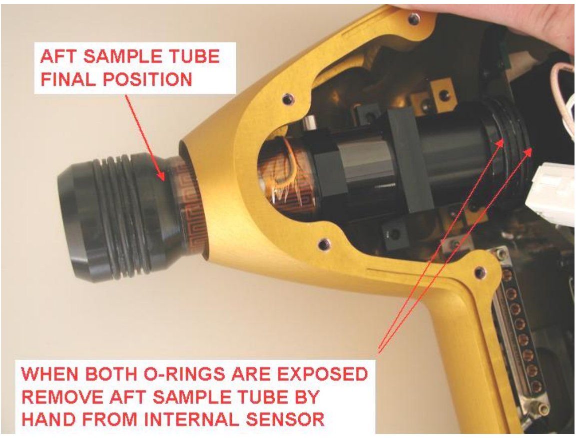


Figure 6.3.16.

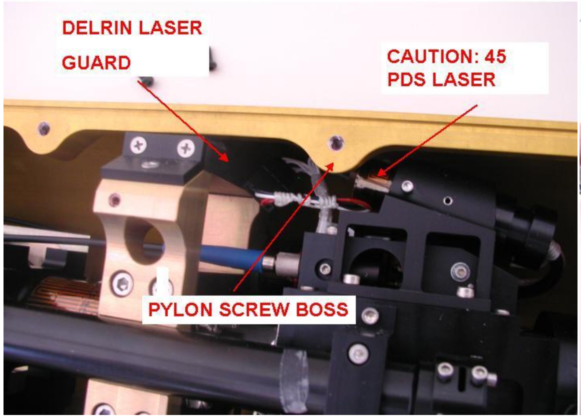


Figure 6.3.17.

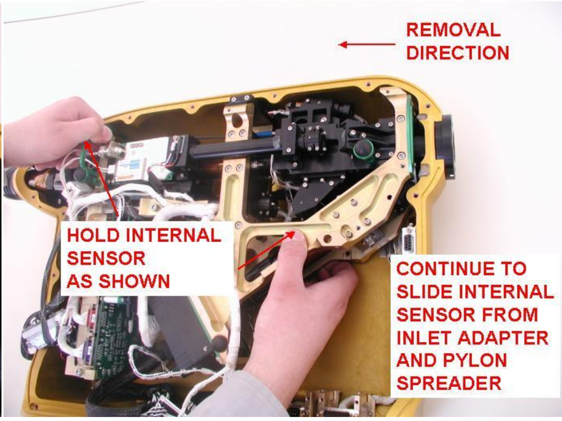


Figure 6.3.18.

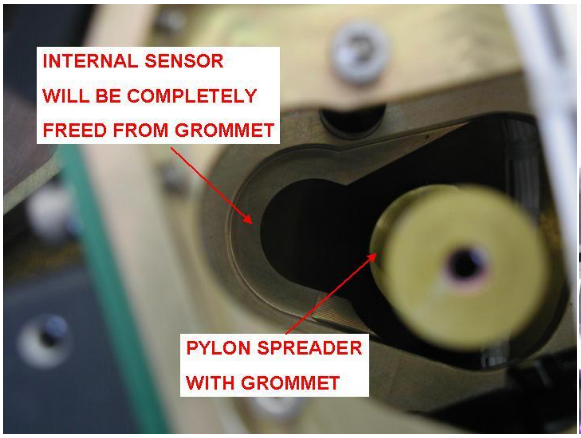


Figure 6.3.19.

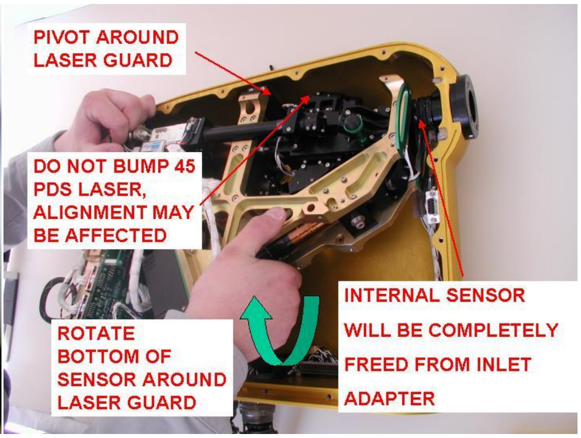


Figure 6.3.20.

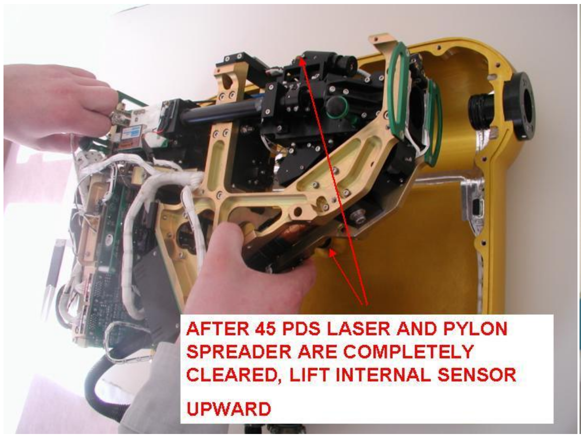


Figure 6.3.21.

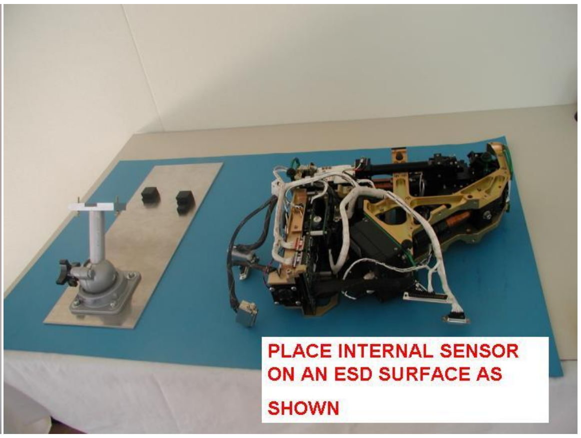


Figure 6.3.22.

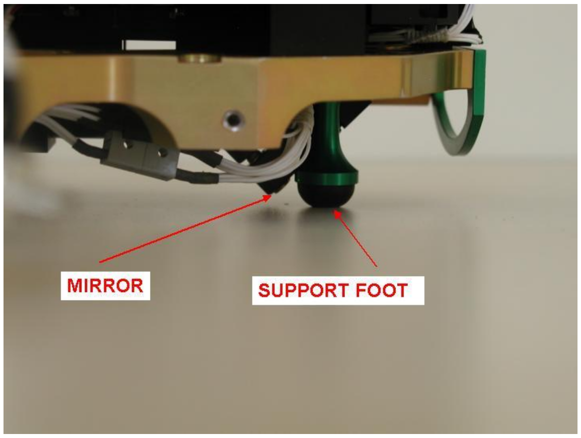


Figure 6.3.23.

6.4 CPI Internal Sensor-Running On Test Stand

The CPI internal sensor should be mounted to the test stand when it is operated in the laboratory out of the pylon. This procedure describes how to mount the internal sensor to the test stand and connect the test cables. Proper ESD precautions should be taken while connecting the test cables and operating the instrument.

Warning! The CPI internal sensor head is a high performance assembly that consists of many optical components, electro-optics assemblies, and ESD sensitive electronics. The pylon serves as a protective housing for the internal sensor head. When the internal sensor head is removed from the pylon, the optics are no longer protected from contamination. The internal sensor head should be worked on in a dust free, ESD protected environment after removal. **Installation of the internal sensor onto the test stand should only be performed by personnel who have read and become familiar with this procedure.**

1. **Figure 6.4.1** shows the CPI test stand and the internal sensor on an ESD safe surface. The green handles shown in **Figure 6.4.1** should be used to handle the internal sensor.

2. **Figure 6.4.2** shows the location of alignment sensitive optical components. Care should be taken not to bump or disturb these components when working with the internal sensor removed from the pylon.

3. Using the green handles, position the internal sensor mount points above the test stand mounting plate (**Figure 6.4.3**).

4. While holding onto the green handles on the internal sensor, screw one of the mount screws into the internal sensor mount point only a few threads (**Figure 6.4.4**).

5. While holding onto the green handles on the internal sensor, screw the opposite mounting screw into the internal sensor mount point only a few threads (**Figure 6.4.5**). When both screws have been started, alternate turning them until they are tight and the mount plate is completely flush with the internal sensor.

6. After the mount screws have been completely tightened, verify the universal joint screw is completely tight (**Figure 6.4.6**).

7. Verify that sensor power and computer power are off.

8. **Figure 6.4.7** shows the connectors for the sensor end of the test cables. Connect the opposite ends of the test cables to the data acquisition system as described in the CPI connection procedure.

9. Using a clamp, strain relieve the test cables to the table to avoid any stress on the connectors when they are mounted to the sensor head (**Figure 6.4.8**).
10. Mate the J21S-DC power connectors (**Figure 6.4.9**).

11. Mate the J20S-AC power connectors (**Figure 6.4.10**).

12. Mate the J22S-DSP data connectors (**Figure 6.4.11**).

13. Mate the camera data connector (**Figure 6.4.12**).

14. Verify all cables have been mated and are strain relieved to the table (**Figure 6.4.13**).

15. The internal sensor is now ready to be operated in the laboratory.

16. To remove the internal sensor from the test stand, verify that sensor and computer power are off and follow the above procedure in reverse.

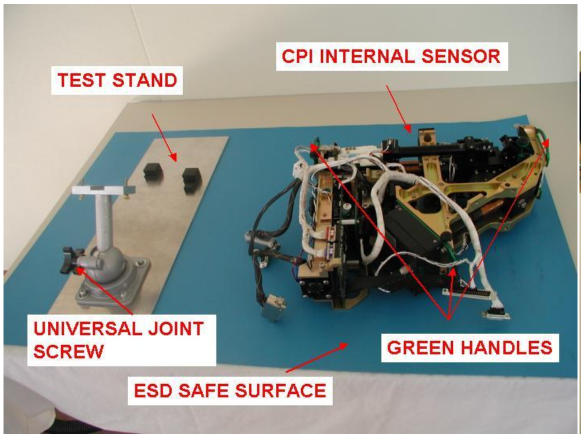
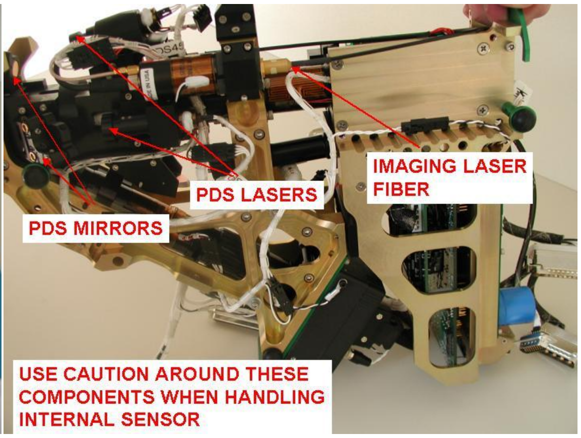


Figure 6.4.1.



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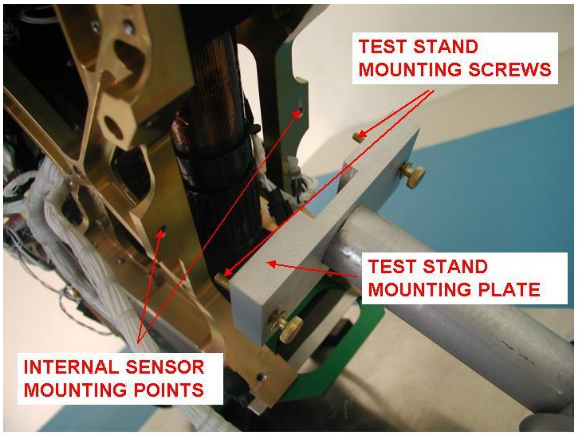

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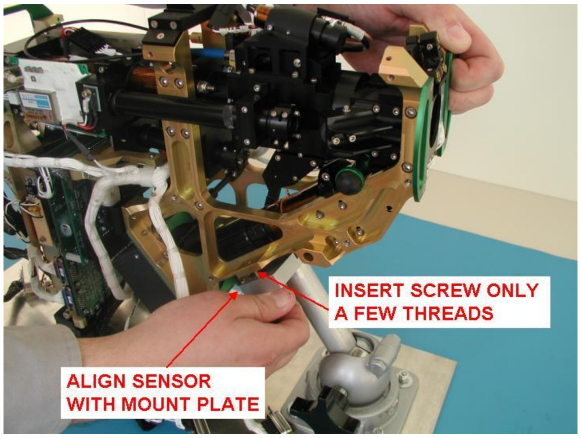
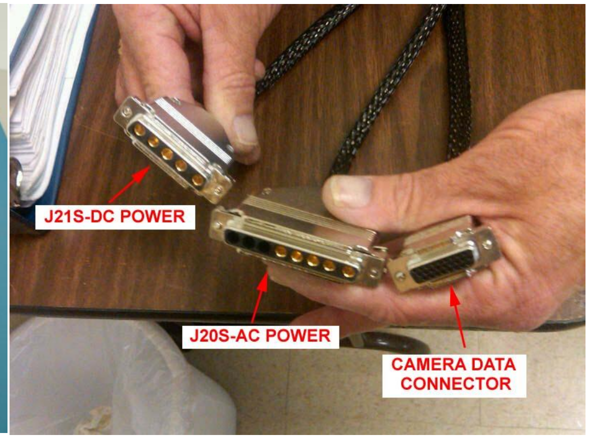


Figure 6.4.4.

Figure 6.4.5.

Figure 6.4.6.



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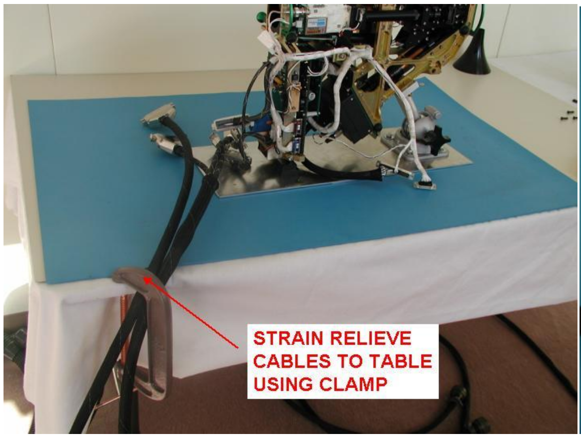

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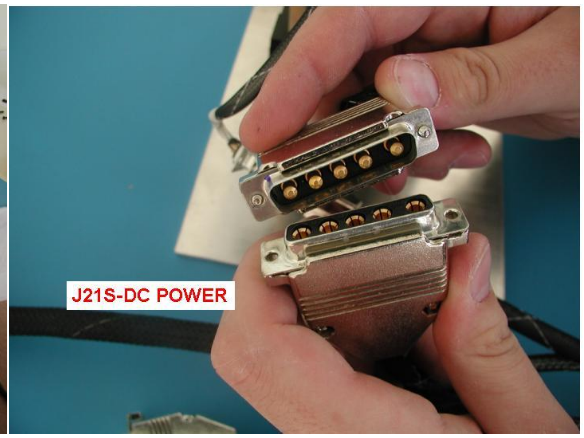
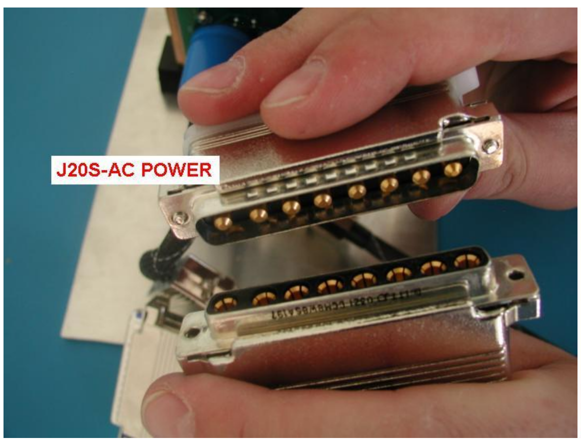


Figure 6.4.9.



