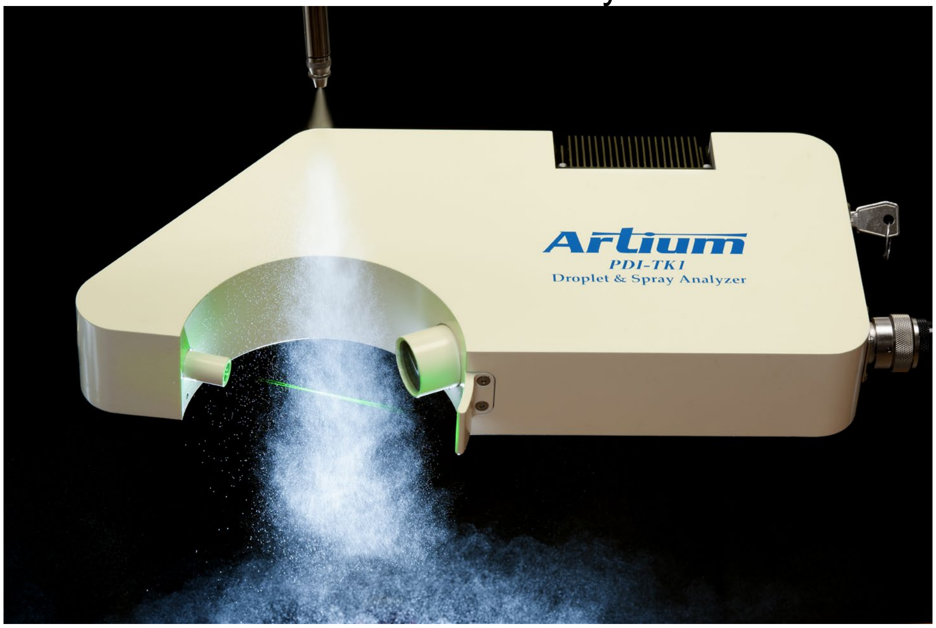
Turnkey PDI User Manual

Operation of the Turnkey Phase Doppler Interferometer (TK-PDI)

For Spray Drop Size and Velocity Measurement

For TK1 and TK2 PDI Systems



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CHAPTER 1

Preface

Thank you for purchasing the TURN-KEY PDI. We are confident that this product will serve you well. Any comments you may have concerning this product or your application are encouraged. Please feel free to call, fax or e-mail us at:

Artium Technologies, Inc.

Tel: (408) 737-2364

Fax: (408) 737-2374

E-mail: info@artium.com

Internet: http://www.artium.com

This manual is designed to be comprehensive and easy-to-understand. However, should you be uncertain about how to do certain things, or the consequences of doing something, feel free to contact us at **Artium Technologies, Inc**. We will be happy to answer any questions you may have. Also, if you have any comments on improving this manual, we would appreciate hearing from you.

CHAPTER 2

Before you start

Upon receipt of the instrument, inspect the shipping carton for any significant external damage. Unpack the unit and inspect for internal damage. If any damage is found, immediately notify the shipper and Artium Technologies Inc.

Retain the shipping carton and packing material. If the **TK-PDI** instrument ever needs repair, the cartons will ensure safe shipment of the unit to Artium Technologies, Inc.

CHAPTER 3

Artium Technologies, Inc.

Artium Technologies, Inc. ("Artium") was established in 1998 to develop advanced instrumentation and to engage in various opportunities associated with laser-based diagnostics for particle field and spray characterization. Since its inception, Artium has been actively involved in conducting research and development, design, manufacture, and sales/marketing of laser-based instrumentation for particle field and spray characterization; for both fundamental research and process/quality control applications. Our instruments have been used in various applications including characterization of sprays used in coating medical devices, cloud measurements for aircraft icing research studies, characterizing sprays in spray combustion, and measuring soot emissions from diesel engines. We have also developed systems for characterizing black carbon for quality control purposes in carbon black production.

Throughout the years, our team has established an excellent record worldwide for providing innovative advanced diagnostics that perform reliably under difficult conditions. Our instruments set the standard for performance and for their capability in producing results.

CHAPTER 4

Warranty

Artium Technologies, Inc. ("Artium") warrants products of its manufacture against defective materials and workmanship for a period of one (1) year from the date of installation by the purchaser or, if shorter, for a period of 13 months from the date of shipment to the purchaser. The liability of Artium under this warranty is limited, at Artium's option, solely to repair or replacement with equivalent products, or appropriate credit adjustment not to exceed the sales price to the purchaser, provided that:

1. Artium is notified in writing by the purchaser within the warranty period promptly upon the discovery of defects,
2. The purchaser has obtained a Return Materials Authorization Number ("RMA.") from Artium, which RMA number Artium agrees to provide to the purchaser promptly upon request,
3. The defective products are returned to Artium, in the original packing material or alternate material approved by Artium, with transportation charges prepaid by the purchaser, and
4. Artium's examination of such products discloses to its satisfaction that defects were not caused by mishandling of the product, careless operation of the system, negligence, misuse, improper installation, accident, or unauthorized attempts to repair or perform alterations.

The original warranty period of any product which has been repaired or replaced by Artium shall not thereby be extended.

THE FOREGOING WARRANTY IS PROVIDED EXPRESSLY IN LIEU OF AND **ARTIUM** HEREBY DISCLAIMS ALL OTHER WARRANTIES, EXPRESS OR IMPLIED, INCLUDING ANY WARRANTY OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE, AND OF ALL OTHER OBLIGATIONS OR LIABILITIES ON ARTIUM'S PART, AND ARTIUM NEITHER ASSUMES STORE AUTHORIZES ANY OTHER PERSON TO ASSUME FOR ARTIUM ANY OTHER LIABILITIES.

The foregoing warranty is only valid for Artium products sold within the United States and Canada. For products sold outside of United States and Canada, please refer to the local authorized Artium distributor for applicable warranty terms and conditions.

LIMITATION OF LIABILITY

The remedies set forth above constitute the sole and exclusive remedies against Artium for the finishing of nonconforming or defective products. In no event, including if the products are nonconforming, effective, delayed, were not delivered, shall Artium be liable for any special contingent, indirect, or consequential damages, even if Artium has been advised of the possibility of such damages, whether under a contract, tort, property, or other legal theory. Such damages for which Artium is not responsible include, but are not limited to, personal-injury, property damage, anticipated profits, labor expended, delays, and loss of use.

CHAPTER 5

About this manual

The purpose of this manual is to provide step-by-step instructions for the proper setup and operation of the TK-PDI instrument. Before attempting to operate the system, the users should familiarize themselves with all aspects of laser safety and ensure that **laser safety glasses are available** to all individuals present when the instrument is operated.

This manual provides a description of the steps required in setting up the system which includes two transmitters and a receiver optics package, a mounting platform and traversing system (optional), a signal processor, and a system computer including the software. Basic electrical and electronic connections for the system are described with diagrams in the manual. A description of how to install the optics packages onto the mounting platform and traverse is outlined. Basic alignment techniques and descriptions of the signal under various alignment conditions are given to help the user recognize when the instrument is properly aligned and when it is not. All optical parameters required for optimal measurements are outlined and the means for selecting these parameters are described. A section on the proper setup of the electronic system is given although the system software is designed to automatically set these parameters reliably. The various calculations for the fringe spacing, sample volume, and the calculations for the various spray droplet sizes are outlined for easy reference.

CHAPTER 6

Laser Safety

Explanations of Terms

Cautions and Warnings used throughout this manual are explained below. Always read and heed this information. It is basic to the safe and proper operation of the system.

WARNING: Hazardous to persons. An action or circumstance which may potentially cause personal injury or loss of life. Mechanical damage may also result.

CAUTION: Hazardous to persons or equipment. To disregard the caution may cause mechanical damage, however it is not likely to cause serious injury or death**.**

Safety Summary

CAUTION: The Solid State Laser Systems (green 532 nm and blue 473 nm) used in the TK-PDI are Class 3B lasers. The laser output beams are, by definition, a safety and fire hazard. Precautions must be taken to prevent accidental exposure to both direct and reflected beams.

Class 3B lasers are defined by the Federal Register 21 CFR 1040.10 laser safety standard. The standard requires that certain performance features and laser safety labels be provided on the product. Reproductions of the warning labels are shown in this section.

The American National Standards Institute publishes a laser safety standard for users titled "American National Standard for the safe use of lasers" (ANSI Z136.1). Artium Technologies, Inc. recommends that laser users obtain and follow the procedures described in this ANSI user standard. Copies may be obtained from:

American National Standards Institute Inc.
1430 Broadway
New York, NY 10018

OR

Laser Institute of America
12524 research Parkway
Orlando, FL 32826

Please refer to the following publications for additional information on laser safety:

Sources of Laser Safety Standards

1. "Safe Use of Lasers" (Z136.1)
   American National Standards Institute (ANSI)
   11th West 42nd Street
   New York, NY 10036 USA
   Phone: (212) 642-4900

2. "A Guide for Control of Laser Hazards"
   American Conference of Governmental and Industrial Hygienists (ACGIH)
   6500 Glenway Avenue, Bldg. D-7
   Cincinnati, OH 45211 USA
   Phone: (513) 661-7881

3. Occupational Safety and Health Administration
   U.S. Department of Labor
   200 Constitution Avenue N.W.
   Washington, DC 20210 USA
   Phone: (202) 523-8148

4. "Safety of Laser Products" (EN60825-1:1994)
   Global Engineering Documents
   15 Iverness Way East
   Englewood, CO 80112-5704 USA
   Phone: (303) 792-2181

Laser Safety Labels

Laser safety labels can be found on various locations both on the outside and inside of the TK-PDI.

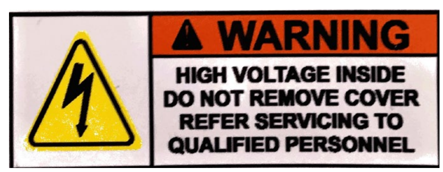
WARNING: Exposure to laser radiation can be harmful. All apertures which can emit laser energy in excess of levels which are considered safe, or areas of the instrument to which exposure to laser radiation can occur due to disassembly, are identified with the appropriate label shown in this section. Take extreme care when working in areas where these labels are placed.

WARNING: Instrument users must provide protective eyewear suitable for the lasers emission wavelength. The lasers' emission wavelengths are indicated in nanometers (nm). The green laser emits at 532 nm.

WARNING: Use of controls or adjustments or performance of procedures other than those specified herein may result in hazardous radiation exposure.

Laser Safety LABELS USED ON THE TK-PDI

1



2

3

LASER SAFETY LABEL PLACEMENT ON THE TK-PDI OPTICAL HEAD

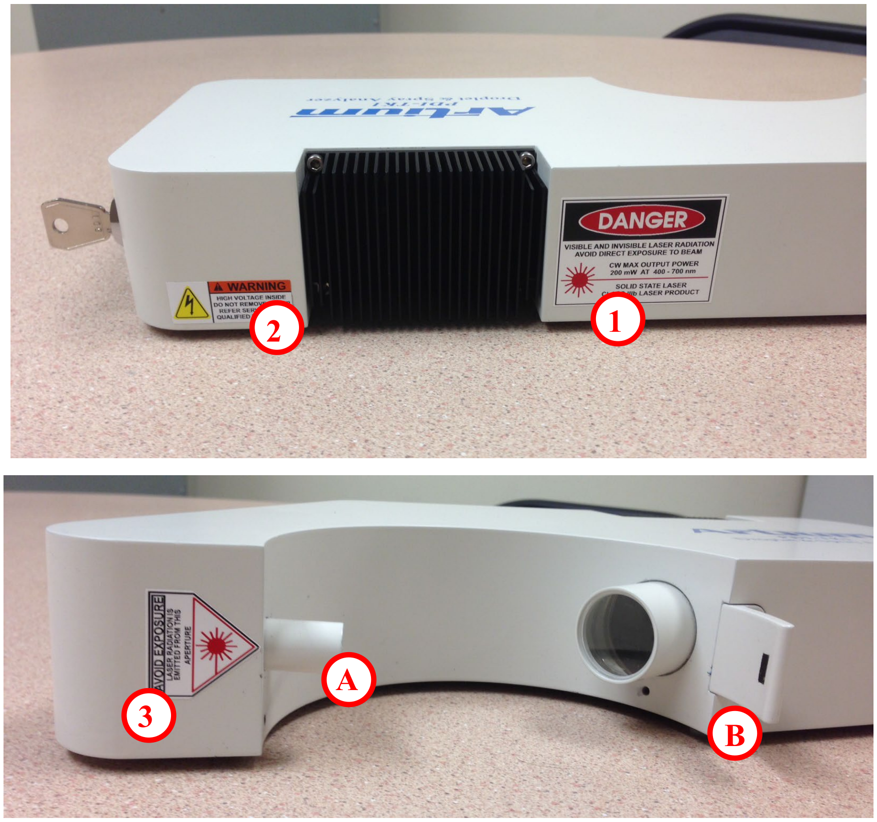


Figure 6.1: Laser beams exit window A and are stopped by beam block B.

CHAPTER 7

Hardware setup/connection

TK-PDI Major Components and connections

1) TK-PDI Optical Head

2) ASA Signal Processor

3) Computer

Figure 7.1: The Artium TK-PDI System.

Figure 7.1 shows the components of the TK-PDI with labels describing each electronics and optics enclosure. A description of the connectors on the electronics and optical enclosures is provided in figure 7.2. In general, the electronic connections can only be made to the proper connectors. However, care must be taken in connecting the signal cables to the proper locations, namely connectors labeled as Input Signals (BNC connectors) on the ASA Signal Processor must be connected to Input 1A, 1B, and 1C with the labeled cables from the receiver cable. Care must be taken to carefully align connectors before plugging them in so that the pins are not damaged or misaligned.

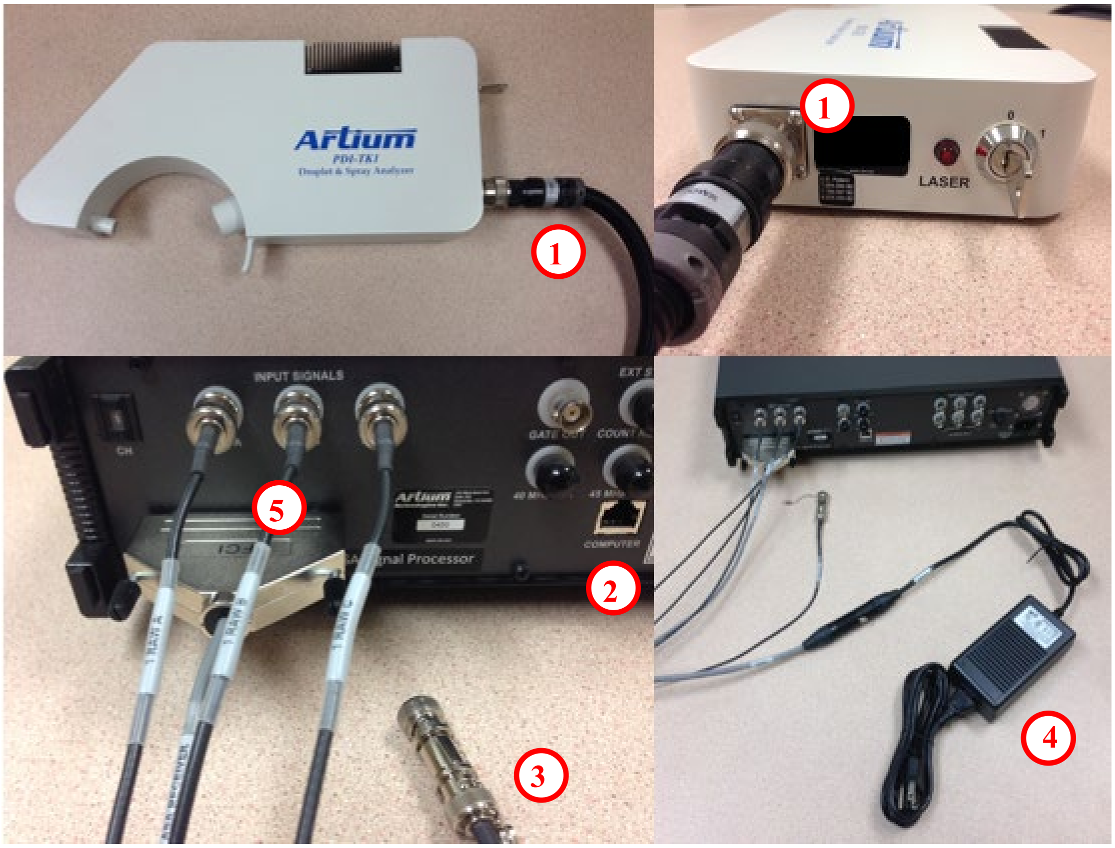


Figure 7.2: Connections for the TK-PDI Instrument.

Descriptions of the Connections

In this section, each of the connections on the electronics and optical enclosures will be described and will refer to figure 7.2.

1. TK-PDI Cable

This six-meter cable connects the optical head to the signal processor. The cable includes three raw signal coaxial cables (indicated as 5 in figure 7.2) and communicates the settings and other functions to the signal processor. This cable is indicated as 1 in figure 7.2.

2. High-Speed Data Cable

Not shown, is the cable that connects the ASA signal processor to the I/O card plugged into the computer. Digitized data is transmitted back to the computer through the high-speed interface card. For ASA2 systems (shown here), the cable is a standard Cat5 ethernet cable. For ASA3 systems, the cable is an optical fiber. This cable connection location is indicated as 2 in Fig. 7.2.

3. Interlock

This connector allows a laser interlock switch located on the door or other access to the laboratory to be activated so that when a connection is broken via the interlock switch, the laser will shut off. For the TK system to operate, this circuit must be closed either thru the door switch or with the shorting cap provided. The interlock is indicated as 3 in figure 7.2.

4. A/C Adaptor

The system is powered by the included 110-240VAC Input; to 24VDC Output; 120w adaptor. Only use this adaptor or others meeting the same specifications to ensure safe, continued operation of the instrument. The adaptor is indicated as 4 in figure 7.2.

ASA Signal Processor CH 1

The ASA signal processor accepts the Doppler burst signals from the TK-PDI and amplifies and filters the incoming analog signals, performs digital and analog signal detection, and presents information on the detected digitized signals to the computer via a high-speed interface card. The signals are processed to produce the size and one component of velocity of the droplets. The following connections are required for proper operation of the instrument.

Input Signals

The BNC cables provided with the instrument must be connected to the proper BNC connectors on the ASA signal processor. The cables are labeled 1A, 1B, and 1C. The other end of the cable is connected to the TK-PDI enclosure indicated as 5 on Fig. 7.2.

RAW A, RAW B, and RAW C BNC Connectors

These connectors are used as monitor points for observing the signals with an oscilloscope. The signals at these points are identical to the signals entering the signal processor at the input signal connectors. It is useful to observe the raw signals with an oscilloscope during alignment of the instrument and during operation to ensure that the quality of the signals is adequate and that there are no problems with the incoming signals.

OUT A, OUT B and OUT C BNC Connectors

These monitor points allow the observation of the signals after they have been filtered by the low pass and high pass filters and amplified logarithmically. The signals observable at this point are digitized and that information is passed to the computer for processing using the complex Fourier transform.

GATE OUT BNC Connector

This monitor point allows the observation of the gate signal which rises to approximate level of 5 V when a signal is detected and falls at the end of the signal. This information is useful in observing the performance of the Doppler signal burst detection.

EXTERNAL INPUT

This connection point allows the input of information from other data gathering devices such as pressure monitoring, temperature monitoring, etc. These data are then appended to the data stream being transmitted to the computer for processing. It can also be connected to a resettable clock so that ensemble averages can be obtained from pulsed injections, for example.

WARNING: Instrument users must provide protective eyewear suitable for the lasers emission wavelength. The laser emission wavelength is indicated in nanometers (nm**)**. The key in the back of the transmitter enclosure turns the lasers on or off. If the power box is turned Off and On again, the key switch must be turned Off and then On to start the laser.

This enclosure contains the green laser which produces hazardous light beam intensities. Caution must be taken in operating the system and protective eyewear must be used when performing alignment. Enclosure also contains the appropriate optics and a Bragg cell is used to shift the frequency and split each laser beam into two equal intensity beams.

TK-PDI Mounting Options

The TK-PDI enclosure can be mounted to an optical table, optical rails, or other supporting fixtures.

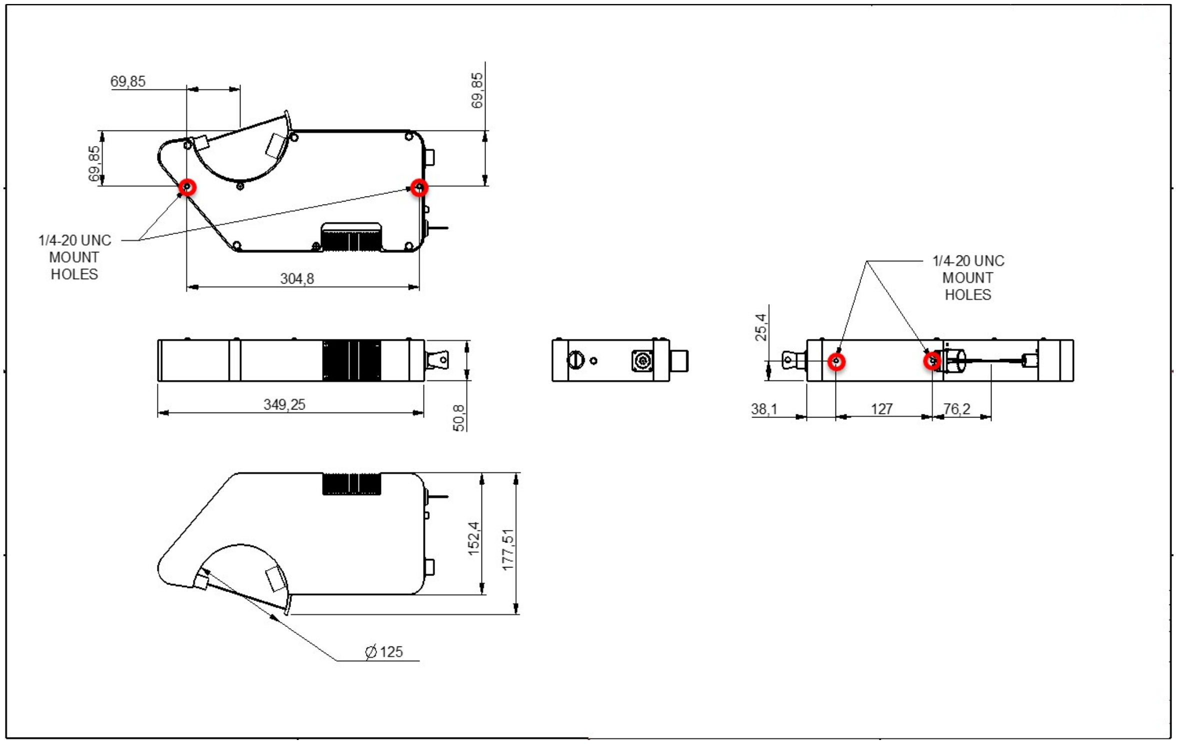


Figure 7.3: Schematic showing the TK-PDI 1 enclosure mounting holes.

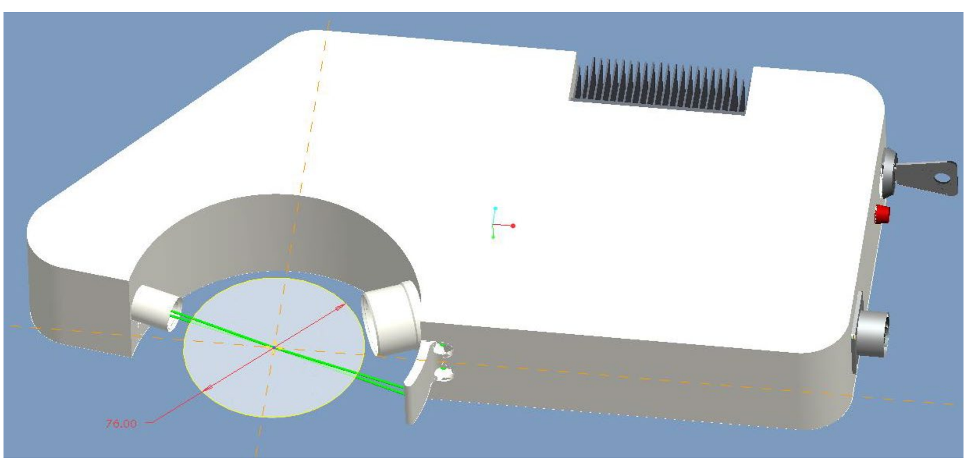


Figure 7.4: Schematic showing the TK-PDI 1 working distance without purge hoods.

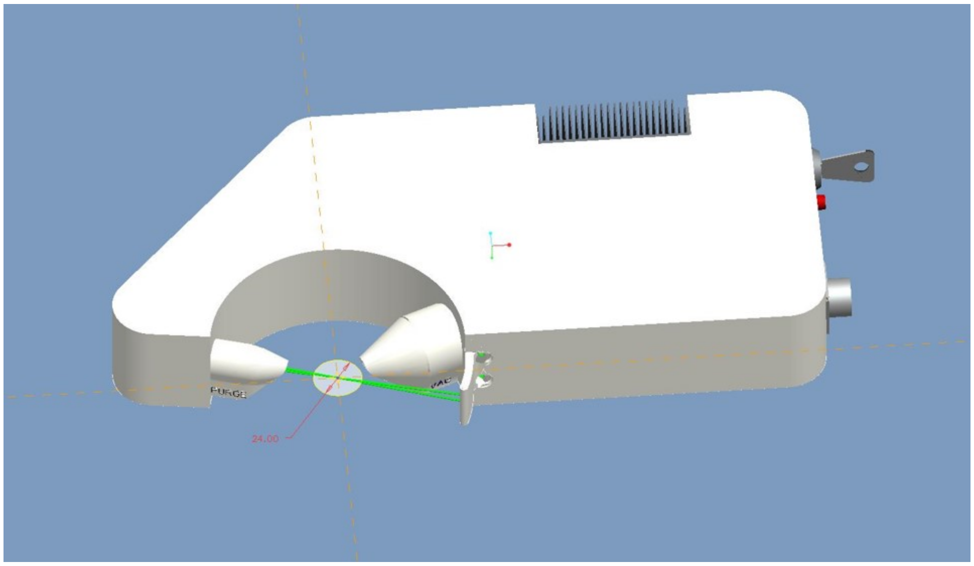


Figure 7.5: Schematic showing the TK-PDI 1 working distance with purge hoods.

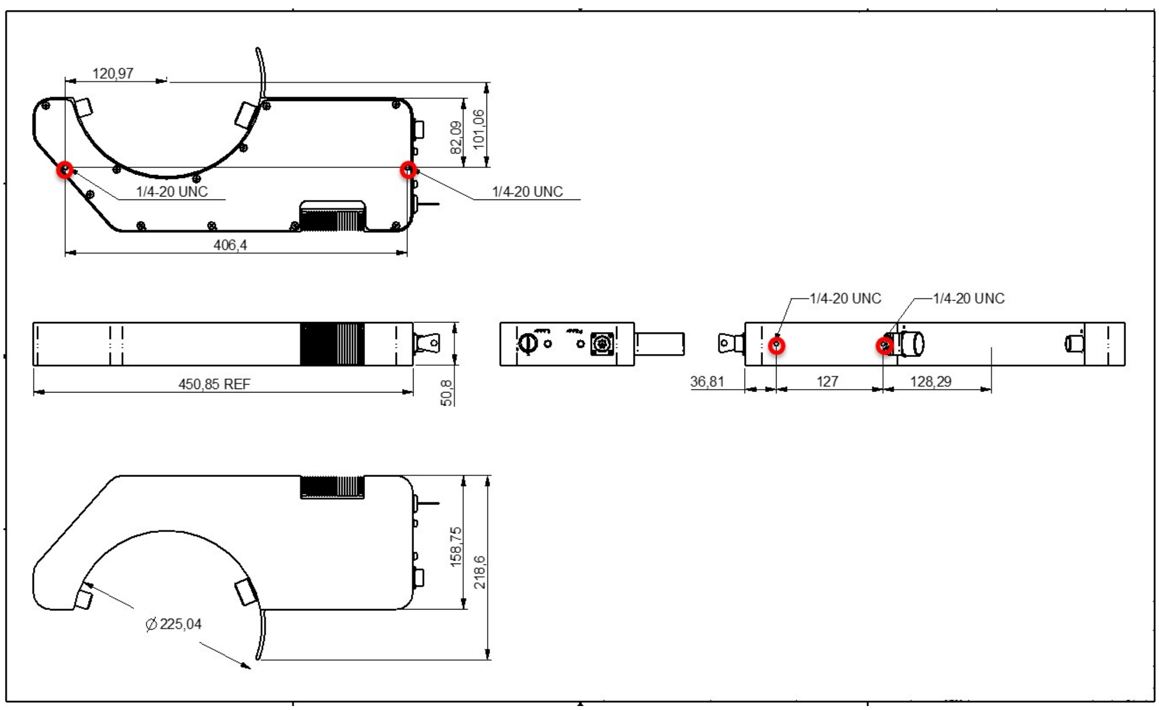


Figure 7.6: Schematic showing the TK-PDI 2 enclosure mounting holes.

