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Environmental Measurements Laboratory

LOW POWER, CONSTANT-FLOW AIR PUMP SYSTEMS

Michael D. Polito and Brian Albert
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LOW POWER, CONSTANT-FLOW AIR PUMP SYSTEMS

ABSTRACT

A rugged, yet small and lightweight constant-flow air pump system has been designed. Flow control is achieved using a novel approach which is three times more power efficient than previous designs. The resultant savings in battery size and weight makes these pumps ideal for sampling air on balloon platforms. The pump package includes meteorological sensors and an onboard computer that stores time and sensor data and turns the constant-flow pump circuit on/off. Some applications of these systems are also presented in this report.

MASTER

Table of Contents

	<u>Page</u>
I. Introduction	1
II. System Description	3
III. System Design	5
Pump Control System	5
DC/DC Converter	6
Pump Operation	7
A. Pump control circuit	8
B. Efficiency	8
C. Performance	9
Meteorologic Sensors	9
Pressure	11
Relative Humidity	11
Temperature	12
IV. Microcomputer	13
Power Management	15
Software	15
Data Storage	17
V. Polyport Sampler	18
VI. VEPS Sampler	18
VII. Field Test Results	19
VIII. Summary	20
Appendix	A-1

I. Introduction

The Department of Energy's Environmental Measurements Laboratory (EML) conducts many experiments requiring air sampling in the lower atmosphere (Chieco, 1993). These studies are carried out to characterize atmospheric transport processes and the distribution of trace gases and aerosols in the environment. To perform these measurements, gas and aerosol samplers are raised, via tethered balloon, to the desired height where sampling takes place. The equipment must be lightweight so that several samplers can be operated simultaneously at different elevations on the balloon. To calculate the concentrations of the gases being sampled, the total volume of air needs to be accurately measured. Therefore, specialized low power, constant volume pumping systems were designed and incorporated into EML's environmental instrument sampling package.

Figure 1 shows the sampling profile used by EML during the MOHAVE (Measurement of Haze and Visual Effects) study at Dolan Springs, Arizona, in July and August of 1992. Lightweight, battery-operated air samplers, designed at EML, were attached to a balloon tetherline at different altitudes up to 500 m above the earth's surface. This tracer experiment was performed to determine the source of the haze in the Grand Canyon National Park. Similar studies are scheduled for this year.

Figure 2 illustrates the planned sampling profile for an upcoming study to measure concentrations of dimethyl sulfide (DMS) in the Grand Bahama Island. Lightweight, battery-operated, gas and aerosol vertical profiling samplers (VEPS), were designed for use in marine environments. The results of these experiments will be used to investigate the process by which DMS gas is oxidized to form sulfate aerosol, which can act as cloud condensation nuclei. As other scientific work in this area has shown, DMS is believed to play a major role in cloud formation in the marine environment and, therefore, could be an important factor in climate change models (Bates, 1992).

Figure 1. Sampling profile used for MOHAVE Project.

Figure 2. Sampling profile used for VEPS Project.

II. System Description

A flow control system was designed based on a simple pressure sensing switch that keeps air flowing at a set rate through the sampler. The design circuitry maintains the volumetric flow at a constant rate even with variations in temperature, voltage supply, and sampling altitude (Figure 3). A DC/DC converter is used as part of the control circuit of the pump. Altitude tests were conducted in our pressure chamber to test the response of the equipment.

Experiments of the type described above require a measurement of the ambient temperature, relative humidity (RH), and atmospheric pressure, and also a means of storing these data. To achieve this, we added small micropower sensors interfaced to a low-power microcomputer (Tattletale Model V Microcomputer, Onset Computer Corporation, 199 Main St., PO Box 1030, North Falmouth, MA 02556-1030). This microcomputer provides flexibility in controlling pump sampling rates and storage of meteorological data.

Previously, a single sampler (Latner, 1986) was lofted to a desired height where air was pumped through a single adsorbent tube for 1 h. Long-term sampling would require lowering the balloon, changing the sampler and raising the balloon again, a tedious procedure which also results in lost sampling time.

The MOHAVE instrument package described in this report uses a multiple port sampler, Polyport (Guggenheim, unpublished data), shown in Figure 3. The Polyport sampler has 12 tubes, each containing Ambersorb (Rohm and Haas, Independence Mall West, Philadelphia, PA 19105), and an adsorbent that traps tracer gases as air is pumped through the tubes. The microcomputer controls which sampling tube is used during the experiment. Indexing the tube every 2 h allows sampling for an entire day without having to raise and lower the balloon. One of the 12 tubes in the Polyport, defined as the home position, is used during transit to the site and for pump flow calibration prior to the flight. At the end of the flight, the microcomputer returns the sampler to the home position. Samples are marked and then returned to EML for trace gas analysis by gas chromatography-electron capture detection (Lagomarsino and Latner, 1992).