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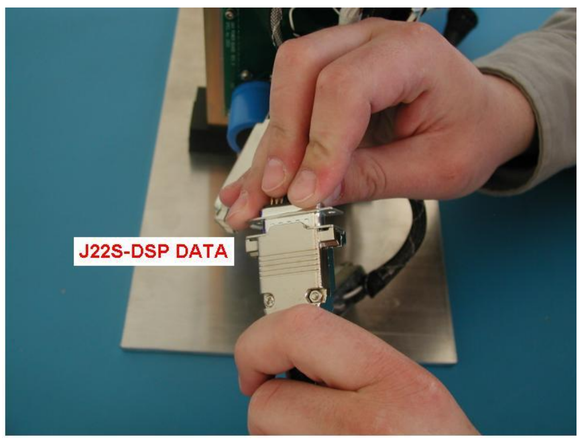


Figure 6.4.11.

Figure 6.4.12.

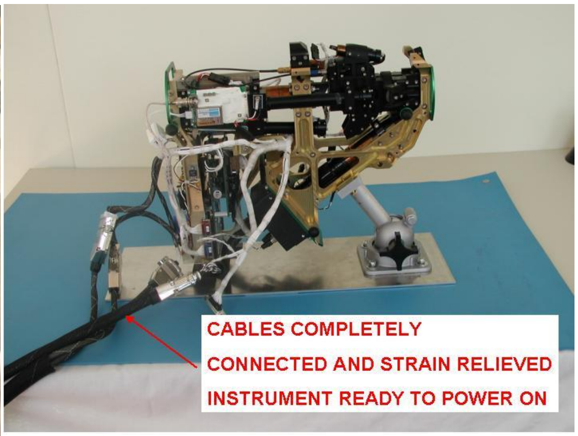


Figure 6.4.13.

6.5 CPI Internal Sensor Installation into Pylon

The CPI internal sensor must be installed into the pylon for airborne operation. The following photographs show the sensor head lying flat on a table. The same procedure is followed if the sensor head is mounted on an aircraft. When not mounted to an aircraft, the pylon should always be placed on a soft material, such as foam, to avoid scratching the outer surface.

CAUTION: *The CPI internal sensor head is a high performance assembly that consists of many optical components, electro-optics assemblies, and ESD sensitive electronics. The pylon serves as a protective housing for the internal sensor head. When the internal sensor head is removed from the pylon, the optics are no longer protected from contamination.* ***Installation of the internal sensor into the pylon should only be performed by personnel who have read and become familiar with this procedure. If this procedure is not followed correctly, the optical alignment of the CPI may be compromised or damage to components of the CPI may result.***

1. Verify CPI sensor head power and computer power are turned off.

2. Remove the internal sensor from the test stand following the correct procedure (**Figure 6.5.1**).

3. Verify the aft sample tube is in the position shown in **Figure 6.5.2**.

4. Review **Figure 6.5.3** through **Figure 6.5.10** before proceeding further.

5. Hold the internal sensor as shown in **Figure 6.5.3** and begin lowering into pylon.

6. Protect the 45 PDS laser from the pylon screw boss by using the Delrin laser guard as a bumper **(Figure 6.5.4)**.

7. Pivot the internal sensor around the laser guard and lower onto the pylon spreader as shown in **Figure 6.5.5**.

8. Align the inlet adapter with the internal sensor as shown in **Figure 6.5.6**.

9. The internal sensor must be below the grommet surface as shown in **Figure 6.5.7**.

10. **Figure 6.5.8** shows the installation direction of the internal sensor into the pylon.

11. Hold the internal sensor as shown in **Figure 6.5.9** and begin sliding onto inlet adapter and pylon spreader.

12. As the internal sensor slides on the inlet adapter and pylon spreader grommet, the gap decreases as shown in **Figure 6.5.10.**

13. When the internal sensor reaches the position approximately shown in **Figure 6.5.10**, the pulling fork tool is required to move the internal sensor into its final position.

14. Insert the aft sample tube into the internal sensor as shown in **Figure 6.5.11**. The sample tube and internal sensor may need to be lifted slightly to clear the mount base.

15. Use the CPI pulling fork to begin sliding the aft sample tube into the internal sensor. Push the fork and the internal sensor in the direction shown in **Figure 6.5.12**. If necessary, pull up slightly on the green handle to help the aft tube clear the mount base as is slides forward.

16. The internal sensor will be in its final forward position when the pylon spreader and internal sensor are fully mated (**Figure 6.5.13**).

17. Continue pushing the aft sample tube into the internal sensor with the fork until the holes in the mount base align with the aft sample tube holes (**Figure 6.5.14**).

18. Install the 2X - #8-32 torx plus fasteners and tighten with the T15 torx plus driver (**Figure 6.5.15**).

19. Check that both fasteners have been completely tightened (**Figure 6.5.16**).

20. **Figure 6.5.17** shows the first set of connectors to be mated.

21. Using a small flat-blade screws driver, fasten connectors J20S and J21S as shown in **Figure 6.5.18**. Use a 3/32” ball driver or hex wrench to fasten the mounting screws for connector J22S.

22. Mate camera connector and J23S as shown in **Figure 6.5.19**.

23. Verify all connectors have been mated and tightened (**Figure 6.5.20**).

24. Before proceeding to install the pylon cover, operate the CPI in the pylon to verify no problems occurred during the internal sensor installation.

25. After operation of the CPI has been verified, turn off the sensor power and proceed to the pylon cover installation procedure.

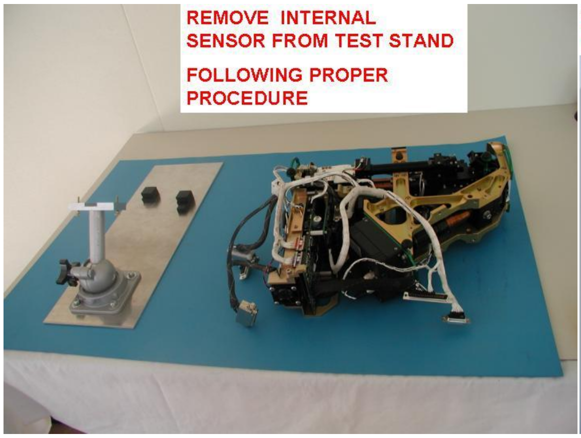


Figure 6.5.1.

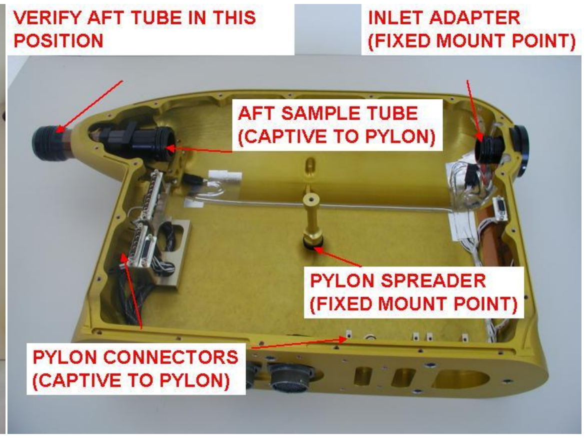


Figure 6.5.2.

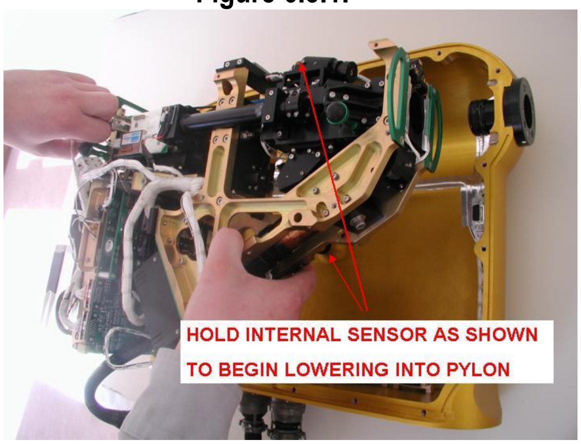


Figure 6.5.3.

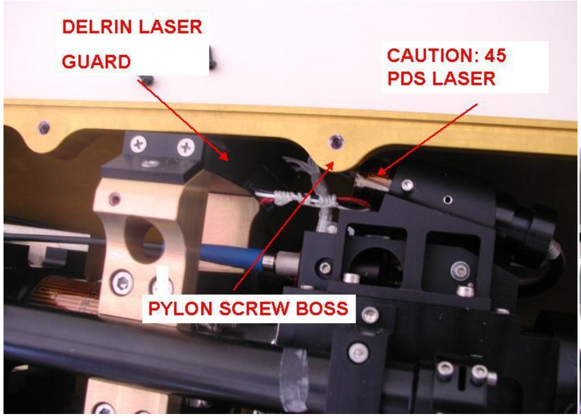


Figure 6.5.4.

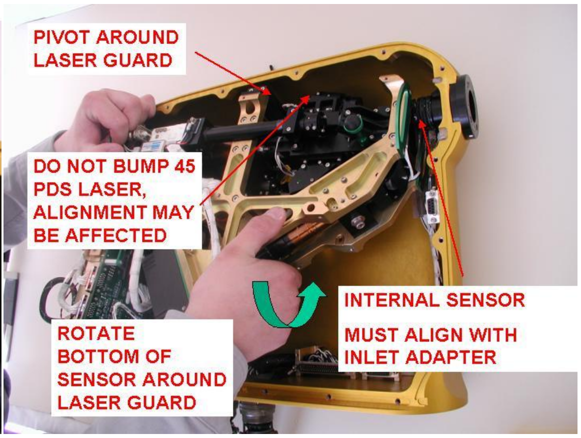


Figure 6.5.5.

Figure 6.5.6.

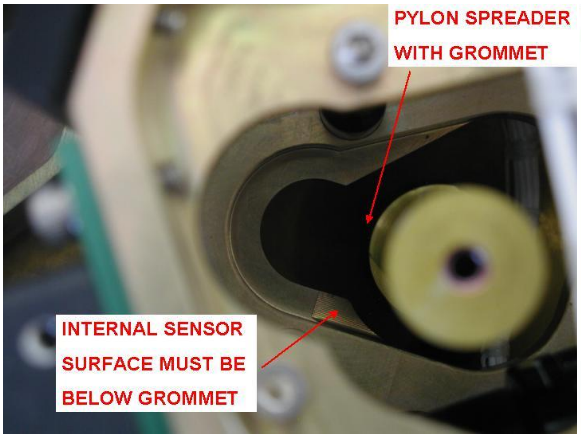
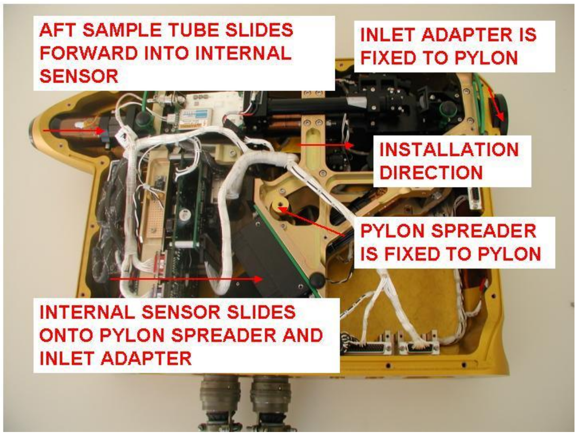


Figure 6.5.7.



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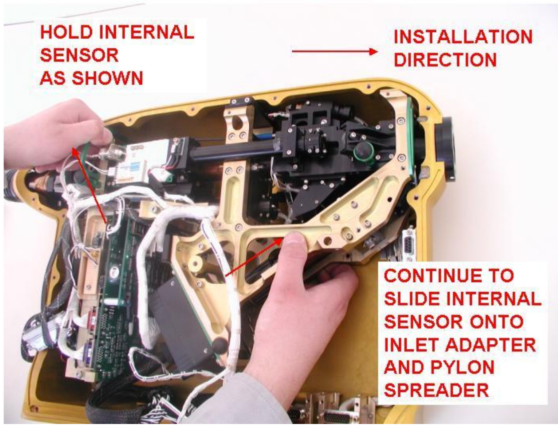
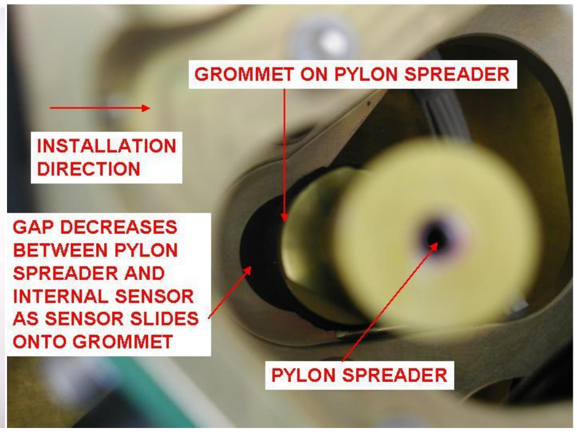


Figure 6.5.9.



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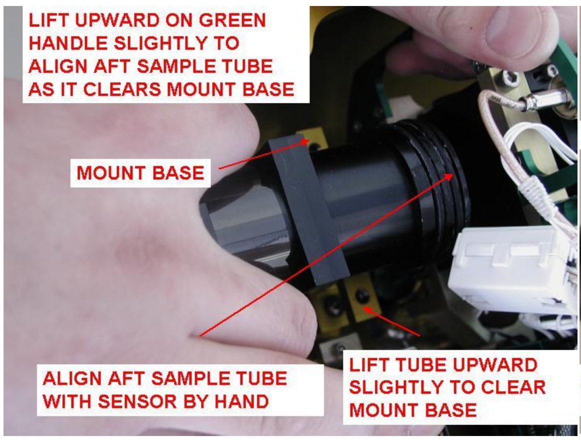

Figure 6.5.11.

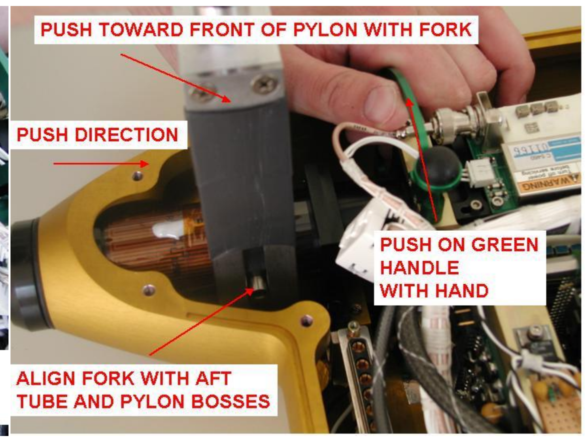

Figure 6.5.12.

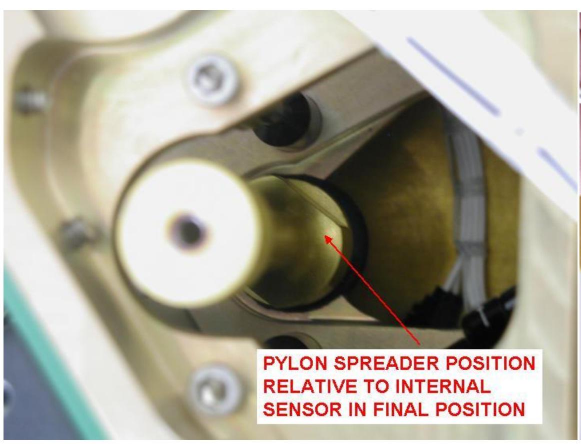

Figure 6.5.13.

