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Counterflow Virtual Impactor (CVI) Inlet Aboard Aircraft (INLETCVI-AIR) Instrument Handbook

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ARM

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Office of Science, Office of Biological and Environmental Research

Acronyms and Abbreviations

AAF	ARM Aerial Facility
ACAPEX	ARM Cloud Aerosol Precipitation Experiment
ARM	Atmospheric Radiation Measurement
ASCII	American Standard Code for Information Interchange
BMI	Brechtel Manufacturing, Inc.
CACTI	Cloud, Aerosol, and Complex Terrain Interactions
CARES	Carbonaceous Aerosols and Radiative Effects Study
CAS	cloud and aerosol spectrometer
CDP	cloud droplet probe
CIRPAS	Center for Interdisciplinary Remotely Piloted Aircraft Studies
CPC	condensation particle counter
CVI	counterflow virtual impactor
DC	direct current
DOE	U.S. Department of Energy
G-1	Gulfstream-159
GPS	Global Positioning System
HEPA	high efficiency particulate air
HI-SCALE	Holistic Interactions of Shallow Clouds, Aerosols, and Ecosystems
ICARTT	International Consortium for Atmospheric Research on Transport and Transformation
IOP	intensive operational period
ISDAC	Indirect and Semi-Direct Aerosol Campaign
LPM	liters per minute
mfc	mass flow controller
netCD	Network Common Data Form
NCAR	National Center for Atmospheric Research
OPC	optical particle counter
PC	personal computer
QC	quality control
SS	stainless steel
TANS	Tactical Air Navigation System
TCAP	Two-Column Aerosol Project
UTC	Coordinated Universal Time
VAC	volts alternating current
VDC	volts direct current

Contents

Figures

1.0 Instrument Title

Counterflow virtual impactor (CVI) inlet aboard aircraft

2.0 Mentor Contact Information

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3.0 Vendor/Developer Contact Information

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Tel: 510-732-9723

4.0 Instrument Description

The counterflow virtual impactor (CVI) inlet separates out and samples cloud elements via inertial impaction. Warm, dry, particle-free carrier gas of known composition is pumped to the tip of the inlet in the direction opposite of the flow of air. The flow lines of the incoming free stream air are split. Larger droplets and ice crystals suspended in the sample air have enough inertia to penetrate the counterflow and enter the sample flow, while smaller, unactivated particles follow the streamlines of the air flowing around the inlet's tip (Noone et al. 1988).

The instrument is capable of sampling cloud elements as a function of cut size by changing the velocity of counterflow at the probe tip. The CVI cut size is usually defined as a diameter of a smallest particle for which penetration rate is 50%. For the U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) user facilityGulfstream-159 aircraft's CVI inlet, that value is usually around 13 microns. The dry heated air, normally used as the carrier gas, also serves to evaporate water from the hydrometeor, leaving the residuals to be sampled by in-cabin aerosol instrumentation.

The number concentration of the droplet residue in the CVI sample line is usually increased with respect to corresponding cloud element number concentration. The CVI performance as a concentrator is usually described via CVI enhancement factor, which is a conversion factor between ambient volumetric concentration (not adjusted to standard temperature and pressure) and volumetric concentration in the CVI sample line.

Further information about the design and theory of CVI operation can be found in Noone et al. (1998). An extensive collection of references to the peer-reviewed publications can be found on the National Oceanic and Atmospheric Administration (NOAA) CVI web page: https://www.esrl.noaa.gov/gmd/aero/instrumentation/cvi.html.

The CVI inlet was designed and manufactured by Brechtel Manufacturing Inc (BMI, Hayward, California). It was mounted on the Gulfstream-1 aircraft (G-1, DOE ARM Aerial Facility, AAF, part of the ARM user facility) and modified by AAF scientists Mikhail Pekour and John Hubbe. The design of this inlet increases sample flow to instrumentation, reducing the need for dilution, and more readily allows for cleaning (Shingler et al. 2012). Additional information can be found on the manufacturer's website. The CVI inlet was mounted on the right-hand side window #1 of the G-1 aircraft. The first deployment of the CVI on G-1 was in March 2010 during the CalWater field study. After the first deployment the CVI was modified. Sample and add flow lines were equipped with mass flow controllers (MFCs), a new version of the software was installed, and a new window mounting plate was outfitted to accommodate larger angles. The CVI faring cone and inlet tip were gold plated. The CVI body was additionally thermo-insulated to improve performance at lower temperatures. This model was used on the Gulfstream-159 aircraft operated by the AAF until 2019. A newer version of this instrument will be deployed on the replacement Challenger 850.

Figure 1. CVI inlet, below, with thermo-insulation layer and equipped with gold-plated fairing cone. The G-1's CVI inlet has a gold-coated tip for reasons described in section 9.

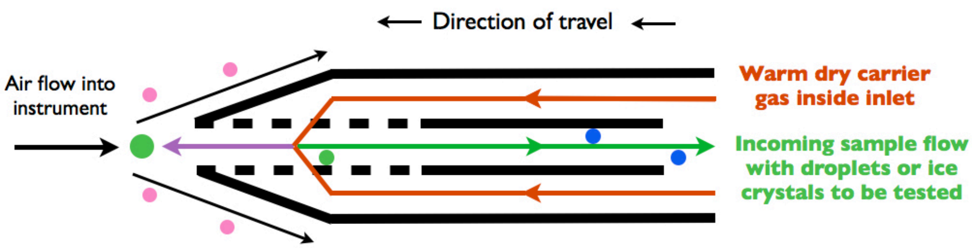

Figure 2. Schematic of CVI inlet design taken from NCAR's website.

