Sonoma Technology, Inc.
1360 Redwood Way, Suite C
Petaluma, CA 94954-1169
707/665-9900
FAX 707/665-9800
www.sonomatech.com

MEASUREMENTS MADE ALOFT BY TWO AIRCRAFT TO SUPPORT THE CENTRAL CALIFORNIA OZONE STUDY (CCOS)

FINAL REPORT
STI-900106-2131-DFR

By:
Martin P. Buhr
Donald L. Blumenthal*
Siana H. Alcorn

***Principal Investigator**

Sonoma Technology, Inc.
1360 Redwood Way, Suite C
Petaluma, CA 94954-1169

Prepared for:
San Joaquin Valleywide Air Pollution Study Agency
c/o Technical Services Division
California Air Resources Board
2020 L Street, Room 122
Sacramento, CA 95814

November 29, 2001

DISCLAIMER

The statements and conclusions in this report are those of the contractor and not necessarily those of the California Air Resources Board. The mention of commercial products, their source, or their use in connection with material reported herein is not to be construed as actual or implied endorsement of such products.

ACKNOWLEDGMENTS

The work described in this report was funded by the San Joaquin Valleywide Air Pollution Study Agency, a joint powers agency (JPA), as part of the Central California Ozone Study. The contract was administered by the California Air Resources Board. Mr. Don McNerny, Chief, Modeling and Meteorology Branch, was the Project Officer; and technical guidance for the project was provided by Dr. Saffet Tanrikulu.

This page is intentionally blank.

ABSTRACT

During the summer of 2000, the Central California Ozone Study (CCOS) was conducted to update aerometric databases for ozone episodes in Central California and to quantify the contributions of interbasin transport to exceedances of the ozone standards in neighboring air basins. Two of six CCOS sampling aircraft were operated by Sonoma Technology: a twin-engine Piper Aztec and a single-engine Cessna 182. The Aztec was based in Santa Rosa and performed boundary measurements of aloft air quality and meteorology offshore from north of Santa Rosa to Paso Robles and in the northern end of the San Joaquin Valley. The Cessna was based in Bakersfield and performed measurements of aloft air quality and meteorology primarily within the San Joaquin Valley north to Modesto and west to Paso Robles. These data are part of the CCOS data archive for use in further analysis and modeling.

This page is intentionally blank.

TABLE OF CONTENTS

This page is intentionally blank.

LIST OF FIGURES

LIST OF FIGURES (Concluded)

LIST OF TABLES

EXECUTIVE SUMMARY

ES.1 BACKGROUND

From July through mid-September, 2000, the Central California Ozone Study (CCOS) was conducted to provide information on boundary conditions and the three-dimensional distribution of ozone and its precursors in the San Joaquin Valley (SJV). Sonoma Technology, Inc. (STI) was selected by the California Air Resources Board (ARB) to perform measurements of aloft air quality and meteorology over water on the western boundary of the study domain, in the SJV, and on one occasion in the Sacramento Valley. Two instrumented aircraft were flown by STI: a Piper Aztec based in Santa Rosa, California, and a Cessna 182 based in Bakersfield, California. Data collected during airborne sampling by both aircraft will provide information on boundary conditions and the three-dimensional distribution of ozone and its precursors in the study domain. The data will be used for (1) model input and evaluation, (2) documenting aloft layers and estimating their effects on surface concentrations, and (3) improving current understanding of tropospheric ozone formation and transport mechanisms within the study domain.

CCOS was sponsored by the San Joaquin Valleywide Air Pollution Study Agency and is part of the Central California Air Quality Studies (CCAQS). CCOS contracts were administered by the ARB.

ES.2 METHODOLOGY

A total of 38 sampling missions (flights) were performed on 15 days between July 5 and September 20, 2000, between the two aircraft. Continuous measurements made by sampling systems on both aircraft included ozone, oxides of nitrogen (NO and NO_y), light scattering (b_{scat} using integrating nephelometry), temperature, relative humidity, altitude, and position. Separate sampling systems were used to collect integrated grab samples for subsequent hydrocarbon and carbonyl analysis. In addition, continuous measurements of carbon monoxide (CO) concentration were made on Aztec. The NO/NO_y, ozone, and CO monitors were audited by the Quality Assurance Section of the ARB. Other quality control (QC) activities included extensive calibrations between flight days and intercomparisons with other aircraft and with surface monitoring stations.

The ARB CCOS management team selected the sampling days and routes to be flown. Typically, each of the aircraft flew two flights on each Intensive Operation Period (IOP) day. The aircraft followed flight routes designed to characterize the flux of ozone and ozone precursors into and through the study domain. At the beginning of an IOP, the Aztec usually followed a route along the Western Boundary of the study domain in the morning (dolphin patterns approximately 100 miles offshore from Santa Rosa to Paso Robles), followed in the afternoon by a coastal flight route (dolphin patterns approximately 10 to 15 miles offshore from Paso Robles to Santa Rosa). On subsequent days, the Aztec flight routes typically consisted of a series of traverses and spirals in the northern part of the SJV from Santa Rosa to Modesto. The afternoon route for these days was a series of traverses and spirals between Modesto and Santa

Rosa. The usual flight route for the Cessna involved a series of traverses and spirals north from Bakersfield to Modesto in the morning and similar patterns in the afternoon proceeding south from Modesto to Bakersfield. On the days when the Aztec was scheduled to fly to Modesto, the Cessna flight route focused on the southern end of the SJV, using Paso Robles as the midday airport.

ES.3 RESULTS AND RECOMMENDATIONS

The air composition and meteorology observations made with the STI aircraft during CCOS comprise a useful database for further exploration of transport and chemical processes in the SJV and upwind regions. The greatest utility of the Aztec data may be in establishing limits on the upwind boundary conditions. The observations made with the Cessna will be useful in exploration of the transport processes and chemical evolution attendant to ozone episodes in the SJV.

Highlights of the observations made with the Aztec include

- High quality data for ozone, NO, NO_y, CO, b_{scat}, and winds collected offshore at altitudes from 500-5000 ft. under a variety of conditions.
- Persistent layers of ozone concentration greater than 50 ppbv in air masses coming from the Pacific Ocean.
- Significant transport of pollutants from onshore sources to points 100 miles offshore. Preliminary evaluation of the air composition in these polluted layers suggest a forest fire source.

Highlights of the observations made with the Cessna include

- Excellent temporal and spatial coverage of the southern SJV during the two principal ozone episodes experienced during summer 2000.
- Good spatial and chemical characterization of the Fresno and Bakersfield urban plumes and their transport to the greater valley.
- Multi-day repetitive flight patterns that will allow exploration of the physical and chemical conditions associated with SJV-wide ozone episodes.

In addition to providing a database useful for model evaluation, these observations could be used to investigate a number of specific topics:

- Compare and contrast ozone distribution and ozone production efficiency at the surface and aloft for the Bakersfield, Fresno, and Angiola field sites.
- Examine rural ozone in the SJV with respect to sources of precursors, dynamics, and local production versus advection
- Contribution of forest fires to SJV ozone and particulate matter.

1. INTRODUCTION

During summer 2000, the California Air Resources Board (ARB) sponsored the Central California Ozone Study (CCOS) as part of the Central California Air Quality Studies (CCAQS). The overall objectives of CCOS were to develop a technical/scientific foundation that will enable meeting the following needs:

- Planning to effectively meet the new ozone and PM standards throughout central California – developing a control strategy that is likely to accomplish this goal and doing so using approaches that are expected to be effective and reliable.
- Assessing the likely impacts of urbanization and development and the introduction of new emissions and emissions controls.
- Providing insight into the relative contributions of local versus transported pollutants and the implications for emissions controls.
- Acquiring an aerometric data base suitable for use in modeling and analysis in support of a year 2003 SIP submission for ozone.

An airborne sampling program was conducted during CCOS to document the three-dimensional distribution of ozone, ozone precursors, and meteorological variables. The data obtained will be used to

- Characterize aloft boundary and initial conditions.
- Document spatial and temporal ozone and precursor patterns in aloft layers.
- Document the mixing depth.
- Estimate transport through "flux planes" for model evaluation and corroborative transport assessment.

The data analyses are not part of this contract.

Upper-air air quality measurements were made by six aircraft. The Department of Energy operated a Gulfstream-1 (DOE G-1); the University of California at Davis (UCD) operated two single-engine Cessna aircraft; the Tennessee Valley Authority operated a Twin Otter; and Sonoma Technology, Inc. (STI) operated a Piper Aztec and a Cessna 182. This report describes the operations associated with and data collected aboard the STI aircraft and provides summary information of the observations collected during CCOS over the western boundary of the study domain off the northern California coast and within the San Joaquin Valley (SJV). During the CCOS sampling program, the STI Aztec performed boundary condition measurements of aloft air quality and meteorology in the western regions of the CCOS study domain, in the northern end of the SJV, and on one occasion in the Sacramento Valley. The aircraft was based at the Santa Rosa airport. The STI Cessna 182 performed measurements of aloft air quality and meteorology throughout the southern half of the SJV. It was based at the Bakersfield airport.

Continuous measurement data collected during STI sampling flights were processed, edited, and reported to the ARB in a two-volume data report entitled "Central California Ozone Study Aircraft Data" (Buhr et al., 2001). The data report details the sampling that was performed and displays plots of the data collected by the continuous sensors aboard the two aircraft. Electronic copies of the final processed data set were also delivered to the ARB as part of the data report.

Integrated grab samples for volatile organic compounds (VOCs) and carbonyl analyses were collected during most flights. Details of the collection of these samples were included in the data report. The grab samples were delivered to other contractors who were responsible for analyzing the samples and reporting the analytical results.

2. OVERVIEW OF THE STI AIRBORNE SAMPLING PROGRAM

STI operated two aircraft during the airborne sampling program: an Aztec and a Cessna 182. The STI Aztec, shown in **Figure 2-1**, was based at the Santa Rosa airport from July 6 through September 19, 2000. Secondary bases of operation were maintained at the Modesto and Paso Robles airports. The STI Cessna, shown in **Figure 2-2**, was based at the Bakersfield airport from July 6 through September 20, 2000. The Cessna also used the same secondary bases of operation. The on-site crew for each aircraft consisted of a pilot, an instrument operator, and a calibration technician.

A total of 38 sampling missions (flights) were performed on 15 days between July 5 and September 20, 2000, between the two aircraft. Continuous measurements made by sampling systems on both aircraft included ozone, oxides of nitrogen (NO and NO_y), lightscattering (b_{scat} using integrating nephelometry), temperature, relative humidity, altitude, and position. Separate sampling systems were used to collect integrated grab samples for subsequent hydrocarbon and carbonyl analysis. In addition, continuous measurements of carbon monoxide (CO) concentration were made from the Aztec platform. The NO/NO_y, ozone, and CO monitors were audited by the Quality Assurance Section of the ARB. Other quality control (QC) activities included extensive calibrations between flight days and intercomparisons with other aircraft and with surface monitoring stations.

Audits of the NO/NOy and ozone monitors operated aboard the aircraft were performed before the start of sampling activities on June 19 and July 3, 2000. Preliminary results were reported to STI by the ARB audit team. The results indicated the instruments were operating normally and within quality assurance (QA) control limits established by the ARB.

After ARB audits had been completed on both STI aircraft and the UCD Cessna 182, the three aircraft performed an inter-comparison flight around Sacramento on July 6, 2000. The data collected were shared between the two groups and delivered to Mr. David Bush. Mr. Bush's review of the data will be submitted in a separate report.

Another inter-comparison flight was made by the Aztec with the DOE G-1 near Fresno on July 5, 2000. The STI data from the inter-comparison flight with the DOE G-1 were processed and delivered to Mr. David Bush.

Figure 2-1. The STI Piper Aztec used during the CCOS sampling program.

Figure 2-2. The STI Cessna and flight crew during the CCOS sampling program.

The CCOS management team selected the sampling days and routes to be flown. Typically, each of the STI aircraft flew two flights on each Intensive operation period (IOP) day. The aircraft followed flight routes designed to characterize the flux of ozone and ozone precursors into and through the study domain. At the beginning of an IOP, the Aztec usually followed a route along the western boundary of the study domain in the morning (dolphin patterns approximately 100 miles offshore from Santa Rosa to Paso Robles), followed in the afternoon by a coastal flight route (dolphin patterns approximately 10 to 15 miles offshore from Paso Robles to Santa Rosa). On subsequent days, the Aztec flight routes typically consisted of a series of traverses and spirals in the northern part of the SJV, landing at Modesto. The afternoon route for these days was a series of traverses and spirals in the northern SJV and southern Santa Clara Valley, landing at Santa Rosa. The usual flight route for the Cessna involved a series of traverses and spirals north from Bakersfield to Modesto in the morning and similar patterns in the afternoon proceeding south from Modesto to Bakersfield. On the days when the Aztec was slated to fly to Modesto, the Cessna flight route focused on the southern end of the SJV, using Paso Robles as the midday airport.

Instruments aboard the aircraft were calibrated the night before the start of an IOP. When the aircraft returned after a day of sampling, the instruments were calibrated again. This routine was performed each day of an IOP.

On a typical sampling day, the aircraft would depart from the home airport (either Santa Rosa or Bakersfield) at about 0430 Pacific Standard Time (PST). It would sample along a pre-selected route through the study domain according to the scenarios described above. Depending on which route was flown, the flights would end at either the Paso Robles or Modesto airport (secondary bases). The carbonyl bags collected during the morning flight were processed through dinitrophenylhydrazine (DNPH) cartridges that were subsequently stored in the aircraft in a cooler with ice-packs. In the afternoon, the aircraft would depart from the secondary base between 1300 to 1400 PST and sample along a route through the study domain different from that of the morning flight. The afternoon flight would end at the home airport.

When the aircraft landed at the home base, the carbonyl grab sample bags and VOC sample canisters were retrieved by either the flight instrument operator or ground personnel; the carbonyl bags processed through DNPH cartridges; and both sample types archived for eventual distribution to the appropriate contractors. The flight crew would notify the aircraft program manager by phone that they had landed. Data discs from the aircraft were copied and flight notes verified. Data processing was initiated, and preliminary reviews of the data were performed during the evening hours. The flight crew also relayed information concerning what they had seen during sampling to the STI program manager. This debriefing normally occurred about 0830 PST.

Processing of the continuous data collected during the sampling flights was continued at the STI office facilities. A two-volume data report (Buhr et al., 2001) was delivered to the ARB in August 2001.

3. DESCRIPTION OF MEASUREMENTS

The aircraft characteristics, their instrument configurations, and the various sampling systems aboard the aircraft are documented in the following sections. Also provided are summaries of the dates and times of sampling flights. The summaries identify the flight routes flown and the number of grab samples collected during each flight. Maps are provided that show the typical sampling routes, and tables are provided that identify each sampling location.

3.1 AIRCRAFT

The STI Piper Aztec (Figure 2-1) is a model PA23-250 twin engine, low-wing aircraft with retractable landing gear. This aircraft was chosen as an air quality sampling platform because of its stable flight characteristics, available electrical power, load-carrying capabilities, and normally low maintenance requirements. In addition, the Aztec can sample for periods of up to four and a half hours. The aircraft has been operated on similar air quality sampling programs since 1985.

The STI Cessna 182 (Figure 2-2) was leased for the CCOS program and fitted with instrument racks and a window-based inlet system to accommodate the sampling instruments.

Each aircraft was equipped with a radar transponder. This allowed Federal Aviation Administration (FAA) flight controllers to determine the position of the aircraft and also provided controllers with a direct readout of the aircraft's altitude (a feature called “Mode C”). These features were required by the FAA in order to coordinate patterns flown by the research aircraft with other air traffic.

Both aircraft were operated in FAA-designated “Restricted Category”. This designation was necessary because of modifications made to the aircraft during installation of sampling equipment. When an aircraft is operated in a restricted category, flight operations over populated areas and at airports providing commercial services are either limited or prohibited unless special operating permits (waivers) are obtained from the FAA. Due to program sampling requirements, waivers were required. The necessary waivers were obtained before the start of the sampling program. The aircraft were inspected and certified for use in this category by the FAA.

Flight plans were reviewed with the appropriate FAA authorities, and all sampling was coordinated with the FAA.

3.2 INSTRUMENTATION

Table 3-1 lists the continuous sampling equipment operated aboard STI’s Aztec and Cessna. The table lists the equipment model and manufacturer, the analysis technique, instrument ranges available for use, the approximate response time to 90%, and the approximate resolution of each instrument. Several instruments aboard the Aztec were not required by the contract.

Table 3-1. Sampling instrumentation operated aboard the STI Aztec and Cessna aircraft.