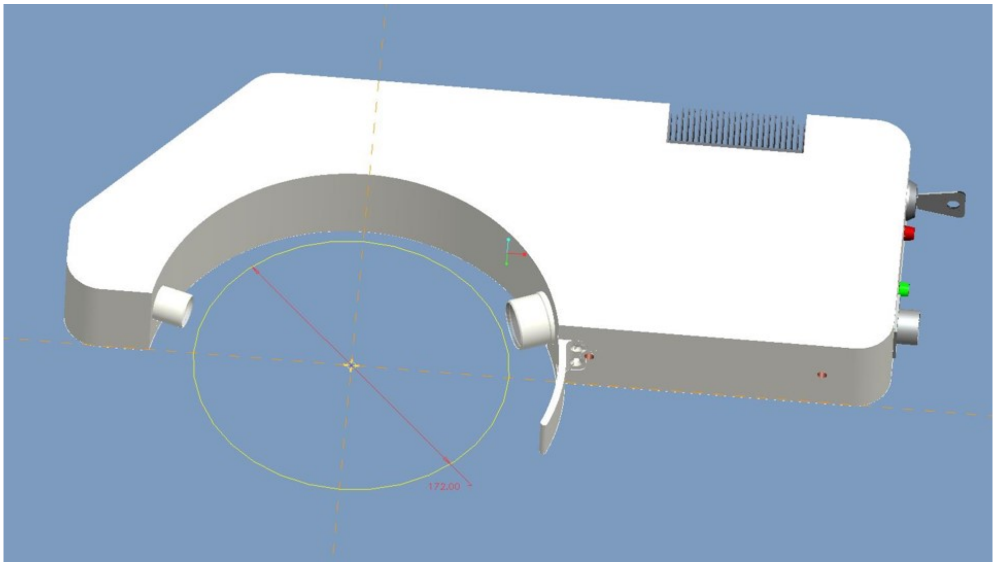


Figure 7.7: Schematic showing the TK-PDI 2 working distance without purge hoods.

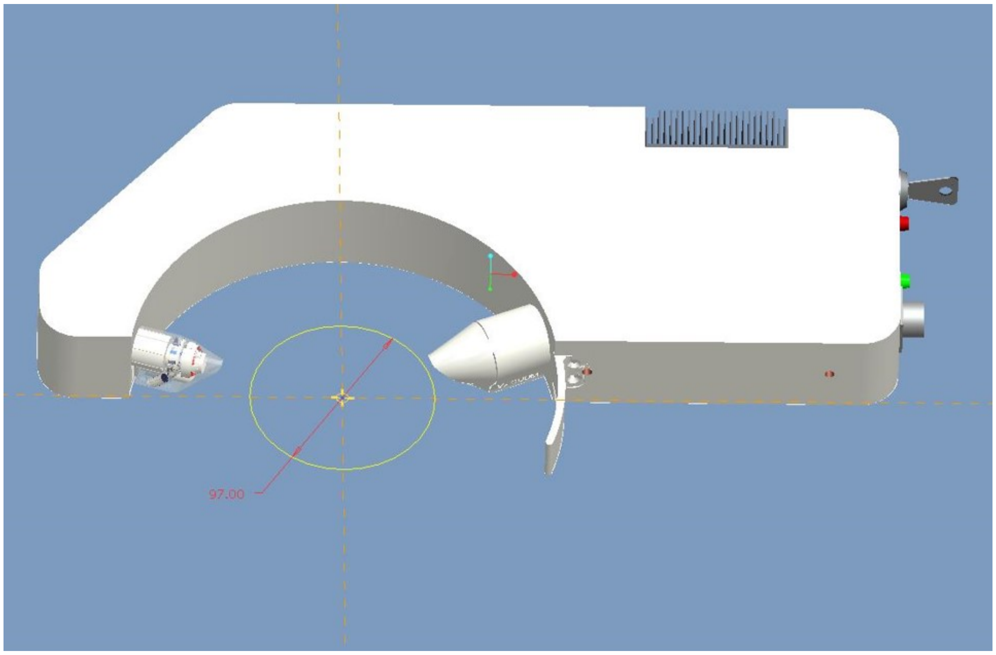


Figure 7.8: Schematic showing the TK-PDI 2 working distance without purge hoods.

Purge hoods / beam shields

The TK-PDI is supplied with hoods that protect the windows from droplets, provide anti-fogging, and protect the light paths in cases of high number density sprays. The purge hoods require both pressurized air and vacuum, and they operate on low air pressure (5-10 psi) and low flow rate. Each hood attaches to the housing with a single M3 cap head screw.

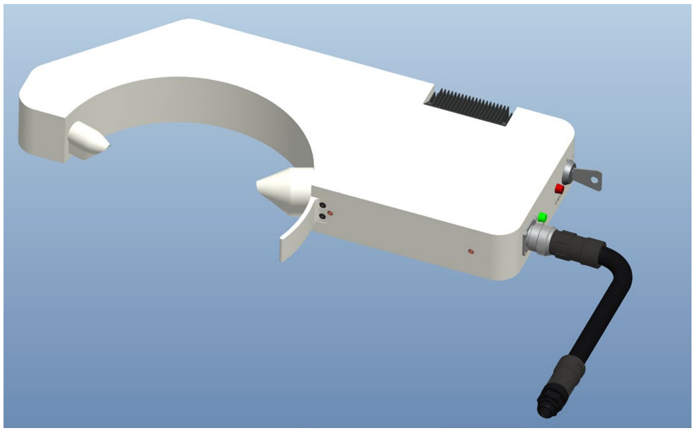


Figure 7.9: Beam shield / purge hoods installed on a TK2.

The design goal is that no air will exit the purge hood and affect the spray flow, but droplets will be prevented from entering the hoods and reaching the windows.

In most cases, the hoods alone are adequate to shield the beams and protect the windows from droplet accumulation. When this is not the case, the hoods are designed to work with both purge air and vacuum. Figures 7.10 and 7.11 show the external and internal construction of the hoods. There is a plenum for purge air that can be supplied via the PURGE port on the hood. Clean Dry Air (CDA) from a compressor or pressure cylinder source, or nitrogen, is required (not supplied by Artium). Artium supplies a pressure regulator and tubing.

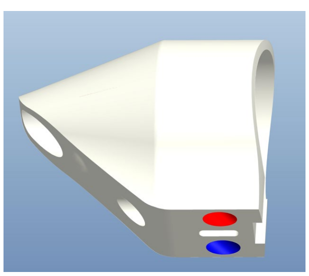


Figure 7.10: Purge hood external construction.

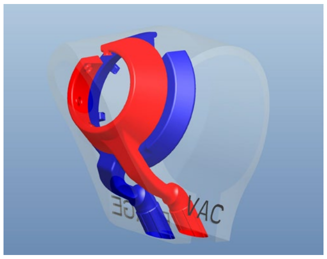


Figure 7.11: Purge hood internal construction.

The air enters the hood through radial ports along the inner circumference of the hood. This will create a slight positive pressure relative to the test flow and aid in keeping small droplets out of the hood and moisture from condensing on the TK windows. Some of this purge air will exit the hood through the open end and enter the test flow. It is important that this air not adversely affect the external flow under test. Only the minimum amount of purge air (a few psi pressure) should be used, and tests should be run to confirm that the test flow is not affected by the purge.

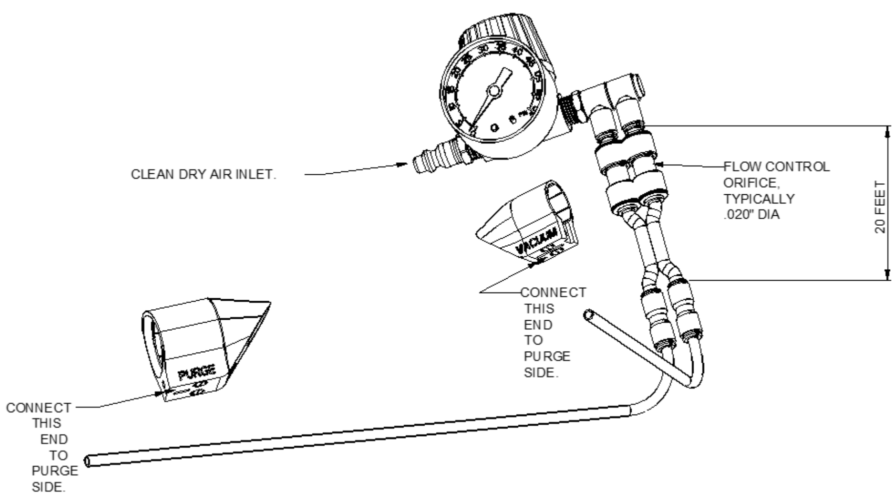


Figure 7.12: Purge hood plumbing supplied by Artium.

In cases where purge air is a necessity and there is the possibility that the air exiting the hood is affecting the external test flow, there is a separate plenum from which air can be drawn out of the hood. That port is labeled VACUUM. Artium does not supply plumbing for this feature. The vacuum plenum will draw air in through radial ports along the inner circumference of the hood. The purge and vacuum flowrates must be balanced so the net flow to the hood is zero. Too much vacuum can also adversely affect the external test flow.

CHAPTER 8

Software setup

AIMS INTRODUCTION

Artium Instrument Management Software (AIMS) is a software application for controlling hardware, data acquisition, data storage, and data analysis. AIMS works with a variety of hardware including:

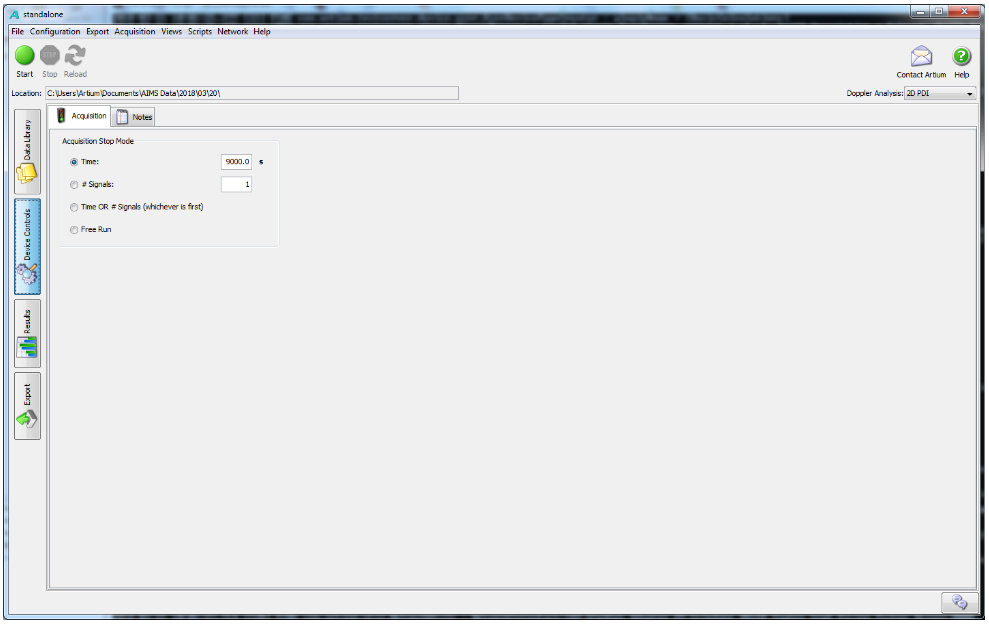
- PDI/LDV (Phase Doppler Interferometry/Laser Doppler Velocimetry)
- LII (Laser-Induced Incandescence)
- High-Speed Imaging
- Traverse (Positioning) Systems
- DAQ (analog and digital I/O) boards

AIMS runs on the Microsoft Windows platform, specifically Windows 7 and higher. Older versions of AIMS ran on Windows XP, but Windows XP is no longer supported.

AIMS GENERAL OPERATION

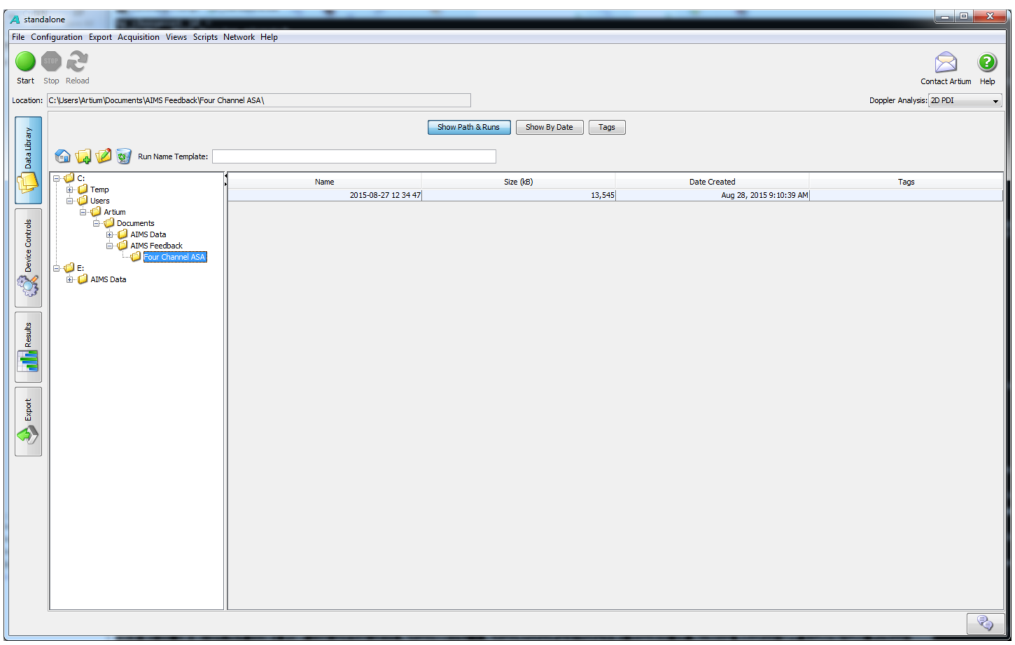
This section covers general (not specific to any instrument) operation of AIMS.

AIMS has four (4) buttons on the left side of the AIMS window: Data Library, Device Controls, Results, and Export. These control what is displayed in the AIMS window and change how the AIMS window operates:



Data Library

The Data Library organizes and displays data files for AIMS:



As files are acquired or added to AIMS, they will appear in the Data Library. The left side of the Data Library is a tree for navigation of directories containing AIMS data files. The runs table on the right side is updated to show available runs in the currently-selected directory.

To open a run, double-click on the run name in the runs table. AIMS will switch to the Results mode and display data as the run is loaded.

Right-clicking on a directory brings up a menu with the following options:

`Show Data Directory in Windows Explorer…`

Opens a Windows Explorer folder displaying the directory

`Reload Data Directory`

Reloads (scans) the data directory for AIMS data files. If AIMS data files are added to the directory manually (not through AIMS), then this will add the files to the AIMS Data Library.

Right-clicking on a run brings up a menu with the following options:

`Show Data File in Windows Explorer…`

Opens a Windows Explorer folder displaying the run

`Add Tag to Run…`

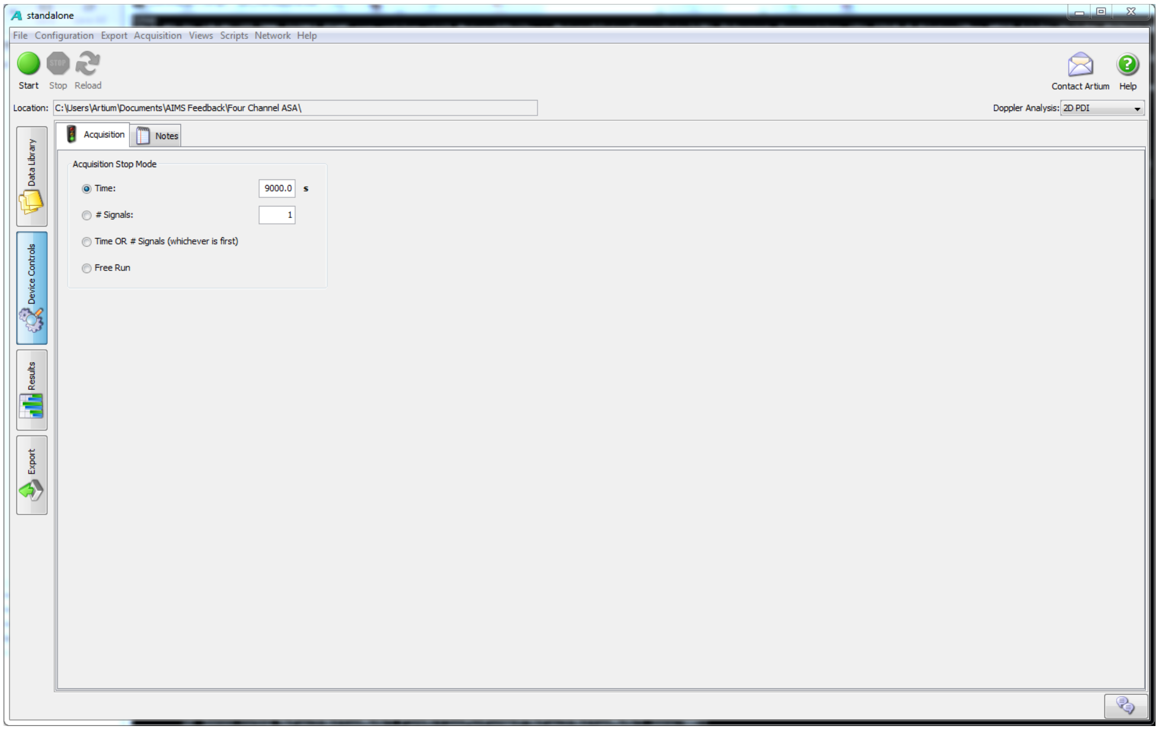
Tags are small phrases that can be associated with a run file. Tags can be used to find runs across the entire Data Library. For example, you may wish to mark runs with a name for a project (maybe “Project A”).

`Remove Tag from Run…`

Removes a selected tag from a run.

Device Controls

This mode displays the controls and settings for devices controlled by AIMS. Each device has one or more tabs covering aspects of operation (settings, calibration, etc.).



IMPORTANT: Changes made to settings in the Device Control mode only affect the current state of the instrument and do not have any effect on existing (saved) data/runs.

The available tabs will depend on what instrument(s) are controlled by AIMS and are device-specific. There are two default tabs that are always present: `Acquisition` and `Notes`.

The `Acquisition` tab set the conditions for AIMS to stop data acquisition:

`Time`

Acquisition will stop when the set time is reached.

`# Signals`

Acquisition will stop when the number of signals/samples is reached. For PDI/LDV, this is the number of valid samples. For LII, this is the number of laser shots. For Imaging, this is the number of frames.

`Time OR # Signals (whichever is first)`

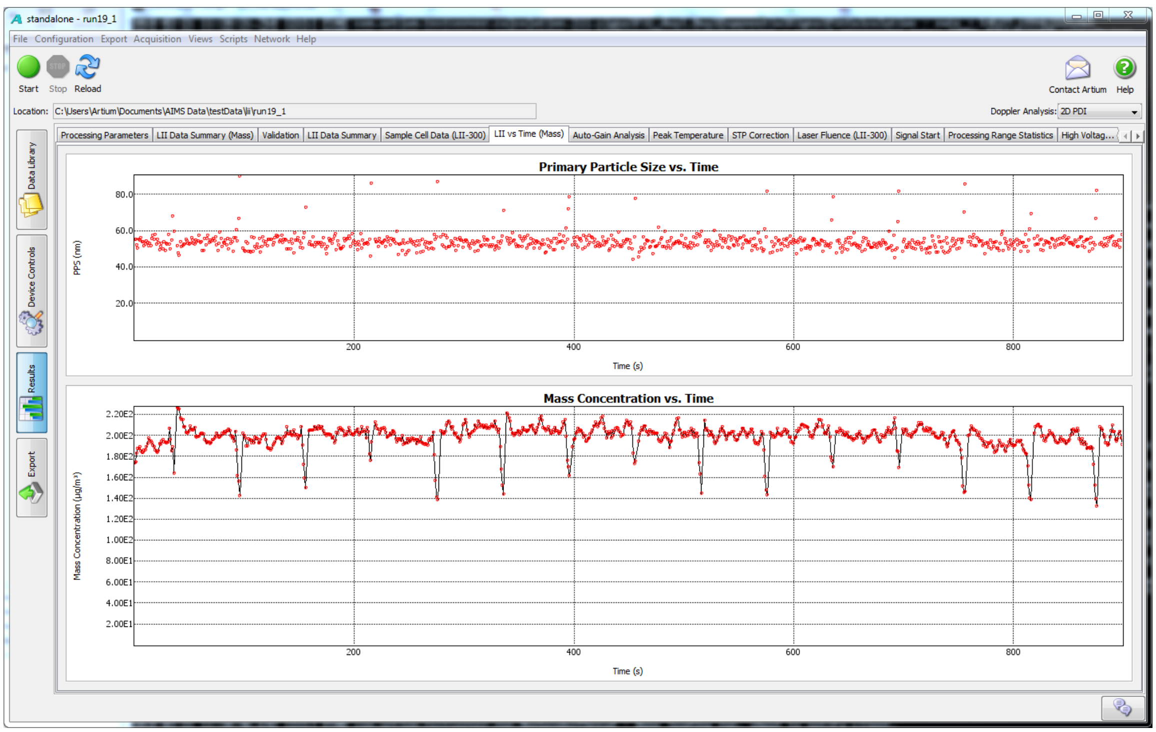
Acquisition stops when either the time or number of signals criterion is met.

`Free Run`

Acquisition stops only when the user stops (via the Stop button or the <Esc> key).

Results

Results mode displays data from one run - either loaded from disk or recently acquired. Each tab represents a different view of the data (graphs, tables, fields, etc.). Tabs/Views can be added from the `Views` menu.



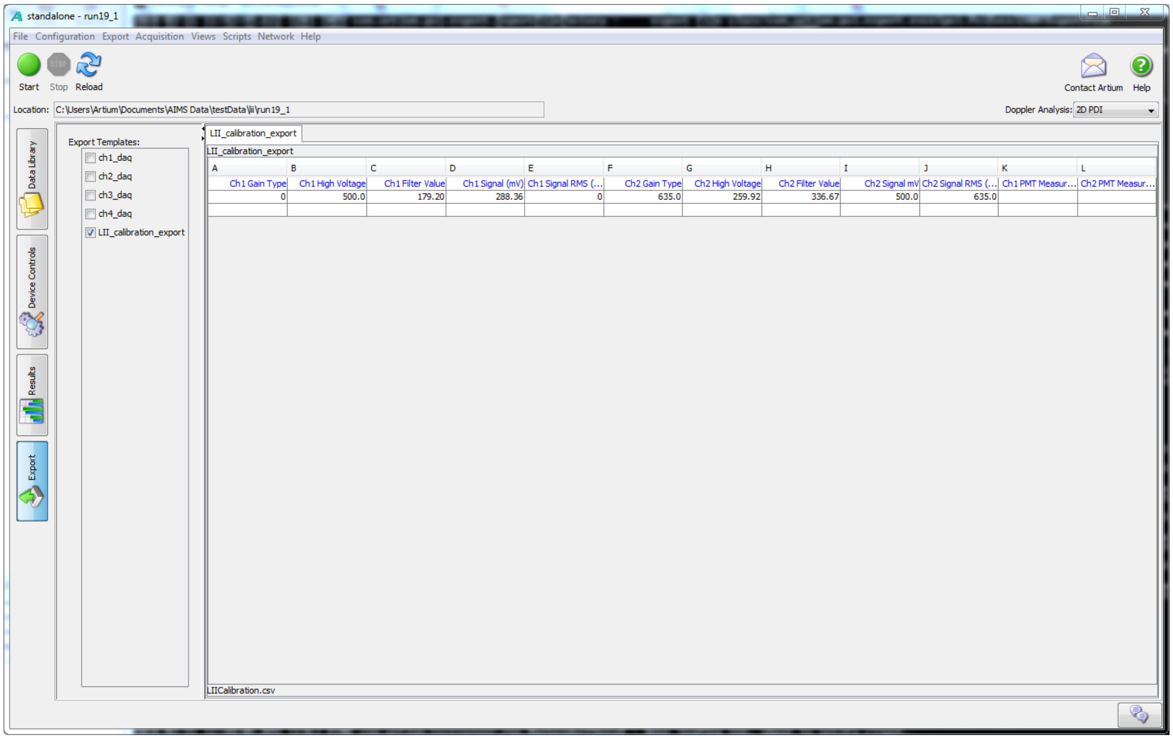
Tabs.Views can be closed by selecting `Views > Close Current View` or by pressing `<Ctrl><W>`.

You can rearrange the order of the tabs/views by clicking and holding on a tab title and then dragging left or right. When you release the mouse button the tab will be moved.

To scroll the tabs, move the mouse cursor to the tab titles and then rotate the mouse scroll wheel.

Export

The Export mode controls how data is exported from AIMS to common formats.



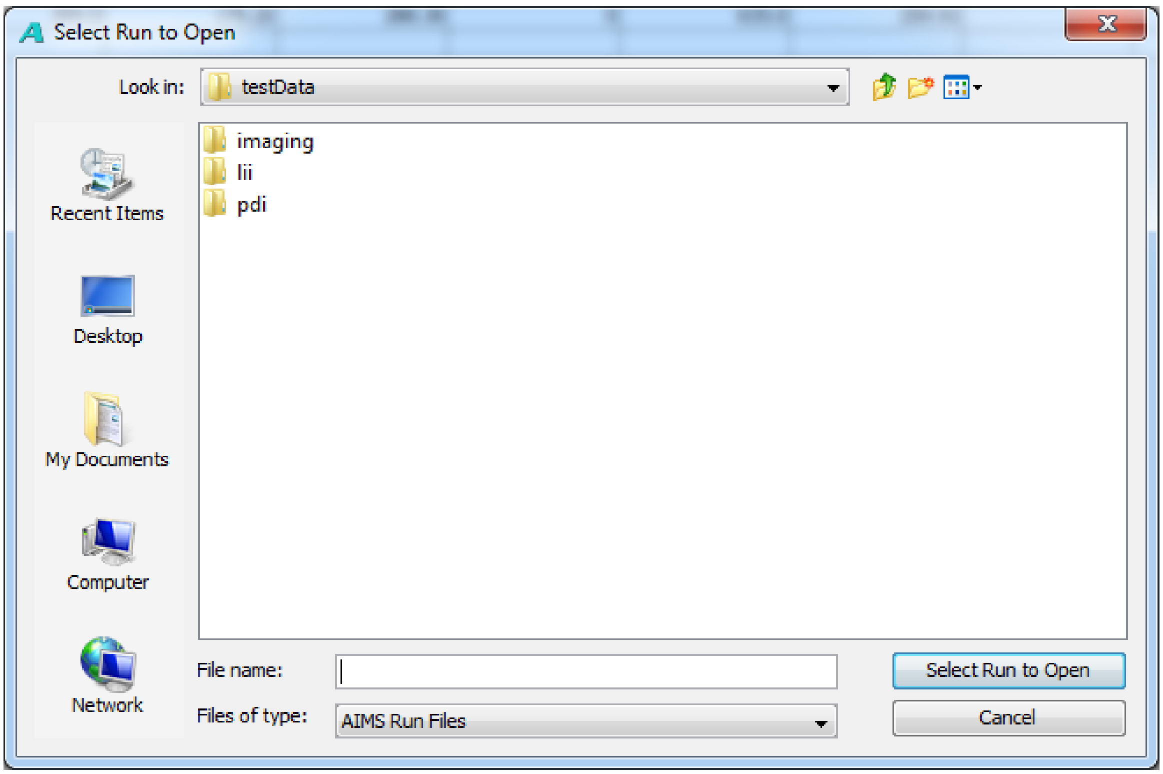
Exporting from AIMS is covered in the section *Exporting Data From AIMS*.

Menus

File Menus

Open Run

Opens a file chooser dialog to select one (1) run. The run is loaded and added to the Data Library:

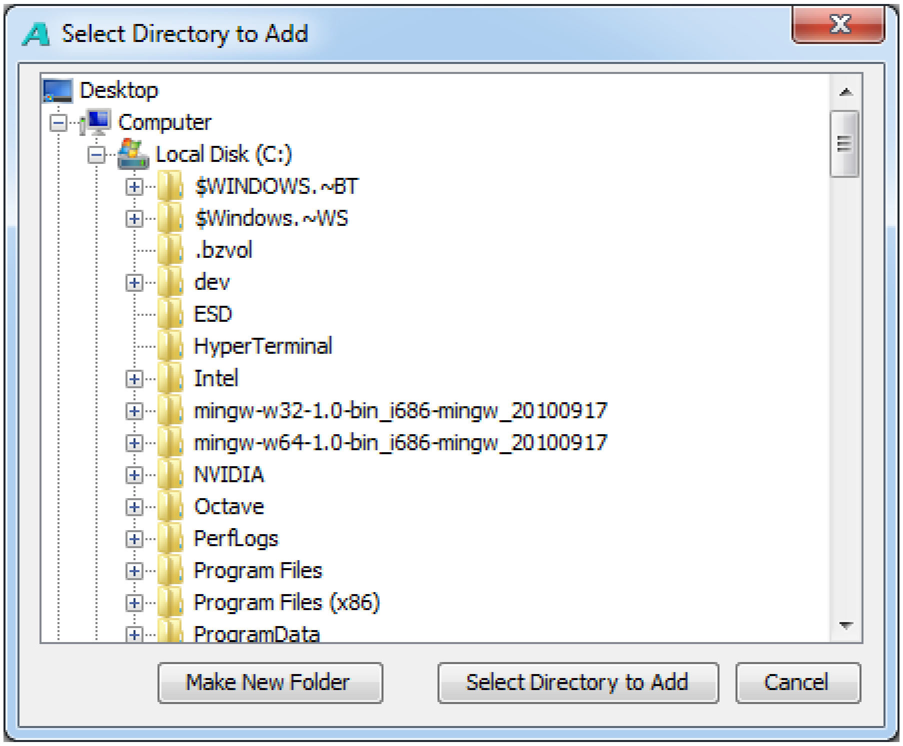


Add Run(s)...