Figure 3. Air sampler package used during MOHAVE Project. Polyport appears at lower portion of figure.

III. System Design

PUMP CONTROL SYSTEM

A description of the pump control system, which consists of a DC/DC converter, a pressure switch, a hypodermic needle, and associated circuit components (as shown in Figures 4 and 5) is given below.

Figure 4. Block diagram of constant-flow design. Power control circuit powers the pump according to the differential pressure across switch.

Figure 5. Motor and pressure-switch waveforms. For MOHAVE $t_1 = 20$ msec, $t_2 = 30$ msec.
For VEPS $t_1 = 12$ msec, $t_2 = 8$ msec.

DC/DC Converter

Constant air flow is achieved by using a DC/DC converter, with its inherent power efficiency, as part of the control circuit of the pump. Normally a DC/DC converter is used to provide a fixed voltage and to maintain that voltage as the load or supply voltage varies. However, in this design the DC/DC converter and a low cost pressure switch are used in a feedback loop to make the pump maintain a constant air pressure at its output port. This pressure switch is a simple mechanical device that uses no electrical power.

The DC/DC converter changes a higher input voltage at low current to a lower output voltage at higher current. The conversion process is very efficient (up to 90%). These devices are available from various manufacturers and require only a few external components.

We define the power efficiency as the ratio of the power delivered to the pump to the power delivered to the DC/DC converter, as shown in Figure 6. Other pump controllers are linear and have series pass elements which carry the same current delivered to the pump. Since up to three-fourths of the supply voltage may be across this element, 75% of the power delivered to the controller can be lost in the series pass element. Our design delivers the power needed to maintain a constant average pressure on the pump without losing power in a series pass element.

Figure 6. DC-DC converter used as flow control for air pump. The text includes efficiencies for each experiment. Also shown are where the voltage waveforms were taken.

Pump Operation

To understand the operation of the pump, refer back to Figure 4. Air is pumped through a hypodermic needle which serves as a restriction, allowing the build up of air pressure across the pressure switch. The control circuit supplies a steadily increasing voltage to the pump, causing the flow and pressure to increase until the pressure exceeds 13 mm (0.5-in) of water. At this pressure, a set of contacts in the pressure switch close. The pump voltage then falls steadily as air flows more slowly through the hypodermic needle. This causes the pressure to decrease until the switch opens again at 7.6 mm (0.3-in) of water; the cycle is then repeated.

A. Pump control circuit.

Figure 6 shows a simplified electrical circuit for controlling the pump. (The actual circuit, Drawing D-2224A, appears in the Appendix.) By charging and discharging a capacitor through a resistor, we control the output of a Linear Technology Corporation LT1173 DC/DC converter. The sense pin provides a means of controlling the output voltage of the converter. When the voltage on the sense pin is below the device's internal reference voltage, which is 1.245 V, an increasing output voltage drives the pump. When the voltage on the sense pin is higher than the reference, the device shuts down resulting in a decreasing voltage on the pump.

The resistor/capacitor network affords a simple means of controlling air flow. A 1 μF capacitor was chosen for both the MOHAVE and VEPS Projects. To meet the flow demands of a particular experiment, all that is necessary is to select a hypodermic needle for the approximate flow rate and adjust the resistor until the exact rate is obtained. The hypodermic needle restrictors chosen for the MOHAVE Project was a 21 gauge, 0.81 mm outside diameter needle. For the VEPS Project an 18 gauge, 1.24 mm outside diameter needle is used. The values for the resistors and potentiometers were chosen so that the required flow occurs at mid-range of the potentiometer, providing an optimum range of flow adjustment. Wiring diagrams for these instruments are included in the Appendix. For the MOHAVE Project, a 22.1 k resistor (R16) was selected, while the VEPS Project uses 18.2 k resistors (R11, R16). A 50 k potentiometer (R10) provides an adjustment range of 100-300 $\text{cm}^3 \text{min}^{-1}$ for the Polyport units, and 50 k potentiometers (R10, R15) provide ranges of 200-500 $\text{cm}^3 \text{min}^{-1}$ for VEPS units. The nominal flow rate for the Polyport is 150 $\text{cm}^3 \text{min}^{-1}$ and 400 $\text{cm}^3 \text{min}^{-1}$ for VEPS units.