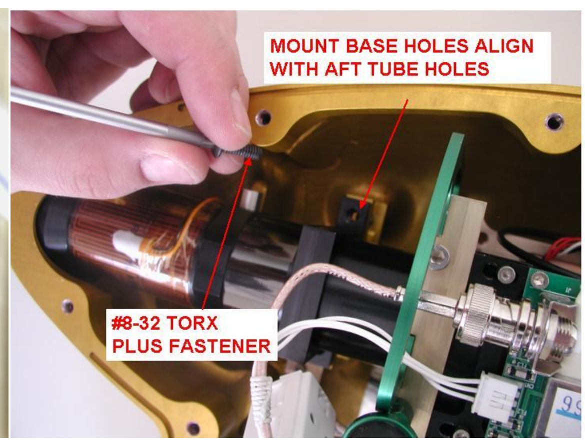

Figure 6.5.14.

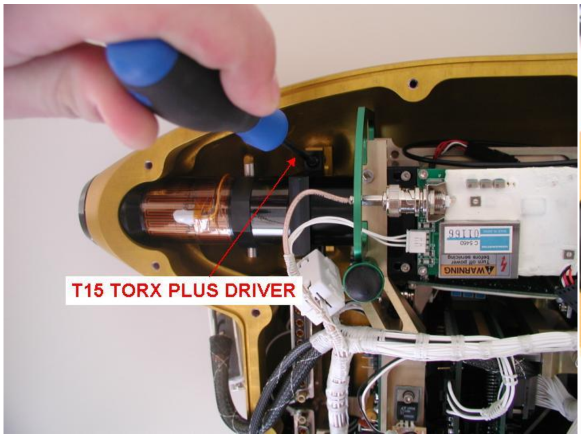

Figure 6.5.15.

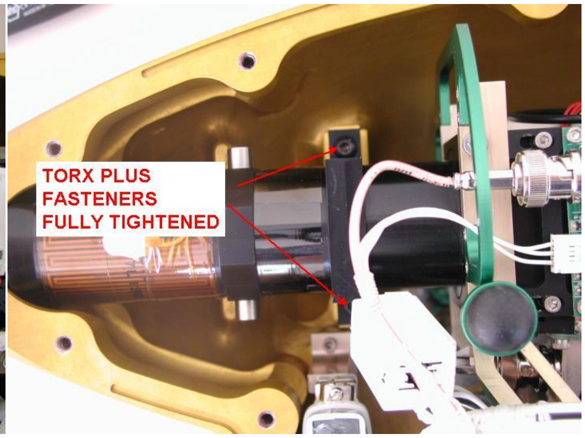

Figure 6.5.16.

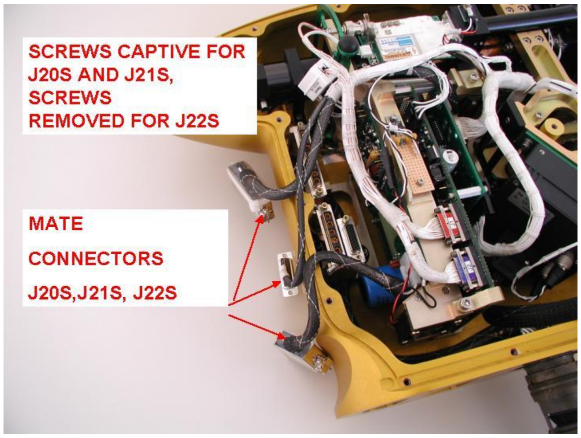

Figure 6.5.17.

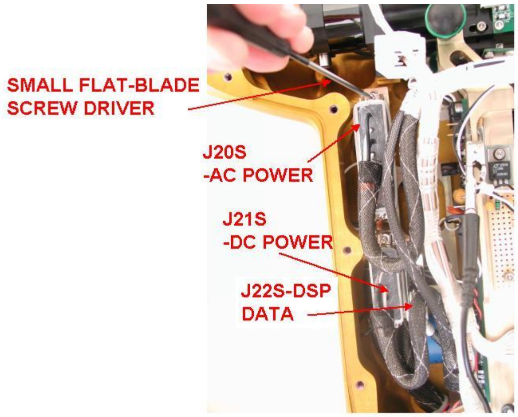

Figure 6.5.18.

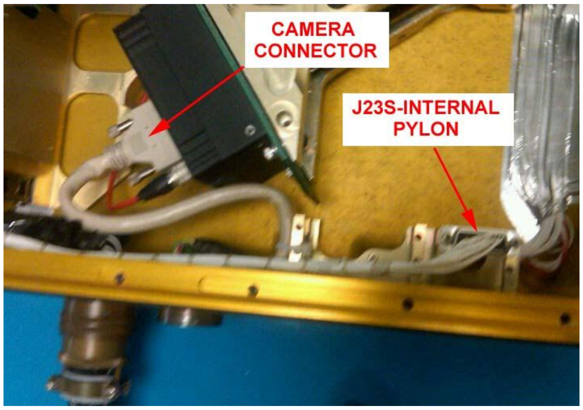

Figure 6.5.19.

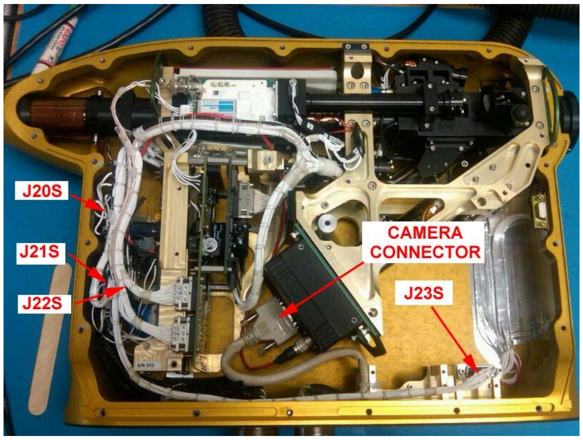

Figure 6.5.20.

6.6 Pylon Cover Installation

The CPI sensor head pylon cover must be installed for airborne operation of the CPI sensor head. The following photographs show the sensor head lying flat on a table. The pylon should always be placed on a soft material, such as foam, to avoid scratching the outer surface. The following procedure should also be used when the sensor head is mounted on an aircraft.

CAUTION: *The CPI pylon is a high performance assembly that serves as a protective housing for the internal sensor head components and as the structural interface to the aircraft. It is hermetically sealed up to approximately 65,000 ft altitude. O-rings and precision-machined surfaces are used to achieve this seal. Improper disassembly/assembly of the pylon or mishandling of the components can result in damage that will compromise the pressure integrity of the pylon. This may result in malfunctioning of the instrument during flight. Disassembly/Assembly of the pylon should only be performed by personnel who have read and become familiar with this procedure.*

1. Verify CPI sensor head power is turned off.

2. **Figure 6.6.1** shows the important areas of the pylon cover that must be aligned during installation of the pylon cover.

3. **Figure 6.6.2** shows the important areas of the pylon body that must be aligned during installation of the pylon cover.

4. Hold the pylon cover as shown in **Figure 6.6.3** and gradually lower onto the pylon body so the tongue and groove and pylon connector are aligned.

5. Gently lower the pylon cover into the position shown in **Figure 6.6.4**. If the pylon cover is not properly aligned, it will not be flush with the pylon body at this time.

6. Study **Figure 6.6.5** through **Figure 6.6.11** before proceeding further.

7. Using the T15 Torx plus driver, install the center pylon fastener, but do not tighten it down completely (**Figure 6.6.5)**. It may be necessary to push the pylon cover down by hand slightly to maintain alignment of the tongue and groove while the center fastener is being tightened.

8. 21X - #8-32 Torx plus fasteners are used to fasten the pylon cover to the pylon body (**Figure 6.6.5 and Figure 6.6.6**). 19 of the fasteners are ¾" long while 2 of the fasteners are only ½" long. The locations on the pylon cover for the shorter fasteners are marked in black below the screw head. Do not install ¾" fasteners in these two locations or the pylon will be damaged.

9. Install the remaining 20 fasteners in the proper locations. Using the T15 torx plus driver, engage all the fasteners but do not tighten completely . As the various fasteners are engaged, verify the pylon cover remains aligned to the pylon body (**Figure 6.6.6**).

10. After all the pylon fasteners have been engaged, begin the process of completely tightening each of the fasteners (**Figure 6.6.7**). The gap between the pylon cover and body will be completely closed as the cover is tightened down. Do not use excessive force on the fasteners as they may break. It will be obvious when the fasteners are completely tight because they will be much harder to turn.

11. Verify all fasteners are completely tightened. The ones initially tightened may require additional tightening after all fasteners are completely installed.

12. Prepare to install the inlet nose cone onto the pylon as shown in **Figure 6.6.8**. It is very important that the alignment pins mate correctly.

13. Align the pins and press the nose cone onto the pylon as shown in **Figure 6.6.9**. The nose cone should completely engage onto the pylon if aligned correctly.

14. 4X - #6-32 socket head cap screws are used to mount the nose cone to the pylon (**Figure 6.6.10**).

15. Install and tighten the mount screws using a 7/64" ball driver as shown in **Figure 6.6.11**. Verify the screws have been completely tightened.

16. **Figure 6.6.12** shows the completely reassembled pylon, ready for aircraft installation.

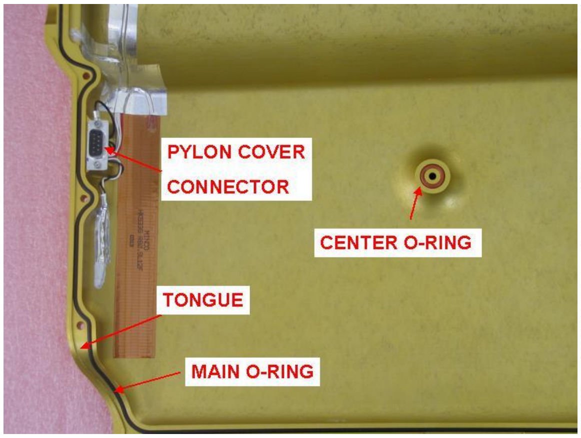

Figure 6.6.1.

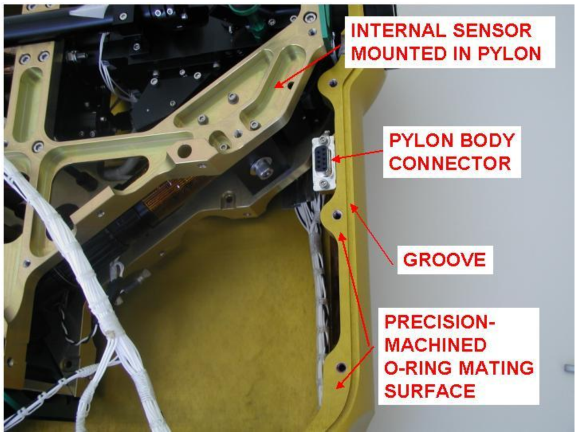

Figure 6.6.2.

Figure 6.6.3.

Figure 6.6.4.

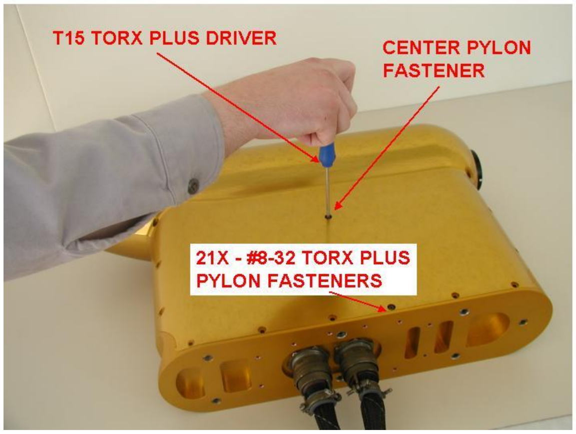

Figure 6.6.5.

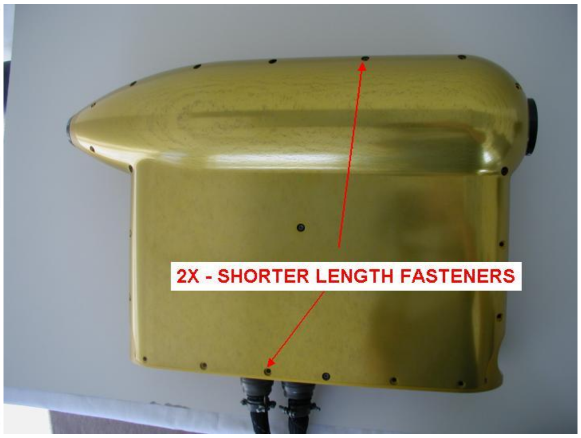

Figure 6.6.6.

Figure 6.6.7.

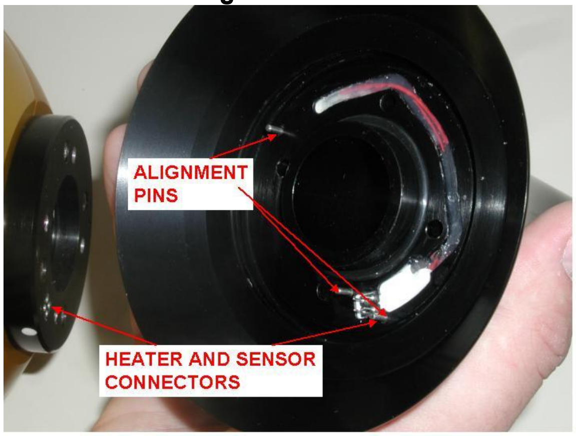

Figure 6.6.8.

Figure 6.6.9.

Figure 6.6.10.

Figure 6.6.11.

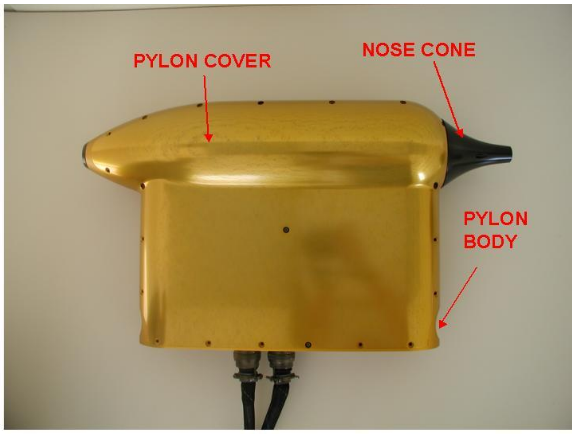

Figure 6.6.12.

6.7 Cleaning CPI Optical Windows

During normal airborne operation, the optical windows of the CPI will become contaminated due to cloud drops and streaming water. Contamination on the windows of the imaging system can result in a decreased image mean and a severely contaminated background over time. Small levels of contamination on the PDS system windows can result in an increased detector DC level (**Figure 6.7.1**) due to light scattering around the dump spot caused by the contaminants. In an extreme case, a large amount of contamination could reduce the detector DC level by blocking most of the laser light. During normal operation, the laser power levels can be gradually reduced as contamination increases to lower the PDS detector DC levels. **When the lasers are being operated at less than half power (20 mW set point), the PDS windows should be cleaned.** The following procedure describes how to properly clean the windows. **The real time software must be operated during cleaning of the windows to provide feedback that the correct result is being obtained.**

Warning! The CPI optical windows are made of sapphire and coated with a high performance anti-reflective (AR) coating. The windows are bonded into the optical block using a thermally conductive epoxy. This interface serves as a hermetic seal between the internal pylon and air flowing through the sample tube. Extreme care must be taken when working around the windows. A special, non-metallic cleaning tool has been provided with the CPI. **DO NOT INSERT SHARP METALLIC OBJECTS INTO THE SAMPLE TUBE THAT CAN SCRATCH THE COATED WINDOWS. ONCE THE AR COATING IS DAMAGED, REPLACING THE WINDOWS IS EXTREMELY LABOR INTENSIVE AND COSTLY. Cleaning of the optical windows should only be performed by personnel who have read and become familiar with this procedure using only the tools and materials described in this procedure.**

32. **Figure 6.7.1** shows the enunciator panel and settings window indicating the PDS detector DC levels are saturated. Reducing the laser power should decrease the DC levels. This is satisfactory

until the laser powers are reduced to below approximately 20 mW for the DC level to drop below 8.8 V. The windows should be cleaned at this time.