Opens a file chooser dialog (like `Open Run`), but only adds the run to the Data Library (the run is not loaded and analyzed).

Add Directory...

Opens a directory chooser dialog (see below) to add all the runs in the selected directory to the Data Library.

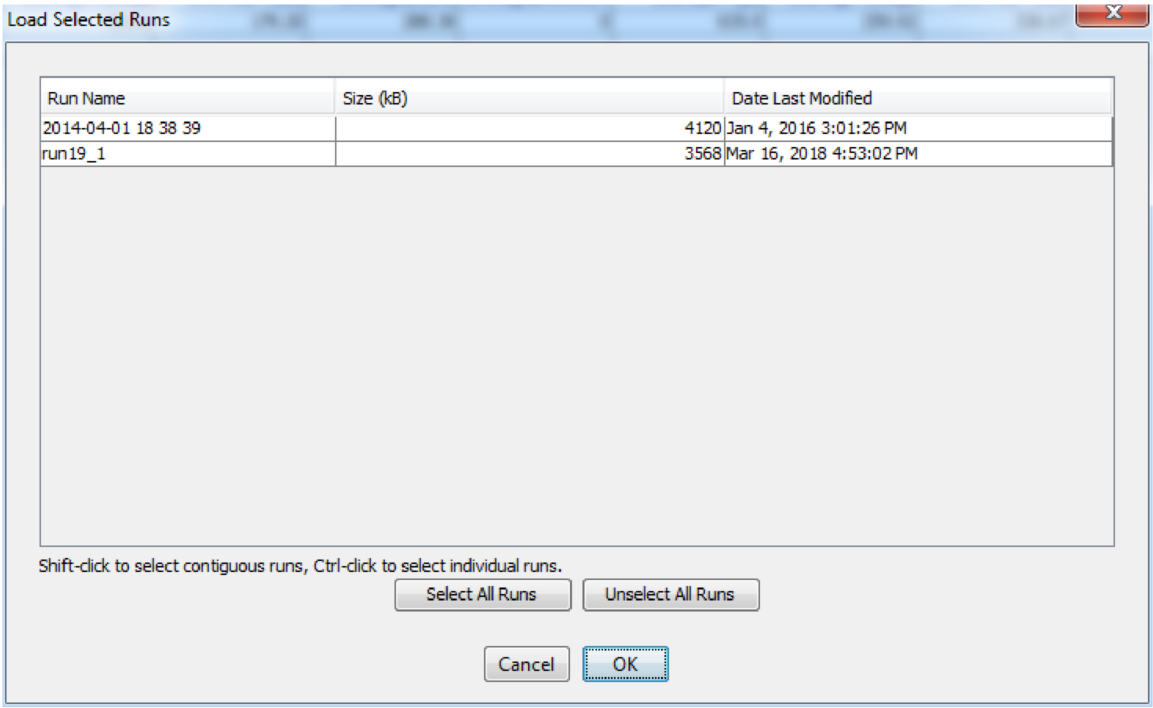


Show Data Library

Switches AIMS to the Data Library mode (same as clicking on the `Data Library` button on the left-side of the AIMS window).

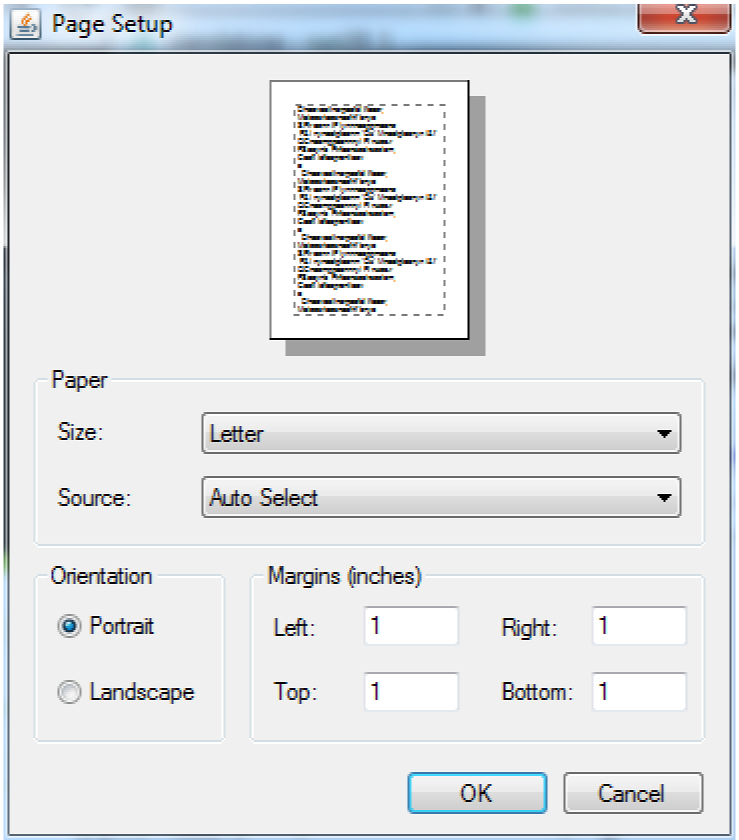
Load Selected Runs…

Displays a dialog to load selected runs (from the currently-selected directory). Selected runs are loaded one after another. This is intended for use with graphs that plot data from multiple runs.



Page Setup…

Displays the printer page setup dialog for setting printing parameters:



Print Current Page…

Prints the currently selected view/tab.

Configuration Menu

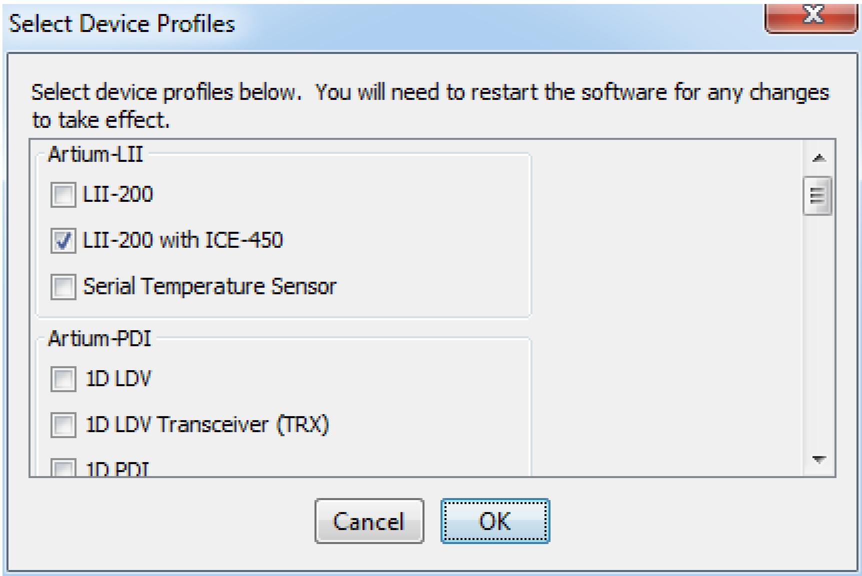
Create Configuration, Select Configuration, Edit Configuration

These options are covered in the Configurations section of this manual.

Hardware > Set Device Profiles…

Displays the Set Device Profiles dialog used to tell AIMS what hardware to look for on startup. If you make any changes in this dialog, you will need to restart AIMS for them to take effect.

IMPORTANT: Unless directed by Artium, you should not need to make any changes to the selected device profiles.



Hardware > Backup Device Databases…

Makes a backup (.zip file) of all the current device databases and displays a file chooser dialog to specify where to save the backup. The device database files contain all of the settings, parameters, and calibration information needed for operation and data analysis using the connected hardware.

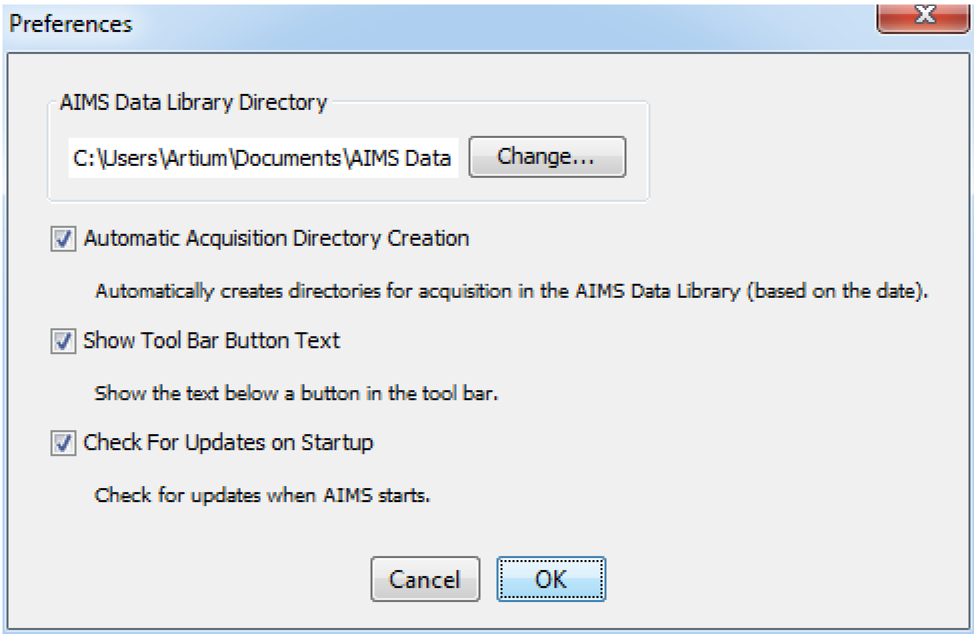
Hardware > Restore Device Databases…

Restores the device databases using a previous backup. Note that AIMS makes a backup copy of the device databases on each startup. Restoring to a backup overwrites the existing device settings, parameters and calibration.

IMPORTANT: Unless directed by Artium, you should not need to restore the device databases.

Preferences

Displays the Preferences dialog:



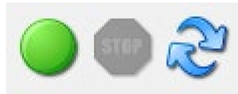
The `AIMS Data Library Directory` is the location where new runs (data) are saved.

If `Automatic Acquisition Directory Creation` is enabled, AIMS will create directories based on the current date (for automatic organization). For example, if the date was August 5, 3025, AIMS would create the following directories:

```
AIMS Data
    \3025
        \08
            \05
```

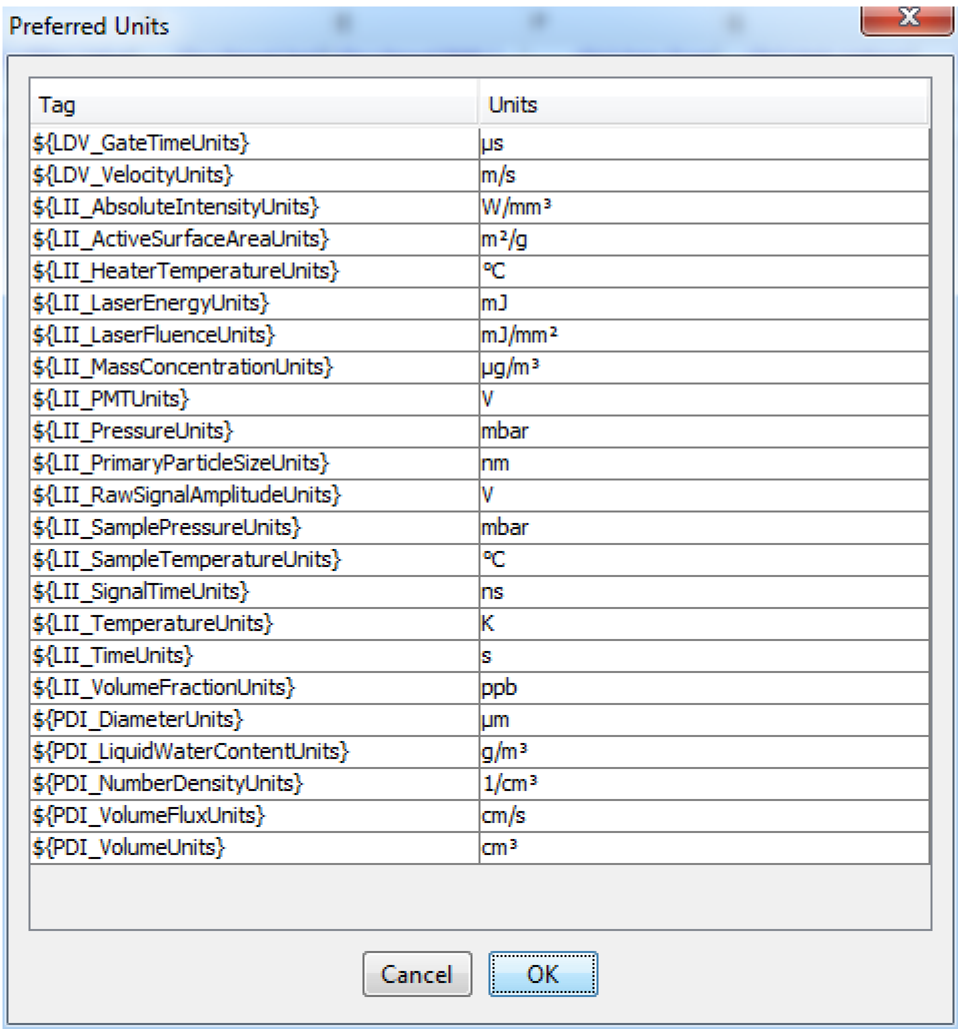
`Show Tool Bar Button Text` controls whether tool bar buttons also have text displayed:

vs.



Set Preferred Units…

Displays a dialog to set preferred display units for various quantities:

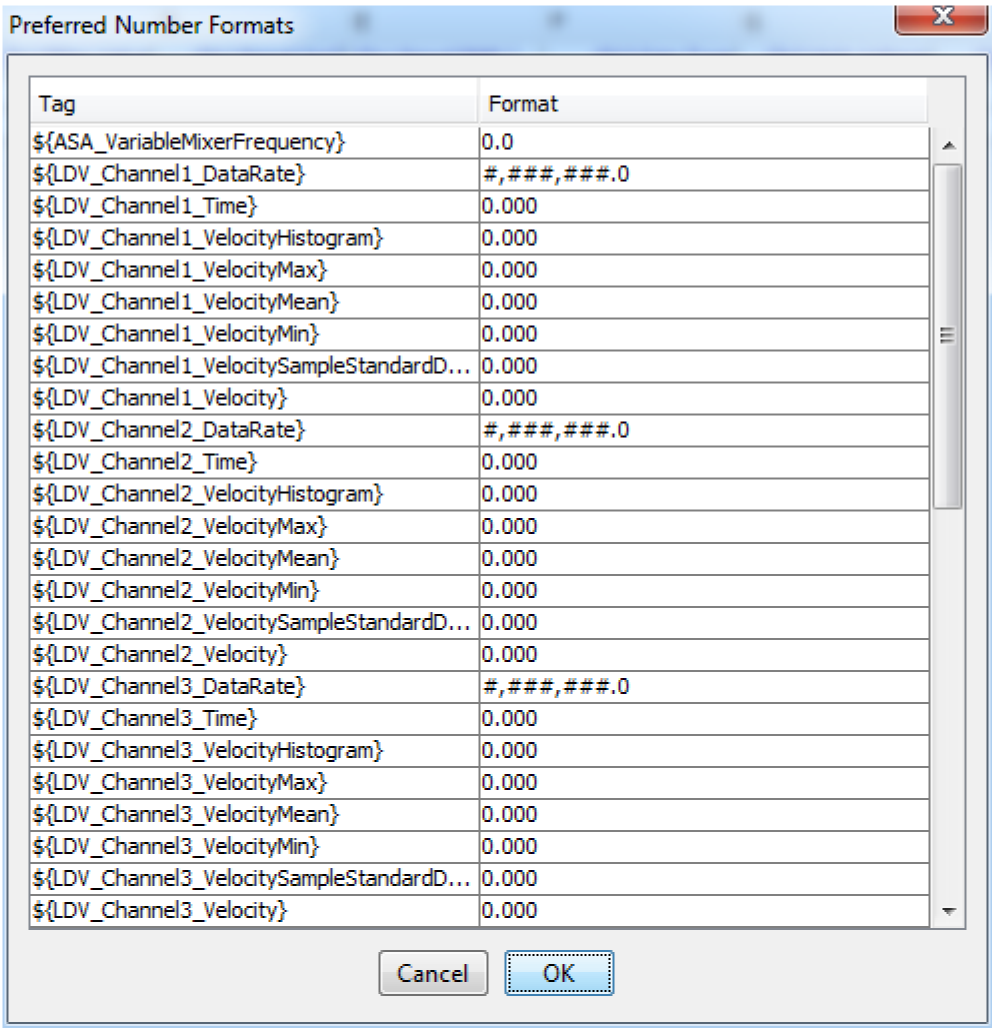


Tag	Units
${LDV_GateTimeUnits}	µs
${LDV_VelocityUnits}	m/s
${LII_AbsoluteIntensityUnits}	W/mm^3
${LII_ActiveSurfaceAreaUnits}	m^2/g
${LII_HeaterTemperatureUnits}	°C
${LII_LaserEnergyUnits}	mJ
${LII_LaserFluenceUnits}	mJ/mm^2
${LII_MassConcentrationUnits}	µg/m^3
${LII_PMTUnits}	V
${LII_PressureUnits}	mbar
${LII_PrimaryParticleSizeUnits}	nm
${LII_RawSignalAmplitudeUnits}	V
${LII_SamplePressureUnits}	mbar
${LII_SampleTemperatureUnits}	°C
${LII_SignalTimeUnits}	ns
${LII_TemperatureUnits}	K
${LII_TimeUnits}	s
${LII_VolumeFractionUnits}	ppb
${PDI_DiameterUnits}	µm
${PDI_LiquidWaterContentUnits}	g/m^3
${PDI_NumberDensityUnits}	1/cm^3
${PDI_VolumeFluxUnits}	cm/s
${PDI_VolumeUnits}	cm^3

Any changes will be reflected the next time AIMS starts. Contact Artium for more information about available units.

Set Preferred Number Formats...

Displays a dialog to set preferred formats for various quantities.



Tag	Format
${ASA_VariableMixerFrequency}	0.0
${LDV_Channel1_DataRate}	#,###,###.0
${LDV_Channel1_Time}	0.000
${LDV_Channel1_VelocityHistogram}	0.000
${LDV_Channel1_VelocityMax}	0.000
${LDV_Channel1_VelocityMean}	0.000
${LDV_Channel1_VelocityMin}	0.000
${LDV_Channel1_VelocitySampleStandardD...	0.000
${LDV_Channel1_Velocity}	0.000
${LDV_Channel2_DataRate}	#,###,###.0
${LDV_Channel2_Time}	0.000
${LDV_Channel2_VelocityHistogram}	0.000
${LDV_Channel2_VelocityMax}	0.000
${LDV_Channel2_VelocityMean}	0.000
${LDV_Channel2_VelocityMin}	0.000
${LDV_Channel2_VelocitySampleStandardD...	0.000
${LDV_Channel2_Velocity}	0.000
${LDV_Channel3_DataRate}	#,###,###.0
${LDV_Channel3_Time}	0.000
${LDV_Channel3_VelocityHistogram}	0.000
${LDV_Channel3_VelocityMax}	0.000
${LDV_Channel3_VelocityMean}	0.000
${LDV_Channel3_VelocityMin}	0.000
${LDV_Channel3_VelocitySampleStandardD...	0.000
${LDV_Channel3_Velocity}	0.000

Any changes will be reflected the next time AIMS starts.

Export Menu

The functionality of the `Export` menu is detailed in the *Exporting Data From AIMS* section.

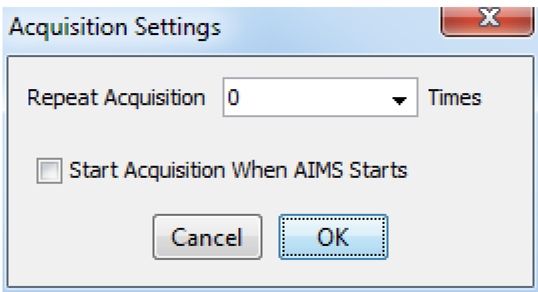
Acquisition Menu

Show Device Controls

Displays the Device Controls mode in AIMS.

Acquisition Settings…

Displays the acquisition settings dialog:



The `Repeat Acquisition` field can be use to repeat acquisition automatically when a run ends. This is useful for breaking up long runs or to acquire data for extended periods of time.

If `Start Acquisition When AIMS Starts` is enabled, data acquisition will begin immediately after AIMS has completed the startup process (finding devices, loading views, etc.).

Start Data

Starts data acquisition. Data is automatically saved to disk.

Stop Data

Stops data acquisition or stops loading a run from disk.

Quick Check (Not Save To Disk)

Starts data acquisition, but the data is NOT saved to disk. This is intended for testing/alignment where the runs are not meant to be saved.

Views Menu

Show Results

Switches AIMS to the Results mode for displaying data (both live acquisition and loading from disk).

Previous Tab

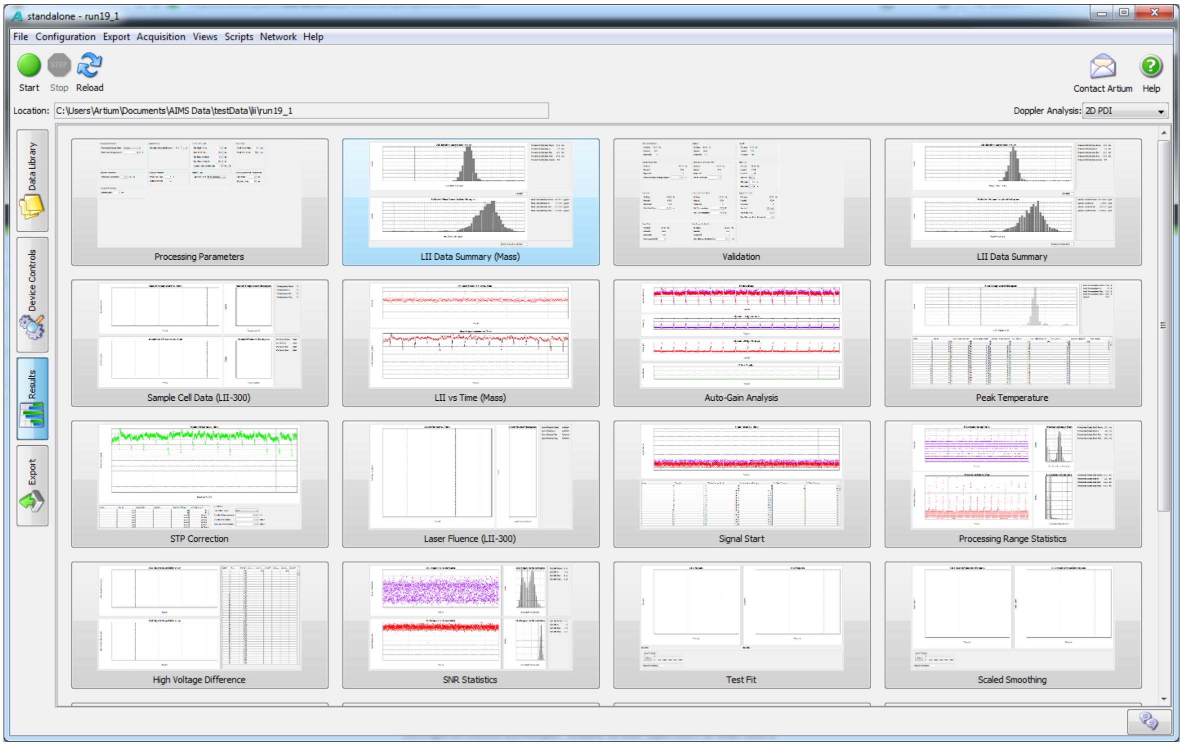
Switches to the next tab (to the right of the current tab).   The keyboard command <Ctrl><Left Arrow> does the same thing.

Next Tab

Switches to the previous tab (to the left of the current tab). The keyboard command <Ctrl><Right Arrow> does the same thing.

Show Tab Selector

Displays the tab selector, a preview of all open tabs:



Clicking on a thumbnail for a tab will open that tab.

Close Current View

Closes the currently-selected tab/view.

Close Views With Multiple Runs

Closes all tabs/views that display data from multiple runs at one time. Most tabs/views show data only from the currently-selected run at one time.

Custom > New Custom Graph View

For more information on this option, see the section *Plotting Data Versus Traverse Position* for an example.

Scripts Menu

The `Scripts` menu is for running and creating AIMSScript programs. AIMSScript is a simple command language for AIMS to automate repetitive tasks (like mapping out a spray using a positioning system).

For information on the syntax/format of AIMSScript see the section *AIMSScript*.

Run Script…

AIMS will present a file selection dialog. Select the script to run which should have a .script extension) and AIMS will parse the script. If no syntax errors are found, the AIMS will open a window to show the progress of running the script. If any syntax errors are found, AIMS will display them in the script window.

Create Script From Points File…

See the *AIMSScript* section for more information.

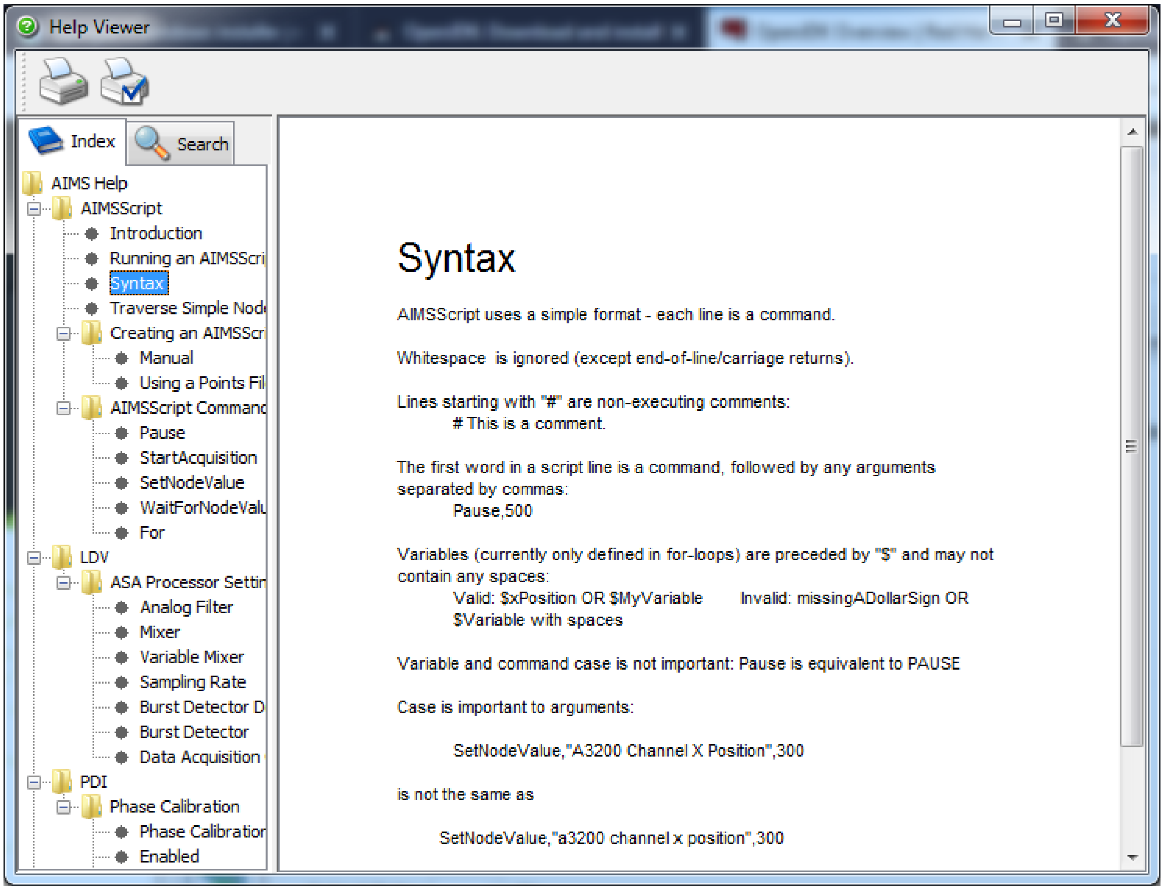
Network Menu

The options in the `Network` menu are explained in the *AIMS Remote Connection* section.