5.0 Measurements Taken

The data set associated with the CVI inlet contains the working parameters and data flags relevant for both the CVI and isokinetic inlets (due to their inexorability): CVI cut size, enhancement factor (for CVI mode), dilution factor (for sub-isokinetic mode), CVI mode flag, CVI QC flag, three aircraft attitude warning flags (total speed, roll, and pitch angle), large droplet warning flag, and inlet selector valve position.

The data is reported in cloud probe time frame, meaning there has been no time adjustment to account for the CVI internal residence time and/or delay in the lines. The CVI cut size is determined during post-processing and is not monitored in real time. The dilution factor represents the sample dilution in the CVI lines due to 'Add Flow' (if any) during operation in sub-kinetic mode. Therefore, it represents a multiplier that should be applied to particle number concentration measured in the CVI lines to restore ambient concentration. The data set OPC-AIR, from the optical particle counter associated with the inlets, is the other inlet housekeeping data set providing information about coarse-mode aerosol size distribution, which may be used to assess the integrity and transmission of the incoming sample aerosol. Several instruments were connected to the inlet selector valve that allowed sampling from one of the two inlets installed on the aircraft: inlet for aerosol sampling (isokinetic) and counterflow virtual impactor inlet (for cloud condensation nuclei).

6.0 Links to Definitions and Relevant Information

Instrument website: https://www.brechtel.com/products-item/aircraft-based-counterflow-virtual-impactor-inlet-system/

For campaign data sets, a readme file is included in the intensive operational period (IOP) area where data is downloaded https://iop.archive.arm.gov/

6.1 Data Object Description

CVI inlet data exists under the instrument class name 'Inletcvi-air'. CVI inlet data submitted as a routine data set are named 'aafinletcvi'. Historically, the naming of individual data sets has been inconsistent. Data submitted as IOP data will have the name 'inleticvi-air' (ISDAC) or 'cvi-air' (Two-Column Aerosol Project [TCAP], ARM Cloud Aerosol Precipitation Experiment [ACAPEX], Holistic Interactions of Shallow Clouds, Aerosols, and Ecosystems [Hi-SCALE]). Before 2017, this data set was submitted on a campaign-by-campaign basis as IOP data. Data since 2016 have been submitted as a routine data set. Data are available in both netCDF format and ASCII format (as an International Consortium for Atmospheric Research on Transport and Transformation [ICARTT] file or CSV text file depending on the campaign).

The recorded data fields include:

- CVI cut size
- Enhancement factor (for CVI mode)
- Dilution factor (for isokinetic mode)
- Inlet mode flag (sampling aerosol vs cloud residuals)
- CVI QC flag
- Aircraft attitude warning flags for total speed, roll, and pitch angle
- Large droplet warning flag
- Inlet selector valve position

In some data sets, the field names can look like this:
(1) Time (UTC): time stamp in form hh:mm:ss
(2) C_50: the CVI cut size estimate in µm
(3) E_f: the CVI enhancement factor [unitless]

(4) Flags: QC flags presented as 4-digit binary number

- No bits set (0000) indicates no errors or warnings.
- The first bit is error flag: CVI controller problem, the cut size is reported as bad.
- The second bit is warning that aircraft roll angle was beyond ±5° band.
- The third bit is warning that aircraft pitch angle was beyond ±3° band.
- The fourth bit is warning that total air speed was out of normal sampling speed range of 90 to 110 m/s.

On the Gulfstream-159, the output data were recorded with 1-Hz resolution with the M300 data acquisition system and with CVI controller (embedded PC). The Challenger aircraft will use an updated data system, but the CVI datastream will remain the same. Separate data files are normally started for preflight tests and for each flight.

6.2 Data Ordering

Data from the CVI inlet can be ordered from https://arm.gov/capabilities/instruments/inletcvi-air (data from campaigns 2016 to present and the Indirect and Semi-Direct Aerosol Campaign [ISDAC]) or https://arm.gov/data/data-sources/cvi-air (for campaigns pre-2016). Data are organized by measurement location and campaign.

6.3 Data Plots

No plots are available for these data on ARM's Data Discovery web-based interface. However, these data can be used for data masking.

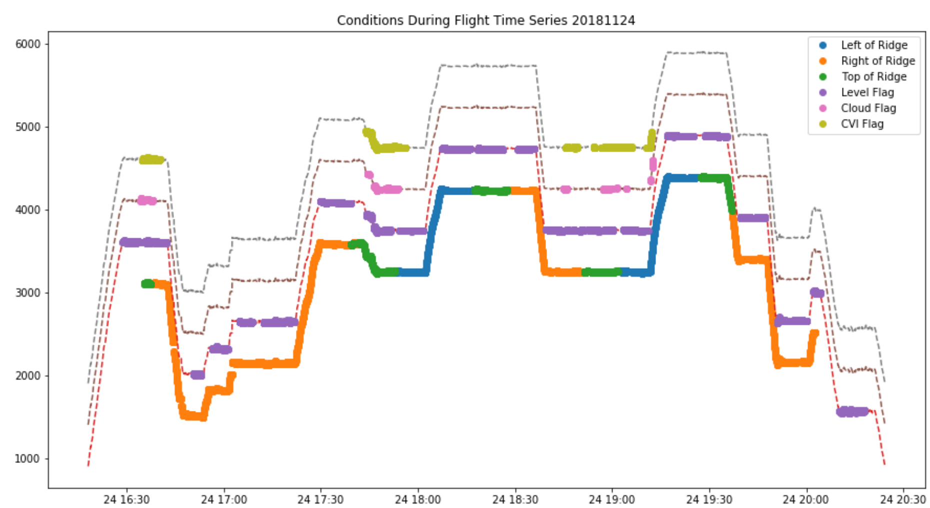

Figure 3. Example of using data masks over the course of a flight from the Cloud, Aerosol, and Complex Terrain Interactions (CACTI) field campaign, 24 November, 2018. When the CVI flag is true, cabin instrumentation is sampling from the CVI inlet. This sampling aligns with cloud transects.