33. **Figure 6.7.2** shows the materials required to clean the windows. A can of electronics grade compressed air is also necessary to blow off particulates (not shown). Purified reagent grade methyl alcohol should be used as a cleaning agent because it does not leave streaks as it evaporates and will not damage the AR coatings. 100% pure cotton swabs and the Delrin cleaning tool provided with the CPI are also necessary. Do not use a type of cotton swab that can damage the window. Can of electronics grade compressed air (not shown).

34. Blow compressed air over each of the windows to remove any particulates that may be present on the windows. Do not tip the canned air as liquid will come out and contaminate the windows.

35. Take a cotton swab, break it in half, and insert one half into the hole at each end of the cleaning tool. Break off the back of the swab so it is nearly flush with the Delrin rod to allow for maximum clearance (**Figure 6.7.3, Figure 6.7.4, Figure 6.7.5**).

36. **Figure 6.7.6** is a drawing showing the relative location of each of the windows in the optical block.

37. Read through each of the following steps before proceeding further.

38. One complete swab will be used for each window. Using the eyedropper from the methyl alcohol, dispense one drop onto one of the half cotton swabs (**Figure 6.7.7**). The wetted swab will first be used in a back and forth motion across the window to remove the contamination. The dry half of the swab will be used to remove the residual alcohol.

39. Verify each window has been sprayed with canned air to remove particulates. Scrubbing a particulate across the AR coated window will damage the coating.

40. As shown in **Figure 6.7.8**, insert the cleaning tool with the wetted end of the swab first, clean and dry only the window you are targeting. Observe the result of the cleaning in the real time software. The cleaning tool is inserted in the direction of airflow through the probe, from the end where the nose cone mounts.

41. Each of the optical systems should be cleaned in order and each window must be specifically targeted (**Figure 6.7.9**). For the PDS systems, verify the lasers are at full power. Observing the PDS 45 detector DC level, clean and dry the input window and observe the DC level. If it slightly decreased or stayed the same, move onto the PDS 45 output window. If the DC level increased during cleaning, that window should be cleaned again until the DC level decreases or stays the same.

42. View the PDS 90 DC level and clean the windows for that optical system.

43. **Figure 6.7.10** shows the DC levels reduced to satisfactory values after cleaning.

44. Clean the imaging system windows (**Figure 6.7.9**). Before cleaning the imaging system windows, run the probe in Live Video Mode and locate any contamination visible by the CCD array. Observe the effect of the cleaning on the CCD array image, there should be fewer contaminants visible after cleaning. Also observe the image mean in real time. The image mean should increase or stay the same after cleaning. If the image mean decreases, or more contaminants are present in the CCD image, repeat the cleaning procedure.

45. Cleaning of the windows can occur when the probe is mounted to an aircraft, or in the laboratory, in or out of the pylon. The nose cone can be removed (see Pylon Cover Removal Procedure) to improve access to the optical windows**. Replace the nose cone after cleaning.**

46. The exact location of the windows depends on the orientation of the probe. This is critical for identifying which window is being cleaned. **Figure 6.7.8** and **Figure 6.7.9** show the internal sensor removed from the pylon in the laboratory with the input windows on top and the output windows on the bottom. The PDS 90 input window is on the right and the output window is on the left in these figures. If the probe is hanging upside down on an aircraft, all the positions will be flipped 180 degrees. Use **Figure 6.7.6**, **Figure 6.7.8**, and **Figure 6.7.9** as a reference to locate the windows in any situation.

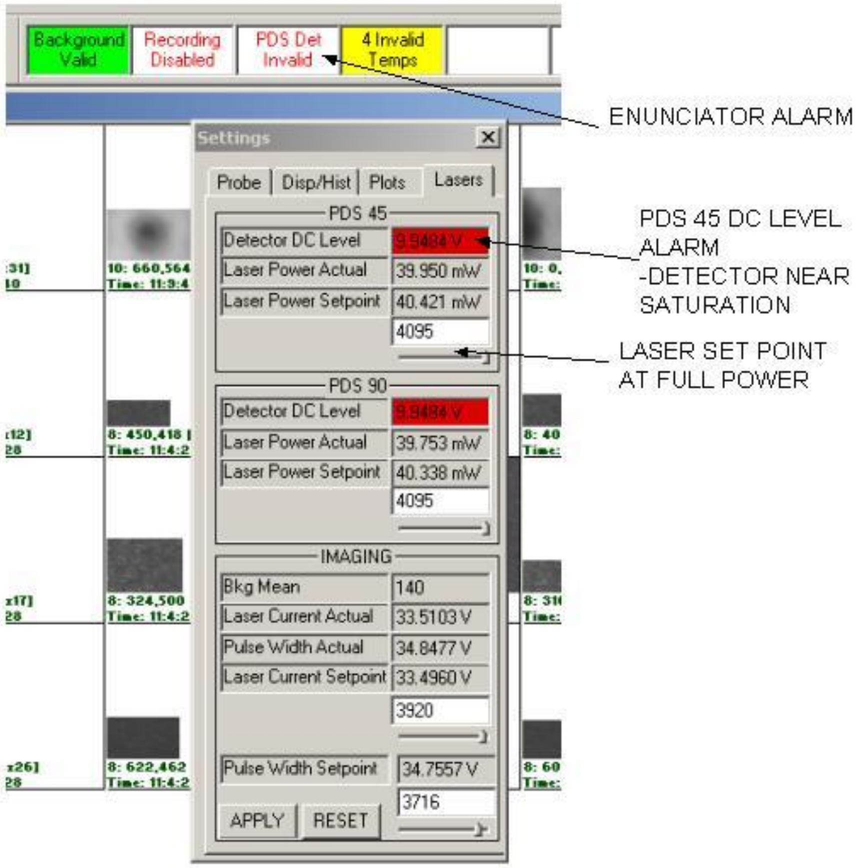

Figure 6.7.1. Enunciator panel shows "PDS Det. Invalid" and settings window showing saturated PDS DC levels.

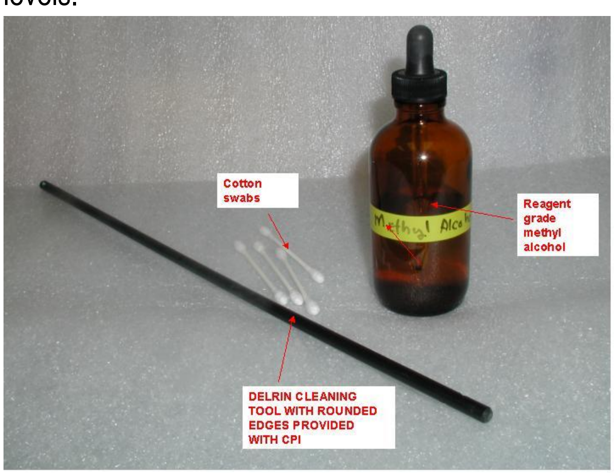

Figure 6.7.2.

Figure 6.7.3.

Figure 6.7.4.

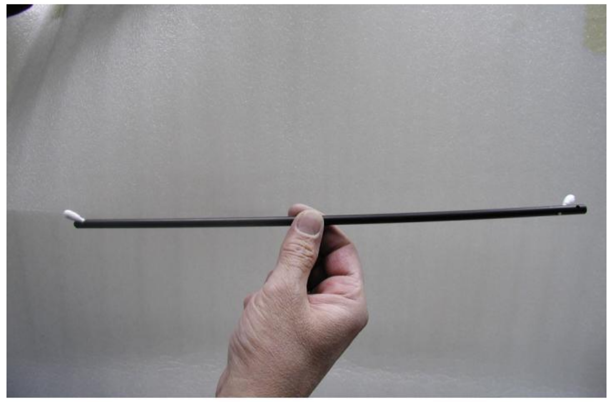

Figure 6.7.5.

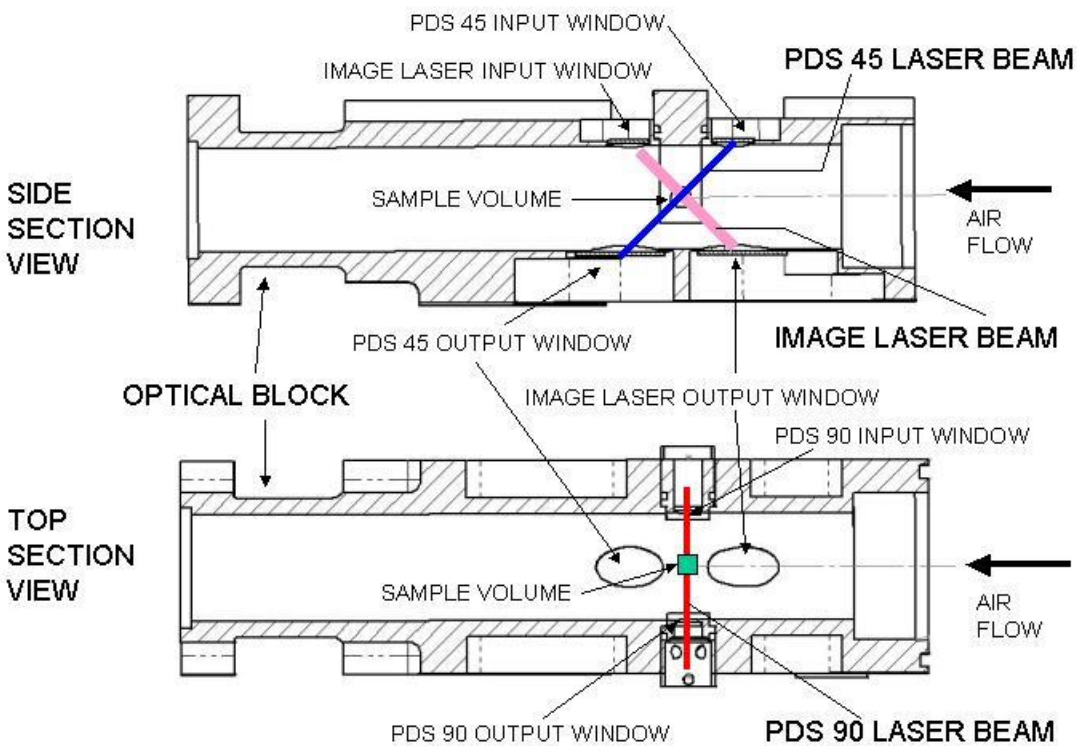

Figure 6.7.6. Cutaway of optical block showing laser beam locations and window locations.

Figure 6.7.7.

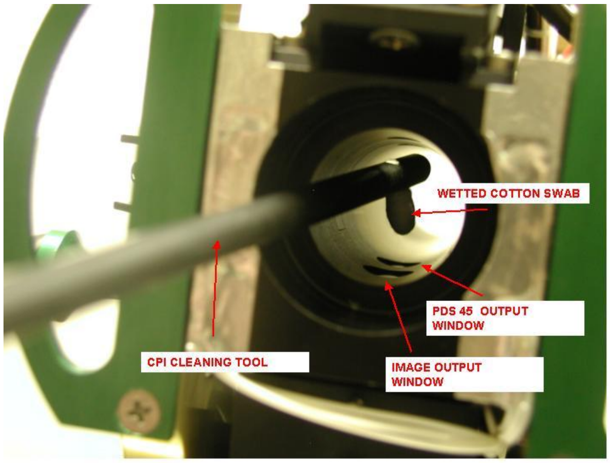

Figure 6.7.8.

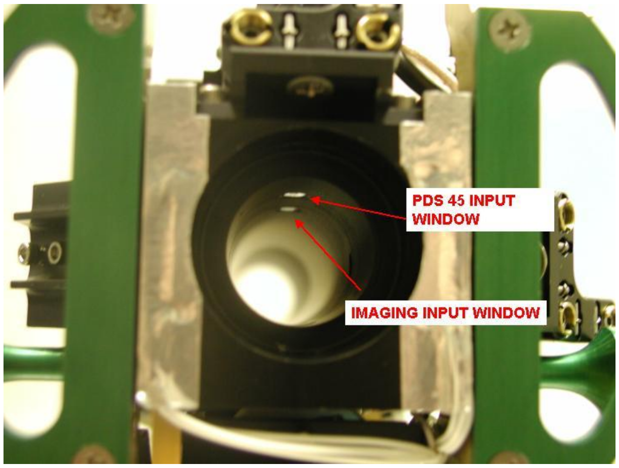

Figure 6.7.9.

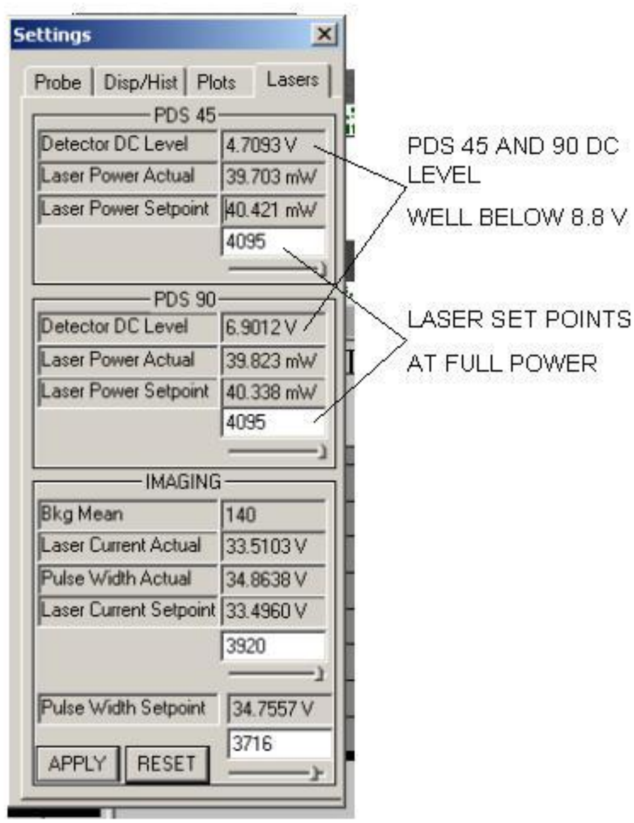

Figure 6.7.10.

6.8 CPI Imaging System Camera Alignment

The CPI imaging system camera may need to be realigned if the imaging system goes out of alignment over repeated airborne operation or it is removed from the instrument for servicing. This procedure provides a fundamental overview for aligning and focusing the imaging system camera and lens assembly.

CAUTION: The overall quality of the images recorded by the CPI depends on the camera being properly aligned and focused. The alignment procedure should only be performed by personnel who have read and become familiar with this procedure.

1. An alignment pin is included with the CPI for use in centering and aligning the imaging system (**Figure 6.8.1**).

2. **Figure 6.8.2** shows the proper way to remove the cover from the alignment pin. The pin has been machined on a lathe to come to a sharp point at an exact distance into the optical block. **Be**

careful not to damage the pin during handling and never touch the end of the pin to any surface, as it will deform.

3. The probe must be operated in Live Video Mode to perform this procedure. Live Video mode shows the full 1024 x 1024 CCD array.