Parameter	Sampler Manufacturer and Model	Analysis Technique	Normal Measurement Ranges (Full Scale)	Time Response (to 90%)	Approximate Lower Quantifiable Limit
NO/NO_y	Thermo Environmental Model 42S	Chemiluminescence	50,100,200, ppb	< 20 sec.	0.1 ppb
O_3	Monitor Labs 8410E	Chemiluminescence	200, 500 ppb	12 sec.	2 ppb
CO[a]	Thermo Environmental Model 48	Gas filter correlation Non-dispersive IR	10,20 ppmv	< 20 sec.	50 ppbv
b_{scat} (light scattering)	MRI (Aztec) and Radiance Research (Cessna)	Integrating nephelometer	100,1000 Mm^{-1}	1 sec. (Aztec); 2 sec (Cessna)	5 Mm^{-1}
Dew Point[a]	Cambridge Systems 137-C	Cooled Mirror	-50 to 50^oC	0.5 sec./^oC	0.5^oC
Altitude	II-Morrow	Altitude Encoder	0 - 5000 m msl	1 sec.	1 m
Relative Humidity	AIMMS-10	Solid state sensor	0-100 %	6 sec.	1%
Temperature	AIMMS-10	Platinum Resistance	-50 to +50^oC	3 sec.	0.1^oC
Broad Band Radiation [a,b]	Epply	Pyranometer	0 - 1026 W m-2 Cosine Response	1 sec.	2 W m^{-2}
Ultraviolet Radiation [a,b]	Epply	Barrier-Layer Photocell	295 - 385 nm 0 - 34.5 W m^{-2} Cosine Response	1 sec.	0.1 W m^{-2}
Position	Garmin 250-Aztec Garmin 295-Cessna	GPS	Lat.-Long.	< 1 sec.	50 m
Winds	AIMMS-10	Calculated from GPS, heading, airspeed	0-360 deg (true) 0-50 m/s	1 sec.	1 ms^{-1} / 5 deg.
Data System	STI Pentium System		$\pm$ 9.99 VDC Disks & Hard Disk	Records data 1 s^{-1}	.005 VDC
ROG/Carbonyl	Grab samples collected using Oregon Graduate Institute and AtmAA, Inc. supplied media and systems				

[a] This instrument was included in the STI Aztec package only.
[b] These instruments were installed on the aircraft and operated, but they were not required by the contract and they were not rigorously calibrated. Data from these sensors have been edited, but STI does not warrant the accuracy of the reported data.

These instruments were operated and their data processed although they were not calibrated. These instruments are also identified in Table 3-1. Data from these instruments were included in the aircraft database, but their data should be used with caution. All required measurements were processed, quality controlled, and reported as “Level 1” quality controlled data.

As shown in Table 3-1, grab samples to be analyzed for VOC and carbonyl concentrations were also collected aboard the aircraft. The collection media and sampling systems were provided by Oregon Graduate Institute and AtmAA, Inc., respectively.

3.3 SAMPLING SYSTEMS

3.3.1 Access to Ambient Air

Figure 3-1 shows the air inlets and sensors on the outside left side of the Aztec. Access to ambient air for the instruments is provided by the three aluminum tubes installed one above the other in a replacement plate fitted to the aircraft window. The purpose of these tubes is to provide access to ambient air. However, as described below, sampled air does not come in contact with the aluminum, except for the air to the nephelometer in the Aztec. The particles sensed by the nephelometer are not affected by contact with the inlet. The tubes are 1-3/4 in. in diameter, extend about 6 in. beyond the skin of the aircraft, and face forward into the airstream. The inlet to each access tube is nearly even with the front of the wing. Exhaust from the aircraft engines exits the engine nacelles under the wing near the trailing edge, well away from the sample inlets.

Figure 3-2 is a schematic drawing of the sample air access systems used for ozone, VOC, and carbonyl sampling. The drawing shows that the top access tube was used for cooling and ventilation of sampling equipment inside the aircraft. The center tube in the Aztec was used for the nephelometer. Sample air for ozone, CO, carbonyl, and VOC sampling was obtained using Teflon tubes strung through the bottom access tube. Two 3/8-in. outer diameter (o.d.) and one 1/4-in. o.d. Teflon sample inlet lines were inserted through the bottom access tube in the window plate. These sample lines were used to deliver sample air used by the ozone analyzer, the CO instrument, the VOC sampling system, and the carbonyl (bag) sampling system. The outside ends of the Teflon lines extended slightly beyond the forward edge of the access tube (Figure 3-1) and were thus exposed directly to ambient air. During flight, airflow through the Teflon lines and access tubes was provided by ram air pressure. The Aztec nephelometer sample was delivered from the aluminum tube to the nephelometer with 1-3/4-in. i.d. flexible tubing.

To address concerns about losses of oxides of nitrogen species in long sampling lines, thus reducing sampler sensitivity to NO_y species, a special sample inlet system was designed, built, and installed on both aircraft. The outside portion (NO/NO_y inlet) can be seen in Figure 3-1. An engineering design drawing of the NO_y inlet system is shown in **Figure 3-3**.

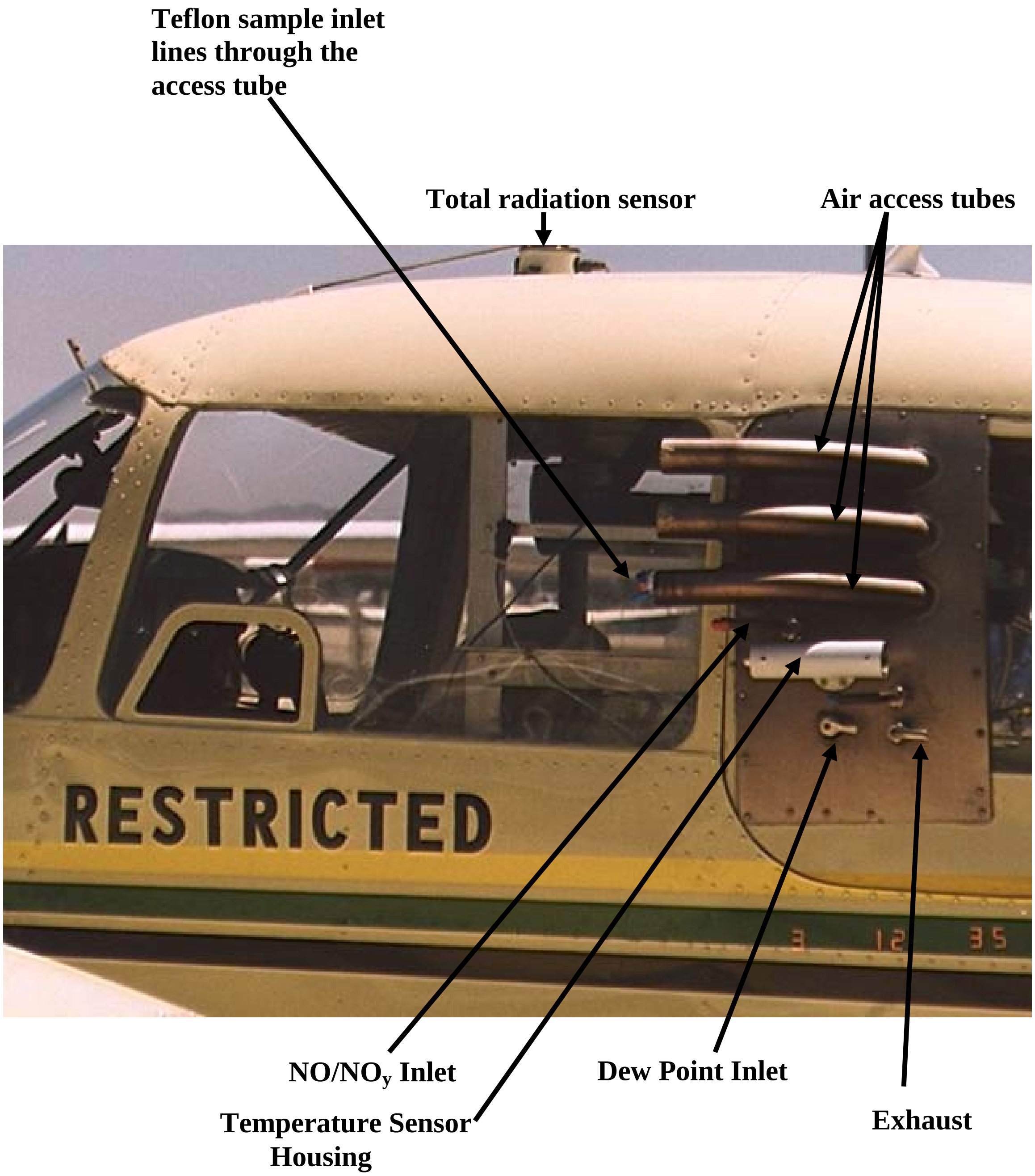


Figure 3-1. Sensor location and sample air inlet systems on the Aztec.

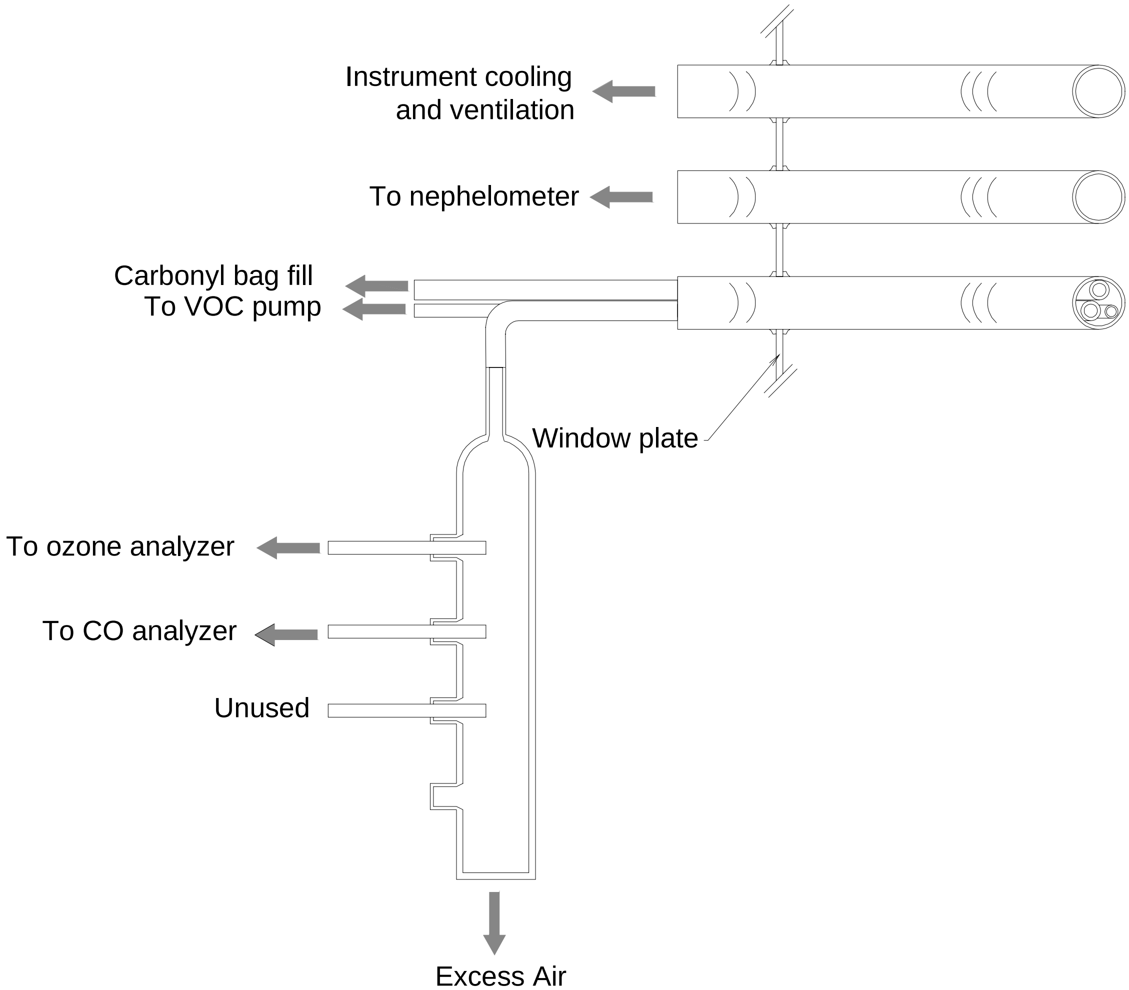


Figure 3-2. A schematic drawing of the sample delivery systems used for ozone, CO, VOC, and carbonyl sampling (as viewed from the front looking back along the right side of the aircraft).

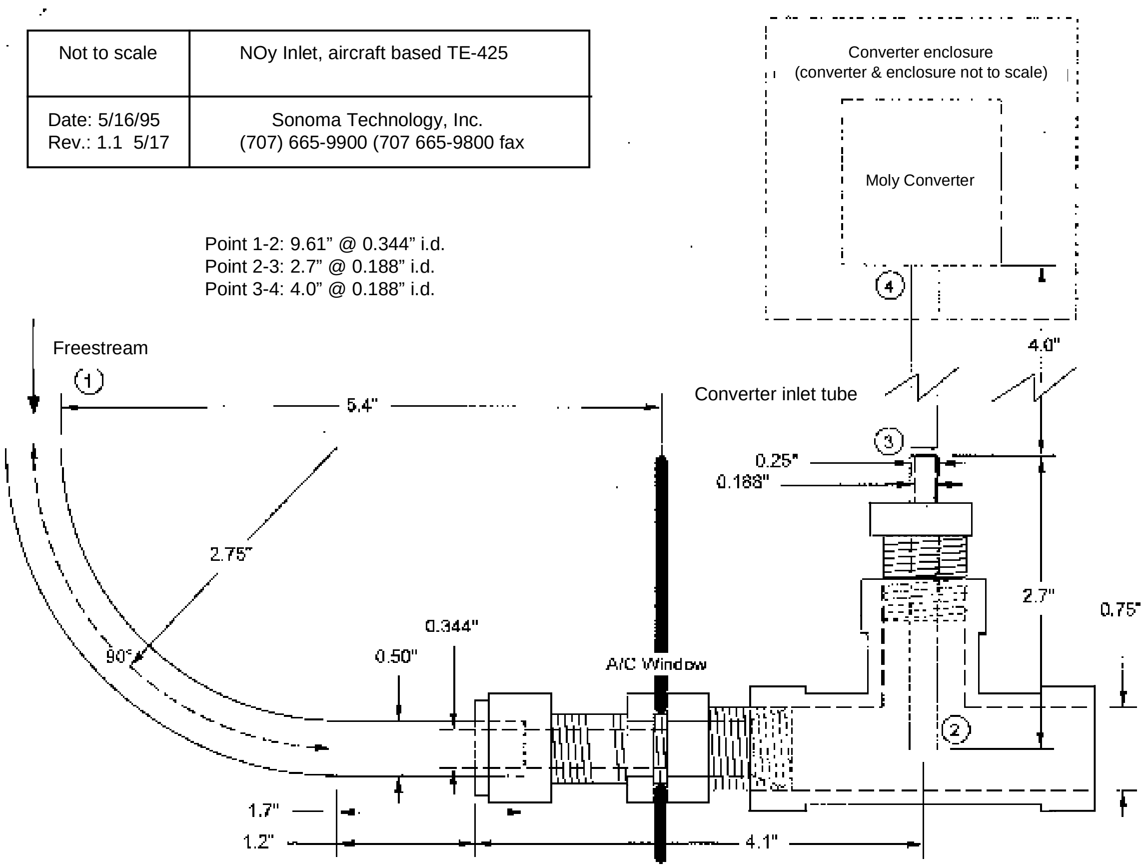


Figure 3-3. An engineering design drawing of the NO_y inlet system used on the STI Aztec and Cessna 182.

The objective of the NO_y inlet design is to prevent absorption of highly reactive species by the wall of the sampling inlet tube by reducing the length of the sampling line from the sample inlet to the NO_y converter. This was accomplished by utilizing a modified NO/NO_y analyzer (TECO 42S after modification) with a removable NO_y converter. The converter was mounted on the inside of the window plate to bring it as near as possible to the sample inlet. Sample air was provided to the converter by means of a Teflon-coated stainless steel inlet tube, a short Teflon-coated stainless steel manifold, and a short, heated stainless steel sample tube to the converter itself.

Transmission of HNO_3 (nitric acid) through the NO_y inlet was not evaluated. However, the Teflon-coated surfaces and short residence time in the inlet are expected to lead to effectively quantitative transmission. The total residence time of the sample in the inlet system was approximately 200 msec . In addition to this short residence time, the portion of the inlet from the manifold (point 3 in Figure 3-3) to the converter (point 4 in Figure 3-3) was stainless steel heated by excess heat generated in the converter core and conducted throughout the length of the inlet tube. Temperatures along the converter inlet tube inside the aircraft were approximately 45-60°C. The converter itself was operated at 350°C. A Teflon particle filter was placed in the NO_y sample line downstream of the converter. NO was sampled from the side-port of an additional Teflon-coated stainless steel tee attached downstream of the NO_y tee (point 2 in Figure 3-3).

The inlet tube for the NO_y systems was removable. Periodically, the tube was removed and cleaned.

The inlet system used on the Cessna 182 aircraft was similar in design to that described for the Aztec. The sample inlets were fitted through holes bored in the right side rear window and included a NO/NO_y inlet identical to the Aztec inlet and two 1-in. o.d. aluminum tubes. One of the aluminum tubes served as the nephelometer inlet, coupled to the nephelometer with flexible tubing, and the other aluminum tube held the 3/8-in. and 1/4-in. Teflon sample lines for the ozone monitor, carbonyl, and VOC sample lines.

The exhaust for the Cessna 182 was pushed under the aircraft and up the left side, away from the sample inlets. Sampling in clean air confirmed that there was no exhaust contamination on the Cessna 182.

3.3.2 Sample Delivery Systems

Continuous sensors

One of the 3/8-in. inlet lines (discussed in Section 3.3.1) was used to provide sample air to a glass manifold from which the ozone (and, in the Aztec, CO) monitors sampled. The manifold consisted of a 3/8-in. inlet into a glass expansion chamber (Figure 3-2) measuring 9 in. in length by 1 in. in diameter. Three 1/4-in. static sample ports were attached to the side of the expansion chamber. Volume expansion inside the chamber slowed the incoming sample airflow. A Teflon sampling line from the ozone monitor was connected to the first port (nearest the manifold inlet). The second port in the Aztec was attached to the CO instrument, and the third port was not used. Excess air from the glass manifold was vented into the cabin of the aircraft. The ozone monitor was operated using a Teflon particle inlet filter.

Two 1/4-in. o.d. Teflon sample lines delivered sample air from the inlet system directly to the NO/NO_y analyzer. The sample lines were cut to the same length in an attempt to time-match recorded concentration values.

