MAY 1983

DEVELOPMENT OF AN ADJUSTABLE BUOYANCY BALLOON TRACER OF ATMOSPHERIC MOTION

Phase II. Development of an Operational Prototype

ATMOSPHERIC SCIENCES RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
RESEARCH TRIANGLE PARK, NC 27711

DEVELOPMENT OF AN ADJUSTABLE BUOYANCY BALLOON TRACER OF ATMOSPHERIC MOTION

Phase II. Development of an Operational Prototype

by

B. D. Zak and H. W. Church
Sandia National Laboratories

E. W. Lichfield
Technadyne Engineering Consultants

M. D. Ivey
Telemetrics Southwest

Interagency Agreement DW930214

Project Officers

J. S. Irwin and R. G. Lamb
Meteorology and Assessment Division
Atmospheric Sciences Research Laboratory
Research Triangle Park, NC

ATMOSPHERIC SCIENCES RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
RESEARCH TRIANGLE PARK, NC 27711

NOTICE

ABSTRACT

An Adjustable Buoyancy Balloon Tracer of Atmospheric Motion is a research tool which allows one to follow atmospheric flows in both the horizontal and the vertical, including the weak sustained vertical motion associated with meso- and synoptic-scale atmospheric disturbances. The design goals for the Tracer Balloon being developed here specify a lifetime $\geq$ 3 days, tracking range $\geq$ 1000 km, a ceiling altitude $\geq$ 5.5 km (500 mb), and the capability to respond to mean vertical flows as low as 1 cm/s. The Tracer Balloon is also to measure and telemeter selected meteorological variables, to be sufficiently inexpensive to permit use in significant numbers, and to be serviced by a ground system capable of handling several Tracers at a time. While the Tracer has applications throughout the atmospheric sciences, the immediate motivation for this effort is to meet the need to evaluate the accuracies of air pollution transport models, to establish source-receptor relationships to distances of order 1000 km, and to assess the inherent limits on the predictability of source impacts at long distances. In Phase I of this project, titled "Systems Design and Demonstration of Feasibility," the authors proposed a generic design for such a system, subjected the design to theoretical analysis, constructed a testbed prototype, and conducted a series of tests with that prototype to evaluate the concept. In Phase II of the project, the subject of this report, the authors developed an operational prototype designed to meet the desired specifications. A limited number of test flights of the operational prototype were conducted south of Albuquerque, New Mexico, in a nearly vacant 350-square-mile (900 km^2) area laced with dirt roads. Flights were made using each of the three currently available control algorithms. Analysis of the data indicated that, in each case, the control system functioned properly. In Phase III of the project, improvements are planned in electronic design, packaging, control algorithms, and in the accompanying ground support system. In addition, an extensive flight program will be conducted to assure that all the design goals are met, and to gain experience with this new atmospheric research tool.

CONTENTS

APPENDICES

FIGURES

ACRONYMS

ADAS - Atmospheric Data Acquisition System

AGL - (Altitude) Above Ground Level

AIR - Atmospheric Instrumentation Research (Inc.)

ASCII - American (National) Standard Code for Information Interchange

CVB - Constant Volume Balloon

DOE - U. S. Department of Energy

EPA - U. S. Environmental Protection Agency

FAA - Federal Aviation Administration

FAR - Federal Aviation Regulations

HF - High Frequency

MSL - (Above) Mean Sea Level

NCAR - National Center for Atmospheric Research

NOAA - National Oceanic and Atmospheric Administration

PC - Personal Computer

PLT - Physical Lagrangian Tracer

PROM - Programmable Read Only Memory

PTT - Platform Transmitter Terminal (Argos)

RAM - Random Access Memory

ACKNOWLEDGEMENTS

The authors would like to thank and to acknowledge the contributions of the following individuals:

- J. S. Irwin and R. G. Lamb of the U.S.E.P.A. for their continued support, guidance, and encouragement.
- E. Martin, C. Keady, and B. Newmark of Technadyne for their assistance and cooperation in many ways.
- G. Brown and S. Sawyer of Sandia Labs for assistance in the field, and for invaluable assistance in reporting, respectively.
- E. J. Graeber of Sandia for suggesting a very clever design for the cutdown device.
- D. Call of Atmospheric Instrumentation Research for the loan of prototype digital sondes for evaluation.
- V. Lally and other members of the Global Atmospheric Measurements Group at NCAR for their advice and moral support.
- Mr. and Mrs. S. Longo, owners of the land from which the test flights were launched, for their warmth and hospitality.
- The Valley Improvement Association, Tierra Grande Subdivision, and G. W. Burris for permission to use the land in the Rio Communities over which they exercise respective control.
- A. Garde of the Valley Improvement Association for permission to reproduce a map of the Rio Communities area.
- W. Halleck and F. Zaccaria of the Federal Aviation Administration for their cooperation in facilitating the flight test program.

This research was funded by the U.S. Environmental Protection Agency in part through the National Acid Precipitation Assessment Program.

1. INTRODUCTION

An Adjustable Buoyancy Balloon Tracer of Atmospheric Motion is a physical Lagrangian tracer (PLT) -- an airborne instrumentation system that follows the flow of air in its vicinity, and that can be tracked electronically.[1] For decades, researchers have sought a Lagrangian tracer to aid in understanding the dynamics of the atmosphere, and more recently, to cast light on long-range air pollution: acid deposition, regional haze and oxidant episodes, and associated ecological effects. Advances in microelectronics, satellite communications, and battery technology have now made such a tracer system feasible. The present effort is primarily motivated by the need to establish source-receptor relationships to distances of order 1000 km, to evaluate the accuracies of air pollution transport models, and to assess the inherent limits on the predictability of source impacts at that distance. In a more basic sense, however, it addresses a broad underlying need for a convenient means of following atmospheric flows.

The need for a physical Lagrangian tracer has led to extensive work with constant volume balloons (CVBs) which has been reviewed by Tatom and King (1977) and by Zak (1983). CVBs follow the horizontal motions of the volume of air in which they are embedded, but not the vertical motions. Coupled with wind shear, this characteristic limits their usefulness. In 12 hours, a CVB may become separated by as much as 1300 km from the air mass in which it was initially embedded (Danielson, 1961).

PLTs are necessarily balloon-borne systems, and consequently must operate under Federal Aviation Regulations Part 101: Moored Balloons, Kites, Unmanned Rockets, and Unmanned Free Balloons. The purpose of this regulation is to strictly limit the hazard to air navigation which such systems might otherwise represent. Part 101 so

---

1 For a detailed discussion of the meaning of the term "Lagrangian" and of how the concept depends upon the spatial scale of application, see Zak (1983).

dominates the design of the Tracer that it is included here for reference as Appendix A. Under this regulation, the U.S. weather services, together with the weather services of other nations around the world coordinated by the World Meteorological Organization, routinely launch hundreds of radiosonde balloons twice daily. Radiosondes measure the meteorological conditions aloft from the surface to beyond 20,000 m above many major airports and certain other selected sites.

It is an explicit design goal that the Tracer Balloon operate under the exemption clauses of FAR 101, as do radiosondes. Under these clauses, if a balloon system carries a payload which meets certain conditions regarding weight, density, and strength of suspension, the system is exempt from most of the other provisions of the regulation. This is important principally because one of those other provisions precludes operating non-exempt balloon systems in clouds, or even in the vicinity of clouds. This provision would severely limit the usefulness of a Tracer Balloon which was not exempt.

Because safety is a major consideration, certain safety features are incorporated in the Tracer Balloon design beyond those specified by FAR 101. For instance, even though the Federal Aviation Administration (FAA) does not require it, when the Tracer Balloon is flown at altitudes available to other aircraft, it will carry an FAA transponder. In this way, the FAA will see the Tracer on radar as prominently as a commercial airliner, and can control air traffic accordingly.

The intended uses also provide other Tracer Balloon design goals:

- Lifetime $\geq$ 3 days.
- Tracking range $\geq$ 1000 km.
- Telemetry of relative vertical air motion, pressure, temperature, and humidity.

- Ground system capable of handling several Tracer Balloons at a time.
- Capable of establishing specified ascent and descent rates under radio command.
- Capable of reaching altitudes up to 5.5 km (500 mb).
- Capable of following mean vertical flows as low as 1 cm/s with acceptable fidelity.
- Sufficiently inexpensive to permit use in significant numbers on an expendable basis.

As currently planned, the project is divided into four phases:

Phase I: Systems Design and Demonstration of Feasibility.

Phase II: Development of an Operational Prototype.

Phase III: Tests and Refinement of the Operational Prototype System.

Phase IV: Addition of Elements Necessary to Create a Practical Research Tool.

Phase I was initiated in fall, 1983, and ran through calendar year 1984. The results were reported by Zak et al (1986). The Phase I report gives the chain of reasoning and the experimental data which led to the operational prototype design described in the following section. Phase II spanned calendar year 1985. The results are presented in this report. Phase III is scheduled to begin during spring of 1986, and will extend into 1987. The timing and duration of Phase IV will be determined by budgetary considerations, and the needs of the National Acid Precipitation Assessment Program.

2. OPERATIONAL PROTOTYPE DESIGN

a. Buoyancy Control Concept

Balloon systems obey Archimedes' Principle: A body immersed in a fluid is buoyed up by a force equal to the weight of the fluid displaced. This implies that a balloon system will be in equilibrium when the weight of the air it displaces is equal to the weight of the system.

Constant volume balloon systems have a unique characteristic. The equilibrium condition is met only at one well-defined altitude, and the CVB seeks that altitude. If it should find itself above the equilibrium altitude, the CVB will experience a net downward force due to gravity because the ambient air is less dense at the higher altitude, and the volume of air displaced is fixed. Likewise, if it should be below its equilibrium altitude, it will experience a net upward force, since the buoyancy force exceeds the gravitational force. Thus, CVBs tend to oscillate around their equilibrium altitude, the oscillations driven by atmospheric turbulence. In atmospheric flows which have zero average vertical velocity, CVBs naturally follow the horizontal flow at their equilibrium altitude. However, in flows in which the vertical component is significant, a CVB will not adequately follow the overall flow.

The Tracer Balloon is a modified CVB. It is designed to sense its deviation from the mean vertical flow, and to adjust its buoyancy to keep its average vertical motion relative to the air surrounding it near zero. Thus, the Tracer follows both horizontal and vertical flows.

The buoyancy adjustment principle used in the Tracer was first put forward by V. E. Lally of the National Center for Atmospheric Research (NCAR) almost twenty years ago (Lally, 1967). He proposed a CVB with an inner bladder, or ballonet, to contain the lift gas (helium). The remainder of the CVB was to be filled with air (Figure 2-1). A system of pumps and valves was included to allow air to be

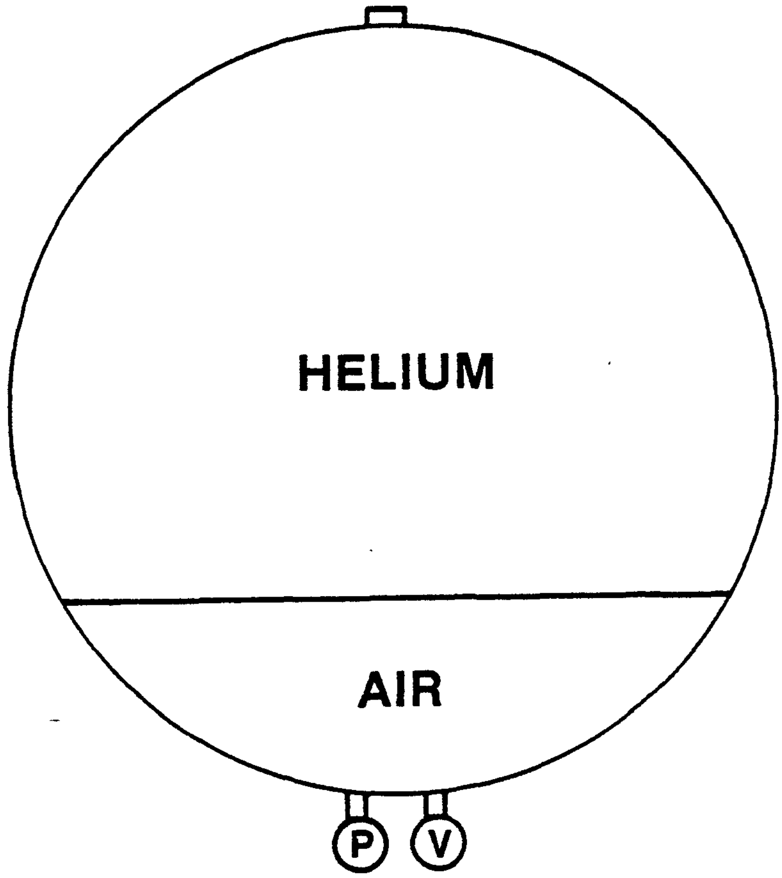


Figure 2-1. Buoyancy Control Principle. The outer skin of the balloon is made of a material which expands very little as the internal pressure increases. A thin polyethylene inner balloon, or "ballonet", keeps the helium lift gas separate from the air ballast. A pump (P) permits more ballast air to be taken on. A valve (V) permits ballast air to be vented. The total volume remains nearly constant, so pumping or valving changes the average density of the system, and thus its altitude.

pumped in or to be released, respectively increasing the mean density of the balloon and thereby decreasing its equilibrium altitude, or decreasing the mean density and thus increasing the equilibrium altitude. Lally's concept was adopted for the Tracer Balloon. Previously, it had been tried by the French on stratospheric balloons with some success, but was not developed further (Blamont et al, 1974).

In Phase I, we examined the behavior in a standard atmosphere of an adjustable buoyancy balloon of the type proposed by Lally. A summary of the equations derived to describe its behavior is given in Appendix B.

b. Buoyancy Control Strategies

For a workable Tracer, it is also necessary to incorporate a means of sensing deviation from the mean vertical air flow. Two approaches are considered here. Both have advantages and disadvantages. The first is to measure the vertical air velocity relative to the Tracer Balloon, and to integrate that velocity with time to obtain relative vertical displacement. The second is to take advantage of the near-adiabatic nature of atmospheric flows, and to use potential (or equivalent potential) temperature as the control parameter.

The first approach is very direct. It yields the desired information with few if any assumptions. On the other hand, it places very stringent demands upon the vertical velocity measurement. If the measurement involves an average systematic bias of only 1 cm per second consistently in the same direction, the control system will create a relative vertical displacement which grows linearly with time at the rate of 36 m/hour. On the other hand, if the same 1 cm/s error is entirely random, the total expected error in a 72 hour flight may be less than 40 m (Zak et al, 1986). Since measurement error is nearly always a mix of both random and systematic, the details of the measurement, which determine the proportions of the mix, are very important. Unacceptable bias may also be present under some meteorological conditions, but not others. For instance, in rain, a propeller-type vertical anemometer would surely give a grossly biased result.

Use of the near-adiabatic character of atmospheric flows poses less of a measurement problem. In the absence of liquid water and of diabatic heating or cooling, the potential temperature is conserved -- that is, trajectories are isentropic (Holton, 1979). Potential temperature is given by:

$$\theta = T(1000/P)^{R_a/c_p} \qquad (2\text{-}1)$$

Here T is the ambient temperature, P the ambient pressure, R_a the gas constant for unsaturated air, c_p the specific heat at constant pressure for air, and $R_a/c_p = .286$. In a standard atmosphere, the vertical gradient of potential temperature at sea level is 3.3×10^{-3} degrees Kelvin per metre. So, if one controls potential temperature to plus or minus a tenth of a degree, the altitude would be controlled to ± 31 m, quite adequate for our purposes.

However, diabatic effects do occur. In the region of interest below 5.5 km, they are strongest near the surface, and decrease with height above ground. Throughout most of the troposphere, diabatic heating and cooling is of order one degree Kelvin per day (Wallace and Hobbs, 1977). Depending upon meteorological conditions, this change may be net heating, net cooling, or interim variation with no net gain or loss. One would expect the diabatic effects to occur primarily during convective mixing. In the absence of a means of taking these effects into account, they would limit the accuracy with which an isentropic Tracer Balloon would reflect air motion.

In the presence of liquid water, condensation and evaporation occur with the result that potential temperature is no longer conserved even if the flow is adiabatic. However, "equivalent potential temperature" is conserved in wet processes (Holton, 1979; Wallace and Hobbs, 1977). It could be used as the altitude control parameter in the presence of liquid water. The equivalent potential temperature is given by:

$$\theta_e \simeq \theta \exp\,(Lq_s/c_pT) \qquad (2\text{-}2)$$

where L is the latent heat of condensation, and q_s is the saturation mixing ratio of water vapor in air at the ambient temperature and pressure.

The operational prototype currently incorporates three control algorithms selectable by radio command. The control parameters for these algorithms are, respectively, relative vertical displacement, potential temperature, and ambient pressure. In a stable (non-convective) atmosphere, in the absence of liquid water, the potential temperature control algorithm is most appropriate. In a stable but saturated atmosphere, an algorithm yet to be written using equivalent potential temperature would be most appropriate. In a convective atmosphere, the gradient of the potential temperature with altitude goes to zero. Hence, under convective conditions, potential temperature is not a satisfactory control parameter. Rather, relative vertical displacement becomes the control parameter of choice. Under convective conditions, over reasonably flat terrain, even the constant pressure control algorithm may be satisfactory.

The question of the most appropriate control strategy to adopt under different meteorological conditions is quite complex. It was discussed at some length in the Phase I report, especially in Appendix J (Zak et al, 1986). It is an area that will continue to receive attention in Phases III and IV. We will return to it in Section 4.

c. Balloon Envelope

A second generation balloon envelope has been designed (Appendix C). However, five first generation balloons remained after the conclusion of Phase I (Figure 2-2). Consequently, as an economy measure, first generation balloons were used in the operational

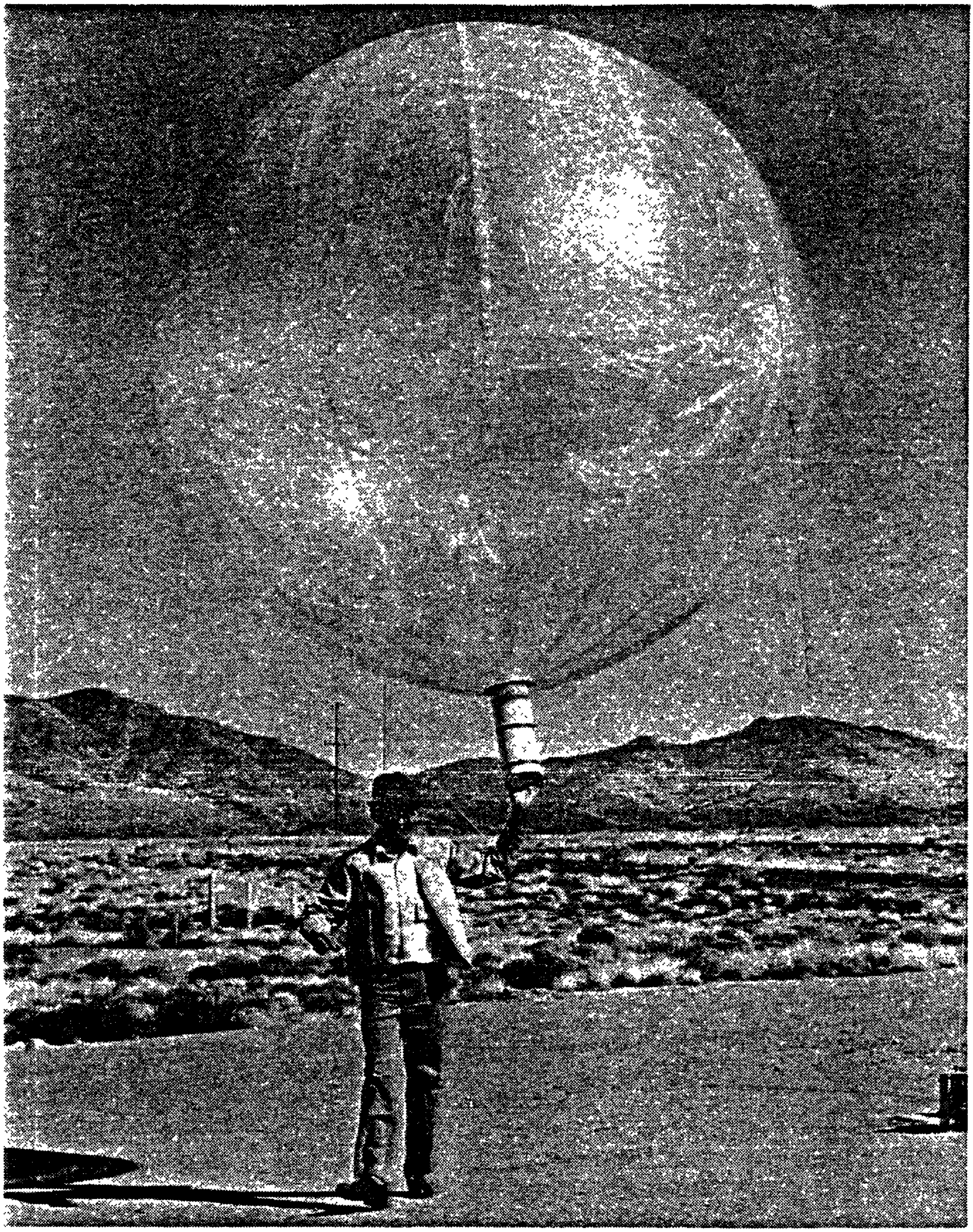


Figure 2-2. Phase I Testbed Prototype Balloon Tracer. It incorporated the same first generation balloon as did the operational prototype flown during Phase II.

prototype system. They were designed and fabricated to our specifications by Raven Industries of Sioux Falls, South Dakota. Their nominal characteristics are:

Shape:	Sphere
Volume:	12.5 m^3
Diameter:	2.9 m
Material:	3.0 mil polyester (bilaminated)
Ballonet:	1.0 mil polyethylene
Weight:	4.4 kg

The inner polyethylene balloon, or ballonet, is attached to the outer polyester (mylar) balloon only at a helium fill fitting located at the top. The bottom fitting is a 16.5 cm diameter external nylon plate fastened with screws to a nylon ring inside the outer balloon. The nylon plate was modified to accept two plastic fittings for air lines, and electrical leads to accommodate a pressure sensor assembly inside the balloon. The plate can be removed, leaving a 11.4 cm aperture which provides access to the inside of the outer balloon.

In the testbed prototype constructed for Phase I, the top fitting on the balloon was closed by a simple screw-on cap. In the operational prototype, a mating fitting was added that incorporated a pair of cutdown devices, and a helium fill line made of "layflat" polyethylene tubing. The cutdown fitting, the attached helium fill line, and an experimental version of the cutdown device is shown in Figure 2-3. In the cutdown device, a polyethylene membrane stretched across an aperture forms a seal for the helium. A pair of electric matches are mounted in such a way that if either one is actuated, a hole is burned in the membrane, and the helium is allowed to flow out. This results in a controlled descent (Appendix D). The flame from the electric match is totally contained within the cutdown device. Nevertheless, a Safe Operating Procedure was required to cover the use of electric matches in this way (Appendix E). The portion of the device which holds the stretched membrane is adapted

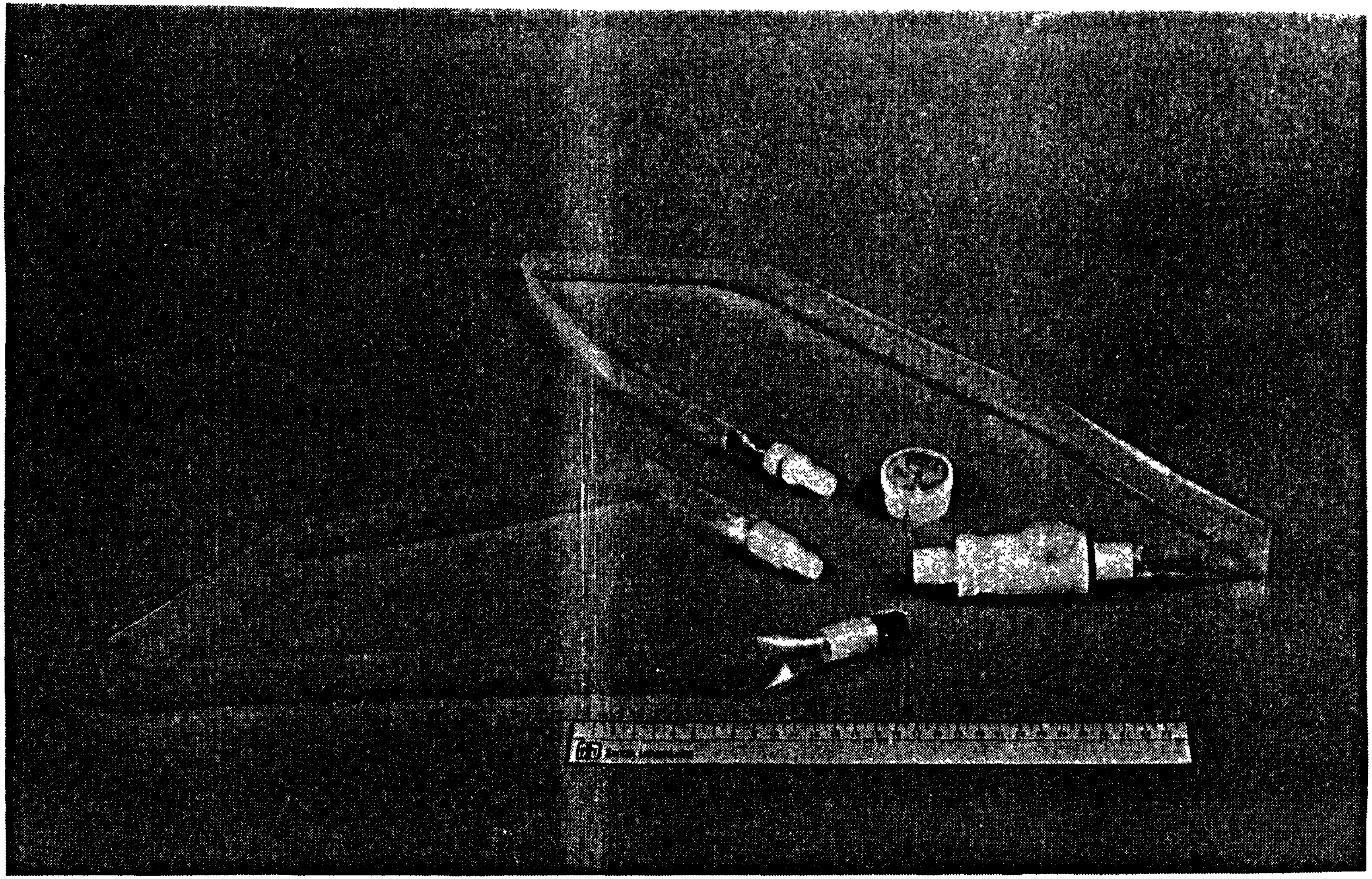


Figure 2-3. Top Fitting and Cutdown Device. The top fitting is on the right, and has a section of "layflat" polyethylene fill line connected to it. It incorporates a cutdown device similar to the prototype shown just above the fitting. A section of layflat which connects the base fitting to the pumping and valving system is shown to the left.

from an inexpensive, commercially-available liquid sample cell used in spectroscopy laboratories.

d. Payload

The operational prototype payload consists of the following elements:

- Buoyancy adjustment subsystem
- Sensor subsystem
- Microcomputer
- Interfaces
- Cutdown timer
- Argos platform transmitter terminal
- Argos antenna
- Radio command receiver
- Command decoder
- Command antenna
- Backup cutdown package
- Tracking aids
- Batteries

Each of these elements is discussed below. A block diagram of the payload is given in Figure 2-4. More detailed schematic diagrams of individual circuit boards are included in Appendix F. An assembly drawing of the operational prototype is given in Figure 2-5. Note that the vertical anemometer and the sensor package are mounted at opposite ends of a long styrofoam boom which allows the measurements to be made at positions where the influence of the balloon itself is negligible.

The buoyancy adjustment subsystem is shown in Figure 2-6. It makes use of the same type of Gilian pumps used in the testbed prototype, but here three pumps are used rather than two. This increases the pumpdown speed obtainable by about fifty percent. The actual pumpdown speed -- the rate at which the equilibrium altitude can be lowered -- is determined both by the temperature lapse rate, and by the pressure head against which the pumps must work, the "superpressure." With thirty millibars superpressure, in a standard atmosphere the calculated pumpdown speed with three pumps is about 15 cm/s. The relevant equations are included in Appendix B.

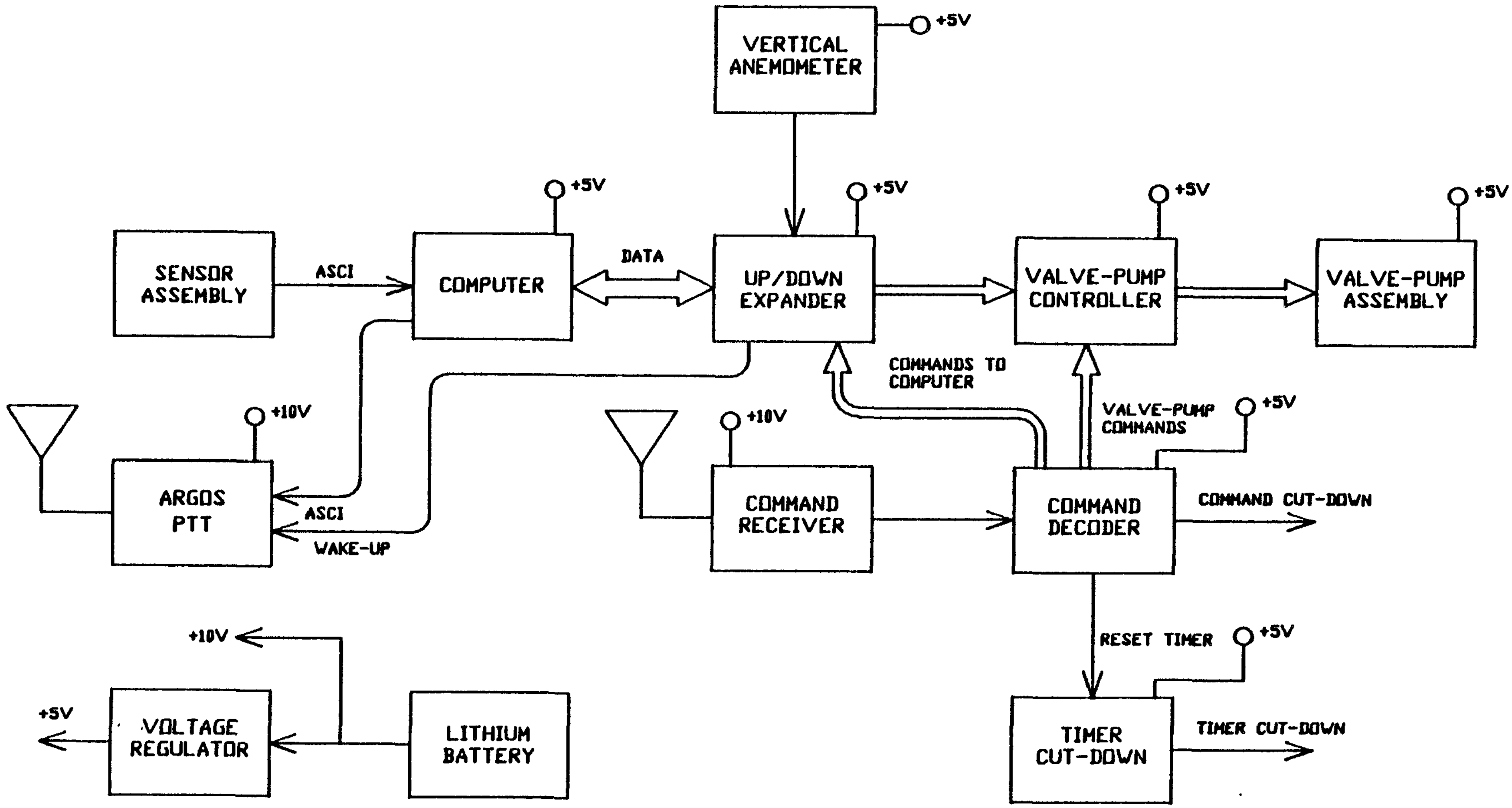


Figure 2-4. Block Diagram of Operational Prototype Payload.

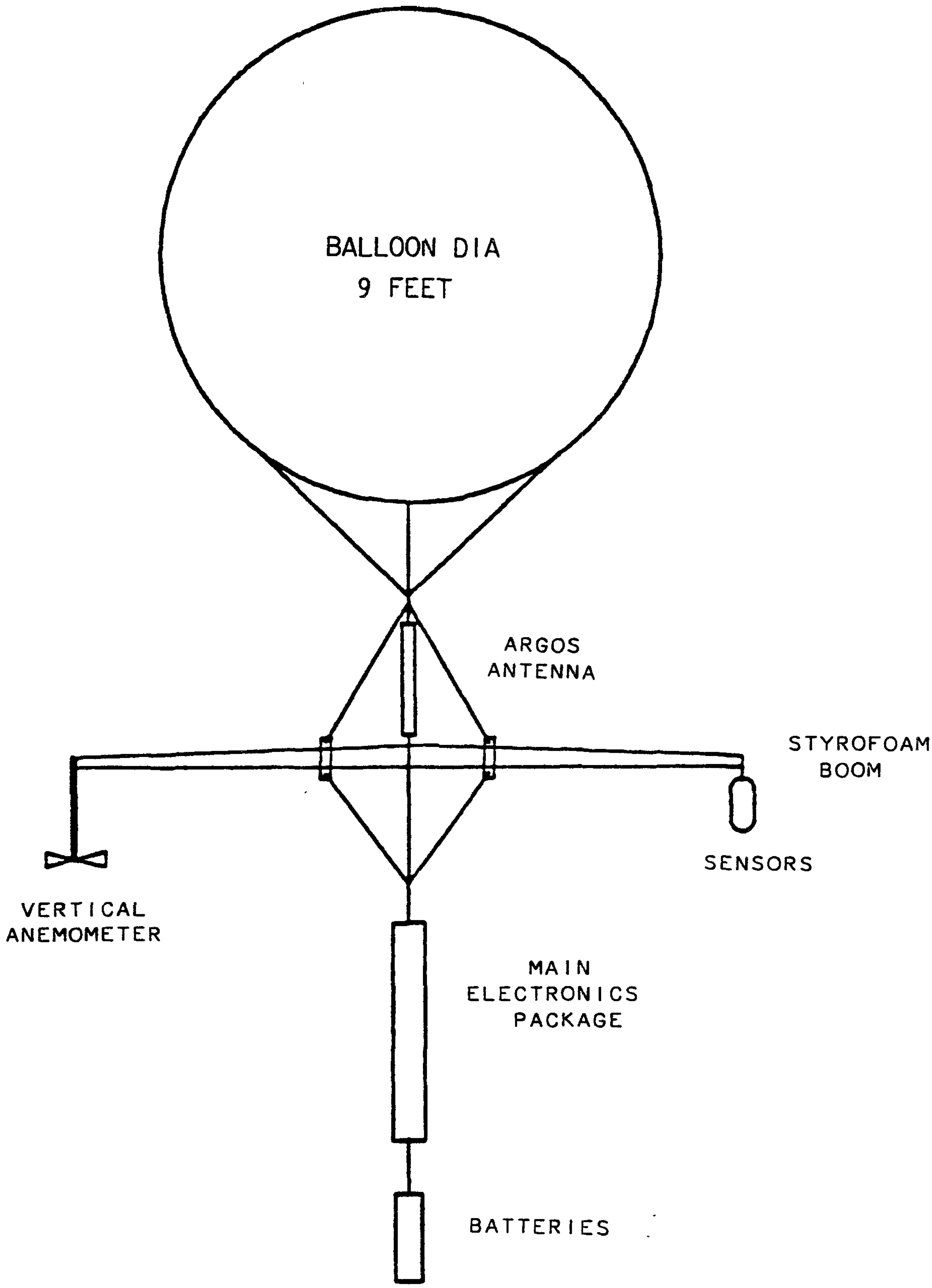


Figure 2-5. System Assembly Drawing.

