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Boulder, Colorado

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The Use of an Airborne Air Sampling Platform for Regional Air Quality Studies

D.L. Wellman, M. Luria,* C.C. Van Valin, and J.F. Boatman

ABSTRACT. A Beechcraft King Air, owned and operated by the Office of Aircraft Operations, National Oceanic and Atmospheric Administration (NOAA), was converted from a passenger airplane into an atmospheric air quality sampling platform. It has been used in several regional air quality studies including the Gulf Coast Experiment, the Western Atlantic Ocean Experiment (WATOX), and the Processing of Emissions by Clouds and Precipitation (PRECP) experiment. The aircraft is equipped to measure atmospheric trace gases (SO_2, O_3, and NO_x), aerosols, and meteorological parameters (temperature, humidity, wind speed, wind direction, atmospheric pressure, and solar radiation). It has grab sampling equipment (for aerosol chemistry and organic compounds) and instruments for continuously recording position and heading. Most of the scientific equipment aboard was provided by the Air Quality Group, Air Resources Laboratory, NOAA, with additional support from several universities and other institutions. The WATOX project is used as an example to demonstrate the capabilities of the aircraft as a regional air quality sampling platform. During this experiment, air samples were taken in the winter and spring seasons of 1985 and 1986 at two locations off the U.S. East Coast (Newport News, VA, and Boston, MA) and in the vicinity of Bermuda. These locations were selected to provide samples representative of contaminated air masses exiting from the continent and being transported over the Atlantic Ocean. Flight tracks were designed to assess the flux of atmospheric pollutants above and within the planetary boundary layer. Through the successful use of the aircraft, it was revealed that most of the pollutant transport within this region was being accomplished inside the boundary layer. Additionally, in several cases, contaminated air masses were observed in the free troposphere.

1. INTRODUCTION

The use of aircraft has become common for studying a wide variety of atmospheric chemical processes on the local, regional, and global scales. Local-scale investigations have focused primarily on large point sources such as power plants, where the major interest was to investigate the processes

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governing gas-to-particle conversion and the rate of SO_2 conversion to sulfate. The early investigations used simple instrumentation, short-term commitments, and usually, a leased, single-engine aircraft. An early implementation of this then-new approach was reported by Gartrell et al. (1963), who studied in situ oxidation of SO_2 in the plume of a coal-fired power plant. The opportunity to measure the vertical and horizontal dimensions and the identity and distribution of the constituents of plumes at various downwind distances without the complications of deposition encouraged numerous researchers to repeat and improve upon the pioneering work of Gartrell et al.

During the 1970's, the use of research aircraft for atmospheric chemistry studies was expanded with the goal of understanding the various aspects of gas-to-particle conversion in plumes emanating from point sources. Van Valin and Pueschel (1981) reported on conversion rates in coal-fired power plant plumes in the western United States; Forrest et al. (1979) reported on the conversion in oil-fired power plant plumes; Meagher et al. (1981, 1983) reported on the seasonal effects on the atmospheric conversion rates of SO_2 to sulfate and the effect of SO_2 scrubbing on these rates; and Husar et al. (1978), as part of the Sulfate Regional Experiment (SURE), demonstrated the diurnal nature of the SO_2 conversion process.

Large aircraft, the four-engine Lockheed Electra and WP-3D (P-3), were instrumented and used in global-scale atmospheric sampling. Examples of these studies include the Global Atmospheric Measurements Experiment on Tropospheric Aerosols and Gases (GAMETAG), conducted by the National Center For Atmospheric Research (NCAR), and the Arctic Gas and Aerosol Sampling Program (AGASP), carried out by the National Oceanic and Atmospheric Administration (NOAA). The objective of GAMETAG (Davis, 1980) was to establish global background levels of trace atmospheric gases, and that of AGASP (Schnell, 1984) was to investigate the composition and characteristics of Arctic haze. It is obvious that such programs require the use of large, long-range aircraft supported by a substantial budget and substantial human resources.

The need to investigate regional-scale air quality issues motivated us to develop an airborne platform capable of providing complete air quality information using limited resources, on the one hand, but retaining the flexibility to operate anywhere within the North American continent, on the other hand. The objectives of the Air Quality Group (AQG), Air Resources Laboratory, NOAA, call for operation over areas that are affected by high levels of anthropogenic pollution; therefore we were able to use a less-sensitive analytical instrument package on board, based on commercially available units. Although units may be less sensitive than experimental or developmental instrumentation, they provide a higher degree of reliability. In early 1984, a Beechcraft King Air C-90 was leased from the Department of Interior (DOI) by the AQG and modified for use as a regional air quality sampling platform. Ownership of the aircraft was later transferred from DOI to the Office of Aircraft Operations (OAO), NOAA. During the first 2 years of its operation, the aircraft was used in a number of regional studies related to the National Acid Precipitation Assessment Program. These studies included the Gulf Coast Experiment (Luria et al., 1986), Processing of Emissions by Clouds and Precipitation (PRECP), and Western Atlantic Ocean Experiment (WATOX).

