NOAA Continuous Light Absorption Photometer (CLAP) Users Manual Revision 2018-12-28

1. Introduction

Reliable measurements of aerosol light absorption are crucial for quantifying the radiative forcing of climate. As a consequence, light absorption measurements are recommended for all stations in the Global Atmosphere Watch network, which is coordinated by the World Meteorological Organization. Aerosol light absorption is often dominated by soot-like particles produced by the incomplete combustion of carbonaceous fuels, commonly termed "black carbon", and optical methods are the primary way that equivalent black carbon concentrations are derived.

There are two basic approaches for determining the aerosol light absorption coefficient, *in-situ* methods where the absorption is measured while the particles are suspended in air, and *filter-based* methods where the particles are deposited on a filter for real-time optical analysis. In-situ methods are inherently more accurate because the physical state of the particles can be changed by the act of filtration. Unfortunately, currently available instruments for in-situ measurements are more expensive and difficult to operate than filter-based methods, making them better suited for use in intensive field campaigns or as laboratory reference instruments. Filter-based instruments, because of their lower cost and simpler operation, have been the preferred choice for long-term measurements of aerosol light absorption in monitoring networks.

NOAA has used filter-based instruments for measuring aerosol light absorption coefficient at baseline observatories for over two decades. Both Aethalometers (Hansen et al., 1984) and Particle/Soot Absorption Photometers (PSAP; Bond et al., 1999) have been used. Both of these instruments, as well as the Multi-Angle Absorption Photometer (Petzold and Schönlinner, 2004), lack one or more desirable features for long-term measurements of aerosol light absorption coefficient for studies of aerosol forcing of climate. As a result, NOAA has developed and built a filter-based instrument, the Continuous Light Absorption Photometer (CLAP), with the following design features:

- operation at three visible wavelengths (blue, green red), to allow calculation of key climate forcing parameters (aerosol single-scattering albedo and radiative forcing efficiency) when combined with a three-wavelength integrating nephelometer;
- high-sensitivity, for operation in relatively clean air;
- heated and temperature-stabilized, to minimize effects of changing room temperature and high ambient dewpoint temperatures;
- multiple filter spots, to enable unattended sampling for up to a week in rural and remote locations;
- internal flow paths optimized for low losses of particles smaller than 10 µm aerodynamic diameter;
- precisely-defined filter spot areas;

- optical configuration and filter media comparable to the PSAP, to allow use of the Bond et al. (1999) correction scheme for errors caused by filter loading and multiple scattering;
- low cost and small size.

This manual describes operation of the CLAP Model 10, so numbered because it was designed in 2010. Several sacrifices in the design were made to provide the above features, including

- a two-part design, where the top half must be manually removed to change the filter. This approach was chosen to keep the mechanical design simple by eliminating the need for moving parts.
- elimination of o-rings to seal the filter. The initial design included an o-ring for each filter spot, but was rejected because the o-ring caused the edge of the spot to be diffuse and variable.
- need for torque driver to secure the top and bottom assemblies after a filter change. The initial design used thumbscrews, but their uncontrolled torque sometimes resulted in incomplete sealing of the two assemblies

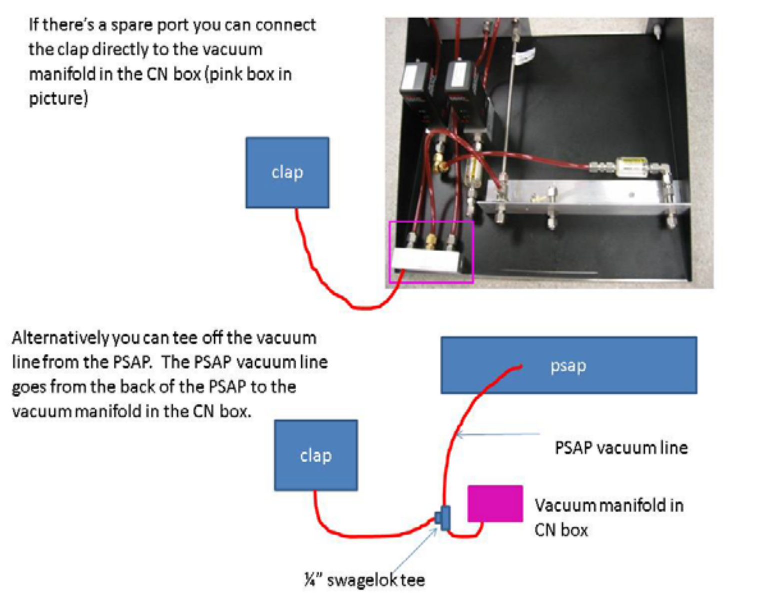
The CLAP contains an embedded microprocessor to measure signals and control valves and heaters, but for simplicity the task of calculating light absorption coefficient is delegated to an external computer. A simple user interface and menu system is provided for manual or computerized control of all CLAP functions. Operation via the manual user interface, as well as with the companion 'cpd' software developed by NOAA, is described in this manual.

2. Instrument Description

2.1. Overview and Instrument Setup

The CLAP provides measurement of the light absorption of particles deposited on a filter, similar to the Radiance Research Particle Soot/Absorption Photometer (PSAP). It differs from the PSAP in that it utilizes solenoid valves to cycle through 8 sample filter spots and 2 reference filter spots, enabling the instrument to run at ideal conditions (filter transmittance, Tr, greater than 0.7) eight times as long as the single-spot PSAP. The CLAP uses 47-mm diameter, glass-fiber filters (Pallflex type E70-2075W), identical to the PSAP filters except for size. These filters are made of two fibrous layers, borosilicate glass fibers overlaying a cellulose fiber backing material (for strength and stability). The cellulose fiber layer is thought to take up water under conditions of high humidity, which is one reason that CLAP has an internal heater to lower the sample relative humidity inside the instrument. The CLAP is typically installed so that it draws its sample air through a modified TSI nephelometer blower bypass block. The CLAP vacuum line is connected to system vacuum (in the NOAA aerosol system that means connecting to a port on the manifold block in the CN box or ‘tee-ing’ off a vacuum line such as the PSAP vacuum line).

	
CLAP sampling from modified nephelometer blower bypass block. *Blower block orientation is important – it should match the orientation in this picture – i.e., pick-off fitting should be closer to neph sampling volume.*	Closeup of modified nephelometer blower bypass block. Your nephelometer may have a blower installed in this location instead of a non-modified blower block. If that’s the case, remove the blower and detach the blower power cable. Insert the modified blower block in the place of the blower.

<table>
<tr>
<td colspan="2">
</td>
<td>There are several options for connecting the CLAP to vacuum. If it is being run in conjunction with the NOAA aerosol system the easiest options are depicted at the right. Otherwise, any stable vacuum source should work.