B. Efficiency.

Typical waveforms of the motor and pressure switch are shown in Figure 5. The scale on the left refers to the MOHAVE experiment where air flow is 150 $\text{cm}^3 \text{min}^{-1}$. The average voltage on the pump is 3.6 V at 11 mA. Current drawn by the DC/DC converter from a 12-V lithium battery source is 4 mA. Under these conditions an efficiency of about 82% is obtained. For a flow rate of 400 $\text{cm}^3 \text{min}^{-1}$, required by the VEPS samplers, the average pump voltage is 7.2 V at 13.25 mA, while drawing only 9.5 mA from the 12-V battery source.

The scale on the right side of the waveform figures refers to the VEPS operation. In order to accommodate the higher flow rate, the pressure switch switches more often and the duty cycle is higher. Duty cycle differences are shown on the horizontal axis of the figure. Switch frequency for the Polyport and VEPS instruments are 20 cycles s^{-1} and 50 cycles s^{-1} , respectively. Power efficiency for the VEPS pumps is 84%. The pump used for both MOHAVE and VEPS is a 1.5-oz Model 3003 from ASF Incorporated (2100 Norcross Pky., Suite 120, Dept. M, Norcross, GA 30071). It pumps air, up to a limit of 1 L min^{-1} (at standard atmospheric pressure), and operates in any position. They are 12-V pumps but they are able to operate at voltages below 3 V when lightly loaded. With a 12-V supply, the 9-V difference offers a wide margin of drive capability.

C. Performance.

Performance tests of the new system were conducted in our laboratory prior to final design. These tests were conducted in order to determine the effects of temperature and elevation on the mass flow. Temperature tests are shown in Figure 7(a). The flow used, $287 \text{ cm}^3 \text{ min}^{-1}$, is about midway between the flow rate requirements of the VEPS and MOHAVE samplers. A total variation of 1.4% occurred over the temperature range 0 to 40°C . Mass flow changed as expected with simulated elevation when tested in our High Altitude Test Chamber (HATCH; Chieco et al., 1992). Figure 7(b) shows that for a nominal mass flow of $760 \text{ cm}^3 \text{ min}^{-1}$ at sea level, $P_0 = 1013 \text{ mb}$, the mass flow decreased to $523 \text{ cm}^3 \text{ min}^{-1}$ at $P = 697 \text{ mb}$ (3.5 km; 10,000 feet). Since $P/P_0 = .69$ we see that the density decrease of 31% due to elevation accounts for the 31% decrease shown in Figure 7(b). Therefore, the volumetric flow is constant.

Meteorologic Sensors

Sensors measuring atmospheric pressure, RH, and temperature were implemented in our packages. Signal conditioning circuits were designed to interface these sensors to the onboard computer.

Figure 7. Performance tests: mass flow (a) temperature (b) elevation.

In keeping with our design goals, only small and lightweight sensors, which take a minimum of support circuitry, would be used. In addition, it was necessary to minimize power drain in the sensors and the associated conditioning circuits. Each sensor had to produce an analog output signal in the 0 to 5 V range to be compatible with the analog-to-digital converter used on the computer board.

A. Pressure.

A solid-state, 0 to 15 psi absolute pressure sensor packaged in a very small integrated circuit configuration was found to be ideal for the application (IC Sensors Corp., 1701 McCarthy Blvd., Milpitas, CA 95035; Model 13A-015A). This sensor, which measures < 1.3 cm (1/2 in) in diameter and weighs only 3 g, is capable of making accurate measurements while drawing only 2.5 to 5.0 mW of power.

The sensor (U2), shown in the schematic diagram in the Appendix, contains piezoresistive silicon sensing elements arranged in a Wheatstone bridge. Precision resistors for gain-set and temperature compensation over a 0 to 50°C range are included in the package. The signal conditioning circuitry (U1) applies a constant current of 0.994 mA (U1/A) to the bridge, which produces a differential output voltage proportional to absolute pressure. This output voltage is in the millivolt range and varies from sensor to sensor. Output is normalized by the use of an instrumentation amplifier circuit (U1/B,C,D) programmed with the sensor's gain-set resistor. This produces a 0 to 5 V output signal that is uniform for all sensors.

Circuit board space was minimized by the use of resistor network packages and use of a quad operational amplifier to implement both current source and amplifier circuits. Precision components were used to assure a total accuracy of 1% of reading without calibrating. Accuracy can be greatly increased with a two-point calibration and a potentiometer to adjust bridge current, given the sensor's 0.05% linearity. However, our application did not require this. The circuit operates on 8 to 12 V and draws only 16 to 24 mW.