In this paper we discuss the use of the King Air as an atmospheric sampling platform for regional air quality studies in general. We use WATOX as the specific example to demonstrate the capabilities of this airborne sampling platform.

2. DETAILS OF THE AIRBORNE SAMPLING PLATFORM

2.1 Description of Aircraft

The Beechcraft King Air C-90 is a twin-engine aircraft equipped with 550-hp Pratt-Whitney PT-6A-20 turbine engines. The aircraft has a useful load of 1600 kg and a gross weight of 4390 kg; it was originally designed to carry a crew of two and up to seven passengers. Its fuel capacity is 1450 L, and the consumption rate is 250 L h^{-1}. The range of the aircraft, fully fueled, is 2400 km at an average speed of 420 km h^{-1} and cruise altitude of 6400 m. The service ceiling of the aircraft is 7600 m. The outside dimensions are 10.8 m (length) by 15.3 m (wing span) by 4.3 m (vertical stabilizer height). The cabin volume available is 8.2 m^3 (excluding pilot compartment), and an additional 1.5 m^3 is available in the baggage compartment at the rear of the cabin. The aircraft is fully equipped for operation under instrument flight rules, can be pressurized, and has complete de-icing capability. When equipped as described in section 2.2 and with a crew of three (pilot, copilot, and scientist-flight director) the aircraft weighs 3560 kg. This allows for 820 kg of fuel and provides for a flight duration of about 4 hours.

2.2 Conversion From Utility to Research Aircraft

The change from a passenger aircraft to an airborne laboratory required several major modifications to the aircraft. The original floor track hardware was used to securely mount aluminum equipment racks for research instruments (Wellman, 1982). To supply power to the instruments (most of which require 110-V AC), lightweight DC to AC inverters were connected to the aircraft 28-V DC electrical system. The power pack consists of three 110-V AC (750 VA) 400-Hz inverters made by FliteTronics Co. Inc., two 110-V AC (1000 VA) 60-Hz units built by Avionics Instruments Inc., and additional 28 V DC (70 A).

The end sections of the wings were reinforced by the addition of spar doublers and torque boxes so that scientific instruments weighing up to 20 kg could be mounted on each wing; wiring was installed in the wings to carry the power and signals for these instruments. To facilitate the sampling of outside air, the fuselage was reinforced over the right-hand side of the forward cabin and a stainless steel air intake system was installed through it. Five shutter assemblies were also installed for in situ or remote sensing purposes as needed. The shutter assembly is a mechanically operated, 5-cm sealable port that opens to the outside air.

For the accurate determination of aircraft position, a Long Range Aid to Navigation (LORAN) system was installed. This system (Advanced Navigation

Inc., model 7000) can be used to determine position to 0.5 km. A radar altimeter (King, KRA10) was installed both to aid in maintaining constant altitude at low elevations (less than 760 m) and to enhance flight safety when low-altitude sampling is required.

2.3 Description of Scientific Equipment

The air intake system aboard the aircraft was designed so that different intakes could be mounted for different applications. For the WATOX study, a five-tube stainless steel configuration was employed to obtain both gas and aerosol samples. Three tubes were oriented in the forward direction and two were mounted vertically. Of the three forward-oriented tubes, one was used for total aerosol sampling; it was designed to be isokinetic at any flight sampling speed by using a tip with an opening of the appropriate diameter. Another was used to supply air for the gas monitors; it was fitted with an inner Teflon tube. A third was used to supply air to a "cyclone" particle separator, described by Boatman and Wellman (1985). The vertical tubes and the shutter assembly at the top center of the fuselage were used to draw additional air samples for intermittent sampling devices. Information on the instruments aboard the aircraft is given in Table 1.