Note: Oscillations/disruptions in the vacuum source may cause the filter to oscillate and affect the measurements.</td>
</tr>
<tr>
<td></td>
<td colspan="2"></td>
</tr>
<tr>
<td>Top view of CLAP with top secured. To open CLAP for filter replacement unscrew the four nuts on top using the torque driver.</td>
<td colspan="2">Top view of CLAP with top removed and clean filter inserted. You can see the 10 holes (8 sample + 2 reference in the CLAP lid).</td>
</tr>
<tr>
<td colspan="3">The front panel contains a red pushbutton with internal indicator lamp, a display that shows the flow rate, and a manual needle valve that adjusts the flow rate.</td>
</tr>
</table>

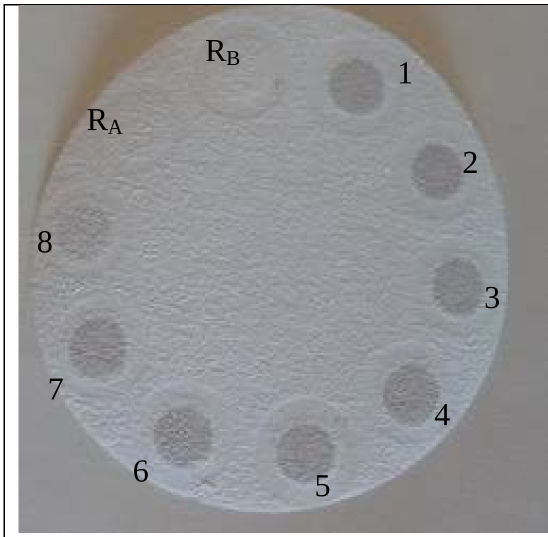
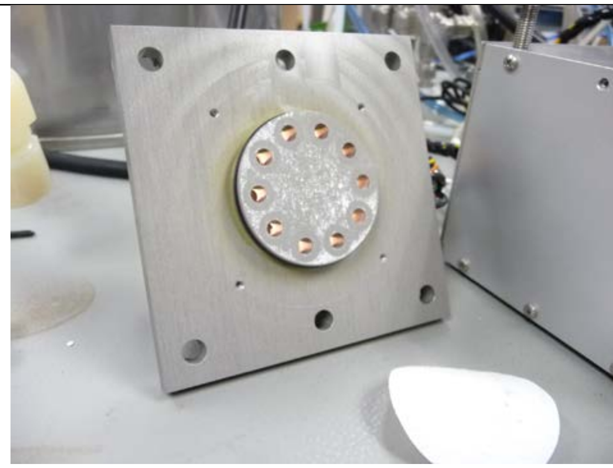


Photo of used CLAP filter. You can see the 8 sample spots (1-8) and the two reference spots (R), which only measure filtered air.



Here you can see some of the filter material stuck to the top of the CLAP. This should be cleaned off (use ethanol and lintless tissue) when doing a CLAP filter change. If any of the filter material gets up into the holes (top or bottom!), blow it out gently using compressed air.

Reference spot R_A is used for the odd-numbered sample spots, and R_B is used with the even-numbered ones. On this filter, spots 1-7 were each sampled until the transmittance reached 0.7. The filter was removed from the CLAP when spot #8 had a transmittance of 0.84, which is why the #8 filter spot appears slightly lighter than spots #1-7.

The CLAP requires an external computer for data logging and instrument control. The internal software in the CLAP provides the minimum functionality for measuring signals (light intensity reaching the ten detectors, flow rate, case temperature, and sample temperature) and controlling the hardware (light source, case heater, and solenoid valves). The internal software detects when the pushbutton on the front panel is depressed and controls whether the red indicator lamp is lit or not.

The red indicator lamp is off during normal sampling and on during a filter change. A blinking lamp indicates an error condition that must be corrected before continuing.

A ‘white filter check’ is required when a CLAP is first installed, when an upgraded LiveCPD system is installed, or when a new box of CLAP filters is started. The procedure is as follows:

(1) Choose 'start white filter check' from the CLAP menu.
(2) Open up the instrument and put a new filter in the CLAP. Make sure it is only a single filter (not two stuck together) and that it is nice and clean and white. This is important because this procedure establishes a baseline range for the instrument.
(3) Close the instrument and use the torque wrench to make sure it is closed to the correct tightness.
(4) Choose 'end white filter check' from the CLAP menu

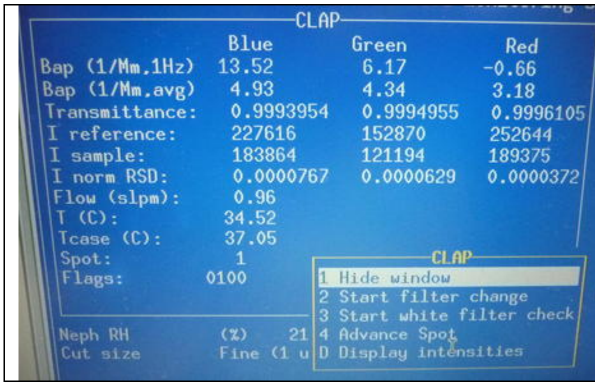
The instrument will wait until white filter stability is reached and then should begin normal sampling (see flow chart on page 8 of this manual).

2.2. Changing the CLAP filter

1. Changing the CLAP filter takes less than five minutes. Tools required are a torque driver, replacement filter, tweezers, zip-closure plastic bag, and a permanent marker.
2. Make a note of the CLAP flowrate, as you will need to compare with the flowrate after the filter change.
3. Press the red button on the front panel to signal the start of a filter change. The red indicator light will turn on to indicate that the CLAP is in filter changing mode.
4. Unscrew the four nuts on the top of the panel using the torque driver, remove the lid, and lay it carefully to the side of the instrument.
5. Remove the filter. Place the filter in a small zip-closure bag and label the bag with the station name and the date the filter was pulled out of the CLAP. The label should have the format: YYMMDD-STN (so December 13, 2000 at Trinidad Head (THD) would be labeled: 001213-THD). Write your initials on the bag.
6. Make sure that the top and bottom surface of the filter holder are clean – use a tissue and ethanol to remove any filter fibers, dirt or obstructions. Use the tweezers to take a new filter from the supply box, making sure that you only took a single filter (sometimes two filters may stick together). Place a new filter in the filter holder, with the white side of the filter facing up. Secure the lid on the CLAP by replacing the lid down onto the centering pins and tightening the 4 nuts using the torque driver. The torque driver will click when the proper amount of torque has been applied. Note: the lid only fits on one way.
7. Press the red button to signal that the filter change is complete. The red lamp should turn off.
8. The CLAP will **not** begin sampling automatically after a filter change. External software must issue commands to the CLAP to begin sampling. The NOAA 'cpd' software will take care of this automatically (see section 3), otherwise the appropriate commands must be issued manually (see section 4).
9. Once the CLAP begins sampling after the filter change, compare the flowrate with the value before the filter change. The flowrate should be at least as high as was measured for the previous exposed filter. If it is lower than before, you should repeat the filter change, in case two filters were stuck together.

3. Operation with NOAA 'cpd' Software

The commands for changing filters can be issued via the front panel of the CLAP (section 2.2), or they can issued via the 'cpd' software. In the latter case, press <Enter><L(or R)><M><2> in the CPD Client window (the blue screen) to select the CLAP menu and signal start of a filter change. The bottom of the CLAP window will indicate that a filter change is taking place. The red light on the front of the CLAP will be illuminated providing an additional indication that a filter change is occurring. Follow the procedure described in section 2.2 to change the filter.



CLAP main window and menu. To start a CLAP filter change you would choose <2> on the menu.

The cpd software monitors the light intensity of the ten detectors to detect when the system has stabilized after a filter change. If the autodetect feature is enabled in the cpd.conf configuration file, cpd will notify the CLAP that the filter change is finished when stable intensities are seen, even if the red pushbutton has not been pressed. Regardless of whether the end of the filter change is detected manually or automatically, the red light will turn off and the CLAP status window in CPD Client will no longer say "Changing filter…".

