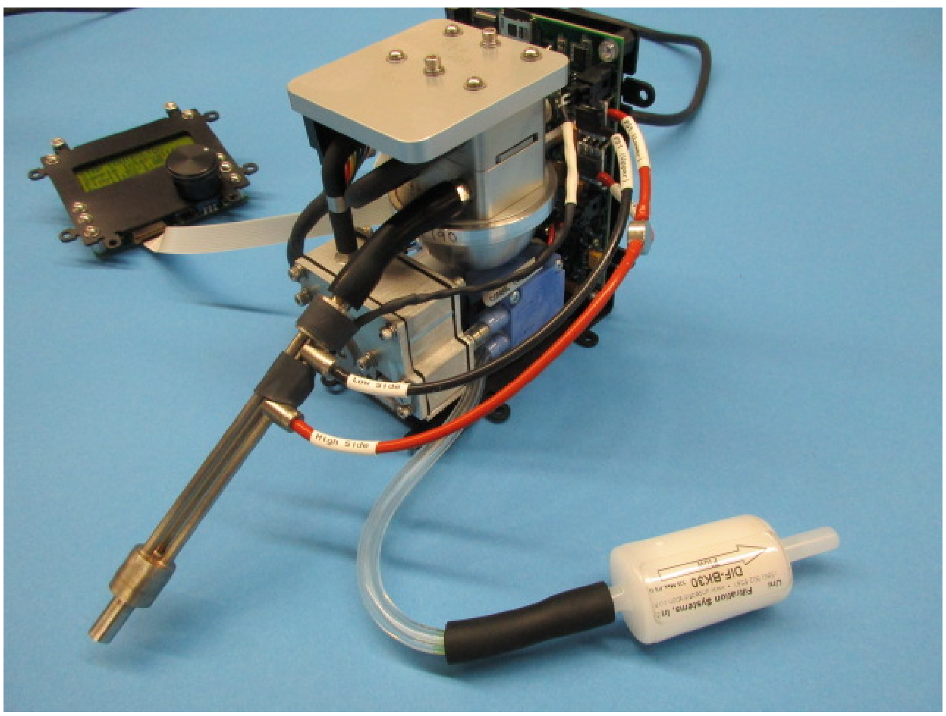
BRECHTEL

Instrument Manual Ver. 3.5

STAP 9406

For UAV Reader version 5.4 and firmware version 7.1



BMI PN: 83-00036-01A

February 16, 2021

Contents

1 Caution

Read this section before running your BRECHTEL instrument. This device has the following operating conditions that can be hazardous or harmful to your product without proper care.

1.1 Electro-static discharge

WARNING:

EXTREME ELECTRICAL SHOCK SENSITIVITY!

Ground yourself before handling STAP

Move STAP only after placing in anti-static bag

Ground STAP using supplied grounding strap after install

Remove RED BRACKET RED SCREWS before first use – replace for shipping – use supplied shorter 'non-red-head' screws for operation

Handle the unit during filter changes and other activities by the metal components, avoid touching the circuit boards and ground yourself before touching the unit.

1.2 Shock during shipping

If the shock watch installed on the shipping case has tripped, contact BRECHTEL. Operate the unit to confirm proper operation before using for actual measurements.

2 Changes

Change Description	Page	Date	Author
v2.6 Update commands	N/A	5/24/2018	FJB
v3.1 Update software discussion	Various	10/26/2018	FJB
v3.2 Add new pictures, ESD	Various	12/8/2018	FJB
v3.3 RS232 hexadecimal command	Various	12/12/2018	FJB
v3.4 Add firmware update procedure	Appendix	5/14/2019	FJB
v3.5 Add calibrator description	Appendix	2/16/2021	FJB

3 Contact BRECHTEL

3.1 Getting Help

Contact BRECHTEL for any questions or assistance with this product.

Include the model *and* serial *numbers when contacting Brechtel.*

1789 Addison Way
Hayward, California 94544

Telephone: (510) 732-9723
Fax: (510) 732-9153
Email: sales@brechtel.com

4 Unboxing

Each BRECHTEL STAP is inspected and tested in-house at BRECHTEL to ensure out of the box operation upon delivery. Prior to opening, inspect the packaging container and ShockWatch impact indicators.

Carefully open the package and inspect the instrument and any accessories for broken parts, scratches, dents or other signs of damage incurred during shipping. Notify BMI within 2 days of receiving the package if the shock indicator (Fig 1) has activated or of any other visible damage.

Notify BMI within 2 days of receiving your product if the shock indicator has activated and/or there is any other visible damage.

Retain all shipping packaging, foam inserts and cushions to ensure a safe delivery should the instrument need to be returned.

Verify the contents of the shipment using the information provided in this manual.

Figure 1: The black arrows on the shock-watch indicate the package experienced excessive shock during shipping. Red arrows indicate no shock above the G level indicated.

4.1 Before First Use

The red shipping bracket and two red-headed bolts must be removed before first use. The red-headed bolts must be replaced with the shorter bolts provided.

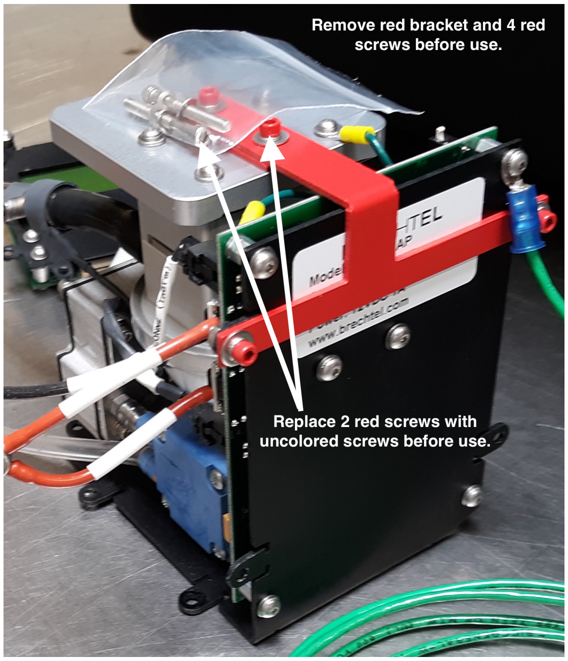


Figure 2: Remove the red brackets and bolts, be sure to replace before shipping.

5 STAP Overview

5.1 Description

The STAP has been designed in a small and light form factor for applications where space, weight and power availability are important constraints. For example, the STAP has been deployed on-board Unmanned Aerial Vehicles (UAVs) over the Arctic and on tethered balloons. The STAP measures the change in light attenuation once per second through a filter upon which the particle sample is collected. A clean reference filter is employed on which no particles are deposited and through which the light attenuation is also measured. From the change in light attenuation the aerosol light absorption coefficient may be derived. If the mass absorption cross-section (MAC) of the aerosol is known, then dividing the absorption coefficient by the MAC allows the mass concentration of absorbing aerosol to be determined.

The STAP sample flow rate is measured by a precision laminar flow element on the inlet and controlled in real-time by modulating the speed of the integrated vacuum pump. The STAP has a single sample filter and a single reference filter through which the sample flow passes downstream of the sample filter. For applications requiring multiple sample channels, Brechtel offers the Model 2901 TAP with 8 sample filter spots and 2 reference filter spots.

The STAP uses 10-mm diameter, glass-fiber filters (Brechtel STAP-FIL100). 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 the STAP sample flow should be dried before entering the unit to decrease the risk of condensation within the instrument. Contact Brechtel if you require a sample flow drying solution.

The STAP does not require an external computer for data logging and instrument control. The internal software in the STAP provides the functionality for measuring signals (light intensity reaching the detectors, flow rate, sample temperature and pressure) and controlling the hardware (light source, vacuum pump, saving data to SD card).

When combined with the STAP Graphical User Interface UAV Reader Software, the STAP reports the change in light transmission through the filter. The UAV Reader uses the

USB connection to communicate with the STAP. All data collected is saved and displayed in real time for analysis. Software communication to the STAP for remote control of the instrument is established through the serial port on the main control board of the instrument using the RS-232 protocol.