Also for WATOX, a centrifugal separator (Fisher-Klosterman Inc.) was installed ahead of the aerosol sampling device to separate the atmospheric aerosol according to size. This separator is 95% efficient for the removal of particles larger than 1.0 μm in diameter and 99% efficient for those larger than 3 μm in diameter (Boatman and Wellman, 1985). Aerosol sampling was performed in two parallel and identical filter systems. The air streams from both the isokinetic intake and the centrifugal separator were directed to three-stage filter packs through a 7° cone 25 cm in length. The filter packs are modularized to permit use of one or more filters in series, as required. In WATOX, the filter material for the first stage was 1.0 μm Fluoropore (Millipore Corp.) for aerosol sampling. The second stage consisted of a nylon membrane (Gelman Inc.) to collect residual nitric acid vapor and SO_2. Whatman 41 filter paper (Whatman Co.), impregnated with glycerol and sodium carbonate for SO_2 detection, was used as a third filter. Air was pulled through each pack independently by a high-speed rotary pump (Staplex) at a flow rate of 100-200 L min^{-1}. The flows were continuously monitored by recording mass flow meters (Kurz Inc.). The filters were analyzed for SO_4^{2-}, NO_3^-, and other anions, and for trace metals and SO_2.

Data from all continuous monitors, aerosol probes, and mass flow meters are digitized using a data acquisition system (Particle Measuring Systems Inc.) and recorded on magnetic tape cartridges (Algo Inc.). These data are displayed onboard the aircraft using an IBM-compatible (Compaq Inc.) computer (Wilkison and Boatman, 1988). The data from the navigation system are recorded on magnetic tape cartridges (Algo Inc.). All magnetic tape data are later merged into one file for analysis using an HP 1000 computer system (Hewlett-Packard Inc.). Data reduction is discussed in section 4.1.

2.4 Guest Investigators

Space and electrical power for the instrument array in the King Air are sufficiently flexible to permit guest investigators to install special-

Table 1. Scientific instrumentation employed in the 1986 WATOX experiment

Parameter measured	Operation principle or instrument	Manufacturer	Sensitivity/ Resolution	Response (s)*
Sulfur dioxide	Pulsed fluorescence	Thermo Electron	1.0 ppb	60
Total sulfur	Flame photometry	Columbia Scientific	0.5 ppb	10
Ozone	UV absorption	Thermo Electron	1.0 ppb	30
Fine particle	Light attenuation	Particle Measuring Systems	d < 3.1 μm	0.1
Coarse particle	Light attenuation	Particle Measuring Systems	d < 45 μm	0.1
Temperature	Resistance	Rosemount	0.1°C	1.0
Dew point	Hygrometer	General Eastern	0.5°C	1.0
Pressure	Transducer	Rosemount	0.1 mb	1.0
Differential pressure	Transducer	Tavis	0.1 mb	1.0
Solar radiation	Photo cell	LI-COR	1.0 W m^{-2}	<1.0
Position	LORAN (radio)	Advanced Navigation	0.2 km	--
Wind speed†	LORAN (radio)	Advanced Navigation	1.0 m s^{-1}	--
Wind direction†	LORAN (radio)	Advanced Navigation	1.0°	--

*Greater than 90% of full scale.
†Calculated value.

application equipment. Table 2 lists the WATOX investigators and their areas of interest.

2.5 Aircraft Operational Procedures

The aircraft is operated by the OAO and employs an OAO pilot and copilot. The scientific personnel aboard include a mission scientist and, if required by the program, an instrument operator-technician. An illustration of the aircraft, configured for scientific research, is given in Fig. 1.

It has been found advantageous to devise a general flight plan well in advance of each field program. Then, about 24 hours prior to departure on a research flight, an initial evaluation of the prevailing weather conditions and a forecast are obtained by inquiries to the National Weather Service (NWS) and/or visits to a nearby Flight Service Station. The weather situation is updated periodically as the time for the research mission approaches; final confirmation is established within the last 4 hours prior to departure.

Table 2. Guest investigators in WATOX, their affiliations, and areas of interest

Investigator	Affiliation	Area of interest
J. Galloway	University of Virginia	Anthropogenic pollutant flux estimates
W. Keene	University of Virginia	Weak organic acids; analysis of anions
D. Hastie	York University (Canada)	Oxides of nitrogen by luminol and by chemiluminescence
A.H. Knap	Bermuda Biological Station	Polycyclic organics
D.M. Whelpdale	Atmospheric Environment Services (Canada)	Inorganic anions
M.O. Andreae	Florida State University	Dimethyl sulfide measurements
H. Westburg	Washington State University	Hydrocarbons (to C_{10}) and CO sampling and analysis
R.A. Rasmussen	Oregon Graduate Center	Sampling and analysis of CO; hydrocarbons (to C_4) and dimethyl sulfide
W. Zoller	University of Washington	Sampling and analysis for trace metals and inorganic anions

Two to three hours before takeoff, the research instruments aboard the aircraft are powered using a ground power unit (GPU). Following sufficient warm-up time, the instruments are calibrated, data tapes are loaded and the data system is tested for proper operation. After completion of ground preparation, the aircraft engines are started and power is switched from the GPU to the aircraft system with no interruption of power to the instruments. After takeoff, a course is established to a predetermined sampling area free of contamination from local sources. En route to the sampling area, real-time wind data are compared with those predicted, and changes to the flight track are considered in order to meet the research goals established for the mission.