4. The full 1024 x 1024 pixels will not fit on the main operators window. The horizontal dimension will fit, but the vertical will not. **Figure 6.8.3, Figure 6.8.4**, and **Figure 6.8.5** show the full horizontal dimension of the array and the vertical scroll bar at the top, bottom, and center positions. Notice that the corners of the array are clipped off by the imaging lens barrel. This is normal.

5. For this alignment procedure, the goal is to center the camera on the point of the pin, which has been manufactured to be in the center of the sample volume. The vertical scroll bar must be positioned exactly in the center, as shown in **Figure 6.8.5**.

6. Insert the alignment pin into the optical block as shown in **Figure 6.8.6**. Be careful not to bump the point of the pin. Insert the pin as far as it will go into the optical block (**Figure 6.8.7**). At full insertion, the pin will be very close to the center of the sample volume.

7. Look at Live Video and you should see the pin as shown in **Figure 6.8.8**. Notice how the scattered light from the PDS 45 laser is visible. Also notice that the pin is exactly in the center of the CCD array in this position.

8. Using a ruler on the computer monitor, locate the exact center of the CCD array and mark it with a piece of tape on the computer monitor. If the pinpoint is not at this position, adjust the image mirror tilt screws (**Figure 6.8.9**), until the pin is centered. It is first necessary to loosen the image mirror lock screw shown in **Figure 6.8.9** before adjusting the tilt screws.

9. Turn off the PDS lasers shown in **Figure 6.8.10** and the point of the pin should be exactly in focus. Slide the pin in and out of the optical block slightly to see how it looks when it goes in and out of focus.

10. If the pinpoint is not exactly in focus, as shown in **Figure 6.8.10**, at this position in the sample volume, it is necessary to adjust the focus. This is accomplished by pulling water drops through the probe and adjusting the image lens focus adjustment shown in **Figure 6.8.9**.

11. Following the procedure describing how to set up the droplet atomizer, pull particles through the probe and observe the ROI images (Live Video Mode must be turned off, PDS lasers turned on).

12. The focus adjustment barrel is locked in place with a piece of aluminum tape and a lock screw. Remove the tape and slightly loosen the lock screw with an allen wrench. The focus adjustment should be rotated (**Figure 6.8.12**) until the majority of the images are in focus as shown in **Figure 6.8.11**. Note: even for the best focus, there will always be some out of focus particles present. The goal is to maximize the number of particles in focus. As you rotate the barrel, it is apparent what constitutes an out of focus image.

13. When the focus is optimized, tighten the lock screws and replace the aluminum tape.

14. Now insert the pin back into the optical block at the full insertion depth and turn off the PDS lasers. If the pin is still in the center, but not in focus, slide the pin out of the optical block slightly until the best focus is achieved. You should not have to move the pin very much to find the best focus.

15. Most likely, the pin will now be in focus slightly off the vertical centerline. Now readjust the image mirror tilt screws to place the pin in the horizontal center of the array. The pin should still be in focus. Now tighten down the image mirror lock screw (**Figure 6.8.9**).

16. Turn the PDS lasers back on and the PDS 45 laser should end up at the end of the pin, looking very similar to **Figure 6.8.8**. By adjusting the focus while pulling drops through the probe, the focus is set to the trailing edge of the PDS beams, where the image laser is set to trigger. Adjusting the tilt of the imaging mirror, slightly relocated the center of the sample volume to optimize the focus and particle detection.

17. The alignment and focusing procedure is now complete.

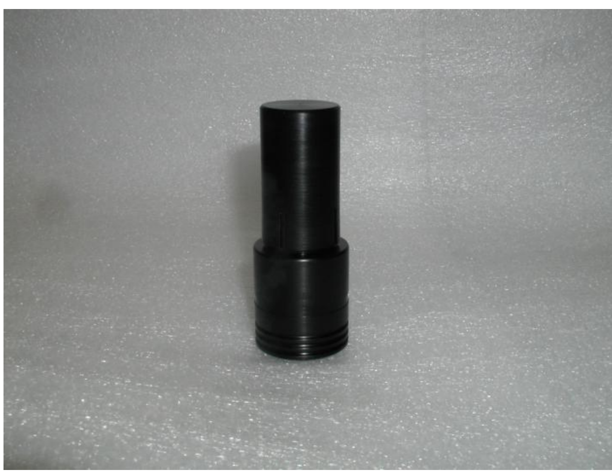

Figure 6.8.1.

Figure 6.8.2.

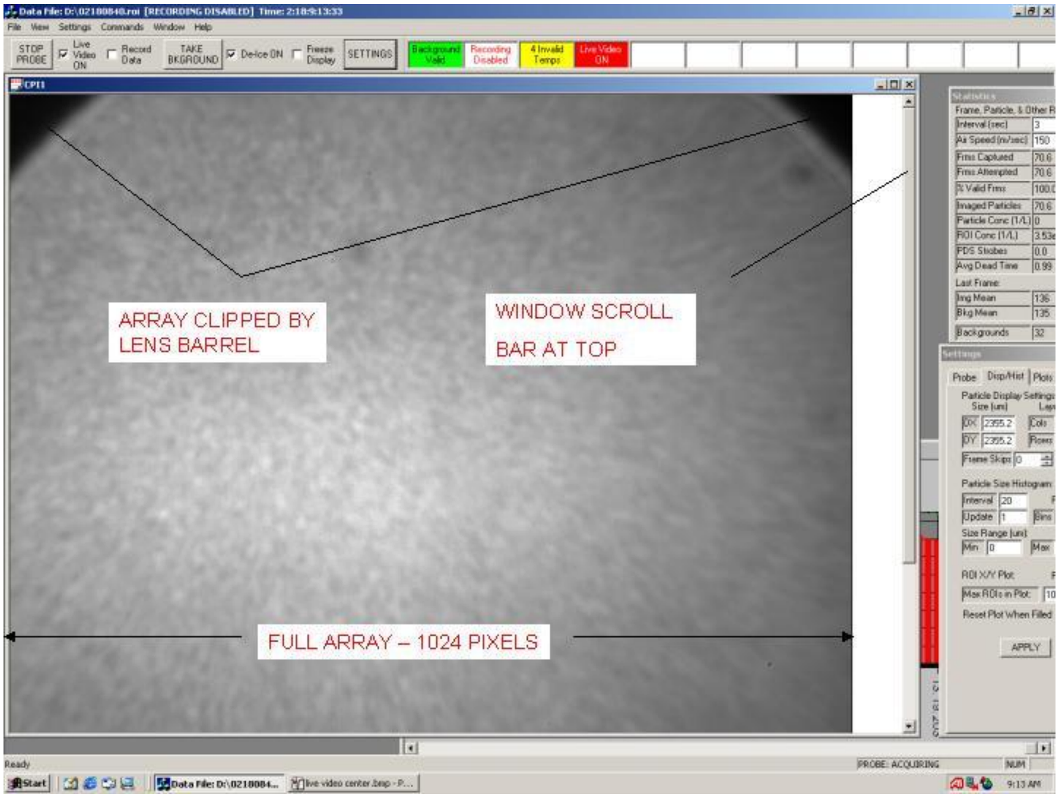

Figure 6.8.3.

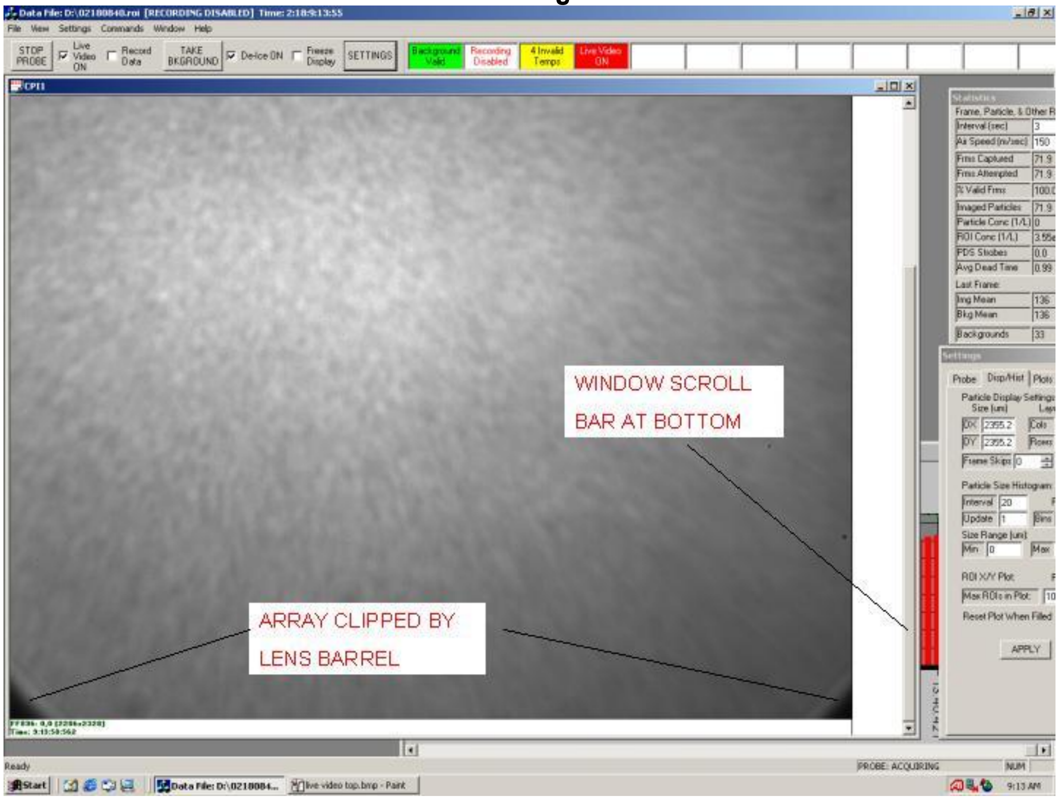

Figure 6.8.4.

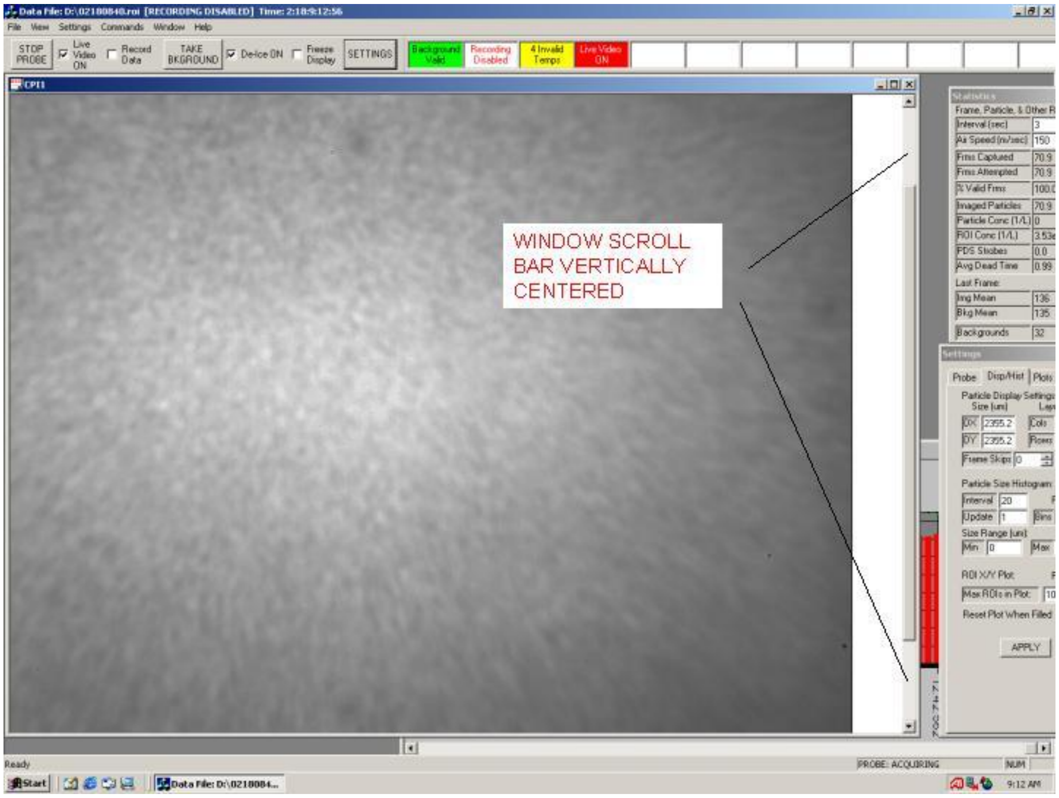

Figure 6.8.5.

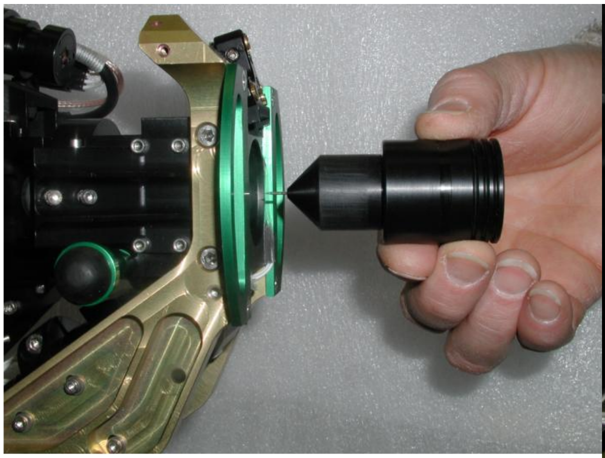

Figure 6.8.6.

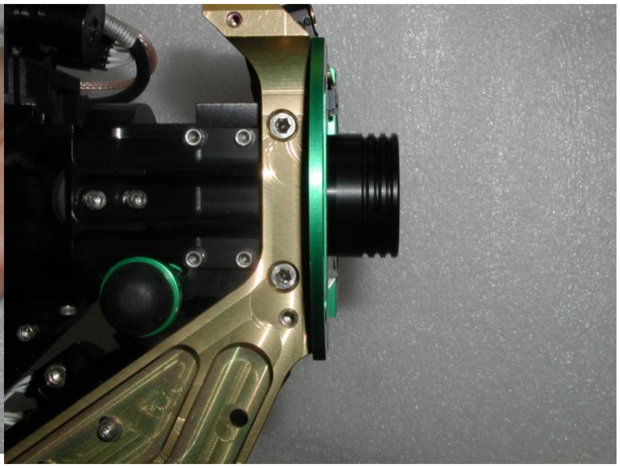

Figure 6.8.7.