All connections used Teflon fittings. Thus, for the gas analyzers, an incoming air sample was only in contact with Teflon, stainless steel, or glass, from the atmosphere to the inlet of a sampling instrument.

VOC grab sampling

The VOC sampling system was provided by the Oregon Graduate Center and consisted of

- A 2.4-m (8 ft) length of 1/4-in.-diameter Teflon sample inlet tube,
- One KNF Neuberger pump (DC voltage),
- A Veriflo flow regulator with a preset 25 psi back pressure,
- A 1.8-m (6 ft) length of 6.5-mm Teflon sample delivery tubing,
- A two-way toggle valve and pressure gauge assembly (called a "purge tee"), and
- 1.5-liter stainless steel canisters.

The sampling system was configured so that the entire sample line up to the canister could be flushed with ambient air prior to collecting a sample. To collect a sample, the purge tee was closed and the canister valve opened. Sample collection took about 30-45 seconds and was complete when the canister pressure was about 25 psig.

As described in Section 3.3.1 and shown in Figure 3-2, the 1/4-in. o.d.Teflon sample inlet tube was inserted through the bottom access tube in the sampling window. The other end was connected to the VOC pumps. The pumps supplied air through the flow regulator and sample delivery tubing to the purge tee. The position of the toggle valve on the purge tee allowed sample air to be either exhausted into the aircraft cabin or directed into the sample canister.

The flow regulator was adjusted to fully pressurize a canister in less than one minute. Since bag and VOC samples were collected together, this fill rate was selected to match the fill time for bag samples (discussed below).

During flight, the pump was run continuously to purge the sampling system. Whenever the aircraft was on the ground, the VOC system was sealed on both ends to avoid contamination. Essentially identical VOC sampling systems were used on both the Aztec and Cessna 182 aircraft.

Carbonyl grab sampling

The system for grab bag collection was provided by AtmAA, Inc. and consisted of a 1.2-m (4-ft) length of 3/8-in. o.d. Teflon tubing that was inserted through the bottom access tube on the sampling window. The inlet tubing terminated in a two-piece reduction assembly consisting of 3/8-in. o.d. tubing and 1/4-in. o.d. tubing telescoped together.

The 40-liter-volume sample bags were constructed of 2-mil Tedlar material. The inlet on each bag was a “Push to Open - Pull to Close” type stainless steel valve. The bag valve was connected to the sample line by a snug friction fit between the valve and the tubing. The bag was filled using ram air pressure. When the system was not sampling, air flow through the inlet tubing provided a continual purge of the system.

After an air sample was collected aboard the aircraft and the sample bag had been disconnected from the sampling system, the sample bag was placed inside a larger dark opaque plastic bag. These bags were used to inhibit photochemical reactions in the sample bags until the contents could be collected onto DNPH cartridges post-flight. Typically, these sample transfers were completed within about an hour of receiving the bag samples. The DNPH cartridges were stored in a cooler except during sample transfer.

Sample bags were reused after ground-based transfer operations had been completed. Conditioning of bags prior to use (or reuse) was performed by STI personnel and included multiple flushes of the bags with zero air, followed by injection of about 10 mL of 1000 ppmv NO in nitrogen (N_2) into the deflated bag. The purpose of the NO was to provide a preferential species for ambient ozone to oxidize once a sample was collected, thus minimizing oxidation of the target carbonyl species.

Again, the sampling system and sample handling procedures were identical for the Aztec and Cessna 182 aircraft.

3.4 SENSOR MOUNTING LOCATIONS

The sensors aboard the aircraft can be divided into two groups: external- and internal-mounted sensors.

3.4.1 External-mounted Sensors

The primary temperature probe used aboard the Aztec was mounted on the outside of the sampling window plate. The vortex housing assembly that contained the bead thermistor sensor is shown in Figure 3-1. Holes drilled through the sampling window provided electrical access to the sensor. A secondary (back-up) temperature probe was mounted under the right wing of the aircraft.

Dew point, turbulence, ultraviolet radiation, and total radiation were also measured. The inlet system for the dew point sensor was mounted on the outside of the sampling window (Figure 3-1), and the sensor head itself was mounted on the inside of the window. The turbulence sensor was mounted under the left wing.

Ultraviolet and total radiation sensors were mounted on the top of the aircraft cabin. Because of their placement, data from these two sensors were subjected to antenna wire shadows, varying aircraft attitudes, and radio transmission interference. Though not part of the required data set, these sensors were operated but they were not calibrated. Their data were edited but STI does not warrant the accuracy of the reported data.

Both the Aztec and the Cessna 182 used an AIMMS-10 wind instrument. On the Cessna, the AIMMS-10 was mounted on the left side wing strut. On the Aztec the AIMMS-10 was mounted underneath the right wing, outboard of the engine.

3.4.2 Internal-mounted Sensors

In the Aztec, the continuous real-time air quality sensors, data acquisition system (DAS), and associated support equipment were mounted in instrument racks installed on the left side of the aircraft cabin, behind the pilot. In the Cessna 182 the DAS and other ancillary equipment was mounted in the instrument rack on the right side of the aircraft.

For both the Aztec and Cessna 182, the primary altitude data were obtained from an encoding altimeter mounted under the aircraft's instrument panel and connected to the aircraft's static pressure system. In the Aztec a secondary (back-up) measurement of altitude was provided by a Validyne pressure transducer mounted in the rear left of the aircraft cabin. Both were connected to outside static air points.

Aztec position data were obtained from a Garmin Model 250 GPS receiver mounted in the aircraft's instrument panel. The digital output from this unit was fed into the on-board DAS. A similar system was employed in the Cessna, using a yoke-mounted Garmin 295 GPS.

3.5 INSTRUMENT EXHAUST SYSTEM

Although the exhaust system of typical air quality instruments contains some provision for scrubbing exhaust gases, airborne safety and the integrity of the sampling being performed requires additional safeguards. For example, the ozone monitor used aboard the aircraft required a steady supply of ethylene (C_2H_4). It is possible that some excess C_2H_4 could have remained in the instrument's exhaust, which could have interfered with VOC measurements if the exhaust was not properly vented. To avoid potential problems, the exhaust streams from all analyzers were combined using an exhaust manifold that vented outside the aircraft. The exhaust tube (external portion of the system) can be see in Figure 3-1. Instrument exhaust gases were pumped out of the cabin and exhausted well aft of sensor inlet systems.

3.6 SUMMARY OF FLIGHTS, TIMES, AND ROUTES

The CCOS management team selected the sampling days and routes to be flown. Typically both the Aztec and Cessna flew two flights on each selected day. Between the two aircraft, a total of 38 sampling missions (flights) were performed on 15 days between July 5 and September 20, 2000. .

Tables 3-2 and **3-3** summarize the date, sampling period, flight route, and number of VOC and carbonyl samples collected during each CCOS flight for the Aztec and Cessna 182, respectively. Each flight was assigned an identifying name that is also shown in the table. Details of each flight are presented in the two-volume data report that was delivered to the ARB.

Table 3-2. Summary of STI Aztec sampling flights during CCOS.

Flight ID	Date	Departure Time (PST)	Landing Time (PST)	Route	Flight Plan[a]	VOC/Carbonyl Samples Collected
AI-1	7/5/00	13:51	15:29	Intercomparison with DOE G-1	N/A	N/A
AI-2	7/6/00	13:00	15:20	Intercomparison with STI and UCD Cessnas	N/A	N/A
A1	7/8/00	7:56	11:58	Santa Rosa – Paso Robles	A-1 (Far offshore)	4/5
A2	7/8/00	15:29	19:03	Paso Robles – Santa Rosa	A-2 (Coastline)	4/4
A3	7/23/00	6:46	10:57	Santa Rosa – Paso Robles	A-1 (Far offshore)	4/4
A4	7/23/00	13:17	17:11	Paso Robles – Santa Rosa	A-2 (Coastline)	4/4
A5	7/24/00	4:37	8:49	Santa Rosa – Modesto	A-4 (SJV)	4/4
A6	7/24/00	12:11	16:33	Modesto – Santa Rosa	A-5 (SJV)	4/4
A7	7/30/00	5:06	8:59	Santa Rosa – Paso Robles	A-1 (Far offshore)	4/4
A8	7/30/00	12:13	15:53	Paso Robles – Santa Rosa	A-2 (Coastline)	4/4
A9	7/31/00	4:32	8:14	Santa Rosa – Modesto	A-4 (SJV)	4/4
A10	7/31/00	12:08	16:25	Modesto – Santa Rosa	A-5 (SJV)	4/4
A11	8/1/00	11:55	16:26	Modesto – Santa Rosa	A-5 (SJV)	4/4
A12	8/14/00	5:16	6:03	Santa Rosa – Paso Robles[b]	A-1 (Far offshore)	4/4
A13	9/17/00	4:55	9:10	Santa Rosa – Paso Robles	A-1 (Far offshore)	4/4
A14	9/17/00	12:26	16:19	Paso Robles – Santa Rosa	A-2 (Coastline)	4/4
A15	9/18/00	4:55	9:19	Santa Rosa – Modesto	A-3 (N. Sacramento Valley)	4/4
A16	9/18/00	12:28	16:54	Modesto – Santa Rosa	A-5 (SJV)	4/4
A17	9/19/00	12:22	16:51	Modesto – Santa Rosa	A-5 (SJV)	4/4

[a] Flight plans are presented in Tables 3-4 through 3-8.
[b] Flight route aborted due to engine failure

Table 3-3. Summary of STI Cessna sampling flights during CCOS.

Flight ID	Date	Departure Time (PST)	Landing Time (PST)	Route	Flight Plan[a]	VOC/Carbonyl Samples Collected
C1	7/23/00	4:32	8:56	Bakersfield – Modesto	C-1	3/3
C2	7/23/00	12:21	16:31	Modesto – Bakersfield	C-2	3/3
C3	7/24/00	7:59	10:47	Bakersfield – Paso Robles	C-4	1/1
C4	7/24/00	12:20	16:47	Paso Robles – Bakersfield	C-5	3/3
C5	7/30/00	4:39	8:38	Bakersfield – Modesto	C-1	3/3
C6	7/30/00	12:30	16:30	Modesto – Bakersfield	C-2	3/3
C7	7/31/00	4:38	8:18	Bakersfield – Paso Robles	C-4	3/3
C8	7/31/00	12:35	14:55	Paso Robles – Bakersfield	C-5	1/1
C9	8/1/00	12:52	14:46	Modesto – Bakersfield	C-2	3/3
C10	8/14/00	5:25	9:22	Bakersfield – Modesto	C-1	3/3
C11	8/14/00	13:45	16:50	Modesto – Bakersfield	C-2	3/3
C12	9/14/00	4:50	9:10	Bakersfield – Modesto	C-1	3/3
C13	9/14/00	12:39	16:55	Modesto – Bakersfield	C-2	3/1
C14	9/17/00	4:49	7:19	Bakersfield – Mendota	C-1	1/1
C14	9/17/00	7:53	9:00	Mendota – Modesto	C-1	2/2
C15	9/17/00	12:42	16:50	Modesto – Bakersfield	C-2	3/3
C16	9/18/00	4:45	8:50	Bakersfield – Modesto	C-1	3/3
C17	9/18/00	12:34	16:50	Modesto – Bakersfield	C-2	3/3
C18	9/19/00	4:36	8:55	Bakersfield – Modesto	C-1	3/3
C19	9/19/00	12:40	16:55	Modesto – Bakersfield	C-2	3/3
C20	9/20/00	4:34	8:44	Bakersfield – Modesto	C-1	3/3
C21	9/20/00	12:32	16:42	Modesto – Bakersfield	C-2	3/3

[a] Flight plans are presented in Tables 3-9 through 3-13.

Tables 3-4 through 3-13 show the flight plans used by the Aztec (Tables 3-4 through 3-8) and the Cessna (Tables 3-9 through 3-13) during the various episode types. The aircraft followed flight routes designed to characterize the flux of ozone and ozone precursors into and through the study domain. At the beginning of an IOP, the Aztec usually followed a route along the western boundary of the study domain in the morning (dolphin patterns approximately 100 miles offshore from Santa Rosa to Paso Robles), followed in the afternoon by a coastal flight route (dolphin patterns approximately 10 to 15 miles offshore from Paso Robles to Santa Rosa). On subsequent days, the Aztec flight routes typically consisted of a series of traverses and spirals in the northern part of the SJV, ending at Modesto. The afternoon route for these days was a series of traverses and spirals in the northern SJV and southern Santa Clara Valley, ending at Santa Rosa. The usual flight route for the Cessna involved a series of traverses and spirals north from Bakersfield to Modesto in the morning and similar patterns in the afternoon proceeding south from Modesto to Bakersfield. On the days when the Aztec was scheduled to fly to Modesto, the Cessna flight route focused on the southern end of the SJV, using Paso Robles as the midday airport.

Figures 3-4 through 3-8 show the Aztec and Cessna morning and afternoon planned flight paths. The maps include both the Aztec and Cessna flight routes that were executed depending on the stage of the IOP. The first two maps (Figures 3-4 and 3-5) show the morning and afternoon routes flown at the start of an IOP. The next two maps (Figures 3-6 and 3-7) show the flight routes executed as an ozone episode developed in the SJV. The final map (Figure 3-8) shows the flight routes executed when the ozone episode included both the Sacramento and San Joaquin Valleys. Pass types (traverses, dolphins, and spirals) are indicated by various symbols on the planned flight path. Maps showing the actual sampling route flown during each STI mission are included in Buhr et al., (2001).

Table 3-4.   Flight plan A-1: Aztec Coastal Flight Plan, Santa Rosa to Paso Robles.

From	To	Pass Type	Altitude (ft msl)	Hydrocarbon Sample Altitude (ft msl)	Distance (NM)	End Point Location	
						Latitude (deg.)	Longitude (deg.)
Santa Rosa (STS)	Santa Rosa (STS)	spiral to	4000		0	38.51	122.81
Santa Rosa (STS)	Offshore San Francisco	traverse	5000		48	37.72	122.66
Offshore San Francisco	Offshore San Francisco	spiral to	100		0	37.72	122.66
Offshore San Francisco	N. Offshore	dolphin (2 cycles)	100-5000		84	37.07	124.30
N. Offshore	S. Offshore	dolphin (4 cycles)	100-5000	cycles 1 and 4: 100-1000 & 1500-2500	168	34.72	122.65
S. Offshore	S. Shoreline	dolphin (2 cycles)	100-5000		84	35.33	121.10
S. Shoreline	Paso Robles (PRB)	climb	5000		30	35.67	120.63
Paso Robles (PRB)	Paso Robles (PRB)	spiral to	100		0	35.67	120.63

Table 3-5. Flight plan A-2: Aztec Coastal Flight Plan, Paso Robles to Santa Rosa.

From	To	Pass Type	Altitude (ft msl)	Hydrocarbon Sample Altitude (ft msl)	Distance (NM)	End Point Location	
						Latitude (deg.)	Longitude (deg.)
Paso Robles (PRB)	Paso Robles (PRB)	spiral to	5000		0	35.67	120.63
Paso Robles (PRB)	S. Coastal	descend to	100		30	35.33	121.20
S. Coastal	Offshore Carmel	dolphin (2 cycles)	100-5000	cycle 1: 100-1000 & 1500-2500	84	36.48	122.22
Offshore Carmel	Offshore San Francisco (2)	dolphin (2 cycles)	100-5000	cycle 2: 100-1000 & 1500-2500	84	37.72	122.76
Offshore San Francisco (2)	Point Arena	dolphin (2 cycles)	100-5000		84	38.95	123.75
Point Arena	Ukiah (UKI)	climb	6000		26	39.13	123.20
Ukiah (UKI)	Ukiah (UKI)	spiral to	100		0	39.13	123.20
Ukiah (UKI)	Santa Rosa (STS)	climb	5000		42	38.51	122.81
Santa Rosa (STS)	Santa Rosa (STS)	spiral to	100		0	38.51	122.81

Table 3-6. Flight plan A-3: Aztec Northern Boundary Flight Plan, Santa Rosa to Modesto.

From	To	Pass Type	Altitude (ft MSL)	Hydrocarbon Sample Altitude (ft msl)	Distance (NM)	End Point Location	
						Latitude (deg.)	Longitude (deg.)
Santa Rosa (STS)	Santa Rosa (STS)	spiral to	5000		0	38.51	122.81
Santa Rosa (STS)	Ukiah (UKI)	traverse	5000		40	39.13	123.20
Ukiah (UKI)	Ukiah (UKI)	spiral to	surface		0	39.13	123.20
Ukiah (UKI)	Willows (WLW)	climb to	4000		52	39.52	122.22
Willows (WLW)	Willows (WLW)	spiral to	surface	orbit @ 2500	0	39.52	122.22
Willows (WLW)	Redding (RDD)	climb to	10000		62	40.51	122.29
Redding (RDD)	Redding (RDD)	spiral to	surface	orbit @ 2500 & 1500-surface	0	40.51	122.29
Redding (RDD)	Oroville (OVE)	climb to	4000		70	39.49	121.62
Oroville (OVE)	Oroville (OVE)	spiral to	surface	orbit @ 2500	0	39.49	121.62
Oroville (OVE)	Lodi (O20)	climb to	4000		85	38.09	121.36
Lodi (O20)	Lodi (O20)	spiral to	surface		0	38.09	121.36
Lodi (O20)	Modesto (MOD)	climb to	3000		34	37.63	120.95
Modesto (MOD)	Modesto (MOD)	spiral to	surface		0	37.63	120.95

Table 3-7. Flight plan A-4: Aztec Northern San Joaquin Valley Flight Plan, Santa Rosa to Modesto.