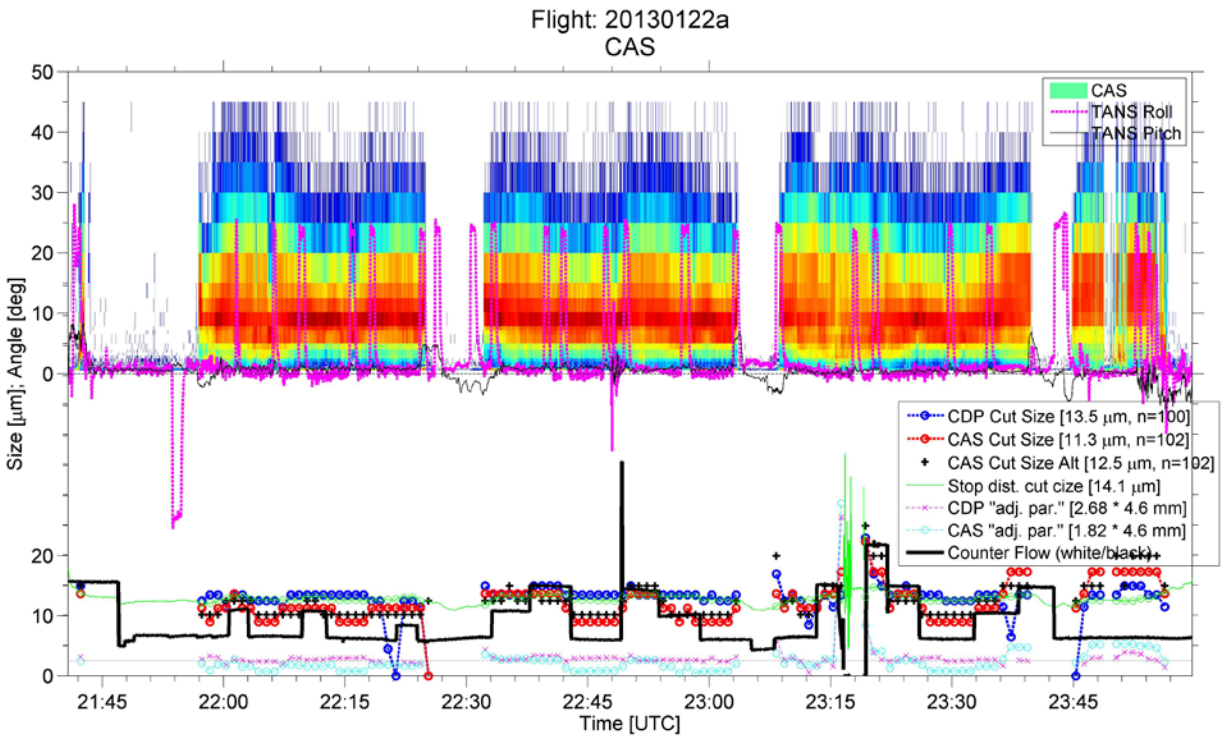

Figure 4. Time series of data collected during test flight on 22 January, 2013. The upper panel shows cloud droplet size distribution as measured by cloud and aerosol spectrometer (CAS) probe; overlapping are traces of aircraft roll and pitch angles as measured by the Tactical Air Navigation System (TANS), magenta and black lines correspondingly. The lower panel shows the CVI counterflow (black line) and two types of derived parameters: (1) CVI cut size estimates based on CAS and cloud droplet probe (CDP) size distributions, and "stopping distance" estimate based on current conditions (aircraft velocity, etc.) and fixed "additional distance" parameter; (2) "additional distance" adjusted to get "stopping distance" cut size matched to CAS or CDP estimate.

6.4 Data Quality

Data quality evaluation involves automatic flagging of data based on criteria developed by instrument mentors. Times when large droplets enter the sample flow are noted due to possibility of their break up in the inlet. Aircraft attitude flags are included as well because the airflow around the inlet can be disturbed during flight maneuvers, biasing the incoming aerosol sample. We recommend using data from instruments sampling off of aerosol inlets only during level flight.

Bad or missing-value place holder is -9999 .0.

6.5 Instrument Mentor Monthly Summary

This instrument is not used for routine measurements, so the mentor does not generate monthly summary reports. The instrument is currently not in use while the Challenger 850 aircraft is being modified for research.

6.6 Calibration Database

Information on this subject is maintained by AAF's Director of Engineering.

7.0 Technical Specification

7.1 Units

- CVI cut size estimate in µm.
- The CVI enhancement factor is unitless.

7.2 Range

The CVI cut size represents a minimum diameter of a cloud element that can be sampled with 50% probability. The CVI cut size is determined during post-processing and is not monitored in real time. The droplet stop distance is a variable estimated using measurements of the free stream velocity and droplet mass and estimations of well-known empirical relationships (Willeke and Baron 2001). It is used to estimate the cut size of the CVI even when the particle's trajectories cannot be calculated/known and $0.5 < Re < 500$. For a more detailed explanation, see Shingler et al. (2012).