Once the detector signals have stabilized following the filter change, cpd will turn on the solenoid valves to enable flow through spot #1. Another stabilization period will follow, because the filter deforms slightly as air flows through it. Once stable conditions are reached, the initial light intensities are recorded and normal sampling begins. At this point, the user should check the flow rate and adjust the valve if necessary to achieve the desired value. The proper flow rate displayed in the CLAP cpdclient window is a mass flow rate that is equivalent to 1.0 lpm by volume. All CLAPs operate at this volumetric flow rate so that they have the same filter face sampling velocity and aerosol particle penetration characteristics. The flow rate indicated on the CLAP instrument front panel is the value calculated using the internal flow calibration, while the value displayed in the CPD Client window is calculated using both the internal flow calibration and the "trimming" multiplier (discussed in Appendix Section 7.4). When cpd establishes communications with the CLAP, it compares the internal flow calibration parameters with the corresponding parameters in the cpd.conf configuration file; if the parameters differ, cpd updates the internal calibration with the parameters from cpd.conf. Note that high altitude sites should show a mass flow reading well below 1.0 slpm.

The following example illustrates how the proper flow rate is determined for a site. The average annual station T and P estimates can be obtained by looking at meteorological records, and they include all times of the day and night and seasons of the year.

Station: Mauna Loa, Hawaii
Elevation: 3396 m (11,141 ft) above sea level
Estimated average annual station temperature (Tstn): 8 degrees C (281.15K)
Estimated average annual station pressure (Pstn): 679 mb

Standard temperature (Tstd) for mass flow measurement: 0 degrees C (273.15K)
Standard pressure (Pstd) for mass flow measurement: 1013.25 mb

We need to have 1.0 lpm by volume (Vstn = 1.0), and we are calculating Vstd (the indicated standard flow to achieve 1.0 lpm volumetric flow).

By the ideal gas law,
(Pstd x Vstd)/Tstd = (Pstn x Vstn)/Tstn

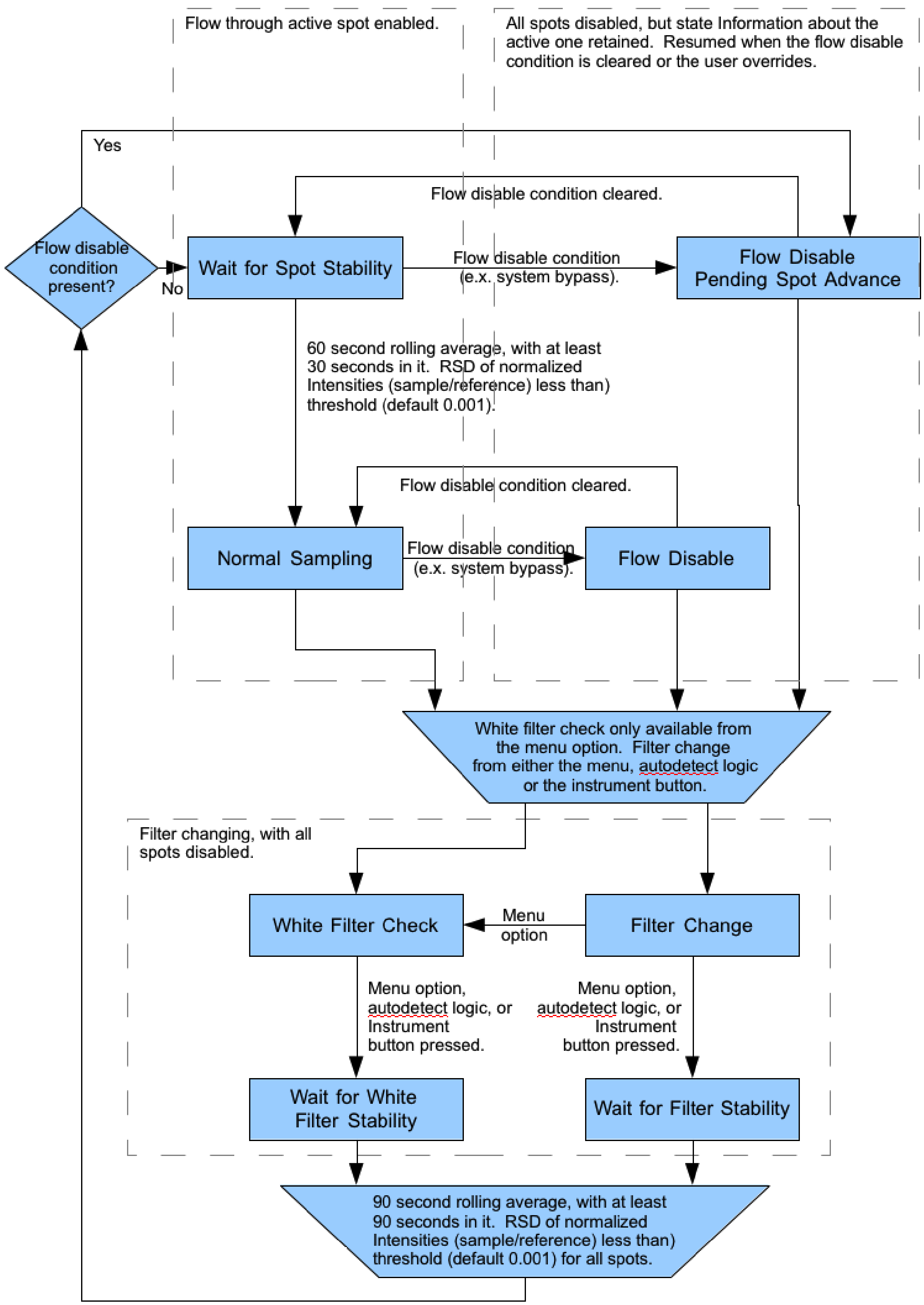
Vstd = ((Pstn x Vstn)/Tstn) x (Tstd/Pstd) = Vstn * (Pstn/Pstd) * (Tstd/Tstn)

Vstd = 1.0 * 679/1013.25 * 273.15/281.15 = 0.65 slpm displayed in cpdclient CLAP window. This gives us an average CLAP volumetric flow of 1.0 lpm.

Thus, at the high altitude station Mauna Loa, a mass flow rate of 0.65 slpm is necessary to achieve a 1.0 lpm volumetric flow rate.

Flags
The operator should note the value of the flags variable on the cpdclient screen. A value of 0000 indicates that the CLAP is operating normally, and a value of 0001 indicates that the filter is being changed; any other value indicates a stabilization period, a warning (e.g., the Tr has dropped to below 0.7), or an error condition that should be investigated. In the picture above the flags value is 0100, indicating a lamp error. The meaning of each flag bit is given in the Appendix (section 7.1 of this manual).

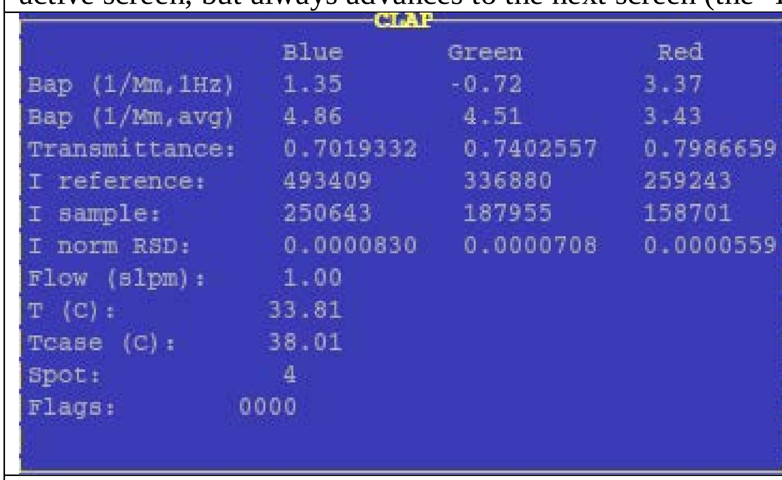
CLAP Operating States
The CLAP has three primary states during operation: normal sampling, sampling disabled, and filter changing. These states and the transitions among them are summarized in the figure.