Help Menu

Display Help Contents

Displays the AIMS built-in help viewer:



About This Program

Displays a dialog that shows version information about AIMS:

About AIMS

AIMS

Standalone Version:5.0

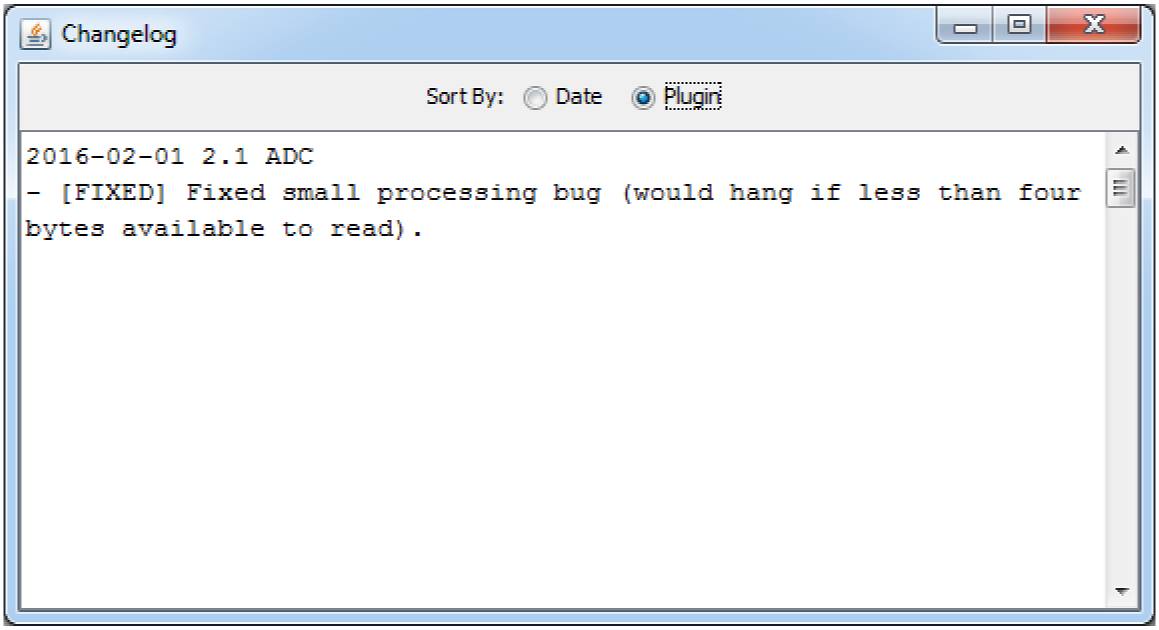
Plugins

Name	Version	Build Description	Branch	Changeset ID
ADC	2.1	2018-Mar-16 1...	default	5f053dce3c64
AkProtocol	1.1	2018-Mar-16 1...	default	5f053dce3c64
BasicCalculations	1.2	2018-Mar-20 0...	default	5f053dce3c64
DualFlightProbe	3.2	2018-Mar-16 1...	default	5f053dce3c64
Flight Probe He...	1.0	2018-Mar-16 1...	default	5f053dce3c64
Imaging	8.1	2018-Mar-16 1...	default	5f053dce3c64
LDV	4.4	2018-Mar-16 1...	default	5f053dce3c64
LII	8.0	2018-Mar-20 1...	default	5f053dce3c64
MeasurementC...	3.1	2018-Mar-16 1...	default	5f053dce3c64
PDI	4.0	2018-Mar-16 1...	default	5f053dce3c64
Traverse	1.0	2018-Mar-16 1...	default	5f053dce3c64
WebServer	1.0	2018-Mar-16 1...	default	5f053dce3c64
UserDevice	-1.-1	- Unknown		

Close

Show Changelog

Displays the changelog for AIMS:



Show Settings Directory…

Opens the AIMS settings directory in Windows Explorer.

Save Current Log File…

Displays a file chooser dialog to specify a location to save the current AIMS internal og file.

Add Note to Log File…

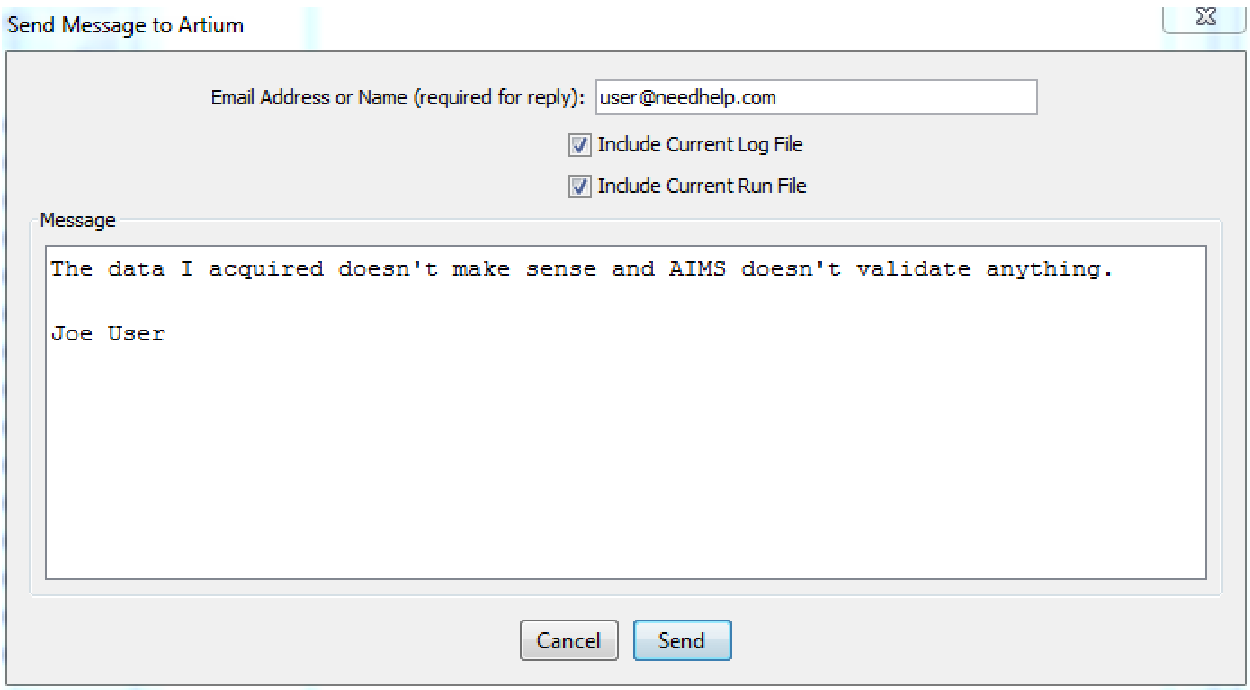
Adds a note to the AIMS internal log file (for troubleshooting).

Capture Screen to PNG…

Takes a screenshot of the AIMS window and saves it to the PNG (Portable Network Graphics) format.

Contact Artium…

If the computer running AIMS is connected to the Internet, you can submit the current log and/or run files directly to Artium via AIMS. Selecting **`Help > Contact Artium...`** from the AIMS menu displays the `Send Message to Artium` dialog:



Make sure to include a valid email address to enable Artium to reply to your message.

Browse to artium.com

Opens the artium.com website in your default browser.

Check For Update…

Checks for an available update to AIMS. This functionality is still being developed.

AIMSScript

Introduction

AIMSScript is a simple, yet powerful, method for automating AIMS data acquisition.

Running an AIMSScript Program

To run an AIMSScript program, select `Scripts > Run Script...` from the program menu. AIMS will present a file selection dialog. Select the script to run which should have a `.script` extension) and AIMS will parse the script. If no syntax errors are found, the AIMS will open a window to show the progress of running the script. If any syntax errors are found, AIMS will display them in the script window.

Syntax

AIMSScript uses a simple format - each line is a command.

Whitespace is ignored (except end-of-line/carriage returns).

Lines starting with `#` are non-executing comments:

```
# This is a comment.
```

The first word in a script line is a command, followed by any arguments separated by commas:

```
Pause,500
```

Variables (currently only defined in for-loops) are preceded by `$` and may not contain any spaces:

Valid: `$xPosition` OR `$MyVariable`
Invalid: `missingADollarSign` OR `$Variable with spaces`

Variable and command case is not important: `Pause` is equivalent to `PAUSE`

Case is important to arguments:

```
SetNodeValue,"A3200 Channel X Position",300
```

is not the same as

```
SetNodeValue,"a3200 channel x position",300
```

Traverse Simple Node Paths

ACS (Serial Port)

`ACSSerial Is Traverse Moving`

Value of 0 indicates traverse has stopped moving.

`ACSSerial Channel X Position`

X-axis position. Y and Z axes are the same format.

ACS Tech 80

`ACS Tech80 Is Traverse Moving`

Value of 0 indicates traverse has stopped moving.

`ACS Tech80 Channel X Position`

X-axis position. Y and Z axes are the same format.

Aerotech A3200

`A3200 Is Traverse Moving`

Value of 0 indicates traverse has stopped moving.

`A3200 Channel X Position`

X-axis position. Y and Z axes are the same format.

Aerotech Soloist

`AerotechSoloist Is Traverse Moving`

Value of 0 indicates traverse has stopped moving.

`AerotechSoloist Channel X Position`

X-axis position. Y and Z axes are the same format.

American Precision Industries (Serial Port)

`AmericanPrecisionIndustries Is Traverse Moving`

Value of 0 indicates traverse has stopped moving.

`American Precision Industries Traverse Channel X Position`

X-axis position. Y, Z, and W axes are the same format.

Compumotor 6K

`Compumotor6K Is Traverse Moving`

Value of 0 indicates traverse has stopped moving.

`Compumotor6K Channel X Position`

X-axis position. Y, Z, and T axes are the same format.

isel Microstep C142

`isel Is Traverse Moving`

Value of 0 indicates traverse has stopped moving.

`isel Channel X Position`

X-axis position. Y and Z axes are the same format.

Manual Traverse

`Manual Traverse X Position`

X-axis position. Y and Z axes are the same format.

OWIS PS90

`OWIS PS 90 Is Traverse Moving`

Value of 0 indicates traverse has stopped moving.

`OWIS PS 90 X Position`

X-axis position. Y and Z axes are the same format.

Seika

`Seika Is Traverse Moving`

Value of 0 indicates traverse has stopped moving.

`Seika X Position`

X-axis position. Y and Z axes are the same format.

Sigma-Koki PAT-001

`PAT-001 Is Traverse Moving`

Value of 0 indicates traverse has stopped moving.

`PAT-001 Channel X Position`

X-axis position. Y and Z axes are the same format.

Parker ACR9000

`Parker ACR9000 Is Traverse Moving`

Value of 0 indicates traverse has stopped moving.

`Parker ACR9000 Traverse Channel X Position`

X-axis position. Y, Z, and W axes are the same format.

Primatics MDC1800

`Primatics MDC1800 Is Traverse Moving`

Value of 0 indicates traverse has stopped moving.

`Primatics MDC1800 X Position`

X-axis position. Y and Z axes are the same format.

Unidex 11/12

`Unidex 11 Is Traverse Moving`

Value of 0 indicates traverse has stopped moving.

`Unidex 11 Channel X Position`

X-axis position. Y and Z axes are the same format.

Velmex VP9000/VXM

`Velmex Is Traverse Moving`

Value of 0 indicates traverse has stopped moving.

`Velmex Channel X Position`

X-axis position. Y, Z, and T axes are the same format.

Yaskawa SMC4000

`Yaskawa Is Traverse Moving`

Value of 0 indicates traverse has stopped moving.

`Yaskawa SMC-4000 Channel X Position`

X-axis position. Y, Z, and W axes are the same format.

Creating an AIMSScript Program

Manual

Open a text editor and type in the AIMSScript by hand. The extension of the file should be `.script`

Using a Points File

This method takes a list of nodes to set, along with a list of values for those nodes generates an AIMSScript program automatically.

For example, if we wanted to move an Aerotech A3200 traverse system across a set of points, we might use a points file like:

```
A3200 Channel X Position,A3200 Channel Y Position
100,300
200,350
300,450
,465
```

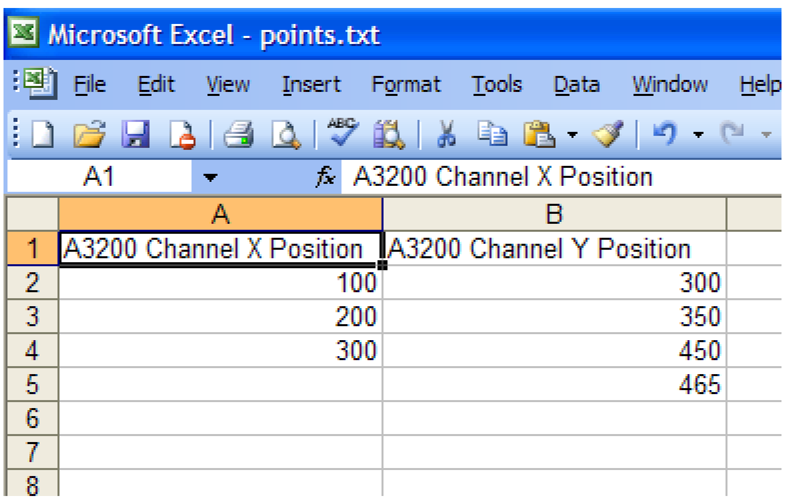
to generate a script program of:

```
# Generated by AIMS from points.script at Thu May 19
15:40:24 PDT 2005
SetNodeValue,A3200 Channel X Position,100.0
SetNodeValue,A3200 Channel Y Position,300.0
StartAcquisition
SetNodeValue,A3200 Channel X Position,200.0
SetNodeValue,A3200 Channel Y Position,350.0
StartAcquisition
SetNodeValue,A3200 Channel X Position,300.0
SetNodeValue,A3200 Channel Y Position,450.0
```

```
StartAcquisition
SetNodeValue,A3200 Channel Y Position,465.0
StartAcquisition
```

The first line in the points file defines the nodes to be set. The remaining lines are the values to set. Note that the last line of the points file only specifies a value for the Y-axis, and that the last set of commands in the script file only include the Y-axis.

In addition to text files, you can also define the points in a Microsoft Excel spreadsheet (even using formulas to define the points). There are some caveats: The points must be on the first sheet of the workbook/spreadsheet, and the node names and points must be the only values on the first sheet.



AIMSScript Command Reference

Pause

Syntax

```
Pause,time
```

Description

The `Pause` command causes AIMS to pause for a specified amount of time (in milliseconds).

Example

```
Pause,500
```

StartAcquisition

Syntax

```
StartAcquisition
```

Description

The `StartAcquisition` command starts data acquisition. It does not take any arguments.

Example

```
StartAcquisition
```

SetNodeValue

Syntax

```
SetNodeValue,node name,value,units
```

Description

The `SetNodeValue` command sets a device node value. The node name is the one-line node name (like `A3200 Channel X Position`). The value is the value to set (like `23.5`). For traverse commands, the units are `#`.

Example

```
SetNodeValue,A3200 Channel X Position,23.5,#
```

WaitForNodeValue

Syntax

```
WaitForNodeValue,node name,value,units
```

Description

The `WaitForNodeValue` pauses a script until the specified node has the requested value. The node name is the one-line node name (like `A3200 Is`

`Traverse Moving`). The value is the value to wait for (like 0 for traverse movement to stop). For traverse commands, the units are `#`.

Example

```
WaitForNodeValue,A3200 Is Traverse Moving,0,#
```

For

The `For` command implements a for-loop - a loop that executes a fixed number of times. Additionally, the for-loop defines a loop variable which is updated every trip through the loop and can be used by commands inside the for-loop.

Syntax

```
for,$variable,start value,end value,num values
endfor
```

Description

The variable name must start with a $ and not have any spaces (like `$loopvariable`). The start value is the first value that the variable will be set to. After the first value, the variable will be set to start value + (delta * current step). delta is defined as (end value - start value) / (num values - 1). current step is an integer value that ranges from 0 to num values.

Example:

```
for,$loopvariable,1.5,10.8,4
    SetNodeValue,A3200 Channel X Position,$loopvariable
    StartAcquisition
Endfor
```

This is equivalent to:

```
SetNodeValue,A3200 Channel X Position,1.5
StartAcquisition
SetNodeValue,A3200 Channel X Position,4.6
StartAcquisition
```

```
SetNodeValue,A3200 Channel X Position,7.7
StartAcquisition
SetNodeValue,A3200 Channel X Position,10.8
StartAcquisition
```

Note that for-loops can be nested, so the following is legal syntax:

```
for,$x,1.5,10.8,4
    for,$y,-5,5,10
        SetNodeValue,A3200 Channel X Position,$x
        SetNodeValue,A3200 Channel Y Position,$y
        StartAcquisition
    endfor
endfor
```

Plotting Data Versus Traverse Position

(Custom Views)

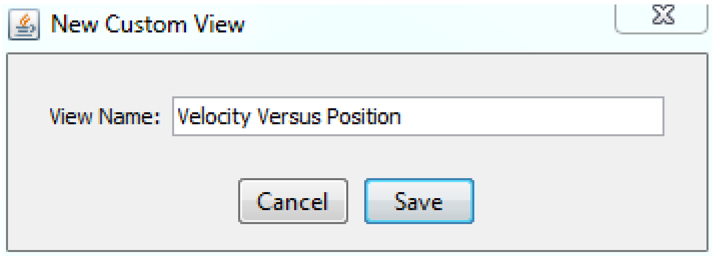
2012-08-07

Introduction

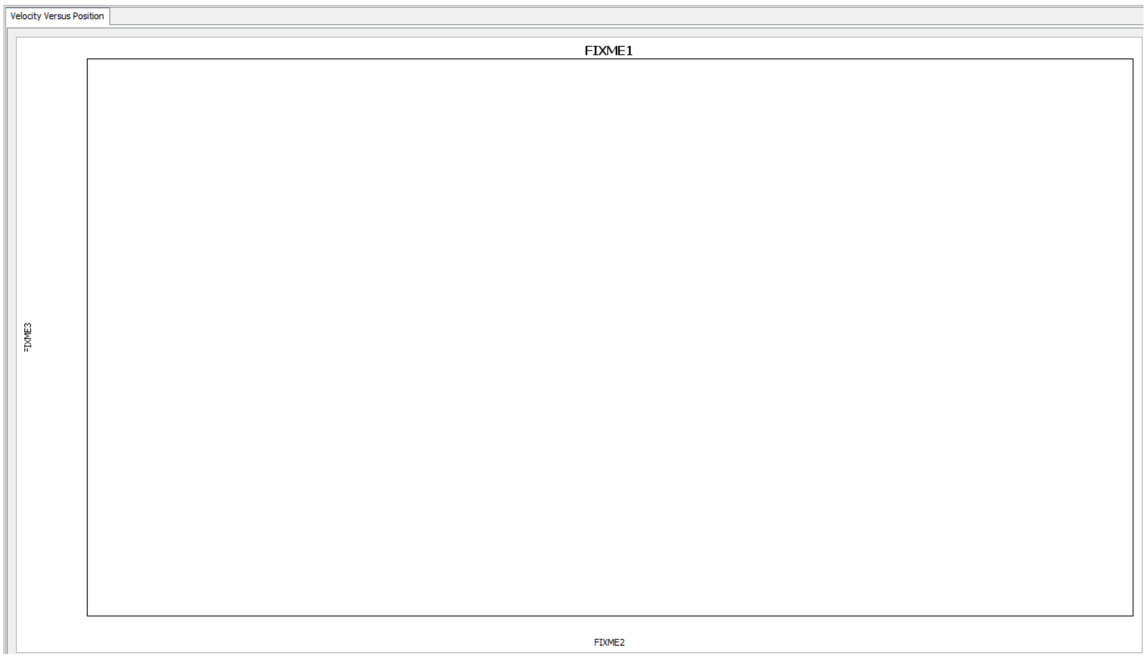
This document details how to create a custom plot of data versus traverse position. The plot can be updated in real-time during a traverse scan, or loaded later from saved data.

Create Custom View

The first step is creating a custom view to hold the new plot. Select **Views > Custom > New Custom Graph View...** and enter a name for the new view:

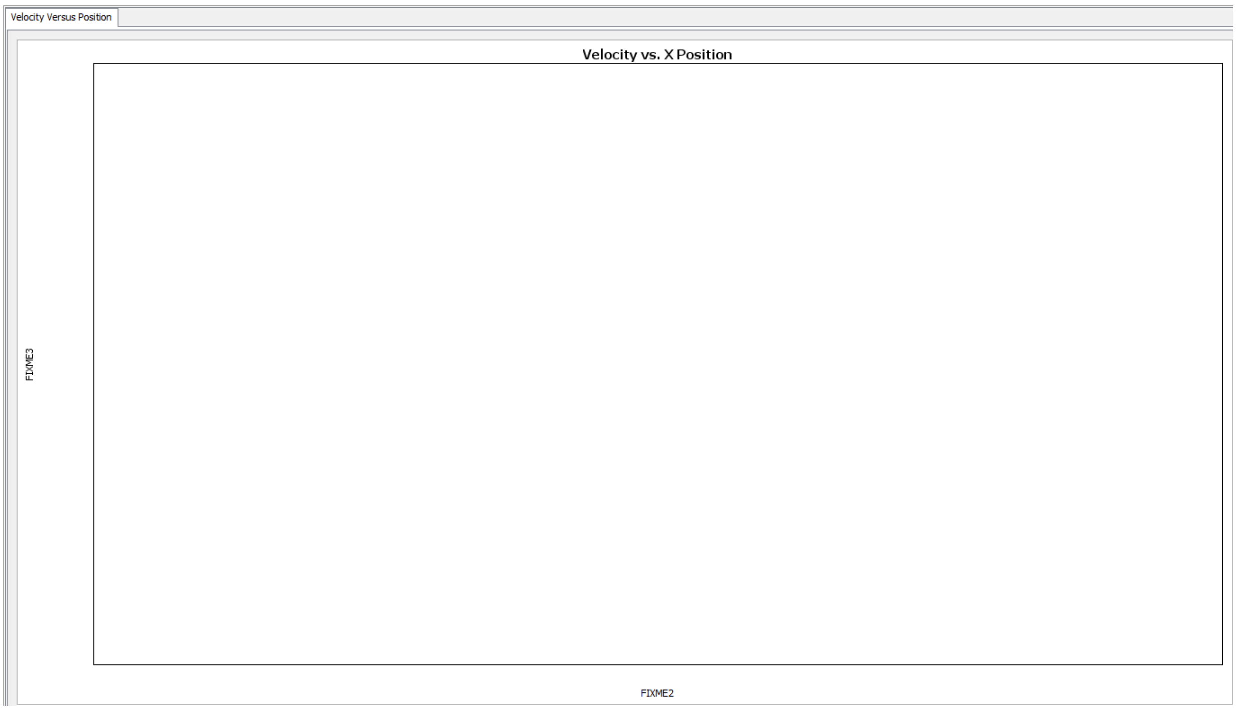


After entering the name, click **Save**. To open the custom view (using the name in the example above), select **Views > Custom > Velocity Versus Position**:



Set Plot Title

Note that the plot and axis titles are are set to FIXME. To change the plot title, right-click on the plot and select **Set Graph Title...**. In this example we will title the plot *Velocity vs. X Position*:

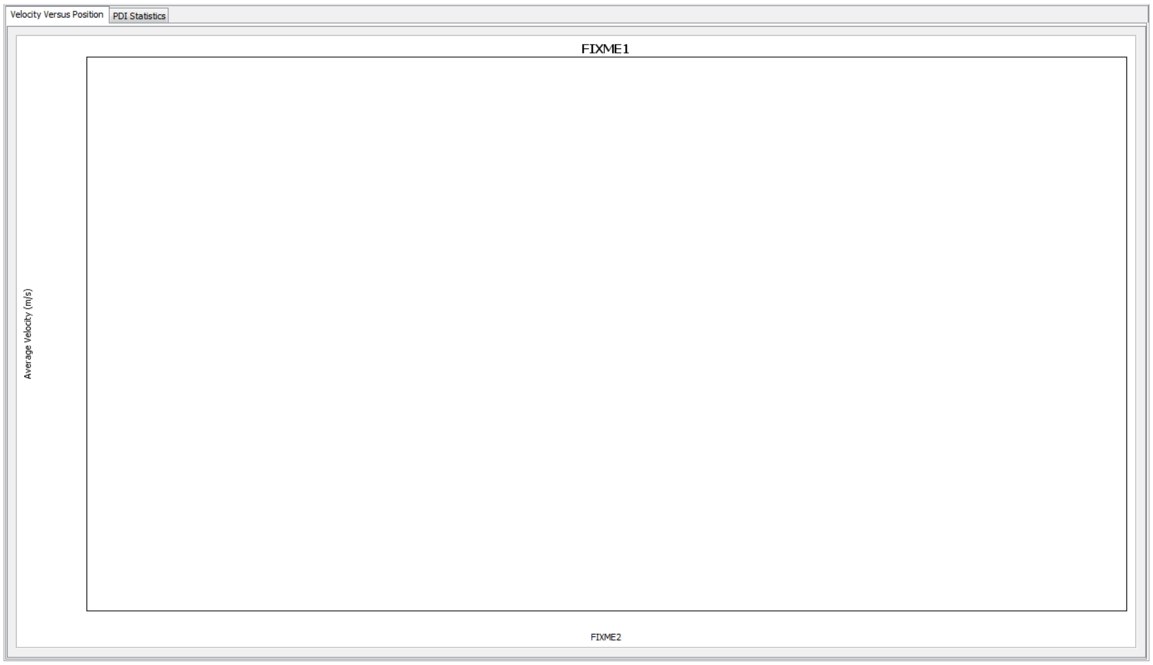


Define Axes

To define the X and Y axes, we need to select data from other views in AIMS. We'll assume the Doppler Mode is set to 1D PDI for this example, but data from any mode is fine. All data must be single-valued, i.e., velocity mean or D_{32}, but not velocity versus time.

Y-Axis

To set the Y-axis, we'll open the PDI Statistics view (**Views > PDI > Results > PDI Statistics**). Then right-click on the *Average Velocity* field and select **Copy Definition to Clipboard**. Now select the *Velocity Versus Position* view and right-click on the plot and choose **Set Y Axis Definition From Clipboard**:



X-Axis

In this example, the X-axis of the plot will be the position of the x-axis of the traverse. There are two places to get the definition of the x-axis position - choose it from the Device Controls traverse view, or select the traverse in **Views > Traverses**. We will use the isel iMC-S8 controller in this example, so select **Views > Traverses > Isel iMC-S8**:

Right-click on Axis 1 Position and select **Copy Definition to Clipboard**. Then select the *Velocity Versus Position* view and right-click on the plot and choose **Set X Axis Definition From Clipboard**:

That’s all there is to creating a custom view - we are finished.

Notes

If you acquire data, it will be added to the plot automatically. If you change directories, the plot will be cleared. You can also clear the plot by selecting **Views > Clear Views with Multiple Runs**.

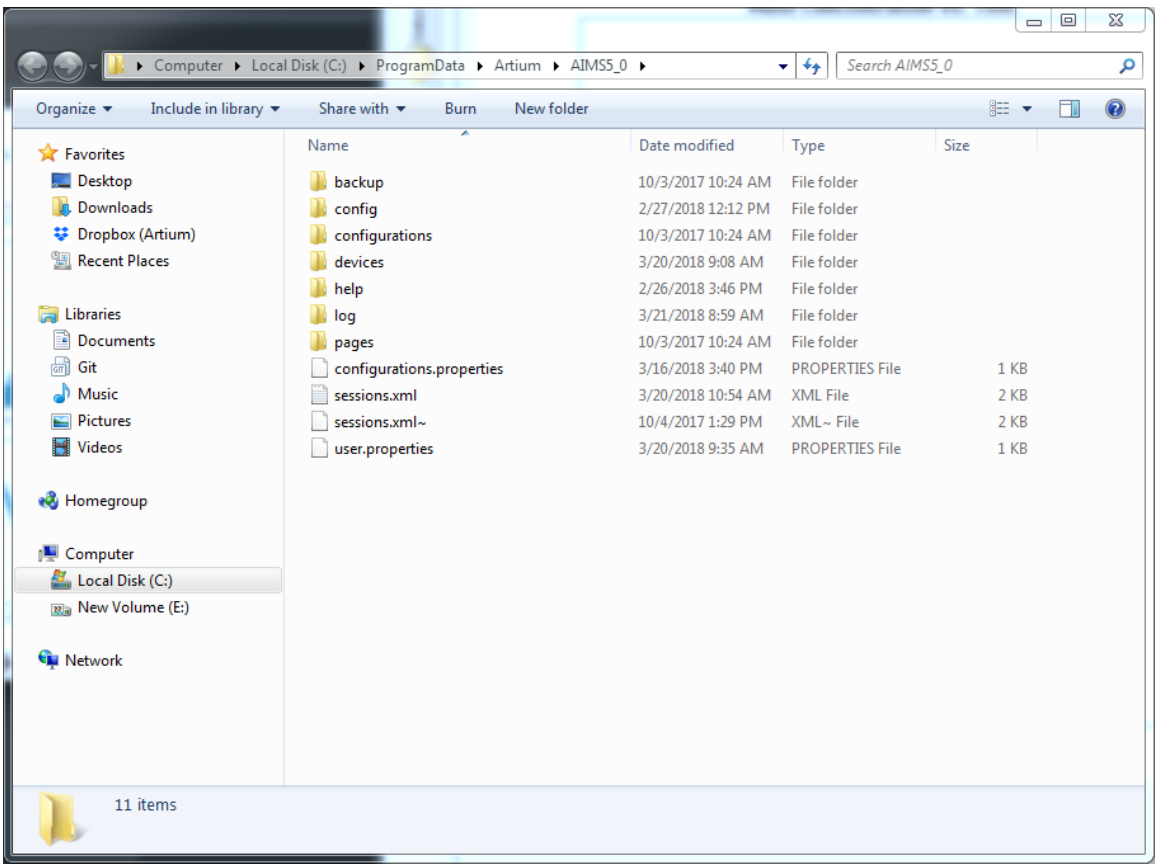
You can also load saved data and the plot will include this data. To load multiple runs (to populate the plot), select **File > Load Selected Runs...**.

AIMS Troubleshooting

Having trouble with AIMS? This section includes steps to prevent problems and steps that will help you resolve issues.

Backing Up Important Files

AIMS has a variety of files needed for correct operation. These files all reside in the Settings directory. You can access the Settings directory from AIMS by selecting Help > Show Settings Directory - this will open the Settings directory in the Windows Explorer:



IMPORTANT - The files in the Settings directory contain calibration data (and user settings) so they should not altered, modified, or moved.