7.3 Accuracy

Traditionally, performance of a CVI has been described in the same terms as ordinary virtual impactors: cut size and cut sharpness. The CVI collection efficiency G(D) can be visualized as a smooth function changing from 0 to 1 within relatively narrow size span in the vicinity of a droplet diameter for which penetration rate is 50% (i.e., cut size, red line in Figure 5). The width of this transition range is characterized by cut sharpness $\sigma = \sqrt{\frac{D|_{G(D)=high}}{D|_{G(D)=low}}}$. Low and high thresholds used in the cut sharpness definition have been usually chosen to simplify comparison of collection efficiency curve with parameters of classical distributions (see C low and C high in Figure 5). Shingler et al. (2012) reports $\sigma = \sqrt{\frac{C_{69}}{C_{31}}} = 1.28 \div 1.34$ for a CVI similar to the one described here. It should be noted that the cut sharpness estimates based on experimental data have a "natural" low limit due to limited resolution of particle sizing instrumentation. It should also be noted that this discussion ignores effects of droplet and/or particle losses in the CVI inlet and lines.

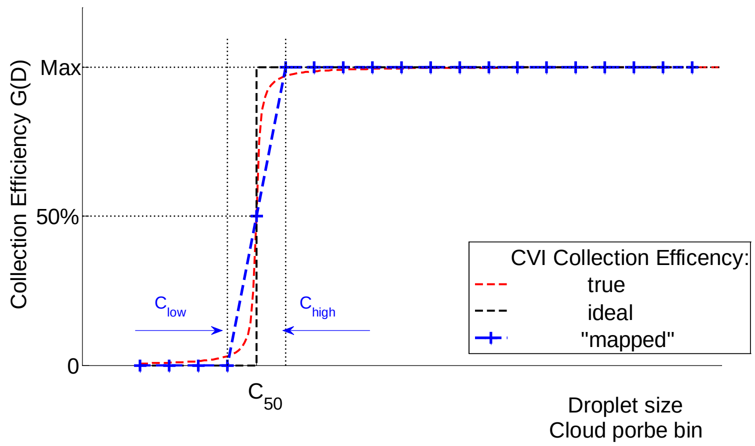

Figure 5. Schematic presentation of true CVI collection efficiency (G[D]) in red, and ideal in black. The blue line represents the cloud droplet size bins from a cloud probe, the cloud and aerosol spectrometer for this plot. The size range used to estimate CVI cut sharpness $\boldsymbol{\sigma} = \sqrt{C_{high}/C_{low}}$ is marked with vertical thin black lines.

7.4 Repeatability

The mounting angle of the CVI has remained unchanged at 9.7° down to align the CVI tip with local flow since 31 December, 2012. Flow distortion by the aircraft body and the wings was verified and flow angle was estimated on 11 November, 2012, 30 November, 2012, and 30 November, 2012 using a Rosemount 5-port gust probe on loan from the Center for Interdisciplinary Remotely Piloted Aircraft Studies (CIRPAS). The CVI positioning was validated on 22 January by location and orientation of ice accumulation on CVI structures. Special horizontally protruding plastic tube was mounted on the outer side of the CVI head to serve as an ice accumulation surface. The inlet itself is outfitted with heating elements to prevent icing.

Figure 6. Icing on the CVI to test ice collection and flow line distortion.

7.5 Sensitivity

Sensitivity in regard to the CVI inlet is with respect to its ability to capture the outside cloud element population accurately. This relates to the inlet's enhancement factor and particle transmission.

The concentration of cloud element residue is usually increased within the CVI sample line as compared to corresponding cloud element concentration. A parameter historically called "enhancement factor" $E_{CVI} = \frac{A_{tip}V_{plane}}{q_{sample}}$ has been used to describe a CVI performance as a concentrator; where A_{tip} is the area of the inlet tip where drops enter, V_{plane} is the speed of the aircraft, and q_{Sample} is the volumetric flow rate in the CVI sample line.

Particle transmission relates to loss in the CVI sample line. Shingler et al. (2012) has presented estimates of particle loss in various sections of the CVI inlet (Figure 7). These efficiency curves have been obtained in a set of wind tunnel experiments with hollow glass beads as a test aerosol. These estimates should be treated as worst case since they do not account for some processes, like droplet evaporation in the lines and subsequent lessening in particle loss rate in the downstream sections.

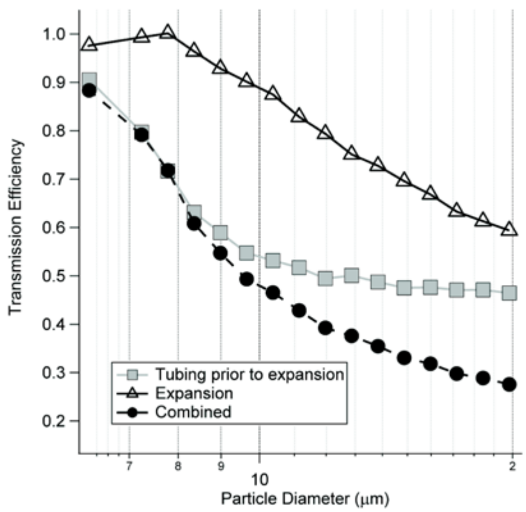

Figure 7. Transmission efficiency from Shingler et al. (2012).