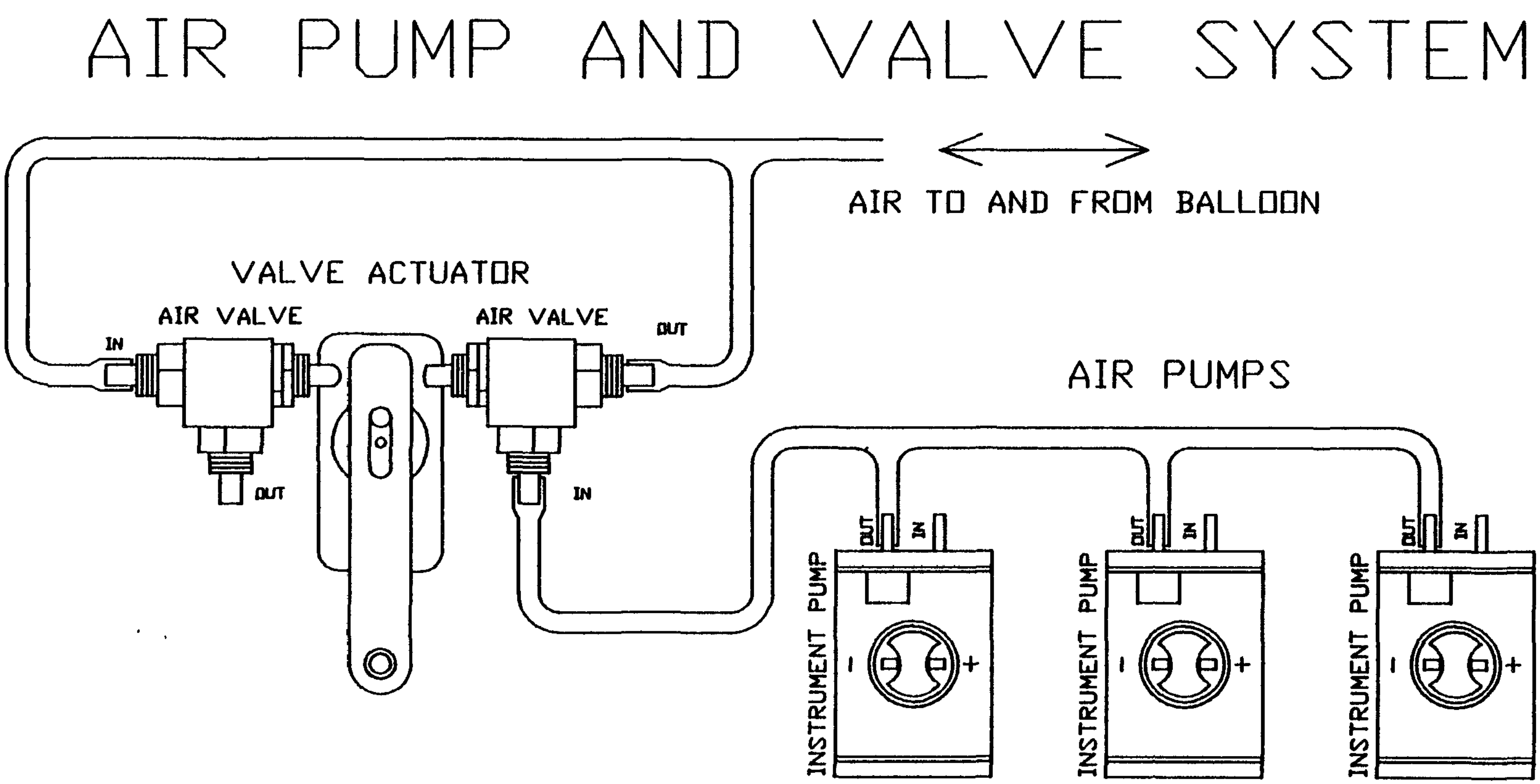


Figure 2-6. Buoyancy Adjustment Subsystem.

The same Klippard valves are used here as in the testbed prototype. The actuator, however, has been modified. In the testbed prototype, these mechanical valves were directly actuated by a servo. In the operational prototype, the servo drives a cam, and the cam actuates the valves. This arrangement has the advantage that the servo only requires power while the cam is turning -- while the state of the valves is being changed. At other times, the servo draws no current. This modification results in significant power savings.

The sensor subsystem consists of two elements. The first is an aspirated sensor assembly which measures ambient pressure, temperature, and humidity. It is a modified AIR Inc. prototype digital radiosonde. The assembly outputs data in ASCII format. The transmitter normally in place has been deleted, and the assembly has been housed in a styrofoam package normally used for a tethersonde, rather than a radiosonde. The tethersonde package makes provision for aspiration. Aspiration is important in the Tracer Balloon application because inadequate natural ventilation takes place.

The second element of the sensor subsystem is the vertical anemometer. It makes use of a stock 22.9 cm (9 in) diameter expanded styrofoam Gill propeller from R. M. Young Inc., and a slightly-modified Spaulding Instruments C1 rotation sensor. The Spaulding sensor is a photoelectric type which gives both rate and direction of rotation. It is modified only in that dust seals normally present were removed to minimize friction. An anemometer of this type was originally designed for Sandia by MacCready (1981). It has a starting speed under 2 cm/s, and a measurement threshold of under 3 cm/s. This starting speed and low velocity performance should allow relative vertical velocity measurements averaged over minutes to be made down to 1 cm/s or less. Even at very low intensities of turbulence, the instantaneous relative vertical air velocities are likely to be considerably higher than the average over a few minutes. The sensor package and the vertical anemometer are shown in Figure 2-7.

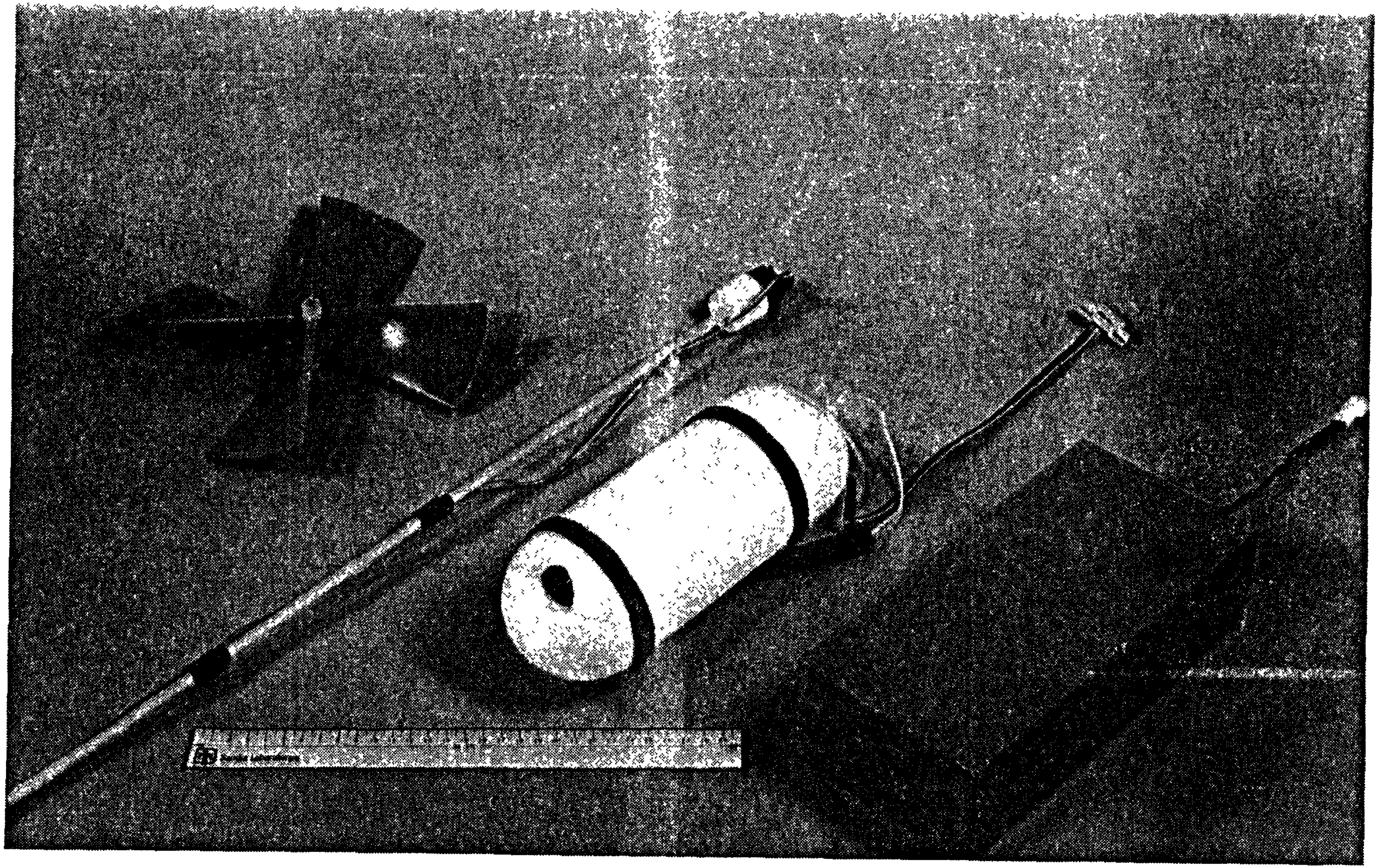


Figure 2-7. Vertical Anemometer, Sensor Package, and Command Receiver. Left to right, the components shown are the propeller for the vertical anemometer; the shaft carrying the anemometer rotation sensor; the aspirated pressure, temperature, and humidity sensor package; and the styrofoam-encapsulated command receiver.

The heart of the control system is an Intel 8052AH BASIC microcomputer. It contains 4 K bytes of random access memory (RAM) and 4 K bytes of programmable read only memory (PROM). The control program is written in BASIC, and was entered into the microcomputer from a terminal. After testing, it was transferred to PROM. Thereafter, when the payload was powered up, the program self-loaded and ran. A listing of the control program used during the field tests is given in Appendix G.

The Intel 8052AH requires a variety of interfaces to other system elements. Those interfaces are combined on the same board with an up-down counter which is part of the vertical anemometer.

The cutdown timer automatically actuates the cutdown device after a preselected period. However, the timer can be reset to zero by radio command. In normal operation, the timer reset command is sent at frequent intervals. As long as those commands are received at intervals not exceeding the preselected period, automatic cutdown is avoided. If, on the other hand, radio communication with the Tracer is lost for a period exceeding that which has been preselected, the Tracer is automatically removed from the sky. This arrangement avoids the possibility of the Tracer becoming a derelict in the event that radio communication is lost. Figure 2-8 shows the cutdown timer, the interface board, and the microcomputer.

The Argos platform transmitter terminal (PTT) was made by Telonics, of Mesa, Arizona. It is uniquely compatible with the flight control microcomputer. It is controlled by ASCII input commands. The first ASCII byte specifies the identification code of the PTT and the way the data are to be processed for transmission. The next 32 bytes are the data to be transmitted. Eight codes are programmed into each PTT. The computer controls which code or codes are used. The Argos data frame used here is given in Appendix H. The Argos antenna is a high gain device designed originally at NCAR for use on high altitude balloons (Figure 2-9). A detailed description of the entire Argos satellite-based data collection and

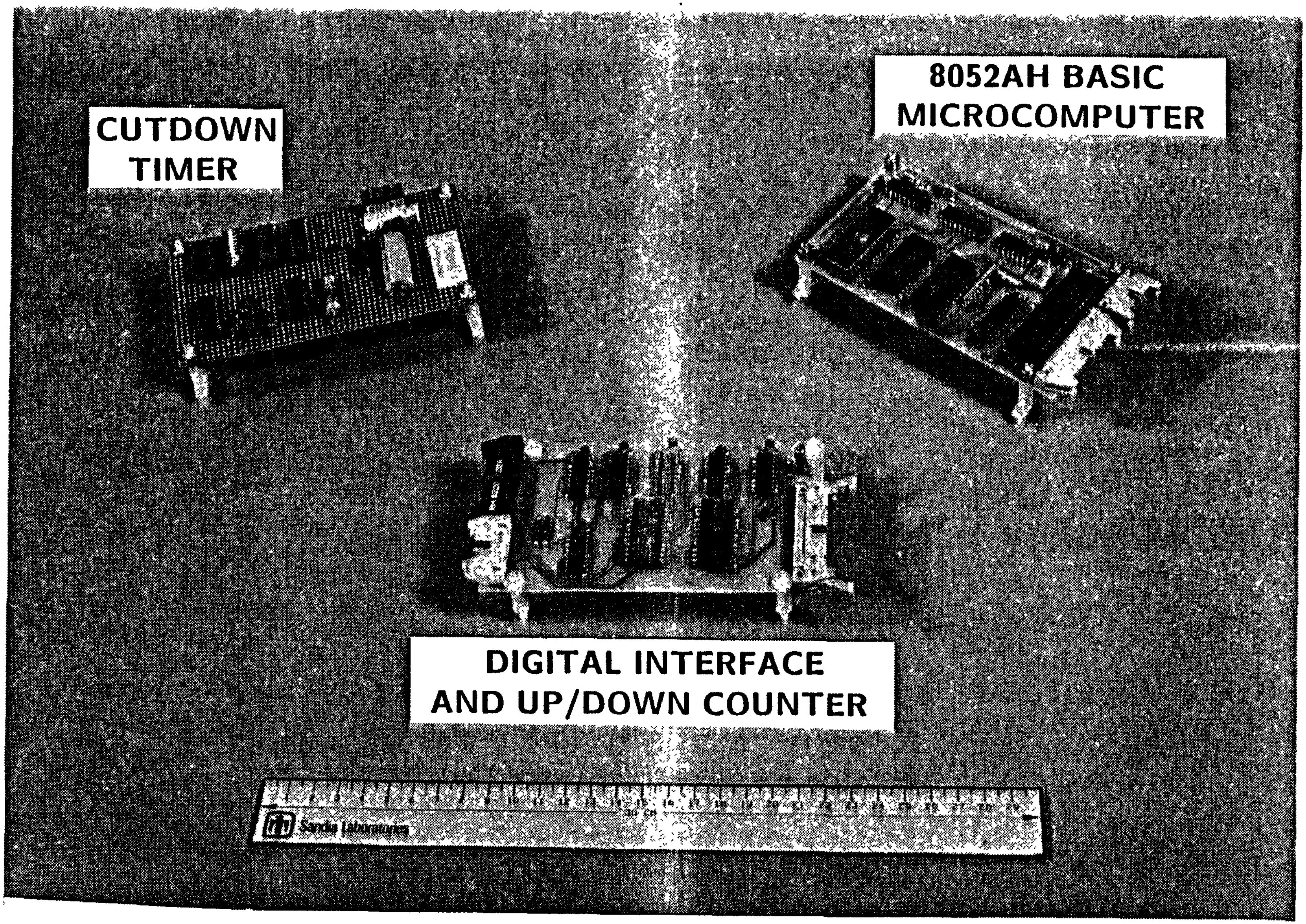


Figure 2-8. Timer Cutdown, Interface, and Microcomputer Boards. The up/down counter mounted on the interface board is part of the anemometer circuitry.

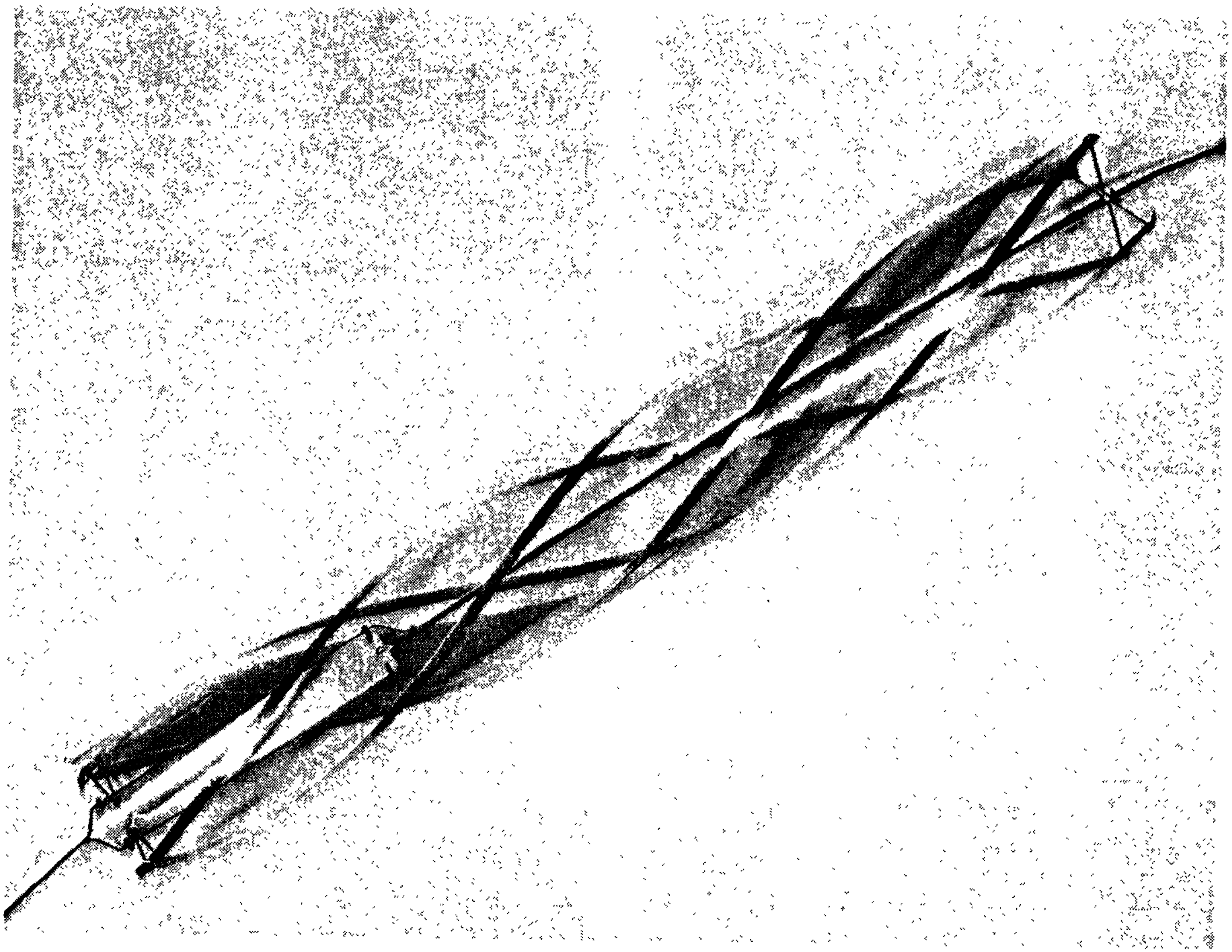


Figure 2-9. Argos Antenna.

platform location system was included in the Phase I report as Appendix H (Zak et al, 1986).

The radio command receiver is a unit designed and built for our application by Hock Engineering of Boulder, Colorado. It operates on 13.8035 MHz, a frequency to which Sandia has access. It has a one microvolt sensitivity. The receiver (packaged in styrofoam) is shown in Figure 2-7. The command receiver antenna is a quarter wavelength wire.

The commands are electronically encoded at the transmitter, and decoded at the receiver. The encoder/decoder circuit pair are commercially available components designed for use in television remote control systems. Since they are mass produced, they are quite inexpensive. The commands currently available are:

- Activate cutdown
- Reset cutdown timer
- Initiate control in pressure mode
- Initiate control in potential temperature mode
- Initiate control in relative vertical motion mode
- Increment current value of control parameter
- Decrement current value of control parameter
- Turn on pumps

The encoder/decoder pair is capable of incorporating many more commands with minimal changes.

For the field tests, a backup command cutdown package was mounted near the balloon top fitting. It made use of a model aircraft radio control receiver to actuate one of the electric matches on command independent of the cutdown timer and the main command system.

The tracking aids were not flown on the operational prototype Tracer during the short flights conducted to date. Consultation with the FAA suggested that for flights under 300 m above ground level (AGL) in the test area, there was no need for them. They were procured, nevertheless. The FAA transponder with encoding altimeter is a unit made by Terra Corporation of Albuquerque. This unit appears to be the lightest and lowest power drain unit on the market. Two different lightweight strobe lights were obtained for nighttime use. A decision has not yet been made as to which would be preferable.

The batteries were lithium thionyl chloride units in AA, C, and D cell sizes procured from Altus Inc. They are reported to have excellent low temperature characteristics. This property will be necessary in order to meet the 5.5 km (500 mb) altitude design goal. At this altitude, low temperatures will be encountered. Preliminary tests with the batteries have been conducted down to -18 C.

Each side of the main electronics package is shown in Figures 2-10 and 2-11, respectively.

e. Ground Support System

The ground support system for the operational prototype tests is shown in Figure 2-12. It consists of a Handar Argos downlink receiver and decoder, an HP85 PC, a command encoder, a Swan command transmitter, and an antenna coupler mounted in a 5 m Airstream trailer. The HP85 converts the Argos data stream from hexadecimal to decimal form, formats it, and prints it out on its integral thermal printer. It also archives the data on its integral magnetic tape cassette recorder. An Argos antenna, and a vertical command antenna were mounted on a crank-up tower on the trailer.

f. Inflation Shelter

Inflation of the Tracer Balloon in the field without suitable shelter would be very difficult. Consequently, a modular

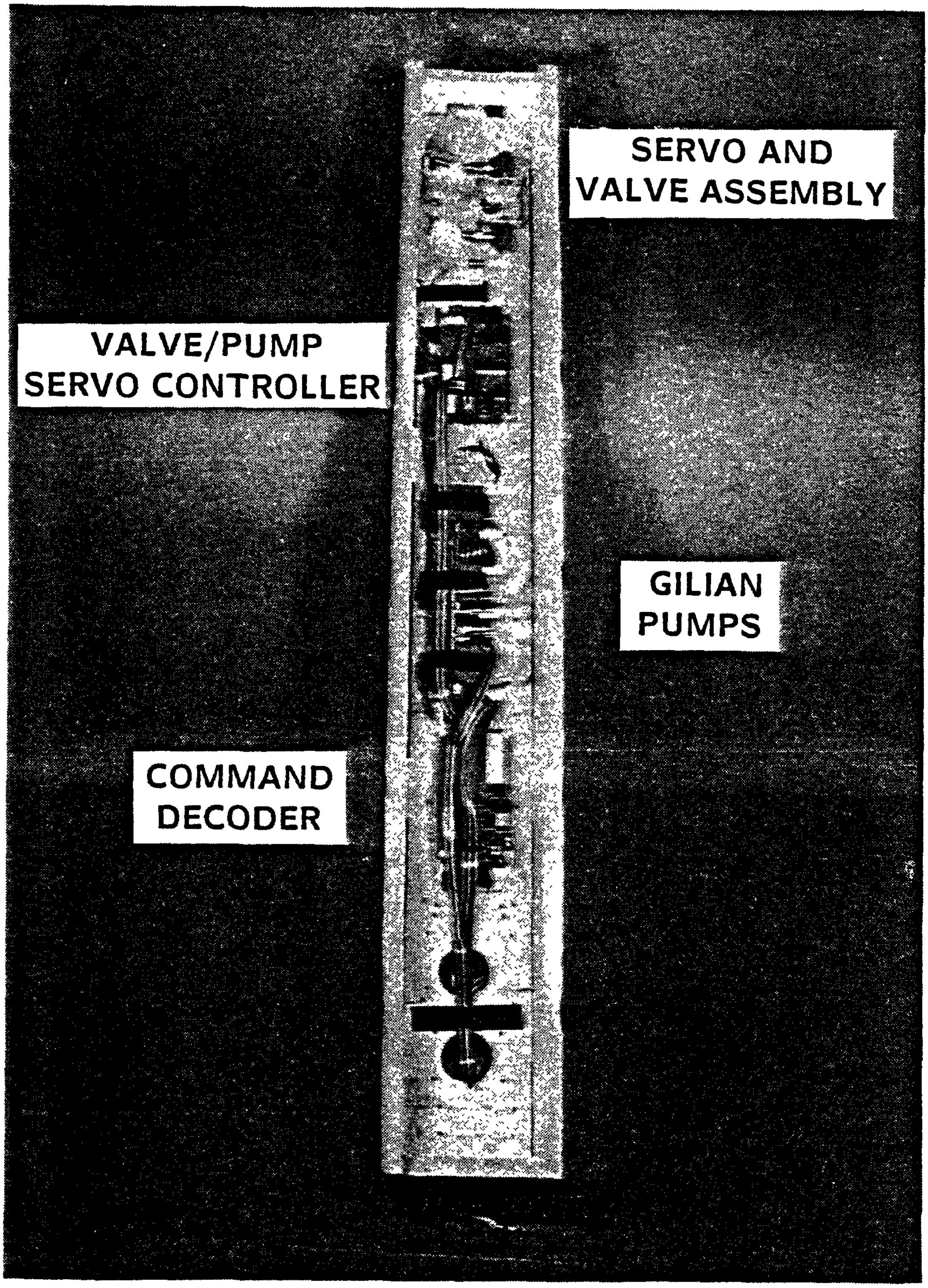


Figure 2-10. Main Payload Package, Side A.

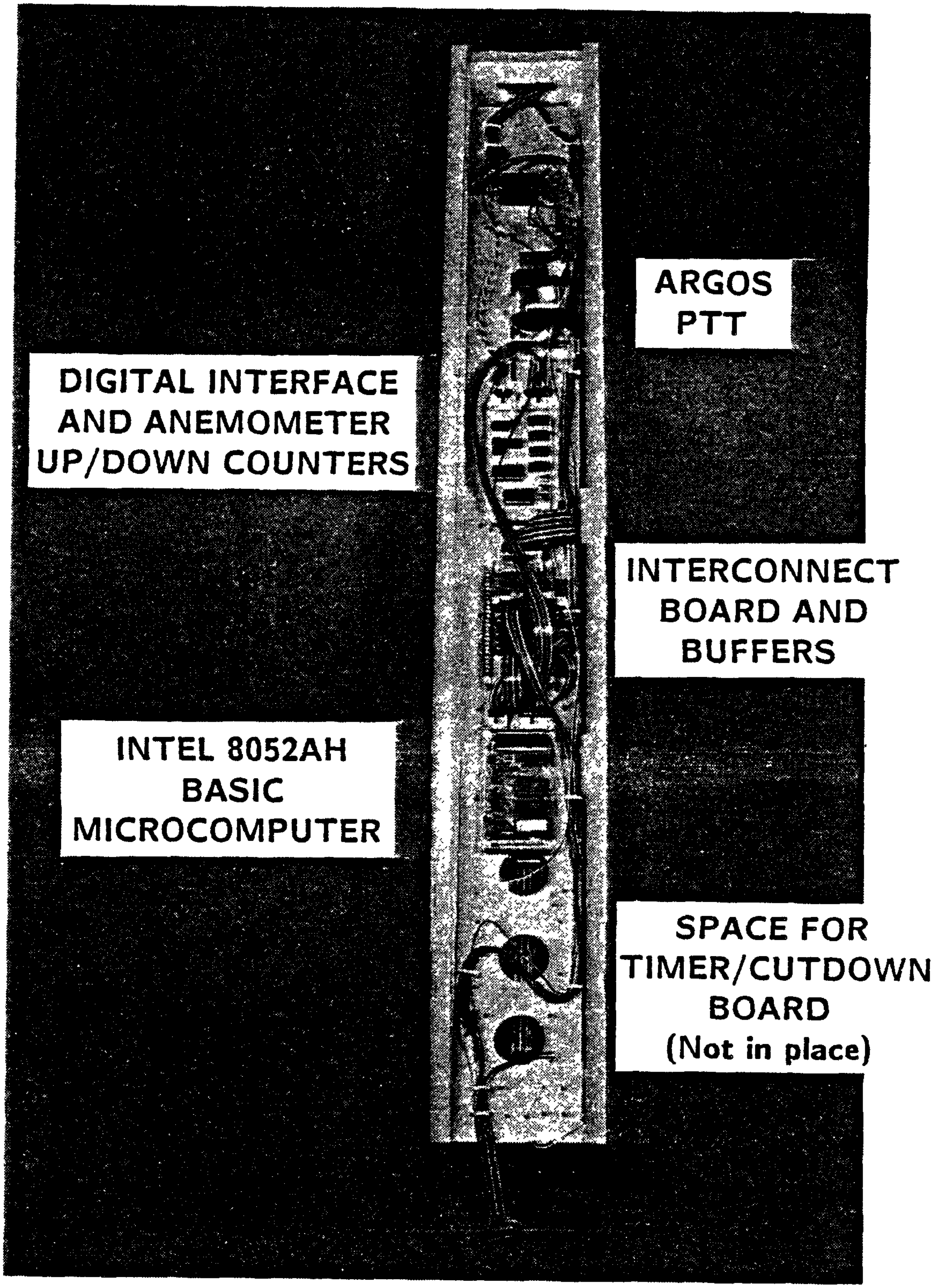


Figure 2-11. Main Payload Package, Side B.

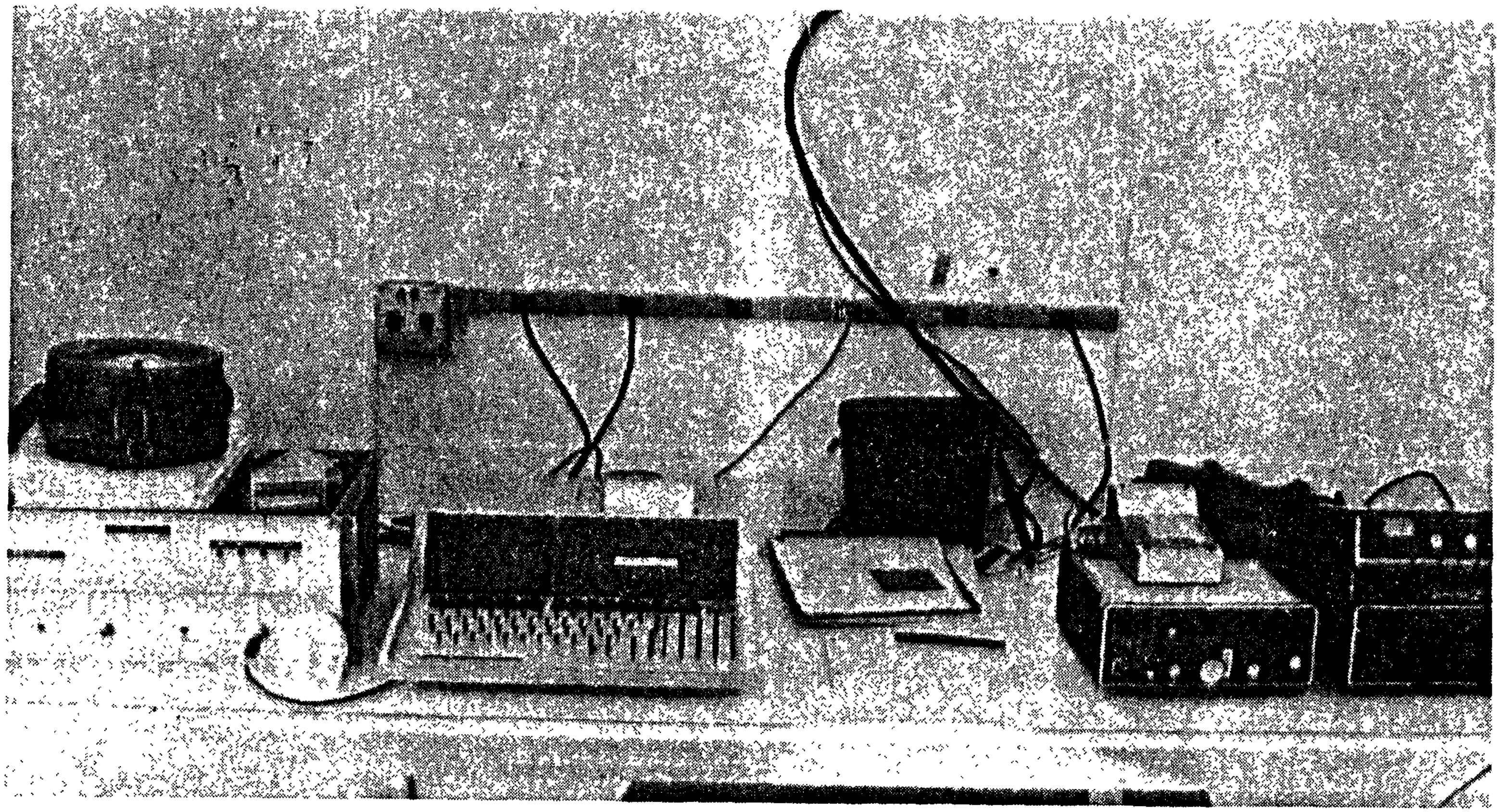


Figure 2-12. Ground Support System. The Argos downlink receiver and decoder are at the left. A portable precision barometer is on top of the receiver. Next to the right is the HP85 PC, and then the Swan command transmitter. The command encoder is on top of the transmitter. An antenna coupler and the transmitter power supply complete the system.

inflation and launch shelter was designed and built (Figure 2-13). It makes use of a specially-fabricated bed for a 2 1/2 ton truck. The bed was built for balloon launch for an earlier DOE project. It is 16' long, and has 4' sides constructed so that they fold down and are supported level with the truck bed, forming a 16' by 16' square area. A 12' x 12' x 12' prefabricated plywood shelter assembled from reinforced panels was built to mount on the expanded truck bed. The back surface of the shelter consists of two full-height hinged doors for moving balloons in and out. The balloon fits comfortably inside the 12 foot cube. For transport to and from a launch site, the shelter is disassembled to its constituent panels, and carried on the truck with the sides and tailgate in the normal upright position. Of course, this shelter is only required when no other suitable indoor space is available near the launch site.