From	To	Pass Type	Altitude (ft msl)	Hydrocarbon Sample Altitude (ft msl)	Distance (NM)	End Point Location Latitude (deg.)	End Point Location Longitude (deg.)
Santa Rosa (STS)	Santa Rosa (STS)	spiral to	5000		0	38.51	122.81
Santa Rosa (STS)	Lodi (O20)	traverse	5000		75	38.09	121.36
Lodi (O20)	Lodi (O20)	spiral to	surface		0	38.09	121.36
Lodi (O20)	Byron (4Q5)	climb to	5000		20	37.84	121.64
Byron (4Q5)	Byron (4Q5)	spiral to	surface		0	37.84	121.64
Byron (4Q5)	Tracy (TCY)	climb to	5000		12	37.69	121.44
Tracy (TCY)	Tracy (TCY)	spiral to	surface		0	37.69	121.44
Tracy (TCY)	NASA Crows Landing (NRC)	climb to	5000		22	37.42	121.10
NASA Crows Landing (NRC)	NASA Crows Landing (NRC)	spiral to	surface	orbit @ 2500 & 1000-surface	0	37.42	121.10
NASA Crows Landing (NRC)	Gustine (3O1)	climb to	5000		12	37.26	120.96
Gustine (3O1)	Gustine (3O1)	spiral to	surface		0	37.26	120.96
Gustine (3O1)	Turlock (O15)	climb to	5000		20	37.49	120.70
Turlock (O15)	Turlock (O15)	spiral to	surface	orbit @ 2500 & 1150-surface	0	37.49	120.70
Turlock (O15)	Don Pedro Reservoir	climb to	5000		20	0.00	0.00
Don Pedro Reservoir	Don Pedro Reservoir	spiral to	surface		0	0.00	0.00
Don Pedro Reservoir	Oakdale (O27)	climb to	5000		20	37.76	120.80
Oakdale (O27)	Oakdale (O27)	spiral to	surface		0	37.76	120.80
Oakdale (O27)	Modesto (MOD)	climb to	5000		11	37.63	120.95
Modesto (MOD)	Modesto (MOD)	spiral to	surface		0	37.63	120.95

Table 3-8. Flight plan A-5: Aztec Northern San Joaquin Valley Flight Plan, Modesto to Santa Rosa.

From	To	Pass Type	Altitude (ft msl)	Hydrocarbon Sample Altitude (ft msl)	Distance (NM)	End Point Location Latitude (deg.)	End Point Location Longitude (deg.)
Modesto (MOD)	Modesto (MOD)	spiral to	5000		0	37.63	120.95
Modesto (MOD)	Don Pedro Reservoir	traverse	5000		28	37.73	120.40
Don Pedro Reservoir	Don Pedro Reservoir	spiral to	900		0	37.73	120.40
Don Pedro Reservoir	Castle (MER)	traverse	2500		21	37.38	120.57
Castle	Castle (MER)	climb/spiral	5000-surface	orbit @ 2500	0	37.38	120.57
Castle	Los Banos (LSN)	traverse	2500		24	37.06	120.87
Los Banos (LSN)	San Luis Reservoir	traverse	2500		12	121.12	37.05
San Luis Reservoir	San Luis Reservoir	spiral to	surface-5000	orbit @ 2500	0	121.12	37.05
San Luis Reservoir	San Martin (Q99)	traverse	5000		22	37.08	121.60
San Martin (Q99)	San Martin (Q99)	spiral to	surface	orbit @ 2500	0	37.08	121.60
San Martin (Q99)	NASA Crows Landing (NRC)	climb	5000	5000	31	37.42	121.10
NASA Crows Landing (NRC)	NASA Crows Landing (NRC)	spiral to	surface		0	37.42	121.10
NASA Crows Landing (NRC)	Tracy (TCY)	traverse	2500		23	37.69	121.44
Tracy (TCY)	Tracy (TCY)	climb/spiral	5000-surface		0	37.69	121.44
Tracy (TCY)	Bethel Island	traverse	2500		22	38.01	121.64
Bethel Island	Bethel Island	climb/spiral	5000-surface		0	38.01	121.64
Bethel Island	Napa County (APC)	traverse	2500		33	38.21	122.28
Napa County (APC)	Santa Rosa (STS)	climb	5000		30	38.51	122.81
Santa Rosa (STS)	Santa Rosa (STS)	spiral to	surface		0	38.51	122.81

Table 3-9. Flight plan C-1: Cessna San Joaquin Valley Flight Plan, Bakersfield to Modesto.

From	To	Pass Type	Altitude (ft msl)	Hydrocarbon Sample Altitude (ft msl)	Distance (NM)	End Point Location	
						Latitude (deg.)	Longitude (deg.)
Bakersfield (BFL)	Bakersfield (BFL)	spiral to	5000		0	35.43	119.06
Bakersfield (BFL)	Button Willow (L62)	traverse	4000		23	35.35	119.48
Button Willow (L62)	Button Willow (L62)	spiral to	surface	1300-surface	0	35.35	119.48
Button Willow (L62)	Angiola	traverse	2000		35	35.93	119.53
Angiola	Angiola	spiral	500-4000	orbit @ 2500	0	35.93	119.53
Angiola	Reedley (O32)	climb	5000		45	36.67	119.45
Reedley (O32)	Reedley (O32)	spiral	surface		0	36.67	119.45
Reedley (O32)	Fresno-Chandler (FCH)	climb to	4000		22	36.73	119.82
Fresno-Chandler (FCH)	Fresno-Chandler (FCH)	spiral to	surface		0	36.73	119.82
Fresno-Chandler (FCH)	Mendota (Q84)	climb	4000		28	36.76	120.37
Mendota (Q84)	Mendota (Q84)	spiral to	surface		0	36.76	120.37
Mendota (Q84)	Madera (MAE)	traverse	2000		19	36.99	120.11
Madera (MAE)	Madera (MAE)	spiral	surface-4000	orbit @ 2500	0	36.99	120.11
Madera (MAE)	Mariposa (O68)	climb	6000		32	37.51	120.04
Mariposa (O68)	Mariposa (O68)	spiral to	surface		0	37.51	120.04
Mariposa (O68)	Gustine (3O1)	traverse	2000		46	37.26	120.96
Gustine (3O1)	Gustine (3O1)	spiral	surface-4000		0	37.26	120.96
Gustine (3O1)	Modesto (MOD)	traverse	4000		22	37.63	120.95
Modesto (MOD)	Modesto (MOD)	spiral to	surface		0	37.63	120.95

Table 3-10. Flight plan C-2: Cessna San Joaquin Valley Flight Plan, Modesto to Bakersfield.

From	To	Pass Type	Altitude (ft msl)	Hydrocarbon Sample Altitude (ft msl)	Distance (NM)	End Point Location Latitude (deg.)	End Point Location Longitude (deg.)
Modesto (MOD)	Modesto (MOD)	spiral to	5000		0	37.63	120.95
Modesto (MOD)	East Valley (Bonanza Hills)	descend to	2500		32	37.66	120.23
East Valley (Bonanza Hills)	Mendota (Q84)	traverse	2500		50	36.76	120.37
Mendota (Q84)	Mendota (Q84)	spiral	surface-5000		0	36.76	120.37
Mendota (Q84)	West Valley	descend to	2500		14	36.65	120.67
West	Madera (MAE)	traverse	2500		46	36.99	120.11
Madera (MAE)	East Valley	traverse	2500	2500	20	37.02	119.67
East Valley	Selma (0Q4)	traverse (circle)	2500		40	36.58	119.66
Selma (0Q4)	Reedley (O32)	climb to	7000		12	36.67	119.45
Reedley (O32)	Reedley (O32)	spiral to	surface		0	36.67	119.45
Reedley (O32)	Kettleman City	traverse	2500		46	36.02	119.97
Kettleman City	Angiola	climb to	5000		22	35.93	119.53
Angiola	Angiola	spiral to	surface	orbit @ 2500	0	35.93	119.53
Angiola	NE of Bakersfield	traverse	2500		33	35.68	118.93
NE of Bakersfield	SE of Bakersfield	traverse	2500		20	35.33	118.75
SE of Bakersfield	S of Bakersfield	traverse	2500	2500	16	35.20	119.08
S of Bakersfield	Bakersfield (BFL)	climb to	5000		15	35.43	119.06
Bakersfield (BFL)	Bakersfield (BFL)	spiral to	surface		0	35.43	119.06

Table 3-11. Flight plan C-3: Cessna San Joaquin Valley Flight Plan, Modesto to Bakersfield.

From	To	Pass Type	Altitude (ft msl)	Hydrocarbon Sample Altitude (ft msl)	Distance (NM)	End Point Location	
						Latitude (deg.)	Longitude (deg.)
Modesto (MOD)	Modesto (MOD)	spiral to	5000		0	37.63	120.95
Modesto (MOD)	Mendota (Q84)	traverse	2500		59	36.76	120.37
Mendota (Q84)	Mendota (Q84)	spiral	surface-5000		0	36.76	120.37
Mendota (Q84)	West Valley	descend	2500		14	36.65	120.67
West Valley	Madera (MAE)	traverse	2500		46	36.99	120.11
Madera (MAE)	East Valley	traverse	2500	2500	20	37.02	119.67
East Valley	Selma (0Q4)	traverse (circle)	2500		40	36.58	119.66
Selma (0Q4)	Reedley (O32)	climb	7000		12	36.67	119.45
Reedley (O32)	Reedley (O32)	spiral to	surface		0	36.67	119.45
Reedley (O32)	Kettleman City	traverse	2500		46	36.02	119.97
Kettleman City	Angiola	climb	5000		22	35.93	119.53
Angiola	Angiola	spiral to	surface	orbit @ 2500	0	35.93	119.53
Angiola	NE of Bakersfield	traverse	2500		33	35.68	118.93
NE of Bakersfield	SE of Bakersfield	traverse	2500		20	35.33	118.75
SE of Bakersfield	S of Bakersfield	traverse	2500	2500	16	35.20	119.08
S of Bakersfield	South	traverse	2500		9	35.02	119.05
SS of Bakersfield	Caliente	traverse	2500		27	35.30	118.62
Caliente	Caliente	climb / spiral	6000-2500		0	35.30	118.62
Caliente	Bakersfield (BFL)	climb	5000		22	35.43	119.06
Bakersfield (BFL)	Bakersfield (BFL)	spiral to	surface		0	35.43	119.06

Table 3-12. Flight plan C-4: Cessna Southern San Joaquin Valley Flight Plan, Bakersfield to Paso Robles.

From	To	Pass Type	Altitude (ft msl)	Hydrocarbon Sample Altitude (ft msl)	Distance (NM)	End Point Location	
						Latitude (deg.)	Longitude (deg.)
Bakersfield (BFL)	Bakersfield (BFL)	spiral to	5000		0	35.43	119.06
Bakersfield (BFL)	Button Willow (L62)	traverse	4000		23	35.35	119.48
Button Willow (L62)	Button Willow (L62)	spiral to	surface	1350-surface	0	35.35	119.48
Button Willow (L62)	Angiola	traverse	2000		35	35.93	119.53
Angiola	Angiola	spiral	500-4000	orbit @ 2500	0	35.93	119.53
Angiola	Reedley (O32)	climb	5000		45	36.67	119.45
Reedley (O32)	Reedley (O32)	spiral to	surface		0	36.67	119.45
Reedley (O32)	Fresno-Chandler (FCH)	climb	4000		22	36.73	119.82
Fresno-Chandler (FCH)	Fresno-Chandler (FCH)	spiral to	surface		0	36.73	119.82
Fresno-Chandler (FCH)	Madera (MAE)	climb	5000		21	36.99	120.11
Madera (MAE)	Madera (MAE)	spiral to	surface	orbit @ 2500	0	36.99	120.11
Madera (MAE)	Mendota (Q84)	climb to	5000		19	36.76	120.37
Mendota (Q84)	Mendota (Q84)	spiral to	surface		0	36.76	120.37
Mendota (Q84)	Five Points	climb to	5000		21	36.45	120.27
Five Points	Five Points	spiral to	surface		0	36.45	120.27
Five Points	San Ardo	climb to	5000		39	36.03	120.92
San Ardo	San Ardo	spiral to	surface		0	36.03	120.92
San Ardo	Paso Robles (PRB)	climb to	5000		27	35.67	120.63
Paso Robles (PRB)	Paso Robles (PRB)	spiral to	surface		0	35.67	120.63

Table 3-13. C-5 flight plan: Cessna Southern San Joaquin Valley Flight Plan, Paso Robles to Bakersfield.

From	To	Pass Type	Altitude (ft msl)	Hydrocarbon Sample Altitude (ft msl)	Distance (NM)	End point location	
						Latitude (deg.)	Longitude (deg.)
Paso Robles (PRB)	Paso Robles (PRB)	spiral to	5000		0	35.67	120.63
Paso Robles (PRB)	San Ardo	traverse	5000		27	36.03	120.92
San Ardo	San Ardo	spiral to	surface		0	36.03	120.92
San Ardo	Coalinga (CLG)	Climb	5000		28	36.16	120.36
Coalinga (CLG)	Coalinga (CLG)	spiral to	surface		0	36.16	120.36
Coalinga (CLG)	West Valley	Climb	2500		31	36.65	120.67
West Valley	Madera (MAE)	traverse	2500		46	36.99	120.11
Madera (MAE)	East Valley	traverse	2500	2500	20	37.02	119.67
East Valley	Selma (0Q4	traverse	2500		40	36.58	119.66
Selma (0Q4)	Reedley (O32)	Climb	7000		12	36.67	119.45
Reedley (O32)	Reedley (O32)	spiral to	surface		0	36.67	119.45
Reedley (O32)	Kettleman City	traverse	2500		46	36.02	119.97
Kettleman City	Angiola	Climb	5000		22	35.93	119.53
Angiola	Angiola	spiral to	surface	orbit @ 2500	0	35.93	119.53
Angiola	NE of Bakersfield	traverse	2500		34	35.68	118.93
NE of Bakersfield	SE of Bakersfield	traverse	2500		20	35.33	118.75
SE of Bakersfield	S of Bakersfield	traverse	2500	2500	16	35.20	119.08
S of Bakersfield	Bakersfield (BFL)	Climb	5000		15	35.43	119.06
Bakersfield (BFL)	Bakersfield (BFL)	spiral to	surface		0	35.43	119.06

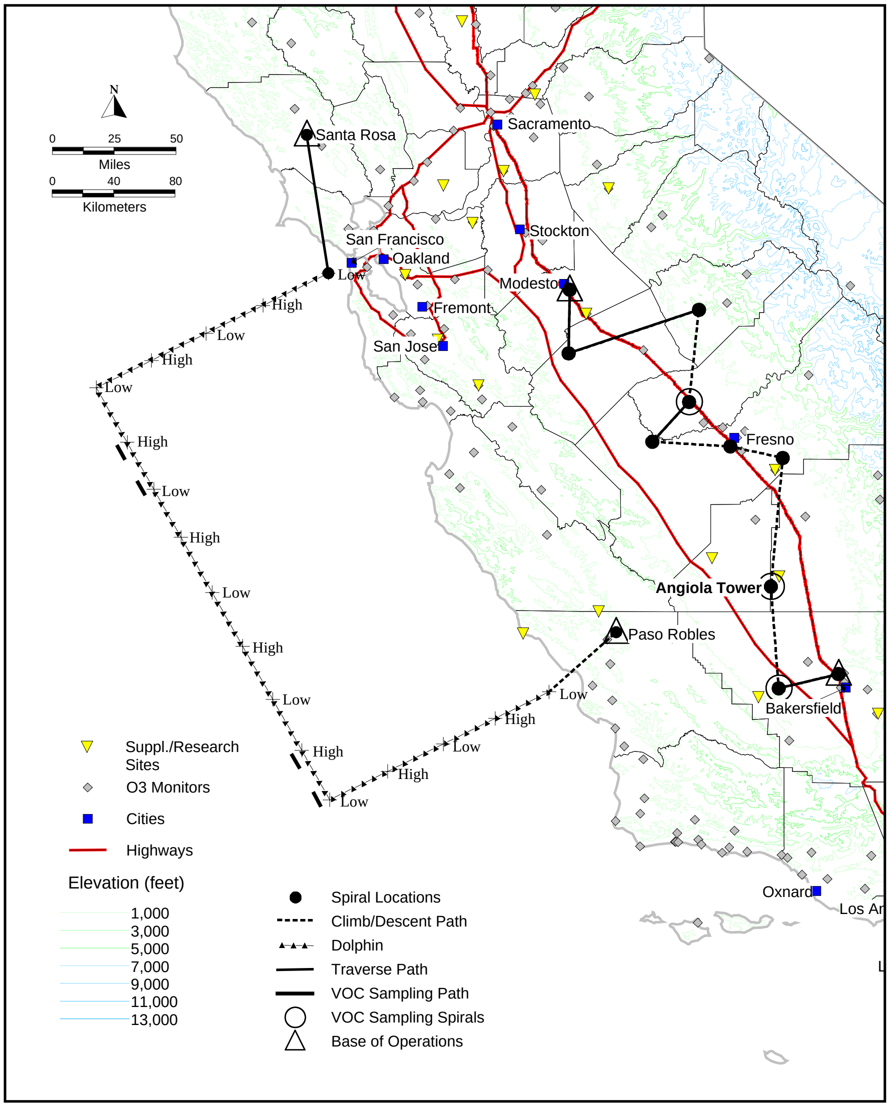


Figure 3-4. Morning flight routes executed by the STI Aztec (endpoint at Santa Rosa) and Cessna (endpoint at Bakersfield) at the start of an IOP period. These flight routes were designed to characterize the flux of ozone and ozone precursors into and through the study domain (Aztec on the western boundary [A1 flight route] and Cessna in the SJV [C1 flight route]).