B. Relative humidity.

A solid-state, capacitive RH sensor was selected due to its small size, low power requirements, and simple operation. (Hy-Cal Engineering, 9650 Telstar Ave., P.O. Box 5488, Elmonte, CA 91734; Model IH-3602A). The sensor comes in an integrated circuit package 3/8-in in diameter with a weight of 1.4 g. Also included in the package is a contaminant filter for eliminating debris and a thermistor for temperature measurements.

When supplied with a 5.0-V power source, the RH sensor produces a linear output voltage, which is nominally 0.8 to 4.0 V over its entire 0 to 100% RH range. Although this

voltage level is adequate for direct interface to the computer, the sensor's output contains high frequency noise and can only supply 50 μ A of current, which is insufficient to drive the analog-to-digital converter. To solve these problems, two signal conditioning circuits were added. A simple low pass resistor-capacitor filter reduces noise in the output signal and a single unity gain operational-amplifier provides enough current to drive the computer's analog-to-digital circuitry. Total current used by the sensor and support circuitry is 0.6 mA.

A two-point calibration for each sensor comes from the factory with output voltages given for 0% RH and 75.3% RH. In use, the onboard computer digitizes the output voltage and can either store this directly or calculate RH from the calibration values. Total accuracy is 2% at 25°C. However, by using a temperature compensation formula, this accuracy is maintained over a temperature range of 5 to 85°C.

C. Temperature.

As mentioned earlier, a thermistor is supplied within the RH sensor package. Although it is normally used as a rough indicator of temperature for the purpose of correcting RH measurements, we found that an accuracy of 0.25°C could be achieved over a 0 to 40°C range by using a two-point calibration.

A thermistor has an electrical resistance, R_t , that varies with temperature in a manner that can be closely approximated by the following expression:

$$R_t = R_{25}e^{[K/T-K/298.15]}$$

where

R_{25} = resistance at 25°C (nominally 100 k),

K = materials constant (nominally 4143), and

T = temperature in °K.

Resistance at 25°C is specified by the manufacturer to be within 5% of 100 k Ω . The materials constant, K , can also vary widely with each unit. By measuring thermistor resistance while in a temperature controlled chamber at 25°C and again at 0°C, precise values for R_{25} and K

were calculated for each sensor. Knowing these values, the temperature is then measured with an accuracy of 0.25°C.

Our circuit design, as shown in the schematic, D-2224A, implements a simple voltage divider that allows the computer to measure the thermistor's resistance, R_t . This value can be stored directly or it can be used with calibration values to directly calculate temperature. A very small current drain of 25 μ A is used by the circuit.

IV. Microcomputer

The sampling package has a microcomputer which performs a number of important functions. The onboard computer provides for on/off pump operation, indexing the Polyport sampler, measuring and storing sensor readings, and controlling the timing of all operations. The ability to program sampling times, delay times, and storage intervals of sensor readings provides a flexible design.

Figure 8(a) shows the total VEPS instrument package while, Figure 8(b) shows just the assembly containing the microcomputer. Manufactured using surface mount technology, the microcomputer packs many powerful features onto a double-sided 3.6 cm x 5.1 cm x 2 cm (1.4 in x 2.0 in x 0.8 in) circuit board, which weighs only 20 g. It has many channels for digital control and measurement of analog signals, along with a real-time clock, and a 28 kilobyte random access memory datafile that is used to store the sensor readings. The computer is easily programmed in BASIC through a standard RS-232 serial port. Once the program is developed, it can be "burned" into electrically programmable, read-only memory (EPROM), which is nonvolatile.

The computer's 16 digital control lines can be independently programmed as either inputs or outputs. At any time, an output line can be set either high or low so that interface circuits can turn a device, such as a pump or motor, on or off. The computer is used in this manner to turn on power to the constant flow pump circuits for a programmed amount of time, and

then switch power off. An LED (light emitting diode) is controlled in a similar manner. The LED is used to signal the operator that the instrument is working properly.

(a)

(b)

Figure 8. (a) Instrument package for VEPS Project. (b) VEPS control board and standby board for the Tattletale Model V. Microcomputer lies between circuit boards. RH and temperature sensors are at the end of the cable.

POWER MANAGEMENT

The microprocessor used in the onboard computer can operate in a standby mode in which all data is retained by a single 3-V lithium battery where current drain is reduced to the microamp range. However, the real-time clock shuts down during standby mode and is reset to zero on the next power up. This single battery can support the standby mode for many months.