5.2 Theory of Operation

Introduction

Light absorption in a medium can be quantitatively described using the Beer-Lambert Law

$$I = I_0 e^{-\sigma[\lambda] l}, \tag{1}$$

where I and I_0 are the output and input intensity of light in Watts per square meter passing through an absorbing medium, σ is the medium's attenuation coefficient in inverse meters at wavelength λ in meters, and l is the path length in meters through the medium. In order to apply this to a light absorption photometer the critical assumption is made that absorption through a length of air at a given time is equivalent to filtering out the absorbing species from the air on a filter and passing the light through this instead. If this is true, then in a given time period Δt this can be expressed as

$$I(t) = I(t - \Delta t) e^{-\sigma_{PSAP}[\lambda] \frac{Q_{PSAP} \Delta t}{A_{PSAP}}}, \tag{2}$$

where $I(t)$ is the intensity of the light reaching the detector at any given time, $\sigma_{PSAP}[\lambda]$ is the average, wavelength-dependent absorption coefficient of the air parcel that passed through the filter in Δt, A_{PSAP} is the filter area, and Q_{PSAP} is the flow through the filter area. A_{PSAP}, Q_{PSAP}, and Δt define the length of the air parcel passing through the filter area.

The PSAP label is used here to match the equations described below for further corrections of the absorption coefficient. This analysis is not unique to the PSAP.

Unfortunately, this assumption does not take into account the filter material or the properties of the bulk developed in depositing the particles both on and in the filter, but we can define a filter-loading correction factor, $f(\tau)$, determined empirically, to correct for this, resulting in

$$I(t) = I(t - \Delta t)e^{-\sigma_{PSAP}[\lambda]\frac{Q_{PSAP}\Delta t}{A_{PSAP}}\frac{1}{f(\tau)}} \tag{3}$$

With some minor rearrangement this becomes

$$\sigma_{PSAP}[\lambda] = f(\tau)\frac{A_{PSAP}}{Q_{PSAP}\Delta t}\ln\left(\frac{I(t-\Delta t)}{I(t)}\right), \tag{4}$$

the most basic description of an absorption photometer's operation.

Absorption Coefficient Correction

The analysis below follows "Comment on 'Calibration and Intercomparison of Filter-Based Measurements of Visible Light Absorption by Aerosols'" by John A. Ogren 2010.

Eqn. 12 in the above work is

$$\sigma_{ap}[\lambda] = 0.85\left(\frac{Q_{PSAP}}{Q_{meas}}\right)\left(\frac{A_{meas}}{A_{PSAP}}\right)\frac{\sigma_{PSAP}[\lambda]}{K_2} - \frac{K_1}{K_2}\sigma_{sp}[\lambda]. \tag{5}$$

Here σ_{ap} is the aerosol absorption coefficient, σ_{sp} is the aerosol scattering coefficient, $K_1 = 0.02 \pm 0.02$ and $K_2 = 1.22 \pm 0.20$ are empirical coefficients defined by the equation

$$0.85\sigma_{PSAP} = K_1\sigma_{sp} + K_2\sigma_{ap}, \tag{6}$$

and Q is the sample flow through both the sample and reference channel, and A is the area of each sensor spot. Here

$$f(\tau) = (1.0796\tau + 0.71)^{-1} \tag{7}$$

is the experimentally determined correction function for filter loading,

$$I(t) = \frac{\langle color - dark\rangle_t}{\langle colorref - darkref\rangle_t} \tag{8}$$

is the ratio of the average intensity of one color at the sample spot to the reference spot over time period Δt, and $\tau = \frac{I(t)}{I_{wf}}$ is the filter transmission. To calculate the transmission we use the color ratio from the most recent $\triangle t$, e.g. for a 5 sec average use the color ratio from the current 5 second interval, not the previous 5 second interval, or the full 10 seconds used for each measurement. I_{wf} is the intensity ratio measured while doing the white filter check. In our instrument $Q_{PSAP} = Q_{meas}$ and $A_{PSAP} = A_{meas}$, so Eqn. 12 simplifies to

$$\sigma_{ap}[\lambda] = 0.85\frac{\sigma_{PSAP}[\lambda]}{K_2} - \frac{K_1}{K_2}\sigma_{sp}[\lambda]. \tag{9}$$

Depending on the version of software you have, you may have an option to define σ_{sp}. If you don't have this option, then the program actually calculates

$$\sigma_{ap}[\lambda] = 0.85\frac{\sigma_{PSAP}[\lambda]}{K_2} \tag{10}$$

instead.

Due to computational limitations in the STAP firmware, absorption coefficient values calculated in real-time by the firmware have higher uncertainties (15%) than values calculated by post-processing the raw data using the IGOR software routine provided by BRECHTEL. The post-processing also allows the scattering correction to be applied, which is NOT applied within the firmware.

5.3 Component Technical Descriptions

The BRECHTEL STAP includes four separate components.

Component 1 STAP main assembly (body, detector board, main board, pump all integrated to 'L' bracket mount)

Component 2 A front panel display connected by ribbon cable to the main board.

Component 3 A sample laminar flow element (LFE) assembly to measure the sample volume flow rate.

Component 4 A ship kit with weatherproof case, power supply, spare filters, tweezers, orings, cables and other items to operate the unit and change filters.

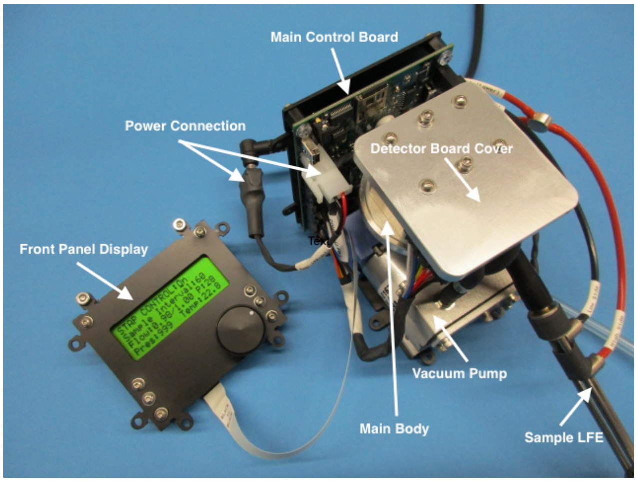


Figure 3: Major components of the STAP.

5.4 STAP Options

There are several optional accessories external to the device that can be added at any time depending on your changing measurement needs.

Table 1: STAP Accessories

PN	Option	Description
8008	0.5 µm Round Jet Impactor	Remove particles larger than 0.5 µm at 0.6 $l\,min^{-1}$
8009	1.0 µm Round Jet Impactor	Remove particles larger than 1.0 µm at 0.6 $l\,min^{-1}$
STAP-FIL250	Pack of 250 10 mm glass fiber filters for 9406 STAP	Consumeable sample and reference filters
ACC-STAPKit	Maintenance Kit for 9406 STAP	Orings, grease, cleaning tools, etc. to maintain your STAP
ACC-PWR	Additional 12 VDC power supply for ground operation of any ACCESS module	Duplicate supply to operate STAP in two locations
ACC-PC	Computer loaded with UAV Reader Software	Easily operate STAP in multiple locations.

5.5 STAP Specifications

Table 2: STAP Specifications

Description	Value
Wavelengths	450, 525, 624 nm
Sample flow	0.5 to 1.7 lpm
Vacuum Requirement	None
Noise level (1 sigma)	$\pm 0.2 Mm^{-1}$ (0.02ugm^{-3} absorbing mass)
Filter	Glass fiber, 10 mm dia
Number of Sample Spots	1
Number of Reference Spots	1
Communications	USB and RS-232
Operating Temperature	-20 to 35°C
Operating Pressure	200-1,100 mb
Operating Humidity	0-95% RH non-condensing
Physical size	5.3 x 4.3 x 3.9 in/13.5 x 10.9 x 9.9 cm
Weight	1.45 lbs/0.66 kg
Supply voltage	12 VDC
Power usage	10 watts
Mounting	Multiple hard mounting points through metal body brackets

6 System Setup

6.1 Packing List

The STAP will arrive in a sturdy weatherproof case holding the STAP base unit and the ship kit. If accessories were ordered with the STAP they may be packaged in the case or in additional boxes.

See the Appendix for a complete list of all the parts that come with the STAP. Table 3 shows the parts needed to prepare the STAP for operation.

6.2 Assembly

The STAP will arrive with the front display and sample LFE uninstalled. Follow the discussion below together with the figure and table to assemble the various pieces.