3. Experimental Program

Testing and refinement of the operational prototype system were assigned to Phase III in the project plan. However, it was felt that at least a minimal test program was necessary as part of Phase II to demonstrate that the operational prototype developed here was in fact functional.

a. Balloon Envelope

Although the balloon system had been tested in Phase I, thought had not been given to how best to fill, check out, and weigh off the balloon system preparatory to launch. As long as only low altitude flights were contemplated, the fill was non-critical. However, if one desires to fill the balloon so that maximum altitude can be attained, and so that day-night temperature cycling and dew accumulation can be overcome, then the fill procedure becomes much more critical.

The procedure we developed is based upon Appendix F of the Phase I report. Knowing the volume of the balloon, the weight of the

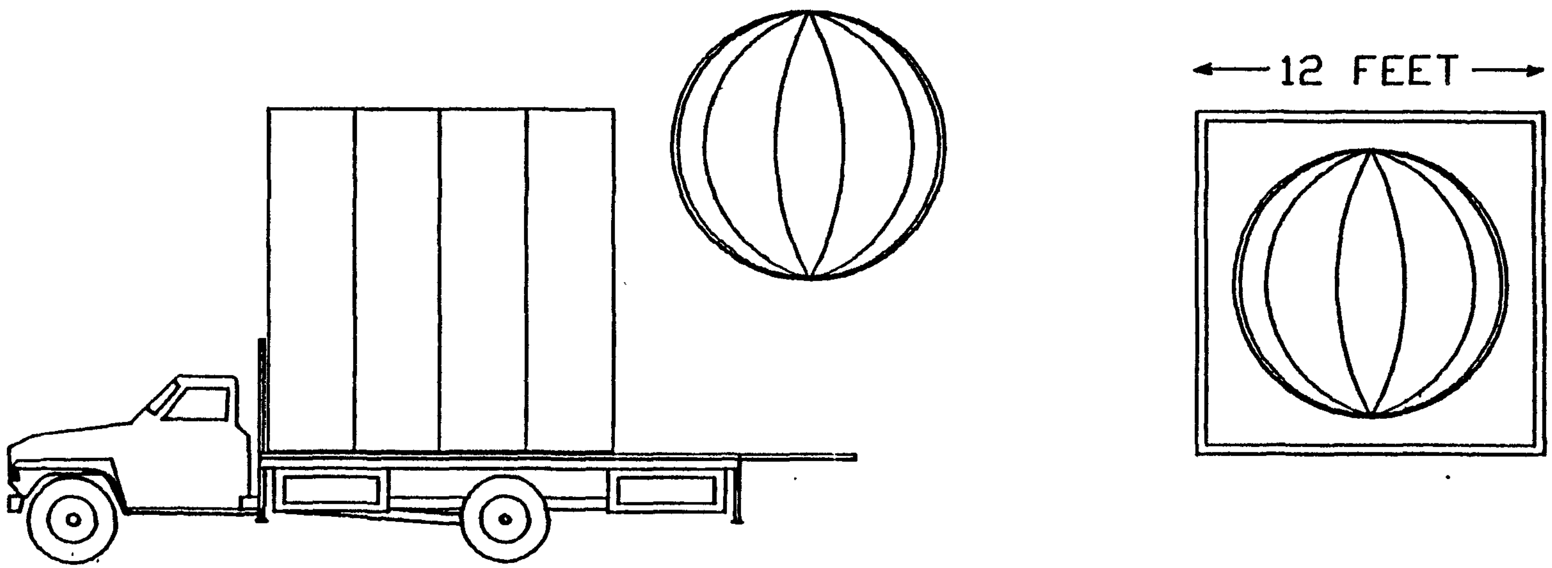


Figure 2-13. Inflation and Launch Shelter.

balloon, the weight of the payload, and the desired superpressure at liftoff, an equation presented there gives the "required lift." That equation is replicated as B-13 in Appendix B. Helium is put into the ballonet with the outer balloon slack until a digital scale indicates that the required lift has been reached. The balloon is fastened to a weight on the digital scale. As helium is put into the balloon, the reading on the digital scale declines to a value equal to the magnitude of the weight on the scale plus the weight of the balloon itself minus the required lift.

Next, the outer balloon is inflated with air using an auxiliary external pump until an external manometer indicates that the desired superpressure has been reached. At this point, the digital scale should indicate that the remaining lift is essentially equal to the weight of the payload. If the payload were attached, the balloon would be approximately neutrally buoyant. Unfortunately, the lift of a constant volume balloon depends not only on the volume of the balloon and the amount of helium it contains, but also on the pressure and temperature of the ambient air. Hence, any changes in ambient temperature or pressure which occur while the fill process is taking place need to be accommodated by "fine tuning" to obtain the desired final lift. This can be done in two ways: adjustment of the amount of helium contained in the ballonet, or adjustment of the amount of air contained in the outer balloon. To simultaneously obtain specified values for both the lift and the superpressure requires that both be adjusted. However, it is felt that the initial superpressure need only be accurate to within a few millibars. Hence, fine tuning can be accomplished with air alone if desired. The fill procedure outlined above was used in the field test program and was found to be adequate.

Balloon checkout was accomplished by weighing off the balloon, and recording the lift and the superpressure, as well as the ambient pressure and temperature. Twenty four or more hours later, the same parameters were measured again. In the absence of significant leaks, the new values of superpressure and lift were related to the old by the gas law and Archimedes' Principle.

The first balloon to be inflated for the test program was found to be defective. There was a serious leak between the inner ballonet and the outer constant volume balloon. Within a matter of a few hours, the helium which had been put into the ballonet had diffused throughout the outer balloon, leaving the ballonet slack. The decision was made to attempt repair. The ballonet was removed from the outer balloon and filled with air. A hole about 2 cm in diameter was found in the ballonet. It apparently was made when the ballonet was inserted in the outer balloon during the manufacturing process. The hole was patched with special balloon repair tape, and the balloon reassembled. In the process of reassembly, silicone vacuum grease and "liquid gasket" sealing material were added at selected interfaces where the original design appeared to have inadequate seals. The reassembled balloon was inflated and checked out perfectly. No residual leaks could be detected.

Once it was established that the repaired balloon was good, the relationship between superpressure and expansion of the outer balloon skin was investigated. At the beginning of the experimental program, it was thought that, properly calibrated, a strain gauge mounted on the skin of the balloon might provide an adequate measure of superpressure. If this were true, it would simplify the payload. A resistive strain gauge can be accommodated through a spare channel on the AIR sensor package; another aneroid pressure sensor cannot.

The strain gauge tried was a spring-loaded linear potentiometer with a range of 0-9.5 K ohms for a travel of about 1 cm. The gauge was fastened to a flexible plastic fixture which in turn was fastened to the skin of the inflated balloon. A 2 cm wide strip of mylar about 50 cm long was connected to the pull rod of the strain gauge, and the far end of the strip fastened to the skin of the balloon. The strip and its attachment points were mounted in the center of a gore, along a polar circumference. The linkage was adjusted so that initially the resistance of the strain gauge was near the center of its range when the superpressure was about 40 mb.

The balloon superpressure was cycled a number of times up to 80 mb, and back to zero. Measurements were made using an external pump, an external manometer, and a digital ohmmeter to read the strain gauge. This was done with the balloon attached to a weight on the digital scale. The scale readings were recorded as well. The information obtained allows one not only to observe how strain varies with superpressure, but how balloon volume does as well (Appendix I). The results are shown in Figures 3-1 and 3-2. The hysteresis exhibited by the strain gauge measurements is sufficiently severe that the resistance of the strain gauge does not provide accurate information on superpressure. Although it was not positively confirmed, it appeared that the ambient temperature also enters into the relationship between superpressure and strain.

After evaluating the data, a decision was made to abandon the strain gauge, and to make direct measurements of the balloon superpressure. This was done on the later flights using a standard AIR radiosonde package mounted on the inside of the balloon bottom fitting, and operated independent of the main payload.

b. Indoor System Tests

The Phase II plan called for the operational prototype Tracer to be exercised first in the elevator shaft of the solar tower at Sandia -- the 7 m square by 52 m high chamber used to test the Phase I system. Unfortunately, the solar tower was not available when the operational prototype was completed. A new heat exchanger system was being installed. Consequently, initial system tests were performed in a hanger on Kirtland Air Force Base instead (Figure 3-3). The modest height of the hanger limited the tests to confirming that the Tracer properly responded to radio commands to change its equilibrium altitude.

c. Free Flight Tests

The site chosen for the initial flight testing of the operational prototype Tracer was a large open area about 60 km south

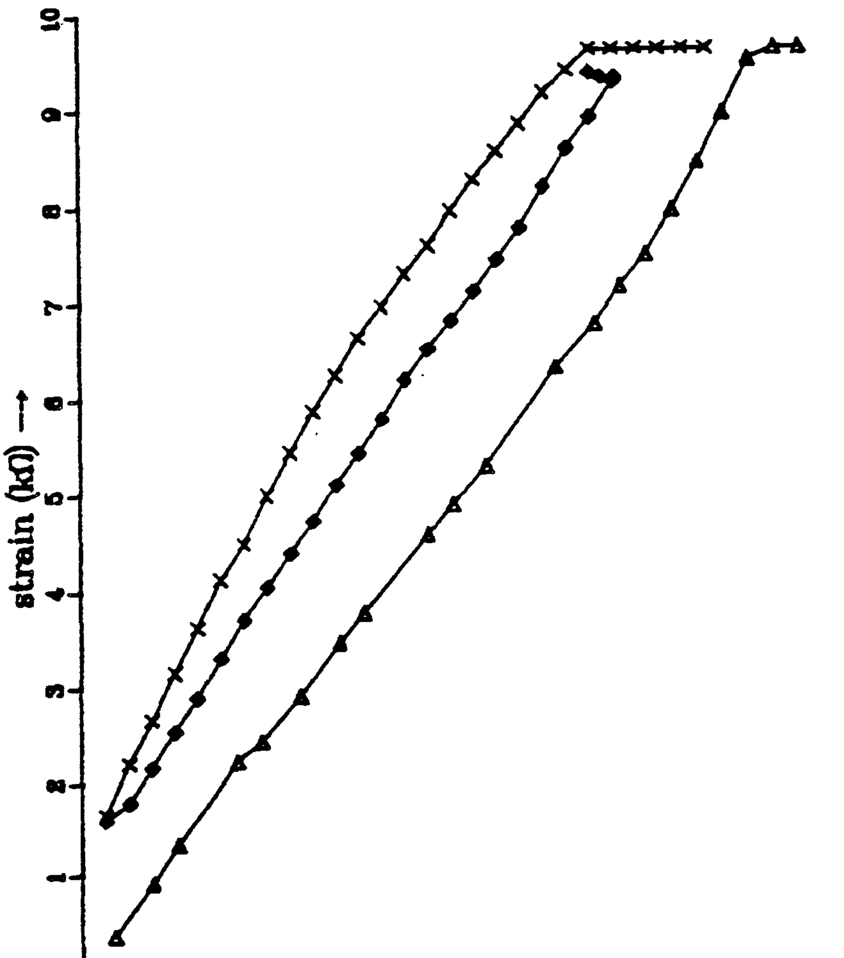


Figure 3-1. Strain vs Superpressure. Starting at zero superpressure, the data marked by triangles were taken first, followed by the data marked by Xs, and then that marked by diamonds. Note that the strain gauge saturates at 9.5 K ohms.

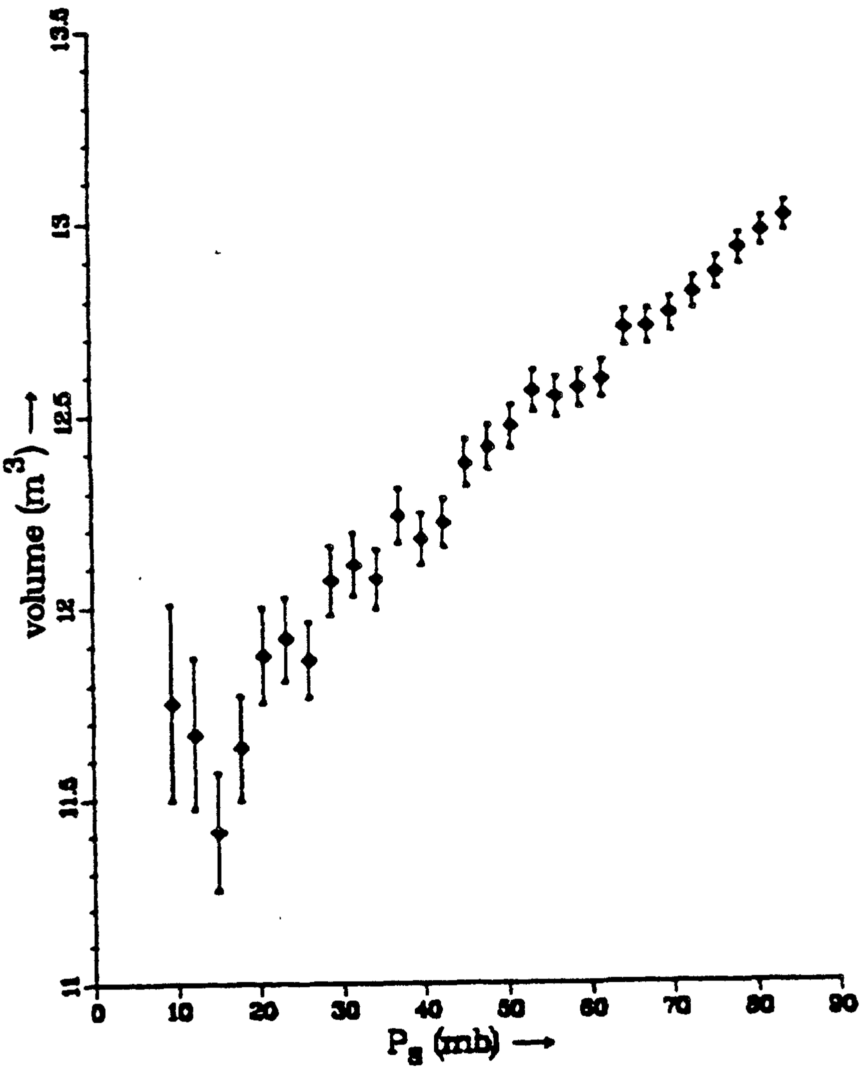


Figure 3-2. Volume vs Superpressure for the Tracer Balloon. It is clear from the data that the constant volume assumption is only a rough approximation. Variation of volume with superpressure is a major reason why passive "constant volume" balloons are not ideal tracers.

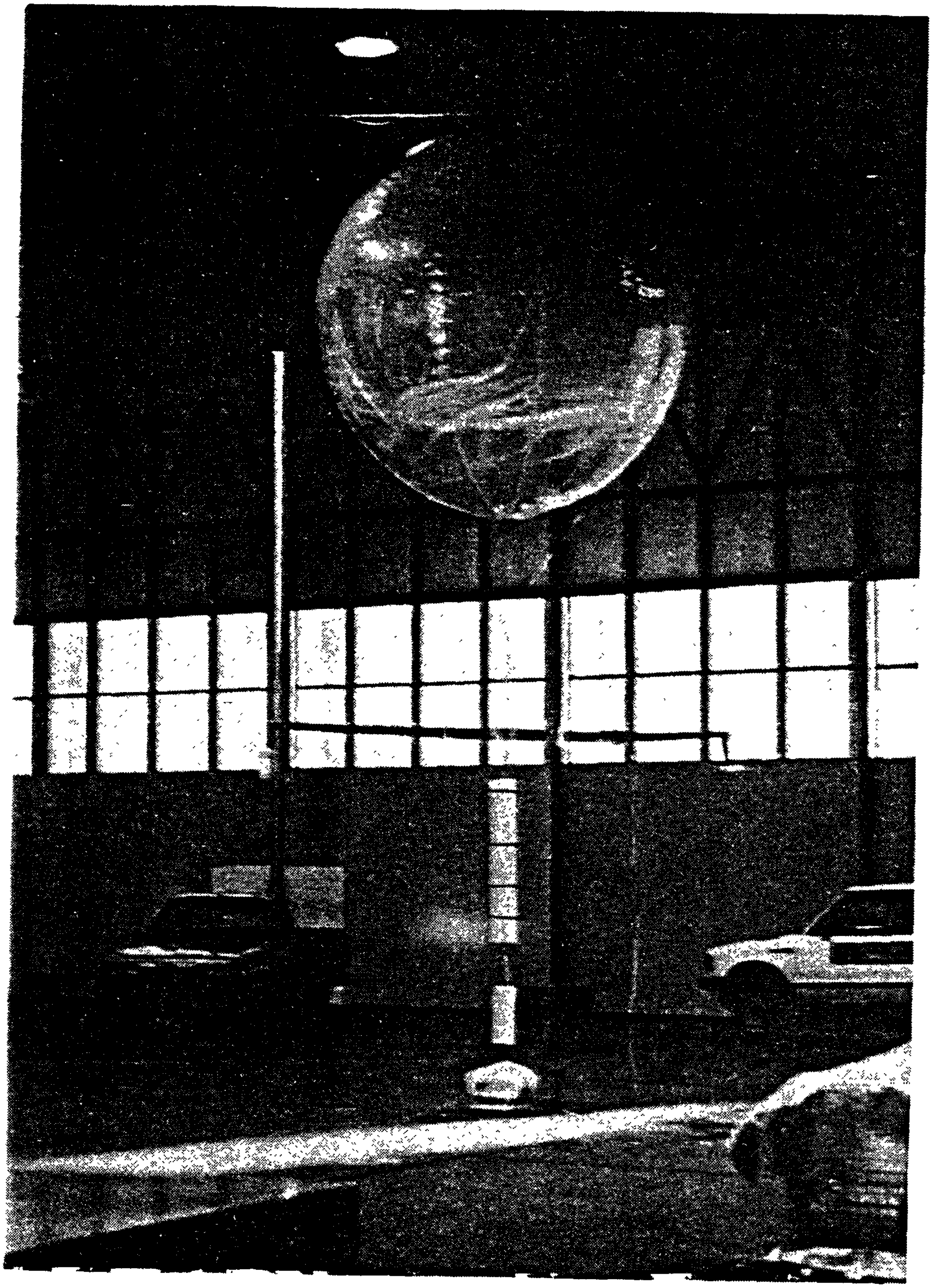


Figure 3-3. Indoor Test of Operational Prototype. The payload is connected with a line to a weight on a digital scale on the floor immediately below it.

of Albuquerque known as the Rio Communities. Some years ago, a number of developers subdivided this land, put in rudimentary roads, and offered it for sale. With the exception of a few small communities along the periphery, the land is still largely vacant. It forms a reasonably flat area of roughly 350 square miles (900 km^2) laced with dirt roads. It slopes from the western edge which is near the Rio Grande River, up to the base of the Manzano Mountains on the east. Permission for use of the land for the tests was obtained from the concerned land owners associations. A map of the area is given in Figure 3-4.

Once the experimental site was chosen, other arrangements could be made. Because the operational prototype Balloon Tracer was designed to fall under the exemption clauses of FAR 101, no coordination with the FAA was formally required. As a matter of good practice, however, liaison was established with both the FAA Albuquerque Approach Control, and with the FAA Albuquerque Air Route Traffic Control Center (Appendix J). It was also learned that one edge of the experimental area was routinely used by helicopters and C130s from the 1550th Combat Crew Training Wing based at Kirtland. Liaison was therefore established with the 1550th as well through its commanding officer and its Training Management Center.

The launch site itself was located on land owned by Mr. and Mrs. S. Longo, very near the center of the experimental area. The inflation shelter was reassembled in place at the launch site. The 16' Airstream trailer containing the ground support system was parked next to it (Figure 3-5).

Successful launch of the Tracer Balloon is a fairly complex undertaking. Many actions must be taken in proper sequence. To assure that those actions would in fact be properly taken, procedures and checklists were developed (Appendix K).

On December 5, the weather criteria for a test flight of the Tracer Balloon were met. Surface winds were extremely light. The balloon itself had been inflated in the shelter and prepared for

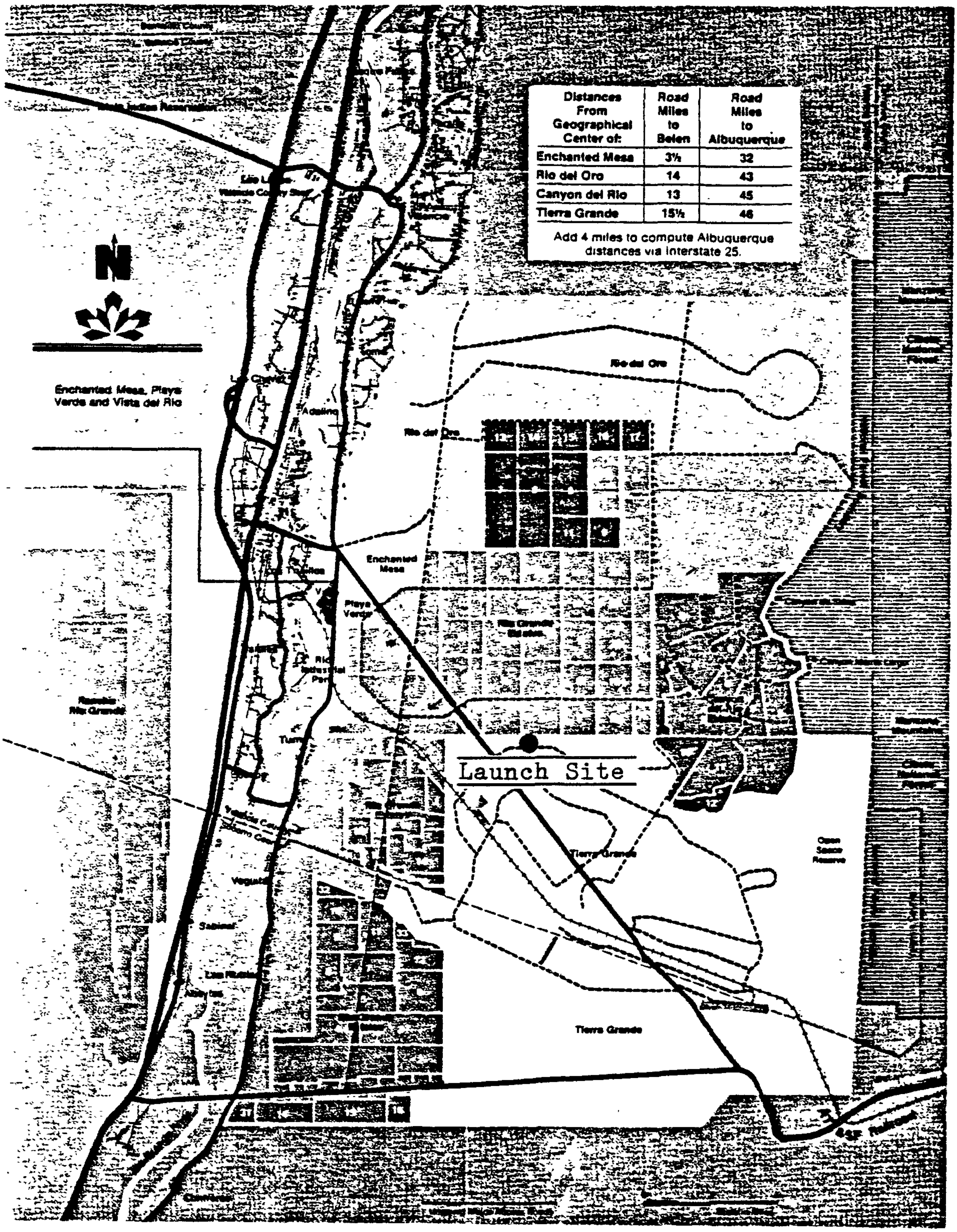


Figure 3-4. Map of Experimental Area.

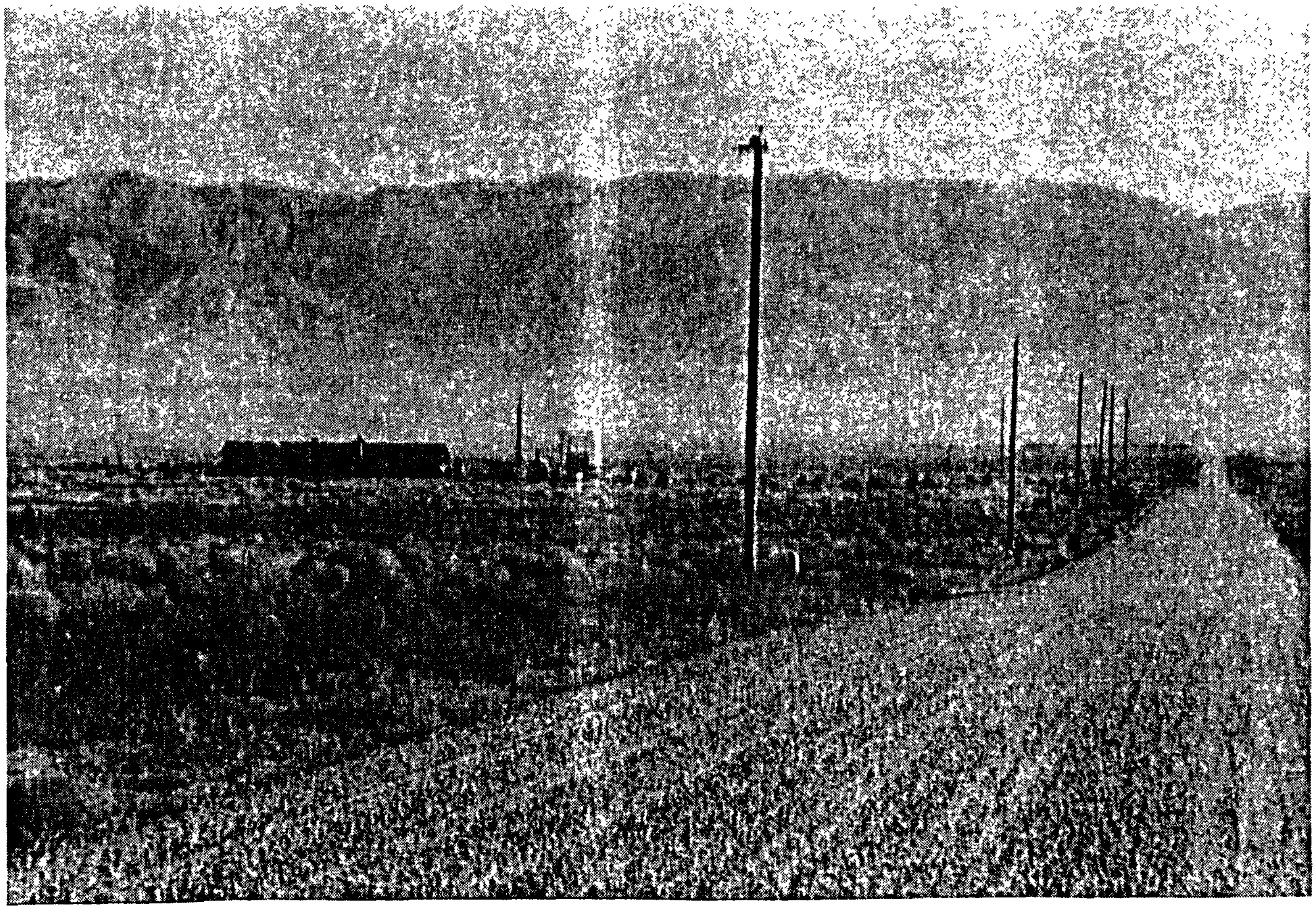


Figure 3-5. Launch Site. The Airstream trailer and the inflation shelter can be seen to the right of the house.

launch over the previous few days. On the morning of the flight, final weigh off was done as part of the launch procedures (Figure 3-6). The Tracer Balloon was launched at 10:41 am (Figure 3-7). The pressure control algorithm was used for the entire flight. The Tracer remained aloft for 2 hours and 20 minutes, and was recovered about 4 miles from the launch site (Figure 3-8). The control algorithm functioned properly. The most relevant data are given in graphical form in Figure 3-9.

After removal of the payload, an attempt was made to return the balloon fully inflated to the launch site by fastening it to the bed of the four-wheel-drive pickup used as a chase vehicle. Even though all five attachment points on the balloon were used, this attempt failed. The balloon got away when the pickup had gone only a few tens of metres. The terrain in the landing area was quite rough. The very rough ride put large stresses on the load patches at the attachment points on the balloon. All five load patches tore off, freeing the balloon. The balloon without payload rose rapidly to an estimated altitude of 1500 m AGL at which it burst. The estimated superpressure at burst was between 150 and 200 mb, about double the maximum operational superpressure of 80 mb. After it burst, the balloon envelope was visually tracked as it came down. The top fitting and the cutdown device which had been left attached were recovered intact from the remains of the balloon envelope about three miles from the point at which the balloon escaped.

The loss of the balloon envelope was not considered a major setback. In project planning, the assumption had been made that the balloon envelope would not be recovered intact in normal use. It now appears that if the balloon is deflated upon recovery, the balloon is likely to be reuseable.

A new balloon was inflated and prepared for use on the next test flight. This time, no leaks were found. The payload was also modified to accomodate the superpressure measurement, and to overcome a flaw which had been found in the way sensor data was entered into the microcomputer. On December 16, weather conditions were again

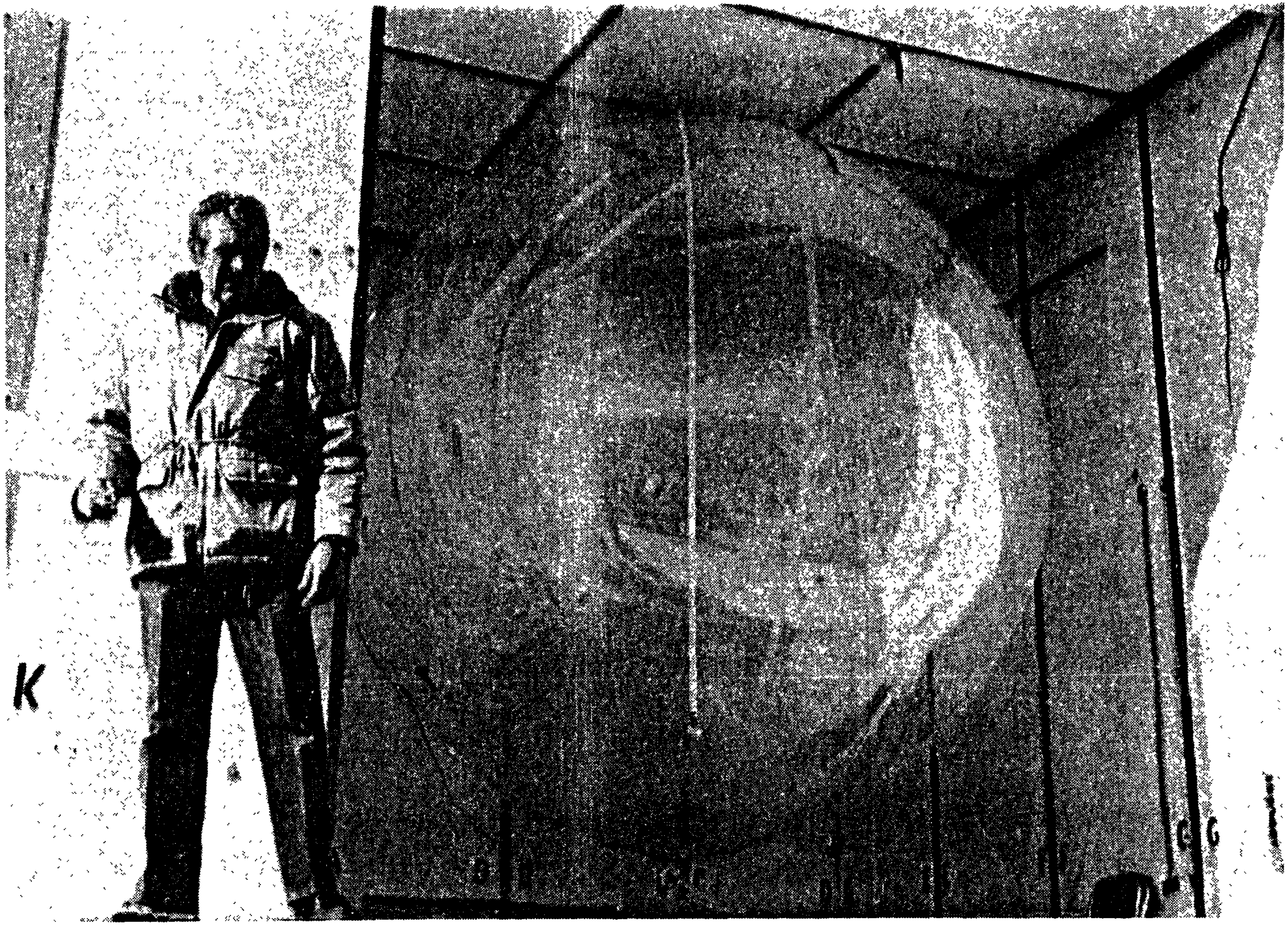


Figure 3-6. Balloon in Shelter after Weighoff.

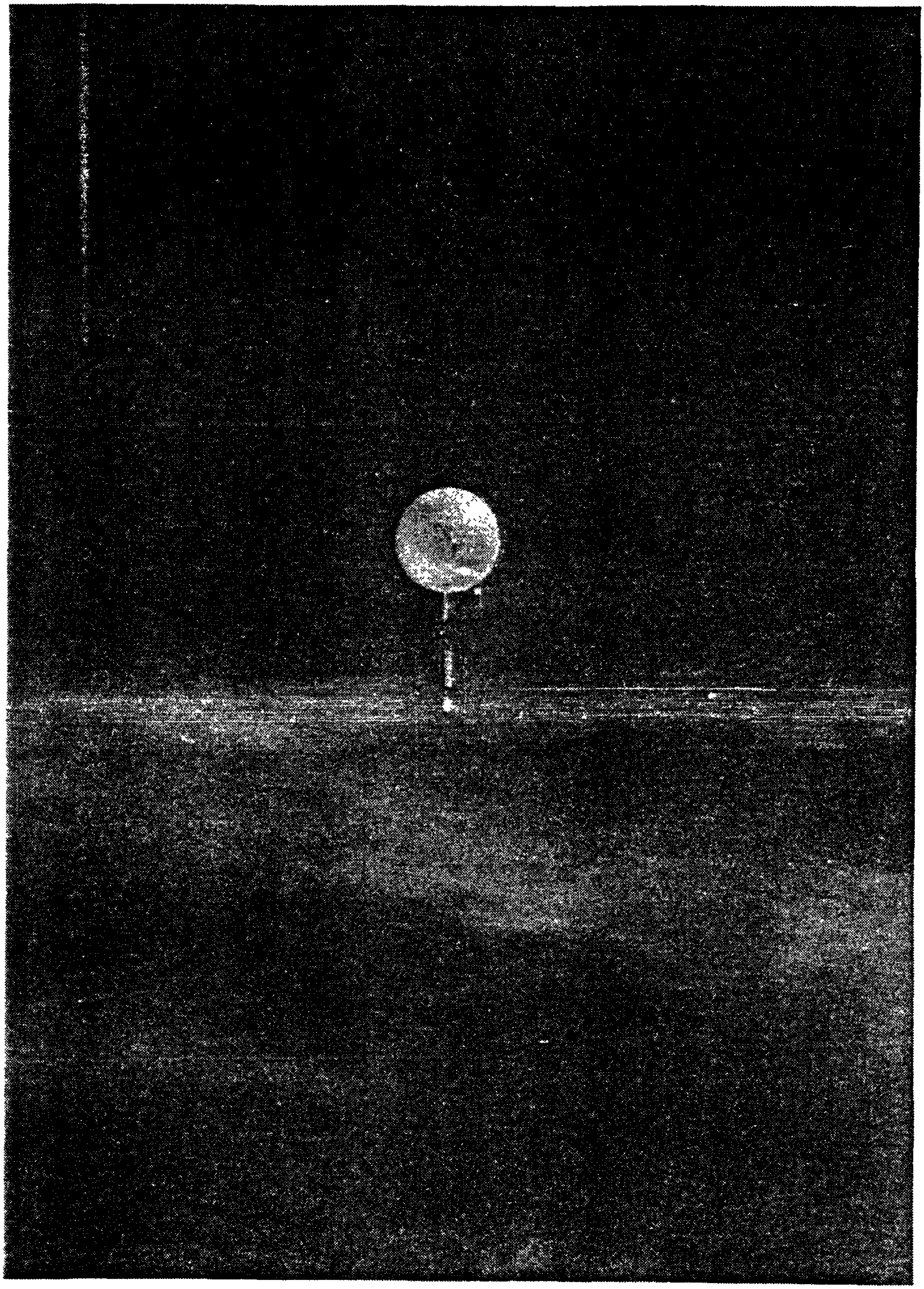


Figure 3-7. Tracer Moments After Launch.