In order to save battery power during shipping and before and after flights, we designed a very small standby circuit board that puts the microprocessor in a standby mode when main power is switched off. Not only does it automatically switch to standby, but it terminates all data and address bus lines, so that total current drain from one lithium battery is only 50 μ A. A schematic of the board is shown in the Appendix. Board layout was designed so that the standby board sits on top of the computer, plugging into its two 20-pin socket strip connectors. In Figure 8(b) the standby board covers the microcomputer, which is between the standby board and the VEPS control board. All components face down toward the computer to conserve space. This compact configuration was done with computer-aided design software from PCAD (Personal Cad Systems, Inc., 1290-T Parkmoor Ave., San Jose, CA 95126).

When the computer is operating, it draws a much larger current from the 12-V battery supply. While actively taking measurements, making calculations, or performing control operations, it draws as much as 7 mA. However, when programmed to an inactive of "sleep" mode, the microcomputer drain is reduced to 2 mA. Unlike the standby mode, in this mode the real-time clock continues to run, maintaining all timing functions. This mode is used in the time interval between meteorological measurements.

Software

Software development for the microcomputer was done on a personal computer using BASIC. The software permits pump sampling times to be easily set and even changed in the field, if necessary. Where the beginning of the sampling process must be delayed so as to allow lofting of the balloons, these delay times can be controlled as can the measurement

intervals for the meteorological sensors. A low-drain backup battery, capable of lasting many months, maintains the meteorological data until it can be downloaded for analysis. A listing of the program used for the MOHAVE experiment is in the Appendix. Programming for the VEPS instruments is nearing completion, however, some measurement parameters have not been firmly established at this point. Some of the routines for processing meteorological data also appear in the Appendix.

Operation is very simple. A power switch on the equipment is all that is necessary to start the unit. At that time, the program takes control. It allows sufficient delay time to loft the balloon before sampling begins. An LED on the unit serves to signal performance to the operator. At start-up the unit goes through a self-test to assure the operator that each component is functioning normally. Pump(s) are turned on briefly and, in the MOHAVE instruments, the Polyport sampler is indexed to its home position. The LED signals the various phases of the self-test. The LED is also used at the end of the flight when it flashes at a 3-s rate to indicate that all samples were taken normally or at a 10-s rate if some failure occurred. Data can then be transmitted to a personal computer via its serial communications port using a software communications program. After data is retrieved, the batteries can be checked and replaced, if necessary.

Our procedure was to replace the lithium batteries every 2 days (two flights) to ensure trouble-free operation even though these batteries have a longer operating life (~ 4 days). Three volt, type DL123A batteries are used.

Control of Polyport samplers was not as simple as expected. Each unit has slightly different characteristics. Even within the same unit some variation occurs. One characteristic that varies is the stopping distance of the indexing arm when power is removed, i.e., coasting. If the power is applied too long, the indexing arm may coast past the proper valve position. Another variation is in the power needed to start the motion of the indexing arm. If power is applied too briefly, the indexing arm might not advance at all.

Each unit behaves differently with variations in battery voltage as batteries discharge. To deal with these problems, dynamic control is used for operating the Polyport samplers. The software supplies a pulse to the motor and checks if it has advanced to the proper position. If not, another pulse is supplied until the motor has advanced to the next valve position. If

the proper response is not obtained in a given time, the probable cause is that the indexing arm has not advanced at all. Thus more power, in the form of a wider pulse, is used to drive the motor. The same software program adapts to all Polyport samplers smoothly under variations in battery voltage and, probably, temperature.

Data Storage

One of the main functions of the microcomputer is to measure the analog signals of the meteorological sensors and to store the results. All sensor circuits were designed to provide 0 to 5-V signals to the computer's analog input lines. Using a 10 bit analog-to-digital converter, the computer digitizes each signal with a resolution of one part in 1024.

For example, a pressure range of 0 to 15 psi can be measured to within 0.0146 psi. Similarly, the RH can be recorded to within 0.1% RH, and the temperature to within 0.1°C. However, the computer stores numbers in memory only in units of bytes. Since a single byte is 8 bits, the 10-bit measurement values must be truncated to fit in one byte of storage. This results in a loss of resolution. Alternatively, the measurement can be stored with full precision in a two-byte word (16 bits). However, memory is not used efficiently in this approach.

For our application, we chose to store pressure and RH measurements in one byte. This reduces the resolution to 0.058 psi and 0.39% RH, respectively, but this is still well within our requirements. However, to keep the 0.1°C tracking ability of the thermistor, we store temperature measurements in a two-byte word.

A single data record, containing time of day, pressure, RH, and temperature information, consists of 6 bytes. If the computer stores a reading once every 20 s, 18 bytes are used every minute or 1080 bytes per hour. Since the size of the datafile is 28 kilobytes, data can be recorded for at least 26.5 hours (28672/1080).