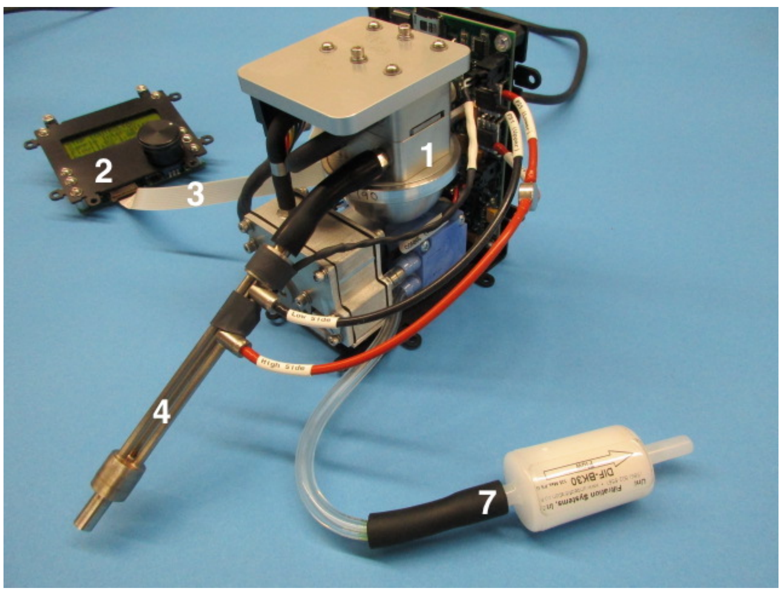


Figure 4: View of STAP assembly. Numbers refer to table items.

Table 3: STAP Assembly Parts

#	Description	QTY
1	STAP Base Unit	1
2	Front Panel Display	1
3	Display Ribbon Cable	1
4	Sample LFE Assy	1
5	Ship Kit	1
6	Power supply	1

6.3 Tubing Connections

Item 7 (filter in ship kit) in Fig. 4 is a pump muffler only used to reduce the pump noise and may be removed. Slide the black tubing of item 7 over the clear tygon tubing from the pump exhaust to attach the filter if desired.

Connect the sample LFE assembly item 4 in Fig. 4 to the metal barb fitting on the STAP base unit item 1 as shown in the figure using the black conductive tubing supplied. Be sure to connect the LFE so the small ports with the red and black tubing are closest to item 1.

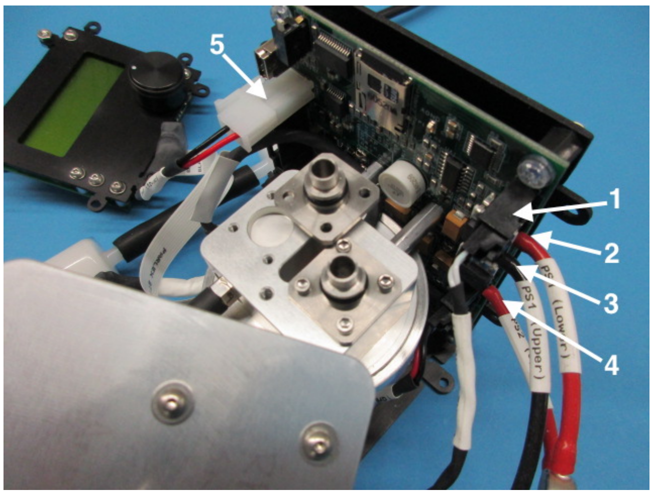


Figure 5: Connecting LFE differential pressure tubing, sample thermistor and DC power.

In figure 5 'PS1' denotes 'pressure sensor 1'. Connect the red tube labelled 'PS1 Lower' to the barb on PS1 closest to the green circuit board. Connect the black tube labelled 'PS1 Upper' to the barb on PS1 farthest from the green circuit board. Connect the red tube labelled 'PS2' to the single barb on Ps2, this is the total pressure sensor.

6.4 Electrical Connections

When connecting ribbon cable item 3 in Fig. 4 be very careful that it is inserted perpendicular to the mating brown connector on the circuit board. Be sure to connect the provided display ribbon cable to the main board before applying power if the instrument will be configured using the user interface via the display.

Warning: Be sure the black colored side at the end of the ribbon is against the darker brown connector clamping piece on the mating connector. Do NOT connect or disconnect the ribbon cable while power is applied.

Connect the AC-DC power supply to the power input connector on two-pin connector item 5 in Fig. 5. Connect item 5 to main board to apply power. To facilitate the use of a battery to power the STAP, DC voltages between 10 and 15 Volts may be used and should be connected to the Molex power in connector provided with the unit. Any AC adapter with an output of 10-15 Volts DC at 1 AMP can be used to power the STAP. The instrument firmware automatically runs when power is connected. Ensure the power plug is fully seated in the connector before connecting the instrument to a computer.

Connect the sample thermistor attached to the sample LFE to the connector item 1 in Fig. 5 on the main circuit board.

If the vacuum pump 2-pin connector is not connected to the main board, then connect it to the receptacle on the main board near the pump head.

6.5 Communication Connections

Connect the various cables provided with the STAP as described in the table below.

Table 4: STAP Cable Connections. Numbers refer to figure below.

Port	Description
1. Prog ↔ Data	Toggle switch for firmware upgrades. Leave in Data mode unless performing firmware upgrade.
2. USB Port	Micro USB port for communication with computer running UAV Reader software.
3. COM Port	Serial communication port between the STAP and user PC.
4. SPI Bus	Not currently used

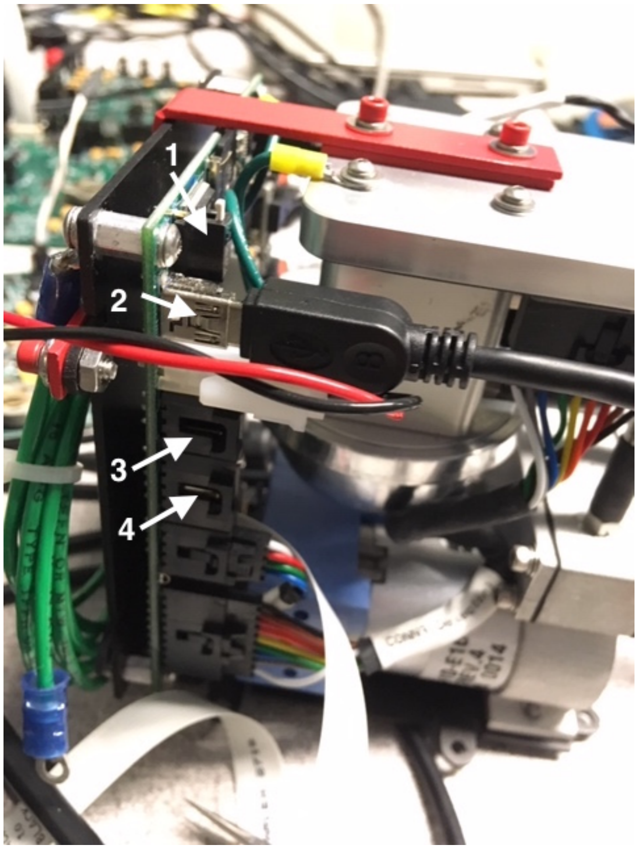


Figure 6: STAP communication connections.

Be sure the program/data toggle switch item 1 in figure 6 is in DATA mode (toggled away from green circuit board) during normal operation. Only toggle the switch to update the firmware. Switch back to data position after the firmware is updated.

Connect the USB cable provided in the ship kit to the USB mini connector on the main board, item 2 in figure 6.

The RS232 port item 3 in figure 6 is used to send remote control commands directly to the STAP from a user computer using the cable provided in the ship kit. The STAP uses a simple 3 wire RS232 connection. The board connector uses a 3 position C-Grid SL connector. A DB9 adapter is included with each STAP ship kit.

The detailed settings for the serial port: RS232: 8 data bits, 1 stop bit, no parity,
Baud rates: 38.4k, 57.6k, 115.2k and USB with 230k.

The SPI bus connector item 4 is not used.

Computer Connections

The UAV Reader interface software requires a USB connection between the control computer and the USB Port on the STAP main board as shown in figure 6. The UAV Reader software may be purchased as an accessory to the STAP installed on a ruggedized tablet, contact BRECHTEL for information.

Connect the USB cable prior to running the software. Do not disconnect the USB cable while the software is running.