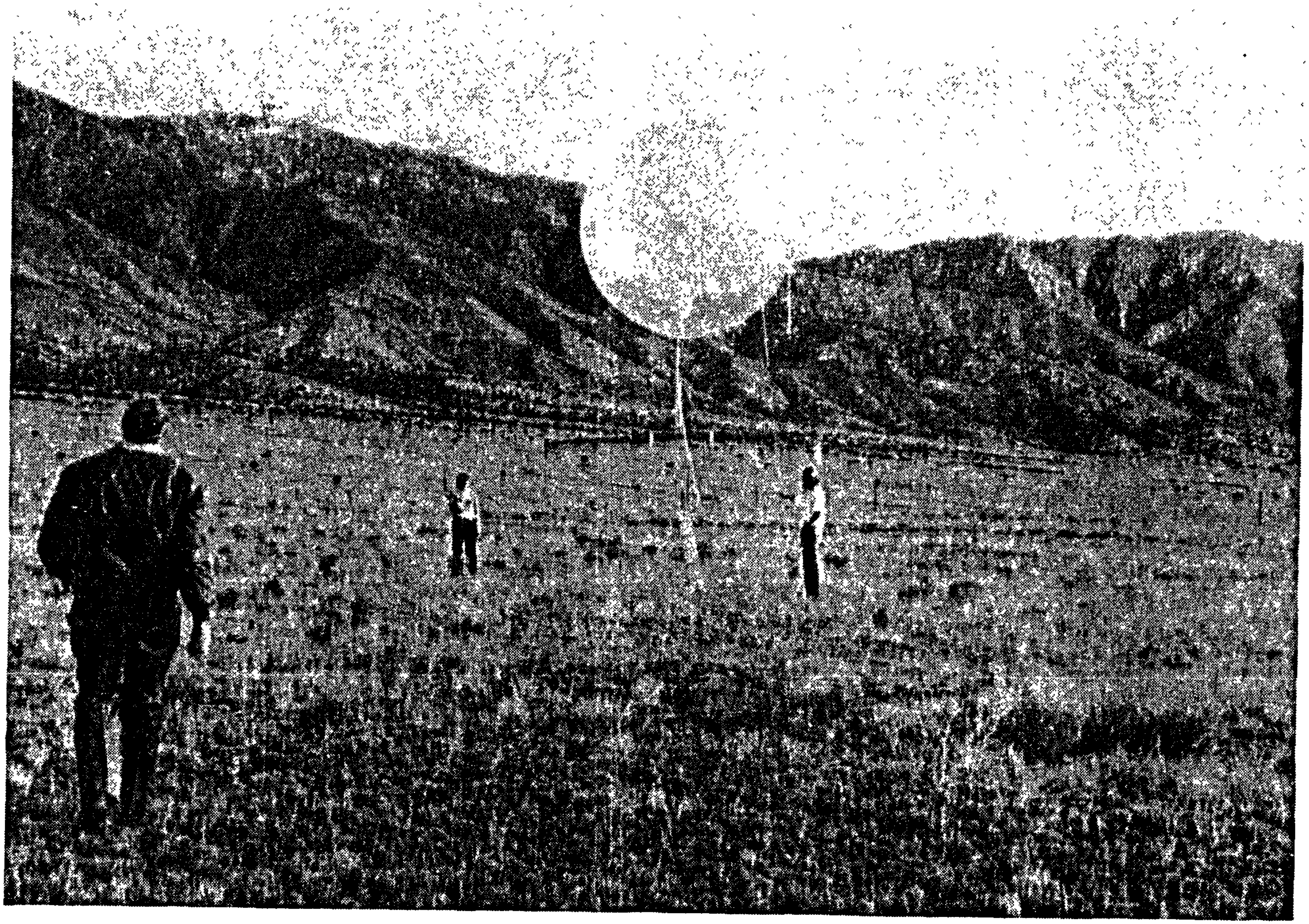


Figure 3-8. Recovery of Tracer from Flight 1.

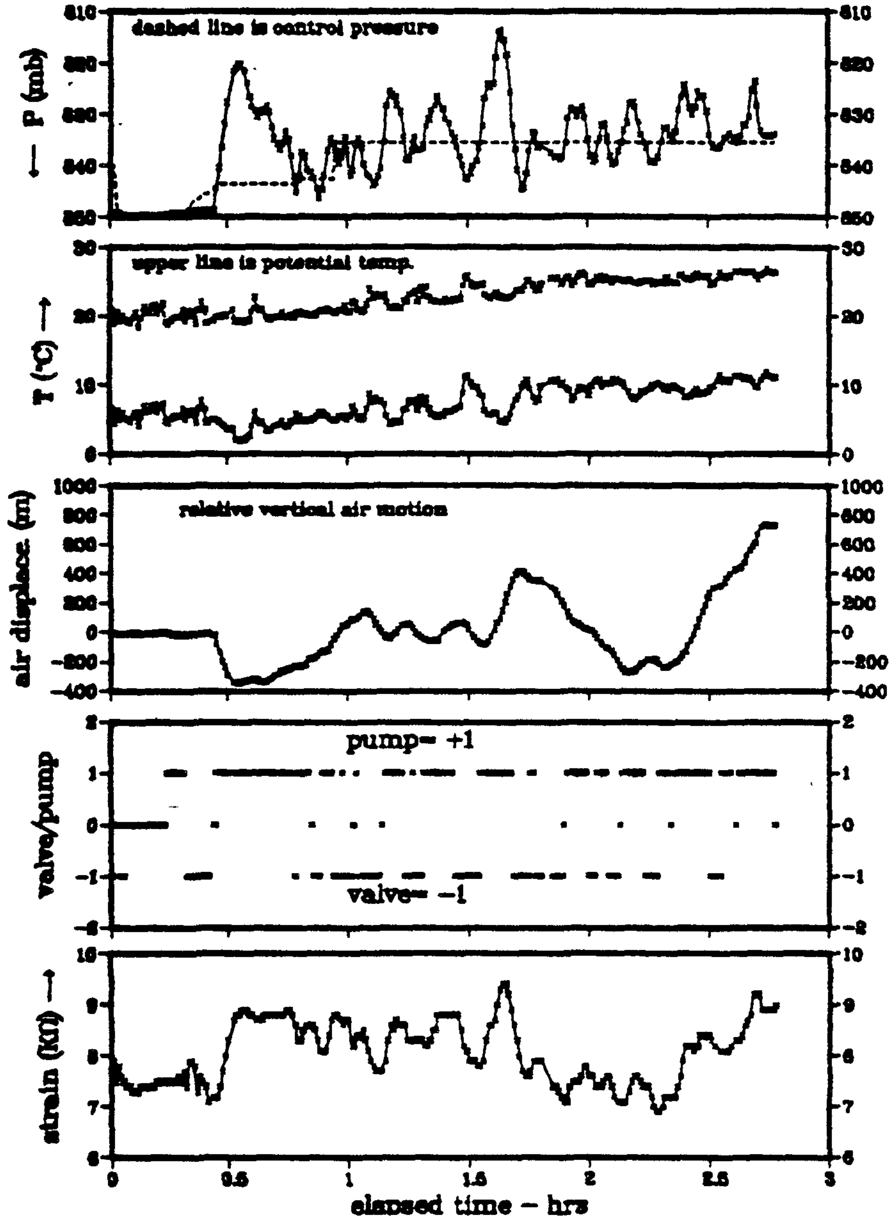


Figure 3-9. Data From Flight 1. Control parameter was pressure. The Tracer was launched with positive buoyancy. In the top graph, note that it overshot the control pressure level, and then pumped itself back down to it. Note also that the landing site was significantly higher than the launch site.

suitable for test flights. The first launch took place at 7:38 am. Shortly after launch, the system was put into the constant potential temperature control mode by radio command. As soon as the Tracer climbed above the surface inversion, it was entrained in the surviving elevated nocturnal jet and took off to the southeast at high speed towards rising terrain. The flight was terminated by the cutdown timer at about 0.4 hrs elapsed time when difficulty was experienced in getting the timer reset command to the payload from the ground station. The relevant data are given in graphical form in Figure 3-10. Here the data record ends before flight termination.

Because the second flight was short and was terminated early in the day, the decision was made to conduct another flight as soon as preparations could be completed. This time, using a different method, the fully-inflated balloon was successfully returned to the launch point (Figure 3-11). The defect noted in the command system was investigated, but in the time available, could not be diagnosed and cured. Hence, it was decided to conduct a final flight with the intent of allowing the cutdown timer to terminate the flight at 30 minutes after launch. This flight duration was chosen to assure that the Tracer Balloon would not be carried by the winds beyond the limits of the testing area. This was necessary to avoid the Tracer being carried either into mountainous or otherwise inaccessible terrain.

At 3:34 pm, the third flight was launched. After climbout, the tracer was put under the control of the zero-relative motion control algorithm by radio command. It too functioned properly. The winds were quite light, so the balloon traveled only a few miles during the half hour flight. The cutdown timer terminated the flight as planned. For the third time, the Tracer was brought down with no damage to either the balloon or the payload. The data from the third flight are given in Figure 3-12.

Tabular data from all three flights are given in Appendix L. An aerial photo mosaic of the test area showing the launch point and all three landing points is given in Figure 3-13.

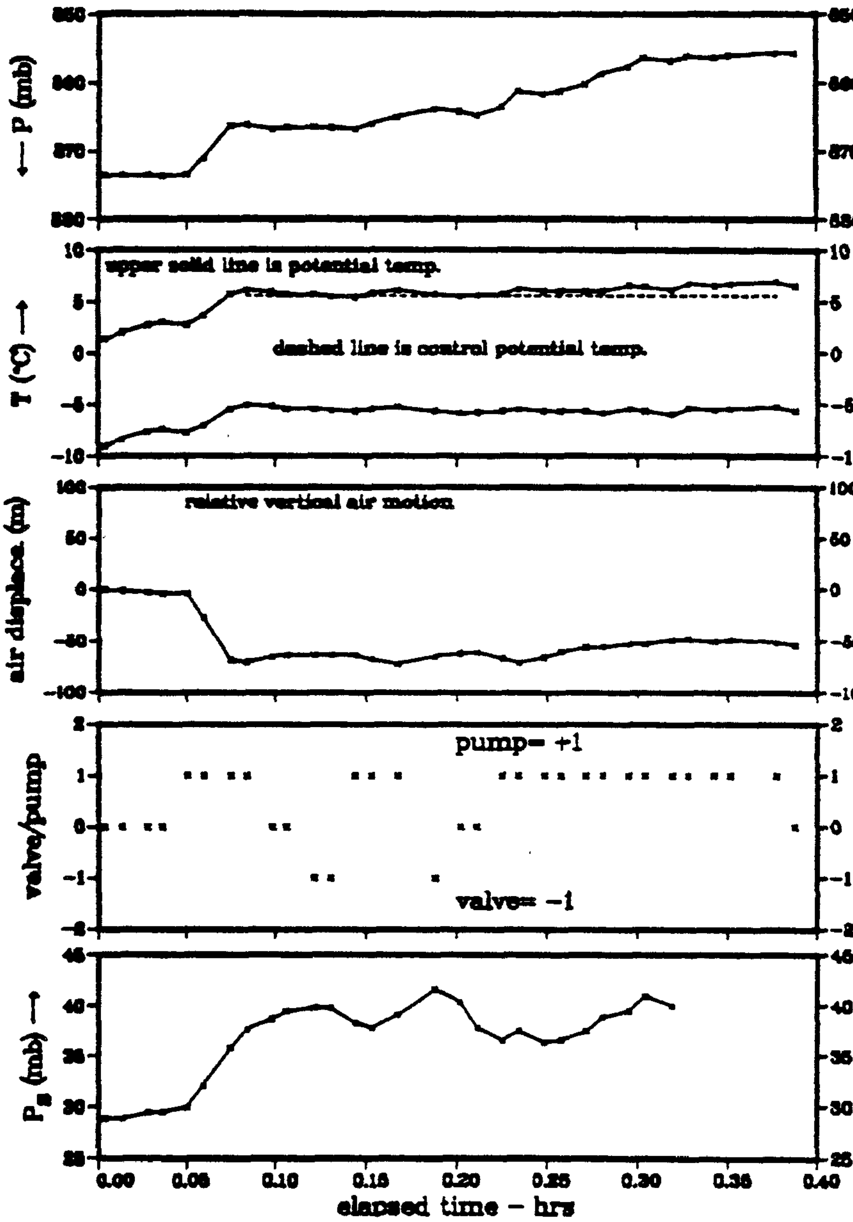


Figure 3-10. Data From Flight 2. Control parameter after launch was potential temperature. The data record ends before the final descent.

Figure 3-11. Inflated Balloon Being Returned after Flight 2.

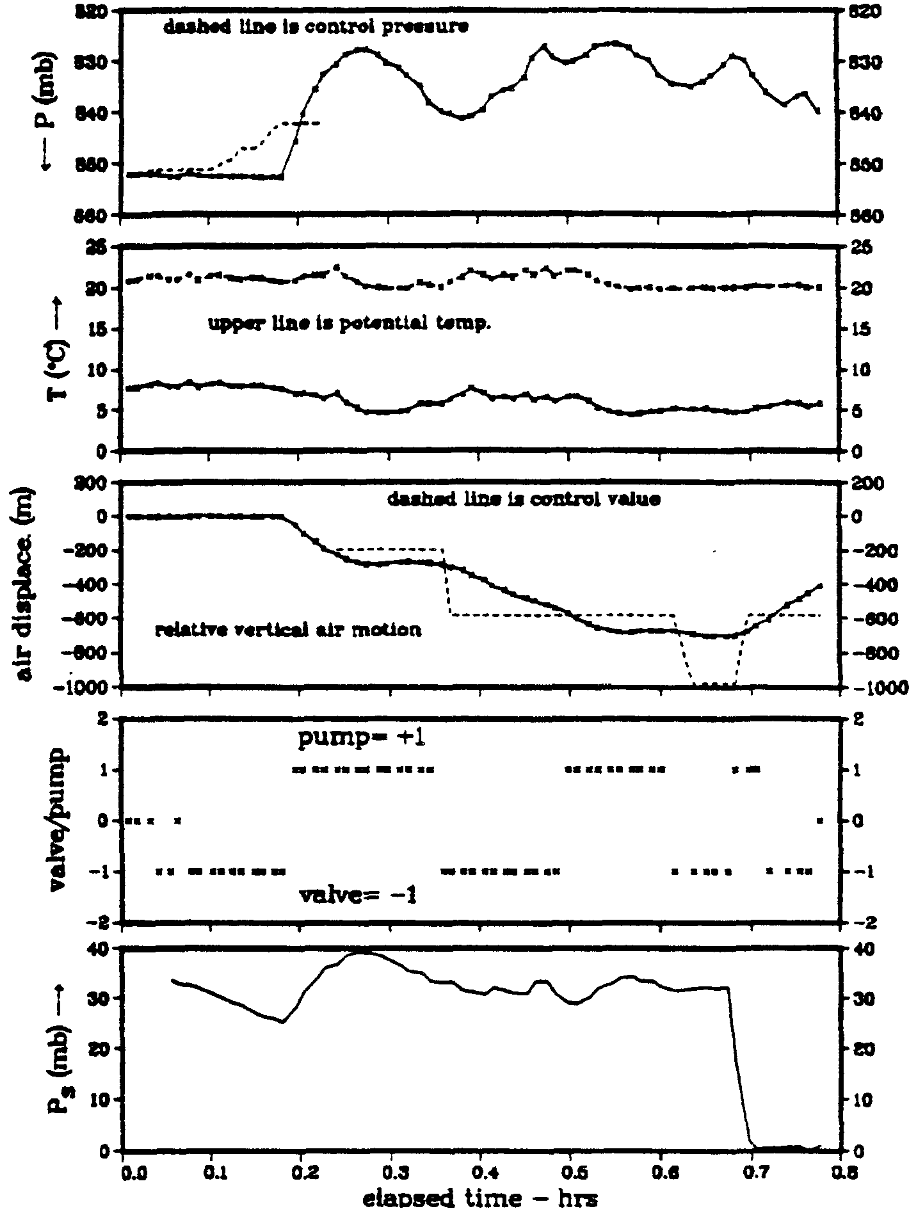


Figure 3-12. Data From Flight 3. Control parameter after launch was relative vertical motion.

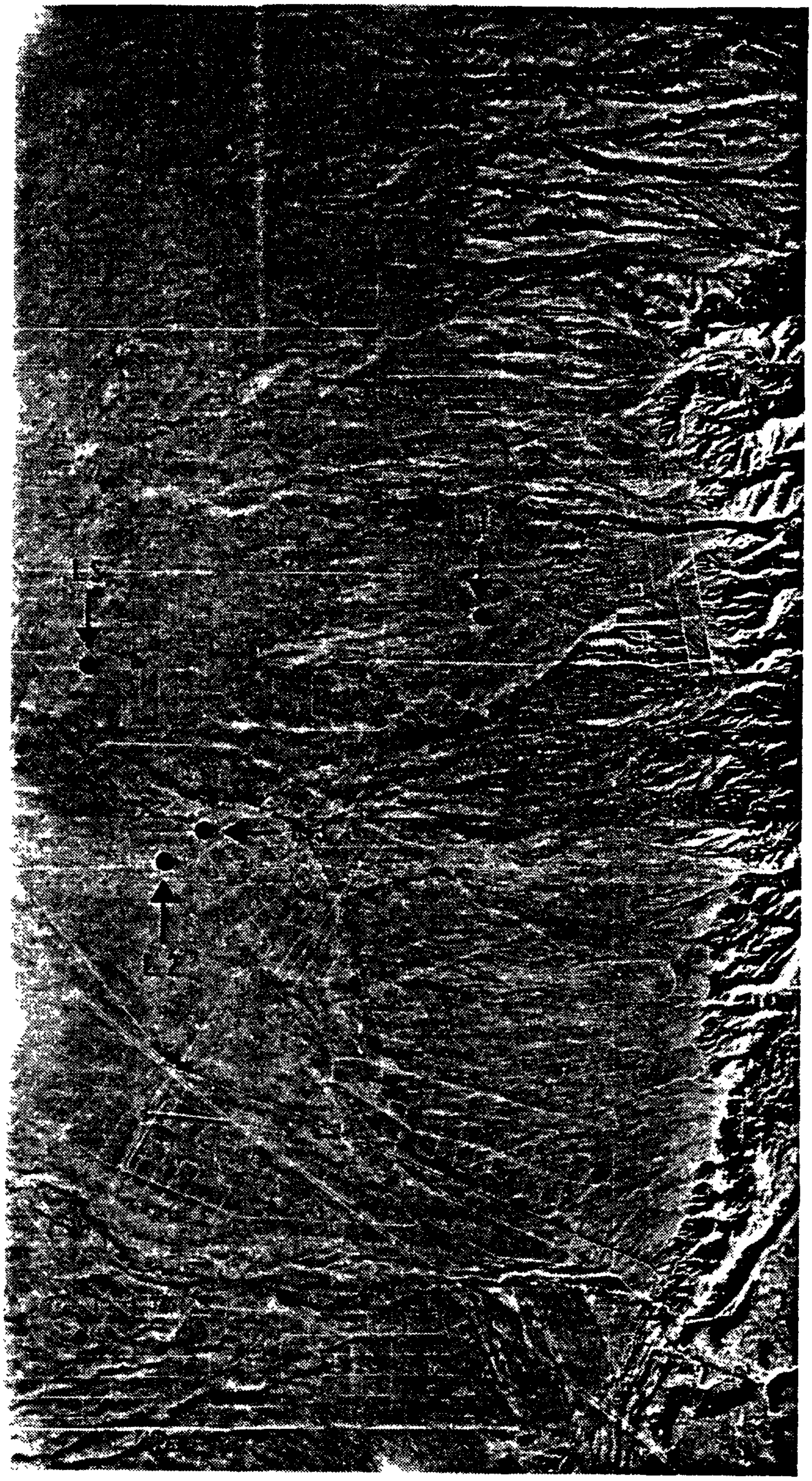


Figure 3-13. Aerial Photo Mosaic Showing Flight History. LS is the launch site; L1-L3 are the respective landing sites.

4. Future Work

a. Required Changes

Certain changes are required to eliminate flaws in the operational prototype Tracer system which were discovered during the experimental program.

In the first flight, the temperature data showed discontinuities of several degrees that clearly could not reflect reality. While at first the temperature sensor was suspected, the problem was ultimately traced to the input port of the 8052AH BASIC microcomputer. The port through which the sensor data are input is normally used as a keyboard input. It was discovered that the 8052 automatically converts bytes coming into this port corresponding to lower case ASCII letters to bytes corresponding to upper case ASCII letters. Nowhere in the literature supplied with the 8052 is this mentioned, but the fact was established unambiguously by laboratory test. Since this port was used here to handle digital data rather than keyboard alphanumeric data, this conversion is unacceptable. When the data falls in certain ranges, it results in an offset of the data received by the 8052 from that sent to it. Note that the temperature data in Figure 3-9 has been appropriately corrected. The anomaly did not affect the buoyancy control of the Tracer because the pressure control algorithm was used on flight 1, and by chance, the ambient pressure did not fall into an affected range. A temporary fix was implemented for flights 2 and 3 by biasing sensor outputs so that the data were not affected, and by removing the bias subsequently in the onboard software. This works satisfactorily only when the data fall into relatively narrow and predictable ranges as was the case for the recent field tests. In Phase III, however, the problem must be eliminated. Intel now makes a version of the 8052 which is not subject to this anomaly.

Mention was made earlier of the fact that a strain gauge mounted on the skin of the balloon did not give an adequate measure of balloon superpressure. While the strain gauge sensor was operative on flight 1, it was replaced with an independent AIR airsonde package for flights 2 and 3. This expedient was acceptable only because the test flights were short, and the Tracer Balloon remained in line of sight of the ground station. The independent telemetry from the 403 MHz sonde could thus be received. In Phase III, it will be necessary to replace the independent sonde inside the balloon with another AIR digital sonde similar to the one on which the sensor package is based. The output from this second digital sonde will then be input to the 8052 microcomputer, and the relevant data on conditions inside the balloon incorporated into the Argos data stream. It will then be recoverable either directly with an Argos downlink receiver, or through the satellite link.

Mention was also made of a problem with the radio command system. While it checked out perfectly in the laboratory, it was found to have a much shorter effective range than anticipated -- of the order of a few miles, rather than a few thousand miles. The first thought was that the command receiver on the Tracer payload might have inadequate sensitivity, but subsequent laboratory tests established that the command receivers have excellent sensitivity. It now appears that the fault lay not with the operational prototype Tracer payload at all, but with the ground station. A single sideband transmitter which was on hand from another project was modified for use as the command transmitter. The modification converted it from single sideband to frequency modulation. The command transmitter appears to be distorting the encoded command waveform. It is speculated that as long as the command signal saturates the command receiver, the distortion is effectively suppressed by the receiver. At greater distances, however, the receiver is not saturated, and the command decoder does not recognise the distorted commands. If the fault does lie in the command transmitter as now suspected, the most cost-effective fix will be to purchase more suitable command transmitters in Phase III. They are estimated to cost ≤$1000 each.

b. Improvements

We begin considering the improvements needed with the balloon envelope. Major improvements were already incorporated into the design of the second generation balloon (Appendix C). During Phase III, a number of such balloons will be procured and used for the latter part of the Phase III test program. The earlier tests will still be conducted using first generation balloons since there are four such balloons remaining.

One of the needed improvements not included in the second generation balloon design concerns the cutdown device. The current device functions well, but it is extremely difficult to mount the electric matches. A more convenient design will be developed.

For flights which may encounter high relative humidity or rain, it will also be necessary to treat the skin of the balloon to minimize water adhesion. Lally's group at NCAR has identified a number of surface treatments which appear to work. Prior to applying a given treatment, a laboratory study will be done to determine which candidate treatment works best.

Finally, the poor visibility of the balloon envelope itself is of concern from an air safety point of view. Bright orange or red banners of appropriate material will be attached to the balloon at the proposed location of the drip skirt on the second generation balloon.

The chief improvement needed in the electronics design beyond eliminating the data transfer glitch is to increase the amount of memory available to the microcomputer. The present system has 4 K bytes of both RAM and PROM. The entire program is limited to about 200 lines of BASIC code. With this constraint, it was not even possible to calculate relative humidity from the sensor data. That calculation had to be sacrificed to stay within the overall memory capacity. Even so, the current control algorithms are quite simple. They check to see if the control parameter falls within a predefined band centered on the selected value. If it does, nothing is done. If it doesn't, the pump or valve is actuated as appropriate for a fixed time -- one Argos cycle, approximately 42 seconds. At the beginning of the next cycle, another check is performed, and so on.

With the current control program, the control algorithm to be used must be selected by radio command. In the improved control program made possible by more memory, the system itself will choose the appropriate control algorithm depending upon the meteorological environment of the Tracer. We plan to quadruple the memory to 16 K bytes of RAM and PROM. The cost in dollars, weight and power consumption are all quite small. This will permit each control algorithm to be more sophisticated, will permit self-selection of the appropriate control algorithm, and will accommodate additional control algorithms as well.

The command system needs certain improvements as well as debugging. The 13.8035 MHz frequency is available to Sandia in the Albuquerque vicinity, and in selected other areas around the country. It is not, however, available nationwide. Launch would be very complicated if instead of the command transmitter being in the field, it were located in Albuquerque. What is needed is another command frequency which is available nationwide, and which has similar long range radio propagation characteristics. We propose to modify the receivers so that they listen for commands on both frequencies simultaneously. The command system will also be modified to accommodate more commands, including "initiate control in equivalent potential temperature mode," and "suspend control."

The Terra Corporation FAA transponder currently uses about 5 watts of power continuously. This power consumption should be brought down. One of the major power consumers in the transponder is a heater circuit in the encoding altimeter. The heater power consumption can be decreased by providing better insulation for the pressure sensor. Elimination of panel lights, and other similar modifications will also be implemented.

An entirely new element should be added to the payload. It is a radio beacon of the type used for animal tracking. Such beacons are extremely light in weight, and use very little power. If each Tracer Balloon were equipped with such a beacon, recovery of the payload would be greatly facilitated, even if the recovery operation were not mounted until days after the Tracer Balloon had come down. In light of the limited resources available to this project, it is imperative that payloads be recovered after each test flight. In Phase II, recovery posed no problem because the flights were short. In Phase III, flights hundreds of kilometres long may be undertaken. The recovery problem will be greatly exacerbated unless beacons are included. Argos data will indicate where a payload is to within a kilometre or two. The beacon will allow the recovery crew to pinpoint it.

Finally, payload packaging is an area where major improvements can and should be made. A new design concept for packaging and deploying the payload is shown in Figure 4-1. Here, the vertical anemometer and the sensor package are no longer mounted on a styrofoam boom. Rather, they are mounted on much smaller rods attached to the balloon skin at the equator. The balloon itself is used as a structural element to facilitate getting the sensors at least 50 cm out beyond the balloon equator. In addition, with the exception of the transponder and the strobe, the other payload packages are attached to the skin of the balloon with Velcro. Here too, the balloon skin becomes a structural element. The net effect of the proposed changes is to markedly simplify the deployment of the payload. This in turn will simplify the launch procedure, and minimize the probability of the Tracer Balloon getting snared by trees or power lines.

With regard to the ground support system, certain improvements should also be made. Of course, the command transmitter must be able to accommodate both command frequencies now seen to be necessary. In addition, the HP85 computer needs to be replaced with a more powerful PC, one that can log data on a hard or floppy disk, and that can talk to a central computer system through a modem. The PC will also be

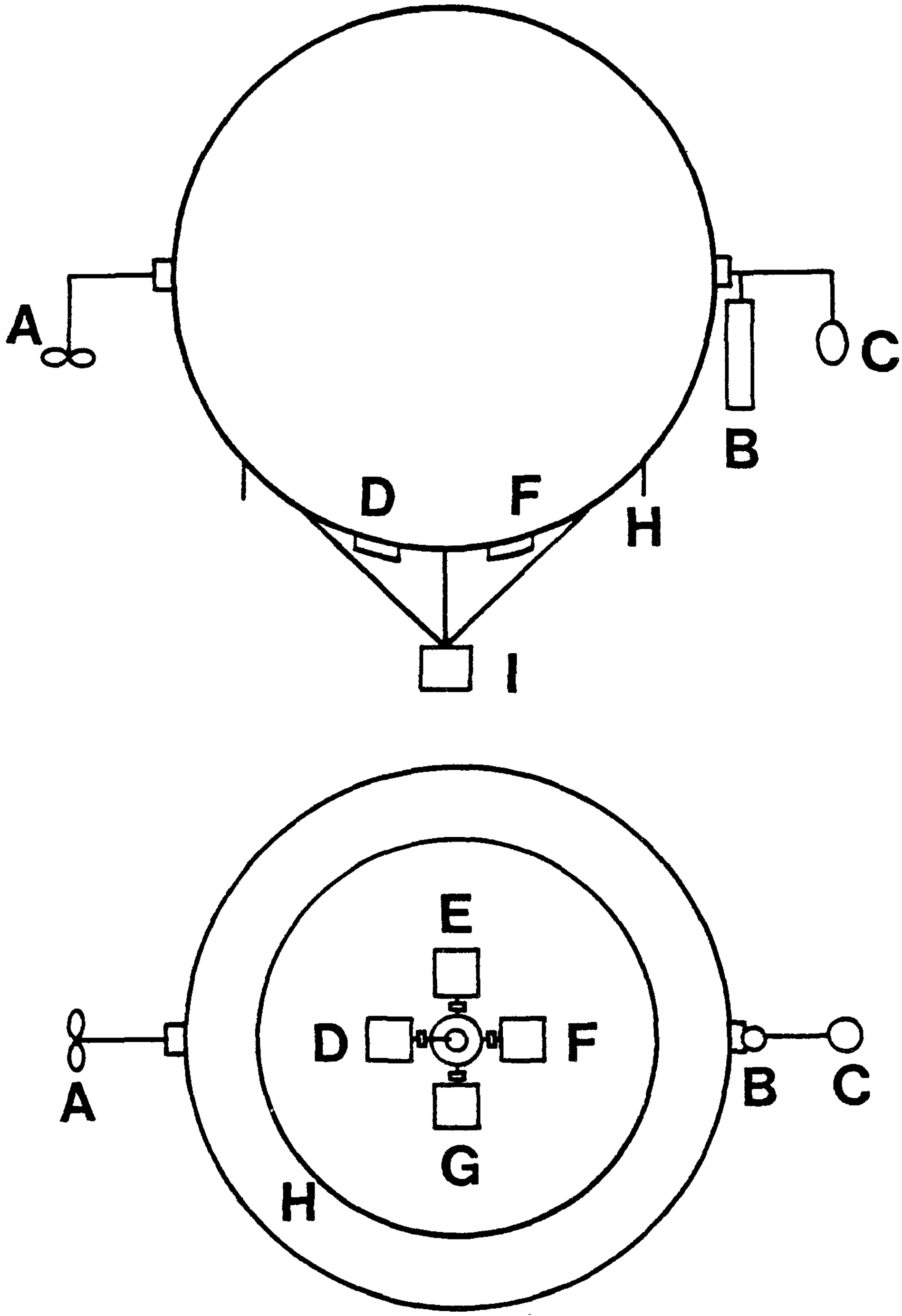


Figure 4-1. New Payload Packaging and Deployment Concept. System Elements: A. Vertical Anemometer; B. Argos Antenna; C. Sensor Package; D. Buoyancy Control Subsystem; E. Main Electronics Package; F. Batteries and Beacon Transmitter; G. Command Receiver and Cutdown Package; H. Drip Skirt; I. FAA Transponder and Strobe Light.

directly coupled to the command encoder and command transmitter so that the cutdown timer reset commands can be sent automatically.

In addition to improvements in the ground support system, a second independent station will be built for location at another site. This is to assure, insofar as possible, that radio command contact be maintained with the Tracer Balloon.

c. Tests

The goal of the test program is to check every significant aspect of the performance of the Tracer Balloon system. Tests will either confirm proper performance, or reveal flaws which, once identified, will be remedied. While resources may limit how thorough the test program can be, it is nevertheless important to keep this goal in mind. There are three categories of tests which can be used to achieve this goal:

- Laboratory tests
- Solar tower tests
- Free flight tests

Benchtop laboratory tests are used to confirm proper function of individual components and subsystems under the ambient conditions found in the laboratory. Such tests are the first step. If a system element doesn't function properly in the lab, it is highly unlikely to perform properly in the field. Next, environmental chamber tests are required to resolve questions regarding whether the sensors and the payload as a whole function properly over the whole range of interest of temperature, pressure, and relative humidity. In free flight tests, questions regarding the accuracy of the data returned from the Tracer cannot be adequately resolved because the atmosphere is an uncontrolled environment, and we have no independent check on the data. Consequently, a program of chamber tests will be undertaken in Phase III.

There are some tests, specifically those bearing on the performance of the vertical anemometer, which cannot easily be addressed in either laboratory chambers or in free flight. To answer these questions, the solar tower is ideal. The operational prototype tracer system or a selected part thereof may be run up and down in the relatively quiescent air of the tower. The integrated relative vertical air motion data obtained from the vertical anemometer can then be compared with the vertical position versus time record obtained with a laser distance measuring device. If the air in the tower has negligible vertical motion, the two sets of data should be compatible. Provided that the solar tower is available in an appropriate time frame, the required tests of vertical anemometer performance will be done in Phase III.