Research flight patterns are determined by sample collection and instrument response requirements in concert with the program objectives. In the WATOX program one objective was to determine the flux of atmospheric trace contaminants within the lowest 3000 m off the U.S. East Coast. This consider-

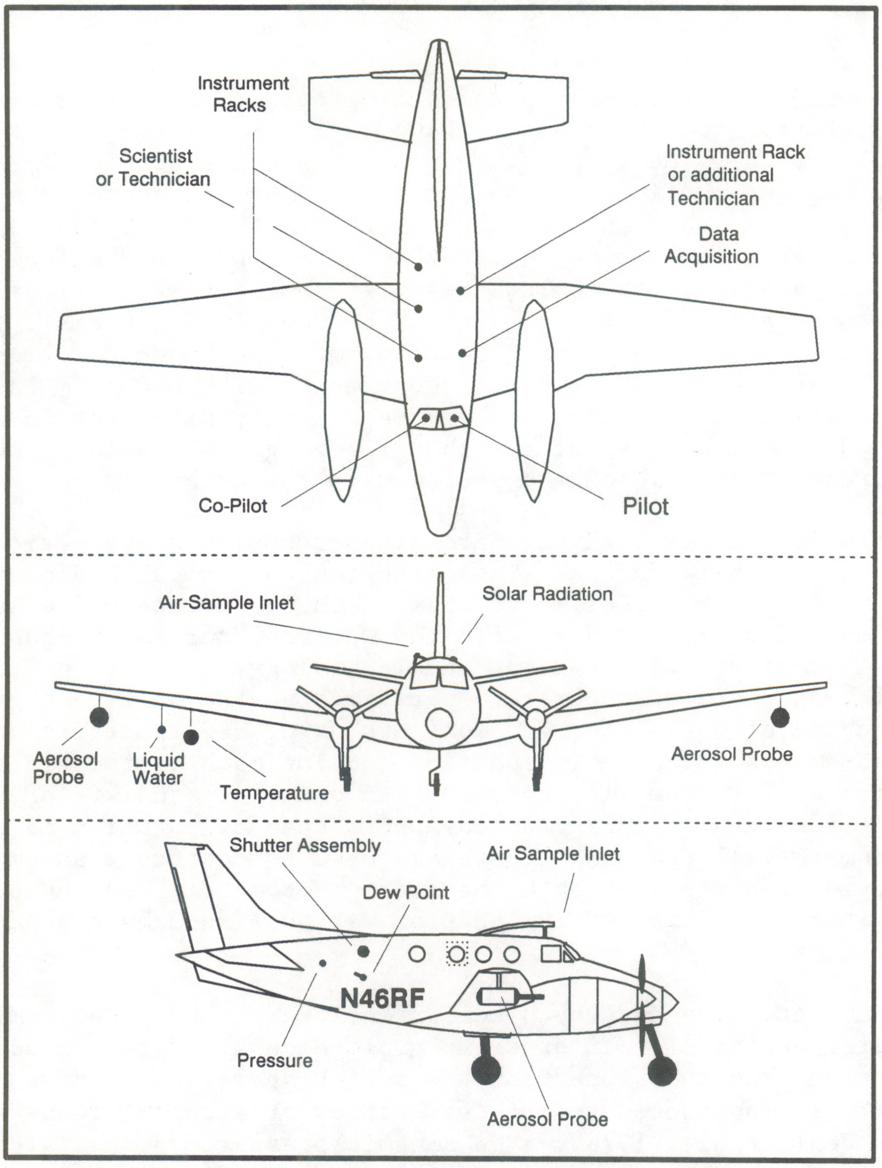

Figure 1. The NOAA King Air C-90, configured for research.

ation made it necessary to obtain representative samples within both the boundary layer and the free troposphere at a sufficient distance offshore so that coastal point pollution sources would not dominate the samples to be collected.