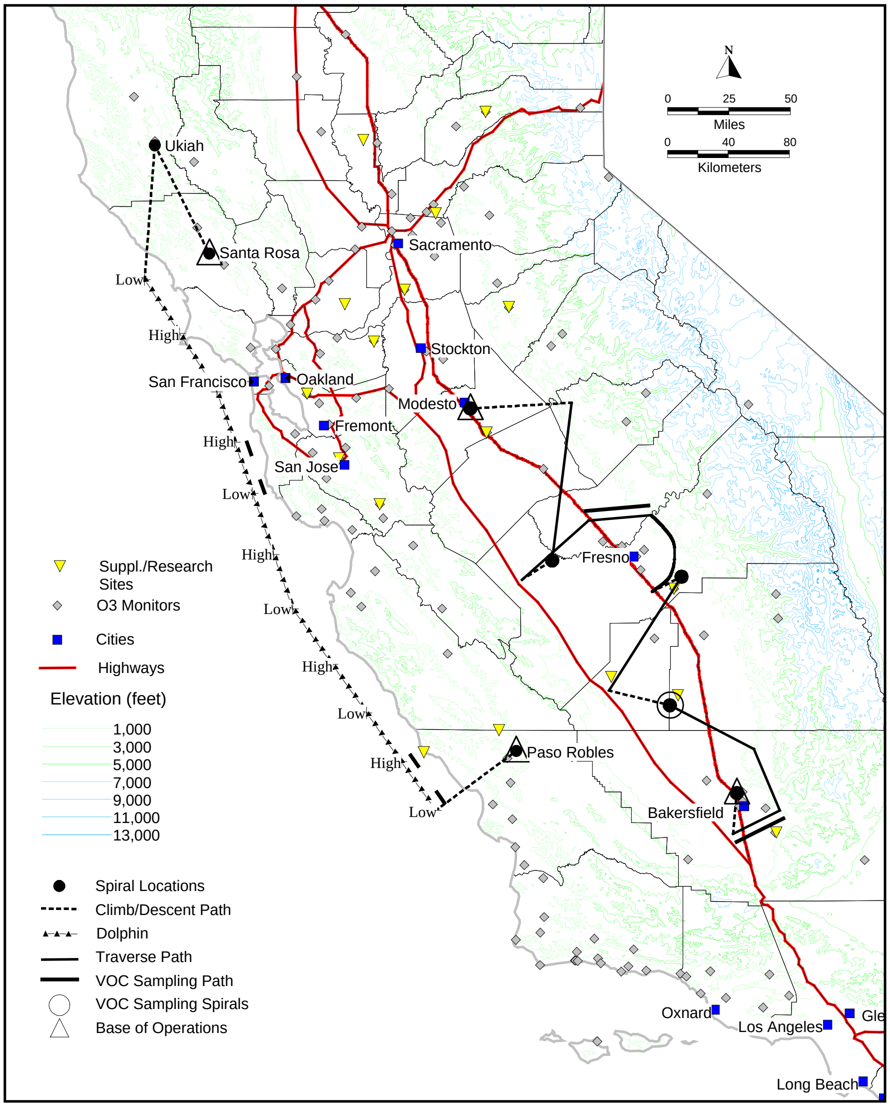


Figure 3-5. Afternoon flight routes executed by the STI Aztec (endpoint at Santa Rosa) and Cessna (endpoint at Bakersfield) at the start of an IOP period. These flight routes were designed to characterize the flux of ozone and ozone precursors into and through the study domain (Aztec on the western boundary [A2 flight route] and Cessna in the southern end of the SJV [C2 flight route]).

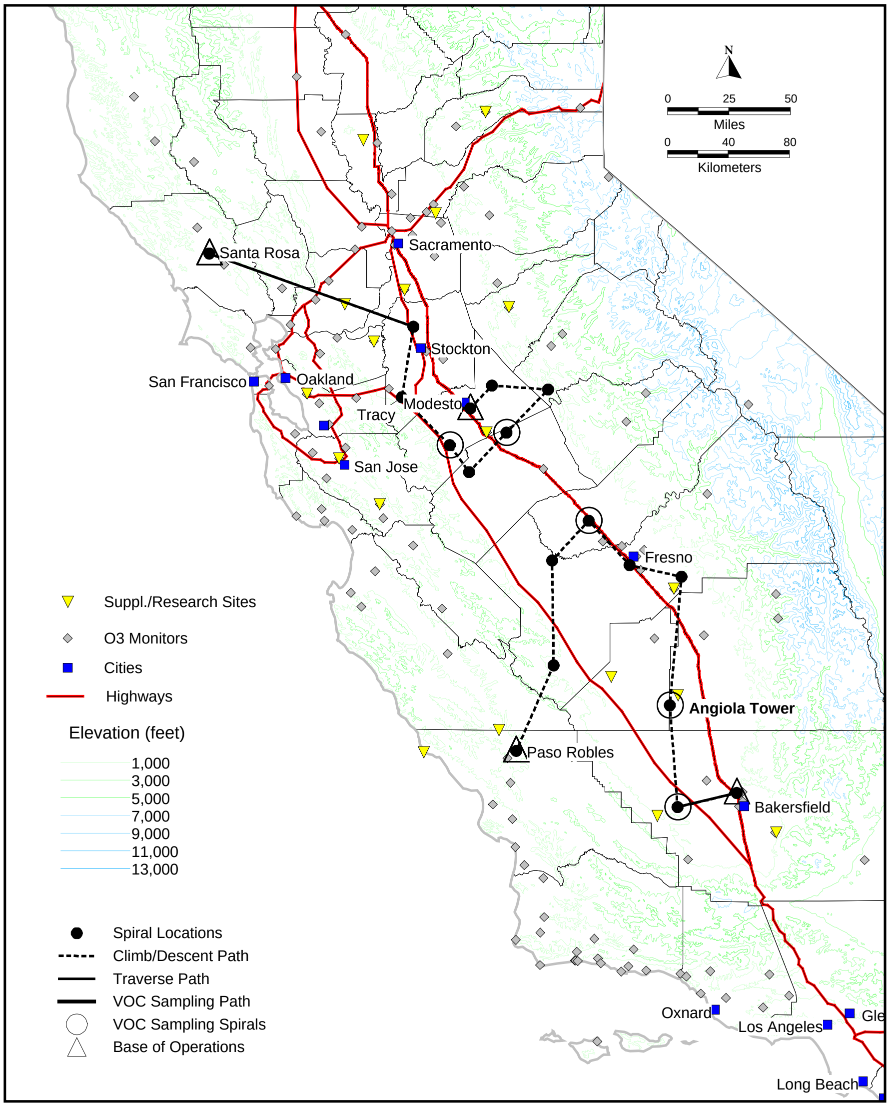


Figure 3-6. Morning flight routes executed by the STI Aztec (endpoint at Santa Rosa) and Cessna (endpoint at Bakersfield) during an ozone episode in the SJV. These flight routes were designed to characterize the flux of ozone and ozone precursors into and through the study domain (Aztec in the northern end of the SJV [A4 flight route], and Cessna in the southern end of the SJV and Salinas Valley [C4 flight route]).

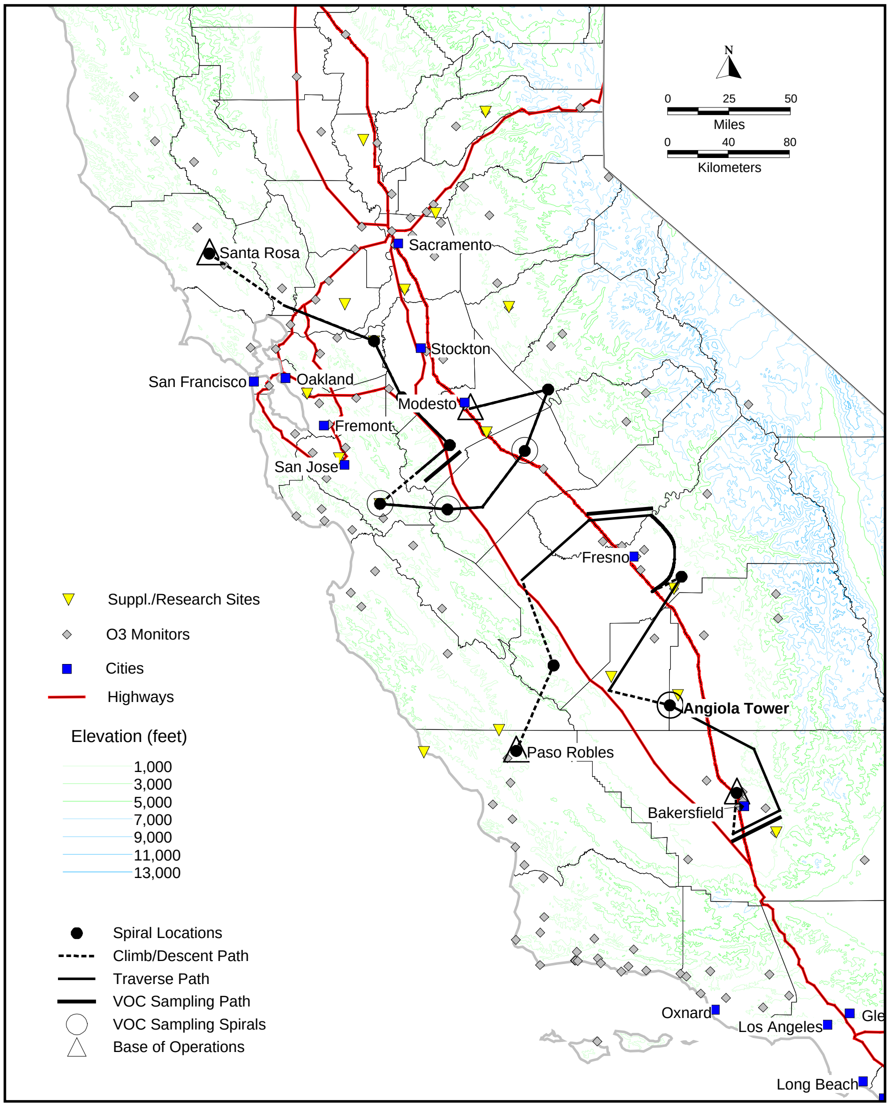


Figure 3-7. Afternoon flight routes executed by the STI Aztec (endpoint at Santa Rosa) and Cessna (endpoint at Bakersfield) during an ozone episode in the SJV. These flight routes were designed to characterize the flux of ozone and ozone precursors into and through the study domain (Aztec in the northern end of the SJV [A5 flight route] and Cessna in the southern end of the SJV and Salinas Valley [C5 flight route]).

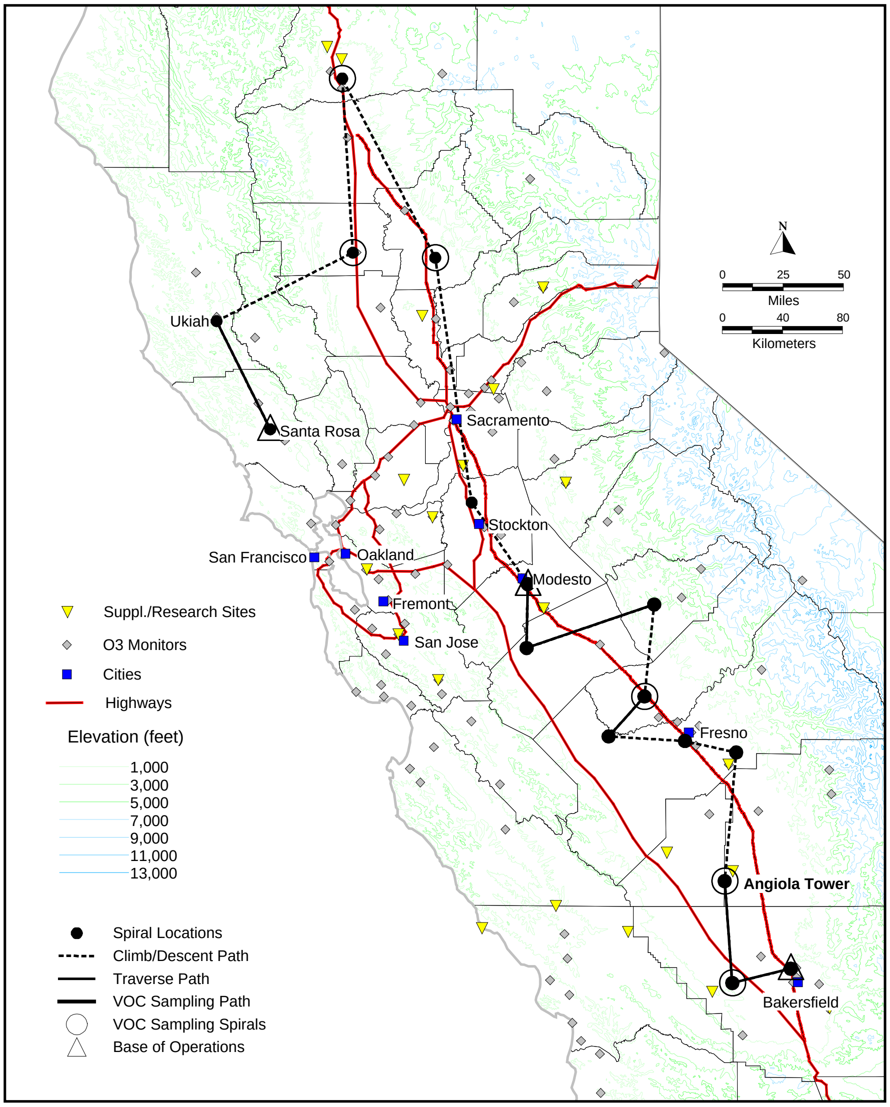


Figure 3-8. Morning flight routes executed by the STI Aztec (endpoint at Santa Rosa) and Cessna (endpoint at Bakersfield) during an ozone episode that included the Sacramento and San Joaquin Valleys. These flight routes were designed to characterize the flux of ozone and ozone precursors into and through the study domain (Aztec in the Sacramento Valley [A3 flight route] and Cessna in the southern end of the SJV [C1 flight route]). The afternoon flight routes for this scenario were the same as those shown in Figure 3-7 for the Aztec and in Figure 3-5 for the Cessna.

4. DATA PROCESSING, FORMATS, AND AVAILABILITY

4.1 DATA PROCESSING

Data documentation began before take-off and continued throughout each flight. During a flight, the sampling instrumentation and the data acquisition system (DAS) were run continuously. A flight consisted of a sequential series of sampling events that included zeroing instruments before takeoff and after landing, spirals, traverses, and dolphins. These sampling events (excluding instrument zeroing) were called "passes" and were numbered sequentially from the beginning of each flight, starting at one. Each flight was processed as a series of passes.

Aboard the aircraft, the on-board scientist (instrument operator) controlled an event switch that was used to flag passes. The data flag was recorded by the DAS and used during data processing steps to identify various sections of data.

During each flight, the operator filled out standardized flight record sheets (flight notes) that summarized each pass. During data processing, the information contained in the flight notes was checked against the flags and other data that were recorded by the DAS.

Initial processing of the data began after the aircraft returned to the base of operations at the end of a sampling day. The objective was to provide a quick review of the data and to identify and correct problems if they existed. The following processing was performed in the field:

- The sampling date, the sampling period (start- and end-times), and the Zip disk identification number were determined from flight notes and compared with the information recorded on the data disk. Differences were reconciled and corrected before other processing steps were initiated.
- During sampling, the continuous sensor data were written to the DAS's hard drive and to a removable backup Zip disk .
- After the flight, a data-processing program was used to read the raw ASCII data files and generate QC values (flags) that were added to the engineering unit file and accompanied each measurement value through all remaining processing steps. Initially these QC values were set to zero by the processing program, indicating that each data point was valid. If later editing changes were made to a data point, the associated QC value was automatically changed to reflect the editing that was performed.
- The processing program also produced a summary of times at which the event switch (recorded by the DAS) was activated or changed. This file was called an “event summary file”.
- The status of the event switch (from the event summary) was compared to the instrument operator's written flight notes, and discrepancies were noted. Appropriate corrective actions were taken.

- The aircraft field manager reviewed each recorded parameter of the raw engineering unit data using the on-screen display function of an editing program.
- Copies of the aircraft data file, the converted raw voltage file, the converted raw engineering unit file, and flight notes were returned to STI for further processing.

At STI the following processing was performed:

- Review and interactive editing of the raw engineering unit data were performed using an editing program. One element of the editing program was the creation (and continual updating) of a separate log file that documented each processing step and logged all corrections that were made.
- The data were reviewed for outliers (typically due to aircraft radio transmissions). These outliers were marked using the editor and then invalidated.
- The editing program was used to add two calculated data fields to the flight data. Altitude in m msl (based on altitude in ft msl), absolute humidity (based on temperature, dew point, and pressure). Each data field had a QC field associated with it. If later editing changes were made to a base measurement, the editing program automatically updated the calculated data field and its QC flags.
- The type of sampling (spiral, traverse, or dolphin) performed during a pass and the location of the sampling (three-letter identifier) were added to the data file using the editing program.
- Using the event summary and flight notes, a tabular sampling summary was produced for inclusion with the data from each flight.
- Instrument calibration data were reviewed, and calibration factors were selected. Pre- and post-flight instrument zero values were checked and compared to calibration values.
- The editing program was used to apply zero values, calibration factors, offsets, and altitude correction factors (when appropriate) to the raw engineering unit data. Each correction or adjustment was automatically recorded in the editing program log file, and QC flags were changed appropriately.
- At this point, preliminary data plots were produced. Using the preliminary data plots, flight maps, sampling summaries, processing notes, and flight notes, a data processing system review was performed.
- Dates, times, locations, and the types of sampling for each pass were checked for each of the various outputs. The plotted data for each measurement were reviewed, and relationships between parameters (e.g., NO/NO_y ratios, etc.) were examined.
- Problems that existed were corrected. Most problems detected were clerical in nature (wrong end point number on the sampling summary, etc.) and were easily corrected.
- After all editing had been completed, final data plots were produced.
- After completion of all processing and editing, the final engineering unit data were copied to permanent storage media (CD-ROM).