Flow through active spot enabled.
All spots disabled, but state Information about the active one retained. Resumed when the flow disable condition is cleared or the user overrides.
Yes
Flow disable condition cleared.
Flow disable condition present?
No
Wait for Spot Stability
Flow disable condition (e.x. system bypass).
Flow Disable Pending Spot Advance
60 second rolling average, with at least 30 seconds in it. RSD of normalized Intensities (sample/reference) less than) threshold (default 0.001).
Flow disable condition cleared.
Normal Sampling
Flow disable condition (e.x. system bypass).
Flow Disable
White filter check only available from the menu option. Filter change from either the menu, autodetect logic or the instrument button.
Filter changing, with all spots disabled.
White Filter Check
Menu option
Filter Change
Menu option, autodetect logic, or Instrument button pressed.
Menu option, autodetect logic, or Instrument button pressed.
Wait for White Filter Stability
Wait for Filter Stability
90 second rolling average, with at least 90 seconds in it. RSD of normalized Intensities (sample/reference) less than) threshold (default 0.001) for all spots.

The CLAP status window in CPD Client allows examination of many different aspects of instrument operation. Pressing "M" when the CLAP status window is activated will display the CLAP menu.

The CLAP menu is context-sensitive, and alters slightly depending on what state the CLAP is in. For example, during a filter change, the options change to "Stop filter change" and "Switch to white filter check".

1 Hide Window - Hides the CLAP window.
2 Start filter change - Start a filter change.
3 Start white filter check - Start a white filter check, or switch the current filter change to a white filter check.
4 Advance spot - Advance the active spot to the next one.
5 Set flow override - Set or clear the flow override state.
D Display intensities - Display the intensities screen. This option will change depending on the active screen, but always advances to the next screen (the "D" hotkey is equivalent).

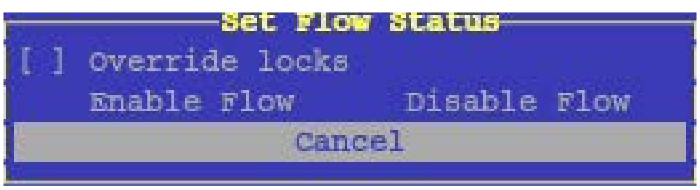


The main CLAP status window summarizes the operating state. The first six lines are broken into three columns, one for each of the color channels. Some values will be missing (blank) when the current mode or system state prevents their calculation. For example, the intensities are not listed when there is no active spot.

Rows:
1: The one-second absorption coefficient, calculated from the last two intensities for the active spot and the last flow.
2: The last 1-minute average of the absorption coefficient.
3: The instantaneous transmittance.
4: The reference ADC counts.
5: The sample ADC counts.
6: The relative standard deviation of the ration of the sample to reference ADC counts.
7: The calibrated flow.
8: The sample temperature.
9: The case temperature.
10: The flags, this is the bitwise OR set by CPD2 and the instrument firmware, in hexadecimal.

If the instrument is in an abnormal state, there will be a further line at the bottom indicating this.

Possible values for abnormal (i.e., non-sampling) state:
"**NO COMMS**" - There is no serial communication with the CLAP.
"**Waiting for spot stability...**" - CPD2 is currently waiting for the spot to be stable (a spot change just ended).
"**Changing filter...**" - CPD2 is currently in a filter change state.
"**White filter check...**" - CPD2 is currently in a white filter check/change state.
"**Waiting for filter stability...**" - CPD2 is currently waiting for filter stability (a filter change just ended).
"**Waiting for white filter stability...**" - CPD2 is currently waiting for white filter stability (a white filter check just ended).
"**FILTER OR LED ERROR**" - CPD2 has detected that the filter parameters are out of range or the instrument has detected an LED problem. This is equivalent to bit 0x0100 in the flags.
"**FLOW DISABLED ON SPOT X**" - A condition (e.g., system in bypass mode) has caused the CLAP to disable its flow (by changing to spot 0) when it was on spot "X". If that condition passes, it will return to spot "X". When this condition occurs, you can override it utilizing the ‘Set Flow Override’ CLAP menu option described below.
"**FLOW DISABLED WITH PENDING SPOT X**" - A condition (e.g., system in bypass mode) has caused the CLAP to disable its flow (by changing to spot 0) when it was pending a change to spot "X" (e.g., the condition arose while it was waiting for spot stability). When that condition passes, it will return to spot "X" and wait for stabilization then start sampling. If this condition occurs, you can override it utilizing the ‘Set Flow Override’ CLAP menu option described below.



The "Set Flow Status" window is shown when the "Set flow override" option is selected. Selecting "Cancel" exits the menu with no effects. Selecting "Enable Flow" clears the user flow disable lock or all locks if the "Override locks" option is set. Selecting "Disable Flow" causes the CLAP to stop flow and sets the user lock. If "Override locks" is chosen, this sets a general lock

Pressing the "D" key will cycle the main CLAP status window through each of the detector intensity windows below.

CLAP

Raw Intensities

	Blue	Green	Red	Dark
I odd ref:	493154	336742	259051	-199
I even ref:	519899	350930	263038	-126
I spot 1:	263705	191949	159843	-199
I spot 2:	257584	191678	164727	-71
I spot 3:	250067	184667	159860	-77
I spot 4:	250446	187837	158565	-121
I spot 5:	380247	262195	200690	-124
I spot 6:	359395	243735	187016	-127
I spot 7:	340712	230094	178024	-129
I spot 8:	337966	229025	174561	-107

Spot: 4

"Raw Intensities" are the detector signals of all spots for all four sample modes (red, green, blue, and dark), as reported by the instrument.

The bottom line shows the currently active spot number, but will change to an abnormal state display as listed above if one is in effect.

CLAP

Raw Intensity RSD

	Blue	Green	Red	Dark
Ig odd ref:	0.0000815	0.0000622	0.0000596	-0.0025424
Ig even ref:	0.0000828	0.0000625	0.0000612	-0.0036657
Ig spot 1:	0.0000819	0.0000633	0.0000606	-0.0017605
Ig spot 2:	0.0000801	0.0000636	0.0000602	-0.0062177
Ig spot 3:	0.0000824	0.0000638	0.0000599	-0.0068697
Ig spot 4:	0.0001913	0.0001366	0.0001126	-0.0027642
Ig spot 5:	0.0000844	0.0000638	0.0000599	-0.0033684
Ig spot 6:	0.0000826	0.0000632	0.0000599	-0.0040295
Ig spot 7:	0.0000846	0.0000635	0.0000602	-0.0028055
Ig spot 8:	0.0000836	0.0000637	0.0000616	-0.0035138

Spot: 4

"Raw Intensity RSD" is the standard deviation divided by the mean of the raw intensities over the "stability" measurement period (normally 90 seconds, but can be changed in the configuration file).

The bottom line will change to the abnormal state display as listed above if one is in effect.