Finally, we come to free flight tests. While these offer the most dramatic evidence of proper function, they are also the most expensive. Consequently, flight testing will be carefully planned to get the most out of the experiments within the budgetary constraints. The aspect of the system to be addressed in the flight tests is the performance of the buoyancy control program under several different meteorological and other environmental conditions: stratified atmosphere, well-mixed atmosphere, convective activity, obstructing terrain, low altitude, high altitude, cloud, rain, day, night, and transition periods. In Phase III, the control program will consist of several control algorithms, and software determining the automatic onboard selection of the algorithm to be used on the basis of the sensor data. The Phase III flight program will consist of a graduated series of short (<10 km), intermediate (<100 km), and long (>100 km) flights, launched most probably from the Phase II test site south of Albuquerque.

Phase IV testing will be limited to answering the questions which have not been adequately addressed in Phase III, and to checking the performance of those elements added to the system in Phase IV to make the Tracer Balloon a practical research tool.

5. Discussion and Conclusions

The stated design goals for the Adjustable Buoyancy Balloon Tracer form a useful frame of reference for evaluating the current status of the effort.

- Operates under the exemption clauses of FAR 101.

FAR 101 permits up to 12 lbs (5.45 kg) of payload, as long as the payload is distributed in packages weighing no more than 6 lbs (2.73 kg) each, which meet a 3 oz/in^2 (13.2 g/cm^2) areal density limit, and which are connected by a "rope or other device for suspension" that requires a force of no more than 50 lbs to part. The weight of the operational prototype Tracer payload as flown was 4.72 kg, well under the 5.45 kg limit. The Phase III operational prototype mechanical design is expected to be about a kilogram lighter. The operational prototype payload met the other exemption conditions of FAR 101 as well.

- Lifetime $\geq$ 3 days

Available battery power determines the Tracer effective lifetime. The major power drain on the Tracer was the set of three Gilian pumps. At 45 mb superpressure, the pumps consume about 1 watt each. If one assumes that they would be on about 1/3 of the time, in a 72 hr flight, they would require 72 watt hours of energy. During the test flights, the pumps were on a greater fraction of the time because the "dead zones" (where no action is taken) in the control algorithms were intentionally made very small. The power for the pumps is supplied by lithium batteries with an energy density of 0.43 watt-hours/g (195 watt-hours/lb). Two D cells in series (to get the required voltage) can supply approximately 100 watt-hours of energy, more than enough for the pumps. The D cells weigh 117 g each.

The main electronics package including the sensors requires about 1.4 watts continuously. Over 72 hours, the need is for 100 watt-hours of energy. Again, 2 D cells will fulfill that need. The battery complement is completed by 3 C cells for the Argos PTT and 2 AA cells for the cutdown device. Because of the low duty cycle, the Argos PTT has a low energy requirement. The cutdown device fires just once, independent of the length of flight. The C cells weigh 58 g, and the AA cells, 21 g each. Thus, for a 72 hour flight, the battery complement for the operational prototype as flown would weigh 684 g. That is just 118 g more than the battery complement included in the Tracer for the Phase II test program.

Accommodating the FAA transponder is another matter. Although it is not required by FAR 101, it is highly desirable that it be carried on any flights above 300 m AGL. It weighs about 800 g including the encoding altimeter, and draws about 5 watts average power. If the transponder were unmodified, it would require 8 D cells weighing a total of 936 g to operate continuously for 72 hours. If the weight savings in the Phase III mechanical design slightly exceeded the anticipated 1 kg, the FAA transponder and its battery complement could just be accommodated within the 5.45 kg total payload limit. However, it appears that the minor modifications described earlier could halve the power drain, reducing the weight of the batteries to 468 g. If those modifications are made, there should not be a problem in accommodating the transponder, and even the strobe light with its battery complement (estimated weight, 250 g) on a 3 day flight.

- Tracking range $\geq$ 1000 km

Argos tracks world wide.

- Telemetry of relative vertical air motion, pressure, temperature, and humidity.

The Argos PTT easily accommodates these variables and can accommodate several others if desired.

- Ground system capable of handling several Tracers at a time.

Argos can handle 200 PTTs in its field of view at a time. The existing command system can accommodate different codes to address each of several Tracers. If a 2 site, 2 frequency HF command system is established as planned, command communication should be reliable over more than 1000 km.

- Capable of establishing specified ascent and descent rates under radio command.

With appropriate additional commands implemented, the equilibrium altitude could be modified over a broad range of rates.

- Capable of reaching altitudes up to 5.5 km (500 mb).

With an appropriately-sized second generation balloon, the balloon should pose no problem. If any problem exists, it is likely to be the inability of some component to operate at the low temperatures encountered at that altitude (20-25 degrees below zero Celsius). The pumps and the batteries have been operated in a freezer at -18 C, but the entire payload must be checked in an environmental chamber. Should some existing component fail the test, a substitute with better low temperature performance will be found.

- Capable of following mean vertical flows as low as 1 cm/s with "acceptable" fidelity.

An experimental test would involve comparison of the trajectory of the Tracer Balloon with that of a gaseous or fine particle tracer released in its vicinity. There is good reason to believe that this specification would be met based on the arguments presented in the Phase I report, and the performance observed to date.

- Sufficiently inexpensive to permit use in significant numbers on an expendable basis.

This goal is inexact. We choose to address it as in Phase I by considering the likely cost of the elements of an operational Tracer procured in small numbers (<10), and in large (>50).

Cost Elements	Cost Each ($K)*	
	1-10	>50
CVB with Ballonet	1.5	1.0
Buoyancy Adjustment Subsystem	0.5	0.3
Sensors	0.6	0.4
Microcomputer	0.2	0.2
Argos PTT	1.5	1.0
Command Receiver and Decoder	0.5	0.3
FAA Transponder and Strobe	1.0	0.8
Batteries	0.2	0.2
Miscellaneous Hardware	0.2	0.2
Assembly Labor	1.0	0.5
TOTAL	7.2	4.9

*CY86 Dollars

These cost estimates reflect the actual experience in building the operational prototype Tracer. They are a bit lower than the estimates made in the Phase I report, in spite of the fact that these numbers are given in CY86 dollars, and the Phase I estimates were given in CY84 dollars. The costs in quantity are approximate, and merely project typical quantity procurement savings.

In field experiments, it is reasonable to expect a 50% return rate of the payloads if they carry a message offering a reward and giving a return address. The balloon envelope itself would not likely be recovered. With these assumptions, in quantity, the Tracers would cost approximately $3.0 K per use.

On the other hand, the payloads are of sufficiently high value that it would be economically attractive to actively seek to recover them. Incorporation of a radio beacon of the type used to track animals would make successful recovery highly likely, and would only add $0.2 K to the cost of the payload. On the assumption that it would take a two man crew a day to find each, the cost of recovery per payload would be about $500. A recovery effort would reduce the cost per Tracer use to $1.5-2.0 K. Some fraction of the time, the balloon envelope itself would also be recovered in reuseable condition. This would further reduce the cost per use.

Either with or without a recovery effort, the cost of a field program using Tracer Balloons would likely be dominated by the cost of maintaining a launch crew in the field, not by the cost of the Tracers.

At the end of the Phase I report, the authors concluded that an Adjustable Buoyancy Tracer Balloon meeting the design goals is both technically and economically feasible. Phase II has confirmed that conclusion.

REFERENCES

Blamont, J., Heinsheimer, T., and Pommereau, J. (1974). "New Method of Study of the Dynamics of the Stratosphere - Principle and First Results," Academie des Sciences (Paris), Comptes Rendus (B) 228, 249.

Danielson, E.F. (1961). "Trajectories: Isobaric, Isentropic, and Actual," J. Meteor. 18, 479.

Holton, J.R. (1979). An Introduction to Dynamic Meteorology, Second Edition, Academic Press, New York, NY.

Lally, V.E. (1967). Superpressure Balloons for Horizontal Soundings of the Atmosphere, National Center for Atmospheric Research Technical Note NCAR-TN-28, Boulder, CO.

MacCready, P.B. (1981). "Turbulence and the Local Flow Field. The AV Experiment on DaVinci I, in Final Report on Project DaVinci: A Study of Long Range Air Pollution Using A Balloon-Borne Lagrangian Measurement Platform, Vol. 2: Reports of Participants in DaVinci I, B.D. Zak Ed., Sandia National Laboratories Report SAND78-0403/2, Albuquerque, NM.

Morris, A.L. (1975). Scientific Ballooning Handbook, National Center for Atmospheric Research Technical Note NCAR-TN/IA-99, Boulder, CO.

Tatom, F.B. and King, R.L. (1977). Constant Volume Balloon Capabilities for Aeronautical Research, NASA Contractor Report NASA CR-2805, Huntsville, AL.

Wallace J.M. and Hobbs, P.V. (1977). Atmospheric Science, an Introductory Survey, Academic Press, New York, NY.

Zak, B.D. (1983). "Lagrangian Studies of Atmospheric Pollutant Transformations," in Trace Atmospheric Constituents: Properties, Transformations, and Fates, Volume 12 in series, Advances in Environmental Science and Technology. S.E. Schwartz, Ed., John Wiley and Sons, New York, NY.

Zak, B.D., Church, H.W., Jensen, A.L., Gay, G.T., and Ivey, M.D. (1986). Development of an Adjustable Buoyancy Balloon Tracer of Atmospheric Motion, Phase I: Systems Design and Demonstration of Feasibility, U.S. Environmental Protection Agency Report PB85-185817/AS; Sandia National Laboratories Report SAND 85-0288.

APPENDIX A

FEDERAL AVIATION REGULATIONS PART 101: MOORED BALLOONS, KITES, UNMANNED ROCKETS, AND UNMANNED FREE BALLOONS

The following is a reprint of the FAA regulation most relevant to the adjustable buoyancy balloon.

Part 101—Moored Balloons, Kites, Unmanned Rockets, and Unmanned Free Balloons

Subpart A—General

§101.1 Applicability.

(a) This Part prescribes rules governing the operation, in the United States, of the following:

(1) Except as provided for in § 101.7 of this Part, any balloon that is moored to the surface of the earth or an object thereon and that has a diameter of more than 6 feet or a gas capacity of more than 115 cubic feet.

(2) Except as provided for in § 101.7 of this Part, any kite that weighs more than 5 pounds and is intended to be flown at the end of a rope or cable.

(3) Any unmanned rocket except—

(i) Aerial firework displays; and

(ii) Model rockets—

(*a*) Using not more than 4 ounces of propellant;

(*b*) Using a slow-burning propellant;

(*c*) Made of paper, wood, or breakable plastic, containing no substantial metal parts and weighing not more than 16 ounces, including the propellant; and

(*d*) Operated in a manner that does not create a hazard to persons, property, or other aircraft.

(4) Except as provided for in § 101.7 of this Part, any unmanned free balloon that—

(i) Carries a payload package that weighs more than four pounds and has a weight/size ratio of more than three ounces per square inch on any surface of the package, determined by dividing the total weight in ounces of the payload package by the area in square inches of its smallest surface;

(ii) Carries a payload package that weighs more than 6 pounds;

(iii) Carries a payload, of two or more packages, that weighs more than 12 pounds; or

(iv) Uses a rope or other device for suspension of the payload that requires an impact force of more than 50 pounds to separate the suspended payload from the balloon.

(b) For the purposes of this Part, a "gyroglider" attached to a vehicle on the surface of the earth is considered to be a kite.

§101.3 Waivers.

No person may conduct operations that require a deviation from this Part except under a certificate of waiver issued by the Administrator.

§101.5 Operations in prohibited or restricted areas.

No person may operate a moored balloon, kite, unmanned rocket, or unmanned free balloon in a prohibited or restricted area unless he has permission from the using or controlling agency, as appropriate.

[§ 101.7 Hazardous operations.

[(a) No person may operate any moored balloon, kite, unmanned rocket, or unmanned free balloon in a manner that creates a hazard to other persons, or their property.

[(b) No person operating any moored balloon, kite, unmanned rocket, or unmanned free balloon may allow an object to be dropped therefrom, if such action creates a hazard to other persons or their property.]

Subpart B—Moored Balloons and Kites

§101.11 Applicability.

This subpart applies to the operation of moored balloons and kites. However, a person operating a moored balloon or kite within a restricted area must comply only with §101.19 and with additional limitations imposed by the using or controlling agency, as appropriate.

§101.13 Operating limitations.

(a) Except as provided in paragraph (b) of this section, no person may operate a moored balloon or kite—

(1) Less than 500 feet from the base of any cloud;

(2) More than 500 feet above the surface of the earth;

(3) From an area where the ground visibility is less than three miles; or

(4) Within five miles of the boundary of any airport.

(b) Paragraph (a) of this section does not apply to the operation of a balloon or kite below the top of any structure and within 250 feet of it, if that shielded operation does not obscure any lighting on the structure.

§101.15 Notice requirements.

No person may operate an unshielded moored balloon or kite more than 150 feet above the surface of the earth unless, at least 24 hours before beginning the operation, he gives the following information to the FAA ATC facility that is nearest to the place of intended operation:

(a) The names and addresses of the owners and operators.

(b) The size of the balloon or the size and weight of the kite.

(c) The location of the operation.

(d) The height above the surface of the earth at which the balloon or kite is to be operated.

(e) The date, time, and duration of the operation.

§101.17 Lighting and marking requirements.

(a) No person may operate a moored balloon or kite [between sunset and sunrise] unless the balloon or kite, and its mooring lines, are lighted so as to give a visual warning equal to that required for obstructions to air navigation in the FAA publication "Obstruction Marking and Lighting".

(b) No person may operate a moored balloon or kite [between sunrise and sunset] unless its mooring lines have colored pennants or streamers attached at not more than 50-foot intervals beginning at 150 feet above the surface of the earth and visible for at least one mile.

§101.19 Rapid deflation device.

No person may operate a moored balloon unless it has a device that will automatically and rapidly deflate the balloon if it escapes from its moorings. If the device does not function properly, the operator shall immediately notify the nearest ATC facility of the location and time of the escape and the estimated flight path of the balloon.

Subpart C—Unmanned Rockets

§101.21 Applicability.

This subpart applies to the operation of unmanned rockets. However, a person operating an unmanned rocket within a restricted area must comply only with subparagraph 101.23 (g) and with additional limitations imposed by the using or controlling agency, as appropriate.

§101.23 Operating limitations.

No person may operate an unmanned rocket—

(a) In a manner that creates a collision hazard with other aircraft;

(b) In controlled airspace;

(c) Within five miles of the boundary of any airport;

(d) At any altitude where clouds or obscuring phenomena of more than five-tenths coverage prevails;

(e) At any altitude where the horizontal visibility is less than five miles;

(f) Into any cloud;

(g) Within 1,500 feet of any person or property that is not associated with the operations; or

(h) [Between sunset and sunrise.]

§101.25 Notice requirements.

No person may operate an unmanned rocket unless, within 24 to 48 hours before beginning the operation, he gives the following information to the FAA ATC facility that is nearest to the place of intended operation:

(a) The names and addresses of the operators.

(b) The number of rockets to be operated.

(c) The size and weight of each rocket.

(d) The maximum altitude to which each rocket will be operated.

(e) The location of the operation.

(f) The date, time, and duration of the operation.

(g) Any other pertinent information requested by the ATC facility.

Subpart D—Unmanned Free Balloons

§ 101.31 Applicability.

This subpart applies to the operation of unmanned free balloons. However, a person operating an unmanned free balloon within a restricted area must comply only with § 101.33 (d) and (e) and with any additional limitations that are imposed by the using or controlling agency, as appropriate.

§ 101.33 Operating limitations.

No person may operate an unmanned free balloon—

(a) Unless otherwise authorized by ATC, in a control zone below 2,000 feet above the surface, or in an airport traffic area;

(b) At any altitude where there are clouds or obscuring phenomena of more than five-tenths coverage;

(c) At any altitude below 60,000 feet standard pressure altitude where the horizontal visibility is less than five miles;

(d) During the first 1,000 feet of ascent, over a congested area of a city, town or settlement or an open-air assembly of persons not associated with the operation; or

(e) In such a manner that impact of the balloon, or part thereof including its payload, with the surface creates a hazard to persons or property not associated with the operation.

§ 101.35 Equipment and marking requirements.

(a) No person may operate an unmanned free balloon unless—

(1) It is equipped with at least two payload cut-down systems or devices that operate independently of each other;

(2) At least two methods, systems, devices, or combinations thereof, that function independently of each other are employed for terminating the flight of the balloon envelope; and

(3) The balloon envelpe is equipped with a radar reflective device(s) or material that will present an echo to surface radar operating in the 200 MHz to 2700 MHz frequency range.

The operator shall activate the appropriate devices required by subparagraphs (1) and (2) of this paragraph when weather conditions are less than those prescribed for operation under this subpart, or if a malfunction or any other reason makes the further operation hazardous to other air traffic or to persons and property on the surface.

[(b) No person may operate an unmanned free balloon below 60,000 feet standard pressure altitude between sunset and sunrise (as corrected to the altitude of operation) unless the balloon and its attachments and payload, whether or not they become separated during the operation, are equipped with lights that are visible for at least 5 miles and have a flash frequency of at least 40, and not more than 100, cycles per minute.]

(c) No person may operate an unmanned free balloon that is equipped with a trailing antenna that requires an impact force of more than 50 pounds to break it at any point, unless the antenna has colored pennants or streamers that are attached at not more than 50-foot intervals and that are visible for at least one mile.

(d) No person may operate [between sunrise and sunset] an unmanned free balloon that is equipped with a suspension device (other than a highly conspicuously colored open parachute) more than 50 feet long, unless the suspension device is colored in alternate bands of high conspicuity colors or has colored pennants or streamers attached which are visible for at least one mile.

§ 101.37 Notice requirements.

(a) *Prelaunch notice.* Except as provided in paragraph (b) of this section, no person may operate an unmanned free balloon unless, within 6 to 24 hours before beginning the operation, he gives the following information to the FAA ATC facility that is nearest to the place of intended operation:

(1) The balloon identification.

(2) The estimated date and time of launching, amended as necessary to remain within plus or minus 30 minutes.

(3) The location of the launching site.

(4) The cruising altitude.

(5) The forecast trajectory and estimated time to cruising altitude or 60,000 feet standard pressure altitude, whichever is lower.

(6) The length and diameter of the balloon, length of the suspension device, weight of the payload, and length of the trailing antenna.

(7) The duration of flight.

(8) The forecast time and location of impact with the surface of the earth.

(b) For solar or cosmic disturbance investigations involving a critical time element, the information in paragraph (a) of this section shall be given within 30 minutes to 24 hours before beginning the operation.

(c) *Cancellation notice.* If the operation is canceled, the person who intended to conduct the operation shall immediately notify the nearest FAA ATC facility.

(d) *Launch notice.* Each person operating an unmanned free balloon shall notify the nearest FAA or military ATC facility of the launch time immediately after the balloon is launched.

§ 101.39 Balloon position reports.

(a) Each person operating an unmanned free balloon shall—

(1) Unless ATC requires otherwise, monitor the course of the balloon and record its position at least every two hours; and

(2) Forward any balloon position reports requested by ATC.

(b) One hour before beginning descent, each person operating an unmanned free balloon shall forward to the nearest FAA ATC facility the following information regarding the balloon:

(1) The current geographical position.

(2) The altitude.

(3) The forecast time of penetration of 60,000 feet standard pressure altitude (if applicable).

(4) The forecast trajectory for the balance of the flight.

(5) The forecast time and location of impact with the surface of the earth.

(c) If a balloon position report is not recorded for any two-hour period of flight, the person operating an unmanned free balloon shall immediately notify the nearest FAA ATC facility. The notice shall include the last recorded position and any revision of the forecast trajectory. The nearest FAA ATC facility shall be notified immediately when tracking of the balloon is re-established.

(d) Each person operating an unmanned free balloon shall notify the nearest FAA ATC facility when the operation is ended.

APPENDIX B

SUMMARY OF RELEVANT EQUATIONS FROM PHASE I

Standard Atmosphere

Most of the relationships derived in Phase I of the project assumed a standard atmosphere. For reference, the expressions used to represent the pressure P, density ρ, and temperature T of the air as a function of altitude z below the tropopause in a U.S. Standard Atmosphere are given below (Morris, 1975):

$$P = P_o \left(1 - \frac{\alpha}{T_o} z\right)^{\frac{Mg}{\alpha R}} \quad \text{(B-1)}$$

$$\rho = \rho_o \left(1 - \frac{\alpha}{T_o} z\right)^{\frac{Mg}{\alpha R} - 1} \quad \text{(B-2)}$$

$$T = T_o \left(1 - \frac{\alpha}{T_o} z\right) \quad \text{(B-3)}$$

where

g	=	9.807 m/s^2, acceleration due to gravity,
M	=	28.96 kg/(kg - mol), average molecular weight of air,
P_o	=	1013.25 millibars or 1.01325 x 10^5 N/m^2(Pa),
R	=	8314.3 J/K (kg - mol), universal gas constant; if pressures expressed in mb, then 83.143,
T_o	=	288.15 K,
z	=	altitude in m MSL, or more strictly, "geopotential meters",
α	=	6.5 x 10^{-3} K/m, standard lapse rate,
ρ_o	=	1.2250 kg/m^3,
$\frac{Mg}{\alpha R}$	=	5.255.

$\frac{\alpha}{T_o}$ = 2.256×10^{-5} m^{-1}

Other Definitions

L = gross lift (Newtons); if divided by the acceleration due to gravity, units become kg (force),

L_s = gross lift of a slack balloon ($P_s = 0$),

L_R = gross required lift to make system neutrally buoyant at initial altitude z_o and superpressure P_{so},

m = mass of balloon system exclusive of gas in balloon (kg),

P_a = ambient pressure of air at balloon altitude, typically expressed in mb,

P_b = absolute gas pressure in balloon, typically expressed in mb,

P_s = superpressure = $P_b - P_a$; typically expressed in mb,

P_{so} = superpressure at altitude z_o; initial superpressure,

S = pumping or valving flow rate (m^3/s),

V = volume of balloon (m^3) (presumed constant),

z = the equilibrium altitude of the balloon in m above mean sea level (MSL),

z_m = maximum altitude attainable; ceiling altitude,

z_o = altitude at which superpressure is set to P_{so},

ρ_a = density of the ambient air at the altitude of the system (kg/m^3),

ρ_b = average density of gas contained in balloon (kg/m^3),

γ = lapse rate = $-dT/dz$ (K/m)

Pumpdown Velocity (v_p)

The rate at which the equilibrium altitude of the balloon (z) can be changed by pumping or valving in a standard atmosphere:

$$v_p = \frac{dz}{dt} = -1.042 \times 10^4 \frac{S}{V} (1 - 2.256 \times 10^{-5} z) \qquad \text{(B-4)}$$

In a nonstandard atmosphere, with an arbitrary lapse rate γ, the pumpdown velocity is given by:

$$v_p = -ST_a/(V(3.416 \times 10^{-2} - \gamma)) \qquad \text{(B-5)}$$

Change of Equilibrium Altitude Resulting from an Increment in Payload Mass

From B-4 and B-5, one can infer the change in equilibrium altitude dz resulting from an increment dm in payload mass. Taking on additional air ballast is equivalent to increasing the payload mass. Here $dm = S\rho_a\, dt$, so

$$\frac{dz}{dm} = \frac{-8.506 \times 10^3}{V} (1 - 2.256 \times 10^{-5} z)^{-3.255} \qquad \text{(B-6)}$$

in a standard atmosphere, or

$$\frac{dz}{dm} = -2.871\, T_a^2 / (P_a V (3.416 \times 10^{-2} - \gamma)) \qquad \text{(B-7)}$$

in an arbitrary atmosphere.

Superpressure As A Function of Equilibrium Altitude

$$P_s = 2.396 \times 10^4 \frac{C}{V} (1 - 2.256 \times 10^{-5} z) \qquad \text{(B-8)}$$

and

$$\frac{dP_s}{dz} = -.541 \frac{C}{V} \qquad \text{(B-9)}$$

Using the expression for P_s, one can evaluate C.

$$C = \frac{VP_{so}}{2.396 \times 10^{4} \; (1 - 2.256 \times 10^{-5} \; z_o)} \tag{B-10}$$

Effect of Temperature Swing on Balloon Pressure

$$\Delta P = 3.52 \; ((1 - 2.256 \times 10^{-5} z)^{4.255} + 83.14 \; \frac{C}{V}) \; \Delta T \tag{B-11}$$

Energy Required for Pumpdown per Unit Altitude Change

dW/dz is expressed in Joules/m; note that 1 Joule/s is a Watt.

$$\frac{dW}{dz} = \frac{9.60 \times 10^{-3} P_{so} \; V}{(1 - 2.256 \times 10^{-5} z_o)} \tag{B-12}$$

Required Lift L_R

To fill the balloon properly, one first puts in helium until the gross lift is measured to be L_R as given below. Then, one seals the inner balloon, and inflates the outer balloon with air, until the desired initial superpressure P_{so} is reached. At that point, the balloon system, after attachment of the payload, should be approximately neutrally buoyant.

$$L_R = (\; m + M \; \frac{P_{so} V}{RT} \;) \; g \tag{B-13}$$

Ceiling Altitude z_m

$$z_m = \frac{1}{2.256 \times 10^{-5}} \quad (\; 1 - (\; \frac{.0164 \; L_s + m}{1.255 \; V} \;)^{0.2350} \;) \tag{B-14}$$

If the balloon was filled optimally, then L_s becomes L_R, the required lift.

APPENDIX C

SECOND GENERATION BALLOON DESIGN

Letter dated October 17, 1984, from Robert M. Enderson, Raven Industries, Inc., to Sandia National Laboratories, Attention Bernard Zak.

RAVEN INDUSTRIES, INC.

RAVEN

P.O. Box 1007 Sioux Falls South Dakota 57117-1007
Telephone (605) 336 2750 TWX910-660 0306

October 17, 1984

Sandia National Laboratories
Applied Atmospheric Research Division
Albuquerque, NM 87185

Attention: Mr. Bernard Zak

Subject: Raven Industries, Inc. Letter Proposal
No. ATD 1084122 For a Variable Density Balloon

Dear Mr. Zak:

Raven is pleased to present this proposal in response to your requirement as discussed during your visit on 29 August.

The basic requirement is for a superpressure balloon capable of supporting a twelve pound payload at an altitude of 500 mb. Additional related requirements are as follows:

- vent fitting at top apex
- full volume bladder
- 3.5 inch inside diameter base fitting (capable of inserting persons arm)
- helium inflation through base fitting
- handling lines
- rain skirt

Raven proposes balloon Model No. S-P3.0-D11.2. The balloon has a diameter of 11.2 feet and is proposed to be fabricated from polyester film. The balloon would be fabricated from twelve gores and incorporate a polyurethane film bladder.

Design details of the proposed balloon are discussed in the following paragraphs.

BALLOON MATERIAL

Polyester film with a thickness of 3.0 mils is the primary film proposed. Raven has this film in stock, and for economic reasons it has to be the primary choice. The computed stress at a superpressure of 80 mb. is 12992 psi, slightly higher than the targeted stress of 12000 psi.

Raven will attempt to locate a stock source of film of a heavier gauge than 3.0 mils before the balloon design is finalized. If a heavier gauge film, up to 4.0 mils, can be located and at acceptable cost, the design will be modified as necessary. A slightly larger balloon would result. A 4.0 mil film would reduce the stress to approximately 10000 psi.

BLADDER MATERIAL

The proposed bladder material is 1.0 mil polyurethane film. The urethane film is proposed over polyethylene because of its lower helium permeability rate. The measured helium permeability rate of 1.5 mil polyethylene is 5.58 liters/m^2/24 hours, that of 1.0 mil urethane film 3.83.

The selection of urethane film is contingent upon acceptable deployment of the bladder being obtained in tests. Polyethylene will be utilized if deployment of a urethane film bladder is unacceptable.

The bladder will be secured to the sphere with the vent fitting at the top apex. This configuration will be the same as in the similar balloons previously supplied.

The bladder will incorporate an inflation tube that will be accessible through the base fitting and of a compatible diameter. Inflation of the balloon/bladder assembly through the base fitting will alleviate the necessity of turning the balloon via the handling lines and the associated stress. The inflation tube can be sealed with a single overhand knot when the inflation is completed.

BASE FITTING

A basic requirement of the end fitting is that it is of a size sufficiently large to allow a persons arm to be extended into the balloon. This will require a minimum inside diameter of the fitting of approximately 3.5 inches. This diameter will be more than adequate to accommodate the 2.25 inch X 4.0 inch involved circuit board.

A threaded fitting and a clamp configuration for securing the fitting to the balloon will both be evaluated. The fitting, with either basic configuration, will incorporate a threaded cap.

LOAD SUSPENSION

The load suspension will consist of three load patches installed on the surface of the main shell with suitable nylon lines extending to a confluence point.

Two load patches will additionally be installed near the top of the balloon for handling the balloon. The strength of the patches will be increased over those previously supplied.

RAIN SKIRT

The balloon will incorporate a rain skirt. The skirt will be installed at a 120^{o} included angle location.

TERMINATION

The proposed balloon will incorporate a 3-wire twisted conductor from the base to the top of the balloon.

The proposed price for the balloon is $1,537.00 each in a quantity of ten. The price is F.O.B. Sioux Falls, S.D. Terms are net thirty days.

Included in the price is an allowance for engineering and testing.

If you have any questions regarding this proposal, please contact me.

Sincerely,

RAVEN INDUSTRIES, INC.

Robert M. Enderson
Sales Engineer
Applied Technology Division

RME/js

APPENDIX D

RATE OF DESCENT ON CUTDOWN

The cutdown system on the operational prototype Tracer uses an electric match to melt a hole in a membrane which seals an exhaust port on the helium-containing ballonet. After the cutdown device fires, the helium vents through the resulting hole which is typically about 1 cm^2 in area. Venting is initially driven by the superpressure in the balloon and, consequently, is fairly rapid. However, as long as any superpressure remains, the volume of the outer balloon is approximately constant. Provided that the pump is not in operation, venting of helium decreases the mass present in the balloon, decreasing the average density of the contained gas. This causes the equilibrium altitude of the Tracer Balloon to rise slightly. Only after the superpressure reaches zero and the volume of the balloon begins to shrink does the system become negatively buoyant and begin to fall. The calculation of descent rate starts at the point at which the superpressure reaches zero.

To examine the behavior of the balloon as lift is lost, we apply Newton's second law to the vertical motion:

$$F_z = m_v \frac{d^2z}{dt^2} \tag{D-1}$$

Here F_z is the net vertical force on the system, m_v is the virtual mass of the system (the actual mass plus the mass of entrained air), and z is the altitude. As the balloon begins descending, there are three components of F_z: the gross lift, the force due to gravity, and the drag force acting on the balloon.

$$F_z = L - mg + \frac{1}{2}\rho_a C_D A_D \left(\frac{dz}{dt}\right)^2 \tag{D-2}$$

Here L is the gross lift, m is the actual mass of the balloon system, A_D is its cross sectional area, and C_D is a drag coefficient. The gross lift L is given by

$$L = (\rho_a - \rho_b)\ V\ g \tag{D-3}$$

In a slack balloon such as we assume for descent ($P_s = 0$), this is equivalent to

$$L = (\rho_a - \rho_{He})\ V_{He}\ g \tag{D-4}$$

where ρ_{He} is the density of helium, and V_{He} is the volume of helium contained in the balloon. The volume of air contained in a slack balloon does not affect gross lift.

Note that the density of a gas is proportional to its molecular weight. Hence, assuming that the helium in the balloon is in thermal equilibrium with its surroundings,

$$\rho_{He} = \frac{4.0}{28.96} \rho_a \tag{D-5}$$

$$(\rho_a - \rho_{He}) = .862 \rho_a \tag{D-6}$$

Furthermore, the behavior of the volume of helium in the balloon is given by the gas law

$$V_{He} = \frac{n_{He} R T_a}{P_a} \tag{D-7}$$

where n_{He} is the number of kg-moles of helium in the balloon and the "a" subscript as elsewhere indicates the ambient values of the respective variables.

Assuming a standard atmosphere, we may substitute the appropriate expressions into D-4 and obtain

$$L = 0.862 \; n_{He} \; M \; g \tag{D-8}$$

This is the interesting and well-known result that as long as the helium in a zero-pressure balloon is in thermal equilibrium with its surroundings, the gross lift depends only on the amount of helium contained, not on the altitude.

We assume that the balloon comes to rest at its zero superpressure equilibrium altitude. Then at $t = 0$, $L - mg = 0$, and we need only concern ourselves with changes in the net lift, L_n:

$$L_n = L - mg \tag{D-9}$$

$$\frac{dL_n}{dt} = \frac{dL}{dt} = 0.862 \; Mg \; \frac{dn_{He}}{dt} \tag{D-10}$$

We may evaluate dn_{He}/dt using the gas law (D-7), provided that we note that $n_{He} = n_{He}(T_a, P_a, V_{He})$, and that $T_a = T_a(z)$; $P_a = P_a(z)$; $V_{He} = V_{He}(z,t)$.

Thus,

$$\frac{dn_{He}}{dt} = \frac{\partial n_{He}}{\partial z}\frac{dz}{dt} + \frac{\partial n_{He}}{\partial t} \qquad \text{(D-11)}$$

We also know from the physics involved that $\partial n_{He}/\partial z = 0$; the number of moles of helium in a slack balloon is independent of altitude if time is held constant.

Hence,

$$\frac{dn_{He}}{dt} = \frac{\partial n_{He}}{\partial t} \qquad \text{(D-12)}$$

Making use of (D-7) and the above relationship, we find

$$\frac{dn_{He}}{dt} = \frac{P_a}{RT_a}\frac{\partial V_{He}}{\partial t} \qquad \text{(D-13)}$$

Morris (1975) gives an expression for the rate of escape of helium through an orifice of area A under assumptions which are reasonable for the present case:

$$\frac{\partial V_{He}}{\partial t} = -12.3 \text{ CA } V_{He}^{1/6} \qquad \text{(D-14)}$$

Here C is an orifice coefficient between 0.5 and 1. Making use of equation D-7, we find:

$$\frac{dn_{He}}{dt} = \frac{P_a}{RT_a}\frac{\partial V_{He}}{\partial t} = -12.3 \text{ CA } \left(\frac{\rho_a}{M}\right)^{5/6} n_{He}^{1/6} . \qquad \text{(D-15)}$$

The net lift becomes:

$$L_n(t) = \int_0^t \frac{dL_n}{dt'} = -10.6 \text{ MgCA} \int_0^t \left(\frac{\rho_a}{M}\right)^{5/6} n_{He}^{1/6} dt' \qquad \text{(D-16)}$$

Substituting into equation D-1, we find:

$$m_V \frac{d^2z}{dt^2} = -10.6\ MgCA \int_o^t \left(\frac{\rho_a}{M}\right)^{5/6} n_{He}^{1/6} dt' + \frac{1}{2}\rho_a C_D A_D \left(\frac{dz}{dt}\right)^2 \qquad \text{(D-17)}$$

This is a fairly complex integro-differential equation which can be solved numerically if desired. However, it is worthwhile to make some approximations to get an intuitive understanding of the descent rate.

Consider a simpler case, the case examined in Chapter Six of the Phase I report, in which the term containing the integral is taken to be constant, as is the product $\rho_a C_D A_D$. This simpler equation can be written as

$$-m_L g + bv^2 = m_V \frac{dv}{dt} \qquad \text{(D-18)}$$

where m_L is the net buoyant mass of the system, b is a redefined drag coefficient, and m_V is as before, the virtual mass, and v = dz/dt.