The RS232 port, item 3 in figure 6, may be used to establish serial communication with the STAP from a user-supplied computer. An interface cable with a serial connector is provided in the STAP ship kit. The port configuration and commands available are described later in this manual.

6.6 Mounting

The STAP is shipped integrated with a mounting bracket that has tabs with holes for mounting bolts. See figures below for detailed mounting dimensions of the various items. Alternatively, the STAP can simply be placed on a table top. The mounting tabs may be bent to provide mounting flexibility. Threaded standoffs may also be used to mount the STAP to a shelf. Be sure to employ at least three hard mounting points to properly support the STAP. Bolts should not extend into the cover so much that they would interfere with the main control board connections. Mount the unit for easy access to the filter changing bolts to facilitate filter changes.

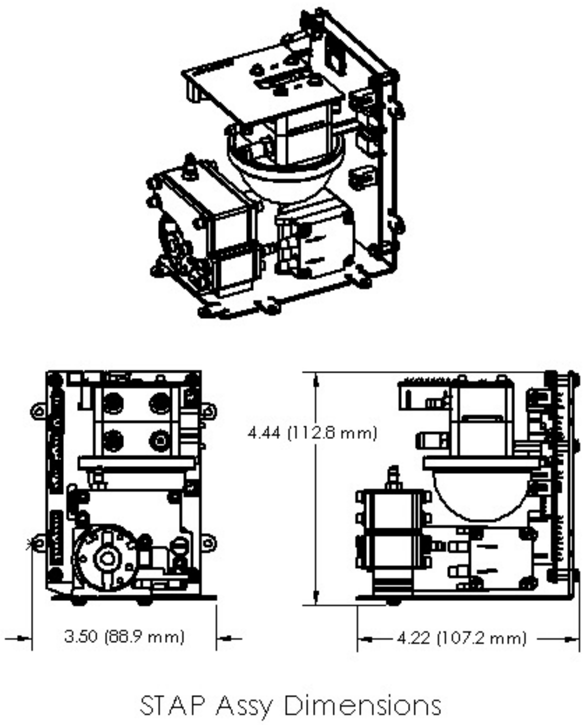
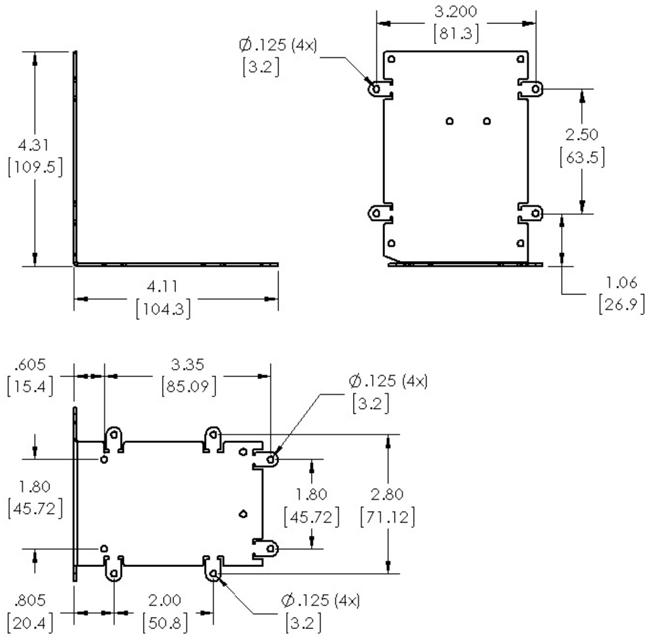
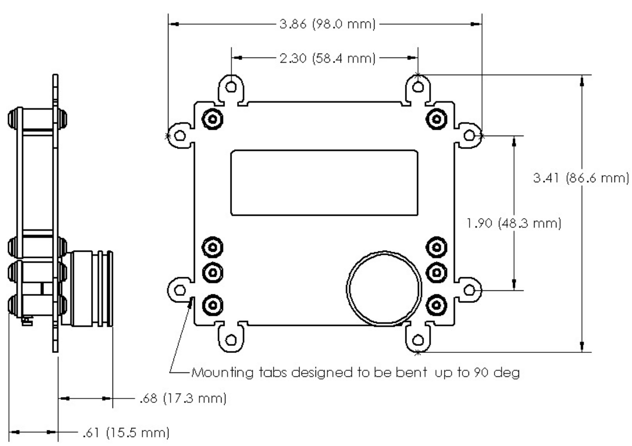


Figure 7: STAP assembly overall dimensions (inches and millimeters in parentheses).



STAP Bracket Mounting Holes

Figure 8: STAP mounting bracket detailed dimensions (inches and millimeters in parentheses).



UAV Instrument Front Panel Dimensions

Figure 9: Front panel display mounting bracket detailed dimensions (inches and millimeters in parentheses).

7 Operating the STAP

The STAP measures the light attenuation by absorbing particles deposited on the sample filter and compares the attenuation to that measured simultaneously through a 'reference' filter on which no particles are deposited. From the change in measured attenuation with time the light absorption coefficient may be determined. The STAP is an extremely sensitive measurement device, capable of signal-to-noise ratios of 1 when sampling only 20-40 ng/cubic meter absorbing mass concentrations.

Practicing good electrostatic discharge (ESD) procedures and understanding how to change and initialize filters in the unit are two key aspects of properly operating the STAP.

There are three ways to interact with the STAP, the mini front panel, serially via a RS232 port, and through the STAP UAV Reader GUI program which runs on windows computers and connects to the mini USB port. The STAP can also store its readings to an on-board micro SD card.

Caution: Each time the STAP is powered up the filter state MUST be defined by the user. Either a new initialization process is required if new filters have been installed or the previous initialization results can be used if the filters have not been changed.

Caution: It is NOT recommended to operate the unit at light attenuation levels lower than 0.7 (a 30% reduction of intensity from clean filter state) as the uncertainties due to filter loading corrections become greater.

Absorption measurements are made by measuring the rate at which the sample filter gets darker as sampled aerosol are deposited on it. The sample flow flows through the sample filter and then flows through a reference filter. The reference filter allows the measurement to be done as the rate of darkening of the sample filter compared to the reference filter. This ratiometric measurement makes the readings much more robust and tolerant to changes in LED brightness.

The STAP uses a 20 bit A/D converter to read the sample and reference photodiodes. This means the raw sample and reference readings range from 0 to 1,048,575. The tricolor

LED has red, green, and blue LEDS. Every second the STAP cycles through the three colors and takes red, green and blue readings for both the sample photodiode and the reference photodiode. In addition to reading the three colors, the STAP also takes sample and reference readings with the LEDs off. These are the black readings. The black readings can be subtracted from the red, green and blue readings to make the color readings more precise. The black readings are also a useful check of the overall system (for example, there is a problem if they change dramatically).

The initialization readings are determined by averaging two minutes worth of readings. The 120 1 Hz raw readings for initialization are not saved in the SD file, only the average readings are saved.

The STAP provides approximate inverse megameter readings for each of the three colors. These approximate readings are shown on the front panel and are stored in the SD card file. These readings are approximations because of the limited math resources available on microcontroller used to run the STAP. For low value inverse mega meter readings (<50) the approximate values are usually within 10% of the actual value. All of the raw intensity and other readings are stored at 1 Hz to allow more accurate absorption coefficient values to be calculated during data post-processing.

Due to computational limitations in the STAP firmware, absorption coefficient values calculated in real-time by the firmware have higher uncertainties (15%) than values calculated by post-processing the raw data using the IGOR software routine provided by BRECHTEL. The post-processing also allows the scattering correction to be applied.

It is important to note that a scattering correction is NOT included in the STAP and needs to be applied by the user.

The "intervl" parameter (shown as "sample interval" on the front panel) controls the number of second readings used to calculate the approximate inverse megameter readings. This setting has no effect on the raw readings reported or stored in the SD Card.

7.1 Electrostatic Discharge Practices

The STAP employs an extremely sensitive detector capable of measuring nanoamperes of current. To protect the detector, good ESD practices are critical to maintaining and operating your device.

- Be sure to always ground yourself before handling the unit
- Be sure to always connect the unit to earth ground with the provided grounding cable
- Be sure the ground wire between the detector cover and the main board maintains good contact

7.2 Changing the Filters

Follow the procedure below to change the two filters inside the STAP.