The location of the Settings directory depends on the version of Windows you are using:

Windows XP

```
C:\Documents and Settings\All Users\Application
Data\Artium\AIMSX_Y
```

Windows 7

```
C:\ProgramData\Artium\AIMSX_Y\log
```

Where `X_Y` is the AIMS version (i.e, 5_0 for AIMS 5.0).

When backing up the Settings directory, make sure to copy the entire contents. The backup should be made on another computer or drive that is separate from the computer running AIMS.

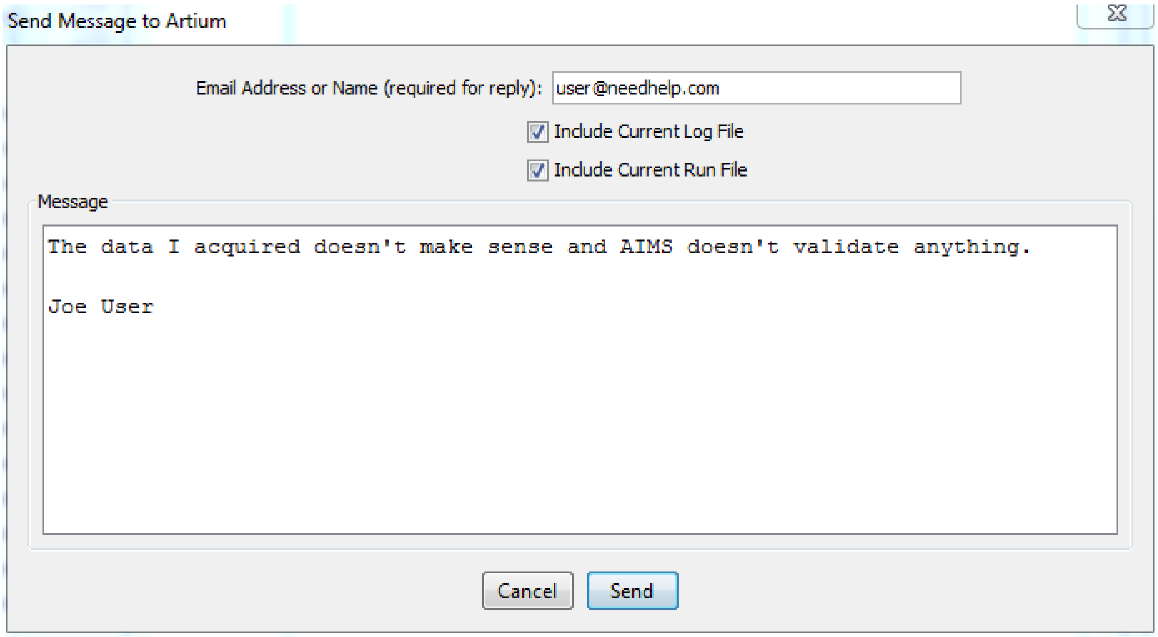
Log Files

When running, AIMS creates a log file that contains information about what AIMS is doing and also any errors encountered during operation. This log can be useful to Artium when troubleshooting issues. Log files are not designed for users to interpret - there is no strict format and may change at any time.

For each day of operation, AIMS creates a log file in the **`log`** directory of the Settings directory. The name of the log file is **`standaloneYYYY-MM-DD.log`**, where `YYYY`=year (2018), `MM`=month(03 for March), and `DD`=day of month.

Contacting Artium

If the computer running AIMS is connected to the Internet, you can submit the current log and/or run files directly to Artium via AIMS. Selecting **`Help > Contact Artium...`** from the AIMS menu displays the `Send Message to Artium` dialog:



Make sure to include a valid email address to enable Artium to reply to your message.

AIMS Remote Connection

Introduction

AIMS can connect to another version of AIMS or an Artium LII-300 instrument via a network connection. This allows full access to the remote AIMS/LII-300 and also the ability to copy data back to the local version of AIMS. For the LII-300, this also allows for more detail/in-depth analysis of LII results.

Compatibility

AIMS versions after 5.0 and LII-300 versions after 9.0 are not network-compatible with older versions.

Requirements

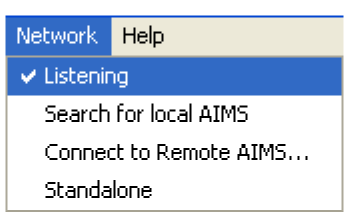
To connect to another version of AIMS, the two computers must be connected via network (Ethernet). You can make a simple network with a router and two ethernet cables. Most "home" routers will automatically supply IP (Internet Protocol) addresses and route information between any computers attached to them.

Getting Started

The first step is to make sure the remote computer has access enabled.

Enable Remote Access (AIMS/Windows)

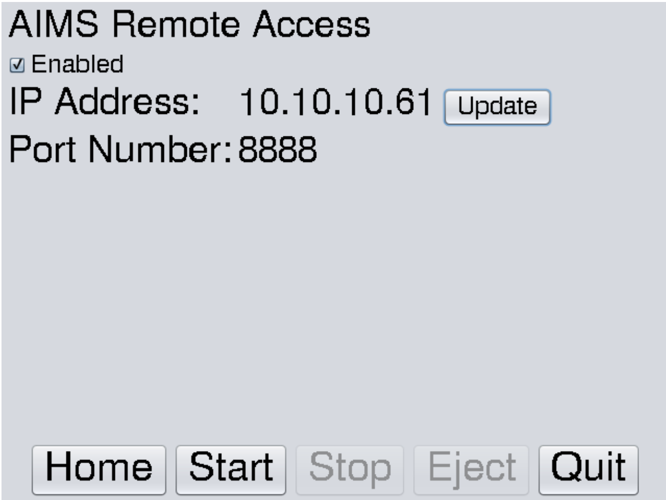
On the remote computer make sure AIMS has a checkmark next to the `Listening` item in the `Network` menu:



If not, select `Listening` to enable it.

Enable Remote Access (LII-300)

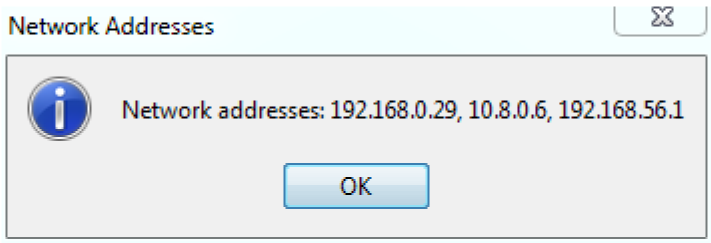
Remote Access allows a normal version of AIMS to talk to the LII-300 via a network connection. Remote Access can be enabled or disabled via the front panel of the LII-300. To reach the Remote Access screen, select `Home > Settings > Remote Access`:



Press the `Update` button to verify the IP address of the LII-300. You will need this and the `Port Number` to connect AIMS to the LII-300.

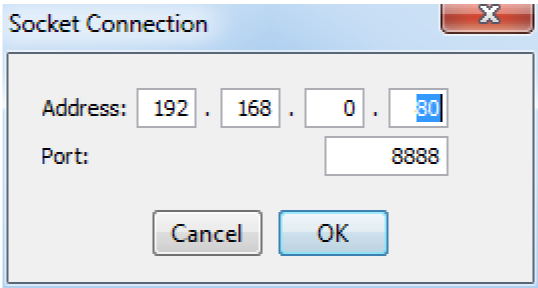
Finding IP Address (AIMS/Windows)

In AIMS, select Network > Show Network Address(es). This will display a dialog with any network addresses that the computer has (there may be more than one):



Connect to Remote AIMS/LII-300

In the local instance of AIMS, select `Network > Connect to Remote AIMS...` This will open the Socket Connection dialog:



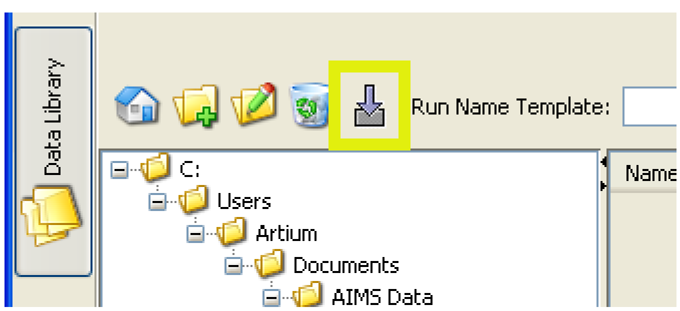
Enter the IP Address and Port number of the remote AIMS/LII-300. The default Port is 8888.

Quit and restart AIMS. When AIMS restarts, it will attempt to connect to the remote AIMS/LII-300. Remote operation will be a little slower than standalone/local operation since AIMS must retrieve data and information from the remote computer.

When in remote/network mode, AIMS has full access to the remote AIMS - you can start/stop acquisition, load data, change device settings - anything you would normally do when AIMS is running in local mode.

Copying Data from Remote AIMS/LII-300

To copy data from the remote AIMS to the local computer, open a run and then click on the download button:



Switching Back To Local/Standalone Mode

To switch the local AIMS back to local/standalone mode (this means AIMS will get all data, etc. off the local hard drive instead of via the network), select `Network > Standalone` and restart AIMS.

Moving AIMS to Another Computer

2017-11-27

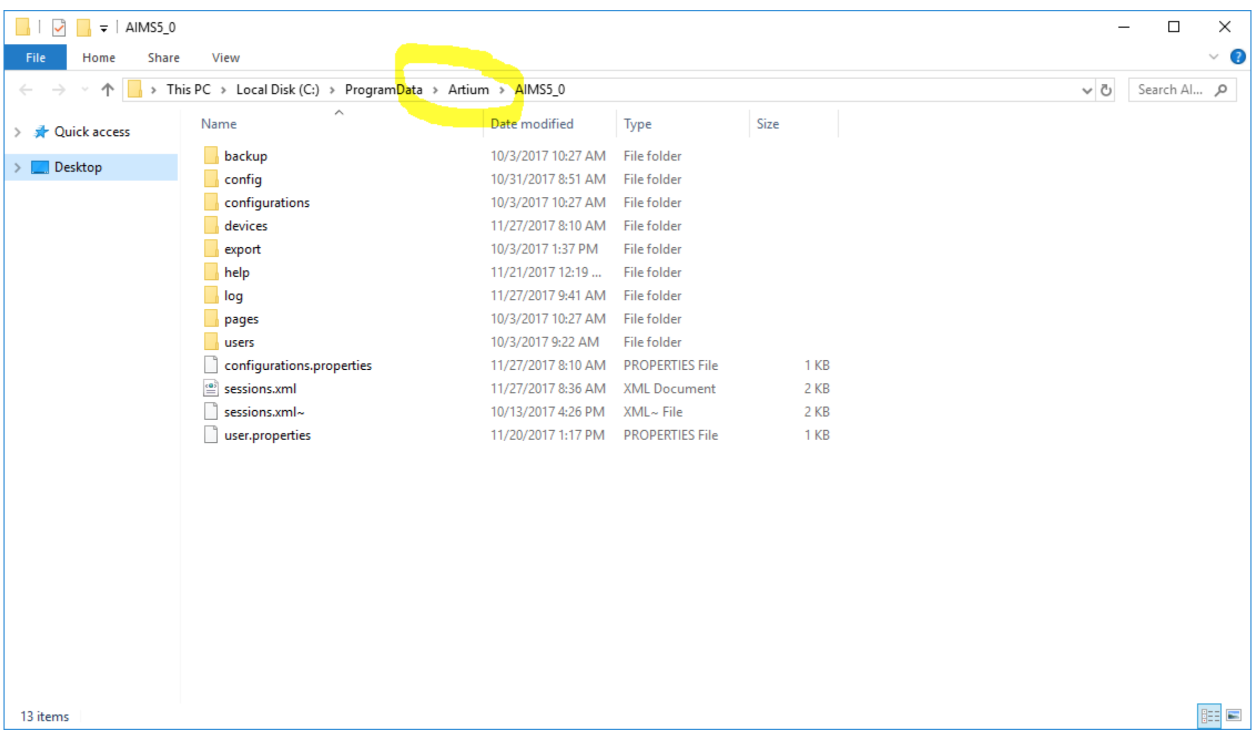
Introduction

This document details how to correctly move an AIMS installation on an existing (**old**) computer to a **new** computer while preserving all data, settings, and other important files. Although AIMS supports other operating systems, the instructions below assume the operating system is Windows (7, 10, etc.).

Preparation on Existing Computer

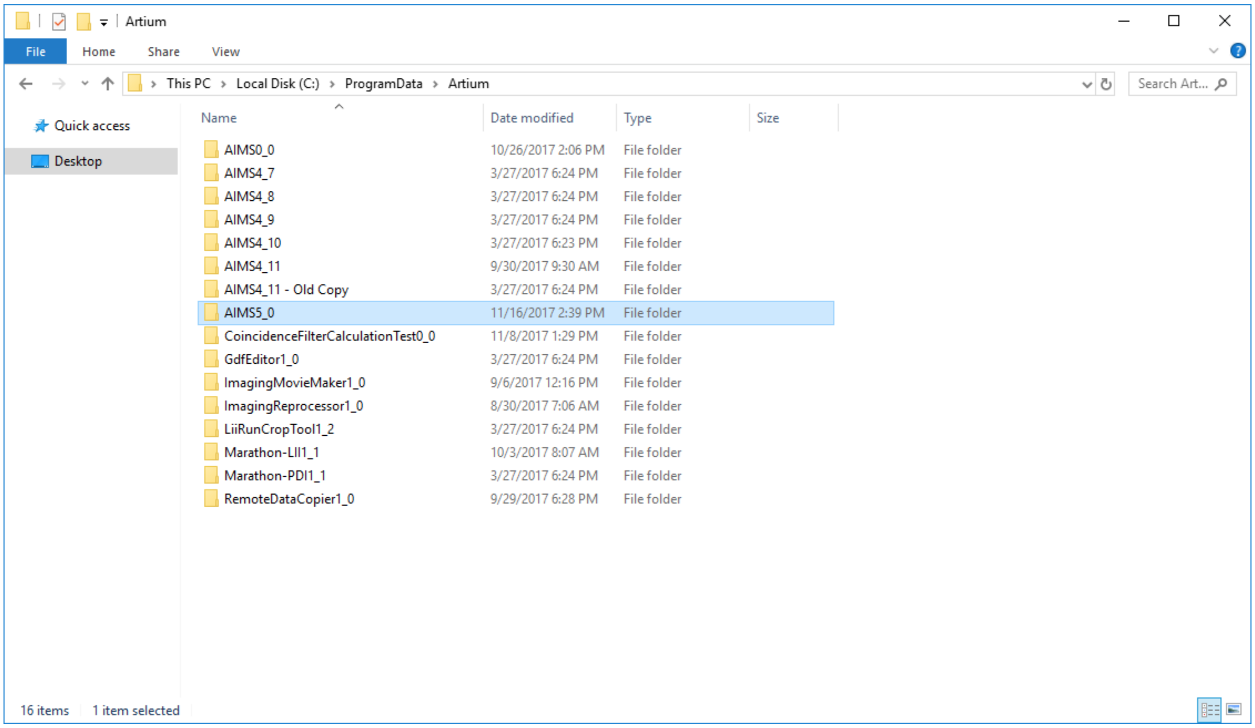
Copying Settings

Start AIMS on the **old** computer and select `Help > Show Settings Directory` from the menu. This should open a Windows Explorer folder:



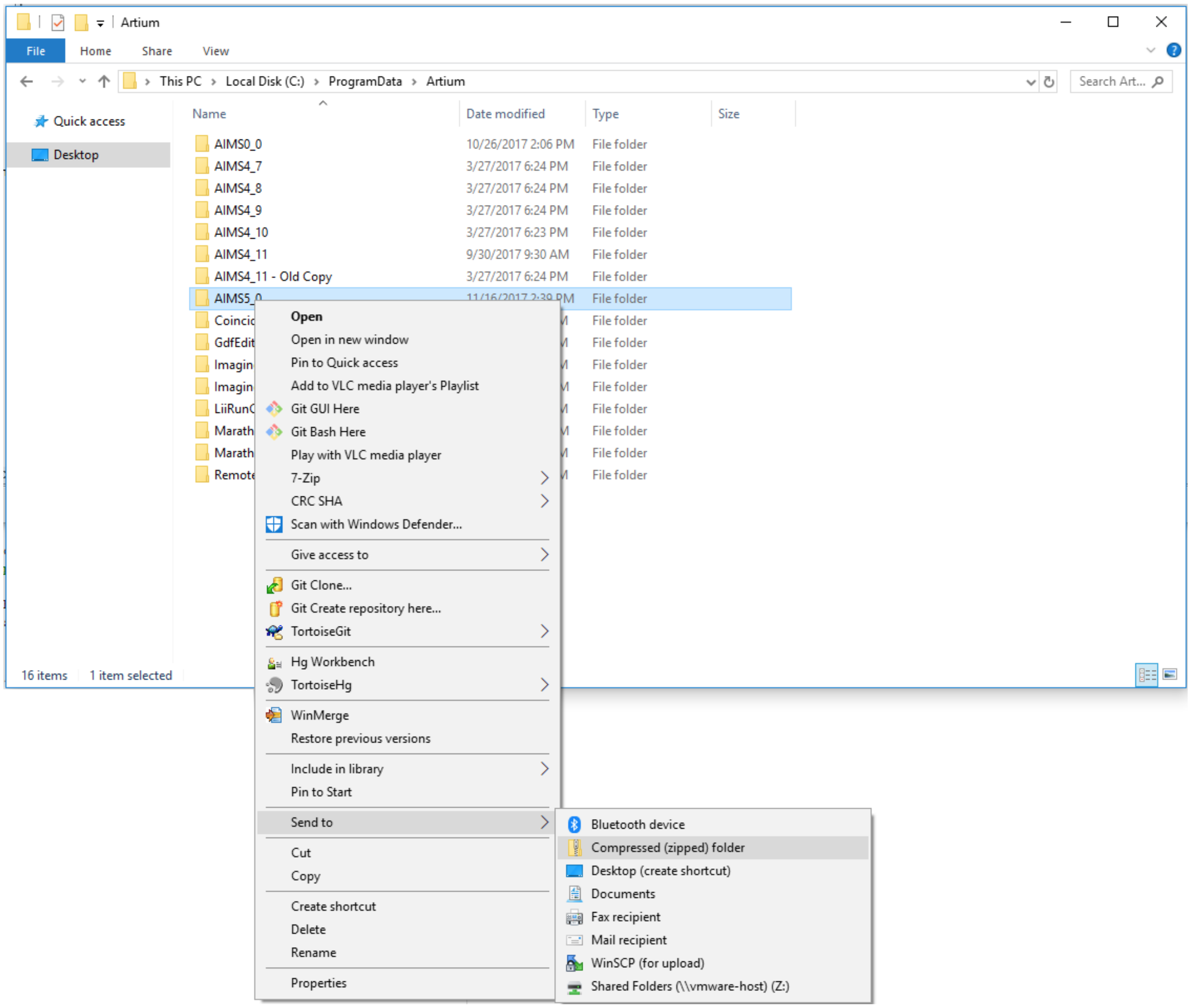
AIMS Setting Folder - Windows 10 shown.

Note that in older versions of Windows (XP), the folder may be different. Navigate to the root of the Artium settings directory by clicking on the word **`Artium`** in the navigation bar (see figure). You should see a list of previous AIMS settings folders:



Example of AIMS Setting Folders

Right-click on the latest folder and choose **`Send To > Compressed (zipped) folder`**:



This will create a zipped file that contains all of the settings for AIMS. This will need to be moved to the **new** computer.

Copying Data

On the **old** computer, start AIMS and click on the **`Data Library`** button to open the Data Library view in AIMS. Next, right-click on the **`AIMS Data`** folder and choose **`Show Data Directory in Windows Explorer`**… This should open a Windows Explorer folder that shows the data acquired by AIMS. The contents of this folder will need to be moved to the **new** computer (see below).

Setup on New Computer

Driver Installation

Before installing AIMS, you need to install any necessary device drivers (that match the version of AIMS you are installing). This may include a driver for a RS-232/Serial to USB converter (depending on your instrument).

AIMS Installation

Run the AIMS installer. This will copy AIMS to the hard drive of the new computer and setup application links, etc. **DO NOT START AIMS AT THIS TIME!**

Copying Settings

In Windows Explorer, navigate to **`C:\ProgramData`**. You may need to change Windows settings to see this folder:

1. Select the **`Start`** button, then choose **`File Explorer`**.
2. Select the **`View`** tab.
3. Check the **`Hidden items`** check box to view hidden items.

Inside the **`ProgramData`** directory, create an **`Artium`** directory. Note that case is important.

Navigate to the **`Artium`** directory and copy the settings backup file (.zip) from the old computer to this directory. Unzip the file by right-clicking on it and choose **`Extract all`**… This will extract the settings files in the correct location.

Copying Data

Navigate to the **`Documents`** directory in Windows Explorer. Create an **`AIMS Data`** directory (note that case is important and there is a space between the two words). Navigate to the `AIMS Data` directory. Copy the data from the **old** computer here.

Start AIMS

At this point you should be able to start AIMS on the **new** computer with all the hardware connected. It should start normally with all of the devices, settings, and data from the **old** computer. Note that it may take a little longer to start the first time as AIMS checks connections, finds serial ports, and verifies data file locations.

AIMS Preferred Units and Formatting

2011-08-05

Introduction

Internally, AIMS tracks units for each node (number or array of numbers). The user can't change this internal value. The user can, however, change the unit used to display the node value on the screen (or exported to a file). The same applies to the format (number of digits, scientific notation) of how the number value is displayed.

Preferred Units

AIMS has a preferred units file, `units.preferences`. From AIMS, select `Help > Show Settings Directory...`, then open the `config` directory. Using a UTF-aware editor (like jEdit), you can change the units that AIMS uses when displaying values to the screen. Here's an example file for LDV/PDI systems:

```
#Units Preferences
#Tue Jul 06 12:57:28 PDT 2010
${LDV_VelocityUnits}=m/s
${PDI_DiameterUnits}=µm
${PDI_LiquidWaterContentUnits}=g/m³
${PDI_NumberDensityUnits}=1/cm³
${PDI_VolumeFluxUnits}=cm/s
${PDI_VolumeUnits}=cm³
```

In the above example, velocity values will be displayed in meters per second (m/s). To display results in miles per hour, the velocity line would be changed to:

```
${LDV_VelocityUnits}=mph
```

You could use other units, like centimeters per second (cm/s) or microns per second(µm/s).

After changing this file, you will need to restart AIMS for the changes to take effect. If you run into any issues, you can safely delete this file - AIMS will regenerate it with default values.

Preferred Formatting

The preferred formatting settings are stored in the formatPattern.preferences file. From AIMS, select `Help > Show Settings Directory...`, then open the `config` directory. Using a UTF-aware editor (like jEdit), you can change the patterns that AIMS uses when displaying values to the screen. Here's an example file for LDV/PDI systems:

```
#Format Pattern Preferences
#Fri Aug 05 12:51:11 PDT 2011
${LDV_Channel1_DataRate}=\#,\#\#\#,\#\#\#.0
${LDV_Channel1_Time}=0.000
${LDV_Channel1_VelocityHistogram}=0.000
${LDV_Channel1_VelocityMax}=0.000
${LDV_Channel1_VelocityMean}=0.000
${LDV_Channel1_VelocityMin}=0.000
${LDV_Channel1_VelocitySampleStandardDeviation}=0.000
${LDV_Channel1_Velocity}=0.000
```

In the above example, mean velocity values will be displayed with three decimal places - for example 10.346. To change this scientific notation, the velocity mean line would be changed to:

```
${LDV_Channel1_VelocityMean}=0.000E0
```

and would be displayed as 1.035E2.

The following table explains the possible format values:

Symbol	Meaning
0	Digit (always shown)
\#	Digit, not shown if leading zero (for example, \#,\#\#\# would display 3452 as 3,452 and 234 as 234).
.	Decimal separator
E	Scientific notation

Note that the hash/pound symbol (#) must be escaped/preceeded with a slash (\).

CHAPTER 9

PDI calculations

CALCULATIONS

This chapter describes the methods by which the software interprets the raw information received from the instrument and computes information to obtain droplet velocity and size. The software resolves the stored raw data into the velocity and size measurements for each particle and then computes the remaining statistical parameters. This section describes the calculations completed by the computer. The nomenclature for this chapter is as follows:

Δ	Spatial Wavelength
δ	Fringed Spacing
ϕ_{12}, ϕ_{13}, ϕ_{23}	Phase shift in degrees between detectors 1 and 2, 1 and 3, and 2 and 3 (also called A, B, and C)
Θ	Receiver Collection Angle
γ	Laser Beam Intersection Angle
α, α_r	Aperture width, resultant aperture width
D_{max}	Diameter of the largest particle size
D_{10}, D_{20}, D_{30}, D_{32}	Mean particle diameters: Arithmetic, Area, Volume, Sauter
d	Diameter of spherical particle
f, f_D, f_m,f_r,f_s, f_t	Frequency: Doppler, mixer, raw, shift, transformed
I, ,I_i, I_o, I_s	Light Intensity: incident, maximum at r = 0, scattered
i	Histogram Bin Number
j or n	Number of samples in histogram bin
K	Optical constant
ND	Number Density
n, n_c	Number of samples in each bin: corrected size count
PA	Probe Area
PV	Probe volume That
PVC	Probe Volume Correction
PVO	Probe volume cut off

RL_1, RL_2	Receiver Lenses: Collimating, Focusing focal lengths
r_w or w	Laser beam radius measured from the centerline of the beam: $I = I_o/e^2$
S, S_{12}, S_{13}	Effect of detector separations: between detectors 1 and 2, and 1 and 3
Σ	Sizing Slope Factor
τ	Particle or droplet transit time through the probe volume
t, t_{tot}	Time: total run time
v	Velocity
VF or F	Volume Flux

Velocity Measurement

The particle velocity is measured by the method typically used for laser Doppler velocimetry. That is, as a particle crosses the interference fringes created by the two intersecting coherent laser beams, figure 10.1, it refracts or reflects the local light intensity onto the receiver. The light intensity pattern projected onto the receiver and directed to the photomultiplier tubes produces a typical Doppler burst signal, figure 10.2. The signal consists of a high frequency Doppler component superimposed upon the low-frequency Gaussian pedestal component. The frequency of the signal is directly related to the velocity of the particle through the relationship

$$v = f_d \delta$$

The fringe spacing of the interference pattern is determined by the wavelength of the laser beam and the beam intersection angle and is given by the following expression

$$\delta = \frac{\lambda}{2\sin(\gamma/2)}$$

The raw signal produced by the photodetectors and received by the signal processor is a combination of the Doppler frequency and the shift frequency produced by the presence of a Bragg cell. The signal frequency is given as

$$f_r = f_D + f_s$$

The raw signal is passed through a high pass filter set at 10 MHz (or 20 MHz) to remove the pedestal component of the Doppler burst signal and any low-frequency noise. The signal is then combined with the mixer frequency and sent through a low pass filter to eliminate the high frequency components including the sum frequency from the mixer and any high-frequency noise. The remaining frequency is given as

$$f_t = f_r - f_m$$

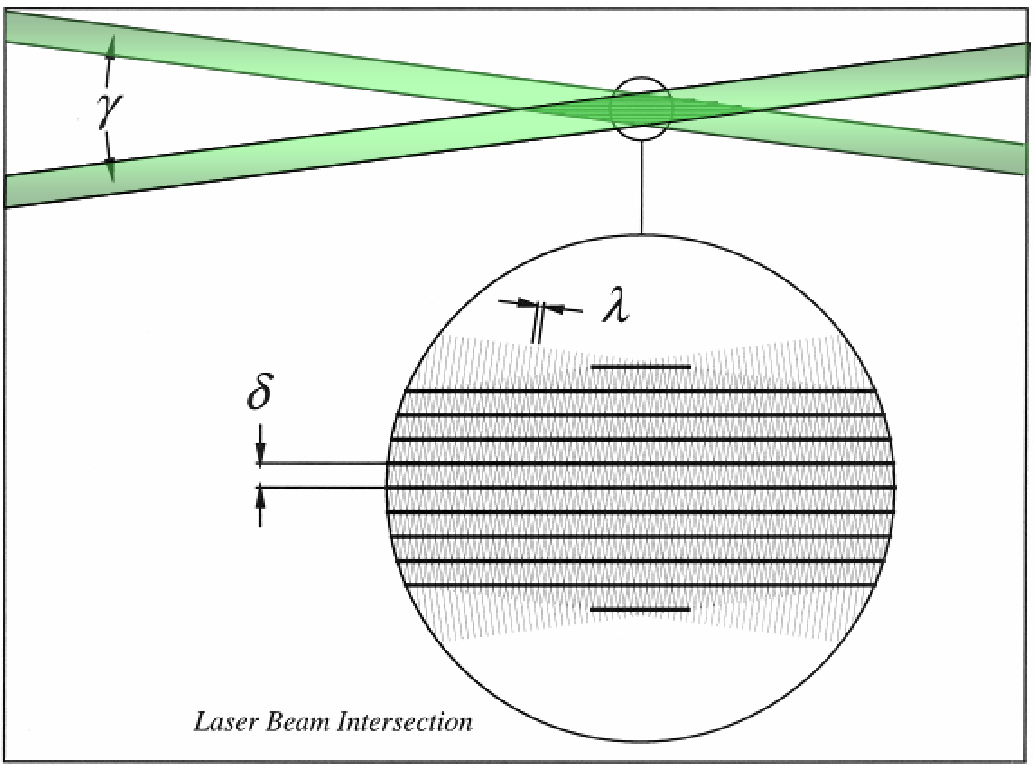


Figure 9.1: Schematic showing the laser beam intersection and the formation of interference fringes in the probe volume.