CLAP

Normalized Intensities

	Blue	Green	Red
In spot 1:	0.5074862	0.5473412	0.6081382
In spot 2:	0.5222500	0.5690857	0.6356704
In spot 3:	0.4810262	0.5262559	0.6077384
In spot 4:	0.5078500	0.5578021	0.6120575
In spot 5:	0.7314485	0.7472255	0.7630630
In spot 6:	0.7287241	0.7237410	0.7218470
In spot 7:	0.6554326	0.6558012	0.6769558
In spot 8:	0.6852543	0.6800284	0.6737363

Spot: 4

"Normalized Intensities" are the ratio of each sample spot intensity and its corresponding reference spot intensity. Odd-numbered spots use the "odd" reference, and likewise for the even-numbered spots. In all cases, the respective dark intensity value is subtracted before division.

The bottom line will change to the abnormal state display as listed above if one is in effect.

CLAP

Normalized Intensity RSD

	Blue	Green	Red
Ing spot 1:	0.0000045	0.0000045	0.0000057
Ing spot 2:	0.0000060	0.0000069	0.0000065
Ing spot 3:	0.0000053	0.0000066	0.0000067
Ing spot 4:	0.0001201	0.0001034	0.0000792
Ing spot 5:	0.0000043	0.0000045	0.0000067
Ing spot 6:	0.0000075	0.0000063	0.0000081
Ing spot 7:	0.0000041	0.0000050	0.0000057
Ing spot 8:	0.0000049	0.0000071	0.0000064

Spot: 4

"Normalized Intensity RSD" is the relative standard deviation of the normalized intensities over the "stability" period (normally 90 seconds, but can be changed in the configuration file).

The bottom line will change to the abnormal state display as listed above if one is in effect.

CLAP

Intensity White Filter Ratio

	Blue	Green	Red
Irw spot 1:	0.6536608	0.6957577	0.7581770
Irw spot 2:	0.6156726	0.6604367	0.7237133
Irw spot 3:	0.6571711	0.6974656	0.7590426
Irw spot 4:	0.6580871	0.7021487	0.7624825
Irw spot 5:	0.9627326	0.9697738	0.9740395
Irw spot 6:	1.0017221	1.0093610	1.0129996
Irw spot 7:	0.9486525	0.9490449	0.9518577
Irw spot 8:	0.9287578	0.9365701	0.9417381

Spot: 4

"Intensity White Filter Ratio" is the ratio of the current normalized intensities to the normalized intensities of the last white filter. This is similar to the transmittance relative to the last white filter (the difference being that the white filter normalized intensities do not account for filter flexing due to flow). At the end of a white filter check, with no flow, all these will be 1.0.

CLAP

Intensity Filter Start Ratio

	Blue	Green	Red
Irz spot 1:	0.7048073	0.7430535	0.8007069
Irz spot 2:	0.7004542	0.7395293	0.7981602
Irz spot 3:	0.7009455	0.7375080	0.7938499
Irz spot 4:	0.7044631	0.7432653	0.8018786
Irz spot 5:	1.0044994	1.0042071	1.0038696
Irz spot 6:	0.9983239	0.9999417	1.0009204
Irz spot 7:	0.9760524	0.9803478	0.9860148
Irz spot 8:	0.9675935	0.9736264	0.9810431

Spot: 4

The Intensity Filter Start Ratio is the ratio of the current normalized intensities to the normalized intensities from the end of the last filter change. This is similar to the transmittance except that it does not account for filter flexing due to flow (this can often be seen by there being a distortion away from 1.0 on unsampled spots for all the even or odd channels, depending on what reference is currently in use). With no flow, all unsampled spots would nominally be 1.0, and sampled spots would be their last transmittance.

CLAP operation is controlled by entries in the cpd.conf file (Appendix Section 7.5).

4. Manual Operation

The CLAP is in an "idle" state when power is initially applied, where all valves are closed so that there is no flow through the instrument. The accumulated sample volume through each filter spot is stored in non-volatile memory, so that resumption of sampling can be as simple as enabling flow through the desired spot. However, the CLAP does not store the intensity readings when a new filter is installed, *so the recommended procedure for manual operation is always to start a new spot after a power interruption*.

The manual user interface consists of three menus, as documented in Appendix Section 7.2. There are two essential tasks for manual operation of the CLAP: changing the filter, and activating flow through the desired spots.

The commands for changing a filter are:

`hide` (stop transmission of data reports)
`main` (make sure that you are in the main menu)
`stop` (stop the active filter)
(at this point, open the instrument, change the filter, and close the instrument)
`go` (inform the CLAP that the filter change is done)
`show` (resume transmission of data reports)

The "`hide`" and "`show`" commands are optional, as the instrument will respond to user commands even while data reports are enabled. Likewise, the "`main`" command is not needed if the user has not entered the "`cfg`" or "`cal`" commands for entering the Configuration or Calibration menus.

The commands for activating flow through a spot are:

```
main
spot=n
```

where `n` is a number between 1 and 8.
To turn off the flow, issue the commands

```
main
spot=0
```

The CLAP does not contain a real-time clock, which means the computer that is logging data from the CLAP is responsible for adding a timestamp to the data reports.

5. Specifications

Wavelengths (centroid (FWHM)), nm	467 (26), 529 (40), 653 (20)
Filter media	Pallflex type E70-2075W, 47 mm diameter
Flowrate (volumetric), lpm	1.0
Noise (standard deviation of 60-sec averages on filtered air), Mm^{-1}	~0.2, all wavelengths
Number of sample spots	8
Number of reference spots	2
Inlet connection	¼" tube
Outlet connection	Hose barb for 1/8" I.D. tube
Dimensions (L x W x H), cm	10 x 10 x 16, excluding back panel connectors
Weight, kg	1.6
Power consumption (heaters on)	36 W @ 120-240 VAC, using supplied adapter 1.5 A @ 24 VDC Or 30 W @ 120-240 VAC, using supplied adapter 0.9 A @ 12 VDC
Power adapter	11 x 5 x 2 cm, weight 0.15 kg
Mounting holes	Four holes in a square pattern centered on bottom, spaced 2.5" (6.35 cm) apart, tapped for 10-32 machine screws
Torque setting for tightening top and bottom sections, N-m	2.5
Serial communications	RS232, 57600 baud, no parity, 8 data bits, 1 stop bit. Data rate in unpolled operation is one record of 460 bytes sent each second (user-controllable interval)

6. References

Bond, T. C., T. L. Anderson and D. Campbell (1999). "Calibration and intercomparison of filter-based measurements of visible light absorption by aerosols." *Aerosol Science and Technology 30*(6): 582-600.

Hansen, A. D. A., H. Rosen and T. Novakov (1984). "The aethalometer - An instrument for the real-time measurement of optical-absorption by aerosol-particles." *Science of the Total Environment 36*(JUN): 191-196.

Petzold, A. and M. Schönlinner (2004). "Multi-angle absorption photometry--a new method for the measurement of aerosol light absorption and atmospheric black carbon." *Journal of Aerosol Science 35*(4): 421-441.

7. Appendices

7.1. CLAP Flags

A 16-bit integer is used to record the status of the CLAP. This is included in the raw data reports and shown in the CPD Client status window. The value is reported as a 4-character hexadecimal value. The five most-significant bits are reserved for use by later data processing, and are not used by cpd or the CLAP software; these bits will be shown as zero. The flags are additive in the hexadecimal system, so a flags value of 0300 would indicate that both a temperature error (0x0200) and a lamp/filter error (0x0100) were detected. In the worst case, you could see a flag value of 07FE which would indicate temperature error, lamp brightness error, lamp error, all the transmittances are below 0.5 and there is a flow error.