7.6 Uncertainty

Another way to estimate the cut size of a CVI is using aerodynamic drag theory, described in Noon et al. (1988). For airborne CVI, the cut size C50 can be directly estimated using the cloud droplet size distribution and/or cloud droplet volume distribution. In an iterative process, the conjectural CVI collection efficiency is varied. Using the conjectural CVI collection efficiency at that time step as a weight function, the cloud droplet size or volume distribution is integrated and the result is compared to the droplet residue concentration or water vapor content in the CVI sample line until a balance is found. Schematic illustration of cloud droplet spectrum, cloud probe output, and a conjectural CVI collection efficiency curve is presented in Figure 8.

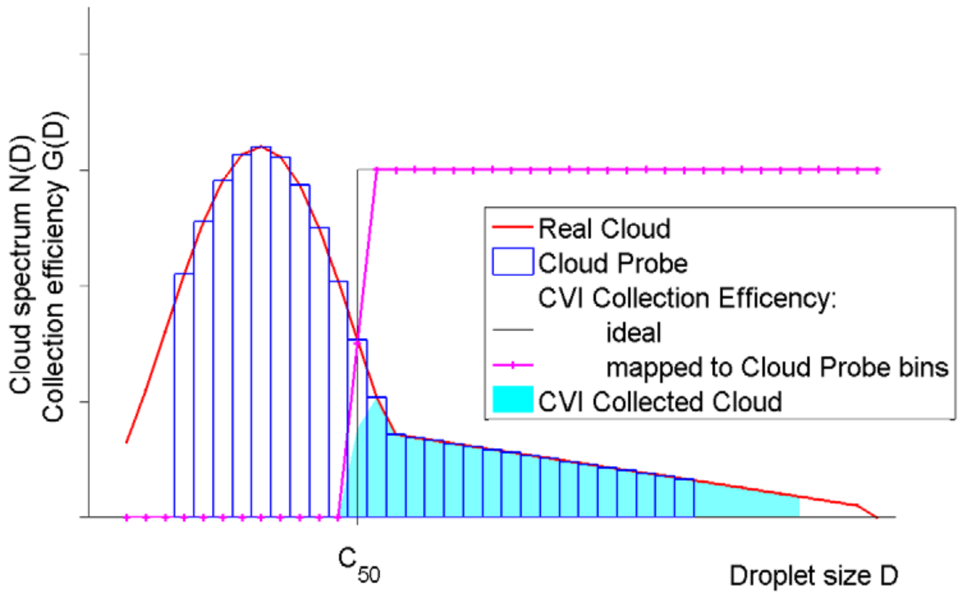

Figure 8. Schematic presentation of cloud droplet size distribution (red line), cloud probe output (blue bars), conjectural CVI collection efficiency (thin black line for "ideal" curve and magenta line with crosses for efficiency mapped to cloud probe bin structure), and portion of cloud droplet spectrum collected by the CVI (cyan shading).

Several more processes can complicate characterization of an airborne CVI inlet: particle loss in the CVI and lines; droplet or ice crystal shattering in the vicinity of the CVI probe due to effects of the CVI inlet and the pylon, aircraft body, wings, and propellers on incoming air flow; droplet shattering in the CVI itself; and interstitial aerosol penetration (piggyback in the wake of cloud droplets).

The concentration of cloud element residue particles in the CVI sample line can be expressed as a function of CVI enhancement factor, aircraft speed, surface area of inlet orifice, sample line flow rate, cloud element size, and inlet collection efficiency. Assuming no particle loss, the cloud element size distribution measured with a cloud probe can be compared to the concentration of cloud element residue particles in the CVI sample line as a check of loss.

7.7 Input Voltage

The CVI control box is usually mounted in the aerosol rack in the cabin of the aircraft. It has two incoming power connections on the back side: one is standard mains power (110VAC): the other is 28 VDC round 16 pins, with black-and-red wires. Note that DC power is used for CVI heaters. Max anti-ice is 725 watts at 28 VDC.

7.8 Input Current

N/A

7.9 Input Values

To initialize the software, the most relevant parameters in the CVI configuration file are directories for data, log file storage, and flow settings (Total Sample and Instrument Sample Flows). It should be noted that Brechtel, the manufacturer, uses 15 LPM as default value for the Total Sample Flow while AAF uses 7.5 LPM.

The CVI control box is outfitted with RS-232 interfaces to transmit data and control the flows. The Add Flow and Sample Flow mass flow controllers (MFCs) are controlled via corresponding RS-232 channels. The RS-232 connectors are also used to provide power to the MFCs.

7.10 Output Values

Usual post-campaign data processing sequence was as follows:

(a) read all the data from appropriate files/location;

(b) introduce appropriate time shift (e.g., 10 s) to the sensors behind the CVI: CVI CPC, TDL, etc;

(c) discard the data before takeoff and after landing (AIMMS TAS<50 m/s);

(d) resample (interpolate) CVI data to M300 timeframe;

(e) level flight test: mask out all the data when aircraft was not in level flight (GPS roll>5° and/or GPS pitch>3°);

(f) average all data over 1 min; missed data are filled up with NaNs. The CVI counterflow is calculated as difference between "Addflow Mass air flow [standard L/min]" and "Sample Mass air flow [standard L/min]"; if Add flow was not stable within averaging time the averaged value of counterflow was set to NaN;

(g) re-bin (interpolate) raw CAS data to a new bin structure to conserve total particle counts and determine relation (linear regression) between the CVI cut size and the counterflow;

(h) estimate CVI cut size from 1-min averaged raw CAS data whenever possible based on "original" and "re-binned" data;

(i) estimate CVI enhancement factor from 1-min averaged data (using aircraft speed);

(j) estimate theoretical CVI cut size using "stopping distance" approach;

(k) aircraft speed test: flag out the data with aircraft speed outside nominal operational range (true airspeed >90 and <105 m/s);

(l) cloud droplet concentration test: flag out the data with low cloud droplet concentration (total CAS counts < 300);

(m) large droplet test: flag out the data with too wide cloud droplet spectrum (number of droplets outside the CAS range is above 5% of total CIP counts).