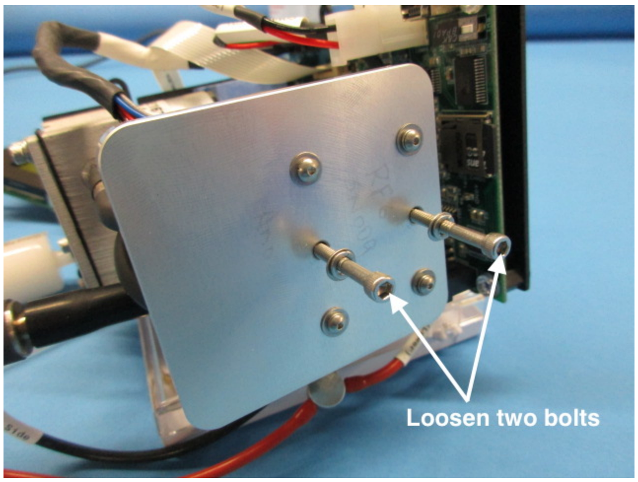


Figure 10: First step to changing STAP filters.

- Shut off the STAP control software and disconnect power.
- Remove the two 4-40 bolts show in Fig. 10 that pass through the detector board and hold the two main STAP body pieces to each other. The allen wrenches required to change the filters are in the ship kit.
- Pull the detector board and underlying aluminum STAP body piece away from the unit to reveal the two stainless steel filter sealing pieces shown in Fig. 11. The two 10 mm diameter filters are held underneath the two stainless steel pieces.

- Loosen and remove the four 2-56 bolts holding each of the two stainless steel filter clamps in Fig. 12. Gently pull the filter clamps up and out of the aluminum body piece. An oring holds them in place, pull upwards to slide the piece out.
- Remove the old filters. They may be discarded if desired. The fine tweezers to remove and install the filters should have been shipped with your unit.
- Clean any filter residue or debris from mating surfaces using a clean ethanol-soaked wipe or Q-tip, taking care to prevent debris from falling into the instrument flow path. This is most easily accomplished by holding the unit such that any debris that falls, falls away from the optical path. If any debris gets into the instrument, gently blow it out with dry filtered air.
- Verify that all O-rings on the stainless steel pieces are present and have grease on them.
- Roughly every 20 filter changes, lightly lubricate all of the o-rings before installing new filters.
- Using a set of tweezers, place two new filters into the STAP cavities (Fig. 12) with the rough white perforated side facing DOWN (toward the dome). Make sure only one filter is installed in each channel; sometimes two filters stick together.
- Re-install the two stainless steel filter clamps and CAREFULLY and EVENLY tighten the four bolts in a pattern so uniform pressure is applied around the perimeter of the filter. Tighten the bolts in a star pattern and visually verify that a uniform gap exists between the square edge of the stainless steel piece and the aluminum main body piece. The flange of the filter clamps should not be touching the LED block.
- Slide the aluminum main body piece with detector board attached over the stainless steel pieces and install and tighten the two clamping bolts (Fig. 10).
- Re-attach the detector board cable to the main PC board if it was disconnected to perform the filter change. (This should not be necessary on newer units.)

- The STAP will not begin sampling automatically after a filter change. The unit must be warmed up for 10 minutes and the filter initialization test (white filter check) completed before sampling may begin.
- Once the STAP begins sampling after the filter change, compare the flow rate with the value before the filter change. If the flow rate is significantly different, the filters may not be fully seated, or you may have accidentally inserted multiple filters.

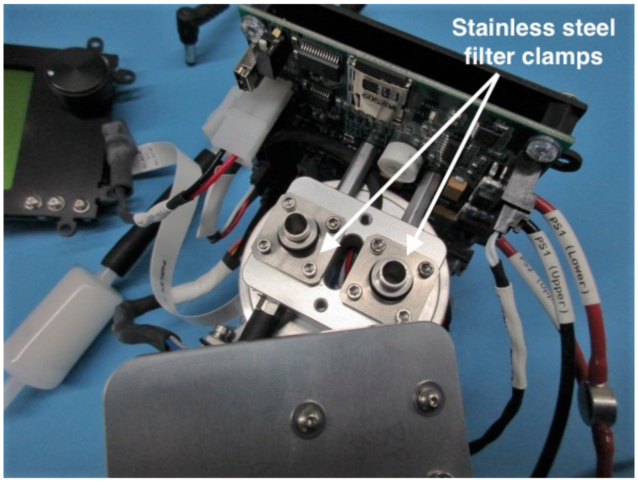


Figure 11: Second step to changing STAP filters.

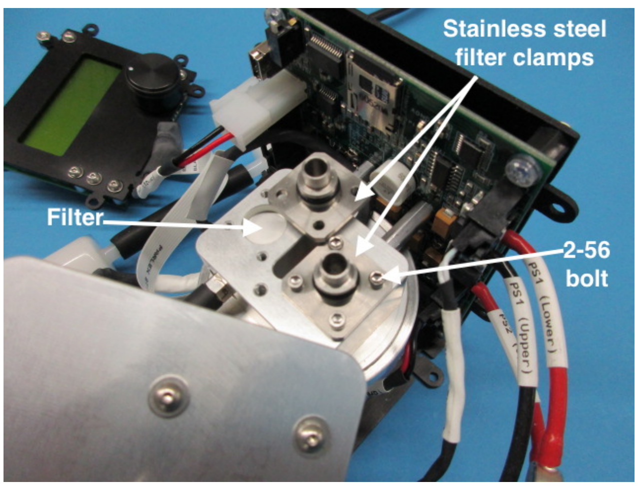


Figure 12: Third step to changing STAP filters.

7.3 White filter check / filter initialization

The white filter check (called filter initialization in the STAP firmware) is a baseline measurement of the intensity measured by the detectors with a new filter using particle-free air. It is important to establish a baseline range for the instrument.

The STAP must be warmed up for at least 10 minutes before performing a white filter test and before acquiring data. First, ensure that a filter is installed on the input flow to the sample LFE. A canister filter has been supplied for this purpose. Install new filters in the STAP, power on the STAP and turn STAP CONTROL to 'On' in the control software. Turn the black data knob clockwise to begin the white filter check. A 10 minute warm up period will occur before the filter check. If the unit is already warmed up, the 10 minute warm up period can be skipped in the software by turning the black data knob appropriately.

The instrument will notify the user when the white filter check is complete, so that the user can remove the filter from the inlet and begin normal sampling. The check normally requires 10 minutes after the warm up period ends.

When the STAP is turned on after having been off for an extended period it is important to allow it to warm up before taking readings or doing the white filter initialization. When an initialization is completed, the readings and LED settings for that initialization are stored in the onboard EEPROM memory. In this way, the STAP can recover from a power outage without going through another white filter initialization.

The "fltstat" parameter (short for filter state) is accessible via the serial port. The fltstat can have the following values.

0 = PREVIOUS (use the initial values read from EEPROM)

1 = INSTALL_HEPA (waiting for user to confirm HEPA filter is installed)

2 = WARMUP (10 minute warm up, this state can be skipped if unit is already warmed up)

3 = RESET_LEDS (resets the LED power levels to 0)

4 = ADJUST_LEDS (adjust the LED brightness)

5 = READING_INIT (take initialization readings)

6 = REMOVE_HEPA (waiting for user to confirm HEPA filter is removed)

7 = INITIALIZED (ready to take absorption readings)

The STAP automatically starts up with fltstat in INSTALL_HEPA state. At power up fltstat = 1, the possible next states are 0, 2 or 3. If fltstat is set to 2 or 3, use the "read" command to monitor fltstat. Once fltstat = 6, then set fltstat = 7 after the HEPA filter has been removed.

For the front panel, this means the startup page is the FILTER page. The front panel has instructions which guide users through the filter states.

7.4 Startup & Shutdown

Start the STAP by applying 12V power to the mainboard after new filters have been installed if necessary. Turn SD Save to 'On' if data is to be stored locally. Install a HEPA filter on the inlet for the warm up period and confirm low readings from the unit while sampling from the filter. Remove the filter for normal operation.

Shutdown the STAP by turning SD Save to 'Off' and then removing 12V power from the unit. Be sure to practice good electrostatic discharge procedures if the STAP will be moved.