- Finally, both the data and QC values were translated to the CCAQS data submittal format and transferred via FTP to ARB.

4.2 DATA FORMATS AND AVAILABILITY

The continuous sensor data have been reported to the ARB in the two-volume data report by Blumenthal et al.(2001). The report contains a separate section for each flight. Each section contains a sampling summary such as the one shown in **Figure 4-1**. The summary details the sampling locations, times, and information concerning the sampling that was performed. The summary also shows sample identifiers, locations, times, and altitudes for each integrated VOC and carbonyl grab sample collected. A sampling route map (**Figure 4-2**) follows the summary page. **Figures 4-3 and 4-4** are examples of data plots for individual passes conducted during a flight

The data plots present "snapshot" views for each pass of a flight. Some portions of data (e.g., while the aircraft was repositioning for the next pass) were not plotted, but these data are contained in the data files that were delivered to the ARB.

The data were provided to the ARB in two formats. First the data were formatted according to the ARB CCAQS data transmittal instructions (California Air Resources Board, 2001) and transferred to the ARB via ftp. In addition, the data were provided electronically on a compact disk (CD) in the format described below. The CD entitled "The real-time measurement data collected aboard the STI aircraft during CCOS sampling" contains the aloft continuous air quality data collected aboard the STI aircraft.

The data files are in a tab-delimited text file format compatible with DOS-based computers. Each variable occupies one column, and columns are separated by tab characters. The chosen format allows the user to read the data with either commercial software (e.g., spreadsheets such as MS Excel and word processors such as WordPerfect) or custom-programmed software (e.g., FORTRAN-based programs).

The data files were named using the following convention:

<u>Format:</u> *AircraftYear_Month_Day_Starttime.dat*

Aircraft	=	Aztec or Cessna
Year	=	2000
Month	=	7 (July), 8 (August), 9 (September)
Day	=	day of the month
Starttime	=	Starttime of the raw data in HHMM.*
Extension *.dat*	=	text file

* Leading and trailing zeros were not included in the file name starttime field.

STI Aircraft Sampling Summary - CCOS

Sampling Date: July 23, 2000 **Flight Number:** A3 **Flight Route:** A1 Santa Rosa to Paso Robles
Aircraft ID: STI Aztec

(See sampling map)

Pass #	Pass Type *	Time (PST) Start	Time (PST) End	Altitude Start (ft-msl)	Altitude Start (m-msl)	Altitude End (ft-msl)	Altitude End (m-msl)	Sampling Location Start	Sampling Location End
1	S	6:46:27	7:03:24	260	79.2	5601	1707.2	Santa Rosa	Santa Rosa
2	T	7:03:24	7:18:53	5601	1707.2	5480	1670.3	Santa Rosa	Offshore S.F.
3	S	7:18:53	7:27:33	5480	1670.3	938	285.9	Offshore S.F.	Offshore S.F.
4	D	7:27:33	7:38:43	938	285.9	4966	1513.6	Offshore S.F.	Offshore D1 high
5	D	7:38:43	7:48:48	4966	1513.6	1147	349.6	Offshore D1 high	Offshore D2 low
6	D	7:48:48	8:00:40	1147	349.6	4929	1502.4	Offshore D2 low	Offshore D2 high
7	D	8:00:40	8:12:06	4929	1502.4	1181	360.0	Offshore D2 high	N. Offshore
8	D	8:12:06	8:21:46	1181	360.0	4941	1506.0	N. Offshore	Offshore D3 high
9	D	8:21:46	8:37:42	4941	1506.0	1201	366.1	Offshore D3 high	Offshore D4 low
10	D	8:37:42	8:44:22	1201	366.1	4954	1510.0	Offshore D4 low	Offshore D4 high
11	D	8:44:22	8:53:19	4954	1510.0	1268	386.5	Offshore D4 high	Offshore D5 low
12	D	8:53:19	9:01:24	1268	386.5	4962	1512.4	Offshore D5 low	Offshore D5 high
13	D	9:01:24	9:09:15	4962	1512.4	879	267.9	Offshore D5 high	Offshore D6 low
14	D	9:09:15	9:18:03	879	267.9	4955	1510.3	Offshore D6 low	Offshore D6 high
15	D	9:18:03	9:38:50	4955	1510.3	22	6.7	Offshore D6 high	S Offshore
16	D	9:38:50	9:52:53	22	6.7	4935	1504.2	S Offshore	Offshore D7 high
17	D	9:52:53	10:02:47	4935	1504.2	640	195.1	Offshore D7 high	Offshore D8 low
18	D	10:02:47	10:14:35	640	195.1	4961	1512.1	Offshore D8 low	Offshore D8 high
19	D	10:14:35	10:26:13	4961	1512.1	307	93.6	Offshore D8 high	S. Shoreline
20	C	10:26:13	10:41:12	307	93.6	4956	1510.6	S. Shoreline	Paso Robles
21	S	10:41:12	10:57:06	4956	1510.6	732	223.1	Paso Robles	Paso Robles

INTEGRATED SAMPLING

Pass #	VOC SAMPLING DETAILS: VOC ID #	Time (PST) Start	Time (PST) End	Altitude (ft-msl) Start	Altitude (ft-msl) End	CARBONYL SAMPLING DETAILS: Bag/ CARB. ID#	Time (PST) Start	Time (PST) End	Altitude (ft-msl) Start	Altitude (ft-msl) End
9	0723-01 / G20	8:28:16 / 8:35:08	8:30:14 / 8:37:04	2420 / 1327	2480 / 1291	6 / 14	8:28:16 / 8:35:03	8:31:05 / 8:37:40	2420 / 1375	2440 / 1212
15	G18 / 0723-04	9:24:51 / 9:32:35	9:26:41 / 9:34:27	2345 / 901	2443 / 924	20 / 4	9:24:50 / 9:32:16	9:27:14 / 9:35:30	2345 / 971	2453 / 932

* *S = Spiral, O = Orbit, D = Dolphin, T = Traverse, C = Climb or Descent*

Comments:

1 foggy out to sea, estimate cloud height 2500' - 3000'.
2
3 clouds high, still seeing O3 spikes with mike, mike 2 spiker
4
5
6
7 Small breaks in cloud cover.
8
9 orbited on lower sample too
10
11
12
13 Clouds broken @ 300' to west and south.
14
15 Orbited for low sample as well.
16
17
18
19
20
21

Figure 4-1. An example flight summary sheet for the Aztec flight conducted on the morning of July 23, 2000.

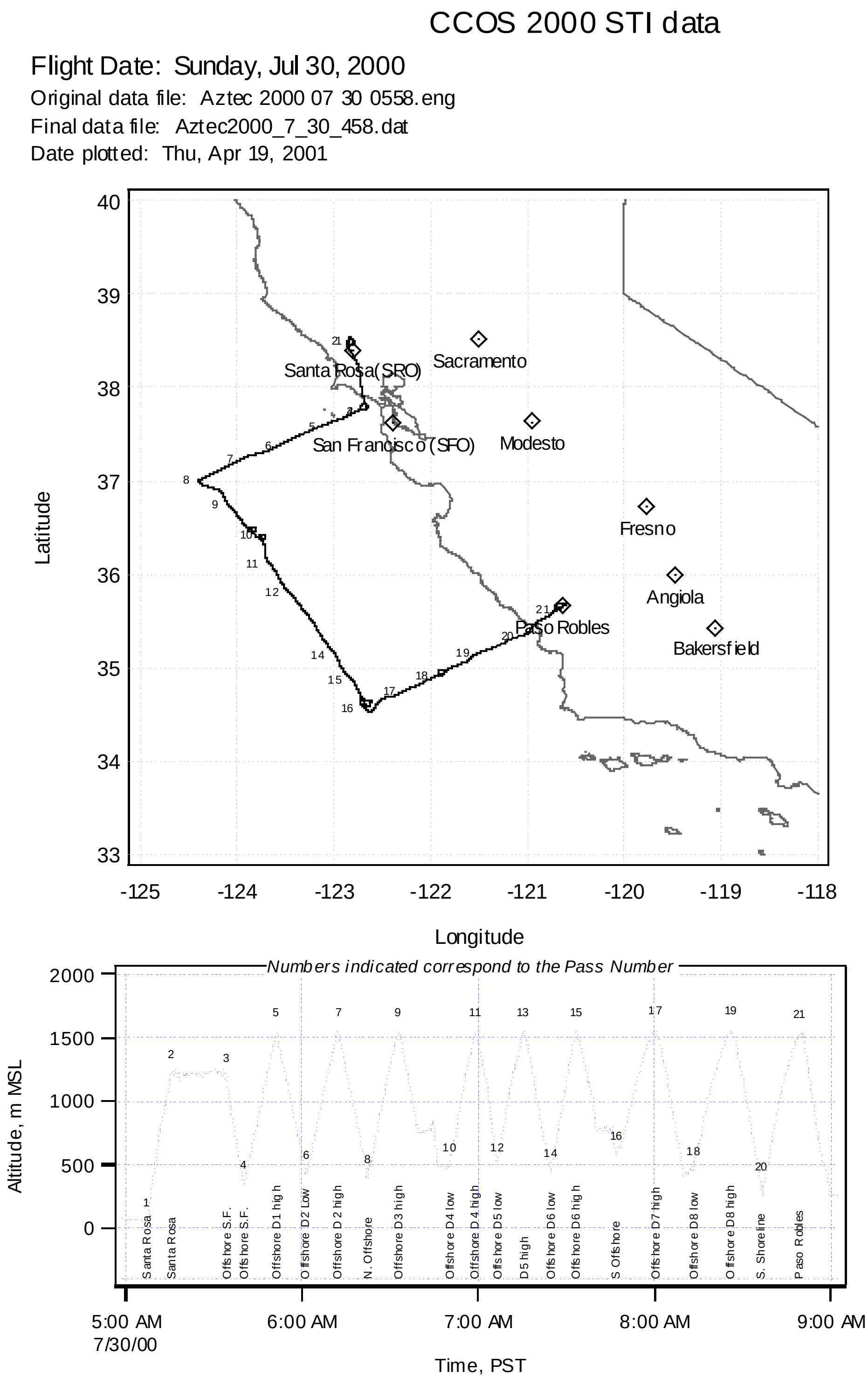
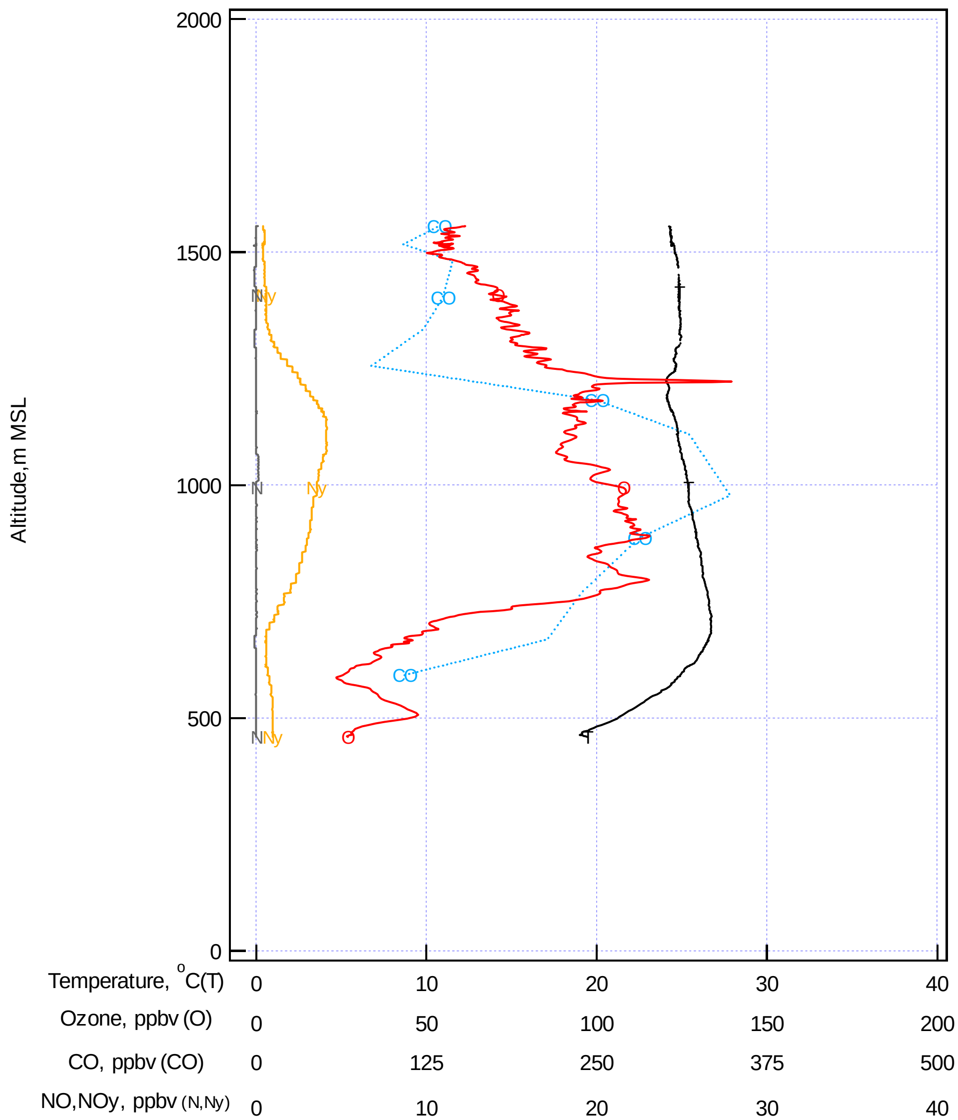


Figure 4-2. An example flight map for the Aztec flight conducted on the morning of July 30, 2000. Pass numbers are shown at the beginning of each pass.



CCOS 2000 Data

Flight Date: Sunday, July 30, 2000

Location: Offshore D8 low to Offshore D8 high

Pass Number: 18

Pass Type: Dolphin

Pass start time: 08:13:05 PST

Pass stop time: 08:26:00 PST

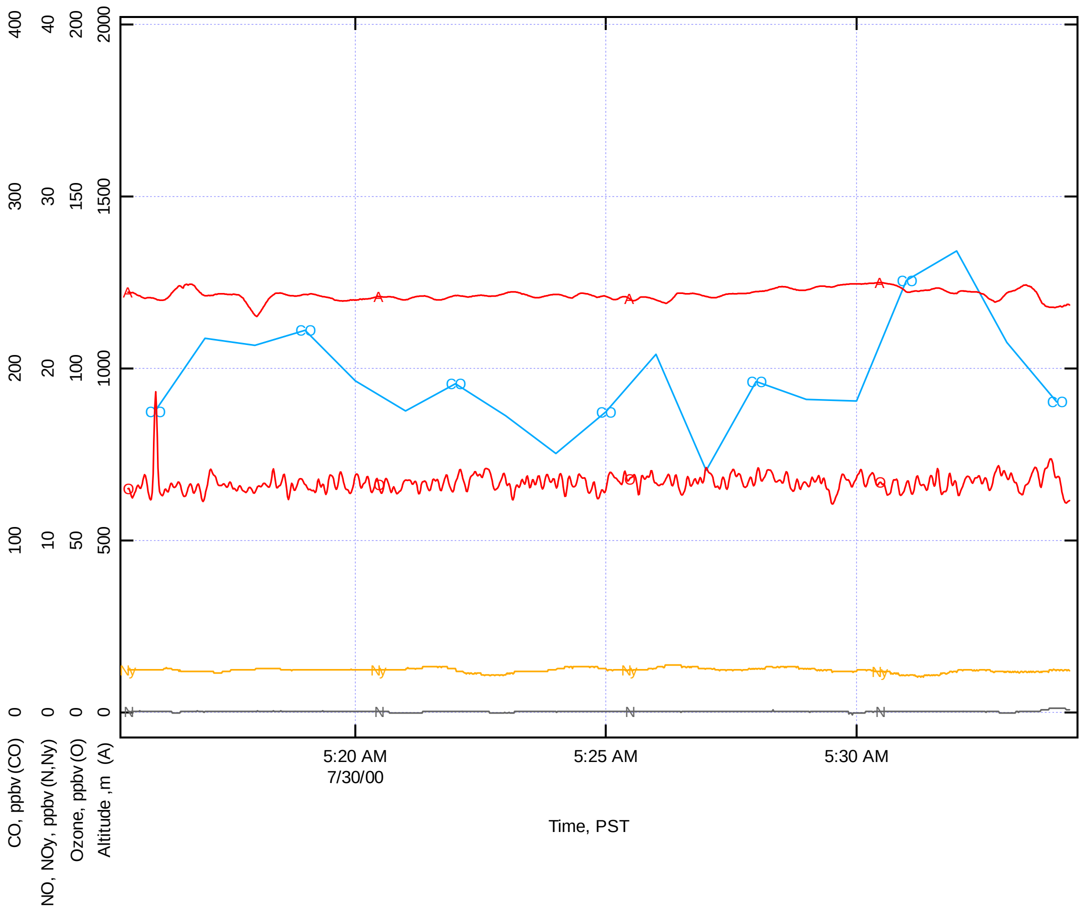
Original data file: Aztec 2000 07 30 0558.eng

Final data file: Aztec2000_7_30_458.dat

Plot file: pass118_D__1

Date plotted: Thu, Apr 19, 2001

Figure 4-3. An example vertical profile from data collected during the July 30, 2000, morning Aztec flight. The same format was used for both spiral and dolphin pass types.