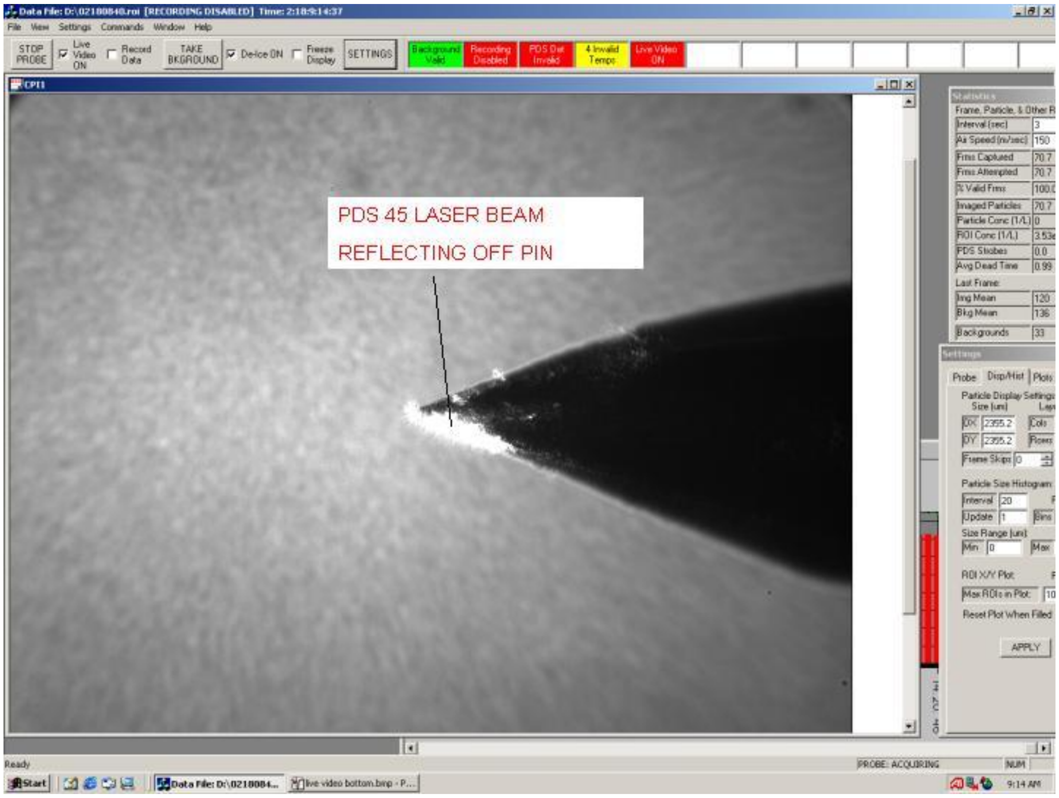

Figure 6.8.8.

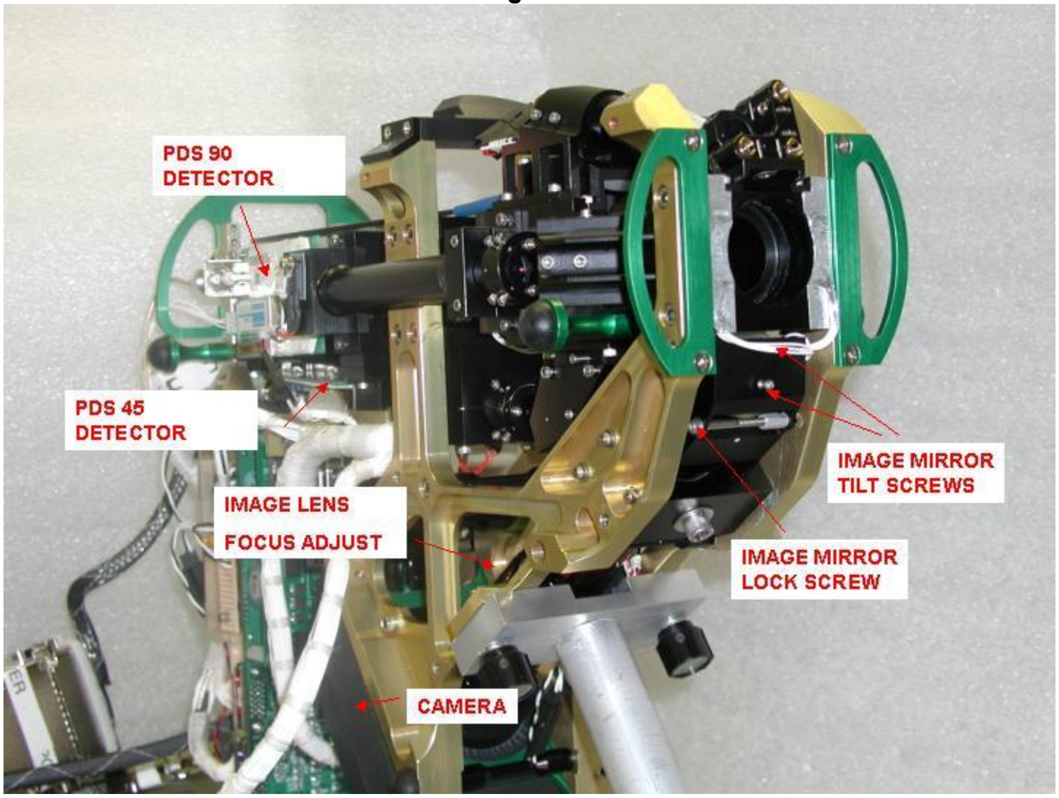

Figure 6.8.9.

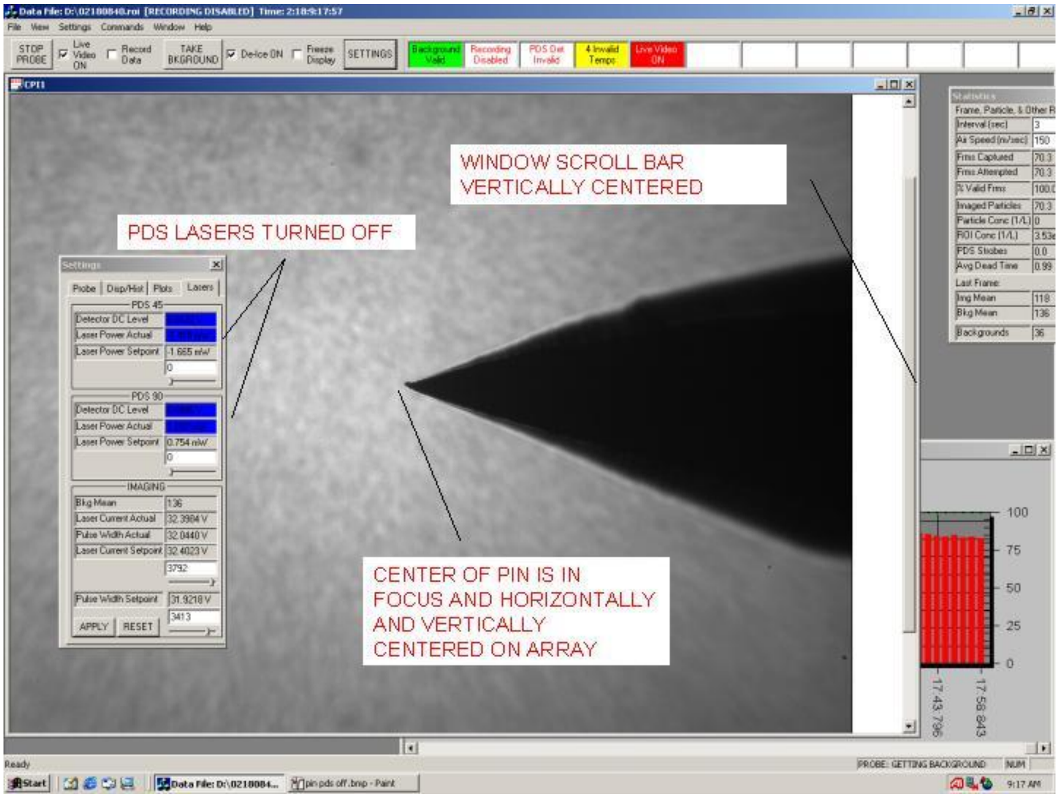
WINDOW SCROLL BAR
VERTICALLY CENTERED
PDS LASERS TURNED OFF
CENTER OF PIN IS IN
FOCUS AND HORIZONTALLY
AND VERTICALLY
CENTERED ON ARRAY

Figure 6.8.10.

Figure 6.8.11.

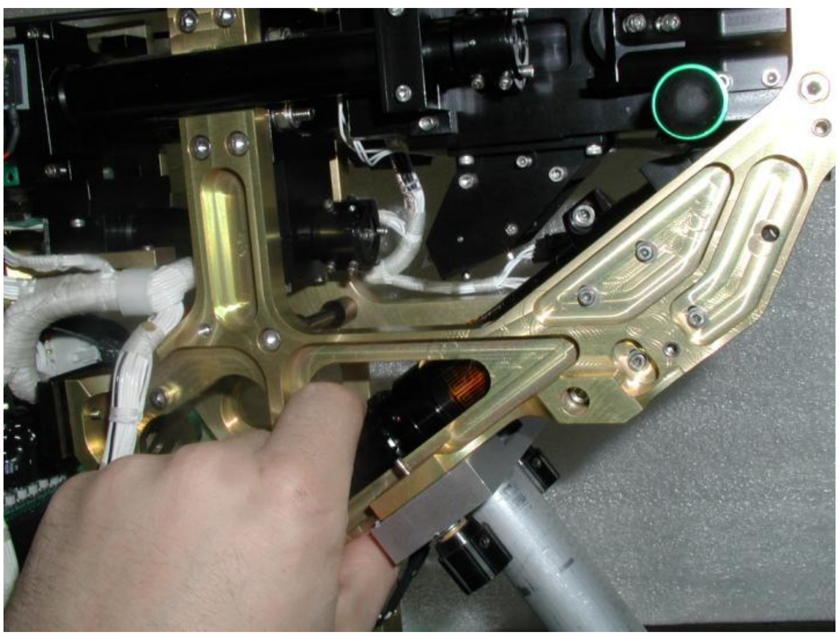

Figure 6.8.12.