7.5 Front Panel & Firmware

Although it is possible to run the STAP without the mini front panel, using the mini front panel makes operating the STAP much easier. The mini front panel has a four line character display with a data knob for user input. As well as turning, the data knob can be pressed. A short press will move the onscreen cursor and change the item that the data knob adjusts. A long press will take users from "READINGS" mode to "DEFAULT SETTINGS" mode and back again. Settings are saved when going from "DEFAULT SETTINGS" mode back to "READINGS" mode. The sections below discuss the details of each menu in the STAP firmware.

SD Card Menu

Rotate the data knob to select the SD Card menu. The menu will display the following lines:

SD Save: (Off/On)
File: (Current Filename)
Files: (Total number of files on SD Card)
Size: (SD Card size in megabytes)
Used: (% of the SD Card currently filled)

The only user-settable item in this menu is 'SD Save', all other items are set by the STAP automatically. A quick push of the data knob will select the SD Save value, rotate the knob to change the value.

Filter Menu

The Filter menu controls new filter initialization and is the default startup menu each time the STAP is powered on. Follow instructions provided by the firmware to initialize a new filter. See details above for the initialization process.

STAP Control Menu

Rotate the data knob to select the STAP Control menu. A quick push of the knob will allow the STAP to be turned Off or On. The menu will display the following lines:

Sample Interval: (1-60 seconds, can only be changed in settings mode)
Flow: measured sample flow / flow setpoint (both in lpm)
P: pump power (0-200 = duty cycle 0-100%)
Pres: (pressure in mbar)
Temp: (temperature in deg C)

Display Menu

The Display menu displays all STAP readings, the data knob is used to select the readings to display. The following readings are available:

Inverse MM (absorption coefficient inverse megameters)
Tao (current ratio of sample to reference intensities)
Intensity (current LED intensities)
CurSamp (current sample intensity)
CurRef LED (current reference intensity)
Power (current LED power)
InitSmp (sample intensity from last filter initialization)
InitRef (reference intensity from last filter initialization)
Init Conditions (pressure, temperature and flow rate during last filter initialization)

Date & Time Menu

The current date and time of the STAP is displayed. Use short knob presses to move the cursor to adjust the time and date if required.

In ”DEFAULT SETTINGS” mode there are six available menus:

COM Defaults Menu

baud_rt: (baud rate: 38.4k, 57.6k, 115.2k, USB)
delimit: (data delimiter: <CR>, TAB, SPACE)
autorpt: (auto report: Off, On)
rpt_lbl: (report labels: Off, On)

Main Defaults Menu

flow_sp: (flow setpoint: 0.5 to 2.0 lpm)
intervl: (averaging interval: 1-60 seconds)
stapctl: (STAP Control: Off, On)
sd_save: (SD card save: Off, On)

Diagnostics Menu

psvolts: (power supply voltage)
err_rpt: (error report numbers)

Calibration Values Menu

flow_c2: (flow x2 coefficient)
flow_c1: (flow x coefficient)
flow_c0: (flow offset coefficient)
flwcalt: (temperature during calibration)
prsslop: (slope for pressure reading)
prsoffs: (offset for pressure reading)
vltslop: (slope for power supply voltage reading)
vltoffs: (offset of power supply voltage reading)

Raw Readings Menu

flw_raw: (raw LFE flow reading (0-4095))
prs_raw: (raw pressure reading (0-4095))
vlt_raw: (raw power supply reading (0-4095))

Manufacture Info Menu

The Manufacture Info menu displays the following lines:

version: (firmware version)
ser_num: (serial number)
mfgyear: (mfg year)
mfg_mon: (mfg month)
mfg_day: (mfg day)

All settings and calibration values are saved to the on board EEPROM memory when users return to "READINGS" mode from "DEFAULT SETTINGS" mode. If changes are made without returning to "READINGS" mode, e.g. powering off while in "DEFAULT SETTINGS" mode, the new settings will not be remembered.

7.6 Data Files

The on-board control software saves collected data to the SD Card. A sample data set is included below. The .txt files contain both raw data obtained directly from the instrument and data (e.g. light absorption coefficient) with processing applied by the control software (see Theory of Operation). The file may be opened with any text editor. The STAP automatically creates new files each time the unit is powered on or when the SD card filesave feature is switched to ON. The file naming convention is “YYMMDDA0.txt”, where “YY” designates the year (e.g. 16 for 2016), “MM” designates the month, “DD” designates the day, and “A0” denotes the first file created on a given day. As new files are created on a given day they are named with “A1”, “A2” etc. at the end. When the sequence reaches “A9”, it changes to “B0”, “B1” etc. This limits the number of files created in a single day to 260. As long as the filter state is equal to 0 (PREVIOUS) or 6 (INITIALIZED), a new file will be created as soon as an SD card is inserted. The header information will also be written even if SD Save is Off. A new file is also automatically created every time a filter initialization is completed.

SD Card

To clear the SD card of old files, it is necessary to FORMAT the SD card (a quick format works) and not just delete the files. The STAP will not be able to use space freed up by simply deleting the files. When formatting an SD card be sure to choose FAT32, that is the only format that the STAP recognizes.

It is HIGHLY RECOMMENDED that SD Save be set to OFF before removing an SD card. This eliminates the possibility of corrupting the SD card. The SD card file format consists of a header and data columns. The lines in the header start with the pound sign ”#”. An example of a file header is shown below. Descriptions of the parameters are shown below and do not appear in a normal header. These parameter names are also used for serial communication.

Data File Format

Raw data at the end of each line has the Dark or Dark Ref value already subtracted from it.

The absorption coefficient is calculated using the analysis in "Comment on 'Calibration and Intercomparison of Filter-Based Measurements of Visible Light Absorption by Aerosols'" by John A. Ogren 2010. Sigma(abs)=f(Tr)*Sigma(0)-s*Sigma(scat): s = 0.02+/-0.02. A sample file header is listed below, the text in parentheses next to each item is not in the header but only shown to describe the parameter.

The header of each data file is defined by the lines with the "#" character as follows:

#STAP Serial Number:98 (serial number of the unit)
#firmware:6.0 (version of the firmware installed on the EEPROM)
#mfg_date:18/3/23 (manufacture date, YY,MM,DD)
(blank line)
#flt_typ=1 (filter material type, 0=Pall, 1=Azumi, 2=Emfab)
#flow_c2=-18153 (quadratic term in sample flow cal eqn)
#flow_c1= 2025 (linear term in sample flow cal eqn)
#flow_c0=-1620 (constant term in sample flow cal eqn)
#flwcalt=21.0 (temperature in degrees C at which sample LFE was calibrated)
#prsslop=3159 (slope of the total pressure sensor calibration equation)
#prsoffs=129 (offset of the total pressure sensor calibration equation)
#vltslop=401 (slope of the input power voltage calibration equation)
#vltoffs=1144 (offset of the input power voltage calibration equation)
(blank line)
#redsmpi=810532 (initial red intensity reading in counts of the sample channel)
#redrefi=1022272 (initial red intensity reading in counts of the reference channel)
#grnsmpi=635457 (initial green intensity reading in counts of the sample channel)
#grnrefi=797826 (initial green intensity reading in counts of the reference channel)
#blusmpi=720904 (initial blue intensity reading in counts of the sample channel)
#blurefi=907378 (initial blue intensity reading in counts of the reference channel)
#blksmpi=8063 (initial black intensity reading in counts of the sample channel)
#blkrefi=8042 (initial black intensity reading in counts of the reference channel)
#red_led=230 (power output setting of red LED)
#grn_led=240 (power output setting of green LED)
#blu_led=225 (power output setting of blue LED)
#initflw=1.00 (average flow during initialization)

#initprs=1001 (average pressure during initialization)
#inittmp=20.6 (average temperature during initialization)
#YY/MM/DD HR:MN:SC invmm_r invmm_g invmm_b red_smp red_ref grn_smp grn_ref blu_smp blu_ref blk_smp blk_ref smp_flw smp_tmp smp_prs pump_pw psvolts err_rpt cntdown fltstat flow_sp intervl stapctl (data column header labels)

Data File Column Definitions

Below the header data in each data file, the numeric data is stored in columns as follows:

1. YY/MM/DD: Year, Month, Day
2. HR:MN:SC: Hour, Minute, Second
3. invmm_r: Absorption coefficient, red (1/Mm)
4. invmm_g: Absorption coefficient, green (1/Mm)
5. invmm_b: Absorption coefficient, blue (1/Mm)
6. red_smp: Raw intensity, red sample
7. red_ref: Raw intensity, red reference
8. grn_smp: Raw intensity, green sample
9. grn_ref: Raw intensity, green reference
10. blu_smp: Raw intensity, blue sample
11. blu_ref: Raw intensity, blue reference
12. blk_smp: Black intensity, sample
13. blk_ref: Black intensity, reference
14. smp_flw: Sample flow measured (lpm)
15. smp_tmp: Sample temperature measured (deg C)
16. smp_prs: Sample pressure measured (mb)
17. pump_pw: Pump power (0-255)

18. psvolts: Power supply or battery input volts measured (volts)
19. err_rpt: Error report
20. cntdown: Count down timer (sec)
21. fltstat: Filter status
22. flow_sp: Sample flow setpoint (lpm)
23. intervl: Averaging interval (sec)
24. stapctl: Stap control (on off)

7.7 UAV Reader Software

The STAP will interface with the Model 9400 Base Module and UAV Reader Software. The reader (see Fig. 13) provides a graphical user interface (GUI) allowing timelines of absorption coefficient data to be viewed in real time on a Windows PC.