See Figure 4 for timeseries of these variables.

8.0 Instrument System Functional Diagram

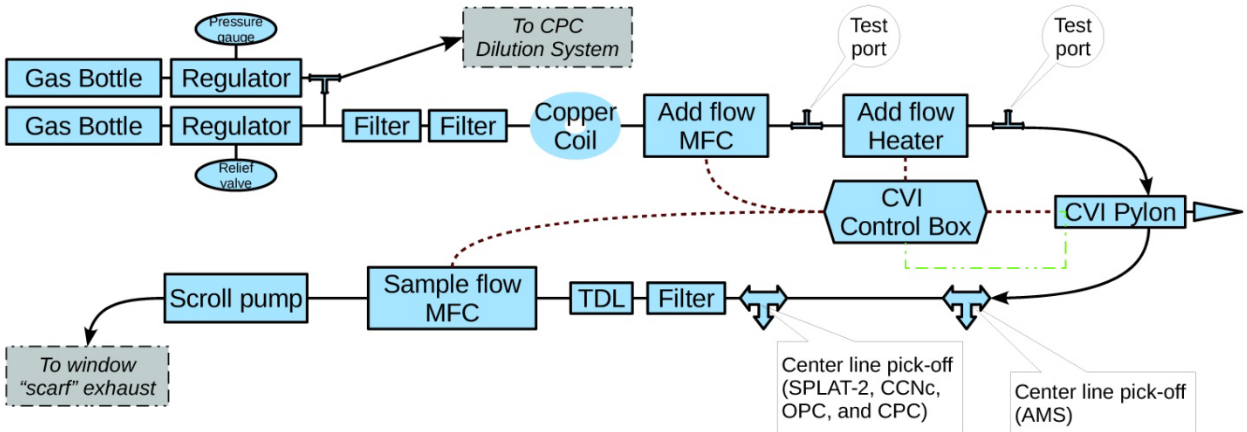

Figure 9. CVI inlet line layout for the Carbonaceous Aerosols and Radiative Effects Study (CARES) campaign. Black solid lines depict air tubing and/or fittings for sample and add flows; red dashed lines show electrical and signal connections; green dot-dashed line shows pneumatic lines from differential pressure sensor to pressure ports on the CVI pylon (Pitot-static tubes).

9.0 Instrument/Measurement Theory

The CVI inlet separates out and samples particle residuals inside cloud via inertial impaction. The outer tube is solid and the inner tube approaching the inlet tip is porous. The probe is oriented such that the centerline of the tubes is parallel to droplet impaction velocity and the probe pylon is sufficiently tall to sample in the free stream. Warm, dry air is pumped to the probe tip via the porous-ended tube with flow rate F1. Part of that air returns in the inlet with the sample air, F2. Part of that flow exits out of the tip of the inlet, F3. The full equation is F3 = F1 – F2, and due to their relationship to F1, each of these flows is adjustable to control the minimum droplet size that the CVI probe will sample. The flow lines of the incoming free stream air are split. Larger droplets and ice crystals suspended in the sample air have enough inertia to penetrate the counterflow and enter the sample flow, while smaller, unactivated particles follow the streamlines of the air flowing around the inlet's tip (Noone et al. 1988).

Theory and principles of CVI operation are well documented in published works (e.g., Anderson et al. 1993); design of a similar CVI is reported in Shingler et al. (2012). Below, we discuss the validation procedures for the AAF CVI inlet.

9.1 The CVI Inlet Cut Size Estimation Procedure

The CVI was characterized against the cloud droplet distribution from the cloud and aerosol spectrometer (CAS, part of the cloud, aerosol, and precipitation spectrometer). Disregarding particle losses in the CVI inlet and lines, and using a simplified form of CVI collection efficiency (two step function 0 to 0.5 to 1.0), concentrations can be compared within the inlet and the cloud probe. CAS concentration is related to the raw counts according to the following formula: $N_{CAS}(D_j) = \frac{n_j}{2V_{air}S_L\Delta t}$, where S_L=*0.24 mm*^{2} is cross-section area of CAS laser beam, and $\Delta t=1\ s$ is CAS measuring time interval. So concentration of cloud droplet residue in the CVI sample line is

$$N_S = E_{CVI}\left(\frac{N_{CAS}\left(D_{i|_{D_i=C_{50}}}\right)}{2} + \sum_{D_j>C_{50}}^{max} N_{CAS}(D_j)\right) = \frac{V_{air}S_{CVI}}{F_S}\left(\frac{n_{i|_{D_i=C_{50}}}}{2V_{air}S_L\Delta t} + \sum_{D_j>C_{50}}^{max} \frac{n_j}{V_{air}S_L\Delta t}\right)$$
$$= \frac{S_{CVI}}{F_S S_L \Delta t}\left(\frac{n_{i|_{D_i=C_{50}}}}{2} + \sum_{D_j>C_{50}}^{max} n_j\right)$$

The CVI cut size can be estimated by calculating the sum with varying low limit (e.g., from 1 to total number of CAS bins) until the right-hand side of the equation becomes less than N_S.