To obtain sufficient loading on the aerosol filters, long sampling times at constant altitude are necessary. Some instruments, in the WATOX case the sulfur gas analyzers, require calibration checks at each altitude. Thus, long sampling times at constant altitude may be necessary as a compromise, with the goal of obtaining detailed vertical profiles. Typical WATOX flights consisted of 45- to 60-min flight legs at each of four altitudes, two within the boundary layer and two within the free tropopause. To minimize possible contamination from ocean spray, the upper-level sampling was usually done first.

2.6 Calibration and Quality Control

During a series of flights prior to a field program, calibrations of the instruments used to determine the meteorological parameters are performed near the Boulder Atmospheric Observatory (BAO), a 300-m instrumented tower 20 km east of Boulder, CO. The temperature sensor is corrected for dynamic heating using the technique outlined by Veal et al. (1978). A comparison of the outside air pressure measured aboard the aircraft with that measured on the tower typically reveals agreement to better than 1 mb. Dew points from the airborne sensor are compared with dew points measured on the tower; values are generally found to agree to 1°C. The accuracy of the LORAN system is tested by making repetitive cross patterns directly above the known position of the BAO. It is found that the LORAN system is accurate to within 0.5 km in latitude and 0.7 km in longitude. This accuracy may be slightly different in other parts of the United States because of the changing geographic relationship between the LORAN transmitters, which the system uses for triangulation.

The mass flow meters and the aerosol spectrometers are periodically calibrated by their manufacturers. The ozone monitor is calibrated using the Geophysical Monitoring for Climatic Change (GMCC) Surface Ozone Network standard instrument that is compared with the National Bureau of Standards (NBS, now National Institute of Standards and Technology) standard photometer. Zero checks (using an ozone scrubber) are performed periodically. A ground zero-span calibration of the sulfur gas monitors using NBS-traceable compressed gases precedes each flight. In addition, during each of the field studies a comprehensive calibration flight is carried out. It consists of five or six constant-altitude tracks during which a zero-span calibration is accomplished. The data from the calibration flights are used to construct an empirical altitude correction function for both the flame photometric and the pulsed fluorescence monitors. A detailed explanation was published by Boatman et al. (1988a).

The temperature sensor, both sulfur analyzers, and the dynamic pressure sensor require calibration in order to yield accurate data. A description of the calibration procedures used for the sulfur analyzers is given by Boatman et al. (1988a). The procedure for calibration of airborne temperature sensors is given by Veal et al. (1978). The dynamic pressure device is calibrated by measuring its voltage at a number of pressures and fitting a least-squares curve to the results.

3. THE USE OF THE KING AIR IN WATOX

The objective of WATOX was to determine the magnitude and fate of selected sulfur, nitrogen, metal, and organic compounds as they were advected eastward from North America. The experiment consisted of two phases: long-term surface measurements of wet and dry deposition on the U.S. East Coast and in Bermuda, and a series of intensive field studies to investigate the processes that control the transport, transformation, and deposition of materials to the western Atlantic Ocean. During the intensive studies, the King Air research aircraft was used to sample atmospheric gases and aerosols off the U.S. East Coast and near Bermuda. In January 1986, the King Air was joined by the NOAA P-3, which flew coastwise flight paths at distances of 150-300 km off shore and extending as much as 1000 km from a starting point near Atlantic

City, NJ. The NOAA P-3 characteristics and instrumentation aboard were similar to those used in the AGASP experiment (Schnell, 1984).

In a preliminary evaluation based on existing data, Whelpdale et al. (1984) calculated the air mass advection above the U.S. East Coast as a function of latitude and altitude. On the basis of this study, and using representative ground-level and elevated concentrations of trace sulfur and nitrogen species, Galloway et al. (1984) estimated the flux of these species; they suggested that a broad maximum in transport of sulfur and nitrogen compounds occurs between 38° and 52° north latitude. This preliminary information led to the establishment of sampling centers on the East Coast--at Newport News, VA, in the south, and at Boston, MA, in the north--and at Bermuda. The dates of the field studies are listed in Table 3.

Air mass back trajectories were calculated for the dates and locations given in Table 3 using the technique outlined by Harris (1982), thus enabling characterization of the time history of the sampled air mass. An example for 5 March 1985 is shown in Fig. 2. On that date the air mass passing Norfolk, VA, at the 850-mb and 700-mb levels had crossed the lower midwest 12 to 24 h earlier. An earlier trajectory analysis showed transport across western North America. At these levels this air mass clearly met the WATOX study criterion for advection of continental air across the continental boundary. Although the lowest level (1000 mb) trajectory indicated transport over land for the last 24 hours, the transport within the PBL was over the Atlantic Ocean for the majority of the last 7 days. Consequently, although the surface wind direction was westerly, the air mass was marginal in terms of the goals of WATOX. On the other hand, the trajectories for air crossing Bermuda on 5 April 1985 (Fig. 3) clearly show its continental origin.