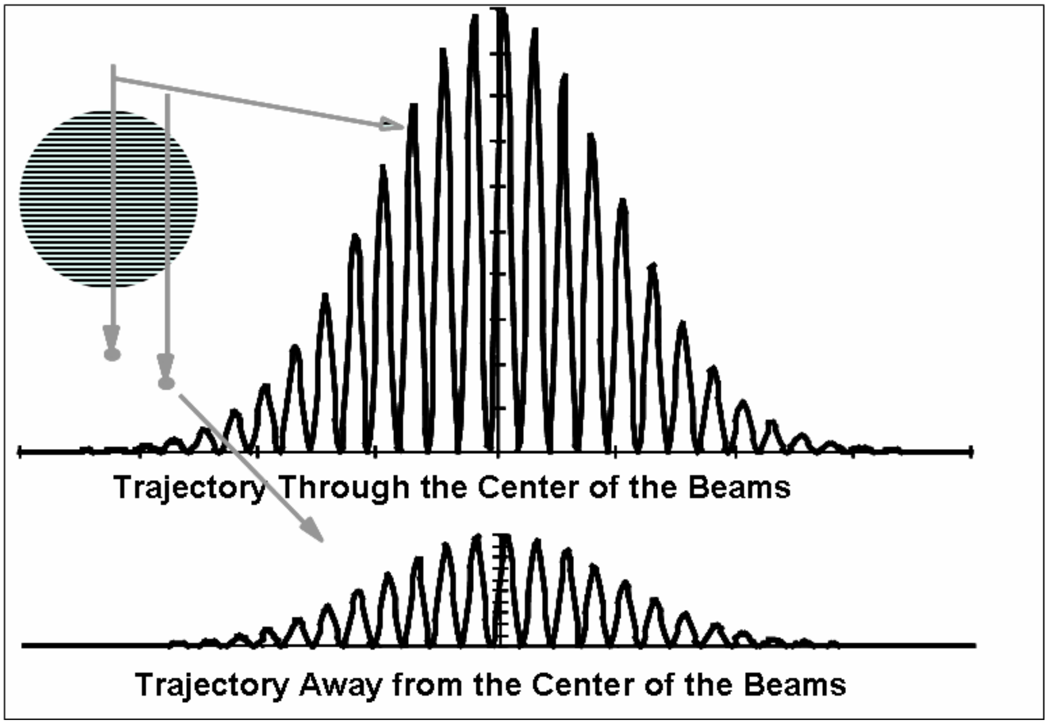


Figure 9.2: Simulated Doppler signals.

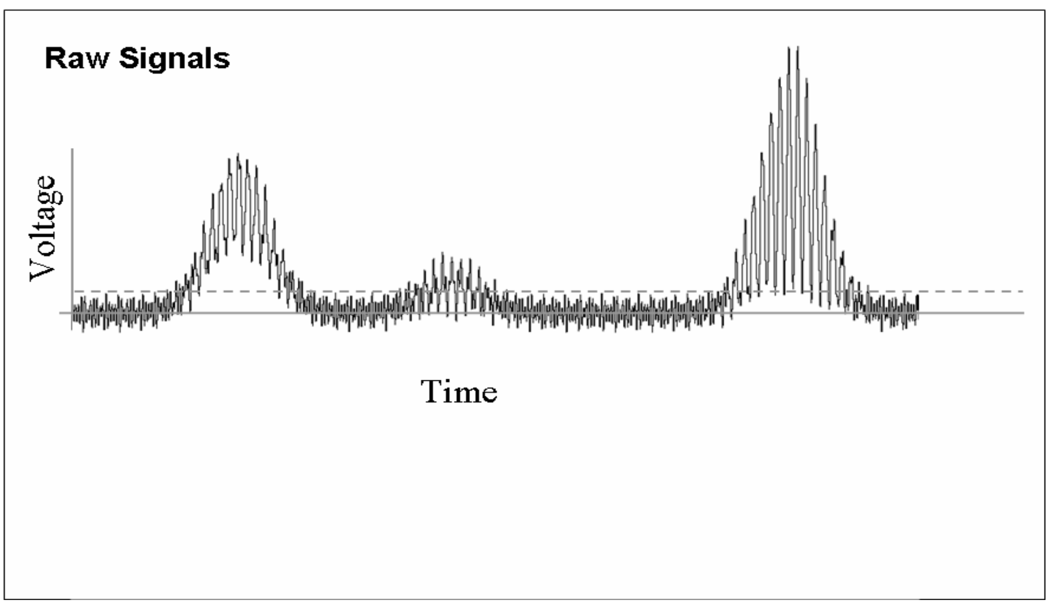


Figure 9.3: Typical Doppler burst signals for different trajectories through the probe volume.

This frequency is processed using the FFT programmed in the system computer. The Doppler frequency is then obtained from the known mixer and shift frequencies and measured raw frequency using following expression

$$f_D = f_t + f_m - f_s$$

Size Measurement

This section describes how the diameter of the particles is determined using the phase Doppler interferometer method. The particle magnifies the interference fringe pattern onto the receiver to different degrees relative to a particle size. The degree of magnification is measured by comparing the spacing of these fringes on the receiver detectors (spatial wavelength Δ) and the fringe spacing. The diameters of the particles are determined using this relationship along with the receiver focal length and the sizing slope factor given as

$$d = \frac{F\delta_r}{s\Delta} .$$

A spatial wavelength, Δ is determined by using the phase shift of the signal between the detectors in the time domain along with the calibrated spacing of the detectors. The spatial wavelength, Δ is obtained from the weighted average of

$$\overline{\Delta} = 360\left[\frac{k_{12}S_{12}}{\phi_{12}} + \frac{k_{13}S_{13}}{\phi_{13}} + \frac{k_{23}S_{23}}{\phi_{23}}\right] / \left[k_{12} + k_{13} + k_{23}\right]$$

Artium Technologies, Inc. uses several proprietary methods for resolving the sizing slope factor for all possible transmitters/receiver configurations. The slope is calculated assuming spherical particles and therefore, the particles to be sized should be spherical or near spherical if accurate results are to be obtained.

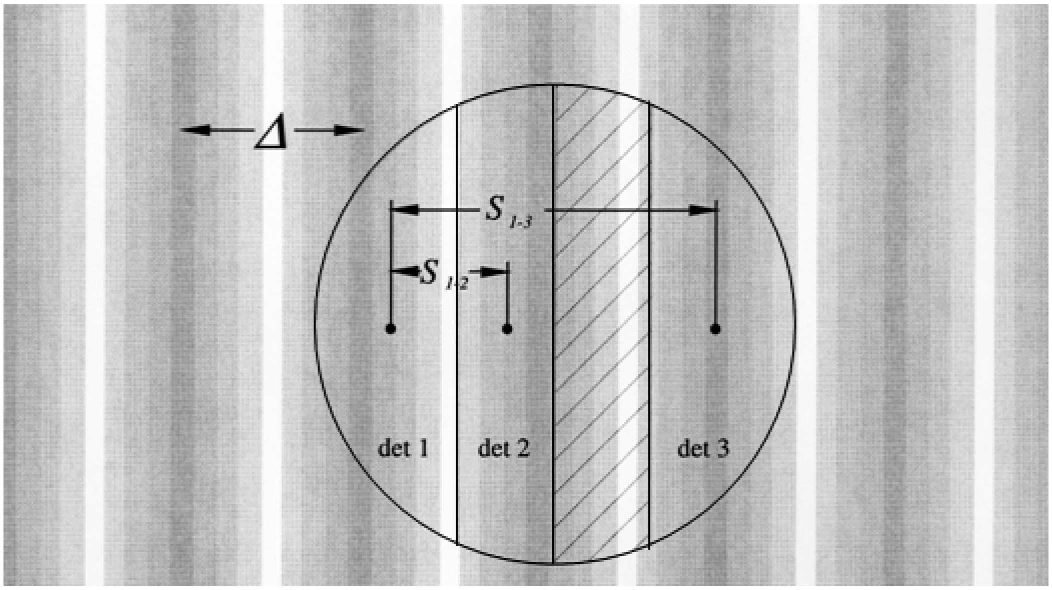
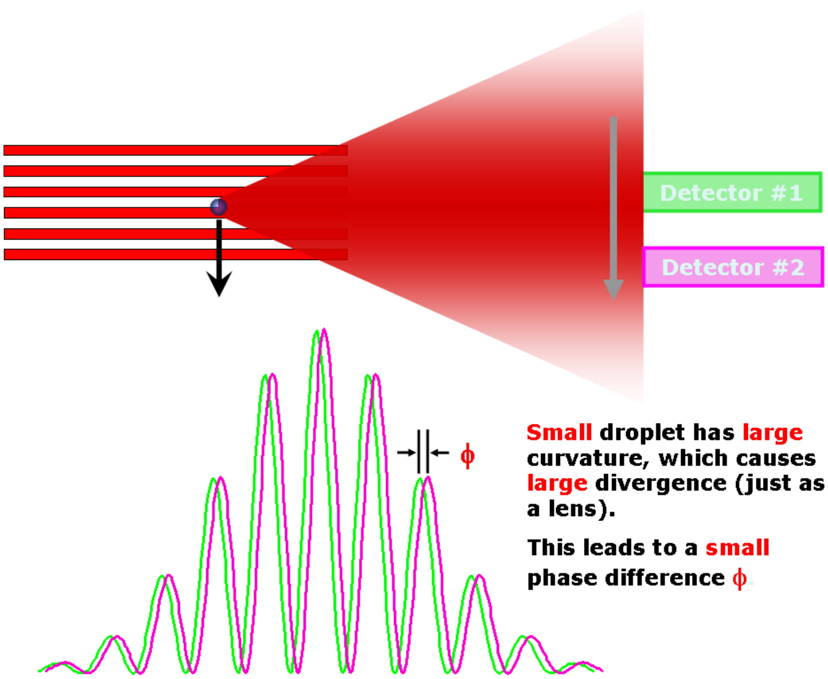


Figure 9.4: Schematic showing the interference fringes produced by the scattered light and projected onto the receiver lens.



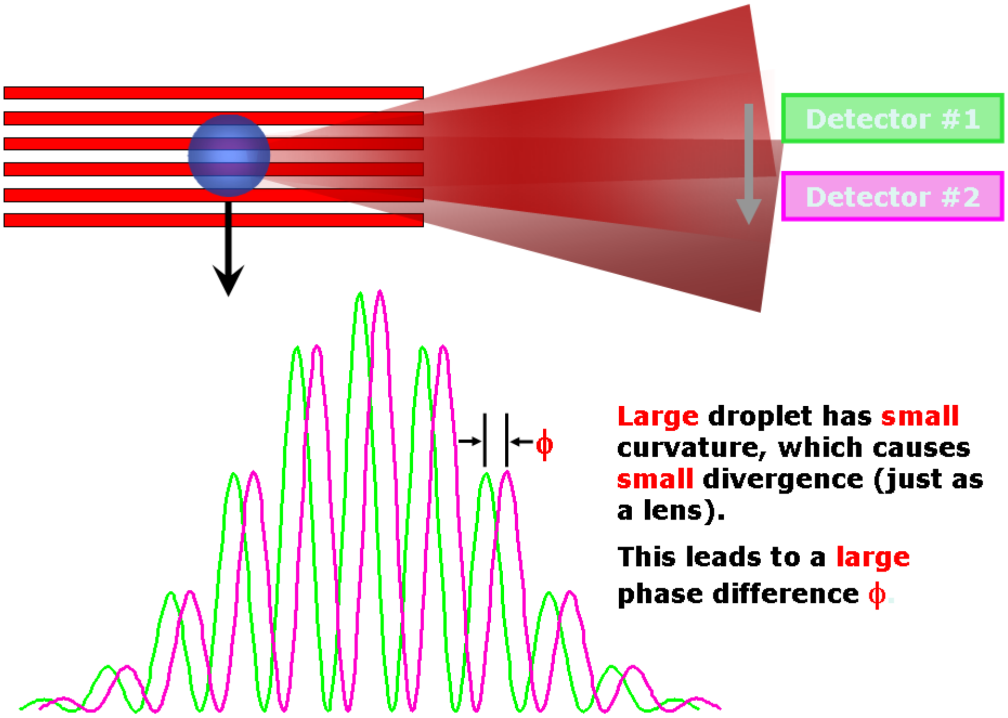


Figure 9.5: Schematic showing the interference fringes formed by the scattered light and the pattern overlaid on the receiver lens and a description of how the droplets produce different phase shifts at the pairs of detectors.

Probe Volume, Probe Area, and Probe Volume Correction

The probe volume is a volume through which particles must pass to be measured by the PDI systems. Probe volume is defined by the focused laser beam diameter and the slit aperture width in the receiver. The shape of the probe volume can be estimated as a slice of a cylinder with oblique ends. The width and angle of the slice are determined by the slit aperture width in the receiver, optics, and the angle of the receiver relative to the transmitted beams. The intersecting beams are at a small enough angle such that they can be assumed as cylindrical in shape within the region seen by the receiver.

The cylindrical diameter of the probe volume increases in diameter for increasing size classes of particles. This is due to the relation between the amount of incident light scattered by particle (proportional to the diameter of the particle squared) and particle size in conjunction with a Gaussian nature of the laser beam intensity profile illuminating the particles. The amount of light incident on the particle is determined by the distance the particle passes from the center of the laser beams and its location along the trajectory through the beams. For two intersecting laser beams the incident light is

$$I_i(r) = I_o e^{\frac{-2r^2}{r_w^2}}$$

The intensity of the light scattered by particle is proportional to the particle surface area. Combining the size relation with the above Gaussian equation results in the expression

$$I_s(r,d) = KI_i(r)d^2 \approx KI_o e^{\frac{-2r^2}{r_w^2}} d^2$$

which is equal to the amount of light incident on the receiver optics relative to a particle size and position.

A minimum amount of light incident on the receiver is needed in order for the instrument to detect a particle. This intensity cut off determines the maximum radius r at which each particle size can be detected yielding a cylindrical diameter D as a function of the ratio of the probe volume diameters to particle diameter is

$$D^2(d) = D_{\max}^2 - 4r_w^2 \ln\left(\frac{d_{\max}}{d}\right)$$

which is used when calculating the probe volume correction, PVC.

The maximum probe diameter is either assumed to be equal to a nominal value by using an analytical method for probe volume correction or is determined in situ by the transit time method. The transit time is the time a particle spends in the probe volume which depends on its speed and the diameter of the probe volume. The measured transit time multiplied by the particle velocity yields the particle path length within the probe volume. Artium Technologies Inc. uses a proprietary method of combining the transit time of all particles passing through the probe volume to determine the maximum probe diameter.

The probe area is determined from the maximum probe diameter of the maximum size bin and is given as

$$PA = \frac{D_{\max} a_r}{\sin\varphi}$$

The resultant aperture size at the laser beam intersection is related to the aperture size within the receiver and the focal lengths of the receiver lenses. The resultant aperture size is given as

$$a_r = a\left[\frac{RL_1}{RL_2}\right].$$

The number of particles in each size class of the distribution is multiplied by the probe volume correction factor to reflect the change in sampling volume with particle size and is given as

$$n_c(d) = n(d)PVC(d)$$

The probe volume correction factor is simply the ratio of the probe area for the maximum particle size bin ratio to the probe area of each individual size bin d. Since the aperture and the angle of light scatter detection, Θ, remain constant, the ratio is determined only by the maximum probe diameter of each particle size class.

$$PVC(d) = \frac{D_{\max}}{D(d)}$$

The in-situ probe volume measurement and correction are dependent on certain factors in order to perform properly. First, the laser beams must have a nearly Gaussian intensity distribution at the beam intersection. The trajectory of the particles should be predominantly normal to the direction of the beams for a two-component system (two orthogonal velocity components measured). For a one component system, the predominant trajectory of the particles should be in the direction of measurement of the velocity. If these conditions are not met the analytical method to define the probe volume correction may be more accurate.

Mean and Median Calculations

In this section, the various mean diameters used in the presentation of data are presented. These mean values are commonly used in spray analysis.

Arithmetic or Linear Mean Diameter (D10)

$$D_{10} = \frac{\sum_i n_{c(i)} d_i}{\sum_i n_{c(i)}}$$

Area Mean Diameter (D20)

$$D_{20} = \sqrt{\frac{\sum_i n_{c(i)} d_i^2}{\sum_i n_{c(i)}}}$$

Volume Mean Diameter (D30)

$$D_{30} = \sqrt[3]{\frac{\sum_i n_{c(i)} d_i^3}{\sum_i n_{c(i)}}}$$

Sauter Mean Diameter (D32)

$$D_{32} = \frac{\sum_i n_{c(i)} d_i^3}{\sum_i n_{c(i)} d_i^2}$$

Total Number

$$tN = \sum_i n_{c(i)}$$

Number Fraction

$$fN = \frac{\sum_i^N n_{c(i)}}{tN}$$

Total Length

$$tL = \sum_i n_{c(i)} d_i$$

Length Fraction

$$fL = \frac{\sum_i^N n_{c(i)} d_i}{tL}$$

Total Surface

$$tS = \pi \sum_i n_{c(i)} d_i^2$$

Surface Fraction

$$fS = \frac{\pi \sum_i^N n_{c(i)} d_i^2}{tS}$$

Total Volume

$$tV = \frac{\pi}{6}\sum_i n_{c(i)} d_i^3$$

Volume Fraction

$$fV = \frac{\frac{\pi}{6}\sum_i^N n_{c(i)} d_i^3}{tV}$$

Number Density and Volume Flux Measurements

Number Density is a measurement of the number of particles per unit volume present in the measurement space. There are two methods used to calculate number density and they are referred to as the swept volume method and the transit time method. The total corrected count (corrected for probe volume) is divided by this volume to calculate the number density and is given as

$$ND = \frac{1}{(PA)(t_{Tot})}\sum_i \frac{n_{c(i)}}{\overline{|v_i|}}.$$

A separate average absolute velocity is calculated for each size bin to eliminate the velocity biasing on the sampling statistics and is given as

$$\overline{|v_i|} = \frac{\sum_j |v_{i,j}|}{n}.$$

With the transit time method which is favored, the number density is determined using the transit times for the particles as they pass the sample volume. The transit time is the measure time that the particle spends within the probe volume. This method uses the computed ratio of time duration when there is a particle in the probe volume to the total sample time for the measured distribution at that point. Transit time ratio divided by the probe volume yields the number density given as

$$ND = \frac{1}{t_{Tot}}\sum_i \frac{\sum_j t_{i,j}}{PV_i}.$$

This method is applied for each size class to accommodate the size biasing of the probe volume as a function of drop size.

Both methods rely on an accurate probe area calculation. The transit time method will work best as long as the beams are partially Gaussian at the intersection. The swept volume method works well if the trajectories of the particles are normal to the direction of the beams in a two-component system or if the trajectories of the particles are in the direction of the velocity component measured for a one component system.

Volume flux is calculated using the following expression

$$VF = \frac{tV}{t_{Tot}PA} = \frac{\pi}{6}\frac{tND_{30}^3}{t_{Tot}PA}.$$

Mass flux can be calculated by multiplying the volume flux by the density of the spray drops or particles being measured.

Liquid Water Content (LWC)

The liquid water content is the volume of liquid water in a given volume of space. Liquid Water Content in gm/m^3 is given as

$$LWC = \frac{\pi}{6}\rho D_{30}^3 ND$$

where ρ is the density of the liquid.

Data analysis

After the PDI hardware has been properly connected and the various software parameters have been properly set, data acquisition may be initiated by clicking on the green button in the software user interface page or pressing the F9 key. The following figures show the various data screens that can be viewed by selecting the appropriate tabs. These screens provide information on the drop size, velocity, mean values, and temporal information on the spray. A short description of the information on each screen is provided to aid the user in interpreting the data being acquired. By right clicking on any of the plots, the plotting parameters may be changed and the graph limits adjusted as desired.

1D PDI Statistics

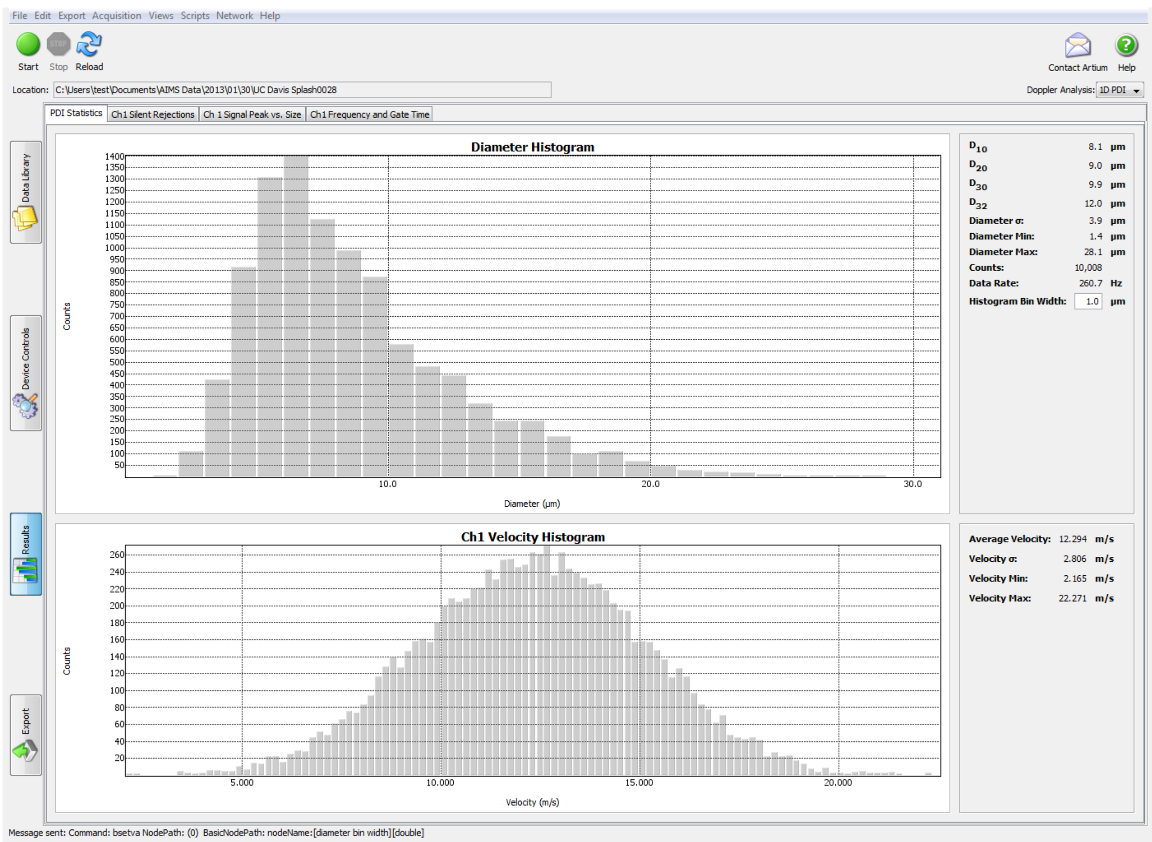


Figure 10.1: Diameter histogram and velocity histogram.

Figure 10.1 shows the screen that displays the histograms of the size and velocity distributions for the measured spray. Note that for the example shown, the spray size distribution has a characteristic log normal shape, but it appears to have a slight increase in counts at around 75 µm. Note also that the velocity distribution appears to be bimodal. This behavior can be further understood by also looking at the size velocity correlation shown in a subsequent screen, Figure 10.5. In short, smaller drops for this spray relax to the ambient flow speed whereas larger drops continue to move at a greater speed because of their initial momentum. Reduced mean values are shown in the right-hand column along with the number of drops measured and the data rate.

1D PDI Statistics (PVC)

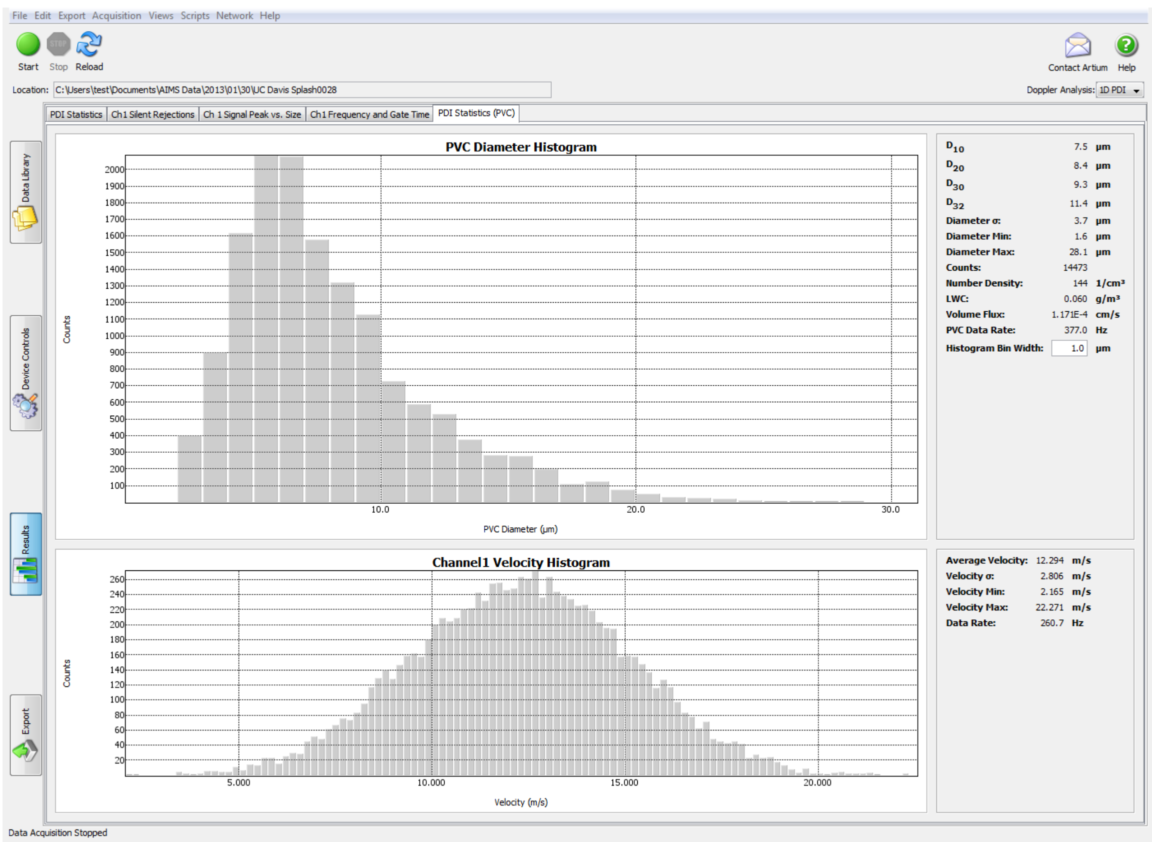


Figure 10.2: Probe volume corrected diameter histogram and velocity histogram.

Figure 10.2 is similar to Figure 10.1 except that the data have been corrected for the effect of varying sample volume on the drop size. Since smaller droplets have a smaller effective sample volume, the number in each size bin must be increased by a factor equal to the ratio of the sample volume for the largest drops to the sample volume for the drops in each size bin. This normalization approach compensates for the sample volume affect by increasing the number of drops in the smaller size bins. As noted from the mean values, especially D10, the mean size is decreased by the sample volume correction. It is important to note that the sample volume correction is necessary for an accurate measurement of the size distribution. This is the size distribution that should be reported.

1D PDI Time History

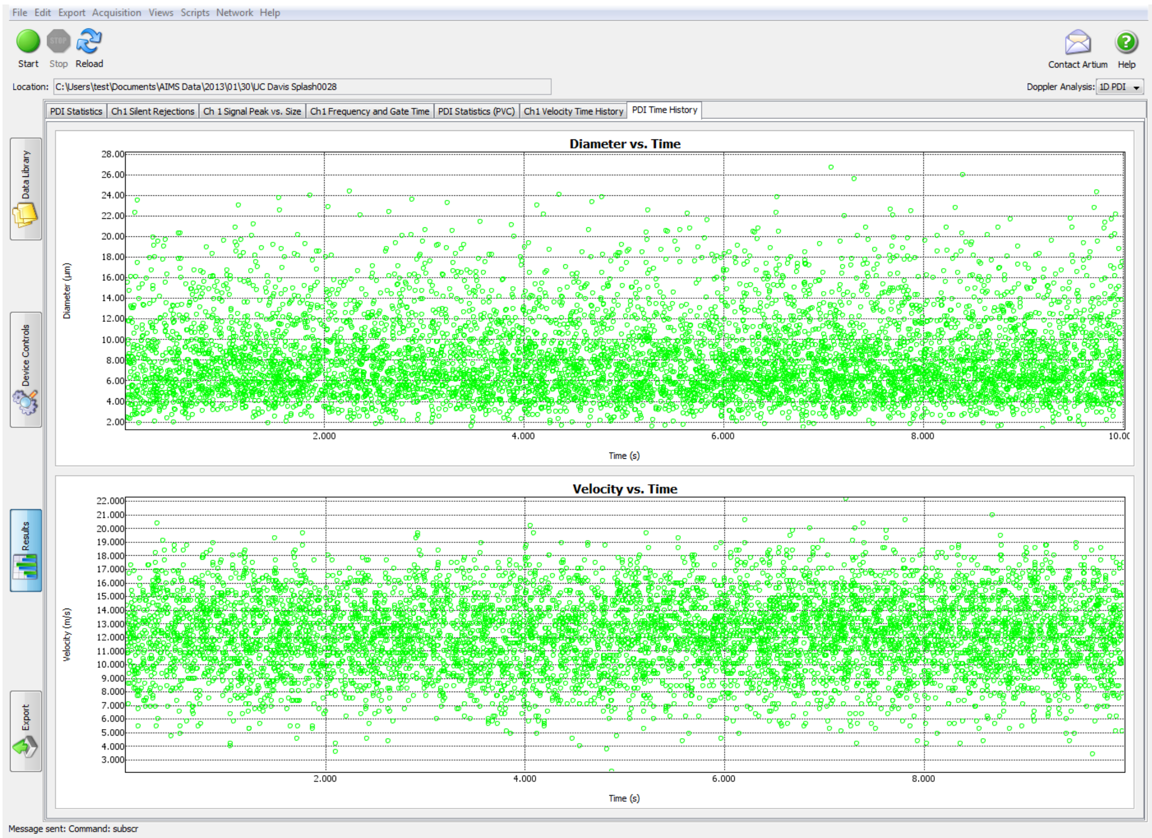


Figure 10.3: Time history plot of diameter and velocity.