The UAV Reader software has been designed to allow multiple instruments to be connected simultaneously so data can logged and instrument performance monitored all using one user interface. Each instrument has a "main" tab (display) in the software as well as a "details" tab (display) where key operating parameters are shwon. If a particular instrument is not connected to the reader software then the tab is greyed out. Multiple STAPs may also be connected to the reader software at the same time, a simple drop-down menu allows selection of the desired serial number unit.

Various instrument settings may also be controlled via the GUI. For example, the STAP control (On/Off) as well as SD Save settings may be controlled using the buttons shown. The current filter state, as well as the progression of states through the initialization process can be controlled via the reader software. If more than one STAP is connected to the reader, any individual unit can be selected by serial number using the drop down button in the top left corner. Data may be stored on the PC in addition to the STAP SD card. The GUI creates the opportunity to remotely control the STAP through external serial port commands. This feature can be useful during UAV flights or remote location deployments.

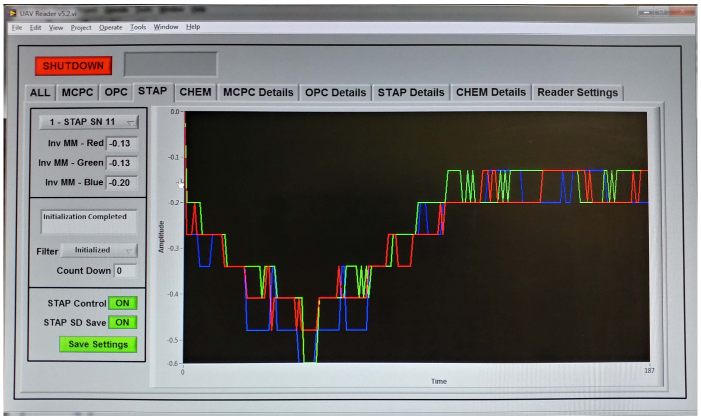


Figure 13: Main STAP tab in UAV Reader software).

When using the reader software with the STAP you must set the STAP firmware baud rate to 'USB'.

The STAP details tab in shown in Fig. 14. Starting in the top left, the percentage of filter life remaining is shown in the three boxes for each wavelength. The current filter readings show the raw measured light intensities for the sample and reference filters for each wavelength. The initial intensity readings acquired during the last white filter check are shown to the right of the current filter readings. The current LED power settings are shown on a 0-255 scale. In the bottom row of the figure are shown the current instrument settings on the left, time and date set in the firmware, diagnostic readings, manufacturing information and finally, calibration coefficient values.

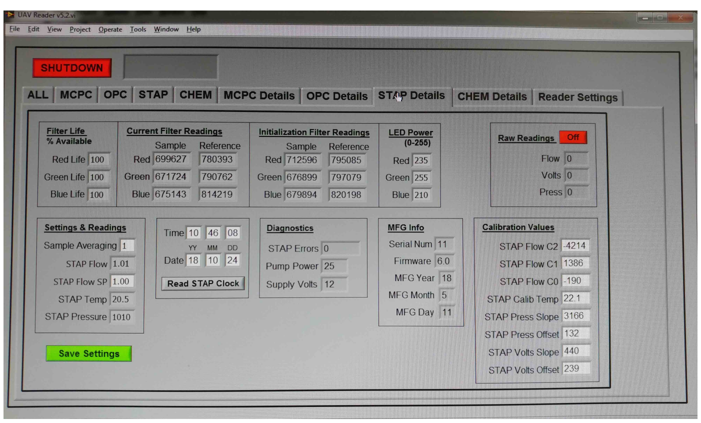


Figure 14: STAP Details tab in UAV Reader software).

If remote control commands will be used via the reader tablet serial port, using the 's_select' command allows the reader to address the desired STAP if multiple STAPs are connected. To delineate the STAP from other instrument modules that may be connected to the reader, the 's_' prefix is added to each command. This prefix is ONLY necessary when sending remote serial commands to the STAP via the UAV Reader tablet.

When using remote control RS232 commands with the reader software and tablet you MUST send the command values in decimal format.

Each time the reader software initiates a new STAP run, the STAP real time clock is synchronized with the clock on the computer running the reader software.

Be sure the computer clock is set to the desired time.

Command syntax for external serial commands to control a STAP via the UAV Reader software/tablet (not for direct serial communication with the on-board STAP RS232 port):

s_read - Returns readings from currently selected STAP
s_settings - Returns settings for currently selected STAP
s_calib - Returns calibration coefficients for currently selected STAP
s_rtclck - Returns real-time clock setting for currently selected STAP
s_mfginfo - Returns serial number, firmware version, and mfg date for currently selected STAP
s_select - sets which STAP to communicate with if there are multiple STAPs connected
s_file_save - sets data file saving on/off by UAV Reader (1=on, 0=off) for currently selected STAP
s_stapctl - sets STAP on/off (LEDs and pump) (1=on, 0=off)
s_sd_save - sets SD Card save on/off (1=on, 0=off)
s_flt_typ - sets filter type (0=Pall, 1=Azumi, 2=?)
s_fltstat - sets filter status, used for filter initialization (see manual for details)
s_flow_sp - sets flow setpoint (lpm)
s_intrvl - sets averaging interval (sec) (not SD save interval)
s_clk_sec - set clock seconds
s_clk_min - set clock minutes
s_clkhour - set clock hours
s_clk_day - set clock day
s_clk_mon - set clock month

s_clkyear - set clock year

7.8 External Serial Commands

Many of the STAP functions and parameters may be controlled or changed via remote RS232 commands from a user-supplied computer. The commands listed below may be sent directly to the RS232 port on the STAP main board using the Serial-USB converter cable and DB9-Cgrid cable provided with the STAP.

DO NOT use the commands below when communicating with the serial port on the tablet computer running the UAV Reader connected to a STAP. Use the commands listed in the UAV Reader Software section of this manual.

Be sure to set the same communication baud rate on the STAP and the computer used to send the serial command. This MUST be a serial baud rate (e.g. 38400) and NOT 'USB'.

When using remote control RS232 commands DIRECTLY with the STAP you MUST send the values within the commands in hexadecimal format.

Command syntax for the STAP when connected directly to the STAP main board RS232 port (e.g. NOT using the reader software):

read - Returns readings from currently selected STAP
settings - Returns settings for currently selected STAP
calib - Returns calibration coefficients for currently selected STAP
rtclck - Returns real-time clock setting for currently selected STAP
mfginfo - Returns serial number, firmware version, and mfg date for currently selected STAP
select - sets which STAP to communicate with if there are multiple STAPs connected
file_save - sets data file saving on/off by UAV Reader (1=on, 0=off) for currently selected STAP
stapctl - sets STAP on/off (LEDs and pump) (1=on, 0=off)
sd_save - sets SD Card save on/off (1=on, 0=off)
flt_typ - sets filter type (0=Pall, 1=EMFAB, Azumi, 2=Azumi)

fltstat - sets filter status, used for filter initialization (see manual for details)
flow_sp - sets flow setpoint (lpm)
intrvl - sets averaging interval (sec) (not SD save interval)
s_clk_sec - set clock seconds
clk_min - set clock minutes
clkhour - set clock hours
clk_day - set clock day
clk_mon - set clock month
clkyear - set clock year

8 Maintenance

8.1 Cleaning the STAP

The filters used in the STAP shed fibers that can contaminate windows and sealing surfaces. During each filter change, visually verify that no filter debris is loose inside the unit. Clean filtered air can be used to blow out the channels to remove debris.