Table 3. Sampling centers, sampling periods, and air mass characteristics for the WATOX experiment

Location	Sampling period		Sample time* (h)		Characteristics of air masses sampled
	From	To	IBL	ABL	
Newport News, VA	2-27-85	3-05-85	6	6	Post cold front, W and WNW flows
Newport News, VA	3-13-85	3-25-85	14	14	W and WNW flows
Bermuda	4-02-85	4-11-85	8	16	W flow
Boston, MA	1-02-86	1-11-86	8	16	W and NW flows
Boston, MA	2-02-86	2-20-86	20	20	W and NW flows
Bermuda	6-01-86	6-17-86	14	8	SW flow

*IBL and ABL, inside and above the boundary layer, respectively.

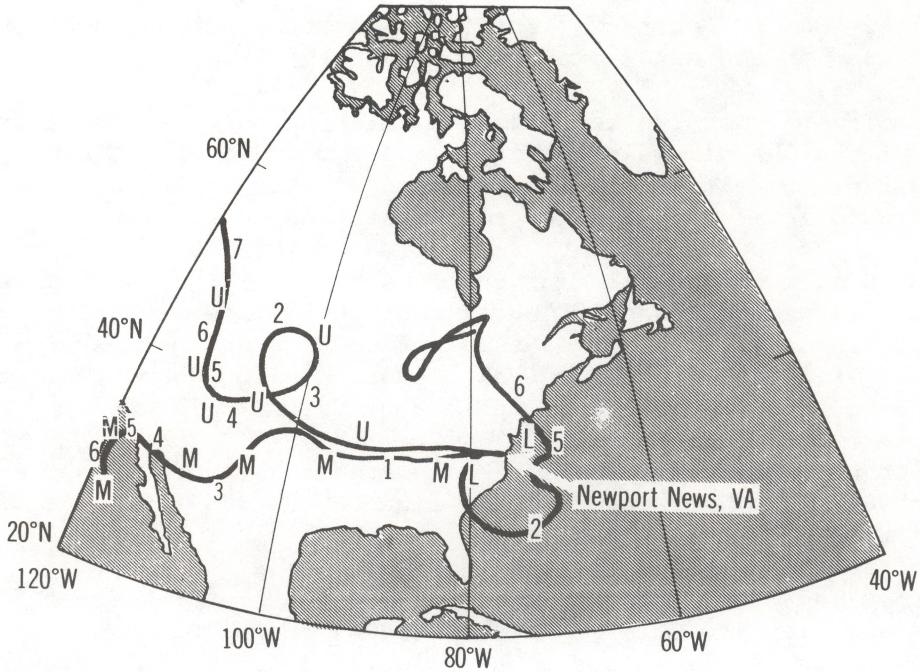

Figure 2. Air mass back trajectories calculated for Newport News, VA, on 5 March 1985 at 2100 LST. The letters L, M and U indicate lower (1000 mb), middle (850 mb), and upper (700 mb) trajectories, respectively. The numbers 1-7 represent the age of the air mass in days.

4. DATA SYSTEM

4.1 Data Reduction

The signals from each scientific instrument aboard the aircraft are converted to digital form within a data acquisition system (Particle Measuring Systems Inc.). The system can digitize the information sent to it at up to 10 Hz. Since the response time of a majority of our instruments is of the order of 1 Hz, we chose to collect data at a 0.5-Hz rate in order to eliminate the recording of excess data.

Once the data are digitized, they are converted to a packed binary form and sent to the tape storage system for recording. This packed binary form allows a large amount of data to be recorded on a small amount of tape, and flights typically require less than two cassette tapes to record all scientific information.

The data acquisition system is configured to accept data from up to 4 laser imaging aerosol probes, 14 analog devices at 10 Hz, and 8 analog devices at 1 Hz. The 14 "fast" analog channels include five channels that will accept DC signals in the range 0 to 1 V, five channels that will accept DC signals in the range 0 to 5 V, and four channels that will accept DC signals in the range 0 to 10 V. The eight "slow" analog channels will accept DC signals in the range 0 to 10 V. Matching the voltage signals from each analog device to an appropriate channel in the data acquisition system maintains adequate signal resolution. The digitized signal from each analog device is recorded as an