CCOS 2000 Data

Flight Date: Sunday, July 30, 2000
Location: Santa Rosa to Offshore S.F.
Pass Number: 2
Pass Type: Traverse

Pass start time: 05:15:28 PST
Pass stop time: 05:34:15 PST

Original data file: Aztec 2000 07 30 0558.eng
Final data file: Aztec2000_7_30_458.dat

Plot file: pass102_T__1
Date plotted: Thu, Apr 19, 2001

Figure 4-4. An example traverse data plot from the data collected during the July 30, 2000, morning Aztec flight.

A separate file was produced for the 1-min averaged CO data and the characters “CO” were appended after the “Starttime”. This file also contains start and stop time, position, altitude, and flight pattern for each record.

Each data file begins with a tab-delimited column (field) descriptor. This descriptor identifies the measurement being reported and the units used to report the measurement data (e.g. – O3_ppbv). The measurement data follow the descriptors. Data are reported for each one-second interval from take-off to landing. Each one second of recorded data is called a record. In the case of CO measurements, each record represents a 1-min average.

Each data point (except time, date, and non-measurement data) has two associated QC flags included in the data files (e.g. – O3_ppbv_QC1, the primary QC flag, and O3_ppbv_QC2, the secondary QC flag). **Table 4-1** contains a quick-reference QC code key. The data were originally edited using a different, single-value, QC code system that included *valid, estimated, suspect*, *missing*, and *invalid* codes. These QC codes were converted to the CCAQS codes when they became available. The CCAQS QC code system uses a primary and secondary QC code. An effort was made to be faithful to the general intention of the original QC codes with the available CCAQS primary and secondary codes.

Table 4-1. Quality control code key.

Primary QC Code	Primary QC Code Description	Secondary QC Code	Secondary QC Code Description
V0	Valid value	CFC	**C**orrection **F**actor **C**alibration
V2	Valid estimated value	OLP	**O**utside **L**imit of **P**recision
V2	Valid estimated value	OOR	**O**utside **O**perating **R**ange
S	Suspect	PCF	**P**erformance **C**heck **F**ailed
M	Missing value	NSQ	**N**ot **S**ufficient **Q**uantity
M	Missing value	ZME	**Z**ero **M**od**E**
I	Invalid value	EMM	**E**lectrical or **M**echanical **M**alfunction

The following sections define each code used.

Valid

Data which were found to be valid during the QC process were assigned a *V0* primary QC flag. This means the data are both reasonable and consistent with adjacent data points. The secondary QC flag is typically indicated as *CFC* (**C**orrection **F**actor **C**alibration). Other CCAQS secondary QC flags may also be applicable.

Valid – Estimated

Data points which were calculated from other data or which were estimated based on available calibrations are marked by a *V2* primary QC flag. Depending on the reason for assigning the estimated primary QC flag, the secondary QC flag is indicated as either *OLP* (**O**utside **L**imit of **P**recision) or *OOR* (**O**utside **O**perating **R**ange).

Suspect

Data points that were judged to be suspect were assigned the *S* primary QC flag and the *PCF* (**P**erformance **C**heck **F**ailed) secondary QC flag.

Missing

Data that for some reason were missing from the data file (inoperative analyzer, lost data) were assigned a primary QC flag *M* (**M**issing value), and a secondary QC flag NSQ (**N**ot **S**ufficient **Q**uantity). The *M* primary QC flag was also used for zero mode data according to the CCAQS convention. In this case the secondary QC flag was assigned as ZME (**Z**ero **M**od**E**). As for invalid data, the value of the parameter in the data file was replaced by *null*.
Two copies of the data report and CD were delivered to the ARB. Copies of the final processed data, individual log files, the original data from the aircraft, and processing notes are stored in archive files at STI. These archives will be maintained for at least five years.

Invalid

Data points which were not reasonable from either a scientific or an engineering standpoint were assigned an *I* (**I**nvalid) primary QC flag and the EMM (**E**lectrical or **M**echanical **M**alfunction) secondary QC flag. The value of the parameter in the data file was replaced by *null*. For example, noise or radio-frequency interference from the aircraft communications equipment sometimes generated "spikes" in some of the data points. These data, which were obviously erroneous, were marked as invalid.

5. DATA QUALITY

Quality control (QC) procedures are discussed in this report in terms of activities ***performed by STI*** to assure the quality of the aircraft data. ***Actions taken by others*** to assure the quality of the aircraft data are discussed as quality assurance (QA) activities. For example, instrument calibrations were an STI QC activity; but, the performance audit by the ARB was a QA activity.

5.1 QUALITY CONTROL

5.1.1 Pre-program Quality Control Measures

The following activities were performed by STI before the start of the program to control the quality of the aircraft data:

- Checklists and log sheets, specific to the instruments and sampling systems operated aboard the aircraft, were designed. These were used throughout the program to standardize operational procedures and to document all activities relating to the measurements.
- Operational bases at the Santa Rosa, Bakersfield, Modesto, and Paso Robles airports were established. Arrangements were made to install needed power circuits at each facility.
- Prior to transfer to Santa Rosa and Bakersfield from the Healdsburg airport, each piece of sampling equipment to be used aboard the two aircraft was cleaned, checked, and calibrated. New inlet particulate filters and sample lines were installed in the sampling instruments.
- The aircraft were instrumented and test flights were flown. Data recorded during these flights were processed and reviewed to ensure that the complete instrumentation package, or system, was operational.
- The calibration systems and an ozone transfer standard (UV photometer) were checked and certified. NIST-certified calibration gas was ordered and delivered to the Santa Rosa and Bakersfield base facilities.
- Aircraft sampling routes were discussed with the FAA and other airport facilities to ensure that desired sampling could be performed. Necessary certifications and waivers were obtained from the FAA.
- A performance audit of the gas monitors (while mounted in the aircraft) was performed on June 19 and July 3, 2001. The audit results are described in Section 5.2.
- The Aztec flew an intercomparison flight with the DOE G-1 aircraft on July 5, 2000.
- Both the Aztec and Cessna 182 flew an intercomparison flight with the UCD 182 on July 6, 2000.

5.1.2 Quality Control Measures During the Field Program

Many checks, procedures, and instrument backups combined to assure the quality of the aircraft data:

- Backup instruments (ozone and NO/NO_y) were maintained at STI. These instruments were calibrated and made ready to be installed in either aircraft, when needed.
- At all four fixed bases of operations, air conditioning was provided to the aircraft to reduce heat loading between flights or IOPs.
- Instruments requiring warm-up periods were turned on after arriving in the field and were operated continuously throughout the remainder of the program in order to maintain their calibrations. When the aircraft landed at the Modesto or Paso Robles airports, the necessary power, hangar, and air conditioning was available to the instrumentation while the aircraft was between flights.
- All sampling coordinates were entered into the GPS unit aboard the aircraft.
- Inlet particle filters were changed periodically throughout the program. Fixed instrument ranges were used for the continuous monitors throughout the sampling program.
- Aircraft sampling system checks were conducted each day and prior to and following scheduled/completed flights.
- Multi-point calibrations of the air quality instruments were performed prior to and following most flight days. Additional details and the results of these calibration activities are reported in Section 5.1.3.
- To detect systematic calibration errors, the instruments were calibrated by different members of the aircraft crew on different days.
- A detailed checklist was used to perform extensive operational checks on each instrument prior to each sampling flight.
- Data were recorded on the data acquisition computer's hard disk drive and on a removable, backup ZIP disk simultaneously to provide redundancy.
- The aircraft field manager debriefed flight crews after each flight to identify and, if necessary, correct any operational problems.
- Data files and flight notes were copied after each flight. The data were carefully reviewed by the aircraft field manager to identify any problems. Problems that were noted were discussed with the flight crew(s).
- After a flight was completed, flight notes were reviewed and VOC and carbonyl grab samples were inventoried and periodically delivered to the appropriate contractors.
- After a carbonyl grab sample had been collected, the sample bag was placed inside a larger opaque bag.

5.1.3 Calibration

After the aircraft arrived in Santa Rosa and Bakersfield, power was connected to the NO/NO_y and ozone monitors, and they were allowed to stabilize. Initial multi-point calibrations were performed using the calibration systems described below. The instruments were typically calibrated before and after each flight day for the remainder of the program. All calibrations performed on the continuous instrumentation were full, multi-point calibrations. Calibration results are shown in **Tables 5-1 and 5-2**.

Table 5-1. Calibrations performed on the Aztec instrument suite during the CCOS operational period.

Page 1 of 2

Calibrator	Instrument	Date	Slope	Intercept (ppb)	R^2	Zero	NO_y Conversion Efficiency
Environics	Ozone	7/7/00	0.94	0.52	1.000	-1.8	
Environics	NO	7/7/00	0.92	-2.77	0.997	1.58	
Environics	NOy	7/7/00	0.92	-1.05	1.000	1.22	99.0
Environics	Ozone	7/11/00	0.97	0.69	1.000	-1.7	
Environics	NO	7/11/00	0.93	-2.10	0.996	1.08	
Environics	NOy	7/11/00	0.93	-1.66	1.000	2.65	98.9
Environics	CO	7/11/00	1.02	-0.05	0.999	0.02	
Environics	Ozone	7/21/00	1.00	1.91		-1.9	
Environics	NO	7/21/00	0.94	-4.71	0.993	0.89	
Environics	NOy	7/21/00	0.94	-1.67	1.000	1.78	98.2
Environics	CO	7/21/00	1.03	-0.33	1.000	0.32	
Environics	Ozone	7/23/00	1.00	1.63		-1.6	
Environics	Ozone	7/24/00	1.07	8.90	1.000	-8.7	
Environics	NO	7/24/00	0.97	-0.94	0.973	0.98	
Environics	NOy	7/24/00	0.98	-1.69	1.000	1.73	99.9
Environics	CO	7/24/00	1.00	-0.69	1.000	0.69	
Environics	Ozone	7/29/00	0.94	1.72		-2.0	
Environics	NO	7/29/00	0.88	-0.23		0.27	
Environics	NOy	7/29/00	0.95	-7.01		7.39	
Environics	CO	7/29/00	0.94	-0.12	1.000	0.12	
CSI	Ozone	7/30/00	0.95	1.78		-1.9	
CSI	Ozone	7/31/00	0.92	10.28		-1.9	
CSI	CO	7/31/00	0.93	-0.39	0.997	0.42	
CSI	Ozone	8/1/00	0.94	4.80	1.000	1.3	
Environics	Ozone	8/11/00	0.99	2.32	1.000	-2.0	
Environics	NO	8/11/00	0.95	-2.39	0.986	1.15	
Environics	NOy	8/11/00	0.96	-2.26	1.000	2.29	98.0
Environics	CO	8/11/00	0.97	-0.44	0.999	0.52	

Table 5-1. Calibrations performed on the Aztec instrument suite during the CCOS operational period.

Calibrator	Instrument	Date	Slope	Intercept (ppb)	R^2	Zero	NO_y Conversion Efficiency
CSI	Ozone	8/21/00	0.94	4.28	1.000	-2.7	
CSI	NO	8/21/00	0.83	1.19	1.000	-0.17	
CSI	NOy	8/21/00	0.84	0.33	1.000	0.87	100.3
CSI	CO	8/21/00	0.80	-0.21		0.26	
CSI	NO	9/9/00	0.82	0.94	0.999	0.02	
CSI	NOy	9/9/00	0.83	0.25	0.999	1.06	98.4
CSI	Ozone	9/10/00	0.89	4.92	1.000	-1.8	
CSI	CO	9/9/00	0.92	-0.06	1.000	0.09	
CSI	Ozone	9/17/00	0.99	5.77	1.000	-1.8	
CSI	NO	9/17/00	1.00	0.76	0.999	-0.03	
CSI	NOy	9/17/00	1.01	-0.72	1.000	1.59	99.7
CSI	CO	9/17/00	0.97	-0.24	0.999	0.28	
CSI	Ozone	9/18/00	1.74	3.34	1.000	-1.9	
CSI	NO	9/18/00	0.96	0.03	1.000	-0.03	
CSI	NOy	9/18/00	0.96	-1.05	1.000	1.09	98.9
CSI	CO	9/18/00	0.98	-0.33	1.000	0.33	
CSI	Ozone	9/19/00	2.07	-2.19	0.999	2.9	
CSI	NO	9/19/00	0.93	0.73	0.999	0.03	
CSI	NOy	9/19/00	0.94	-0.32	1.000	1.32	99.5
CSI	CO	9/19/00	0.92	-0.12	0.999	0.23	
Environics	Ozone	10/3/00	0.90	3.20	1.000	-1.9	
Environics	NO	10/3/00	1.04	-2.60	0.981	1.01	
Environics	NOy	10/3/00	1.06	-2.03	1.000	1.72	99.5
Environics	CO	10/3/00	1.11	-0.63	0.989	0.37	
CSI	Ozone	10/3/00	0.84	5.17	1.000	-2.0	
CSI	NO	10/3/00	0.92	0.81	0.999	0.03	
CSI	NOy	10/3/00	0.92	0.12	1.000	0.82	99.2
CSI	CO	10/3/00	0.90	-0.20	0.999	0.32	
Environics	O3	10/4/00	0.88	1.46		-1.7	

Table 5-2. Calibrations performed on the Cessna 182 instrument suite during the CCOS operational period.

Calibrator	Instrument	Date	Slope	Intercept (ppb)	R^2	Zero	NO_y Conversion efficiency
CSI	Ozone	7/7/00	1.00	0.78	0.999	-1.0	
CSI	Ozone	7/13/00	0.63	3.13	0.999	-1.5	
CSI	NO	7/21/00	1.10	Span check only		0.00	
CSI	NOy	7/21/00	1.11	Span check only		0.58	99.5
CSI	Ozone	7/23/00	0.69	3.36	0.989	0.0	
CSI	NO	7/23/00	1.25	0.29	1.000	0.20	
CSI	Ozone	7/24/00	0.76	-5.18	0.998	2.7	
CSI	Ozone	7/25/00	1.02	0.69	0.999	-0.5	
CSI	NO	7/25/00	1.06	4.92	0.997	0.29	
CSI	NOy	7/25/00	1.06	5.42	0.997	2.92	98.4
CSI	Ozone	7/29/00	1.04	0.40	1.000	0.0	
Environics	Ozone	7/30/00	1.02	-1.89	1.000	-0.5	
Environics	Ozone	8/14/00	1.08	-1.24	1.000	-1.2	
Environics	NO	7/29/00	1.02	-3.52	0.995	1.33	
Environics	NOy	7/29/00	1.03	-2.00	1.000	1.85	96.8
Environics	NO	7/31/00	1.07	8.12	1.000	8.20	
Environics	NOy	7/31/00	1.07	9.26	1.000	9.80	98.5
Environics	NO	8/1/00	0.99	5.68	0.998	0.10	
Environics	NOy	8/1/00	0.99	8.14	0.998	3.10	97.3
Environics	NO	8/13/00	0.80	4.22	0.998	0.20	
Environics	NOy	8/14/00	1.01	Span check only		1.60	100.2
Environics	Ozone	9/7/00	1.05	1.66	1.000	-0.8	
Environics	NO	9/7/00	1.01	-3.61	0.999	2.62	
Environics	NOy	9/7/00	1.03	-4.32	0.999	3.42	96.8
Environics	Ozone	9/13/00	0.98	0.65	0.999	-1.2	
Environics	Ozone	9/14/00	1.12	2.71	1.000	-1.4	
Environics	NO	9/14/00	1.02	-3.42	0.996	0.03	
Environics	NOy	9/14/00	1.02	-3.28	0.999	1.82	96.6
Environics	Ozone	9/17/00	1.16	-3.15	0.999	-1.2	
Environics	Ozone	9/18/00	1.14	1.64	1.000	-0.7	
Environics	NO	9/18/00	0.95	2.35	0.997	0.00	
Environics	Ozone	9/19/00	1.12	1.23	1.000	-0.9	
Environics	NO	9/19/00	1.15	-6.44	0.994	3.82	
Environics	NOy	9/19/00	1.15	-5.24	0.998	4.86	96.1
Environics	Ozone	9/20/00	1.14	0.88	1.000	1.9	
Environics	NO	9/20/00	0.98	-4.58	0.995	0.06	
Environics	NOy	9/20/00	0.99	-5.67	0.999	1.26	99.0
Environics	Ozone	9/22/00	1.14	-2.82	0.999	-1.2	
Environics	NO	9/22/00	0.94	4.47	0.998	0.20	
Environics	NOy	9/22/00	0.94	5.28	0.998	0.62	96.8

In processing the data, the calibration history of a particular instrument was considered before applying the appropriate sensitivity slope and zero offset to the data. If the results of a calibration showed either a sensitivity or zero offset that was not consistent with previous or subsequent calibrations, a decision was made whether to use that calibration data or to apply values consistent with the neighboring calibrations. The calibration values were applied using the following formula:

$$\text{Calibrated\_measurand} = (\text{measurand} + \text{zero\_offset}) * \text{slope}.$$

Calibration equipment

The dynamic calibration system for each aircraft consisted of a portable calibrator, a zero air system/module (ZAM), an ozone transfer standard, and a NIST-traceable gas cylinder containing a certified level of NO, SO_2, and CO in nitrogen. The calibrators used alternately with both aircraft were an Environics Series 100 and a Columbia Scientific Industries (CSI) Model 1700. Each calibrator contained two mass flow controllers which provided known flow rates of dilution air from the ZAM and span gas from the standard gas cylinder. The calibrator was capable of delivering the desired gas concentrations by adjusting each mass flow controller to provide previously determined flow rates. The dilution airflow controller had a nominal range of 1,000 to 10,000 standard cubic centimeters per minute (sccm), and the span gas flow controller had a nominal range of 5 to 100 sccm.