V. Polyport Sampler

Shown in the lower portion of the photograph, Figure 3, is the Polyport sampler used during the MOHAVE project. Each of its 12 sampling tubes is equipped with a valve which is opened at a preset sampling time. A small motor, P3 in drawing D-2224A, inside the Polyport sampler advances a valve indexing arm when energized by the microcomputer through its digital interface line, I/O-8. An important feature of this sampler design is its dual use of valves as switches. As each valve is opened, the valve assembly itself closes an electrical contact. This ensures that the switch does not close unless the valve is actually open. The design also ensures that no two valves can be opened at the same time. The switch closure is sensed by the microcomputer which uses this information to control indexing.

As shown in the photographs, Figures 3 and 8(a), strong lightweight materials such as styrofoam and polyethylene are used for housing these instruments. To provide a strong, slip-proof attachment to the tetherline for the MOHAVE tests in Dolan Springs, Arizona, a set of square teeth were cut in the styrofoam housing. A mating section of styrofoam, also cut with square teeth, was used to mesh with the housing, trapping the line between the teeth. The entire package was then secured with velcro straps. Two of these packages were tethered to the line, 300 m apart, for these tests. The number of samplers that can be attached to the line depends on the lift of the balloon and the height above sea level at the launch site as well as the weight of the packages.

VI. VEPS Sampler

Figure 8(a) shows the VEPS instrument package that we designed and built for flight on a 71-m tethered aerostat (TCOM, L. P., 7115 Thomas Edison Drive, Colgate, MD 21046-2113). With a weight of 766 g (27 oz) and a 11 cm (4 1/2 in) diameter, by 20 cm (8 in) height, the units easily attach to the tetherline brackets where flashlights of about the same size and

weight are normally secured. As many as six units can be placed on the tetherline at various intervals.

The VEPS unit contains two, previously described, lightweight pumps. Each has a flow rate of $400 \text{ cm}^3 \text{ min}^{-1}$ and draws $< 10 \text{ mA}$ from the 12-V battery supply; they are independently controlled. In use, air first passes through an oxidant trap, which removes ozone and other oxidants. The air then passes through a gold adsorbent, where DMS is adsorbed with 100% efficiency.

The package also contains a high flow-rate pump and an impactor for the purpose of aerosol analysis (impactor, USDOE Environmental Measurements Laboratory, Drawing No. D-2207; impactor pump, Model TD4-NA 12 VDC; adjustable stroke vacuum pump, Brailsford and Co., 670 Milton Rd., Rye, NY 10580). Impactor design is such that a steady flow of $\sim 1.1 \text{ L min}^{-1}$ is achieved through the jet of the impactor when a differential pressure of 15-in Hg or greater is maintained across it. The pump draws 150 mA of current in order to maintain enough pressure to support this high flow rate.

All three pumps are switched on and off at appropriate times by the microcomputer, which also reads and stores data from the meteorological sensors. Software allows field personnel equipped with a portable computer to make last minute changes in sampling time and delay time for each pump. Despite the large current drain of the impactor pump, the package operates for over 2 h.

VII. Field Test Results

Equipment for the MOHAVE experiment operation was relatively trouble free, although some wind shear problems were encountered at the site which were strong enough to cause balloons to crash and rupture. Performance of the pump circuits was excellent. However, we noted an increase in the overall power efficiency of the pump as it was used. This is attributed to seals improving during use. These are long-lived pumps capable of at least a year of continuous operation and a certain amount of wear-in should be expected. As these

pumps begin to wear, seals improve. In the future, these pumps will be run for a few hours to allow them to wear-in before they are installed. The VEPS sampler was not field tested at the time of the writing of this report.

VIII. Summary

The new pump control design, which uses very small and lightweight equipment, is ideal for balloon packages. While precisely controlling the volume of air flowing through the sample, it achieves power efficiency three times greater than standard designs. This greatly improved efficiency allows for much longer sampling times and reduced weight. Constant flow pump control, meteorological data storage, and the flexibility of a microcomputer in a lightweight package make for a platform that is a highly valuable tool for free troposphere air sampling. As the MOHAVE and VEPS packages show, this design can be implemented in a wide variety of air sampling projects.

Future plans include a change in the design of the Polyport controller. Most of the package weight, about 454 g (16 oz), is from the Polyport. A change in design using magnesium rather than aluminum is planned, reducing this weight to 340 g (12 oz). The circuit board shown in Figure 3, weighs 250 g with four type DL123A batteries installed. These batteries weigh 16 g each. The combined weight of the circuit board and Polyport is 704 g which, while heavier than earlier designs, nevertheless offers the flexibility of a onboard computer and the ability to make meteorological measurements. Smaller lithium batteries, such as DL1/2AAL, which weigh only 7.6 g, could suffice for operation up to a single day. The larger batteries were chosen for ease of operation and to ensure trouble-free operation for at least 2 days. However, if future needs require further reductions in weight, three rather than four of the smaller DL1/2AAL type batteries could perform well with 6-V ASF pumps instead of the 12-V pumps used for the MOHAVE tests. The combined weight would then be less than 550 g.