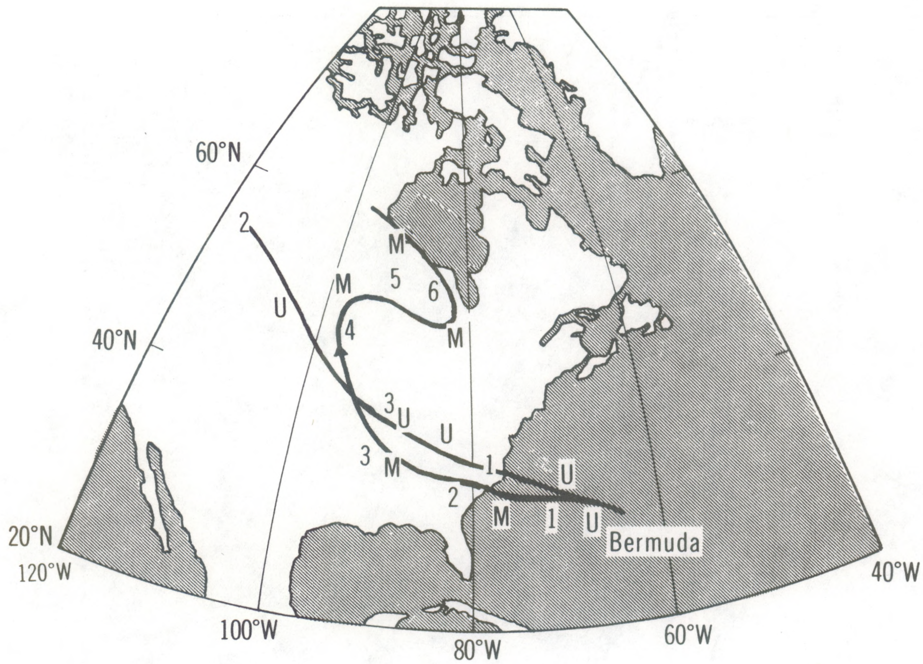

Figure 3. Air mass back trajectories calculated for Bermuda on 5 April 1985 at 0800 LST, as in Fig. 2. Data were available only for the middle and upper levels.

integer number of counts. The number of counts at any given time is proportional to the voltage output for the instrument at that time. The counts can be converted back to voltage using the following equation:

$$V_I = c\ V_{chan}\ d_{rate}\ 10,000\ [(E_{max} - E_{min})/V_{max}] + E_{min} \quad (1)$$

where

V_I = instrument voltage

c = the number of counts (0 to 10,000)

V_{chan} = the maximum voltage allowed in the channel (1, 5, or 10 V)

d_{rate} = data collection rate (0.5 s)

E_{max} = the maximum engineering unit output from the istrument

E_{min} = the minimum engineering unit output from the instrument

V_{max} = the maximum voltage output from the instrument.

See Wilkison and Boatman (1988) for details.

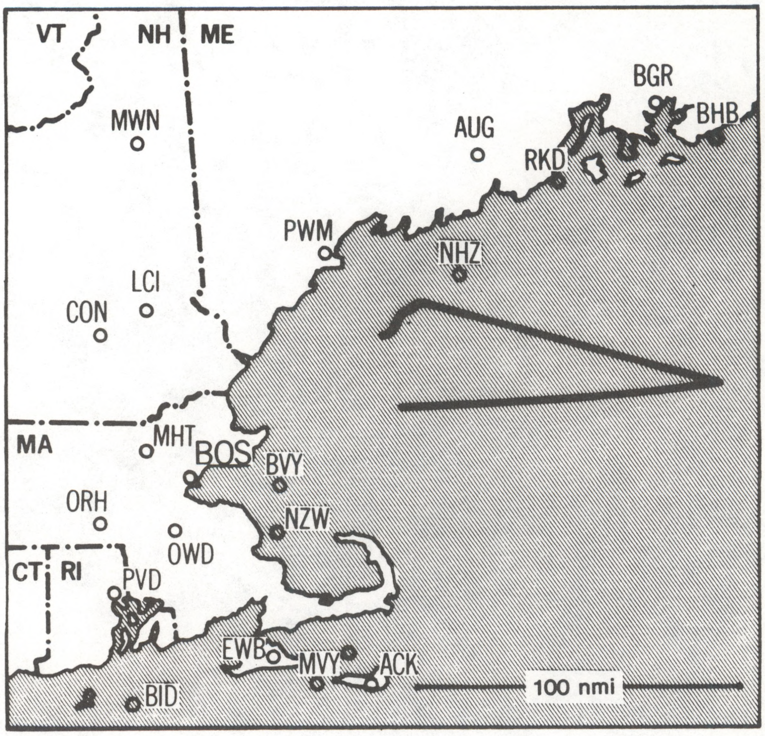

Figure 4. The King Air flight track east of Boston, MA (BOS), on 8 January 1986 during an intercomparison with the NOAA P-3.