The solution to this equation, starting from rest relative to the air, is known:

$$v = v_T \tanh \beta t \qquad \text{(D-19)}$$

where v_T is the terminal velocity:

$$v_T = \sqrt{\frac{m_L g}{b}} \qquad \text{(D-20)}$$

Here $b = \frac{1}{2}\rho_a C_D A_D$, and

$$\beta = \frac{1}{m_V}\sqrt{b m_L g} \qquad \text{(D-21)}$$

This solution implies a characteristic relaxation time τ to reach (1 - 1/e) of terminal velocity v_T:

$$\tau \simeq 0.75 \frac{m_V v_T}{m_L g} \qquad \text{(D-22)}$$

In these terms,

$$m_L = 10.6 \text{ MCA} \int_0^t \left(\frac{\rho_a}{M}\right)^{5/6} n_{He}^{1/6} \, dt' \qquad \text{(D-23)}$$

Neither $(\rho_a/M)^{5/6}$ nor $n_{He}^{1/6}$ change very rapidly, so we may approximate the expression by taking these factors outside the integral sign. Then

$$m_L = 10.6 \text{ MCA} \left(\frac{\rho_a}{M}\right)^{5/6} n_{He}^{1/6} \, t \qquad \text{(D-24)}$$

Consider descent from 5.5 km (the design goal ceiling altitude) in a standard atmosphere. Under our assumptions, at $t = 0$, $(\rho_a/M)^{5/6} = 4.48 \times 10^{-2}$, $n_{He} = .818$, and thus for a 1 cm^2 hole with an orifice coefficient of 1, $m_L = 1.125 \times 10^{-3}\ t$. This expression for m_L implies that initially, the negative buoyancy is accumulating at a rate of a little over 1 g per second.

Consider the situation at 1000 seconds (16.7 minutes) after cutdown activation. We assume $C_D = 0.5$, and use the initial values for $(\rho_a/M)^{5/6}$ and n_{He}, as well as for the balloon cross-sectional area and ρ_a. Then m_L (1000) = 1.125 kg, b(1000) = 1.14, and $v_T(1000)$ = 3.11 m/s. These results are consistent with the assumptions.

We obtain an estimate of the total time for descent from 5.5 km by extending the assumptions made above beyond 1000 seconds, and by assuming that at all times, $v = v_T$ -- that is, that the relaxation time τ is negligible. Since at 1000 seconds, we find that τ is less than 4 seconds, this assumption is reasonable.

Thus we have:

$$\frac{dz}{dt} = v_T = -9.84 \times 10^{-2}\ t^{1/2} \qquad \text{(D-25)}$$

and

$$z_o - z = 6.56 \times 10^{-2}\ t^{3/2} \qquad \text{(D-26)}$$

For z_o = 5.5 km, and z = 0, we find t = 1916 seconds (32 minutes), m_L = 2.16 kg, and v_T = 4.31 m/s (14.1 ft/s). This is to be compared with a rate of descent of a personnel parachute of about 6 m/s. Cutdown from lower altitude would, of course, result in lower time to touchdown and lower terminal velocity at touchdown.

Finally, it is worthwhile to note that this result is relatively insensitive to the assumptions that $(\rho_a/M)^{5/6}$ and $n_{He}^{1/6}$ are constant and equal to their initial values at 5.5 km. The assumptions influenced the result through the terminal velocity, v_T. After expanding the expression for v_T, one finds that the terminal velocity is directly proportional to $(n_{He}/\rho_a)^{1/12}$, which decreases only about 7% from 5.5 km to sea level.

APPENDIX E

SOP No. 29400 8512

Originating Org. 6324

Safe Operating Procedures
for
Handling and Using Electric Matches
in
Balloon Cutdown Devices

1/6/86		12-2-85	
J. E. Stiegler (6320)	Date	D. Rost (3442)	Date
11/27/85		12/2/85	
B. D. Zak (6324)	Date	for D. Joe (3442)	Date

1.0 References

Federal Aviation Regulations, Part 101 (Appendix A)

2.0 General

2.1 Scope

This SOP covers the handling of electric matches for use in both free and tethered balloon cutdown devices. Federal Aviation Regulations (FAR 101) specify the conditions under which cutdown devices must be carried by balloons. Pursuant to these regulations, a convenient cutdown device utilizing electric matches has been developed.

2.2 Location

Cutdown devices will be deployed whenever and wherever balloons requiring them are to be used. It is expected that those cutdown devices will henceforth use electric matches.

3.0 Description of Hazardous Materials

3.1 The electric matches we plan to use are from Atlas Powder Company, and are designated "electric match, 12" leads, without tube." These are available from Woodard Explosives at 3305 Coors Blvd., SW, in Albuquerque, for less than $1 each. Electric matches of similar characteristics are made by a number of manufacturers of pyrotechnic devices. They are interchangeable.

3.2 Electric matches consist of a small nodule of readily combustible material deposited on a bridgewire. The nodule consists of material similar to that incorporated in friction matches, and is between the size of a paper and a wood match head. The match is lit by passing approximately a half amp of electric current through the bridgewire. The hazard associated with the flame resulting from lighting the match is the same as the hazard associated with striking a friction match. Nonetheless, electric matches are technically considered class C explosives.

3.3 There are two main sources of hazard associated with electric matches. The first is that they are electrically operated, and hence may be inadvertently lit more easily than friction matches. The second would arise from storing large numbers in close proximity and in an inappropriate container. Under those conditions, should one match be inadvertently lit, all might go off. If the container were not designed to stop flame propagation to surrounding combustible materials, a significant fire hazard would be created.

4.0 Personnel

4.1 The personnel authorized to work with electric matches for balloon cutdown are given in Appendix B. Additions to this list of authorized personnel may be made as necessary from time to time.

4.2 Each individual on the list in Appendix B shall sign and date this SOP in the space provided to acknowledge that he or she has reviewed and understands the provisions of this document.

4.3 Enforcement of the requirements of this SOP shall be the responsibility of the individual operating the balloon system equipped with an electric match cutdown device.

5.0 Storage

Electric matches will be stored in "Mound" cases. These cases, developed by the Mound Laboratory, are specifically designed to safely contain class C explosives. Electric matches contained within a Mound case will not be required to be stored in an explosives igloo. According to explosives expert Paul Cooper (7132), the hazard associated with electric matches contained in a Mound case is negligible, and does not justify the major inconvenience of igloo storage.

6.0 Transportation

Electric matches may be hand carried on any public or private means of transportation in a Mound case with the exception of commercial passenger aircraft. Means of shipment must also exclude commercial passenger aircraft. Shipment will be controlled by Transportation Division 3423, in accordance with U.S. Department of Transportation regulations.

7.0 Fire Hazard Control

The cutdown devices shall be designed so that the flame associated with the electric match is completely contained in the device itself, and cannot propagate to other combustible materials in the vicinity.

8.0 Misfire Procedures

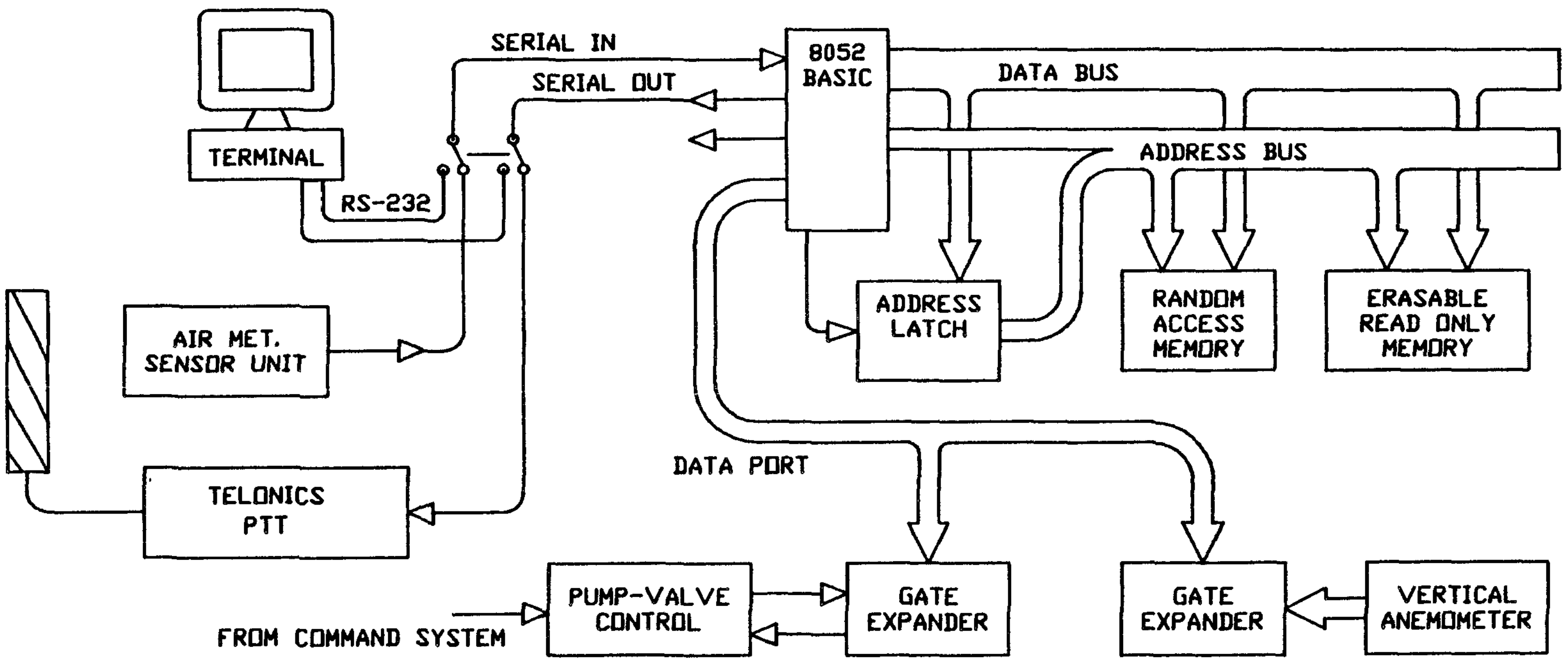
In the unlikely event of a misfire, the defective electric match will be removed from the cutdown device and destroyed. A match which has misfired does not represent a special hazard. Ignition with a friction match will suffice.

APPENDIX F

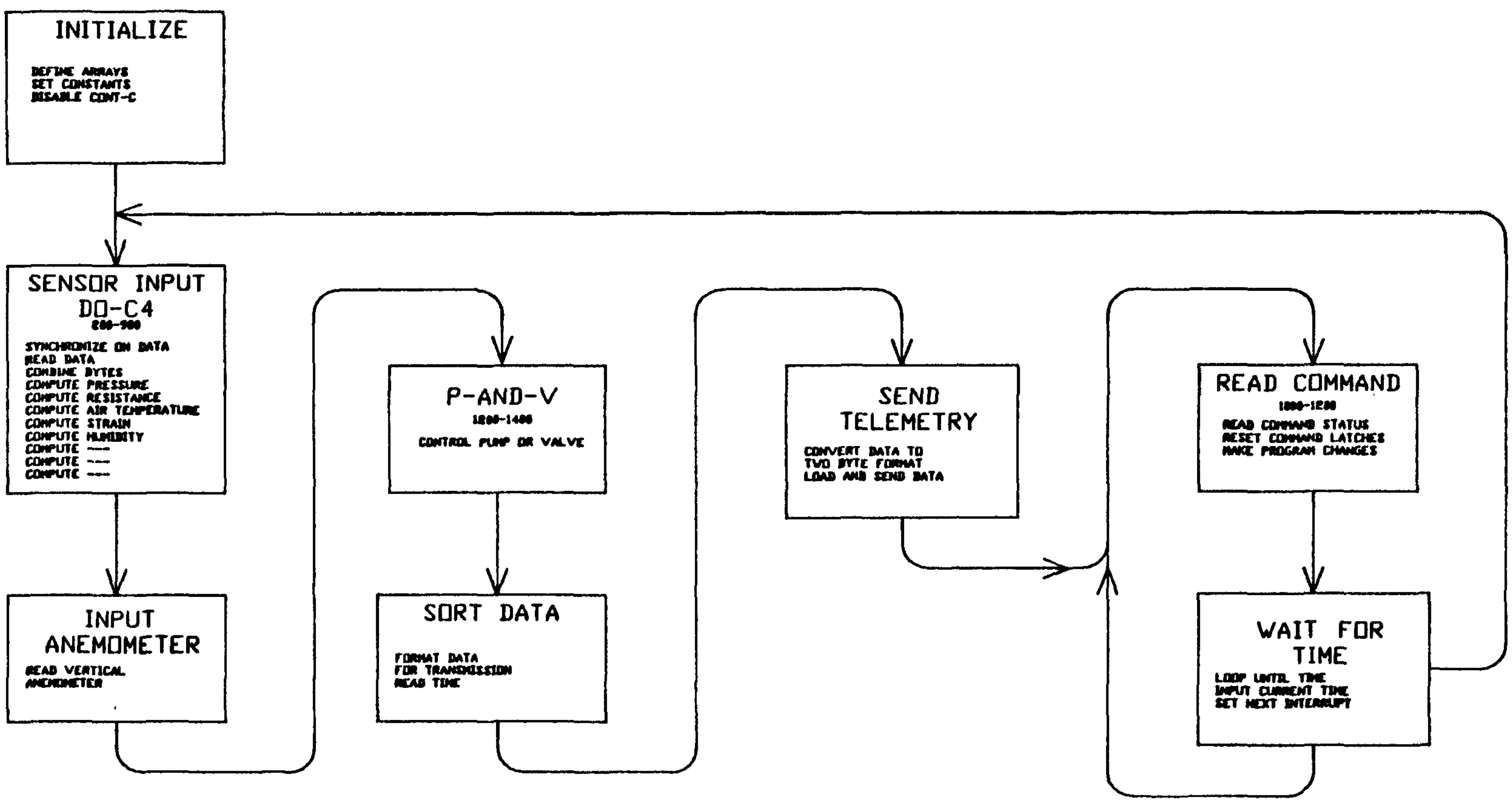
OPERATIONAL PROTOTYPE

SCHEMATIC DIAGRAMS

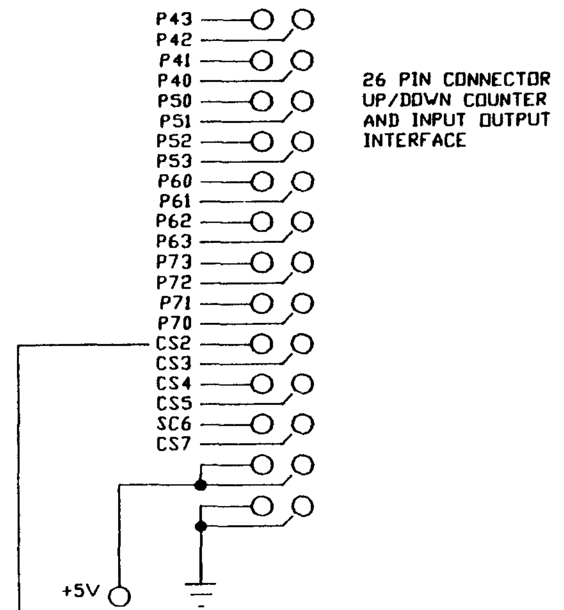
TRACER BALLOON COMPUTER CONTROL SYSTEM



F-1


INITIALIZE
DEFINE ARRAYS
SET CONSTANTS
DISABLE CONT-C
SENSOR INPUT
DO-C4
SYNCHRONIZE ON DATA
READ DATA
COMBINE BYTES
COMPUTE PRESSURE
COMPUTE RESISTANCE
COMPUTE AIR TEMPERATURE
COMPUTE STRAIN
COMPUTE HUMIDITY
COMPUTE ---
COMPUTE ---
COMPUTE ---
INPUT
ANEMOMETER
READ VERTICAL
ANEMOMETER
P-AND-V
CONTROL PUMP OR VALVE
SORT DATA
FORMAT DATA
FOR TRANSMISSION
READ TIME
SEND
TELEMETRY
CONVERT DATA TO
TWO BYTE FORMAT
LOAD AND SEND DATA
READ COMMAND
READ COMMAND STATUS
RESET COMMAND LATCHES
MAKE PROGRAM CHANGES
WAIT FOR
TIME
LOOP UNTIL TIME
INPUT CURRENT TIME
SET NEXT INTERRUPT

F-2



STORE DATA IN M ARRAY

```
10 DIM M(32)
20 FOR N=1 TO 32
30 M(N)=N+50
40 NEXT N
```

ACTIVATE WAKE UP

```
50 REM WAKE UP
60 PORT1=255
70 PORT1=160 ;chip select 2
80 FOR N=1 TO 10
90 A=SIN(N)
100 NEXT N
110 PORT1=255
```

LOAD DATA BUFFER 1 AND TRANSMIT

```
120 REM LOAD DATA
130 BAUD 1200
140 PRINT# CHR(48),
150 FOR N=1 TO 32
160 PRINT# CHR(M(N)),
170 NEXT N
180 END
```

**** NOTE ****
SEE LINE 140 PRINT# CHR(48),
THE 48 SELECTS ID CODE 0
TO SELECT ID CODES 0 THROUGH 7
ADD 0 THROUGH 7 TO 48
THE SAME APPLIES TO ALL OTHER EXAMPLES

LOAD DATA IN BUFFER 2 AND TRANSMIT

```
120 REM LOAD DATA
130 BAUD 1200
140 PRINT# CHR(64),
150 FOR N=1 TO 32
160 PRINT# CHR(M(N)),
170 NEXT N
180 END
```

LOAD DATA IN BUFFER 1 NO TRANSMIT

```
120 REM LOAD DATA
130 BAUD 1200
140 PRINT# CHR(16),
150 FOR N=1 TO 32
160 PRINT# CHR(M(N)),
170 NEXT N
180 END
```

LOAD DATA IN BUFFER 2 NO TRANSMIT

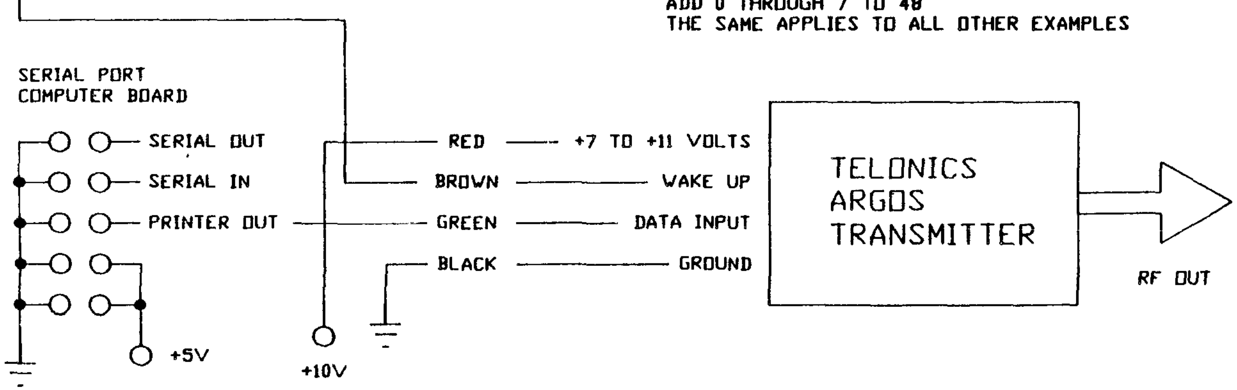
```
120 REM LOAD DATA
130 BAUD 1200
140 PRINT CHR(32),
150 FOR N=1 TO 32
160 PRINT# CHR(M(N)),
170 NEXT N
180 END
```

TRANSMIT DATA FROM BUFFER 1

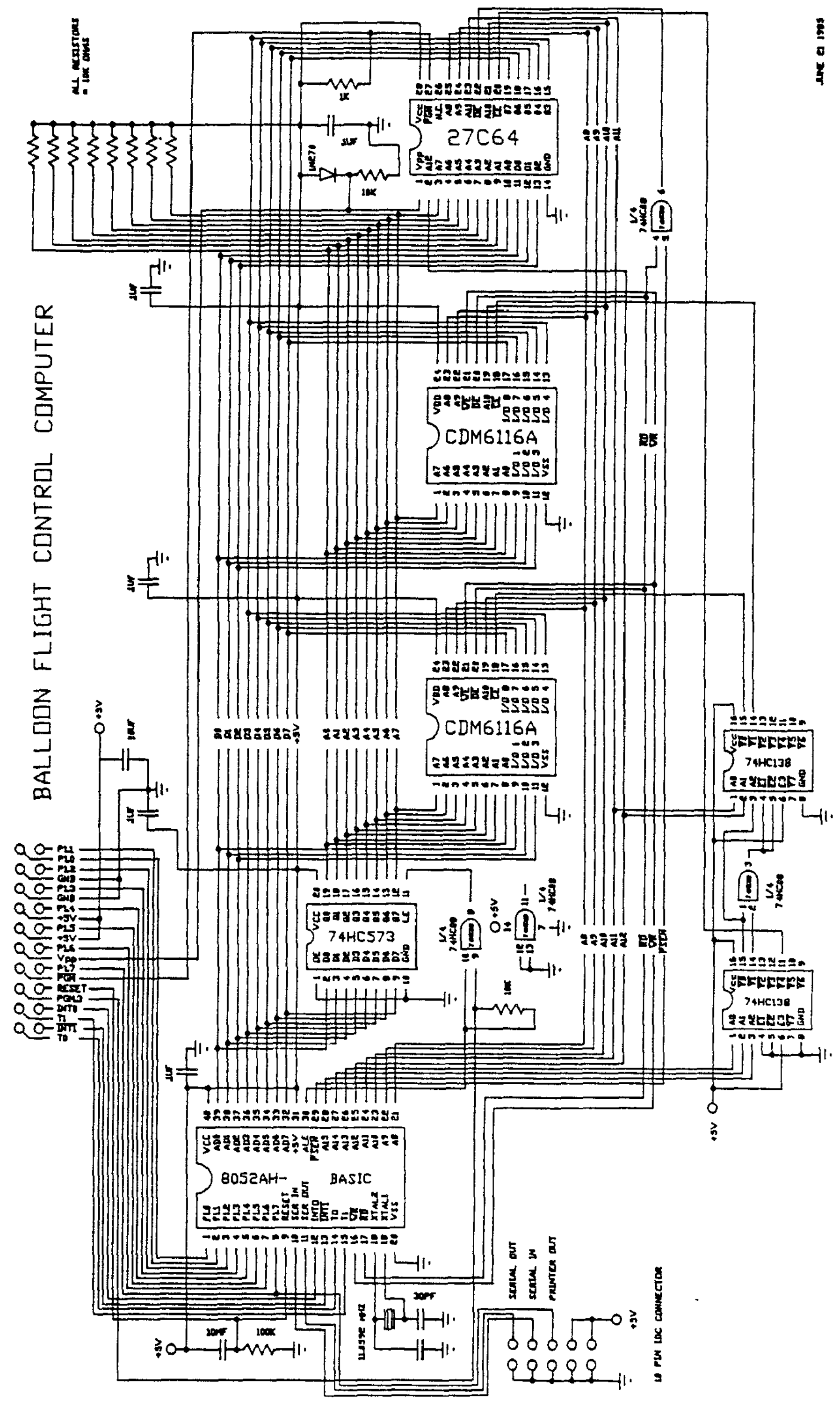
```
120 REM TRANSMIT DATA
130 BAUD 1200
140 PRINT# CHR(80),
150 END
```

TRANSMIT DATA FROM BUFFER 2

```
120 REM TRANSMIT DATA
130 BAUD 1200
140 PRINT# CHR(96),
150 END
```



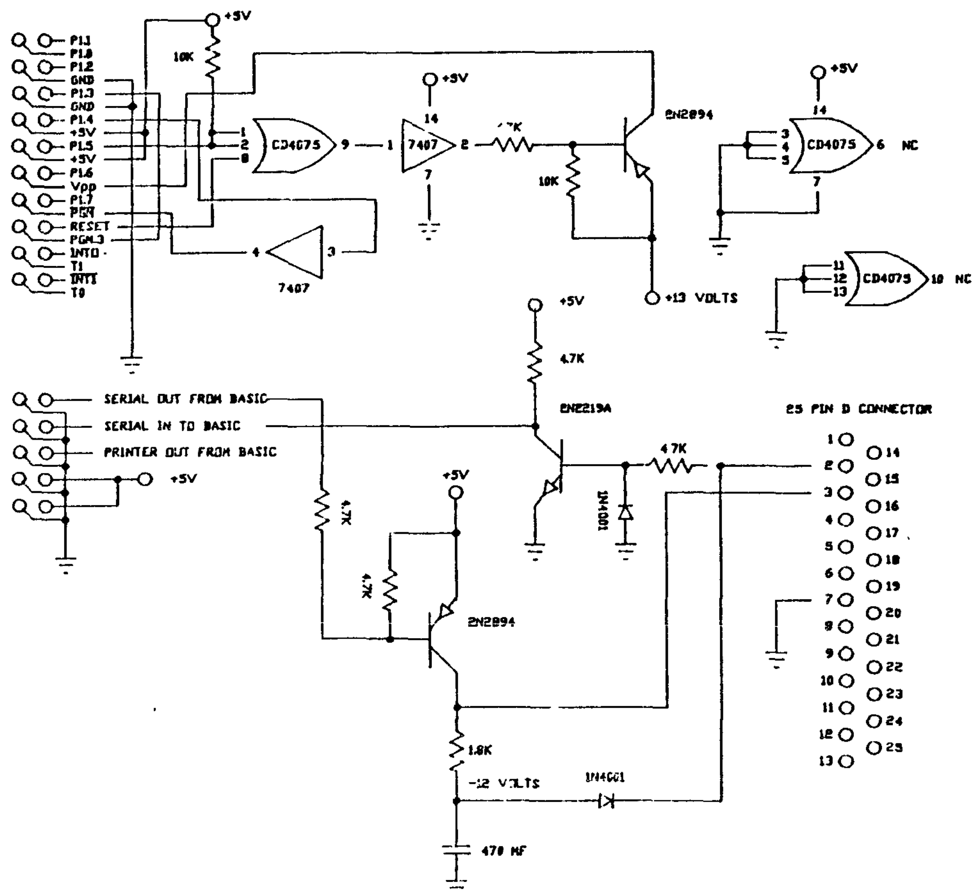
F-3


BALLOON FLIGHT CONTROL COMPUTER
27C64
CDM6116A
CDM6116A
74HC573
8052AH- BASIC
74HC138
74HC138
18 PIN IDC CONNECTOR

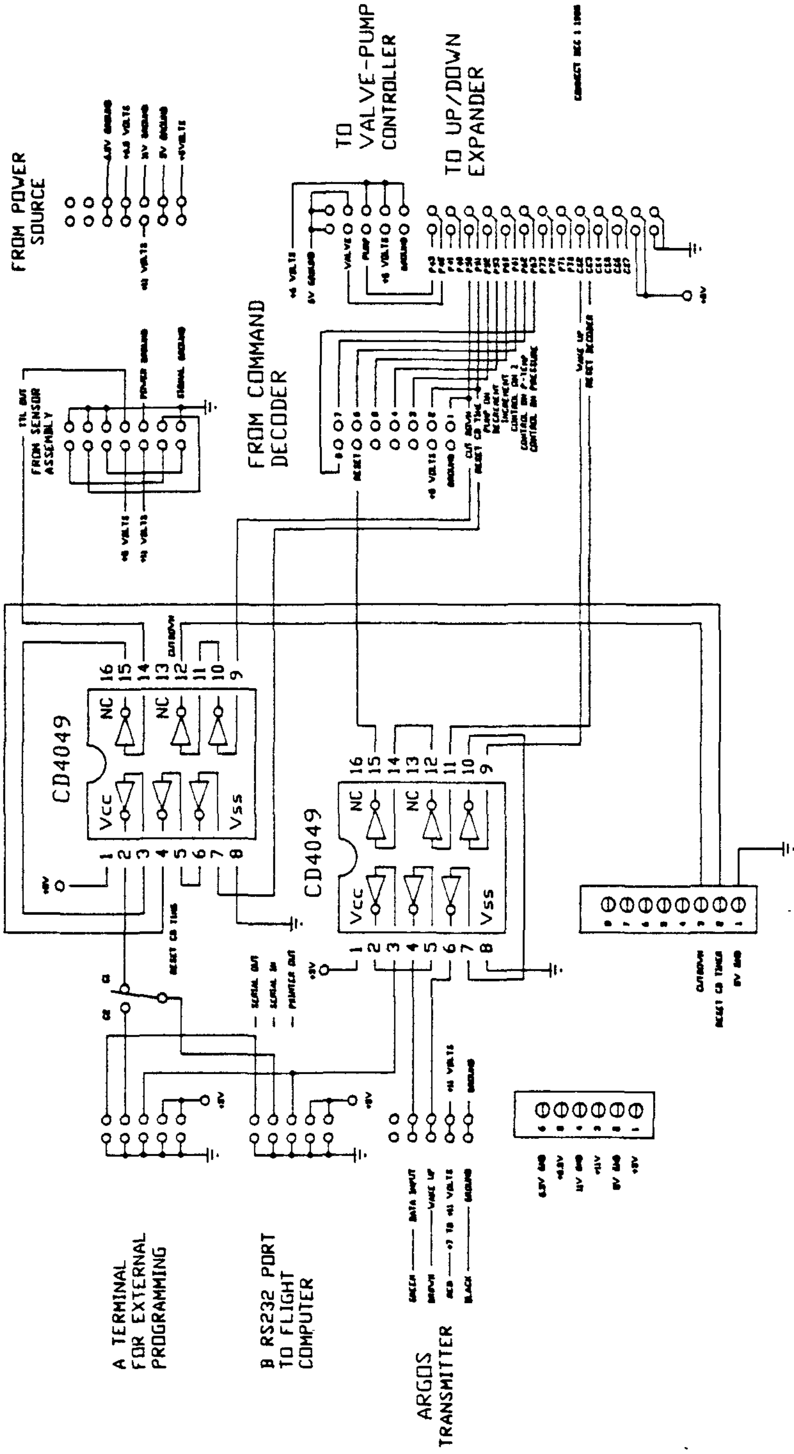
F-4

8052AH-BASIC

RS232 AND EPROM INTERFACE

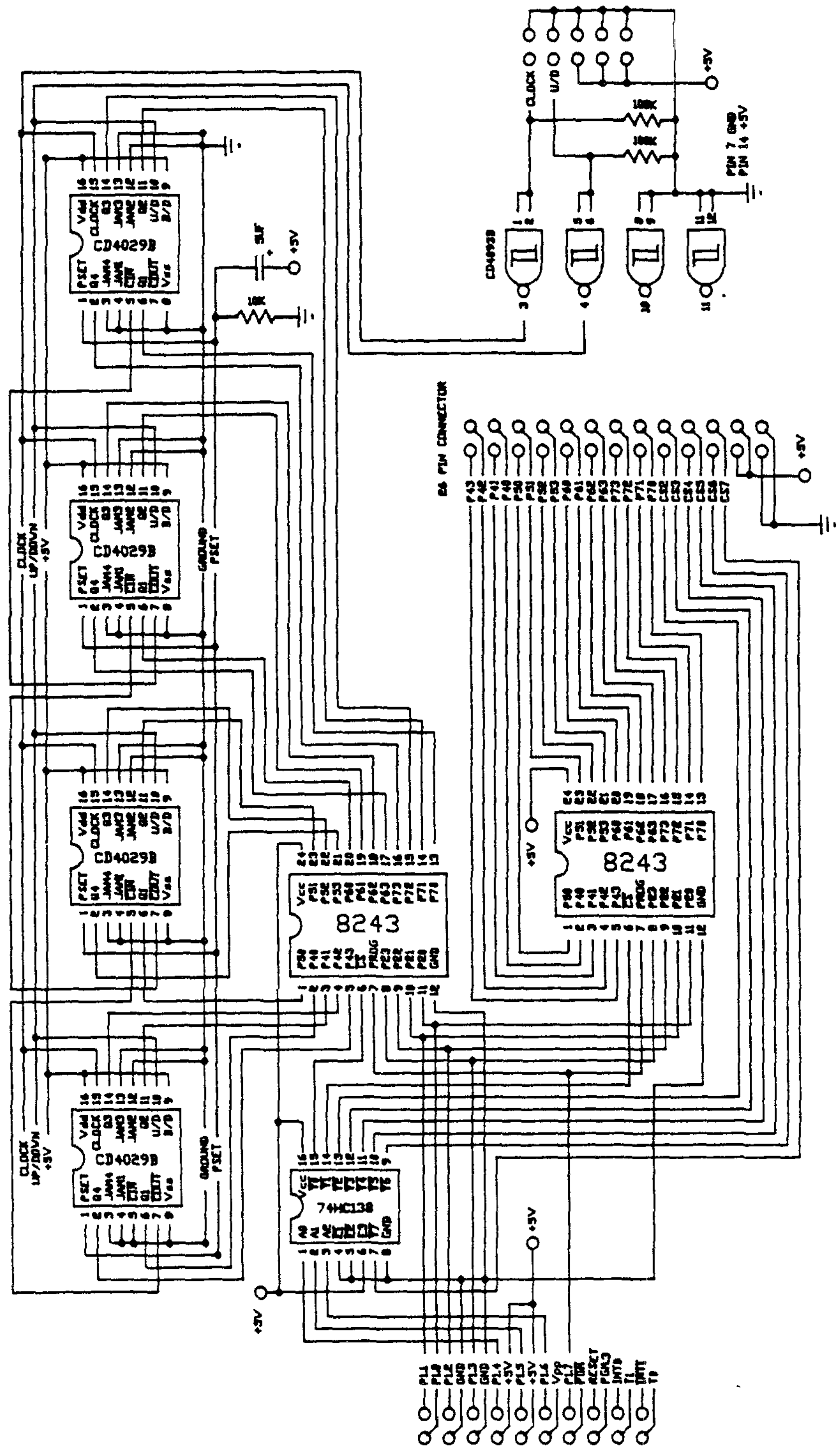


F-5

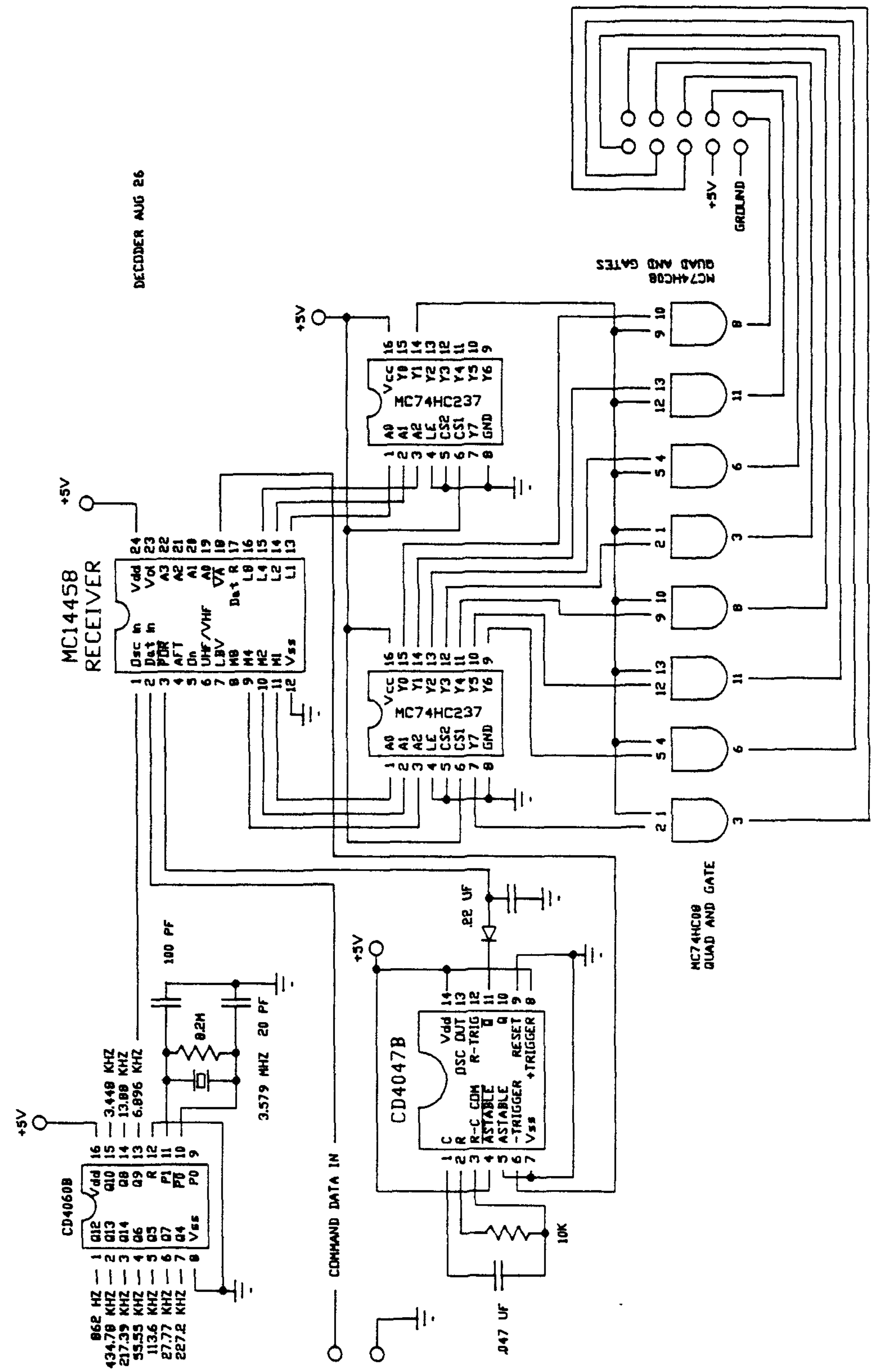

FROM POWER SOURCE
TO VALVE-PUMP CONTROLLER
TO UP/DOWN EXPANDER
FROM SENSOR ASSEMBLY
FROM COMMAND DECODER
CD4049
CD4049
A TERMINAL FOR EXTERNAL PROGRAMMING
B RS232 PORT TO FLIGHT COMPUTER
ARGOS TRANSMITTER