Flag bit	set by inst?	set by cpd	Description
0x8000	no	no	reserved for future correction flag
0x4000	no	no	CTS correction applied
0x2000	no	no	Bond correction applied
0x1000	no	no	Weiss correction applied
0x0800	no	no	Not used by CLAP
0x0400	yes	no	Case temperature unstable
0x0200	yes	no	Temperature error (inlet or block)
0x0100	yes	yes	Lamp or filter error
0x0080	no	yes	Transmittance IrR_cAxx < 0.5
0x0040	no	yes	Transmittance IrR_cAxx < 0.7
0x0020	no	yes	Transmittance IrG_cAxx < 0.5
0x0010	no	yes	Transmittance IrG_cAxx < 0.7
0x0008	no	yes	Transmittance IrB_cAxx < 0.5
0x0004	no	yes	Transmittance IrB_cAxx < 0.7
0x0002	yes	no	Flow error
0x0001	yes	yes	Filter changing

7.2. CLAP Troubleshooting

7.2.1. Case Temperature Unstable

The case temperature is controlled by the CLAP. The case temperature setpoint is typically between 35 and 40ºC depending on site and instrument settings. There are two scenarios that can set the temp flag; case temp above setpoint and case temp below setpoint.

If the case temperature is warmer than the setpoint, which is due to self heating from the electronics (the solenoids get rather warm) then to clear the flag we need to either raise the setpoint, expand the acceptable temperature deviation for "good" temperatures (currently ± 1.0 ºC), or remove the side panels to allow for convective cooling. If the CLAP has external insulation (i.e., a box and or foam) then the external insulation can be removed to lower the

CLAP temperature. A future modification may be to provide side panels with ventilation louvers or cutouts, for deployments where overheating is a problem.

If the case temperature is cooler than the setpoint temperature then we need to minimize convective cooling on the outside of the instrument. Tests have shown that something as simple some external insulation (such as a cardboard box) placed over the instrument has a significant impact in this situation.

7.3. Serial Interface

The CLAP reports measurement results at user-selectable intervals over a serial (RS232) interface. The serial port settings are 57600N81.

7.3.1. CLAP Record Format

Each data record consists of 49 comma-separated data values (458 bytes), terminated by a carriage return and line feed, as follows.

record type (currently only type 03 is used),
flags (16-bit hex integer),
elapsed time (seconds; 32-bit hex integer)
filter ID (16-bit hex integer),
active spot (00-08, 00 off),
flowrate (slpm; fixed point decimal),
sample volume for active spot (m^3; fixed point decimal),
case temperature (ºC; fixed point decimal),
sample air temp(ºC; fixed point decimal),
ch0 DRGB, ch1 DRGB, ... ch9 DRGB

example (line feeds added for legibility):

```
03, 0002, 00003ef7, 0008, 00,
0.000, 0.00000, 37.00, 34.22,
c343ef6c, 48b09b55, 4834423c, 486dc150,
c3423a45, 48758f3c, 48011951, 4827deac,
c2bd6321, 487189bf, 47fc6640, 48213bd4,
c2ab3f0d, 48756a90, 480020b0, 48250060,
c2c627a3, 486fdf58, 480007a6, 4828f8c7,
c2f23422, 48702856, 47f488a6, 481fa9d0,
c38221db, 4883722d, 480480a7, 4830920e,
c3893305, 4881ff54, 47ff16d0, 48289c3b,
c3301adc, 48880fb4, 4806eb88, 4833d955,
c358a903, 48a4f341, 48246cf4, 4857f0f1
```

Four intensity values are reported for detectors 0-9, corresponding to dark, red, green, and blue illumination (DRGB). These intensities are single-precision IEEE floating point numbers (32-bits) that are coerced to 32-bit long integers and written in hexadecimal.

Detector 0 is the reference detector for the even-numbered spots, and detector 9 is the reference detector for the odd-numbered spots. Detectors 1-8 correspond to sample spots 1-8.

7.3.2. CLAP Menus

There are three menus, "Main", "Configuration", and "Calibration". The current menu is displayed by pressing "?". Commands are issued by typing the command name, an optional argument, and pressing the <Enter> key. The commands "?", "main", "cfg", "cal" all pause transmission of unpolled data reports for about 15 seconds.

Main Menu
NOAA/ESRL/GMD C3WV3 - 10.105

Command	Action	Arguments	Description
?	Show menu		
cfg	Configuration Menu		
cal	Calibration Menu		
hide	Stop unpolled data		
show	Enable unpolled data		
stop	Stop active filter		Begins filter changes
go	End filter change		Indicates filter change is completed
spot	Report active spot, or activate specified filter spot.	=n =+	Switch to filter spot n and begin sampling. Stop sampling if spot=0. Switch to next spot with spot=+.

Configuration Menu

Command	Action	Arguments	Description
?	Show menu		
main	Return to main menu		
hide	Stop unpolled data		
show	Enable unpolled data		
sn	Show serial number		nnnnn
setsn	Set serial number	=nn.nnn	
fw	Show firmware version		
rst	Reset to defaults		
oint	Show/Set output interval (seconds)	=n	
lpf	Show/Set digital filter settings	=a0,b1,b2,b3,b4 (0.218, 1.267, -0.602,	Default is 4-stage, single-pole, low-pass filter, effective first-order

		0.127, -0.010)	time constant 2.6 seconds
hsp	Show/Set case heater setpoint (deg C)	=dd.d	
stbl	Show/Set case heater stable window (+/- deg C)	=dd.d	

Calibration Menu

Command	Action	Arguments	Description
?	Show menu		
main	Return to main menu		
hide	Stop unpolled data		
show	Enable unpolled data		
Tc	Show/Set case temperature calibration	=a0,a1,a2,a3	Third-degree polynomial, constant term first
Ta	Show/set air temperature calibration	=a0,a1,a2,a3	Third-degree polynomial, constant term first
flow	Show/set flow calibration	=a0,a1,a2,a3	Third-degree polynomial, constant term first. Clips internally to [0.0,3.0] slpm Defaults= -8.03700e-01, 1.20400e+00, -4.99400e-01, 9.74000e-02
pid	Show/set PID gain settings	=p,i,d	
led	Show/set LED mode and intensity setting	=a,r,g,b	Defaults 1,100,100,100

7.4. Flowmeter Calibration Procedure

The flowmeter is calibrated with a mass flow calibrator device, which should be set to standard conditions of 1013.25 hPa and 273.15 K. The inlet of the calibrator should be open to room air, and the outlet should be connected to the inlet of the CLAP. Calibrations can be done with or without a filter installed.

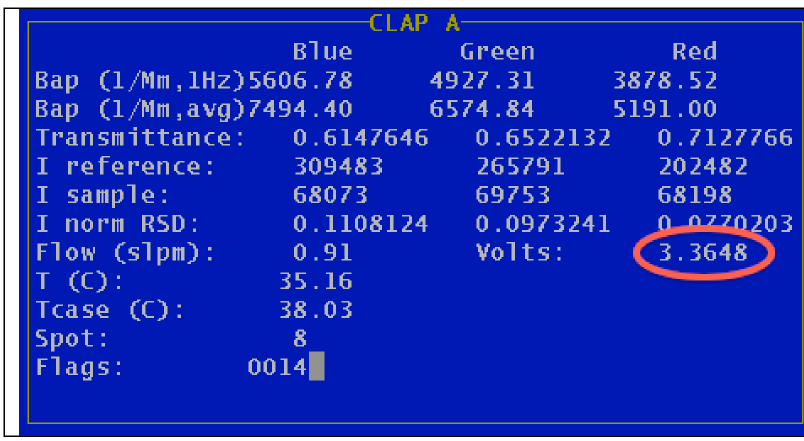
There are two types of calibrations of the CLAP flowmeter. A full calibration uses many calibration points spanning 0-1.5 slpm flowrates, while a 1-point calibration uses a single calibration point at the nominal operating volumetric flowrate of 1.0 lpm. The full calibration is used to determine the coefficients of a best-fit third-degree polynomial, which are stored in non-volatile memory in the CLAP. These coefficients are used to calculate the flowrate and accumulated sample volume that are reported in the CLAP serial output records, and also to calculate the flowrate displayed on the front panel of the CLAP.