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APPENDIX

Program Used On MOHAVE Project

```
' MOHAVE.BAS 6/18/92.
' Dwell = 57 minutes.
,
' D8=Polyport, D13=Air pump, D14=ADC, D15=LED
' A0=Pressure, A1=R.H., A2=Temp.
,
5 DIM(0,26000)
8 X=0:Y=0:C=0:R=0
,
' Turn ON LED and ADC. Turn OFF Pump #2.
,
10 D=2:PSET15:PSET14:PCLR9:GOTO 120
,
' Stop Polyport motor, air pump and LED.
,
100 PCLR8:PCLR13:PCLR15
102 PRINT' * MENU *,\7
103 PRINT' (0) Read Data (2) Run Test (4) Clear Data'
104 PRINT' (1) Run (3) TT BASIC (5) Verify'
105 INPUT' ENTER CHOICE: 'N:IFN=4|N=5PRINT'WAIT...':GOTO800
106 IFN=1 GOTO 8
108 IFN=2 Y=1:GOTO 10
109 IFN=3 PRINT:PRINT' Program terminated.':STOP
110 GOSUB 7000:GOTO 102
,
120 L=1:GOSUB 150:PSET13:F=10:M=25:GOSUB700:PCLR13
125 PRINT' Found HOME position.'
,
' Test Poly
,
126 IF Y=1 W=1:GOSUB 400:GOTO 190
,
' Wait 57 min. then pump on for 3 min.
' ( 10 sec. per unit W, i.e., 57 x 6 = 342 )
,
128 W=342:GOSUB 400:W=18:PSET13:GOSUB400:PCLR13:GOTO 190
,
' FIND HOME SUBROUTINE
,
150 Z=?:IF PIN(10) GOTO 180
' Pulse Poly
155 GOSUB 500:IF(?-Z)>3000GOSUB510:GOTO150
170 IF PIN(10)=0 GOTO 155
180 RETURN
,
' ADVANCE ONE POSITION
,
190 Z=?
' Pulse Poly
200 GOSUB 500:IF(?-Z)>600GOSUB510:GOTO190
' Until open
210 P=PIN(16):IF P=1 GOTO 200
215 Z=?
,
' Pulse poly
220 GOSUB 500:IF(?-Z)>600GOSUB510:GOTO215
' Until closed
230 P=PIN(16):IF P=0 GOTO 220
240 PCLR8
260 F=1:M=20:GOSUB 700:PRINT'Position # ',L
```

Appendix (Cont'd)

```
265 IF Y=1 W=1:GOSUB 400:GOTO 280
'
' 20 sec per unit W, 120 minutes x 3 = 360.
'
270 RTIME:STOREX,?(2):STOREX,?(1):R=1:PSET13:W=360
'
' Pump for 2 hours
'
275 GOSUB 400:PCLR13
280 L=L+1:IF L=12 GOTO 300
290 IF PIN(16)=0 PRINT' CONTACT ERROR'
295 GOTO 190
300 GOSUB 150
305 PRINT' DONE'
310 F=1:M=5:GOSUB 700:SLEEP0:SLEEP300:GOTO310
'
' Wait 10 seconds per each W, subroutine
'
400 FORI=1 TO W
405 IF R=1 GOSUB 1000:GOTO 420
410 SLEEP0:SLEEP1000
420 NEXTI:RETURN
'
' Pulse Polypport motor.
'
500 PSET8:SLEEP0:SLEEPD:PCLR8:SLEEP20:RETURN
'
' Poly failure - low battery voltage.
'
510 IFD<8D=D+2:RETURN
520 SLEEP0:PSET15
530 SLEEP5:PCLR15:SLEEP1000:GOTO520
'
' Pulse LED F times at rate M.
'
700 FOR I=1 TO F
710 PSET15:SLEEP0:SLEEPM:PCLR15:SLEEPM
720 NEXTI:RETURN
'
' CLEAR DATAFILE AND VERIFY
'
800 IFN=4GOSUB8000:GOTO102
810 IFN=5GOTO9000
820 GOTO100
'
' Store Met
'
1000 REM
1010 IF C C=C+200: GOTO 1030
1020 C=?/10
1030 SLEEP0:SLEEP 1000
1035 SLEEP 950
1040 IF (?/10-C)<200 GOTO 1040
1050 GOSUB 550
1060 RETURN
'
' Pressure subr
'
550 REM
560 A=CHAN(0)
570 STORE X,A/256
580 P=(A*15000)/65536
```