Each calibrator contained an ozone generator, which was used for ozone calibrations. The ozone stream could be directed into the dilution air stream to enable these calibrations. Gas-phase titration (GPT) could also be performed by directing the ozone stream into the NO span gas stream. Each calibrator had a reaction chamber and a mixing chamber of appropriate dimensions, which, when taken together with the flow rates that were used, complied with the U.S. Environmental Protection Agency (EPA) requirements for NO_2 generation by means of the GPT procedure.

As required by the EPA, high concentration span gases came in contact with only stainless steel, Teflon, and glass. Diluted gases came in contact with only Teflon and glass and were sampled from the calibrator at ambient pressure by means of a small sample manifold, to which the calibrator effluent and analyzer sample line were connected.

Zero air module

Zero air for the calibrator was generated from ambient air using a portable ZAM. The ZAM contained a compressor, a drier, Purafil, activated charcoal, Hopcalite, and a 5-micron molecular sieve particle filter. The ZAM delivered dry air, which was free of NO, NO_2, and ozone, at a flow and pressure which met the specifications of the dilution mass flow controller in the calibrator.

Compressed gas standard

The NIST-traceable NO and CO span gas cylinders used during the project were purchased from Scott-Marrin, Inc. These cylinders were used with the dilution calibrators to calibrate the NO/NO_y and the CO (Aztec only) analyzers.

Ozone transfer standard

A Dasibi 1003 was used as a transfer standard for both aircraft at the start of the program. It was traceable to a primary standard and was certified using the primary standard. Ozone concentrations generated by the CSI calibrator were measured using the transfer standard. The Environics calibrator provided a direct readout of the ozone concentration generated.

Procedures

The calibrator and transfer standard were checked and tested by STI's QA laboratory in Bakersfield prior to use in the program. Mass flow controllers received multi-point flow checks. The ozone transfer standard was certified against a primary standard before the program and again after the program.

For ozone calibration, the sample delivery line from the calibrator was connected to the inlet of the glass manifold inside the aircraft. The analyzer sampled normally from the glass manifold. Temperature (in the photometer cell) and pressure measurements were made during calibrations and were applied to calculations to determine true ozone concentrations.

For calibration of the NO analyzers, the sample delivery line from the calibrator was connected to what was normally the exhaust port of one of the inlet systems. The analyzers sampled normally from their inlet system. Following most multi-point calibrations, a converter efficiency check was performed on each monitor using standard GPT methods.

5.2 QUALITY ASSURANCE AUDITS

As part of the overall QA plan for the project, an audit of the gas analyzers aboard the aircraft was performed by personnel from the ARB's Quality Assurance Section. The audit was performed on July 3, 2001 at the Healdsburg airport. The audit results for the chemical sensors, shown in **Tables 5-3 and 5-4**, will also be reported by Mr. David Bush.

Table 5-3. Preliminary audit results reported by the ARB for instrumentation audited aboard the STI Aztec during the July 3, 2000, performance audit.

	Audit Concentration (ppbv)	Percent Difference*	Average Percent Difference	Standard Percent Difference	Correlation
NO/NO_y (Audit results for NO_2)	27	7.4			
	53	5.7			
	76	7.9			
			7.0		0.99970
Carbon Monoxide	3700	2.7			
	6200	1.6			
	7300	1.4			
			1.9		1.00000
Ozone	68	1.5			
	168	4.2			
	.381	4.2			
			3.3		0.99999

$$\text{* Percent Difference} = \frac{\text{Station Response - Audit Concentration}}{\text{Audit Concentration}}$$

Table 5-4. Preliminary audit results reported by the ARB for instrumentation audited aboard the STI Cessna during the July 3, 2000, performance audit.

	Audit Concentration (ppbv)	Percent Difference*	Average Percent Difference	Standard Percent Difference	Correlation
NO/NO_y (Audit results for NO_2)	27	7.4			
	54	7.4			
	77	7.8			
			7.5		0.99999
Ozone	68	0.0			
	163	3.7			
	368	4.1			
			2.6		0.99999

$$\text{* Percent Difference} = \frac{\text{Station Response - Audit Concentration}}{\text{Audit Concentration}}$$

5.3 RESULTS OF THE INTERCOMPARISON FLIGHTS

Two intercomparison flights were performed. On July 5, 2000, the STI Aztec flew an intercomparison with the DOE G-1 near Fresno. On July 6, 2000, both STI aircraft flew an intercomparison flight with the UCD Cessna 182 around Sacramento. For the comparison with the DOE G-1 a flight route was agreed upon by the crews of both aircraft, including a series of traverses and vertical profiles, and was executed separately. This was necessary because of a significant disparity in speed between the two aircraft. The data collected aboard the Aztec for that flight was submitted to Mr. David Bush.

For the comparison between the two STI aircraft and the UCD aircraft, a flight route, including several traverses and a vertical profile, was executed; all three aircraft flew in a formation with the STI Aztec in the lead, followed by the STI Cessna and the UCD Cessna, respectively. Data from that intercomparison were shared between the participants and were submitted to Mr. David Bush. The ozone, NO, and NO_y measurements made aboard the three aircraft all agreed to within the stated uncertainties for the different instruments. The nephelometer mounted on the STI Cessna was not operational for the intercomparison flight. The results from the STI Aztec b_{scat} measurement and the UCD Cessna b_{sp} measurements agreed well once the difference of Rayleigh scattering (measured with the Aztec instrument [~ 11 Mm^{-1}]) was accounted for. **Figures 5-1 through 5-3** show the time series data collected aboard the STI aircraft during the July 6, 2000, intercomparison. The times were adjusted slightly to account for the distance between the aircraft.

5.4 COMPARISON OF AIRCRAFT, SURFACE, AND UPPER-AIR OBSERVATIONS

During the data validation process the measurements collected aboard both the STI Aztec and Cessna 182 were compared to several ground-based and wind profiler data sets. For the Aztec, wind profilers located at Bodega Bay and Tracy were used to check the wind measurements collected with the aircraft-mounted AIMMS-10 system. Ozone measurements made aboard the Aztec were checked against measurements made at the surface at Bethel Island and Parlier. The Cessna 182 measurements for wind speed and direction, NO, NO_y, ozone, and b_{sp} were checked against the measurements made at the Angiola field site. In all cases the aloft and surface-based measurements showed good agreement for afternoon, well mixed observations.

5.5 DESCRIPTION OF DATA COMPLETENESS, PRECISION, ACCURACY, AND LOWER QUANTIFIABLE LIMIT

This section is currently under preparation and will be forwarded to ARB on or before December 19, 2001.

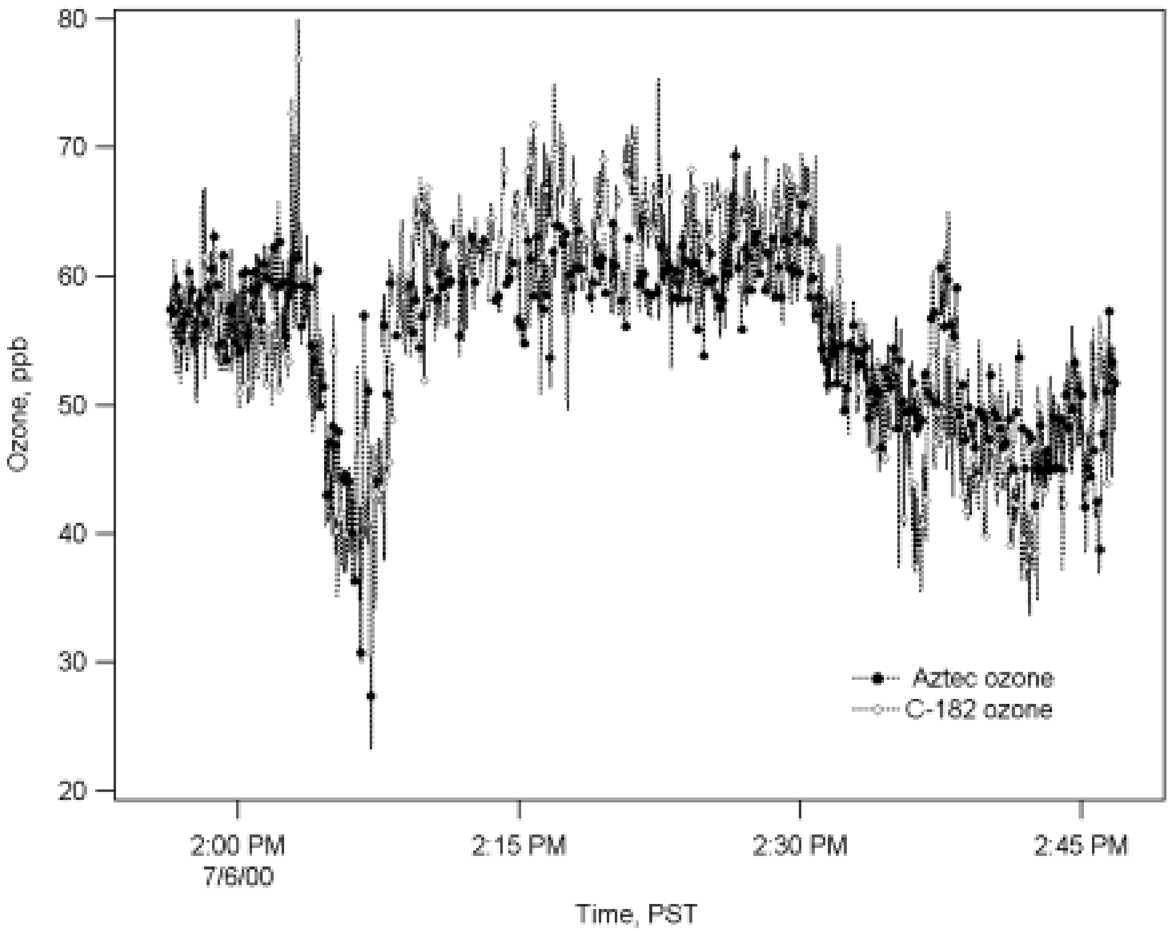


Figure 5-1. Time series of the ozone data collected aboard the STI Aztec and the STI Cessna 182 during the July 6, 2000, intercomparison flight.

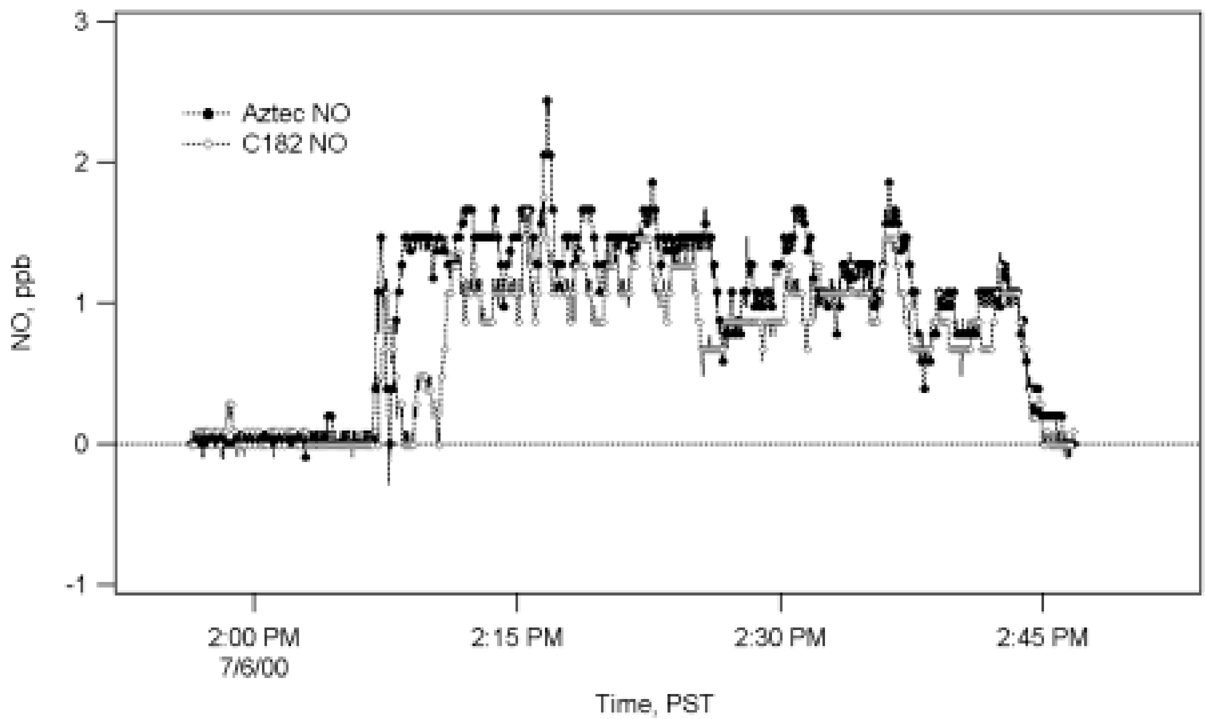


Figure 5-2. Time series of the NO data collected aboard the STI Aztec and the STI Cessna 182 during the July 6, 2000, intercomparison flight.

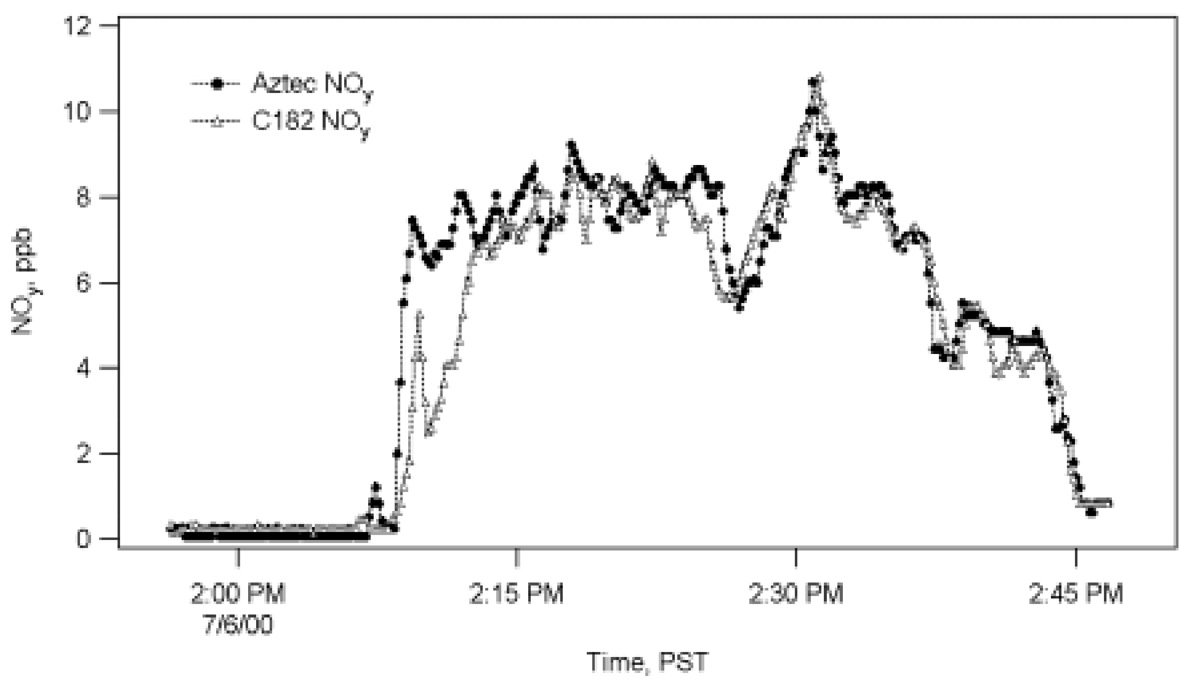


Figure 5-3. Time series of the NO_y data collected aboard the STI Aztec and the STI Cessna 182 during the July 6, 2000, intercomparison flight.

6. RESULTS AND RECOMMENDATIONS

The air composition and meteorology observations made with the STI aircraft during CCOS comprise a useful database for further exploration of transport and chemical processes in the SJV and upwind regions. The greatest utility of the Aztec data may be in establishing limits on the upwind boundary conditions. The observations made with the Cessna will be useful in exploration of the transport processes and chemical evolution attendant to ozone episodes in the SJV.

Highlights of the observations made with the Aztec include

- High quality data for ozone, NO, NO_y, CO, b_{scat}, and winds collected offshore at altitudes from 500-5000 ft. under a variety of conditions.
- Persistent layers of ozone concentration greater than 50 ppbv in air masses coming from the Pacific Ocean.
- Significant transport of pollutants from onshore sources to points 100 miles offshore. Preliminary evaluation of the air composition in these polluted layers suggest a forest fire source.

Highlights of the observations made with the Cessna include

- Excellent temporal and spatial coverage of the southern SJV during the two principal ozone episodes experienced during summer 2000.
- Good spatial and chemical characterization of the Fresno and Bakersfield urban plumes and their transport to the greater valley.
- Multi-day repetitive flight patterns that will allow exploration of the physical and chemical conditions associated with SJV-wide ozone episodes.

In addition to providing a database useful for model evaluation, these observations could be used to investigate a number of specific topics:

- Compare and contrast ozone distribution and ozone production efficiency at the surface and aloft for the Bakersfield, Fresno, and Angiola field sites.
- Examine rural ozone in the SJV with respect to sources of precursors, dynamics, and local production versus advection
- Contribution of forest fires to SJV ozone and particulate matter.

7. REFERENCES

Buhr M.P., Alcorn S.H, and Blumenthal D.L. (2001) Central California Ozone Study Aircraft Data. Report prepared for the California Air Resources Board, Sacramento, CA by Sonoma Technology, Inc., Petaluma, CA, STI-900106-2074-DV, August.

California Air Resources Board (2001) Central California Air Quality Study Data Transmittal Format Document for CCOS. Release: CCOS021401A, February 14. Available at <http://www.arb.ca.gov/airways/CRPAQS/lookups.htm>.