F-6

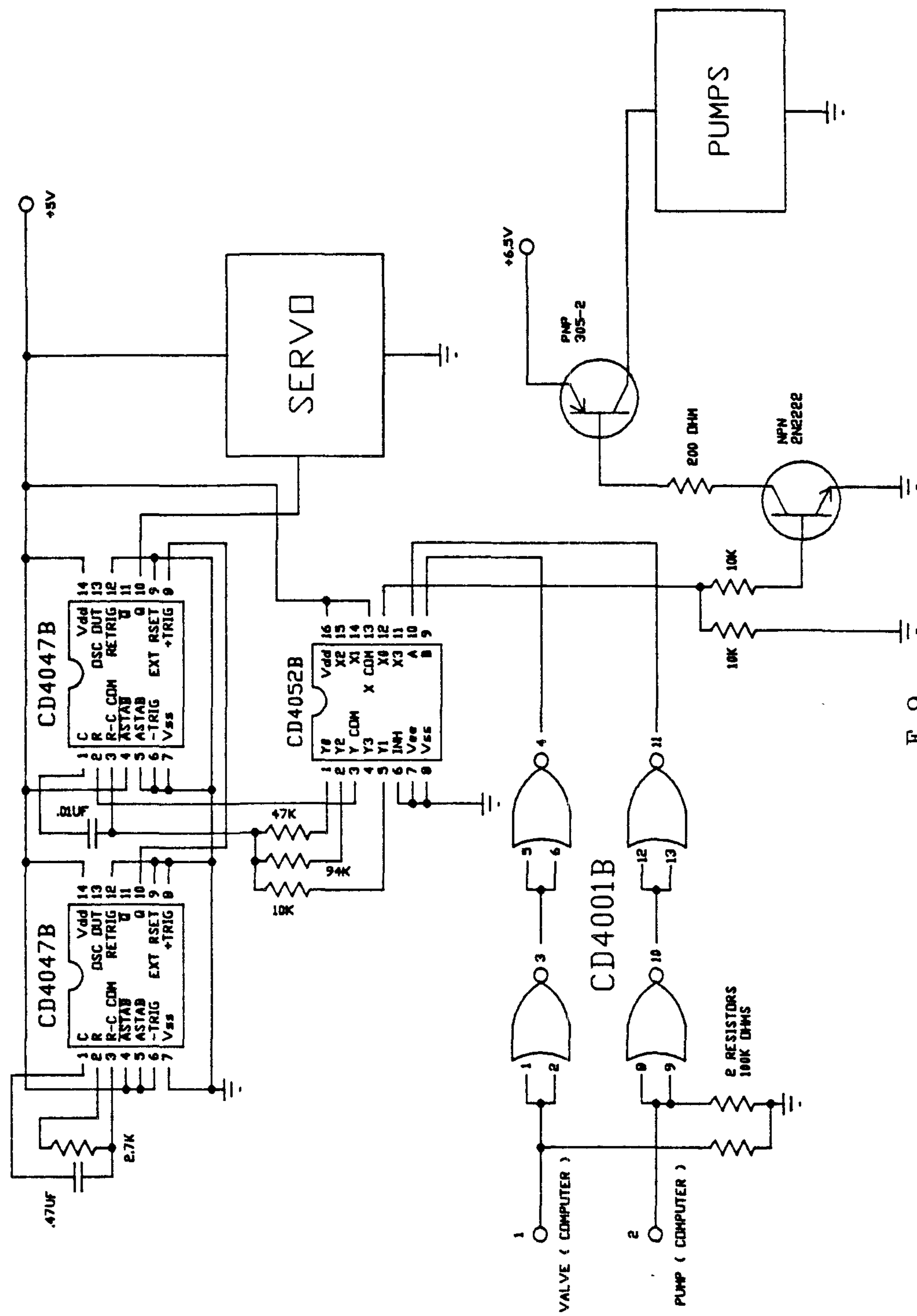
UP/DOWN COUNTER AND IN/OUT INTERFACE



F-7

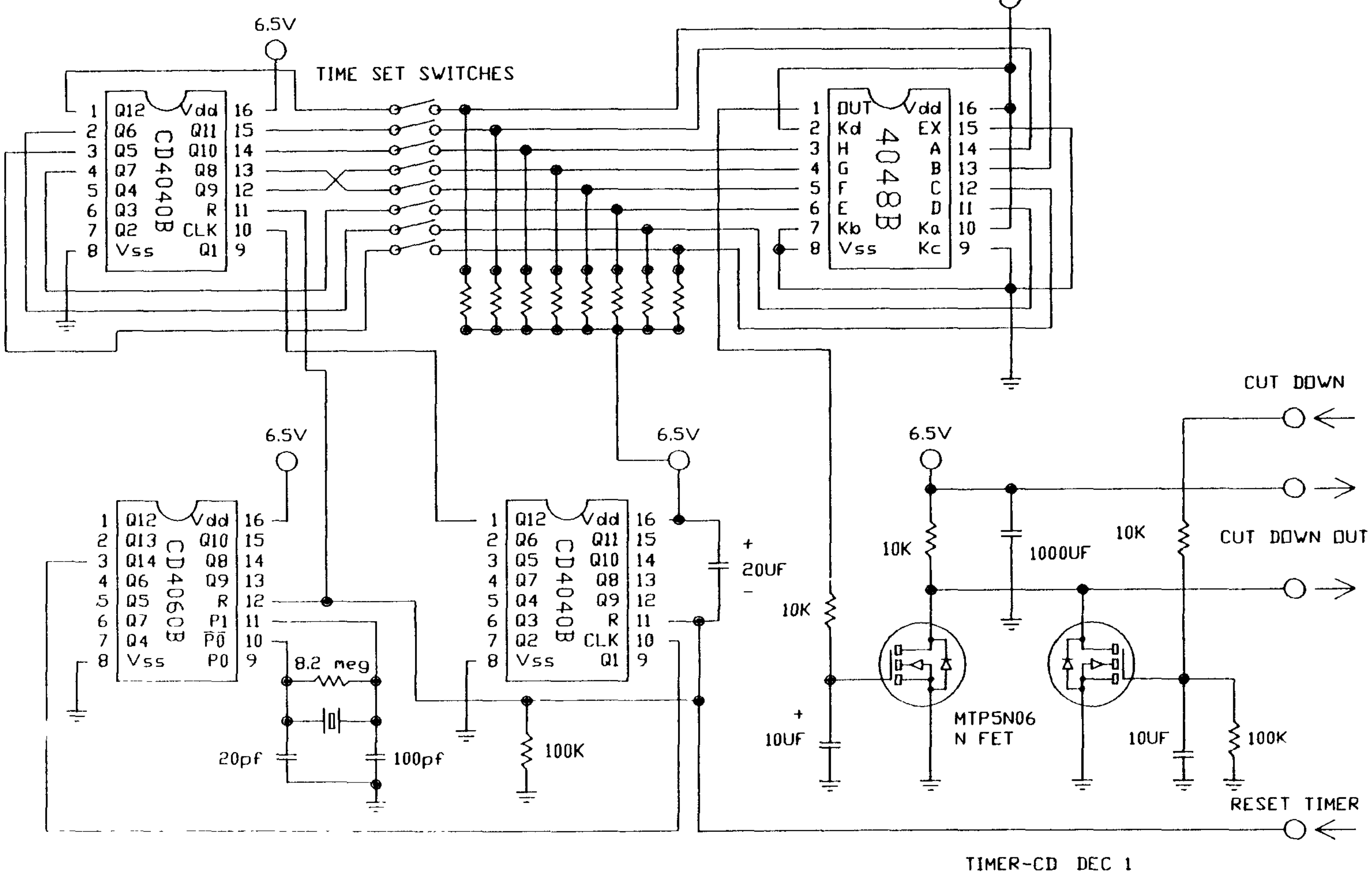

DECODER AUG 26
MC14458
RECEIVER
MC74HC237
MC74HC237
MC74HC08
QUAD AND GATES
MC74HC08
QUAD AND GATE
CD4060B
CD4047B
+5V
GROUND
COMMAND DATA IN
100 PF
20 PF
8.2M
3.579 MHZ
.22 UF
10K
.047 UF
862 HZ
434.78 KHZ
217.39 KHZ
55.55 KHZ
113.6 KHZ
27.77 KHZ
227.2 KHZ
3.448 KHZ
13.88 KHZ
6.896 KHZ

F-8


CD4047B
CD4047B
CD4052B
CD4001B
SERVO
PUMPS
+5V
+6.5V
PNP
305-2
NPN
2N2222
200 OHM
10K
10K
47K
94K
10K
.01UF
.47UF
2.7K
2 RESISTORS
100K OHMS
VALVE (COMPUTER)
PUMP (COMPUTER)

F-9

INDEPENDENT TIMER CUT DOWN



F-10

APPENDIX G

CONTROL PROGRAM

```
10    REM   COM-D
20    K1=1 : K2=840 : K3=15 : K4=10000
30    T9=2 : T8=0 : V1=0 : V2=0
40    DIM R(27) :  ONERR 200
50    TIME=0 :  CLOCK 1 :  ONTIME 20,2500
170   REM     ** PRT-2 **
190   DBY(38)=DBY(38).OR.1
200   REM   ** SEN-1A **
205   PRINT "SENSOR"
210   N=0
220   C=1
230   P=DBY(35).AND.001H
240   IF P=0 THEN  GOTO 230
250   A=GET
260   IF C>5 THEN  GOTO 320
270   IF A=42 THEN  GOTO 300
280   IF C>4 THEN  GOTO 320
290   GOTO 220
300   C=C+1
310   GOTO 230
320   N=N+1
330   IF N>27 THEN  GOTO 390
340   R(N)=A
350   P=DBY(35).AND.001H
360   IF P=0 THEN  GOTO 350
370   A=GET
380   GOTO 320
390   IF R(1)=8 THEN  GOTO 410
400   GOTO 200
410   FOR M=1 TO 9 : S=0
420   FOR N=1 TO 3 : Q=N+(M-1)*3
430   S=S*128+R(Q) :   NEXT N : R(M)=S :  NEXT M
440   REM              SENSOR #0057
450   C0=283.9377 : C1=3347.001 : C2=12490
460   C3=-14672.46 : C4=8112.58 : C5=-1795.773
470   C6=-14817.31 : C7=262.0390 : C8=7765.842
480   U1=(R(2)-R(4))/(R(1)-R(4))
490   U2=(R(3)-R(4))/(R(1)-R(4))
500   P=C0+C1*U1+C2*U1**2+C3*U1**3+C4*U1**4+C5*U1**5
510   P=P+C6*U1*U2+C7*U2*U1**2+C8*U1*U2**2
520   A1=100000 : A2=10000
530   M1=R(6)*A1/(R(5)-R(6))-A2
540   M2=A1*R(7)/(R(5)-R(7))-M1
542   M2=M2-19600
550   M3=A1*R(8)/(R(5)-R(8))-M1
560   M4=A1*R(9)/(R(5)-R(9))-M1
570   R1=14000
580   L1=LOG(M2/R1) : L2=L1*L1 : L3=L2*L1
590   T5=1/(.0032987+L1*4.7764E-04+L2*3.0029E-06+L3*1.5108E-06)
600   T1=T5
610   REM            ** COMPUTE P-TEMP **
620   T2=T1*(1000/P)**.286
810   H=M3 : P1=P : T9=1
1000  REM        * PRT-3 *
1010  FOR N=1 TO 4
```

```
1020 P=N-1 : PORT1=128+P
1030 PORT1=P : PORT1=15
1040 A=PORT1 : PORT1=128+P : R(N)=A*16**(N-1)
1050  NEXT N
1060 Z=R(1)+R(2)+R(3)+R(4)
1200  REM      ** PRT-4 **
1210  IF K1=1 THEN  GOTO 1270
1220  IF K1=2 THEN  GOTO 1300
1230  IF K1=3 THEN  GOTO 1330
1240  IF K1=4 THEN  GOTO 1360
1250  IF K1=5 THEN  GOTO 1370
1260  GOTO 1270
1270  IF P1>K2+1 THEN  GOTO 1360
1280  IF P1<K2-1 THEN  GOTO 1370
1290  GOTO 1350
1300  IF T2<K3-0.1 THEN  GOTO 1360
1310  IF T2>K3+0.1 THEN  GOTO 1370
1320  GOTO 1350
1330  IF Z>K4+500 THEN  GOTO 1360
1340  IF Z<K4-500 THEN  GOTO 1370
1350 A=0 :  GOTO 1380
1360 A=4 : V1=V1+1 :  GOTO 1380
1370 A=8 : V2=V2+1
1380 PORT1=148 : PORT1=20
1390 PORT1=A+16 : PORT1=144+A
1400 PORT1=255
1500  REM          * PRT-5 *
1510 R(1)=TIME : R(2)=P1*10 : R(3)=T1*10
1520 R(4)=H/100 : R(5)=T2*10 : R(6)=M4/100
1530 R(7)=Z : R(8)=V2 : R(9)=V1
1540  IF K1=3 THEN R(10)=K4 :  IF K1=2 THEN R(10)=K3*10
1550  IF K1=1 THEN R(10)=K2*10 :  IF K1>3 THEN R(10)=0
1560 R(11)=K1 : R(12)=T8
1570  FOR N=13 TO 16 : R(N)=0 :  NEXT N
1600  REM           ** S-TEL **
1610 PORT1=255 : PORT1=160
1630  FOR N=1 TO 10 : A=SIN(N) :  NEXT N
1660 PORT1=255 :  BAUD 1200 : Q=48 :  PRINT #CHR(Q),
1700  FOR N=1 TO 16 : A=R(N)
1710  IF A<0 THEN A=A*(-1) : B=INT(A/256)
1730 C=INT(A-256*B) :  PRINT #CHR(B), :  PRINT #CHR(C),
1760  NEXT N
1800  REM     * VIEW *
1810  FOR N=1 TO 16 : A=INT(R(N))
1815  IF A<0 THEN A=A*(-1) :  PRINT A, :  NEXT N
1820  PRINT  : T8=0 : D=0
2000  REM     *PRT-6A*
2010  IF T9=2 THEN  GOTO 200
2020 PORT1=145 : PORT1=17
2030 PORT1=31 : A=PORT1
2040 PORT1=145 : A=A-16
2050 PORT1=146 : PORT1=18
2060 PORT1=31 : B=PORT1
2070 PORT1=146 : B=B-16
2080 C=A+16*B
```

```
2082  IF C=D THEN  GOTO 2090
2084 D=C :  GOTO 2000
2090  IF C=128 THEN  GOTO 2260
2100  IF C=64 THEN  GOTO 2250
2110  IF C=32 THEN  GOTO 2240
2120  IF C=16 THEN  GOTO 2200
2130  IF C=8 THEN  GOTO 2160
2140  IF C=4 THEN K1=5
2145  IF C=1 THEN  GOTO 2280
2150  IF C=0 THEN  GOTO 2300
2155  GOTO 2270
2160  IF K1=1 THEN K2=K2-1
2170  IF K1=2 THEN K3=K3-1
2180  IF K1=3 THEN K4=K4-500
2190  GOTO 2270
2200  IF K1=1 THEN K2=K2+1
2210  IF K1=2 THEN K3=K3+1
2220  IF K1=3 THEN K4=K4+500
2230  GOTO 2270
2240 K1=3 : K4=Z :  GOTO 2270
2250 K1=2 : K3=T2 :  GOTO 2270
2260 K1=1 : K2=P1 :  GOTO 2270
2270 PORT1=16*3+128
2280 T8=C :  PRINT "COMMAND"
2300  IF T9=3 THEN  GOTO 2460
2305  FOR N=1 TO 20 : M=SIN(N) :  NEXT N
2310 PORT1=255
2320  GOTO 2000
2460 T9=2 :  RETI
2500  REM      TIME INTERUPT
2510 A=TIME
2520  ONTIME A+42,2500
2530  IF T9=2 THEN  GOTO 2550
2540 T9=2 :  RETI
2550 T9=3 : K1=5 : T1=0
2560 P1=0 : T2=0 : H=0
2570  GOTO 1000
REM
```

APPENDIX H

TRACER BALLOON: ARGOS DATA FRAME ASSIGNMENT

A typical data frame transmitted by the Tracer balloon might be:

F64CBA 0D B6 20 56 0B 58 01 92 1B F9 01 8B 03 48 00 0B
01 FF 20 5E 01 1C 00 01 00 00 00 00 00 00 00 00

These data, excepting the identification number, are hexadecimal-encoded sensor data.

Data word no.	Value in example	Assignment
1	F64CBA	Identification number
2,3	0D,B6	Elapsed time since launch (sec.)
4,5	20,56	Pressure (mb*10)
6,7	0B,58	Air temp. (deg. Kelvin*10)
8,9	01,92	Humidity (sensor resistance, ohms*10)
10,11	1B,F9	Potential temp. (deg. Kelvin*10)
12,13	01,8B	Strain (ohms/100))
14,15	03,48	Vertical anemom. (revolutions*50)
16,17	00,0B	Count of pump cycles
18,19	01,FF	Count of valve cycles
20,21	20,5E	Current control value
22,23	01,1C	Control code
24,25	00,01	Last command code
26 to 33	All 00	Not assigned

Control Codes:
1= Pressure
2= Potential temp.
3= Vertical anem. count
4= Pump only

Last Command Codes:
128= Control on pressure
64= Control on potential temp
32= Control on vert. anem. count
16= Increment current parameter
8= Decrement current parameter
4= Pump only
2= Reset cutdown timer
1= Cut down command

APPENDIX I

Determination of Balloon Volume vs Superpressure

The volume of the balloon as a function of superpressure was determined using a digital scale, a manometer, a thermometer, and a barometer. The digital scale used here had a 20 kg capacity, and 1 g resolution. The wall-mounted manometer was made from tygon-tubing and a metre stick. The manometer fluid was ethylene glycol (antifreeze). The superpressure measurements were adjusted for the density of the ethylene glycol. All measurements were made in quiescent air so that stable readings could be obtained on the scale.

First, the balloon itself (empty) and the attachments which were to be in place during the test were weighed, and the weight recorded. Next, a weight of magnitude greater than the buoyant force the balloon could generate when filled with helium was placed on the scale. In this case, a concrete block was used. Its weight was recorded.

Next, the balloon was attached to the weight on the scale, and the ballonet was partially filled with helium until the measured lift L_s was approximately equal to the "required lift" L_R (Equation B-13).

L_s is given by

$$L_s = (m_w + m_b - m_s)g \qquad \text{(I-1)}$$

Here m_w = mass of weight (kg), m_b = mass of balloon (kg), and m_s = scale reading (kg). At this point, the lift is given by Equation D-8.

$$L_s = (1 - M_{He}/M)n_{He}\,Mg = 0.862\, n_{He}\, Mg \qquad \text{(I-2)}$$

This expression assumes that the gas in the balloon is in thermal equilibrium with its surroundings, and that the balloon is slack.

The gross lift depends only on how much helium is in the balloon, independent of how much air is also present. Since L_s is effectively measured by the scale, this equation allows n_{He} to be measured. Throughout all subsequent measurements, n_{He} remains fixed.

Next, the manometer was attached to the outer balloon, and an auxiliary pump used to inflate the outer balloon with air.

No significant change in scale reading occurred until the superpressure became non-zero. Then the reading on the manometer (which reads superpressure) and the reading on the scale both began to rise. Periodically, the scale reading, the superpressure, the ambient pressure, and the ambient temperature were all recorded. This data allowed the volume of the balloon to be determined as a function of superpressure.

The derivation of the relationship is as follows:

The lift is given by

$$L = (\rho_a - \rho_b)Vg \qquad (I\text{-}3)$$

where ρ_a, the density of the displaced ambient air can be calculated from the gas law and the measured values of ambient pressure ρ_a and temperature T:

$$\rho_a = MP_a/(RT) \qquad (I\text{-}4)$$

ρ_b, the density of the gas in the balloon is given by the mass of that gas divided by the volume.

$$\rho_b = (n_{He}\ M_{He} + n_A\ M)/V \qquad (I\text{-}5)$$

where n_A = number of kilogram moles of air in the balloon. Expanding, we find

$$n_A = P_aV/(RT) - L/(Mg) - n_{He}\ M_{He}/M \qquad (I\text{-}6)$$

Next, note that the superpressure is given by

$$P_s = P_b - P_a \qquad (I\text{-}7)$$

$$P_s = (n_{He} + n_A)RT/V - P_a \qquad (I\text{-}8)$$

P_s is measured by the manometer, T by the thermometer, P_a by the barometer, and n_{He} can be determined from Equation 1-2. The unknowns are n_A and V. The expression given in Equation I-6 for n_A may be substituted, leaving an equation in one unknown, the volume V.

$$V = (n_{He}\ (1 - M_{He}/M) - L/(Mg))\ RT/P_s \qquad (I\text{-}9)$$

Using Equation I-2, this can be rewritten as

$$V = (L_s/g - L/g)\ RT/(MP_s) \qquad \text{(I-10)}$$

The term $(L_s/g - L/g)$ is just the difference in the scale readings at zero superpressure, and at superpressure P_s. As can be seen from Equation I-1, the masses of the weight and of the balloon drop out.

Note that the accuracy of balloon volume determinations made using this expression is limited by the accuracy with which the manometer and the scale can be read. Air currents acting on the balloon are the major cause of error in the scale measurements. Hence, the need for quiescent air.

APPENDIX J

Test Description Provided to the FAA

Description of Balloon Tests Planned for Area East of Belen Submitted to the Federal Aviation Administration

B. D. Zak
Sandia National Laboratories
November, 1985

Introduction

The U. S. Environmental Protection Agency has commissioned the Applied Atmospheric Research Division of Sandia National Laboratories to develop an Adjustable Buoyancy Balloon Tracer of Atmospheric Motion. This Balloon Tracer (BT) is a successor to the passive constant volume balloons (tetroons) that have been used for decades to follow atmospheric flows. Whereas constant volume balloons seek a pre-determined density altitude independent of the motions of the air in which they are embedded, the new balloon tracer is programmed to sense and follow the air motion.

The principal purpose for which the Environmental Protection Agency is developing the tracer is to carry out a series of experiments to validate the computer models which have been written to simulate the atmospheric chemistry and transport leading to acid rain. However, such a tracer has been sought by the atmospheric research community at least since the late 1950s. Hence, the BT is expected to have many other research applications.

Balloon Tracer Description

The Environmental Protection Agency has provided a list of specifications which the balloon tracer system is to meet. For the present purpose, the most important spec is that the BT meet the exemption conditions specified in Federal Aviation Regulations, Part 101.1 (a) (4):

101.1 Applicability

(a) This Part prescribes rules governing the operation, in the United States, of the following:

(4) Except as provided for in #101.7 of this Part, any unmanned free balloon that-

(i) Carries a payload package that weighs more than four pounds and has a weight/size ratio of more than three ounces per square inch on any surface of the package, determined by dividing the total weight of the payload package by the area in square inches of its smallest surface;

(ii) Carries a payload package that weighs more than 6 pounds;

(iii) Carries a payload of two or more packages, that weighs more than 12 pounds; or

(iv) Uses a rope or other device for suspension of the payload that requires an impact force of more than 50 pounds to separate the suspended payload from the balloon.

To meet the exemption conditions, the BT has been designed and built so that payload packages have a weight/size ratio of less than three ounces/square inch on the smallest surface; so that no payload package weighs more than 6 pounds; so that the total payload weighs less than 12 pounds; and so that an impact force of less than 50 pounds is required to separate the suspended payload from the balloon.

These are the same conditions met by radiosonde balloons, the so called "weather balloons" launched twice a day by the National Weather Service from over a hundred sites within the U.S., mostly airports, to provide routine soundings of upper air winds and thermal structure for forecasting purposes.

Thus, the restrictions specified by Part 101 on the operations of unmanned free balloons do not apply to the BT, with the exception of #101.7 which reads:

101.7 Hazardous Operations

(a) No person may operate any moored balloon, kite, unmanned rocket, or unmanned free balloon in a manner that creates a hazard to other persons, or their property.

(b) No person operating any moored balloon, kite, unmanned rocket, or unmanned free balloon may allow an object to be dropped therefrom, if such action creates a hazard to other persons or their property.

No provision exists to drop any object from the BT, and Sandia National Laboratories has every intent to operate the BT in such a manner that it does not create a hazard to other persons or their property.

Pursuant to the intent on the part of Sandia to avoid creating any hazard, even though the BT is formally exempt from the other conditions of FAR 101 for unmanned free balloons, those conditions have been taken as a guide for the design of the tracer. Thus, the BT is equipped with two totally independent cutdown systems which operate to terminate the flight of both the balloon and its payload. One of the cutdown systems provides for flight termination either by radio command, or by an onboard timer. The timer is set for two hours or less, depending upon the nature of the experiment to be undertaken. The timer will terminate the flight at the end of the specified period unless a radio command is received in the interim to reset the timer. Thus, for sustained flight, the BT must remain in radio contact with the ground command station, and periodically receive a timer reset command. For flights above 1000 ft AGL, the BT will be equipped both with a broadband radar reflective device, and with an FAA transponder with an encoding altimeter. The transponder will permit the FAA to identify the BT, and to track its position and altitude on all FAA radars. The inclusion of an FAA transponder goes beyond the requirements of FAR 101 even for unmanned free balloons not meeting the exemption conditions. The payload of the BT consists of electronics and other components packaged in styrofoam, and covered with brightly-colored (orange and yellow) plastic film of the type used to cover model airplanes. As a result, the payload is highly visible. Should operations be undertaken which involve flight between sunset and sunrise, the BT will be equipped with a strobe light.

The balloon itself is a sphere made of .003" thickness polycarbonate film approximately 9 feet in diameter. It contains an inner sack or "ballonet" which is made of .001" polyethylene film. The inner ballonet contains the lift gas, which is helium. Between the inner and the outer balloon, the ballast gas, air, is maintained under slight pressure. The amount of air which is onboard controls the buoyancy of the balloon, and hence its float altitude. Air is taken on or released as needed by miniature pumps and valves.

The payload consists of a number of packages containing sensors, electronics, and other components connected to the balloon by low breaking strength fishing line, fine wires, and a "layflat" polyethylene film fill line to take on or release air. The components of the connections between the balloon and the payload, and between payload packages have been laboratory tested to assure that a force of less than 50 pounds would part the balloon from the payload, and would part payload packages from each other. The payload packages are suspended a maximum of 15 feet below the balloon. Immediately below the balloon, two sensors are deployed a foot and a half beyond the balloon diameter on either side to assure that they are not significantly influenced by the flow field near the balloon itself. These sensors are mounted at opposite ends of a styrofoam arm. A schematic diagram of the balloon and its payload is attached.

The payload continuously transmits meteorological data via radio telemetry. The signal may be monitored directly if a receiver is within radio range of the BT, or the data may be acquired through the ARGOS satellite-based data collection and platform location system. Visual, radio, radar, and satellite methods provide for tracking. For extended experiments, the ARGOS satellite system will provide the principal tracking information. ARGOS has global tracking capability.

Experimental Site

The experimental site chosen for initial flight testing of the tracer is a large open area to the east of Belen known as the Rio Communities. Some years ago, a number of developers subdivided this land, put in rudimentary roads, and offered it for sale. With the exception of a few small communities along the periphery, this land is vacant. It forms an area of roughly 350 square miles from the southern boundary of Isleta Pueblo on the north, to U.S. Highway 60 on the south, and from State Highway 47 on the west to the boundary of Cibola National Forrest on the east. The Applied Atmospheric Research Division of Sandia has obtained the permission of the Valley Improvement Association, which represents the Rio Communities landowners, and that of the Tierra Grande development, to use the land in this area for testing the balloon tracer.

Test Program

Typically, launch will be from a site approximately one mile north of State Highway 6, in the Tierra Grande subdivision, from land owned by Mr. and Mrs. S. Longo, who have graciously given permission for use of their land. This site is located at Lat. $34^{0}33'$, Long. $106^{0}37'$, just east of an FAA microwave relay tower.

Initially, the test program will consist of a large number of short flights at less than 1000 ft altitude AGL. The flights will be terminated within the area described above. Subsequently, flights to higher altitude will be undertaken. Because the BT falls under the exemption clauses of FAR 101, no FAA notification of launch is formally required. However, notification will be made of the Albuquerque Approach Control at:

FAA
Albuquerque Control Tower
243-3785

as requested by the FAA. Notification will be made the day before, as well as immediately prior to balloon operations. Notification will also be given upon completion of airborne operations for the day.

The flight test program is expected to begin on or about December 1, 1985, and be completed by December 31.

Points of Contact

Questions regarding the tracer flight tests should be addressed to:

Bernard Zak, Supervisor
Applied Atmospheric Research
Division 6324
Sandia National Laboratories
P.O. Box 5800
Albuquerque, NM 87185
Office (505) 844-7328
Message 844-4363
Home 281-2664

Alternate contacts are:

Ernie Lichfield
Office 265-8544
Home 298-6649

Hugh Church
Office 844-9123
Home 299-2175

During the business day, when flight testing is taking place, a radio message can be passed to the test crew in the Belen area by phoning (505) 844-1011 and asking that Lichfield or Zak be paged by radio.

APPENDIX K

LAUNCH PROCEDURE AND CHECKLIST

LAUNCH PROCEDURE

-Designate Launchmeister
-Designate checklistmeister
-Call 1550th (TMC 844-2961)
-Call FAA
    If above 1000 feet AGL, Control Tower (243-3785)
    If above 3000 feet AGL, Control Tower and ARTCC (821-3802)
-Synchronize watches
-Set up ground station
    Argos
    Command
    ADAS
-Enter barometer pressure plus monometer superpressure as initial pressure on ADAS for airsonde inside balloon
-Check out radios and leave on
-Put up tethered balloon for wind-finding
-Check out chase vehicle contents
-Weigh off balloon
-Lay out payload train
-Attach ribbon to timer cutdown
-Rotate balloon and turn top package on
-Tie back doors
-At direction of Launchmeister, move balloon out from shelter
-Implement 3 point tether on back of truck bed
-Hook up payload
    attach cross-arm
    connect Argos antenna
    connect cutdown wires
    connect layflat
    check for tangles and strain relief
-Connect airsonde battery

- Turn on main package
- Spin up anemometer to mid-range
- Attach anemometer propeller
- Activate timer cutdown and remove ribbon
- Payload checkout
    - ARGOS telemetry
    - Airsonde telemetry via ADAS
    - Verify anemometer spin-up
    - Verify cutdown timer reset
    - Aspirator function
- Log surface pressure from barometer and telemetry
- Set to pressure mode
- "Memorize" pressure
- DECISION POINT: determine point from which to launch
- Man all lines--one person each on handling lines; one person on payload
- Take balloon off three point tether
- Let balloon up to suspend payload
- Recheck TM
- Begin sequence to decrement pressure 10 mb
- Confirm decrement from TM
- Release lines at direction of Launchmeister

CHASE VEHICLE CONTENTS

- -Full gas tank
- -Briefcase with:
  - Logbook
  - Maps
  - Procedures
- -Two way radio
  - Antenna on roof of vehicle
- -RC cutdown transmitter
  - Spare batteries
- -100 pound test cord
- -Tool kit
- -Bubble poly
- -Tarp for deflation
- -Compass
- -Binoculars
- -Theodolite w/tripod
- -Inflated pibal

RECOVERY PROCEDURE

-Cutdown followed by "Pumps on" command

-Snare handling lines to catch balloon

-Lay battery pack and main payload on ground, leaving arm aloft

-After few data frames confirmed from ground, turn off package

-Lay out tarps

-Allow balloon to deflate on tarps

-Turn top package off

-Wrap balloon in tarps

-Stow balloon and payload in pickup

-Set up theodolite and determine position of landing

-Return to launch point

-Confirm completion of flight to 1550th and FAA

APPENDIX L

DATA FROM TEST FLIGHTS

Notes

The data column headers have the following meanings:

a. "HP TIME" refers to the HP-85 real time clock value at the time the data frame (line of data) was received by the Ground Support System.

b. "ONBOARD TIMER" is a cumulative timer from the balloon payload computer (8052AH BASIC). The values given correspond to the number of seconds since last power-on reset.

c. "PRESSURE" is the ambient pressure in millibars measured by the sensor package.

d. "AIR TEMP" and "POT TEMP" are the ambient and potential temperatures in degrees Celsius as measured and calculated by the payload.

e. "HUMIDITY" is the humidity sensor output in ohms times 10.

f. "STRAIN" is the strain sensor output in kohms/10.

g. "VERT ANM" is a cumulative up/down count of the number of revolutions of the vertical anemometer propeller. Overflow occurs at 1310.7. Graphed data has been adjusted to take overflow/underflow into account.

h. "PUMP" and "VALVE" are running counts of the pump-on and valve-on periods, respectively The length of each pump/valve cycle is equal to the time interval between data frames -- 42 s.

i. "CTRL VAL" is the current control value times 10 for pressure and potential temperature, and control value times 50 for relative vertical motion. "CTRL CODE", the control code, designates which one of the three possible control parameters is selected. Control code and last command code assignments are given in Appendix H.