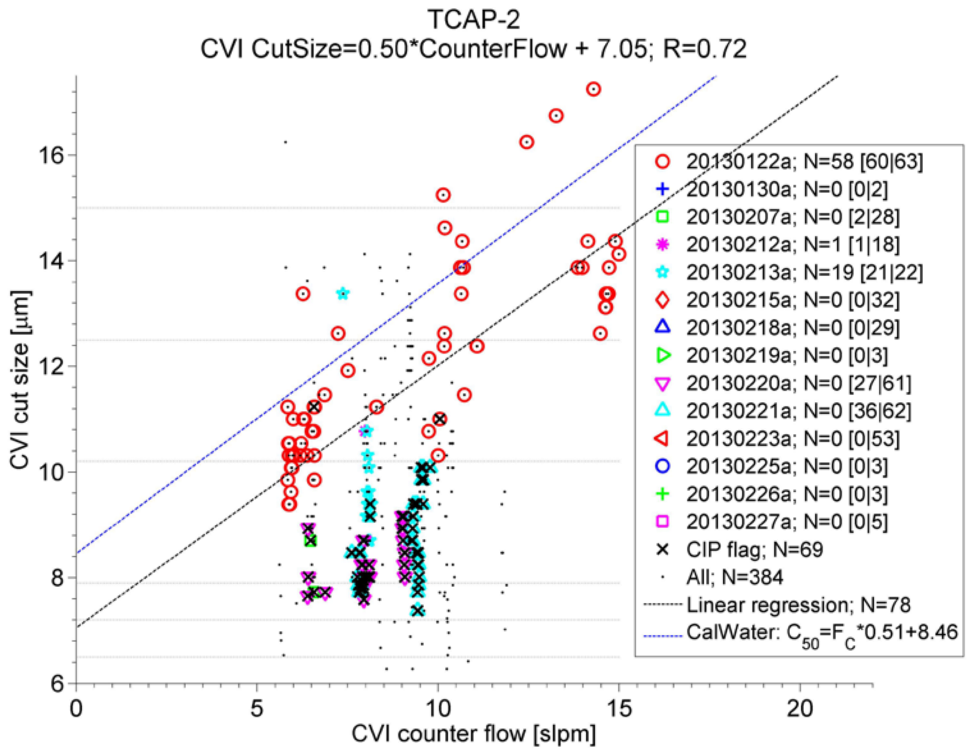

Figure 10. CVI cut size versus CVI counter flow. All 1-min average estimates that passed air speed and "level flight" tests are plotted as black dots (not sorted by the flight). The number for every flight is listed in the legend (second number in the brackets). Colored markers show data that passed level flight/air speed and minimal droplet number test sorted by the flight (first number in the brackets); black "x" mark data that failed large droplet test. Linear regression was calculated for the data that passed all tests. The first number in the legend (N=) is the number of 1-min estimates that passed all tests. The blue dotted straight line represents linear regression obtained during the CalWater field campaign. Thin black dotted lines represent borders of CAS bin structure.

9.2 Accounting for CVI Particle Loss

A "worst case" transmission efficiency is "best case" in terms of "lowest estimated" cut size, so correction for unrealistically high losses should result in extremely low cut sizes. A "worst case" transmission efficiency curve is generated by mapping the published combined efficiency curve (from Shingler et al. 2012, Figure 7) on the CAS bin space (pylon-based aerosol size distribution instrument on the AAF research aircraft) and extrapolating it to lower and larger sizes with constant values of 0.9 and 0.3 respectively. Particular values chosen for extrapolation do not matter very much since anticipated CVI cut size is well above 6 um (lower end of published curve), while particles with sizes above 20 um (upper border of the published curve) are rather rare and do not make much input in total number concentration.

Size-resolved particle losses in the CVI described by particle loss function L_j can be easily incorporated into calculations:

$$N_S = \frac{S_{CVI}}{F_S S_L \Delta t}\left(L_{i|_{D_i=C_{50}}} \frac{n_{i|_{D_i=C_{50}}}}{2} + \sum_{D_j>C_{50}}^{max} L_j n_j \right)$$

A scatter plot similar to Figure 10 with all 1-min estimates of CVI cut size and particle loss accounted for is presented in Figure 11.