7.0 APPENDICES

7.1 Mechanical Drawing for Installation On Aircraft

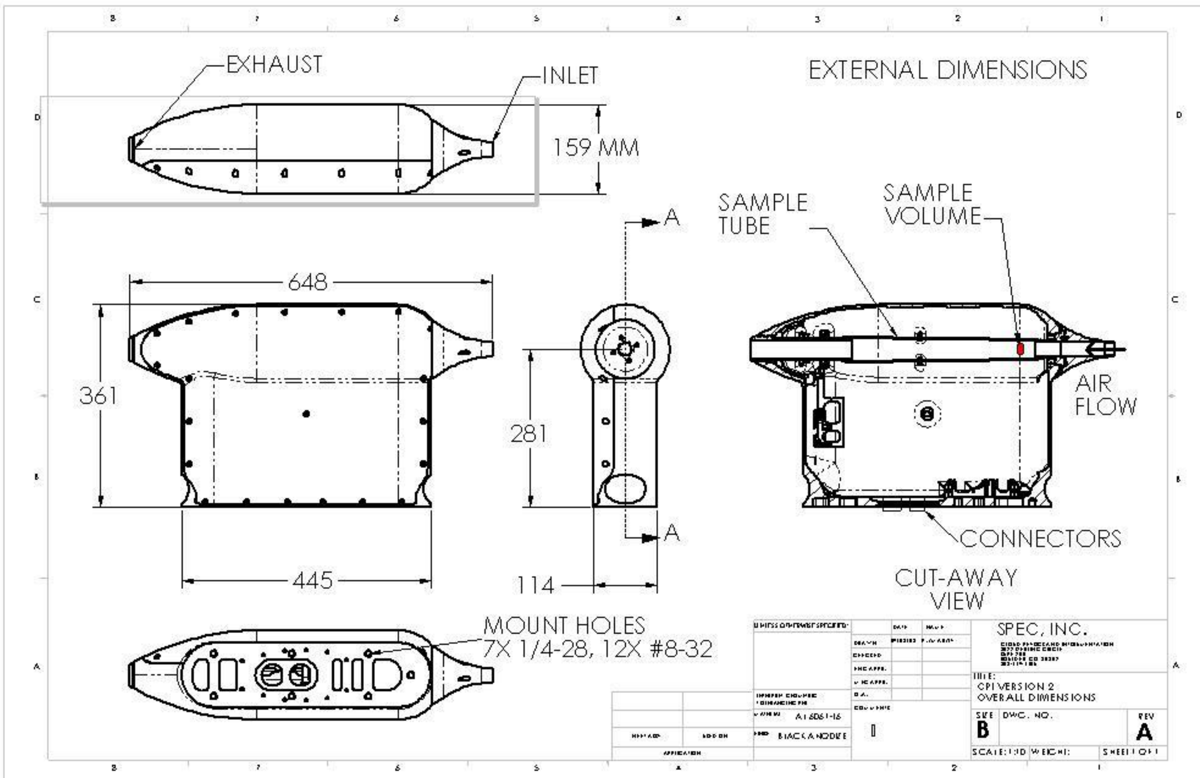

Figure 7.1.1 CPI External Dimensions

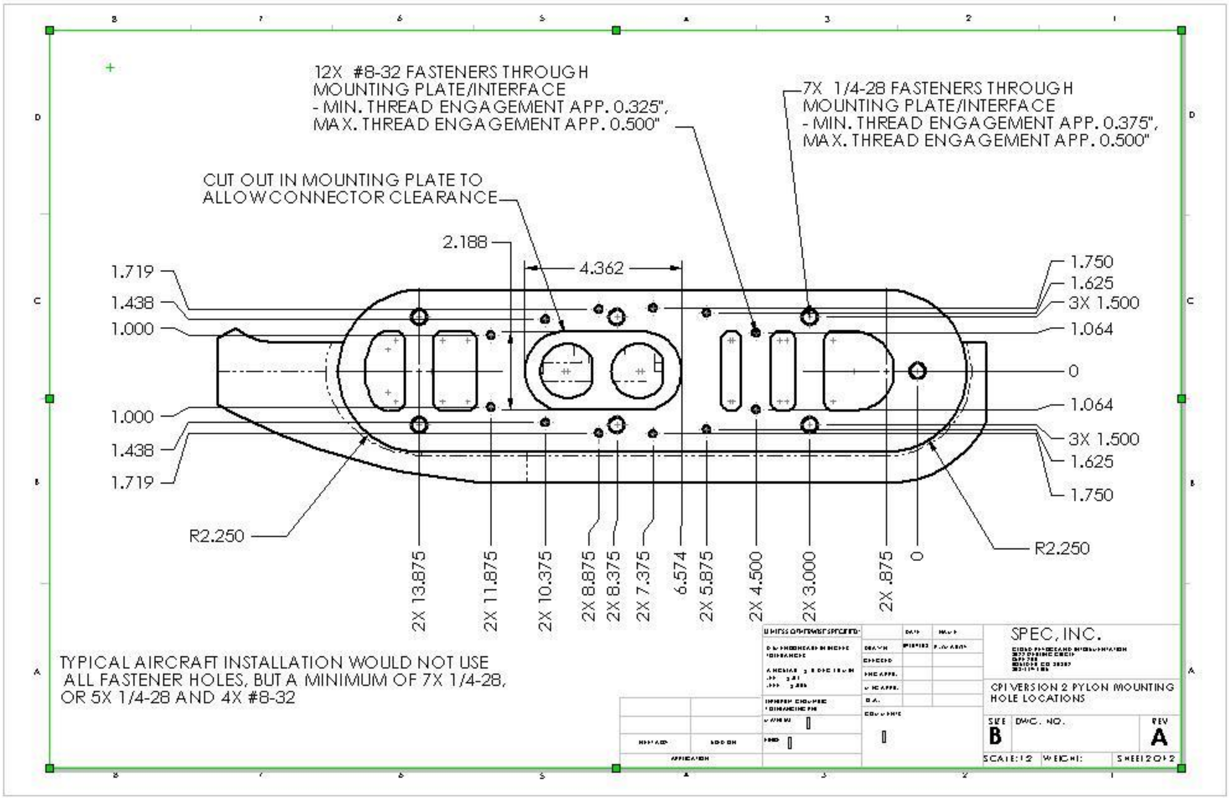

Figure 7.1.2 Pylon Interface

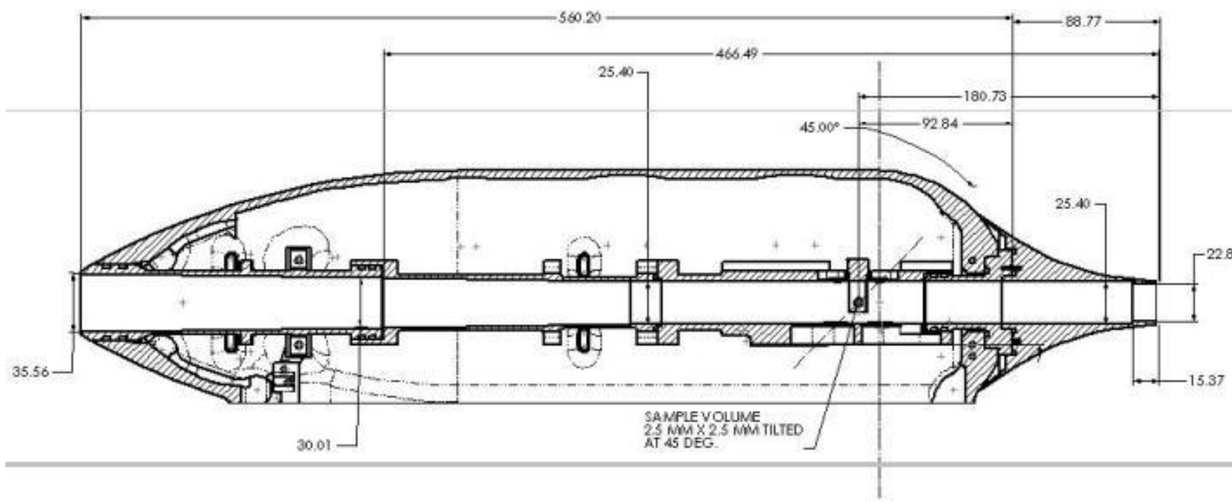

Figure 7.1.3 Flow Geometry Dimensions

7.2 CPI INI

```
1. [System]
2. CameraType=1
3. ProbeRev#=3
4. PixelPolarity=0

5. [ROI Parameters]
6. ImageType=33280
7. DispMode=0
8. StartDrive=4 1 15
9. DriveCount=1 1 6
10.      BackgroundRate=600 10 36000
11.      BkgPDSThreshold=10 1 35
12.      ROIThreshold=40 20 150
13.      ImgMeanMin=63 1 70
14.      ImgMeanMax=195 160 255
15.      ROIMinSize=4 0 400
```

```
ROIAspectRatio=640 2 900
ROIFillRatio=0.000006 0.000000 0.800000
ROIXPad=15 0 50
ROIYPad=6 0 50
DebugMode=0
FullFrame_Skips=0 0 10000
[Probe Settings]
Mode=3
Heaters=16383
Heaters2=0
;Setting1 = Forward Sample Tube Temp set point
Setting1=957 0 957
;
;Setting2 is the Upper Optical Block Temp set point
Setting2=957 108 1057
;
;Setting3 is the Lower Optical Block Temp set point
Setting3=957 108 1057
;
;setting 4 is the Central Sample Tube Temp set point
Setting4=1036 108 1057
;
;setting5 is the Aft Sample Tube Temp set point
Setting5=1057 -64 1057
;
;setting 6 is the nose temp set point
Setting6=957 -64 957
;
;setting 7 is the pylon temp set point
Setting7=1057 -64 1057
;
;setting 8 is the camera temp set point- currently has no heater installed
Setting8=813 -64 1057
;
; setting 9 is the APD45 temp set point
Setting9=1057 108 1057
;
;setting 10 is the electronics temp set point - currently no heater installed
Setting10=241 -64 1057
;
;setting 11 is the imaging laser temp set point
Setting11=296 290 1057
;
;setting 12 is the PDS45 laser temp set point
Setting12=290 290 1057
;
;setting 13 is the PDS90 laser temp set point
Setting13=298 290 1057
;
;setting 14 is the PDS45 laser power set point
Setting14=4095 0 4095
;
```

```
;setting 15 is the PDS90 laser power set point
Setting15=4095 0 4095
;
;setting 16 is the PDS45 threshold set point
Setting16=207 100 1000
;
;setting 17 is the PDS90 threshold set point
Setting17=207 100 1000
;
;setting 18 is the Imaging laser current set voltage
Setting18=3792 0 3920
;
;setting 19 is the imaging laser pulse width set voltage
Setting19=3413 0 4000
;
;setting 20 is the minimum transit time set point
Setting20=35 10 255
; rev31 only
;Setting21=1035 10 50
;
;setting 22 is the APD90 amplifier temp set point
Setting22=458 0 1139
;
;Setting 23 is the camera temp set point
Setting23=59 0 992
;
;setting 24 is the PMT temp set point
Setting24=237 0 970
;
;setting 25 is the SLS laser temp set point
Setting25=1255 0 1555
;
;setting 26 is the SLS laser power set point
Setting26=25 0 4095
;
;setting 27 is the PMT high voltage set point
Setting27=26 0 1255
;
;setting 28 is the pylon cover patch temperature set point
Setting28=867 -1500 1057
;
;setting 29 is the imaging lens temperature set point
Setting29=838 450 1057
;
;setting 30 is the laser trigger timer threshold set point
Setting30=0 0 4095

[Gains/Offsets for Readings]
;
;Gain/offset1 is the Forward Sample Tube Temperature (AD590) on J2-1 and J2-19
Gain/Offset1=0.029356 1.877500 10.000000 35.000000
;
;G/O2 is the Upper Optics Block Temp (AD590) on J2-2 and J2-20
```

```
Gain/Offset2=0.029356 1.877500 20.000000 35.000000
;
;G/O3 is the Lower Optics Block Temp (AD590) on J2-3 and J2-21
Gain/Offset3=0.029356 1.877500 20.000000 35.000000
;
;G/O4 is the Central Sample Tube Temp (AD590) on J2-4 and J2-22
Gain/Offset4=0.029356 1.877500 10.000000 35.000000
;
;G/O5 is the Aft Sample Tube Temp (AD590) on J2-5 and J2-23
Gain/Offset5=0.029356 1.877500 10.000000 35.000000
;
;G/O6 is the Nose Temp (AD590) on J2-6 and J2-24
Gain/Offset6=0.029356 1.877500 5.000000 35.000000
;
;G/O7 is the Pylon Temp (AD590) on J2-7 and J2-25
Gain/Offset7=0.029356 1.877500 5.000000 35.000000
;
;G/O8 is the old Camera Filter/Drop Cop Tube (AD590) J2-8 and J2-26
Gain/Offset8=0.029356 1.877500 -60 60.000000
;
;G/O9 is the APD45 Temp (AD590) on J2-50 and J2-51
Gain/Offset9=0.029356 1.877500 0.000000 35.000000
;
;G/O10 is the Outside Air Temp (AD590) J2-10 and J2-28 (power supply?)
Gain/Offset10=0.029356 1.877500 0.000000 46.000000
;
;G/O11 is the DSP card Temp (AD590) J1-2 and J1-41
Gain/Offset11=0.029356 1.877500 0.000000 60.000000
;
;G/O12 is the PMT Temp (Thermistor) J2-16 and J2-34
Gain/Offset12=0.013736 21.7308 -20.000000 50.000000
;
;G/O13 is the SLS Laser TMP (Thermistor) on J2-17 and J2-35
Gain/Offset13=0.013736 1.877500 -40.00000 60.000000
;
;G/O14 is the Inside Air TMP (AD590) on J2-9 and J2-27
Gain/Offset14=0.029356 1.877500 0.000000 60.000000
;
;G/O15 is the Camera TMP (Thermistor) on J2-11 and J2-29
Gain/Offset15= 0.013736 21.7308 0.000000 39.000000
;
;G/O16 is the Imaging Laser TMP (Thermistor) on J2-12 and J2-30
Gain/Offset16= 0.013736 21.7308 0.000000 35.000000
;
G/O17 is the PDS45 Laser TMP (Thermistor) on J2-14 and J2-32
Gain/Offset17= 0.013736 21.7308 0.000000 35.000000
;
;G/O18 is the PDS90 Laser TMP (Thermistor) on J2-13 and J2-31
Gain/Offset18= 0.013736 21.7308 0.000000 35.000000
;
;G/O19 is the PDS45 Laser Power J1-22 (from photodiode monitor)
Gain/Offset19= 0.0246752 -1.6774 15.000000 41.000000
```

```
;
;G/O20 is the PDS45 DC Voltage on J1-42
Gain/Offset20= 0.00486000 0.000000 2.000000 8.800000
;
;G/O21 is the PDS90 Laser Power on J1-3(from photodiode monitor)
Gain/Offset21= 0.0232 0.7538 15.000000 41.000000
;
;G/O22 is the PDS90 DC Voltage on J1-23
Gain/Offset22= 0.00486000 0.000000 2.000000 8.800000
;
;G/O23 is the Imaging Laser Current Set Voltage Measured J1-47
Gain/Offset23= 0.0161133 27.5 20.000000 36.000000
;
;G/O24 is the Imaging Laser Pulse Width Voltage Measured J1-8
Gain/Offset24= 0.0161133 27.5 20.000000 38.000000
;
;G/O25 is the -5V Supply on J1-4
Gain/Offset25= 0.0029296875 -12 -5.25 -4.0
;
;G/O26 is the +5V Supply on J1-44
Gain/Offset26= 0.002930 0.000000 4.7500000 5.2500000
;
;G/O27 is the +12V Supply on J1-24
Gain/Offset27= 0.007354 0.000000 11.500000 12.500000
;
;G/O28 is the -12V Supply on J1-43
Gain/Offset28= 0.007354 -30.12 -12.500000 -9.000000
;
;G/O29 is the PDS45 Laser Power Set Point
Gain/Offset29= 0.0102775 -1.664985 12.000000 43.000000
;
;G/O30 is the PDS45 Threshold Set Point
Gain/Offset30= 0.000610352 0.000000 0.000000 60.000000
;
;G/O31 is the PDS90 Laser Power Set Point
Gain/Offset31= 0.0096665 0.754 12.000000 43.000000
;
;G/O32 is the PDS90 Threshold Set Point
Gain/Offset32= 0.000610352 0.000000 0.000000 40.000000
;
;G/O33 is the Imaging Laser Current Set Point
Gain/Offset33= 0.0085449 0.000000 0.000000 35
;
;G/O34 is the Imaging Laser Pulse Width Set Point
Gain/Offset34= 0.009353 0.000000 0.000000 38
;
;G/O35 is the Minimum Transit Time Set Point
Gain/Offset35= 20.83333e-9 0.000000 0.000000 1000.000000

; Dead Time:
Gain/Offset36= 1.0 0.000000 0.000000 0

; Rev31 only
;
```

```
;G/O37 is the APD90 Amplifier Temp (From Where?)
Gain/Offset37= 0.029356 1.877500 10.000000 35.000000
;
;G/O38 is the Vref10 Voltage (From Where?)
Gain/Offset38= 0.001464843 0.000000 1.000000 35.000000
;
;G/O39 is the Pressure Sensor
Gain/Offset39= 0.011014 -3.7594 0.000000 35.000000
;
;G/O40 is the SLS laser power setpoint- mw
Gain/Offset40= 0.007324219 0.000000 0.000000 0.600000
;
;G/O39 is the PMT voltage
Gain/Offset41= 0.007324219 0.000000 0.000000 0.400000
;;
;G/O42 is the pylon cover patch - therm
Gain/Offset42= 0.013736 21.7308 0.000000 35.000000
;
;G/O43 is the image lens temperture-ad590
Gain/Offset43= 0.029356 1.877500 10.000000 30.000000
;
;G/O44 is thelaser trigger timer thresh.
Gain/Offset44= 20.83e-9 0.000000 0.000000 2.3e-6

[Display Options]
ROI DX=132
ROI DY=87
ROI Columns=5
ROI Rows=4
Pixel Size(um)=2.3
Flags=32790
Display Frame Skips=0
Histogram Bins=20
Histogram Min Size=0
Histogram Max Size=109
Histogram ITime=10000
Histogram Refresh=1000
Rates ITime=3000
Air Speed(m/s)=150
ROI XY Plot Max ROIs=1000
ROI XY Plot Reset When Filled=1

[Serial Data Parameters]
PortSettings=COM1: baud=9600 parity=N data=8 stop=1
;BlockSize=72
BlockSize=197
BlockMark=;\r
NumFields=30
Field1= [Hour] %02d
Field2= [Minute] %02d
Field3= [Second] %02d
Field4= [Pressure(mb)] %6.1f
Field5= [Temperature(C)] %6.1f
Field6= [Relative Humidity(%)] %5.1f
```

```
Field7= [Wind Speed(m/s)] %5.2f
Field8= [Wind Direction(degree magnetic)] %5.1f
Field9= [Latitude(deg)] %11.7f
Field10= [Logitude(deg)] %12.7f
Field11= [Altitude(m)] %7.1f
Field12= [East Velocity(m/s)] %6.1f
Field13= [North Velocity(m/s)] %6.1f
Field14= [Vertical Velocity(m/s)] %6.1f
Field15= [4PI Top Channel a] %5ld
Field16= [4PI Top Channel b] %5ld
Field17= [4PI North Channel a] %5ld
Field18= [4PI North Channel b] %5ld
Field19= [4PI East Channel a] %5ld
Field20= [4PI East Channel b] %5ld
Field21= [4PI South Channel a] %5ld
Field22= [4PI South Channel b] %5ld
Field23= [4PI West Channel a] %5ld
Field24= [4PI West Channel b] %5ld
Field25= [4PI Bottom Channel a] %5ld
Field26= [4PI Bottom Channel b] %5ld
Field27= [Primary Voltage(V)] %5.1f
Field28= [Primary Current(A)] %5.3f
Field29= [Extra Voltage 1(V)] %7.5f
Field30= [Extra Voltage 2(V)] %7.5f
SampleInterval=1
HistoryLength=20

; Below are parameters for the cycling of settings
; Section below is required, and SettingsSamples must be greater than 1
[Settings Sampling]
; Turns cycling ON/OFF
DoSettingsSampling=0
; Number of setting cycles
SettingsSamples=4

; Section below is required, and SampleDuration must be greater or equal to 10
[ROI Parameters Period1]
; Duration of cycle period1 in seconds (>= 10)
SampleDuration=11
; Below you can specify any or no settings to change
BkgPDSThreshold=35
ROIThreshold=25
ROIMinSize=4
ROIAspectRatio=900
ROIFillRatio=0.000006
ROIXPad=6
ROIYPad=6

[Probe Settings Period1]
; Probe Settings values for Period 1
; These are optional
; PDS45 Threshold
```

```
Setting16=800
; PDS90 Threshold
Setting17=800


[ROI Parameters Period2]
SampleDuration=12.5
ROIThreshold=45
ROIXPad=14
ROIYPad=14

[Probe Settings Period2]
Setting16=600
Setting17=601

[ROI Parameters Period3]
SampleDuration=10.5
ROIThreshold=55
ROIXPad=10
ROIYPad=10

[Probe Settings Period3]
Setting16=700
Setting17=701

[ROI Parameters Period4]
SampleDuration=10.5
ROIThreshold=65
ROIXPad=10
ROIYPad=10

[Probe Settings Period4]
Setting16=800
Setting17=801
```

7.3 DSP Memory Address Decodes and Heater Controls

A Programmable Logic Device (PLD) (U3) decodes the DSP’s external data memory for the CPI as described in **Table 7.3.1**.

Table 7.3.1 DSP Memory Map

Address	Size (words)	R/W	Description
0x2000	2	R/W	Housekeeping ADC AD7878
0x2001	2	R	AD7878 Status Read

0x2002	2	W	Housekeeping Control Register
0x2004	1	W	System Control Register
0x2006	1	W	General Purpose Latch
0x4000	1	R	Dead Time Counter
0x4000	1	W	Set Minimum Transit Time
0x5000	1	R	Transit Timer
0x5000	1	W	Clear Hold
0x5001	1	R	Total Particle Counter
0x5001	1	W	Clear Total Particle Counter
0x5002	1	R	PDS Status Register
0x5002	1	W	Clear PDET and IRQ Bits
0x5005	1	W	Laser Pulse Timer

Each of these reads and writes is discussed below.