In addition to the calibration curve used internally in the CLAP, 'cpd' can apply a multiplier, to compensate for possible residual error in the best-fit calibration curve at the normal operating flowrate. This scheme of two sequential calibration corrections is needed because the flowmeter response is highly non-linear, and 'cpd' cannot correct for errors in the accumulated volume with more than a simple multiplier.

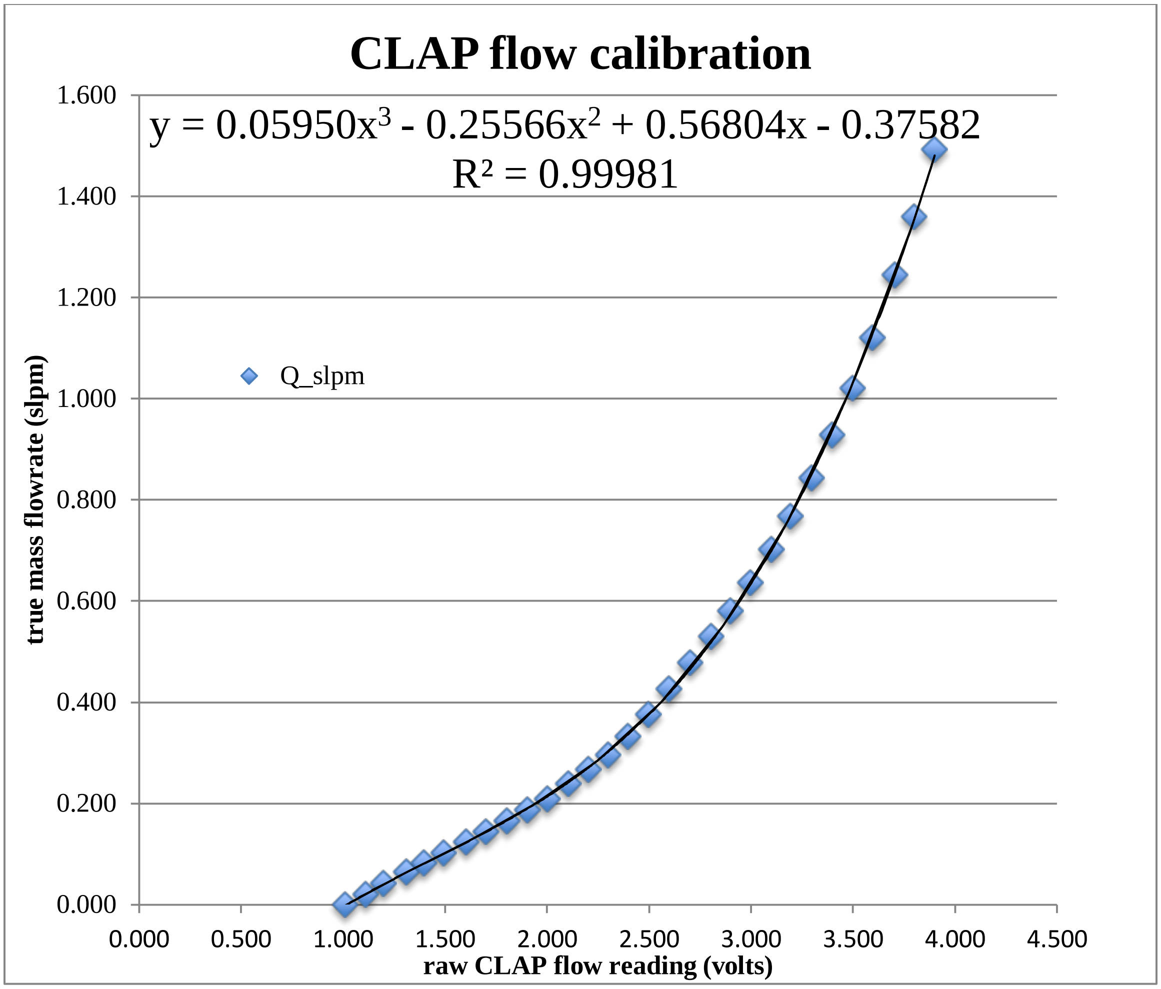
The CLAP status window in the 'cpd' client software displays the raw voltage output from the mass flowmeter. To see this window, press `<Enter>` to see the main menu, use the arrow keys to highlight the CLAP entry, and press `<Enter>` to activate the CLAP status window. The mass flowmeter output voltage is displayed on the same line as the mass flowrate; the displayed voltage is an average taken over the previous ten seconds.

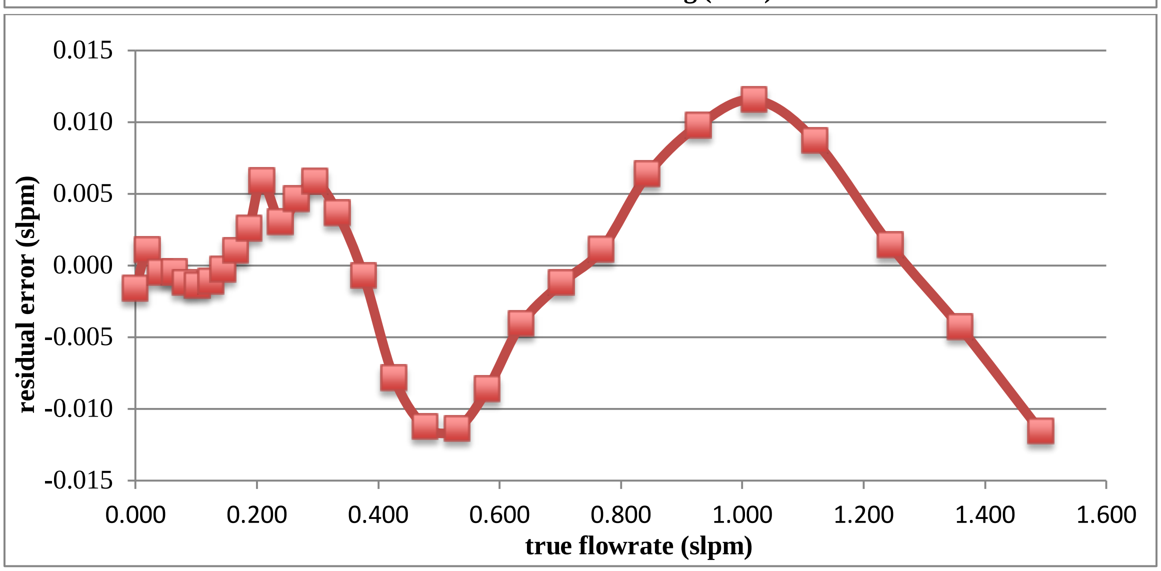
You are now ready to perform the calibration. Use the front panel valve to adjust the CLAP flowrate, in increments of no more than 0.2 volts, from the maximum flow voltage (typically at least 3.0) down to ~1.0 volts. This corresponds to a flow calibration range of ~1.5 slpm → 0.1 slpm.