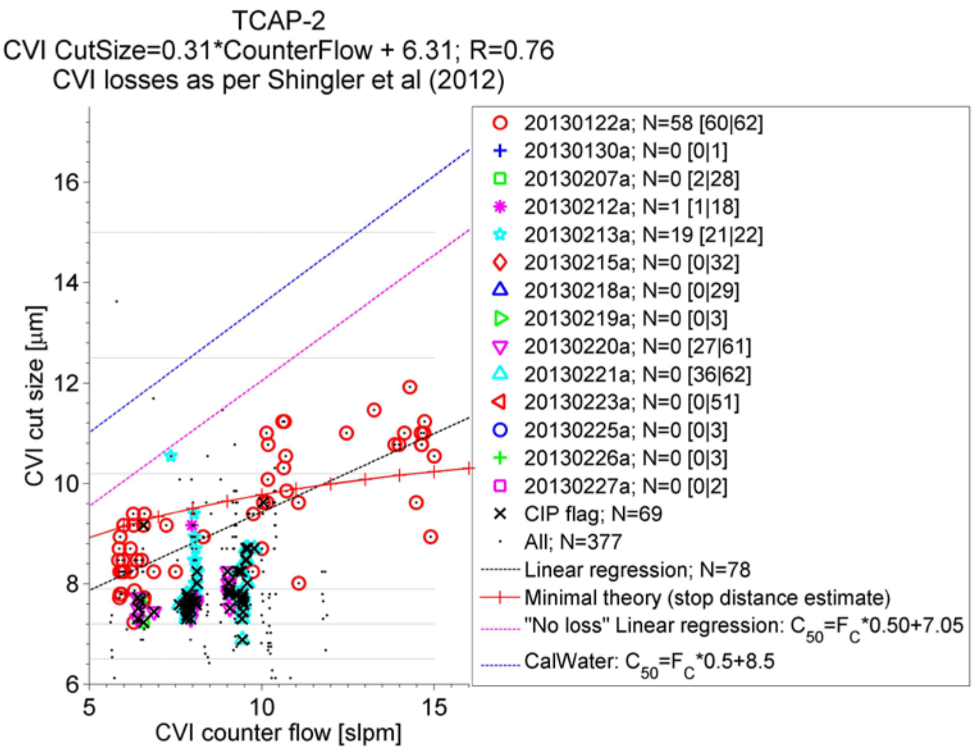

Figure 11. CVI cut size versus CVI counter flow with particle loss function from Shingler et al. (2012). All 1-min average estimates that passed air speed and "level flight" tests are plotted as black dots (not sorted by the flight). Number of dots for every flight is listed in the legend (second number in the brackets). Colored markers show data that passed level flight/air speed and minimal droplet number test sorted by the flight (first number in the brackets). Black "x" mark data that failed large droplet test. Linear regression was calculated for the data that passed all tests. The first number in the legend (N=) is number of 1-min estimates that passed all tests. Red solid line with crosses represents theory estimate of minimal cut size. Blue dotted straight line represents linear regression obtained during the CalWater field campaign. Thin black dotted lines represent borders of CAS bin structure.

The theoretical estimate for the minimal C_{50} is presented in Figure 11 by a red solid line with crosses. The estimate was made using aerodynamic drag theory and stopping distance approach (following Anderson et al. 1993, using stopping distance relation from Hinds 1999) for minimal reasonable value of "additional length parameter" of 2 mm. Estimates for C_{50} corrected for particle losses are mostly below the theoretical minimum line, which is expected since particle losses are largely overestimated.

10.0 Setup and Operation of Instrument

The CVI head was mounted on the right-hand side of the aircraft on the first window below the isokinetic inlet. The mounting angle was set to 9.7° down to align the CVI tip with local flow in January 2013. Two or three filament-wound aluminum gas cylinders (with regulators, pressure gauges, and a safety valve) were used as a source of clean dry air for the Add Flow (see Figure 4). Two HEPA capsules were connected in series to ensure total removal of the particulate matter from the Add flow. Particle removal was verified by measuring particle concentration with a condensation particle counter (CPC; TSI 3010) at the two test ports. Because air coming from the compressed air bottle cooled during expansion to the regulated pressure, a piece of copper coil was used to heat it up to cabin temperature upstream of the Add Flow mass flow controller and Add Flow heater.

Sample air for the instrumentation was deviated from the CVI sample line via pick-offs (¾ tube with ¼" center line); the pick-offs were separated by approximately 3"-long ¾ SS tube. Sample flow was drawn by a dry scroll vacuum pump (IDP-3) mounted on the floor between the data and aerosol racks.

The CVI data are transmitted via RS-232 interface. The control box also controls the heating elements on the pylon and CVI tip used to protect the CVI from icing.

Data collection from the most part of probes and sensors on board of G-1 is performed with the M300, onboard data collection system. Therefore, all data processing was made in its timeframe with appropriate time adjustments applied to the datastreams collected by other computers.

Concentration of cloud element residue particles in the CVI sample line was measured by a CPC (TSI 3010) and an OPC (house build).

11.0 Software

The CVI software is a LabView standalone application written and built with LabView (several versions used over the years) that requires appropriate LabView Runtime Engine and VISA drivers installed on the imbedded computer. The most relevant parameters in the CVI configuration file are directories for data and log file storage ([File Paths] section) and flow settings (Total Sample and Instrument Sample Flows, [Air Flow] section). Since the Total Sample Flow cannot be changed at runtime, it should be set to the desired value in the configuration file. The Instrument Sample Flow (the flow that is used by the instrumentation) can be corrected on the fly, but it is advisable that it to be set to anticipate the value in the configuration file. It is very important to set these flows right, since the CVI software determines the flow set point for the Sample Flow MFC as the difference between the Total Sample Flow and the Instrument Sample Flow. An incorrect setting of these flows will result in incorrect counterflow, which determines the CVI cut size. It should be noted that Brechtel use 15 LPM as default value for the Total Sample Flow while AAF uses 7.5 LPM.

12.0 Calibration

The calibration procedures and records are maintained by the instrument mentor.

13.0 Maintenance

The inlet should be cleaned before every campaign. This is suitable enough for most sampling regimes, though an accelerated cleaning schedule is recommended for environments with particularly heavy aerosol loadings, such as flying through smoke.

Two test ports (upstream and downstream of the Add Flow heater) are used to check for leaks and to ensure no aerosol particles are introduced into the Add Flow from the heater, or passed through the filters from the gas bottles. Both ports were made of standard Swagelok Ts.

14.0 Safety

Not applicable. Inlet installed at a height such that operators on the ground should be clear of the inlet at all times.

15.0 Citable References

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