Figure 10.3 shows each drop size and velocity measurement as a function of the time of arrival. Each point on the plot represents one drop measurement. This information is useful in determining if there is any unsteadiness, clustering, or other temporal phenomenon in the spray. For example, pulsatile sprays can be observed to reveal pulse variations in the spray. If the spray is interacting with turbulent flows, spray drop clustering may be observed in this plot. By right clicking on the plot, any section of the time record can be selected and expanded to observe the details.

1D PDI Strip Chart

Figure 10.4 also shows the diameter and velocity information as a function of time but displays it as a strip. This display is useful for viewing long time records over a short, elapsed time period to observe any time-dependent details in the spray.

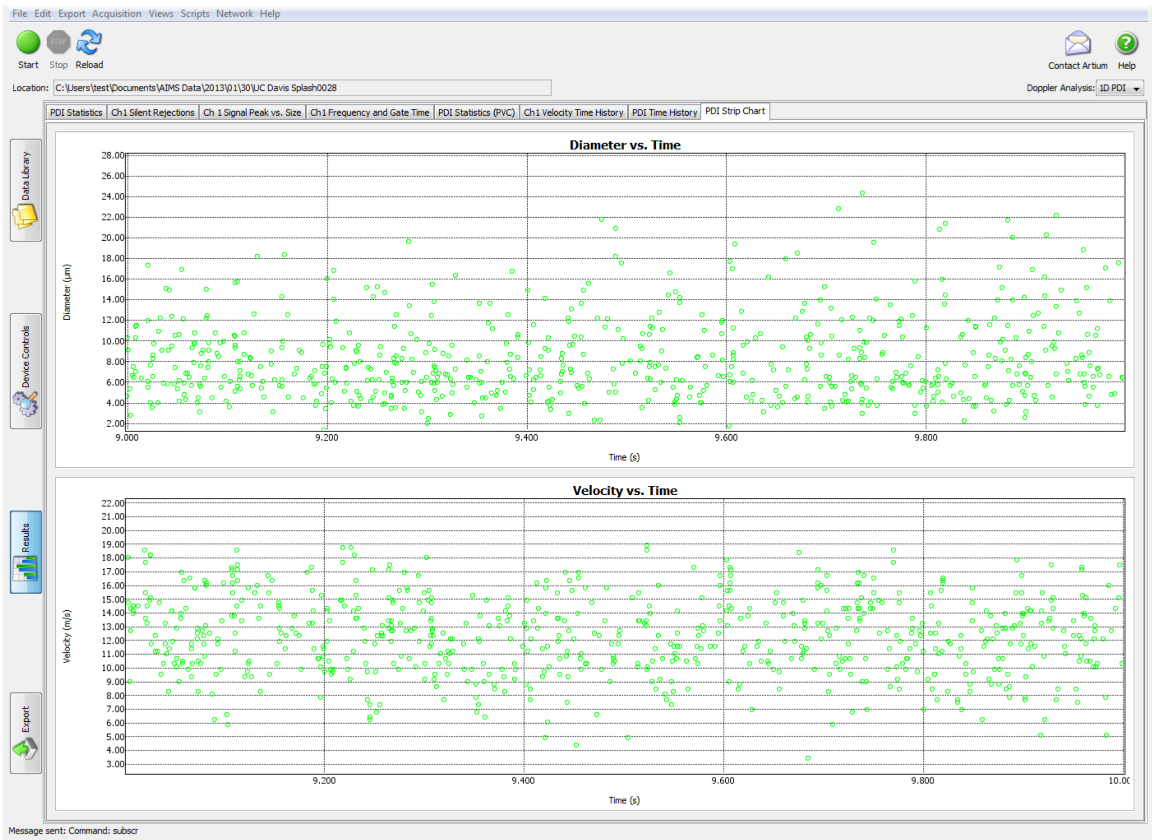
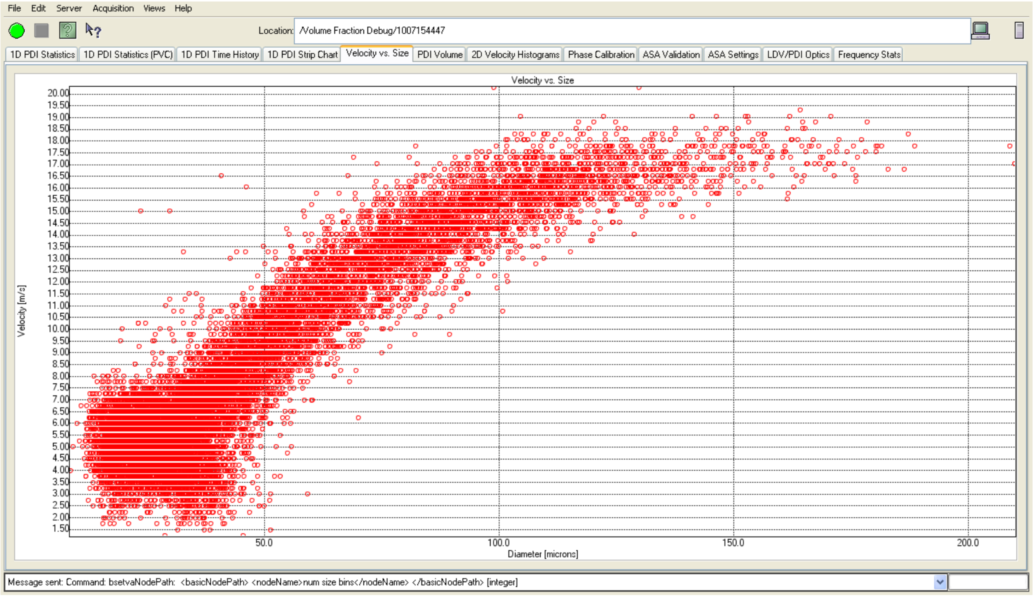


Figure 10.4: Strip chart plot of diameter and velocity.

Velocity vs. Size

Figure 10.5 shows a very useful plot for observing the droplet dynamics. Each point on the graph is a single drop measurement of the drop and velocity. In this case, it is easy to see that the small drops have relaxed to the slower ambient flow velocity and that the larger drops have a higher velocity because of their greater initial momentum.

Since the PDI instrument responds to droplet flux, the relative velocity of the drops will affect the size distribution. To convert the size distribution to a concentration dependent distribution, the number of counts in each size bin needs to be normalized to remove the effect of the drop velocity for each size class. This needs to be done, for example, when the results are being compared to imaging techniques or to a line-of-sight ensemble light scatter detection method. The shape of this size versus velocity plot also helps to explain the shape of the size distribution described previously. Counts in the bins of the size histogram are affected by the relative velocities of the drops in the different size classes.



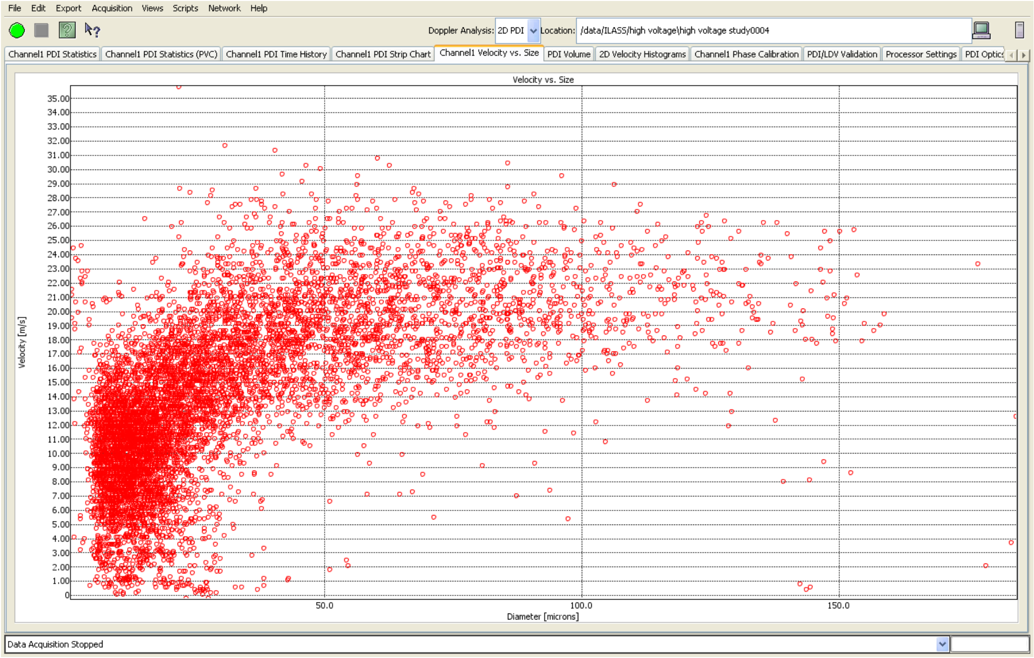


Figure 10.5: Examples of Velocity vs. Diameter plots.

PDI Volume

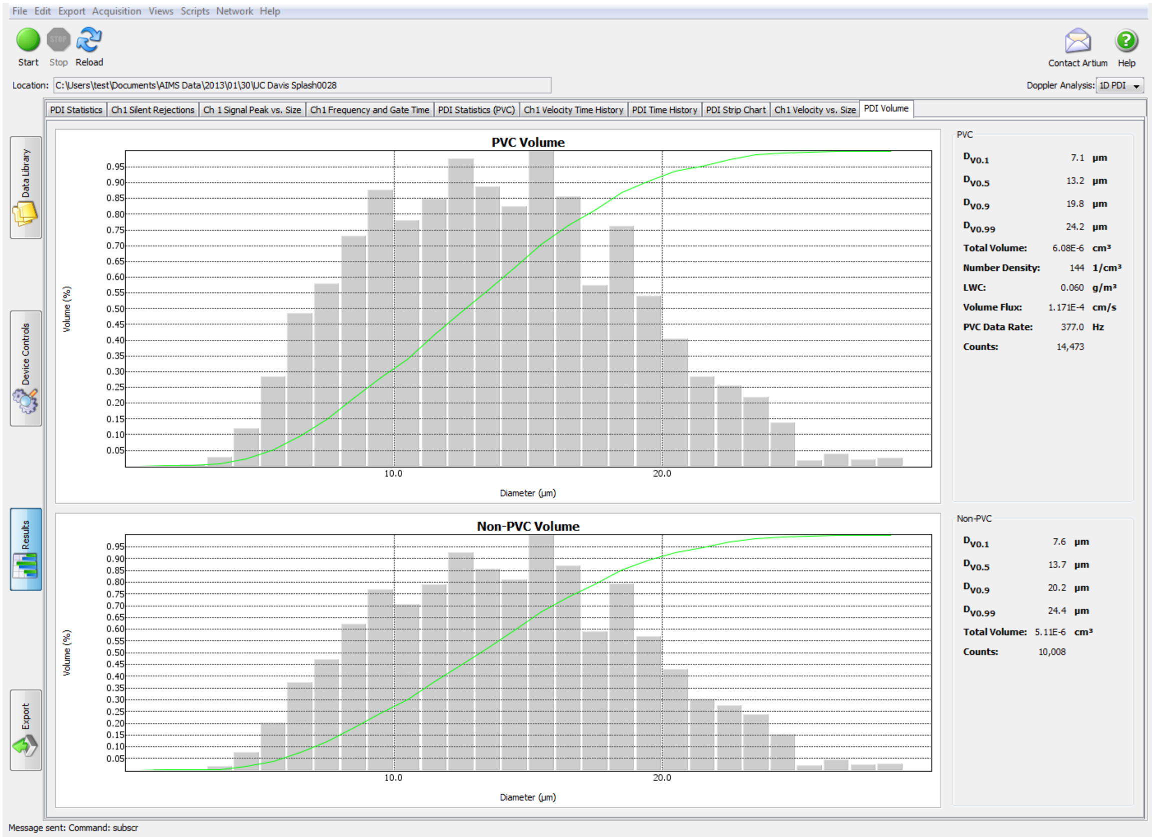


Figure 10.6: Volume distribution (PVC and non-PVC).

Figure 10.6 shows the volume contribution for each size class of the spray drop size distribution. Also shown in the plot is a cumulative volume contribution for the various size classes. The 0.5 point on the plot is used to obtain the median volume diameter (MVD). The upper plot shows the size distribution that has been corrected for the probe volume affect (PVC) whereas the lower plot is the volumetric contribution for the uncorrected raw data (Non-PVC). The PVC corrected data is what should be used in reporting the measurements.

ASA Validation

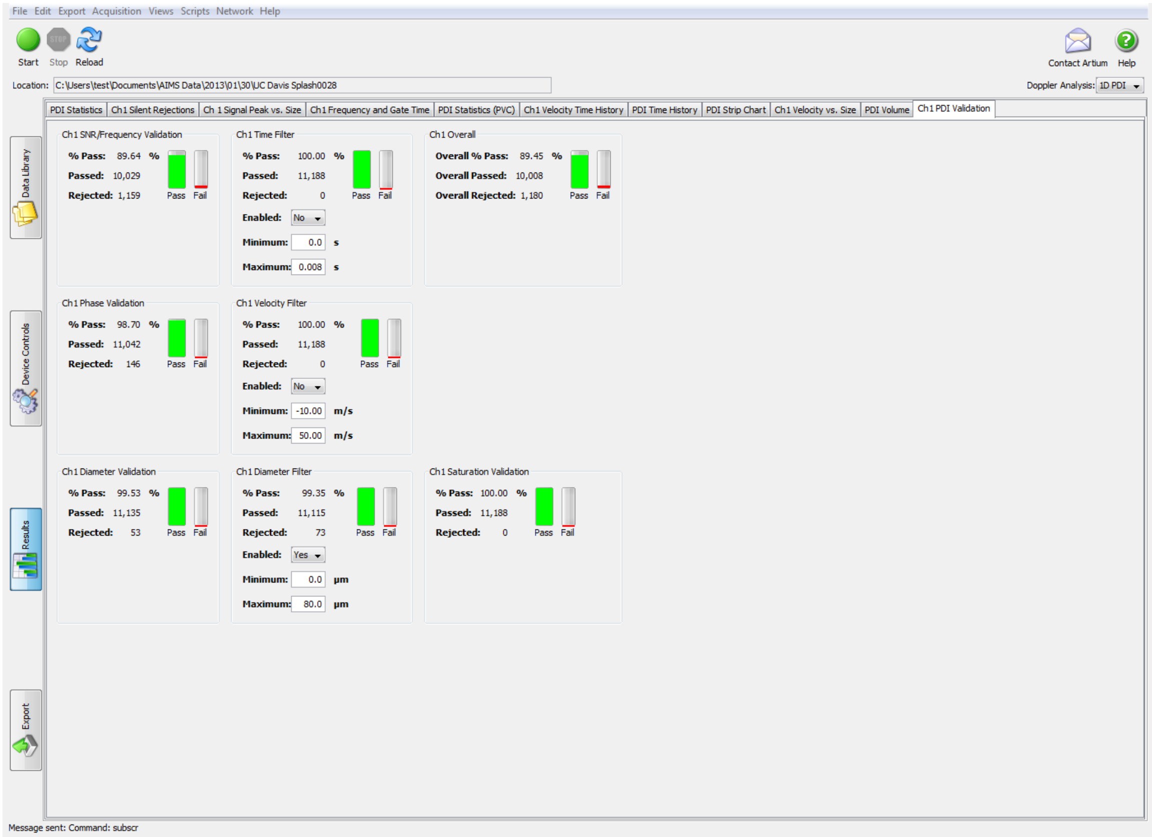


Figure 10.7: Channel 1 data validation results.

Figure 10.7 shows the screen that provides information on the percentages of attempted measurements that pass the various criteria before a measurement is accepted as a valid estimation of the drop size and velocity for Channel 1. The validation percentage provides an indication of the quality of the signals being detected but low validation rate does not necessarily mean that the instrument is making faulty measurements. Our proprietary digital Doppler signal detection method is programmed to detect signals based on their coherency (whether or not they have sinusoidal characteristics). Since we do not want to miss any droplets the detection is set to attempt measurements of even low amplitude, low SNR signals. The small drops will produce the weakest signals with low amplitude and low SNR, but we do not want to bias the measurements by missing the small drops in the distribution. Furthermore, false signal detections will be discarded once the signals are processed with the full complex FFT and the remaining validation criteria have been applied. If the detection is set too conservatively, the validation will be very high but at the expense of missing the small drops.

Our innovative burst signal detection system has been designed to reliably detect even the smallest signals while minimizing false signal detection. Thus, the validation rates are usually high. However, in difficult sprays (dense sprays, sprays with very small drops but that are large in area, etc.) the validation rate may be expected to fall somewhat.

Each of the validation criteria have been described in the Device Control section under the Validation Tab. The rates shown here are in response to the criteria described in that section.

ASA Settings

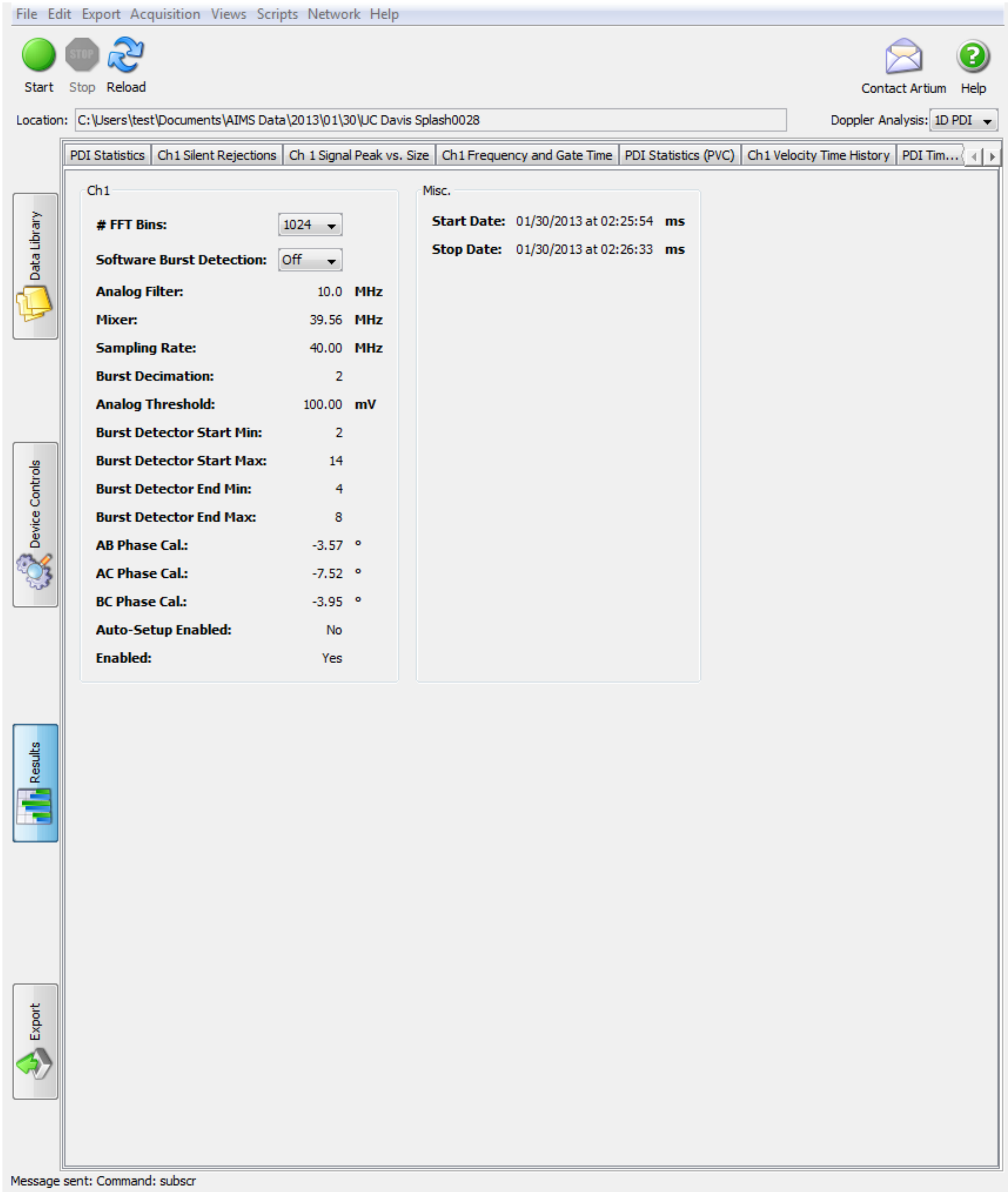


Figure 10.8: ASA Processor settings.

Figure 10.8 shows the screen that provides a summary of the ASA signal processor settings for this measurement point. This information is saved with the data file and allows the user to recover the settings for that data and if desired, repeat the measurements with those settings.

LDV/PDI Optics

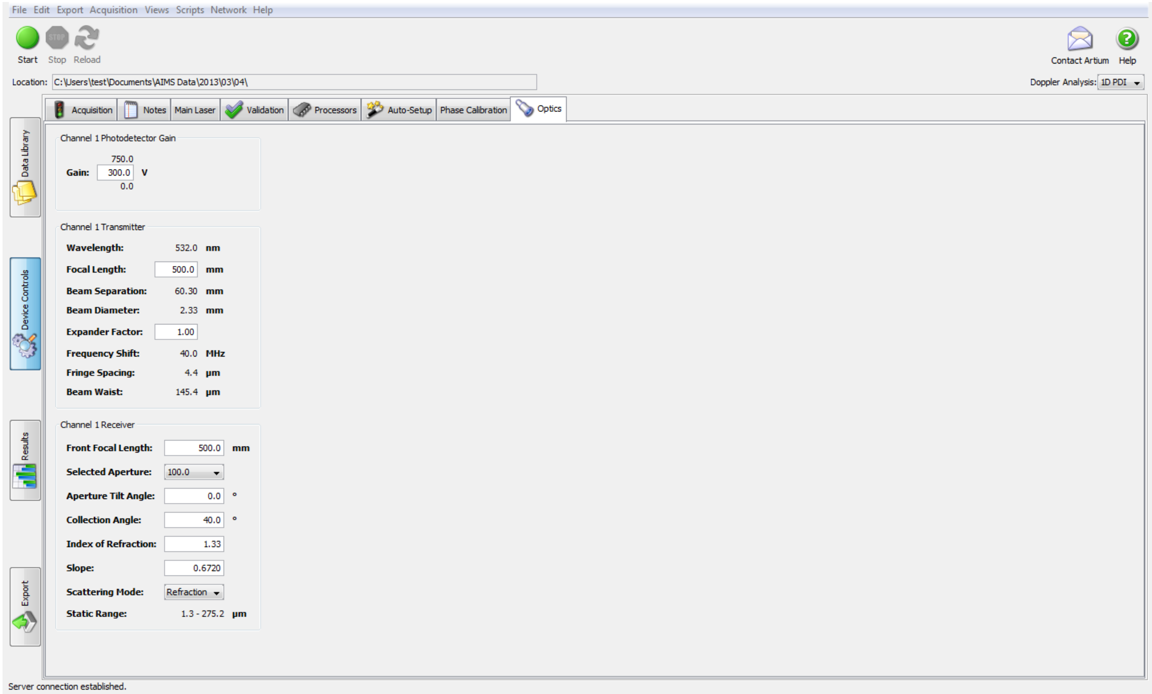


Figure 10.9: LDV/PDI Optics Settings.

Figure 10.9 provides the information on the optical setup used to acquire this data point. This information is stored with each measurement so that the user may, for example, recover this information and if desired, repeat the measurement at the same conditions or assess whether the setup was correct or not.

APPENDIX A

Theory of operation

PHASE DOPPLER INTERFEROMETRY

Bachalo (1980) theoretically described the light scattering from spherical particles and showed that the phase shift of the light scattered from two intersecting beams could be used to accurately and reliably measure the diameter of spherical particles. With the use of pairs of detectors to enable the measurement of the interference fringe pattern formed by the far field interference of the scattered light, a method for reliably and accurately measuring spray drop size even in difficult measurement environments was realized, Bachalo and Houser (1984). Following the initial development of the phase Doppler interferometry method, significant research and development has been devoted to the improvement of this important instrument and numerous publications have been written on the subject [Bachalo et al. (1993); Dodge (1987)]; Sankar et al. (1991); Sankar and Bachalo ((1995); Bachalo and Sankar (1988); Bachalo and Houser (1985); Bachalo et al. (1988); Ibrahim et al. (1990); Ibrahim et al. (1991); Ibrahim and Bachalo (1992); Ibrahim and Bachalo (1994);].

The Phase Doppler Interferometer (PDI) instrument, formerly known as the Phase Doppler Particle Analyzer (PDPA), has advanced as the standard laser-based diagnostic instrument for simultaneously measuring the size and velocity of individual spherical particles in polydisperse flow environments. The success of the method may be attributed to the measurement principles upon which it is based, namely, light scattering interferometry. Light scattering interferometry utilizes the wavelength of light as the measurement scale and, as such, the performance is not as easily degraded as it is for systems using light scattering intensity information for the estimation of the particle size. In addition, the method does not require frequent calibration. Over the decades, the instrument has proven to need only an initial factory calibration. The parameters affecting the measurement which include the laser wavelength, beam intersection angle, transmitter and receiver focal lengths, and the detector separation do not change with age and require deliberate intervention by the user or serious mistreatment of the instrument before they lose adjustment. Another important characteristic of the method that is often missed is related to the signals generated by the device. Unique sinusoidal signals are produced which can be easily detected even in the presence of noise using the Fourier analysis.

As an aid to understanding the measurement method, it will be useful to consider the simplest form of light scattering by a sphere. A geometrical optics description of the light scattering phenomena is illustrated in Figure A1. At the first interface, part of the incident light is reflected from the surface of the sphere and these rays are referred to as p = 0 following the convention of van de Hulst (1957). The light transmitted and refracted by the sphere is referred to as p = 1 rays and rays reflected from the interior surface and refracted in the backward direction are p = 2 rays. The relative light energy reflected from and transmitted through the sphere may be calculated using the Fresnel reflection coefficients.

A schematic of the optical and electronics components for a basic PDI system is presented in Figure A2. The optical requirements are identical to that of a one-component laser Doppler velocimeter (LDV), except that three detectors are used in the receiver, and the receiver must be located at a known off-axis angle to the transmitted beams. The preferred light collection position for the receiver is at an off-axis angle of from 25 to 45 degrees to the transmitted beam direction measured from a plane passing through the two intersecting beams. The optical axis of the receiver should be in a plane that passes

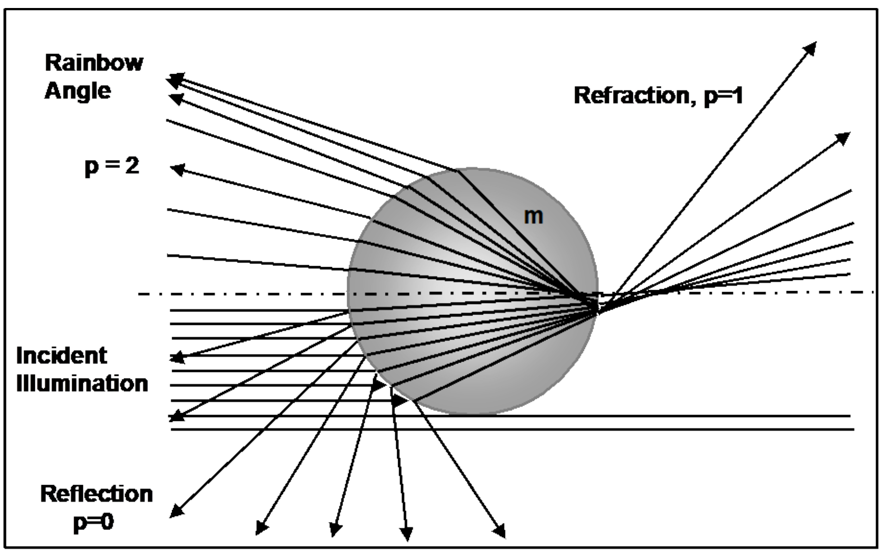


Figure A1: Simple ray diagram showing the deflection of the light rays incident on a spherical particle illustrating the p = 0, 1, 2, and 3 rays.