Record the raw CLAP flowmeter voltages and the true mass flowrate values (from the flow calibrator) for each flow setting. The figures below show the results of a linear regression analysis and the residuals.



CLAP status window, with the MFM voltage output circled.





Calibration results are entered into the cpd.conf configuration file. When cpd starts, the coefficients of the third-degree calibration polynomial are written to the CLAP if the appropriate entry exists in cpd.conf, but only if the coefficients stored in the CLAP are different from the values in cpd.conf. For example, if the CLAP is designated as instrument "A11" in cpd.conf, the line for the above calibration would be:

```
Instruments;A11;!Cal;QHardware,-0.37582;0.56804;-0.25566;0.0595
```

For installations where the CLAP is operated at a constant flowrate, the best results are achieved by providing a multiplier to correct for possible errors in the fit at the nominal operating flowrate. For example, the figure above shows a fit error of 0.012 slpm if the instrument is operated at 1.0 slpm. This error can be trimmed out with a multiplier of 1.000/1.012=0.988. To apply this multiplier to instrument "A11" in 'cpd', enter the following line in cpd.conf:

```
Instruments;A11;!Cal;Q,0.988
```

You should always make an entry in the on-line logbook whenever you change the CLAP flowmeter calibration coefficients.

7.5. Description of CLAP configuration lines in cpd.conf

```
Instruments;A11;Cal;Q # Calibration Polynomial applied to the reported
    flow rate.
Instruments;A11;Area_m2;[1-8] # Numeric spot size in m^2 for the Nth spot.
    Defaults to 1.7814E-5.
Instruments;A11;Smoothing;Stability;Max # Maximum number of points
    (seconds) to smooth looking for filter stability.  This is the total
    time to inspect the filter detection logic.  Defaults to 90.
Instruments;A11;Smoothing;Stability;Min # Minimum number of points
    (seconds) to smooth looking for filter stability.  This is the minimum
    number of points required for filter detection, must be less than or
    equal to the max.  Defaults to 90.
Instruments;A11;Smoothing;Stability;RSD # Minimum RSD to consider stable
    for a filter.  Zero disables.  Defaults to 0.001.
Instruments;A11;Smoothing;Normalize;Max # Maximum number of points
    (seconds) to smooth looking for spot normalization stability.  This is
    the total time to inspect the spot stablity detection logic.  Defaults
    to 60.
Instruments;A11;Smoothing;Normalize;Min # Minimum number of points
    (seconds) to smooth looking for spot normalization stability.  This is
    the minimum number of points required for spot stablity, must be less
    than or equal to the max.  Defaults to 30.
Instruments;A11;Smoothing;Normalize;RSD # Minimum RSD to consider stable
    for spot normalization.  Zero disables.  Defaults to 0.001.
Instruments;A11;FilterDetectDelay # Delay in seconds between detecting
    filter events from the instrument.  Defaults to 2.0.
Instruments;A11;FilterWhiteBand # Normalized intensity band to trigger
    white filter detection, e.g., 1.0 triggers at half and twice.  Zero
    disables.  Defaults to 0.9.
Instruments;A11;Autodetect # Filter change auto detection mode.  One of
    "START", "STOP", "BOTH", or "NONE".  Defaults to none.
Instruments;A11;Autodetect;Start;RSD # Maximum RSD in reference
    intensities to allow before starting a filter change.  Defaults to
    0.001.
Instruments;A11;Autodetect;Start;Band # Intensity band relative to filter
    start to trigger filter change start, e.g., 1.0 triggers at half and
    twice.  Zero disables.  Defaults to 1.9.
Instruments;A11;Autodetect;End;Band # Intensity band relative to white
    filter to allow filter change end, e.g., 1.0 triggers at half and
    twice.  Zero disables.  Defaults to 0.9.
```

Instruments;A11;Autodetect;End;Timeout # Maximum time to allow a white filter check (does not apply to normal filter changes) to go on before ending it. Zero disables. Defaults to one hour.
Instruments;A11;Flow;RestartFlushTime # Time to force "contaminted" flushing after a flow restart (e.g., during a spancheck). Default 30 seconds.
Instruments;A11;Flow;Flow;DisableWithBypass # Boolean to disable flow when the system is bypassed. Default true.
Instruments;A11;SpotAdvanceTR # Minimum transmittance before advancing a spot on any channel. Defaults to 0.7.
Instruments;A11;SpotAdvanceTR;B # Minimum transmittance before advancing a spot on the blue channel. Defaults to SpotAdvanceTR.
Instruments;A11;SpotAdvanceTR;G # Minimum transmittance before advancing a spot on the green channel. Defaults to SpotAdvanceTR.
Instruments;A11;SpotAdvanceTR;R # Minimum transmittance before advancing a spot on the red channel. Defaults to SpotAdvanceTR.
Instruments;A11;DowntimeDeltaTR # Maximum transmittance change during downtime to extrapolate through on any channel. Defaults to 0.02.
Instruments;A11;DowntimeDeltaTR;B # Maximum transmittance change during downtime to extrapolate through on the blue channel. Defaults to DowntimeDeltaTR.
Instruments;A11;DowntimeDeltaTR;G # Maximum transmittance change during downtime to extrapolate through on the green channel. Defaults to DowntimeDeltaTR.
Instruments;A11;DowntimeDeltaTR;R # Maximum transmittance change during downtime to extrapolate through on the red channel. Defaults to DowntimeDeltaTR.
Instruments;A11;LogRTIntensities # Boolean enabling the logging of the real time one second intensity values. Defaults to FALSE.
Instruments;A11;Config;Wavelength;B # Wavelength for the blue channel, default "465;CLAP".
Instruments;A11;Config;Wavelength;G # Wavelength for the green channel, default "523;CLAP".
Instruments;A11;Config;Wavelength;R # Wavelength for the red channel, default "660;CLAP".

7.6. Example of CLAP entries in cpd.conf for a field instrument

```
Instruments;A12;Startup,cpd2.clap3w
Instruments;A12;Port,/dev/ttyUSB2:57600N81
Instruments;A12;DisplayName,CLAP 10.003
Instruments;A12;IdentifierChar,L
Instruments;A12;!fil;name,A12
Instruments;A12;!inst;SerialNum,10.0003
Instruments;A12;!Area_m2;1,1.7814E-5
Instruments;A12;!Area_m2;2,1.7814E-5
Instruments;A12;!Area_m2;3,1.7814E-5
Instruments;A12;!Area_m2;4,1.7814E-5
Instruments;A12;!Area_m2;5,1.7814E-5
Instruments;A12;!Area_m2;6,1.7814E-5
Instruments;A12;!Area_m2;7,1.7814E-5
Instruments;A12;!Area_m2;8,1.7814E-5
Instruments;A12;!Cal;Q,1.003
Instruments;A12;!Cal;QHardware,-3.2014;3.7031;-1.362;0.1947
Instruments;A12;Autodetect,BOTH
Instruments;A12;SpotAdvanceTr,0.5
Instruments;A12;SpotAdvanceTr;G,0.7
Instruments;A12;Smoothing;Stability;Max,90
```

```
Instruments;A12;Smoothing;Stability;Min,90
Instruments;A12;Autodetect;Start;RSD,0.01
```