These writes occur in I/O memory space and require two separate I/O 1K pages. The first will be at page 8: 0x2000

7.3.1 Reads

1. Housekeeping ADC (R/W 0x2000)

   On a read, the AD7878 ADC is read from the control board into data bus D[0:11].

2. Dead Time (Read 0x4000)
   A 24 bit counter is clocked off of the 12 MHz clock whenever a particle event that is transit time qualified is not occurring. The upper 12 bits of this counter, DT[23:12], are read and cleared by reading this address.

3. Transit Timer (Read 0x5000)
   This 11 bit counter is clocked at 48 MHz for the duration of a valid particle event. It should be read every time a particle event interrupt from the PDS state machine occurs.

4. Total Particle Counter (Read 0x5001)
   This 10 bit counter is clocked every time a valid particle event occurs. If MT[12] is a 1, a valid particle event is one in which the particle is detected for a minimum transit time (default); otherwise it occurs whenever both PDS signals show a particles presence.

5. Status Register (Read 0x5002)
   This PDET bit, read on D0, is high if a particle event interrupt has occurred.

7.3.2 Writes

1. House keeping control (Write 0x2002)
   On a write, data bus bits D[0:8] are latched into CTRL[0:8] in the DSP_HSKP logic.
   CTRL[0:4] are clocked into TEMP_ADD_I[0:4],
   TEMP_ADD[0:2] = TEMP_ADDI[0:2] = CTRL[0:2]
   TEMP_ADD[0:2] are MUX selects on the relay board.
   TS0 = !TEMP_ADD_I[3] = !CTRL[3]
   TS1 = TEMP_ADD_I[3] = CTRL[3]
   TS0 and TS1 are MUX enables on the relay board.
   CTRL[5:8] are clocked into CC[0:3], the house keeping state machine down counter.

2. System Control Register (Write 0x2004)
   Data bus bit D[1] is inverted and latched, with the latch output driving the watchdog IC, the MAX6823. The DSP should write to this address, toggling the value on D[1] on each write.

3. Laser Pulse Timer (Write 0x2005)
   A write to this address latches data bus bits D[0:12].
   If D[11] = 1, a timer counts down from the value latched off of D[0:10,] at 48 MHz, firing the laser after the count reaches 0 in the presence of a particle. This allows programmable delay for firing the laser and should come from the data system. Writing a 0 to bit D[11] disables this feature.
   If D[12] = 1, the PDS state machine goes into diagnostic mode (FORCE_TRIG in the NewStateMachine.ppt slide #4. This bit should be a 0 in regular operation, and should be controlled by the data system.

4. General Purpose Latch (Write 0x2006)
   A 9 bit general purpose register that latches data bus D[0:8] to GP[0:8] in the DSP_HSKP CPLD. The bits are defined as:
   GP[1]: General purpose bit going to the SLS board; presently undefined.
   GP[2]: XMIT HDLC. When pulsed high, an HDLC transfer is initiated.
   GP[3:7]: Undefined.
   GP[8]: Heater Enable. When high, TMR0 and TMR1 outputs drive the PMT and SLS laser heaters. They are disabled at reset in case of DSP failure.

5. Set Minimum Transit Time (Write 0x4000)
   A write to this address latches data bus D[0:12] to the TT_PDS logic's MT[0:12] bits.
   D[0:11] sets the minimum transit time count that is counted down at 48 MHz.
   Writing a 1 to D[12] enables minimum transit time qualification, 0 disables. This comes from the data system, but on power up, it should be enabled, and currently it is, with MT[0:11] = 3.

6. Transit Time Qualifier Enable / Set (Write 0x4000)

Writing a 1 to data bus bit D[12] requires the PDS state machine to transit time qualify particle events. A down counter is preset to the value written in D[11:0] and counts down using A 48 MHz clock. If a particle stops being detected before the counter reaches zero, it is not imaged, so long as D[12] was written with a value of 1. The state machine defaults to MT[12] (MT[12:0] is the registered latch that holds values written to this address) = 1, MT [11:0] = 3. Thus, by default, a particle must be present for three 48 MHz clock periods.

7. Clear Hold (Write 0x5000)
The HOLD bit in the PDS state machine goes high when a valid particle event, the expiration of the transit time threshold in the case of a long duration particle event, or an EXTRIG signal comes from the data system computer. It forces the state machine to wait until the DSP responds to the interrupt that is generated at the same time the HOLD bit goes active.

8. Clear Total Particle Counter (Write 0x5001)
See item 2. A write to this address clears the counter.

9. Clear PDET Bit and IRQ0 Bit (Write 0x5002)
See item 3. A write to this address clears the PDET and IRQ0 bits.

10. Trigger Threshold Value (Write 0x5005)
If written with data bus bit D[11] = 1, the imaging laser will fire when the transit timer (see 1, above) reaches the value written at address 0x5005 on the data bus bits D[10:0].

D[12] = 1 forces the PDS state machine in to diagnostic mode, where camera frames will be sent to the PC data system no matter what the state of particle events. If a PDS channel gets stuck high, the state machine will not work in normal operation. Setting D[12] = 1 while writing to this address will bypass that problem. Normally, D[12] should be set to 0.

The DSP controls the PDS trigger thresholds with a 12-bit, four output AD5327 Digital to Analog Converter (DAC) which outputs voltages between 0 and 2.5 V. Two other DACS of the same type will be used on the system, and all three utilize the SPI serial interface protocol. One is used to control the PDS45, PDS90 (SLS systems will not have a PDS90 signal) and imaging laser power set points; the other, on a system with an SLS, will control the PMT high voltage set point and the SLS/PDS laser power. These DACS replace the need to perform writes to addresses 0x0404 through 0x0407 and 0x3001 and 0x3002.

All heaters on the UAV CPI are controlled by turning on bits in the data written, using the SPI1 channel, with SPI1_SEL1 (PF3). The SLS system PMT and laser heaters are driven by TMR0 and TMR1 outputs, respectively. These outputs feed into the DSP_HSKP CPLD, and require that GP[8] be written with a value of one to enable the heater (see WRITES, item 4, above). The relays and FETs that control power are on the relay and sensor board that piggybacks the main DSP control board (see **Figure 3**).

Table 7.3.2. Heater Control Bits and Applied Power

Bit	Location	Supply Voltage	Power (Watts)	Relay / FET	
0	FWD Sample Tube[NOTE 1]	115 AC	159	K2	
1	Optics Block Upper[NOTE 1]	115 AC	197	K4	
2	Optics Block Lower[NOTE 1]	115 AC	197	K5	
3	Central Sample Tube	115 AC	100	K6	
4	AFT Sample Tube	115 AC	190	K7	
5	Imaging Lens	115 AC	--	K8	
6	PDS 45 APD	115 AC	6.6	K9	
7	PDS 90 APD	115 AC	6.6	K10	
8	Pylon Cover Patch	115 AC	330	K12	
9	Pylon Slug	115 AC	330	K13	
10	Pylon Base Patch	115 AC	400	K14	
11	IMG LSR	115 AC	48	K1	
12	PDS 45 LSR	15V DC	7.7	Q2	
13	PDS 90 LSR	15V DC	7.7	Q3	
14	Spare DC	15V DC	--	Q4	
15	Camera	115 AC	30	K15	
TMR0	PMT (SLS)	115 AC	???	K11	
TMR1	SLS LSR	115 AC	30	K3	

NOTE 1: K2, K4 and K5 can be depopulated and Q5, Q6 and Q7 (normally not installed) can be populated to provide an alternate set of 3 +15V DC heaters.

7.4 CPI ROI Data File Format

(as given by Jeffrey Schuenke to Brad, Paul, and Tara Jenson on 6/23/1999)

A raw .roi file is structured as follows:

{File header} {House Keeping block } {House Keeping block } … {Frame Block}… {House Keeping block }…

Where the HK blocks occur on 1 second intervals until a frame block is output. The frame block has priority, so multiple frame blocks may occur before the next HK block. If the frame blocks take more time to output than 1 second, the required HK blocks are buffered, and output when possible. Each HK block and each Frame block has a time stamp in seconds of year. Each Frame block has a matching HK block with the same time stamp. This HK block will always come after the Frame block and has the deadtime value associated with the frame.

File header structure

Field name	Type	Description
Ver	Int	File version
Year	Int	Year
Month	Int	Month
DX	Int	Max Width of frame
DY	Int	Max Height of frame
Text	BYTARR(70)	Misc. text descriptor

Frame header Structure

Field name	Type	Description
BlockNum	0	Header Block Marker
ItemSize	0L	Total bytes in this frameheader only
Ver	0	Version number of this frame
ROIsCount	0	number of ROI's in this frame
TotROIsSize	0L	total bytes of IMAGE data
day	0B	time of frame 1-31
hour	0B	time of frame 0-23
minute	0B	time of frame 0-59
sec	0B	time of frame 0-59
msec	0	time of frame 0-999
ImgType	0	bit array with data information
Sx	0	upper left X corner of image
Sy	0	upper left Y corner of image
Ex	0	lower right X corner of image
Ey	0	lower right Y corner of image
BGRate	0	time between backgrounds in tenths of a second, 0 means no bckgnds
BkgPDSThresh	0	number of machine strobes before a background can be collected
FrmsProc	0L	total number of frames processed so far

IThresh	0B	Image threshold 0-255, 0 means no thresholding done.
ROIErr	0B	ROI Rejection/Failure code
ROIMinSize	0	min particle rejection size
ROIAspect	0.0	particle aspect criteria
ROIFill	0.0	min value for (#pixels within ROI threshold)/# pixels in ROI)
ROIFCount	0L	# pixels within ROI above threshold
ImgMean	0B	image mean value
BkgMean	0B	background mean value
Spare1	0	Unused
ROIXPad	0	width of border around sides of particle in pixels
ROIYPad	0	width of border around top/bottom of particle in pixels
StrobeCount	0L	Probe's strobe count per image
FrmsSaved	0L	number of frames saved to disk so far
ImgMinVal	0B	min image mean for an acceptable frame
ImgMaxVal	0B	max image mean for an acceptable frame
ROIsSaved	0L	total number of ROI's saved so far
ChkSum	0	Checksum
PDSHead	INTARR(3)	PDS data block
Time	0L	seconds of year
ArrivalT1	0	Arrival time ???
ArrivalT2	0	Arrival time ???
TransitT	0	Transit time ???
Missed	0	number of particles missed while processor is busy
PHeight1	0	??
PHeight2	0	?? Note: header file only has one of these listed!!
PDSChkSum	0	check sum
ProbeMode	0	probe mode

Image header - Data contained in the raw ROI file from the instrument

Field Name	**Type**	**Description**
BlockMark	0	Block mark
ROIInfoSize	0L	Total bytes in this block (variable because of the last two fields)
ROIVer	0	Tracks this structures version
sx	0	Start X upper left corner of roi (relative to CCD frame)
sy	0	Start Y upper left corner of roi (relative to CCD frame)

ex	0	End X upper left corner of roi (relative to CCD frame)
ey	0	End Y upper left corner of roi (relative to CCD frame)
PixBytes	0	Bytes per pixel in image
Flags	0	Contains info about particle (see definition below)
Len	0.0	Computed Length of particles major axis
SLen	0L	1D index coordinate of start of length vector
ELen	0L	1D index coordinate of end of length vector
Wid	0.0	Computed width of particle (perpendicular to length vector)
SWid	0L	1D index coordinate of start of width vector
EWid	0L	1D index coordinate of end of width vector
Dark	0	Info on particle depth and cut-off (See definition below)
Area	Float	Area of roi in pixels
Perimeter	Float	Perimeter of roi in pixels

(ROI image data follows each image header. The .min file leaves this data out)

Object Structure Version 30

Field name	Organization	Type	Description
BlockMark	Scalar	Int	Block mark
ROIInfoSize	Scalar	Long	Total bytes in this block (variable because of the last two fields)
ROIVer	Scalar	Int	Tracks this structures version
Sx	Scalar	Int	Start X upper left corner of roi (relative to CCD frame)
Sy	Scalar	Int	Start Y upper left corner of roi (relative to CCD frame)
Ex	Scalar	Int	End X upper left corner of roi (relative to CCD frame)
Ey	Scalar	Int	End Y upper left corner of roi (relative to CCD frame)
PixBytes	Scalar	Int	Bytes per pixel in image **(if zero then image data excluded!)**
Flags	Scalar	Int	Contains info about particle (see below)
Len	Scalar	Float	Computed Length of particles major axis
Slen	Scalar	Long	1D index coordinate of start of length vector
ELen	Scalar	Long	1D index coordinate of end of length vector
Wid	Scalar	Float	Computed width of particle (perpendicular to length vector)
SWid	Scalar	Long	1D index coordinate of start of width vector
EWid	Scalar	Long	1D index coordinate of end of width vector
Dark	Scalar	Int	Info on particle depth and cut-off (See definition below)
Area	Scalar	Float	Area of object in square pixels
Perimeter	Scalar	Float	Perimeter of object in pixels
Centroid	1D Array	Int	Centroid of particle (2 elements)
Roundness	Scalar	Float	Measure of particle roundness
X_Moment	Scalar	Float	1/2 area on each side of vert line
Y_moment	Scalar	Float	1/2 area on each side of horiz line
Rubber_Band	Scalar	Float	Measure of boundary roughness
Fractal_dim	Scalar	Float	Fractal dimension
Harmonic_len	Scalar	Int	Number of elements in Harmonic array
Bound_len	Scalar	Int	Number of elements in Boundary array
Sample_period	Scalar	Float	Sample period of harmonic array in pixels
Focus	Scalar	Byte	% focus 0-100 Mean of 20 points on perimeter
FocusMin	Scalar	Byte	Min of 20 points on perimeter
FocusMax	Scalar	Byte	Max of 20 points on perimeter
FocusStdDev	Scalar	Float	Std Dev of 20 points on perimeter
FocusGoodSamples	Scalar	Byte	?
CutOff	Scalar	Byte	% particle is cut-off 0 – 100

Crystal	Scalar	Byte	Scalar type index meaning TBD
Confidence	Scalar	Byte	Factor assessing confidence in particle use 0-10
P1	Scalar	Float	1 if manual features set
P2	Scalar	Float	Place holder
P3	Scalar	Float	Place holder
P4	Scalar	Float	Place holder
Harmonics	1D Array	Float	Circular harmonics of boundary(var. len)
Boundary	1D Array	Int	Location of boundary pixels in ROI array (1D indicies) (var. len)

(note: roi image data may follow at this point if PixBytes not equal to zero. Option not currently implemented)

An object file consists of a file header (see below), and a sequence of object frames. Object frames conatin a frame header and a sequence of object headers, one for each ROI in the original frame.

Dark: 2-byte word

Byte	Meaning
1st byte	darkness number
2nd byte	LS 5-bits = Particle cutoff index: 0-31 (no cut-off to almost fully cut-off)

Flags: 2-byte word

Bit Number	Meaning
0-7	out of focus number
8-11	crystal type 0=circular 1=column 2=stellar 3=other
12	Not used.
13	ROI was drawn manually.
14	Crystal type was manually corrected.
15	Particle was manually rejected.

Scan List structure; used to gather file info at load time

Field Name	**Type**	**Description**
BlockMark	int	Marker
Fpos	long	File position
ImgType	int	Image type 1 = normal frame with roi's 2 = background 0 = error type -1 = house keeping block

HTime	long	House keeping time
day	byte	Day From header unless HK, then computed from Htime
hour	byte	Hour From header unless HK, then computed from Htime
minute	byte	Minute From header unless HK, then computed from Htime
sec	byte	Sec From header unless HK, then computed from Htime
msec	int	Msec From header unless HK, then 0
ROIsCount	int	Number of ROI's in block, 0 for HK blocks
HouseSize	int	Size of House Keeping block or 0 if Image block