If windows within the STAP become dirty, use a Q-tip soaked in IPA to clean them.

O-rings inside the STAP will become dry with use. Apply fresh grease to the O-rings exposed during filter changes roughly every 15 filter changes. Visually inspect the o-rings for damage and replace any that appear cracked or deformed.

Under persistent high aerosol loading conditions, the sample LFE may become clogged or partially blocked with particles. Remove the LFE from the unit and flush with clean DI water and IPA. Sonicate for 2 hours submerged in water. Blow dry with filtered air after sonication and re-install.

9 STAP Errors

Each STAP error is assigned a bit in the STAP ERROR number. Convert the STAP ERROR number to binary to check the bits. If an error is occuring, the bit for that error will be 1 instead of 0.

Bit Number	ERROR
1	EPROM ERROR
2	BAD Stored Value
3	Clock - Check time
4	Clock ERROR
5	SD Card ERROR
6	SD Format not FAT32
7	SD Card Space ERROR
8	Bad Thermistor ERR
9	PUMP MAXED OUT ERR
10	RED LED ERROR
11	GREEN LED ERROR
12	BLUE LED ERROR
13	BLACK NOISE ERROR

One common error in the STAP is "BAD Stored Value" error. This error shows up if there was trouble with the previous filter initialization. The initialization readings are stored in the EEPROM after initialization. If the readings are too low, the "BAD Stored Value" error will appear at the next power up because the EEPROM values are checked when they are read at power up.

10 Troubleshooting

Table 5: Common Troubleshooting Solutions

Problem	Likely Cause	Solution
Will not power on	No AC/DC pwr	Plug in supply
	Connector not plugged in	Plug in connector
Firmware resets	Program-Data Switch set to program	Set switch to data
Sample flow too low	Multiple filters installed	Ensure only one filter installed
	LFE clogged	Ensure LFE is clean
	Pump failure	Replace pump
Noise level too high	Dirty filters	Install new filters
	Debris on windows	Clean windows
	Detector damage	Replace detector board
	LEDs too dim	Replace LED board
Sample flow incorrect	Calibration drift	Recalibrate LFE
	LFE clogged	Clean LFE
	Sensor failure	Replace main board
Absorption too low	Detector failure	Replace detector board
	LED failure	Replace LED board
	Sample flow incorrect	Calibrate LFE

11 Appendix

11.1 Updating the STAP firmware

Follow these steps to update your product firmware when instructed to do so by the factory or your regional technical representative:

- Download the microprocessor programming tool to your Windows-based computer (this software may also have shipped on the USB stick with your product): ”Setup-Propeller-Tool-v1.3.2.exe”
- Install the microprocessor programming tool on your computer by double clicking on ”Setup-Propeller-Tool-v1.3.2.exe”.
- Connect the mini-USB port on your product to a USB port on your computer using the supplied USB cable.
- Turn the power on to your product.
- Confirm that you have a copy of a recent data file from your product listing the calibration coefficients (you should not need to re-enter the calibration coefficients after updating the firmware but it is a good idea to have them).
- The small white program/data switch is located on the top edge of the main board next to the SD Card slot. Move the switch from the data position to the program position (push the switch toward the green circuit board). The firmware will NOT update if the switch is in the wrong position.
- Run the installed microprocessor programming tool created by the software installation: ”Propeller.exe”.
- Click ”File->Open” and navigate to the new firmware version eeprom file ”XXXX.eeprom” supplied by BRECHTEL that has been saved to your computer.
- Open the file.
- This will bring up the ”Object Info” window. Click on the ”Load EEPROM” button near the bottom of the window.

- Confirm no errors during installation and that the firmware update runs with a successful message window when completed.
- Move the program/data switch back to the data position (push the switch away from the green circuit board).

For products with older versions of firmware (e.g. before version 3.0), contact the factory for additional instructions on manually entering the calibration coefficients.

11.2 Calibrating the STAP

BRECHTEL provides the ”STAP Calibrator.exe” program to allow you to easily recalibrate your sample flow LFE, absolute pressure sensor, or the input power voltage reading. To use the program, you must have a Windows PC (ver 7 to 10) with Labview 2011 Runtime Engine installed and a free USB port. Obtain the program from BRECHTEL or your local technical representative if you cannot find it on the USB stick that shipped with your STAP. Copy the program to the ”STAP” folder on the C drive. Connect the STAP via a USB cable to the PC USB port and be sure the STAP baud rate is set to USB in the firmware.

Sample Flow LFE

Follow the steps below to re-calibrate the LFE in the STAP.

- Be sure to warm up the device for atleast 30 minutes before performing a calibration.
- You will need a small vacuum pump (2 lpm of critical flow), tubing, and a regulating needle valve to control various air flow rates through the LFE.
- Run the calibrator program and select the correct version of firmware
- In the program under Filter select ”Previous”
- In the program, set STAP Control to OFF
- Record the current values of the calibration coefficients and calibration temperature

- Temporarily disconnect the LFE thermistor from the main board and disconnect the LFE from the flexible tubing connecting it to the STAP body. Be sure not to pull on the LFE tubes.
- Attach the needle valve to the outlet end of the LFE that was attached to the STAP
- Attach a reference flow meter to the inlet of the LFE
- In the program select the Flow Cal Tab
- With the pump off, push the "Take Raw Readings" button next to the 0.0 lpm flow setpoint value and hold the button down with the mouse until atleast 45 data points are acquired for the zero flow condition. It is IMPORTANT to KEEP THE BUTTON DEPRESSED.
- Turn on the pump and use the needle valve to set a 0.2 lpm flow rate as indicated by the reference flow meter
- It is not critical that the measured flow values match the desired setpoints exactly, only that the flow is steady during each setpoint calibration
- Measure the 0.2 lpm flow with the reference flow meter and enter the measured flow value in the white box next to the 0.2 lpm label.
- Do NOT ALLOW the flow meter to make continuous measurements while acquiring raw readings with the program!
- Set the flow to 0.4 lpm by adjusting the needle valve and repeat above procedure, inputting the measured flow and then taking raw readings
- Repeat above steps until the 2.0 lpm setpoint is completed
- You should observe a straight line in the graph
- If the calibration looks good, select the "Save Flow Cal" button in the lower right corner to automatically save the new calibration coefficients and calibration temperature to the STAP firmware.
- Confirm the new coefficients were properly written to the STAP firmware by verifying their presence in the Defaults Calibration Coef menu on the STAP.

A Packing Lists

A.1 STAP Ship Kit, PN 53-00036-01A

Part Number	Description	QTY
001720002B	Certificate of Origin	1
001720003B	Certificate of Conformance	1
21-00250-01A	Bracket Spacer, STAP	1
21-00251-01A	Shipping Bracket, STAP	1
83-00036-01A	Product Manual, STAP	1
900200016A	Filter, Capsule, 3.23L x 1.00 OD x .25 Tube	2
900700036A	Tubing, Conductive Rubber, 1/4 ID x 3/8 OD, Black	0.5 ft
901102003A	Bolt, Socket Head, 4-40 T,3/8 L	2
901102010A	Bolt, Socket Head, 4-40 T,1-1/4 L	2
901302002A	Washer, Flat, #4, SS	4
901303001A	Washer, Lock, #4, SS	4
901402001A	Nut, 4-40 T, SS	4
99-00001-01A	Plastic Tweezer, Acetal Blunt Tip	1
99-00001-02A	Hex L-Key, 3/32 x 2-1/8 Long	1
99-00002-02A	Hex L-Key, 5/64 x 3-3/8 Long	1
902800040A	Power Supply, 12v, 100 W, 8.3 A, Desktop	1
903100027A	Flash Drive, 4 GB, USB 2.0	1
903100030A	Flash Memory, SD Card, 4 GB, Micro and Adapter	1
903100031A	Memory Card Reader, USB	1
96-00004-01A	IM2450 - foam filled (Pick n Pluck) - black case	1
96-00007-02A	Shock Label, 7/8" x 2", 25 G Sensitivity, Resettable	1
	POWER CORD (OPTION by Country/Voltage)	1