Appendix (Cont'd)

```

590 PRINT "PRESSURE= ",#02,P/1000,".",#03,P%1000," PSI      ";
,
' RH & Temp subr
,
605 H=CHAN(1)/256
610 T=CHAN(2)/64
615 STORE X,H
' Look-up Table used to go here
625 STORE X,#2,T
630 PRINT "R.H.= ",#3,H,"      ";
635 PRINT "TEMP = ",#4,T
640 RETURN
,
' READ DATA SUBR
,
7000 Q=0
7005 FORI=1TO11
7010 PRINT' TIME: ',GET(Q),' : ',#02,GET(Q)
7015 PRINT' PRES          RH          TEMP'
7020 FORJ=1TO360
7025 SLEEP0:SLEEP4:FORK=1TO4
7030 IFK%3PRINTGET(Q),'          ';;GOTO7034
7033 PRINTGET(Q,#2):K=K+1
7034 NEXTK
7035 NEXTJ:PRINT:NEXTI
7040 RETURN
,
' Erase data
,
8000 Q=0
8010 STOREQ,#4,0:IFQ>15862RETURN
8020 GOTO8010
,
' Verify erased data
,
9000 Q=0
9010 IFQ>15862PRINT' EMPTY':GOTO102
9020 IFGET(Q,#4)<>0PRINT' FAIL BET. ',Q-4,' & ',Q:GOTO102
9030 GOTO9010

```

Appendix (Cont'd)

Met Data Calculation Subroutines

```
'
'   Subroutine to Calculate Temperature from Sensor Reading and
'   Calibration Values
'
'   Enter calibration values for the sensor. S is thermistor resistance
'   at 25 degrees Celsius. K is materials constant.
500 S=100000
510 K=4143
'
'   Take sensor reading from channel 2. (New operating system gives
'   16 bit reading, so divide by 64 to get 10 bit resolution).
515 T=CHAN(2)/64
'
'   If sensor reading is extremely high or low, store the raw sensor
'   reading only. Log calculation will crash otherwise.
520 IF (T<=20)|(T>=950) RETURN
'
'   Calculate thermistor resistance from the sensor's voltage reading.
525 R=(100000*T)/(1023-T)
'
'   Implement the following formula to calculate temperature in tenths
'   degree Celsius using log algorithms for integer arithmetic:
'    $T = K / (\ln(R/S) + (K/298.15))$ 
530 R=R/100:S=S/100
535 Q=(R*65535)/S
540 Q=(LOG(Q)*1000)/65535
545 T=((K*1000)/Q+(K*1000)/298))-2731
550 RETURN
'
'   Subroutine to Calculate Relative Humidity from Sensor Reading
'   and Calibration Values.
'
'   A and B are millivolt readings taken from calibration sheet at
'   0% RH and 75.3% RH, respectively. Enter A and B for the sensor.
500 A=814
505 B=3117
'
'   Calculate A/D reading for each calibration voltage.
510 @ (0)=1023*A/5000
515 @ (1)=1023*B/5000
'
'   Take sensor reading from channel 1. (New operating system gives
'   16 bit reading, so divide by 64 to get 10 bit resolution).
520 H=CHAN(1)/64
'
'   Use linear interpolation formula to calculate RH. Scale so that
'   result is in thousandths percent.
525 H=75300*(H-@ (0))/(@ (1)-@ (0))
'
'   Calculate temperature in tenths degree Fahrenheit from temperature
'   calculation which was already done for tenths degree Celsius.
530 F=T*9/5+32
'
'   Calculate temperature correction factor for RH measurement.
'   (multiply each number in formula by 1000 to keep full precision)
535 C=(((-1*6100)+((165*F)/10)-(4310000/F))*(H+6700))/100000
```

Appendix (Cont'd)

```
'  
' Correct for temperature. Final result in tenths percent RH.  
540 H=(H+C)/100  
545 RETURN  
'  
'  
' Subroutine to Calculate Pressure from Sensor Reading.  
'  
' No calibration needed. Take 16 bit sensor reading from channel 0  
' and convert to psi in thousandths.  
600 P=(CHAN(0)*15000)/65535
```

Figure A-1. Main circuit board showing micorcomputer interface between pump controller, meterologic sensors and Polyport (or impactor).

Figure A-2. Model 5 Tattletale Standby Board Schematic.

END

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