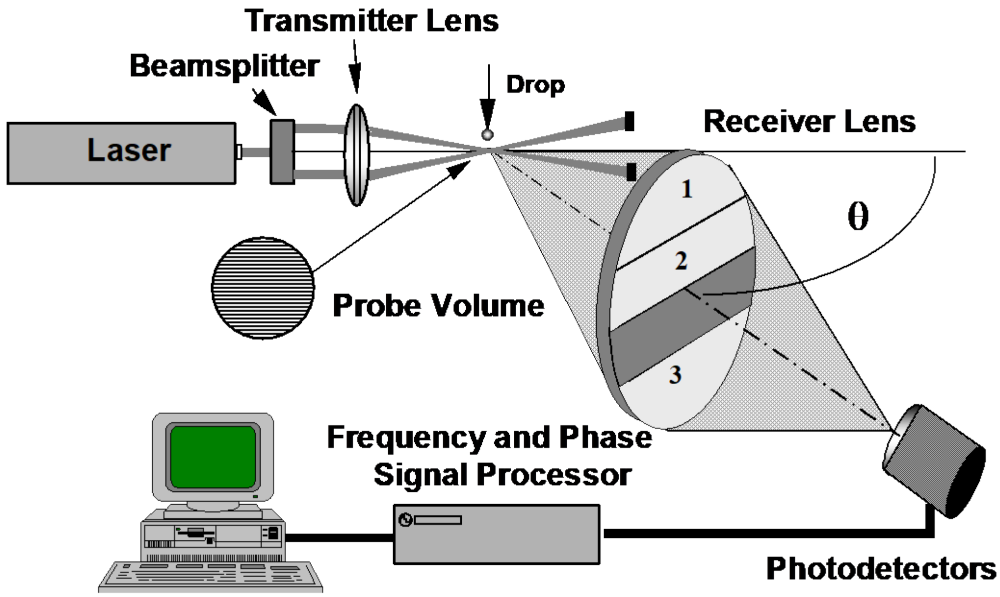


Figure A2: Schematic of the basic Phase Doppler Interferometer (PDI) system.

through the intersection of the beams and is orthogonal to the plane formed by the two intersecting beams. Other receiver angles and configurations have been suggested but we do not recommend that they be used unless no alternative exists due to some other constraints of the experiment.

In the basic PDI optical system, the laser beam is split into two beams of equal intensity. The beams are then focused and made to intersect using a transmitter lens. Frequency shifting is used to compress the frequency dynamic range and resolve the direction ambiguity that would occur for drops passing in a reverse direction. Particles passing through the beam intersection will scatter light that is collected by the receiver lens. A single aperture is used in the receiver to allow only light scattered by particles crossing a small region of the beam intersection to reach the photodetectors. Shown in figure A3 is a schematic depicting a spherical particle located at the intersection of the two laser beams. An enlarged view of the sphere with a light ray from each beam incident upon it is also shown. Since the rays from each beam enter at different angles, they must pass on different paths to reach a common point P. The sphere has an index of refraction, m, that is different than the surroundings. Thus, the difference in the optical path length of ray 1 from beam 1 relative to ray 2 from beam 2 will produce a phase shift between light waves traveling in the directions shown by ray 1 and ray 2 to the point P. An interference fringe pattern will form in the distant space surrounding the drop. Under ideal conditions, the interference fringe pattern will have a sinusoidal intensity distribution and will form a hyperbolic set of curves when projected onto a plane.

The wavelength of the pattern at a given location will be inversely proportional to the drop diameter. This phase shift can be calculated easily and exactly using the geometrical optics theory. Given a specific location in space (points on the receiver lens aperture) the phase shift between the light scattered from each beam will vary in proportion to the drop diameter.

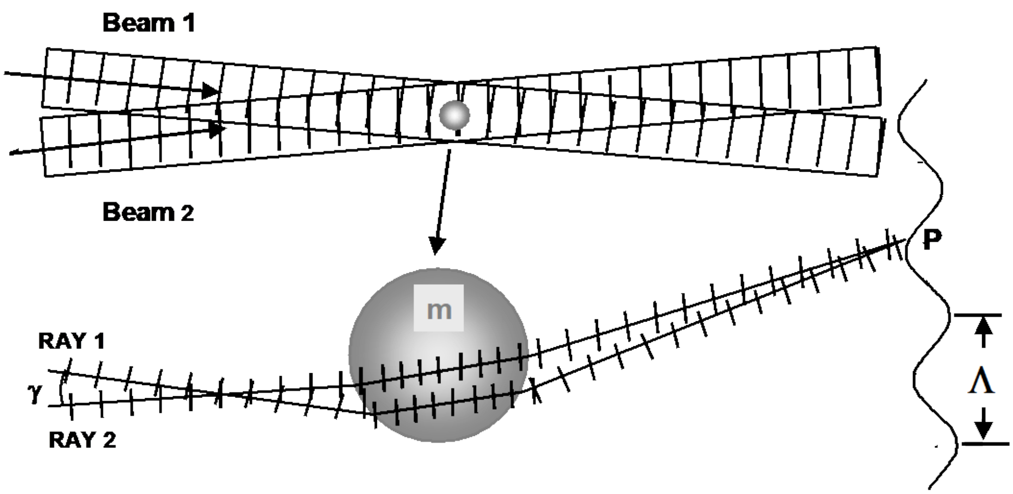


Figure A3: Simple diagram showing the light rays and waves incident on a spherical particle and the phase shift resulting from the passage of the light through the drop on different optical paths.

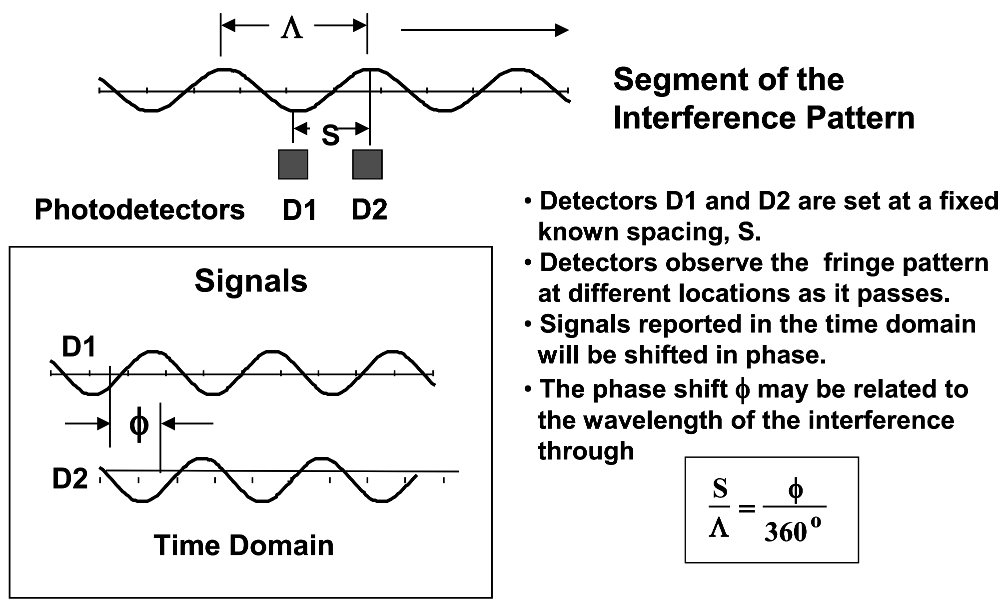


Figure A4: Scheme used for rapidly measuring the spacing, L of the interference fringes produced by the scattered light.

Measurement of the spacing of the interference fringes produced by the scattered light is accomplished in a straightforward manner using pairs of detectors, figure A4. For this approach, pairs of detectors are located in the fringe pattern, or an image of it, and the separation S between the detectors is known. When the particle or drop is moving, the usual Doppler shift in the frequency of the scattered light occurs. The difference in the Doppler frequency shift between the light scattered from beam 1 and beam 2 causes the fringe pattern to appear to move.

As the pattern sweeps past the detectors at the Doppler difference frequency, each detector produces a signal that is similar in frequency but shifted in phase. The phase shift is related to the spacing of the scattered fringe pattern through the following relationship:

$$\frac{s}{\Lambda} = \frac{\phi}{360^O}$$

where s is the detector spacing and ϕ is the phase shift between the signals. The wavelength Λ is the spacing of the interference fringes formed by the scattered light and is inversely proportional to the drop diameter. Three detectors are used to avoid ambiguity in the measurements, to provide redundant measurements of the pattern, and to improve the resolution for the small particles. The ambiguity could occur when the fringe spacing, Λ is less than the detector separation. In this case, the phase shift would be greater than 360 degrees but is reported as ϕ - 360.

A unique three-detector separation arrangement originally invented by Bachalo (US Patent 4,540,283) and first reported in 1982 (NASA Technical Report) is shown in figure A5. The phase versus diameter curves that correspond to these detector separations are also shown. With this configuration, the phase shift between the signals from the closely spaced detectors, D1 and D2 follow the smaller slope on the phase-diameter plot indicated by the dotted lines. The phase between the signals for the detectors with the larger spacing, D1 and D3, follow the curves with the greater slope. With this arrangement, the phase may be measured for detector separations that extend over several fringes (1 fringe corresponds to a measured phase shift of 360°) when placed in the field of the scattered light. More recently (patent pending), Bachalo has reported the use of three pairs of detectors (ϕ_{12},ϕ_{13}, and ϕ_{23}) to be used in the measurement as shown in the updated diagram of phase versus diameter

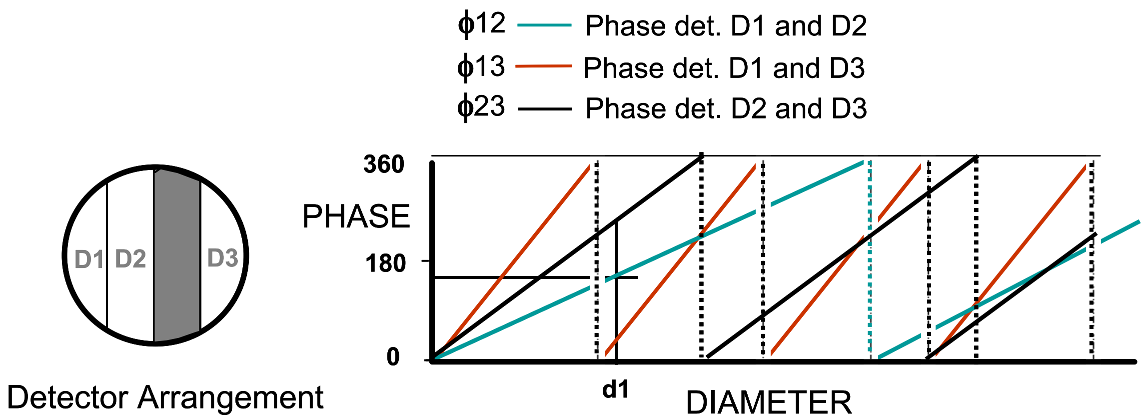


Figure A5: Three-detector configuration and the resulting phase diagram used to avoid ambiguity and extend the measurement range with high resolution.

It is relatively easy to see that the interference fringe pattern produced by reflection will appear to move in the opposite direction to that produced by refraction. With the three detectors set to detect the phase shift for refraction, as shown in figure A6, the correct phase shifts for ϕ12, ϕ13 and ϕ23 will be detected. However, when the dominant light scatter is by reflection, the wave will travel in the opposite direction. For this case, the relationship between ϕ12, ϕ13, and ϕ23 will no longer pass the phase comparison criteria so these samples will be rejected.

Unfortunately, spray droplets will also pass on trajectories through the Gaussian beam, which will result in a significant superposition of scattered light intensity by reflection and refraction. In this case, the resultant interference fringe pattern is no longer a pure sinusoidal wave but a superposition of several interference patterns. Additional means are required to reject particles passing on these trajectories to avoid or minimize measurement errors. Bachalo (1980) recognized this problem, and it was the primary reason for selecting the 30^{o} light scatter detection angle wherein refraction is approximately 80 times the reflection (assuming a uniformly illuminated sphere). Bachalo and Houser (1984) addressed this problem experimentally by traversing monodisperse drops along controlled trajectories within the measurement probe volume for a range of drop-size-to-beam-diameter ratios. Fortunately, the redundant phase information coupled with other information has been proven successful in mitigating or eliminating this source of measurement error.

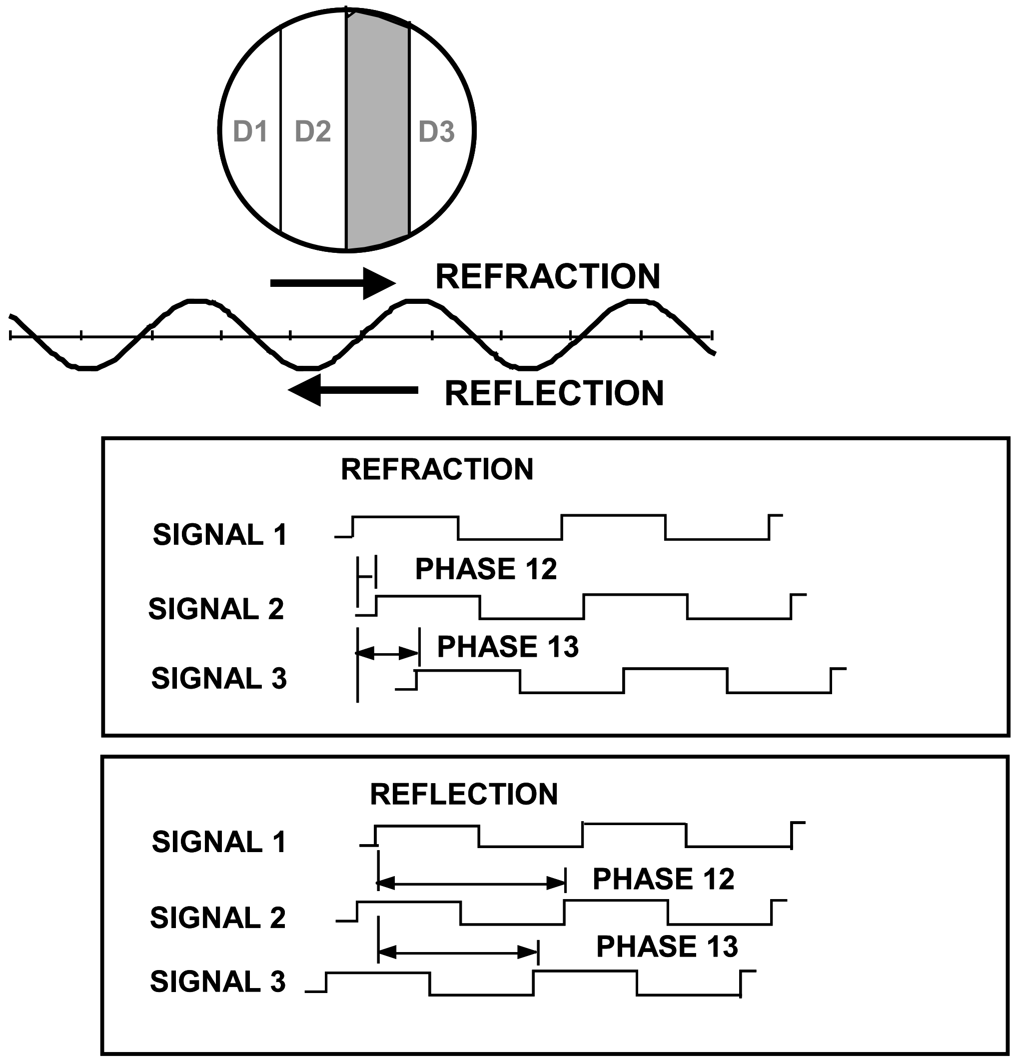


Figure A6: Three-detector configuration used by Bachalo, 1982 to resolve the phase ambiguity and to extend the measurement range and resolution.

The key parameter in the analysis of this problem is the drop diameter-to-beam diameter ratio, $\Gamma = d / D_o$ where d is the drop diameter and D_o is the diameter of the focused beams at the sample volume, figure A7. At this point, it is useful to consider the problem in three regimes: particles smaller than the focused beam diameter, ($\Gamma << 1$) particles similar in size (Γ□~1), and particles larger than the beam diameter ($\Gamma >> 1$). In the first case, the particles can be assumed to be approximately uniformly illuminated so the trajectory error is not a problem. In the case of the particles being of similar diameter to the focused beam diameter, the trajectory problem is most difficult since the scattering intensities from reflection and refraction can be of similar order producing a complex interference fringe pattern with a progressively increasing magnitude of error. If the particles are larger than the focused beam diameter, then either reflection or refraction will dominate the scattering. For this case, the phase ratio will be effective in rejecting signals produced by the wrong scattering component.

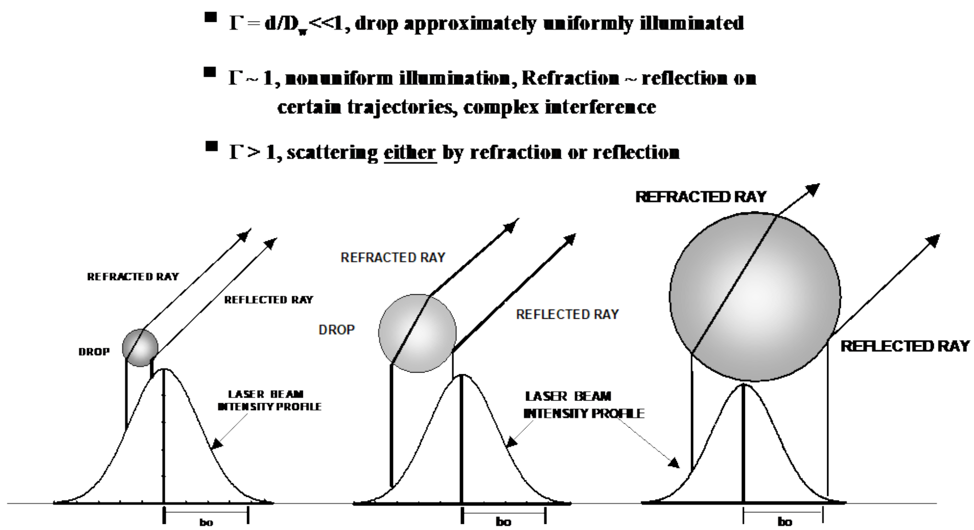


Figure A7: Schematic illustrating the three drop size cases passing a Gaussian beam; □<<1, □~1, and □>1.

Sankar et al. (1992) have shown that the trajectory-dependent sizing errors can be minimized by the proper selection of the optical parameters, namely, the beam intersection angle and using the two-detector-pair arrangement of the PDI. This work represented the first recognition of the importance of the relative phase difference between the reflected and the refracted light in resolving the trajectory-dependent error problem. Increasing the beam intersection angle serves to increase the difference between the phase of light scattered by refraction and reflection, allowing a more effective discrimination using the phase ratio from the two pairs of detectors. In a later paper by Sankar et al. (1995), it was shown that with the proper selection of the optical parameters, the phase Doppler response for particles passing along the error-prone trajectories could be forced to always result in a size over-prediction, if at all, and never an under prediction. This information can then be used in conjunction with the scattered light intensity level for each particle to eliminate the erroneous measurements (Bachalo, US Patent 4,986,659).

The intensity validation method is based on the observation that when particles pass on the "bad" trajectories near the edge of the beam, the incident intensity and hence, the scattered light is at least an order of magnitude lower than for particles passing on a trajectory through the center of the beam. In addition, if the light scattering by reflection is detected, the signal will be approximately two orders of magnitude lower than for the light scattered by refraction because of the lower light scattering efficiency. Thus, calculating a minimum acceptable light intensity level for each size class and measuring the signal amplitudes along with the drop size can provide information for eliminating the particles passing on the trajectories susceptible to errors from consideration. Using this approach, the definition of the edges of the sample volume are better defined at higher levels than is possible on the wings of the Gaussian wherein a small uncertainty in amplitude corresponds to a large change in the size of the sample volume. Detailed experimental studies and theoretical simulations have been conducted to evaluate the reliability of the intensity validation method. Sankar et al. (1995) and Strakey et al. (2000) have shown that the method is effective in controlling trajectory errors.

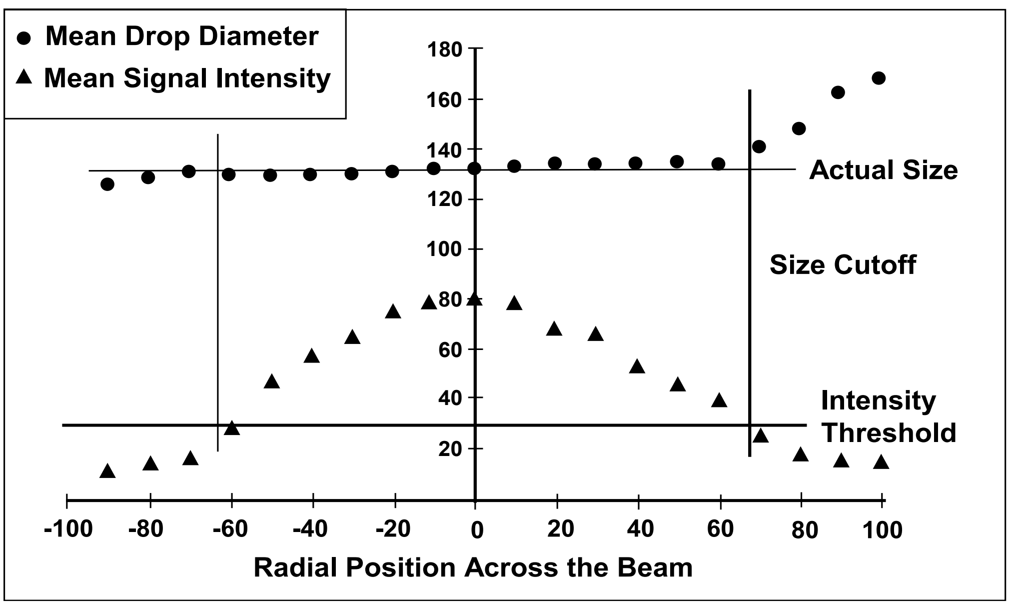


Figure A8: Plot showing the light scattering intensity and the measured drop size for a monodisperse drop stream traversed through the sample volume from one side to the other.

Numerous experimental evaluations of the method have been conducted. Figure A8 shows the results of traversing a monodisperse stream of droplets through the probe volume. The drops had a nominal size of 132 μm. The plot shows the resulting light scattering intensity which is nearly Gaussian and the measured size as the stream is traversed from one side of the beam to the other (-100 μm to +100 μm).

The scattered light intensity profile will not be completely Gaussian in shape since the light scattering mechanisms change from one side of the beam to the other (more reflection detected on one side as a result of the location of the receiver). If a threshold intensity level is set (as shown in figure A8) for each drop size class, the error in the measured size at the side with the reflective light scattering may be eliminated. For the "bad" trajectories, the measured size begins to deviate from the true value but setting a threshold signal amplitude level serves to exclude these readings. In principle, the adaptive threshold validation method limits the region of detection over the sample volume for each particle size class.

Examples of PDI Applications

Numerous examples are available in the literature wherein the PDPA has been used to investigate spray characteristics in highly complex environments. This includes study of sprays injected into turbulent flow fields, reactive fuel sprays in swirl-stabilized combustors, characterization of rocket injectors in a high-pressure environment using cryogenic liquids, and the study of transient fuel sprays such as in spark ignition (SI) and diesel engines. The usefulness of the PDPA (now referred to as the PDI instrument) in understanding various complex spray and combustion processes becomes apparent through the following brief description of some of the results that have been obtained to-date by various researchers.

Spray Combustion Measurements

The development of the Phase Doppler Interferometer (PDI) has enabled the detailed measurement of drop size, velocity, number density and volume flux in realistic spray combustion environments [Bachalo et al. (1990); Edwards and Rudoff (1990)]. Chehroudi and Ghaffarpour (1991) investigated the effects of swirl and dilution air flow rates on the shape and stability of a kerosene flame on a model combustor with comparisons made of the non-combusting and combusting cases. The gas temperature was also measured within the flame using a thermocouple. Flow visualization showed nonuniformly-distributed separated finger-like regions of visible flames wrapped around the spray sheath. These structures were possibly due to large-scale eddies formed by the swirling flow. At the center of the spray, drops with a reversed flow velocity were measured indicating a region of recirculation, figure A9. In the burning case, no drops were detected in this region indicating that only vitiated air is recirculated toward the injector. At the uppermost end of the flame brush, a significant number of large drops were measured with velocities of approximately 10 m/s indicating that unburned drops were exiting the flame.

Transient Fuel Sprays

Transient spray injection such as that used in Diesel and spark ignition engines shows some unique atomization characteristics. Diesel injection may take place into a relatively quiescent environment at pressures of approximately 15 atmospheres and at injection pressures of between 50 and 180 MPa. The important combustion parameters are the fuel penetration, mixing, and vaporization. These parameters depend upon the spray drop velocity and trajectory, the drop size distribution, and the turbulent gaseous flow field. The characterization of sprays having droplets of high velocity, small diameter, and high number density, which are typical of Diesel engines, is a challenging task, Harrington (1995). This is particularly true for smaller bore, light-duty, and medium-duty Diesel engines that utilize relatively short distances from the injector tip to the piston-bowl impact point. The combination of the above factors with high beam extinction in the spray core, and the need for a high pressure optical chamber, leads to difficulties in all laser diagnostic methods. In spite of these challenges, the advanced frequency domain signal processors that are available for the PDPA has allowed for the reliable characterization of Diesel sprays.

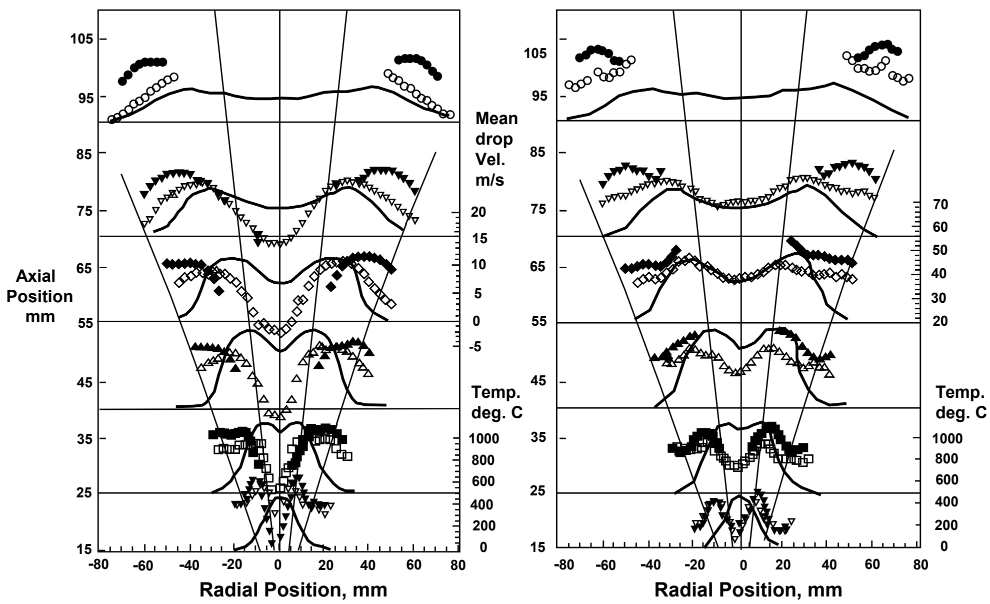


Figure A9: Drop size and velocity data obtained in a swirl-stabilized combustor comparing the results with and without combustion. The solid symbols are for the reacting case. Also shown is the gas temperature (solid line) obtained with a thermocouple (Courtesy of Chehroudi and Ghaffarpour [1991]).

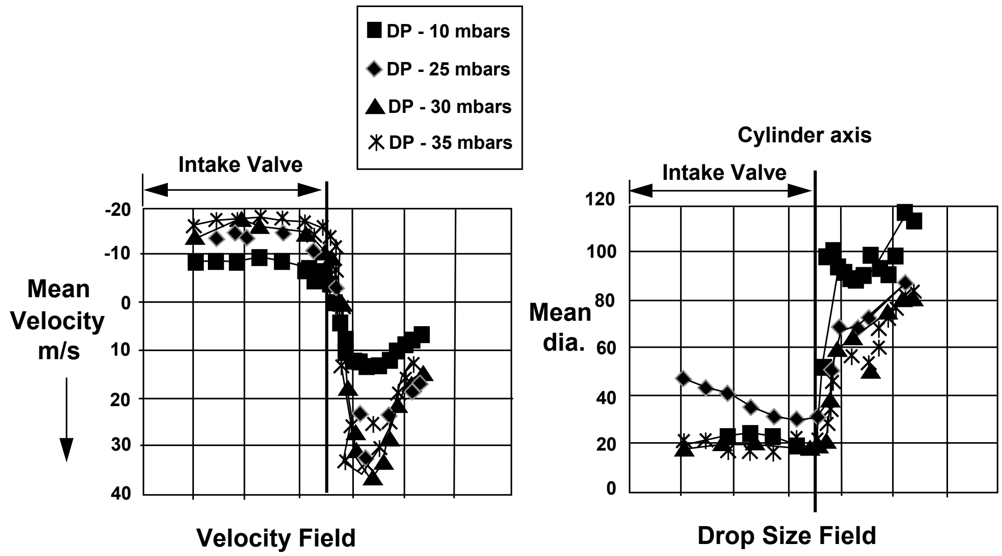


Figure A10: Air flow rate effect on drop size and velocity fields inside a SI engine cylinder.

As with Diesel engines, the atomization for spark ignition (SI) engines is highly transient and must be accomplished over a wide range of operating parameters. Vannobel et al. (1992) have used the PDPA to perform measurements in a gasoline spray inside the inlet port and downstream of the induction valve of a SI engine. Their interest was in studying quality of the air/fuel mixture and its dependence upon injection timing, injector position, and orientation within the manifold. The PDPA measurements were made inside the engine cylinder. The various curves in figure A10 representing the different air pressures, illustrate the trajectories followed by the drops.

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