4.2 Data Validation—Intercomparison Flights

Aircraft scientific instruments can and should be compared with laboratory standards whenever possible. However, since these instruments were obtained for use aboard aircraft they must also be checked and/or compared under airborne sampling conditions. The best method for accomplishing such a calibration check is by intercomparing with other research aircraft during flight. Figure 4 shows a portion of the flight track flown by the King Air near Boston, MA, on 8 January 1986 during an intercomparison with the P-3. The geographic and political boundaries in the area are depicted along with the locations and three-letter identifiers for various NWS reporting stations, including Boston (BOS). The intercomparison portion of the flight occurred between the hours of 0850 and 1000 local standard time (LST). The King Air has undergone an extensive program of airborne intercomparisons, the results of which are given by Boatman et al. (1988b).

5. DISCUSSION

The use of aircraft for atmospheric sampling enables the synthesis of a three-dimensional picture of the local atmosphere. The clarity of this picture, including resolution, is limited by aircraft speed, ceiling and range, and flight duration. For the 1985 experimental WATOX program, the basing of the King Air first at Newport News, VA, and later in Bermuda made it possible to formulate the atmospheric state at the continental border and at a location to formulate the atmospheric state at the continental border and at a location remote from the continent by about 48 hours of transport time. Sampling at the two locations occurred about 25 days apart in order to minimize seasonal and latitudinal variability. The research flights probed the zones that are most important in terms of pollutant transport (the lower free tropopause and the boundary layer) during offshore flow conditions. The 1986 WATOX program included seasonal and latitudinal factors. The flights conducted east of Cape Cod in January and February characterized the lower troposphere during transport from Canada and the northern United States during the winter. The flights near Bermuda in June placed the research effort into the subtropical environment with easterly or southerly airflows.

Measurable amounts of anthropogenic pollutants were observed within the boundary layer during all WATOX data flights originating at the East Coast, including those extending 100 km offshore. The concentrations of gaseous sulfur and NO_x obtained from the continuous analyzers were below the detection limit during most of the sampling flights performed near Bermuda. In a few instances in Bermuda, concentrations above background were observed, but the aircraft flight path and an analysis of local winds indicated that the sources were likely to be nearby rather than from long range-transport (Luria et al., 1987). It was expected that detection limits for sulfur gases and NO_x would not be exceeded, since models predict that these reactive species will be either oxidized or deposited during the 1200-km boundary layer transport from the East Coast to Bermuda. The continuous monitors for sulfur gases and NO_x seldom indicated measurable levels in the free tropopause. The occasional measurement of sulfur gases and NO_x in the free tropopause was attributed to local pollution.

One example of local pollution was observed on 18 March 1985, when a plume was detected over the ocean 75 km ESE of Norfolk, VA, at an elevation of about 2300 m. Back-trajectory analysis combined with plume width estimates suggested a large point source hundreds of kilometers upwind (Luria et al., 1987). Another case of free tropopause contamination was observed in Bermuda on 10 April 1985. In this event an ozone "bulge," peaking at 110 ppb (approximately 60 ppb above background), was recorded at 3000 m. The hydrocarbon concentrations in this air parcel were also greater than the levels typical of the free tropopause. Potential temperature profiles calculated for this area suggested the upward thermal transport of a parcel of boundary layer air (Van Valin and Luria, 1987).

Grab samples for hydrocarbons, dimethyl sulfide, and polyaromatic hydrocarbons were usually sufficient for comprehensive chemical analysis. The amount of material collected for aerosol anion and cation analysis was found to be marginal in the nominally clean atmosphere. Within the time constraints of airborne sampling, as indicated earlier, the tradeoff was between the need for longer times at constant altitude and the program requirement for vertical resolution. This conflict will be eased for future work with the installation of a more efficient pumping system.

6. CONCLUSIONS

It has been demonstrated that a light aircraft can be successfully utilized for intermediate-range atmospheric chemistry studies. The entire aircraft operation including the scientific and aviation crew can be maintained on a reasonable budget while performing about 300 hours of sampling flights per year.

The instrument package on board provided essential information on the state of the atmosphere during several atmospheric chemistry studies. With regard to the WATOX experiment, it was demonstrated that a small aircraft can be used successfully to characterize the atmosphere both above the East Coast of the United States and at an island location approximately 2 days transport time away.

7. ACKNOWLEDGMENTS

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