2. The "Airsonde Data" column headers have the following meanings:

a. "ADAS TIME" is the time from the clock internal to the AIR Atmospheric Data Acquisition System and corresponds to the time at which that data frame (line of data) was received (hours minutes seconds).

b. "TEMP" and "PRESSURE" are the temperature and pressure measured by the AIR Airsonde device inside the Tracer balloon, given in degrees Celsius and millibars.

3. A constant bias of 38.0 millibars was added to the Airsonde data from Flight #2 so that the difference between the pressure measured inside the balloon and that measured outside the balloon by the payload would be 28.8 mb, the superpressure measured by the manometer prior to flight. The Airsonde pressure data reported by the ADAS depends upon a value entered into the device during setup. The discrepancy indicates that the initial value entered was in error.

4. A constant bias of 0.6 millibar was subtracted from the Airsonde data from Flight #3 so that the superpressure as measured by the difference between ADAS and payload data would be zero at the end of the flight after the cutdown device had fired.

DATA FROM FLIGHT #1, DECEMBER 5,1985

HP TIME	ONBOARD TIMER	PRESSURE	AIR TEMP	HUMIDTY	POT TEMP	STRAIN	VERT ANM	PUMP	VALVE	CTRL VAL	CTRL CODE	LAST CMND
11:16:54	3.00	849.80	11.40	1.72	25.00	0.79	1310.44	0	1	8400	1	0
11:17:26	24.00	849.10	6.60	1.83	20.90	0.79	1300.32	0	2	8400	1	0
11:17:57	67.00	849.20	4.60	2.17	18.90	0.75	1276.26	0	3	8400	1	0
11:18:51	108.00	849.10	6.30	1.42	20.60	0.78	1264.42	0	3	8492	1	128
11:19:25	150.00	849.00	5.10	1.43	19.30	0.76	1263.82	0	3	8492	1	0
11:20:10	191.00	849.60	5.90	1.51	20.10	0.75	1264.52	0	4	8492	1	0
11:20:45	234.00	849.60	5.30	1.46	19.50	0.74	1273.98	0	5	8492	1	0
11:21:39	275.00	849.50	5.00	1.54	19.20	0.74	1280.10	0	5	8496	1	128
11:22:12	318.00	849.60	4.80	1.56	19.00	0.73	1283.52	0	5	8496	1	0
11:23:00	361.00	849.50	5.60	1.58	19.90	0.73	1284.22	0	5	8496	1	0
11:23:32	402.00	849.50	6.20	1.54	20.50	0.73	1283.10	0	5	8496	1	0
11:24:24	444.00	849.50	4.20	1.58	18.40	0.74	1275.62	0	5	8496	1	0
11:24:56	485.00	849.50	5.50	1.62	19.70	0.74	1269.78	0	5	8496	1	0
11:25:47	528.00	849.50	7.00	1.51	21.30	0.74	1267.78	0	5	8496	1	0
11:26:20	569.00	849.50	6.20	1.42	20.50	0.74	1275.58	0	5	8496	1	0
11:27:11	612.00	849.50	6.20	2.17	20.50	0.74	1276.02	0	5	8496	1	0
11:27:45	655.00	849.50	7.10	2.19	21.50	0.74	1283.32	0	5	8496	1	0
11:28:35	696.00	849.50	7.20	2.19	21.60	0.75	1287.06	0	5	8496	1	0
11:29:09	739.00	849.70	6.20	2.15	20.50	0.75	1291.38	0	5	8496	1	0
11:29:59	780.00	849.60	6.90	2.20	21.20	0.75	1299.24	0	5	8496	1	0
11:30:33	822.00	849.60	7.50	2.11	21.80	0.75	1309.54	0	5	8496	1	0
11:31:22	863.00	849.40	4.80	2.24	19.10	0.75	1291.98	0	5	8496	1	0
11:31:56	906.00	849.30	4.60	1.55	18.80	0.75	1273.52	1	5	8496	1	0
11:32:46	947.00	849.00	5.20	1.58	19.40	0.75	1256.24	2	5	8496	1	0
11:33:24	990.00	849.10	5.50	1.56	19.80	0.75	1253.48	3	5	8496	1	2
11:34:16	1033.00	849.20	5.60	1.50	19.90	0.76	1243.74	4	5	8496	1	0
11:34:44	1074.00	849.00	5.60	1.53	19.90	0.75	1254.64	5	5	8496	1	0
11:35:40	1116.00	849.10	6.70	2.27	21.00	0.77	1255.08	6	5	8496	1	2
11:36:11	1157.00	849.00	5.00	2.39	19.30	0.74	1251.62	7	5	8496	1	0
11:37:03	1200.00	848.90	6.30	2.18	20.70	0.79	1264.84	7	6	8476	1	8
11:37:35	1241.00	849.00	5.80	2.25	20.10	0.79	1270.16	7	7	8476	1	0
11:38:27	1284.00	848.80	6.30	1.44	20.60	0.78	1235.10	7	8	8466	1	8
11:38:59	1325.00	848.80	4.50	2.42	18.80	0.73	1265.32	7	9	8466	1	2
11:39:47	1368.00	848.90	6.70	2.19	21.00	0.76	1277.24	7	10	8466	1	2
11:40:25	1411.00	848.90	7.70	2.14	22.10	0.75	1278.66	7	11	8456	1	8
11:41:14	1451.00	848.70	6.50	2.17	20.90	0.74	1269.32	7	12	8456	1	0
11:41:44	1494.00	848.80	4.60	2.41	18.90	0.71	1281.68	7	13	8456	1	0
11:43:17	1578.00	848.60	5.10	1.51	19.40	0.72	1246.48	7	15	8446	1	0
11:43:49	1619.00	844.40	5.10	1.46	19.80	0.72	1040.40	7	15	8446	1	0
11:44:45	1662.00	840.40	4.80	1.51	20.00	0.74	833.60	8	15	8436	1	2
11:45:18	1705.00	836.30	4.30	1.54	19.90	0.77	649.06	9	15	8436	1	0
11:46:04	1746.00	831.70	4.10	1.59	20.20	0.80	516.78	10	15	8436	1	0
11:46:38	1788.00	827.70	3.60	1.61	20.00	0.83	339.98	11	15	8436	1	0
11:48:15	1872.00	821.60	3.70	1.60	20.90	0.87	164.82	13	15	8436	1	2
11:48:48	1915.00	820.90	2.10	1.66	19.20	0.88	142.10	14	15	8436	1	0
11:49:34	1956.00	820.00	2.10	1.78	19.30	0.88	151.88	15	15	8436	1	0
11:50:08	1999.00	820.40	1.90	1.92	19.10	0.89	172.20	16	15	8436	1	0
11:50:58	2039.00	821.50	2.20	1.95	19.20	0.89	203.14	17	15	8436	1	0
11:51:32	2082.00	824.00	2.40	1.80	19.20	0.89	224.74	18	15	8436	1	0
11:52:22	2123.00	826.70	2.80	1.74	19.30	0.88	228.02	19	15	8436	1	0
11:52:56	2166.00	828.50	4.20	1.61	20.60	0.88	239.08	20	15	8436	1	0
11:53:50	2207.00	829.30	6.20	2.14	22.70	0.87	228.48	21	15	8436	1	2
11:54:23	2250.00	830.40	4.90	2.04	21.10	0.87	207.40	22	15	8436	1	0
11:55:11	2292.00	829.50	4.50	2.05	20.80	0.87	181.34	23	15	8436	1	0
11:55:43	2333.00	829.20	4.60	2.04	20.90	0.88	170.50	24	15	8436	1	0

11:56:39	2376.00	828.30	3.50	2.23	19.90	0.88	193.84	25	15	8436	1	2
11:57:11	2417.00	829.60	3.40	1.48	19.60	0.88	239.72	26	15	8436	1	0
11:57:58	2460.00	832.40	3.60	1.53	19.50	0.88	271.84	27	15	8436	1	0
11:58:32	2503.00	834.80	4.10	1.49	19.80	0.88	323.24	28	15	8436	1	0
11:59:26	2544.00	835.80	4.30	1.49	19.90	0.88	368.66	29	15	8436	1	2
12:00:00	2586.00	836.90	4.50	1.46	20.00	0.88	432.52	30	15	8436	1	0
12:00:45	2627.00	835.60	4.80	1.44	20.50	0.88	435.06	31	15	8436	1	0
12:01:20	2670.00	833.20	3.90	1.48	19.80	0.89	446.48	32	15	8436	1	0
12:02:09	2711.00	834.90	4.20	1.46	19.90	0.89	484.96	33	15	8436	1	0
12:02:47	2754.00	838.10	4.80	1.48	20.20	0.88	508.14	34	15	8436	1	2
12:03:39	2797.00	842.30	4.90	1.48	19.90	0.86	548.54	35	15	8436	1	0
12:04:07	2838.00	845.10	5.90	2.25	20.60	0.83	549.12	35	16	8436	1	0
12:04:58	2881.00	842.00	5.50	2.17	20.50	0.83	525.18	36	16	8436	1	0
12:05:35	2921.00	837.50	4.90	2.24	20.40	0.85	560.96	37	16	8426	1	8
12:06:26	2964.00	838.20	4.80	1.42	20.20	0.86	573.74	38	16	8426	1	0
12:06:55	3005.00	840.80	5.00	1.43	20.20	0.86	694.48	39	16	8426	1	0
12:07:46	3048.00	841.20	4.90	1.43	20.00	0.86	717.64	40	16	8426	1	0
12:08:20	3091.00	842.50	5.20	2.30	20.10	0.85	731.80	40	16	8426	1	0
12:09:10	3132.00	844.40	5.50	2.29	20.30	0.83	788.20	40	17	8426	1	0
12:09:44	3175.00	846.30	6.20	2.26	20.80	0.81	843.62	40	18	8426	1	0
12:10:33	3216.00	844.60	6.20	2.17	21.00	0.81	863.44	40	19	8426	1	0
12:11:08	3258.00	841.70	5.70	2.12	20.80	0.81	884.86	41	19	8426	1	0
12:12:02	3299.00	837.00	5.60	2.15	21.10	0.84	917.66	42	19	8426	1	2
12:12:35	3342.00	834.60	5.00	2.24	20.80	0.87	1030.20	43	19	8426	1	0
12:13:21	3383.00	835.60	4.90	2.27	20.60	0.88	1154.24	44	19	8426	1	0
12:13:59	3426.00	837.10	5.00	2.28	20.50	0.88	1239.32	44	20	8356	1	128
12:14:50	3469.00	839.50	5.60	2.25	20.90	0.87	49.50	44	21	8356	1	0
12:15:19	3510.00	838.30	5.50	2.23	20.90	0.86	146.90	44	22	8356	1	0
12:16:10	3552.00	834.50	5.70	2.21	21.60	0.87	162.36	45	22	8356	1	0
12:16:42	3593.00	837.00	5.10	2.26	20.60	0.87	204.42	45	23	8356	1	0
12:17:34	3636.00	842.00	5.60	2.27	20.70	0.83	287.24	45	24	8356	1	0
12:18:06	3677.00	841.00	7.10	2.13	22.30	0.82	296.00	45	25	8356	1	0
12:18:57	3720.00	835.80	6.20	2.13	21.90	0.84	291.72	45	25	8356	1	0
12:19:32	3763.00	834.60	5.10	2.23	20.90	0.84	363.80	46	25	8356	1	0
12:20:21	3804.00	836.50	5.10	2.26	20.70	0.85	433.64	46	26	8356	1	0
12:20:55	3846.00	839.80	5.50	2.26	20.80	0.83	462.04	46	27	8356	1	0
12:21:45	3887.00	841.70	6.70	2.16	21.80	0.81	459.48	46	28	8356	1	0
12:22:19	3930.00	842.30	8.80	1.99	24.00	0.79	389.26	46	29	8356	1	0
12:23:09	3971.00	843.80	7.70	1.96	22.60	0.78	283.02	46	30	8356	1	0
12:23:43	4014.00	843.30	8.20	1.95	23.20	0.77	171.18	46	31	8356	1	0
12:24:34	4057.00	841.90	7.80	1.97	22.90	0.77	90.70	46	32	8356	1	0
12:25:07	4098.00	840.50	7.70	1.98	23.00	0.77	4.34	46	33	8356	1	0
12:25:58	4141.00	835.40	7.30	1.99	23.20	0.79	1227.66	46	33	8356	1	0
12:26:30	4181.00	828.30	5.60	2.00	22.10	0.83	1180.24	47	33	8356	1	0
12:27:26	4224.00	825.50	4.40	2.15	21.20	0.86	1168.40	48	33	8356	1	2
12:27:58	4265.00	826.10	4.50	2.29	21.10	0.85	1239.70	49	33	8356	1	0
12:28:45	4308.00	826.70	4.80	1.46	21.40	0.87	1297.62	50	33	8356	1	0
12:29:19	4351.00	828.20	4.80	1.46	21.30	0.86	66.04	51	33	8356	1	0
12:30:09	4392.00	829.70	4.80	1.46	21.20	0.86	148.88	52	33	8356	1	0
12:30:47	4434.00	834.40	6.50	2.22	22.40	0.86	179.36	53	33	8356	1	2
12:31:33	4475.00	838.80	6.60	2.13	22.10	0.83	189.92	53	34	8356	1	2
12:32:11	4518.00	839.00	7.70	1.99	23.20	0.83	151.16	53	35	8356	1	0
12:32:56	4559.00	837.20	7.70	1.94	23.40	0.83	74.74	53	36	8356	1	0
12:33:31	4602.00	834.50	7.70	1.98	23.60	0.83	1285.40	54	36	8356	1	0
12:34:22	4645.00	837.10	6.40	2.04	22.00	0.83	1250.52	54	37	8356	1	0
12:34:58	4686.00	836.80	8.40	1.96	24.20	0.83	1176.04	54	38	8356	1	2
12:35:50	4728.00	836.50	7.30	1.90	23.00	0.82	1130.16	54	39	8356	1	0
12:36:18	4769.00	832.30	8.10	1.94	24.30	0.82	1119.90	55	39	8356	1	0
12:37:09	4812.00	830.90	6.60	1.95	22.80	0.83	1097.70	56	39	8356	1	0
12:37:42	4853.00	829.30	5.90	2.02	22.30	0.85	1091.62	57	39	8356	1	0

12:38:33	4896.00	828.40	5.70	2.09	22.20	0.85	1116.74	58	39	8356	1	0
12:39:07	4939.00	826.50	5.50	2.09	22.10	0.88	1134.64	59	39	8356	1	0
12:40:40	5022.00	829.10	5.70	2.14	22.10	0.88	11.28	61	39	8356	1	0
12:41:12	5063.00	831.00	6.30	2.11	22.50	0.88	81.26	62	39	8356	1	0
12:42:03	5106.00	831.80	6.20	2.11	22.30	0.88	117.12	63	39	8356	1	0
12:42:36	5147.00	833.70	6.40	2.10	22.30	0.88	170.90	64	39	8356	1	0
12:43:27	5190.00	834.60	6.60	2.07	22.50	0.88	189.00	65	39	8356	1	0
12:44:01	5233.00	836.40	6.90	2.03	22.60	0.88	205.80	65	40	8356	1	0
12:44:51	5274.00	838.40	7.00	2.02	22.50	0.85	206.72	65	41	8356	1	0
12:45:25	5316.00	840.00	8.90	1.90	24.40	0.82	208.96	65	42	8356	1	0
12:46:15	5357.00	842.40	11.30	1.74	25.60	0.81	155.44	65	43	8356	1	0
12:46:48	5400.00	842.60	11.50	1.65	25.80	0.79	52.96	65	44	8356	1	0
12:47:38	5441.00	841.40	10.40	1.65	24.70	0.79	1246.04	65	45	8356	1	0
12:48:12	5484.00	840.10	9.80	1.69	24.20	0.79	1174.90	65	46	8356	1	0
12:49:04	5527.00	839.00	9.80	1.70	24.40	0.78	1104.00	65	47	8356	1	0
12:49:36	5568.00	836.50	8.80	1.75	24.60	0.78	1050.18	65	48	8356	1	0
12:50:28	5610.00	832.20	8.50	1.75	24.70	0.79	1016.30	66	48	8356	1	0
12:51:00	5651.00	826.90	6.40	1.91	23.10	0.83	1032.68	67	48	8356	1	0
12:51:51	5694.00	824.10	5.80	2.01	22.80	0.86	1097.12	68	48	8356	1	0
12:52:23	5735.00	824.60	5.80	2.08	22.70	0.86	1222.20	69	48	8356	1	0
12:53:15	5778.00	823.90	6.20	2.13	23.20	0.87	54.34	70	48	8356	1	0
12:53:49	5821.00	818.90	6.00	2.10	23.50	0.90	219.84	71	48	8356	1	0
12:54:39	5862.00	813.70	4.90	2.13	22.90	0.93	299.74	72	48	8356	1	0
12:55:12	5904.00	813.50	4.80	2.17	22.90	0.94	482.88	73	48	8356	1	0
12:56:02	5945.00	815.40	4.80	2.23	22.70	0.94	686.30	74	48	8356	1	0
12:56:36	5988.00	818.30	5.20	2.20	22.80	0.92	864.50	75	48	8356	1	0
12:57:26	6029.00	825.70	6.00	2.15	22.80	0.89	1032.80	76	48	8356	1	0
12:58:00	6072.00	832.20	7.10	2.06	23.20	0.86	1192.10	77	48	8356	1	0
12:58:51	6115.00	836.80	8.00	1.97	23.70	0.83	1305.64	77	49	8356	1	0
12:59:23	6156.00	840.90	8.50	1.90	23.80	0.80	67.00	77	50	8356	1	0
13:00:15	6198.00	844.60	9.80	1.82	23.80	0.77	69.92	77	51	8356	1	0
13:00:47	6239.00	844.40	10.30	1.73	24.40	0.76	28.92	77	52	8356	1	0
13:01:39	6282.00	841.50	10.80	1.67	25.20	0.76	1267.68	77	53	8356	1	0
13:02:11	6323.00	837.10	9.60	1.71	25.30	0.77	1195.38	77	54	8356	1	0
13:03:03	6366.00	833.60	8.40	1.78	24.50	0.79	1153.36	78	54	8356	1	0
13:03:36	6409.00	833.70	7.70	1.84	23.80	0.79	1167.64	79	54	8356	1	0
13:04:26	6450.00	836.50	8.10	1.84	23.90	0.79	1175.26	79	55	8356	1	0
13:05:00	6492.00	835.90	9.90	1.80	24.70	0.79	1166.14	79	56	8356	1	0
13:07:47	6660.00	837.50	10.80	1.69	25.60	0.74	1006.34	79	60	8356	1	0
13:08:39	6703.00	838.30	10.80	1.67	25.50	0.74	951.46	79	61	8356	1	0
13:09:11	6744.00	838.40	10.80	1.66	25.50	0.73	838.96	79	62	8356	1	0
13:10:03	6786.00	838.90	10.10	1.69	24.70	0.72	701.22	79	63	8356	1	0
13:10:35	6827.00	838.30	10.30	1.69	25.00	0.71	574.96	79	64	8356	1	0
13:11:27	6870.00	835.70	9.60	1.71	25.50	0.71	442.20	79	64	8356	1	0
13:11:59	6911.00	830.80	9.30	1.74	25.70	0.74	328.70	80	64	8356	1	0
13:12:50	6954.00	828.80	7.80	1.80	24.40	0.75	246.58	81	64	8356	1	0
13:13:24	6997.00	829.30	8.40	1.83	25.00	0.75	198.56	82	64	8356	1	0
13:14:14	7038.00	830.60	9.20	1.80	25.70	0.75	171.48	83	64	8356	1	0
13:14:48	7080.00	829.30	9.70	1.76	26.30	0.76	139.66	84	64	8356	1	0
13:15:38	7121.00	828.50	9.60	1.74	26.30	0.78	74.06	85	64	8356	1	0
13:16:12	7164.00	830.70	9.40	1.74	25.90	0.78	58.30	86	64	8356	1	0
13:17:01	7205.00	834.90	8.60	1.76	24.60	0.76	44.86	87	64	8356	1	0
13:17:35	7248.00	838.20	10.00	1.73	24.70	0.76	16.76	87	65	8356	1	0
13:18:27	7291.00	839.20	10.60	1.70	25.20	0.74	1259.42	87	66	8356	1	0
13:18:59	7332.00	838.70	10.90	1.66	25.60	0.74	1166.72	87	67	8356	1	0
13:19:51	7374.00	834.60	10.80	1.65	25.90	0.74	1075.92	88	67	8356	1	0
13:20:23	7415.00	832.10	9.80	1.67	25.10	0.75	1009.44	89	67	8356	1	0
13:21:14	7458.00	831.90	10.30	1.67	25.60	0.76	961.66	90	67	8356	1	0
13:21:46	7499.00	834.50	10.30	1.66	25.40	0.76	926.16	91	67	8356	1	0
13:22:38	7542.00	838.20	10.30	1.66	24.90	0.74	873.84	91	68	8356	1	0

13:23:12	7585.00	839.70	11.00	1.65	25.50	0.72	786.00	91	69	8356	1	0
13:24:02	7626.00	839.60	10.80	1.64	25.40	0.71	679.98	91	70	8356	1	0
13:24:36	7668.00	837.20	10.60	1.66	25.40	0.71	567.96	91	71	8356	1	0
13:25:25	7709.00	835.50	10.30	1.67	25.20	0.71	471.34	91	71	8356	1	0
13:25:59	7752.00	833.10	9.80	1.69	25.00	0.71	388.98	92	71	8356	1	0
13:26:49	7793.00	831.60	9.10	1.74	25.40	0.73	399.62	93	71	8356	1	0
13:27:23	7836.00	827.80	8.40	1.76	25.10	0.75	398.24	94	71	8356	1	0
13:28:15	7879.00	827.70	8.10	1.80	24.80	0.76	427.16	95	71	8356	1	0
13:28:47	7920.00	828.50	8.20	1.83	24.80	0.76	487.00	96	71	8356	1	0
13:29:38	7962.00	831.50	8.50	1.82	24.80	0.75	543.98	97	71	8356	1	0
13:30:10	8003.00	834.00	9.20	1.81	25.20	0.74	622.12	98	71	8356	1	0
13:31:02	8046.00	835.40	9.10	1.78	25.10	0.74	647.02	99	71	8356	1	0
13:31:34	8087.00	836.60	9.40	1.77	25.20	0.74	691.02	99	72	8356	1	0
13:32:26	8130.00	839.00	9.70	1.75	25.20	0.72	697.50	99	73	8356	1	0
13:33:00	8173.00	839.30	10.10	1.73	24.70	0.70	685.34	99	74	8356	1	0
13:33:50	8214.00	839.20	10.30	1.69	24.90	0.69	656.64	99	75	8356	1	0
13:34:23	8256.00	838.20	10.40	1.67	25.00	0.69	591.16	99	76	8356	1	0
13:35:13	8297.00	835.10	10.00	1.69	24.90	0.70	507.94	100	76	8356	1	0
13:35:47	8340.00	832.50	9.40	1.72	25.60	0.72	494.72	101	76	8356	1	0
13:36:37	8381.00	832.70	9.30	1.75	25.60	0.72	540.62	102	76	8356	1	0
13:37:11	8424.00	834.10	9.90	1.75	24.90	0.72	597.38	103	76	8356	1	0
13:38:02	8467.00	835.40	9.90	1.74	24.80	0.72	631.82	103	76	8356	1	0
13:38:35	8508.00	833.40	9.60	1.75	24.80	0.74	651.94	104	76	8356	1	0
13:39:26	8550.00	829.00	9.40	1.75	26.10	0.76	724.72	105	76	8356	1	0
13:39:58	8591.00	826.60	9.20	1.77	26.10	0.79	801.40	106	76	8356	1	0
13:40:50	8634.00	824.30	8.40	1.78	25.50	0.82	865.54	107	76	8356	1	0
13:41:22	8675.00	825.90	8.40	1.80	25.30	0.82	1007.12	108	76	8356	1	0
13:42:14	8718.00	828.70	8.60	1.80	25.30	0.82	1131.74	109	76	8356	1	0
13:42:47	8761.00	830.10	9.20	1.81	25.80	0.81	1275.22	110	76	8356	1	0
13:43:37	8802.00	828.60	9.60	1.79	26.30	0.82	126.76	111	76	8356	1	0
13:44:11	8844.00	825.40	8.80	1.78	25.80	0.84	291.54	112	76	8356	1	0
13:45:01	8885.00	826.50	8.90	1.82	25.80	0.84	460.92	113	76	8356	1	0
13:45:35	8928.00	826.40	8.90	1.80	25.80	0.84	620.56	114	76	8356	1	0
13:46:25	8969.00	829.40	9.20	1.80	25.80	0.84	775.90	115	76	8356	1	0
13:46:59	9012.00	834.00	9.70	1.77	24.70	0.83	899.94	116	76	8356	1	0
13:47:50	9055.00	836.40	10.00	1.74	24.80	0.82	1001.82	116	77	8356	1	0
13:49:18	9138.00	836.70	11.60	1.67	26.50	0.81	1045.92	116	79	8356	1	0
13:49:46	9179.00	836.10	10.80	1.64	25.70	0.81	1076.42	116	80	8356	1	0
13:50:37	9222.00	834.60	10.50	1.67	25.50	0.81	1142.42	117	80	8356	1	0
13:51:10	9263.00	834.40	10.80	1.70	25.90	0.81	1241.98	118	80	8356	1	0
13:52:01	9306.00	833.70	10.60	1.67	25.80	0.82	4.86	119	80	8356	1	0
13:53:16	9390.00	834.50	11.50	1.61	26.60	0.83	109.10	120	80	8356	1	0
13:54:08	9432.00	835.50	11.40	1.64	26.40	0.83	156.58	120	80	8356	0	0
13:54:40	9473.00	834.20	11.30	1.62	26.40	0.84	169.04	121	80	8356	1	0
13:55:31	9516.00	832.00	11.00	1.65	26.30	0.86	258.80	122	80	8356	1	0
13:56:04	9557.00	832.10	11.00	1.64	26.40	0.87	438.02	123	80	8356	1	0
13:56:55	9600.00	830.50	11.00	1.66	26.50	0.88	550.22	124	80	8356	1	0
13:57:29	9643.00	825.30	10.50	1.64	26.50	0.92	636.94	125	80	8356	1	0
13:58:19	9684.00	823.60	9.80	1.69	25.90	0.92	719.30	126	80	8356	1	0
13:58:53	9726.00	828.40	9.80	1.72	25.40	0.92	917.44	127	80	8356	1	0
13:59:43	9767.00	833.30	10.90	1.72	26.10	0.89	1095.08	128	80	8356	1	0
14:00:16	9810.00	834.10	11.40	1.62	26.50	0.89	1147.16	129	80	8356	1	0
14:01:06	9851.00	834.10	11.90	1.66	27.00	0.89	1138.70	130	80	8356	1	0
14:01:40	9894.00	834.20	11.40	1.64	26.50	0.89	1128.60	131	80	8356	1	0
14:02:32	9937.00	834.10	11.30	1.62	26.50	0.89	1115.70	132	80	8356	1	0
14:03:04	9977.00	834.00	11.10	1.67	26.20	0.90	1116.60	133	80	8356	1	0

DATA FROM FLIGHT #2, DECEMBER 16,1985

HP TIME	ONBOARD TIMER	PRESSURE	AIR TEMP	HUMIDTY	POT TEMP	STRAIN	VERT ANM	PUMP	VALVE	CTRL VAL	CTRL CODE	LAST CMND
07:23:26	4.00	864.50	-9.30	88.60	1.90	3.98	0.00	0	1	8400	1	0
07:23:37	24.00	865.10	-9.00	155.20	2.10	3.98	0.00	0	2	8400	1	0
07:24:32	67.00	866.80	-9.00	377.66	2.10	3.98	0.00	0	3	8400	1	0
07:25:05	108.00	868.10	-8.70	367.81	2.20	3.98	0.00	0	4	8668	1	128
07:25:56	151.00	870.60	-8.60	308.46	2.10	3.98	0.00	0	5	8668	1	0
07:26:25	192.00	871.80	-8.50	224.46	2.00	3.98	1012.52	0	6	8668	1	0
07:27:16	235.00	872.70	-8.50	89.38	2.00	3.98	725.34	0	7	8668	1	0
07:27:52	276.00	872.60	-8.50	62.74	2.00	3.98	234.70	0	7	8727	1	128
07:28:44	319.00	872.80	-9.10	636.31	1.30	3.98	229.20	0	7	8727	1	0
07:29:12	360.00	872.90	-9.60	52.34	0.90	3.97	224.60	0	7	8727	1	0
07:30:08	402.00	872.80	-10.30	91.05	0.10	3.98	212.38	0	7	8727	1	2
07:30:40	443.00	872.60	-9.60	532.35	0.90	3.98	203.40	0	7	8727	1	0
07:31:27	486.00	872.70	-9.30	530.19	1.10	3.98	200.04	0	7	8727	1	0
07:32:00	527.00	873.40	-9.20	404.47	1.20	3.98	190.06	0	7	8727	1	0
07:32:52	570.00	873.50	-8.90	319.94	1.50	3.98	177.18	0	7	8727	1	0
07:33:28	611.00	873.60	-8.70	216.17	1.70	3.98	162.86	0	7	8727	1	2
07:34:19	654.00	873.60	-9.20	91.95	1.20	3.98	147.76	0	7	8727	1	0
07:34:49	697.00	873.50	-9.10	149.82	1.30	3.98	135.64	0	7	8727	1	0
07:35:39	738.00	873.50	-9.00	134.07	1.40	3.98	125.30	0	7	8727	1	0
07:36:15	779.00	873.50	-8.30	99.76	2.10	3.98	120.52	0	7	8727	1	2
07:37:07	822.00	873.50	-7.60	550.29	2.80	3.98	116.08	0	7	8727	1	0
07:37:37	865.00	873.60	-7.40	98.78	3.10	3.98	111.26	0	7	8727	1	0
07:38:27	906.00	873.50	-7.70	93.15	2.80	3.98	111.30	0	7	8727	1	0
07:39:01	948.00	871.00	-7.00	96.90	3.70	3.98	34.00	1	7	8727	1	0
07:39:55	989.00	866.30	-5.40	92.78	5.80	3.98	1208.56	2	7	8727	1	2
07:40:28	1032.00	866.20	-5.00	110.78	6.20	3.97	1199.58	3	7	2788	2	64
07:41:19	1073.00	866.80	-5.10	64.01	6.00	3.97	1218.86	4	7	2788	2	0
07:41:48	1116.00	866.50	-5.40	55.23	5.80	3.97	1222.56	4	7	2788	2	0
07:42:43	1157.00	866.50	-5.40	54.39	5.80	3.97	1223.04	4	7	2788	2	2
07:43:16	1200.00	866.60	-5.50	54.00	5.60	3.97	1223.34	4	8	2788	2	0
07:44:04	1243.00	866.80	-5.60	55.62	5.50	3.97	1223.04	4	9	2788	2	0
07:44:36	1284.00	866.10	-5.40	54.63	5.90	3.97	1209.36	5	9	2788	2	0
07:45:28	1327.00	865.00	-5.20	54.46	6.20	3.97	1195.26	6	9	2788	2	0
07:46:43	1410.00	863.90	-5.60	55.21	5.80	3.97	1218.66	7	9	2788	2	0
07:47:33	1451.00	864.20	-5.80	61.32	5.60	3.97	1228.56	7	10	2788	2	0
07:48:07	1494.00	864.80	-5.70	64.72	5.70	3.97	1230.62	7	10	2788	2	0
07:48:57	1535.00	863.60	-5.60	66.18	5.80	3.97	1211.82	7	10	2788	2	0
07:49:30	1578.00	861.20	-5.40	62.78	6.30	3.97	1198.94	8	10	2788	2	0
07:50:21	1619.00	861.70	-5.60	58.63	6.10	3.97	1215.80	9	10	2788	2	0
07:50:54	1662.00	861.30	-5.60	58.84	6.10	3.97	1234.06	10	10	2788	2	0
07:51:44	1703.00	860.20	-5.60	59.33	6.10	3.97	1248.56	11	10	2788	2	0
07:52:18	1746.00	858.60	-5.80	59.90	6.10	3.97	1249.44	12	10	2788	2	0
07:53:10	1789.00	857.70	-5.40	55.93	6.60	3.97	1259.02	13	10	2788	2	0
07:53:42	1830.00	856.30	-5.60	47.46	6.50	3.97	1260.32	14	10	2788	2	0
07:54:34	1872.00	856.70	-5.90	46.68	6.20	3.97	1271.14	15	10	2788	2	0
07:55:06	1913.00	856.10	-5.30	51.99	6.80	3.97	1274.56	16	10	2788	2	0
07:55:58	1956.00	856.30	-5.50	57.06	6.60	3.97	1266.10	17	10	2788	2	0
07:56:29	1997.00	856.00	-5.40	55.48	6.80	3.97	1271.72	18	10	2788	2	0
07:58:02	2081.00	855.70	-5.20	70.96	7.00	3.98	1263.06	20	10	2788	2	0
07:58:40	2124.00	855.70	-5.60	65.88	6.60	3.98	1255.66	21	10	4096	126	4095

AIRSONDE DATA FOR FLIGHT #2, DECEMBER 16, 1985

ADAS TIME	TEMP	PRESSURE
72948	-9.73	862.5
72952	-9.74	862.6
72957	-9.64	862.7
73002	-9.63	862.7
73007	-9.62	862.7
73012	-9.61	862.9
73017	-9.59	862.8
73022	-9.62	863.0
73026	-9.50	863.0
73031	-9.49	863.0
73036	-9.46	863.1
73041	-9.60	863.1
73046	-9.71	863.2
73051	-9.72	863.3
73056	-9.68	863.3
73100	-9.63	863.4
73105	-9.52	863.3
73110	-9.54	863.4
73115	-9.58	863.4
73120	-9.56	863.5
73125	-9.52	863.6
73130	-9.51	863.6
73134	-9.49	863.6
73139	-9.43	863.6
73144	-9.50	863.7
73149	-9.45	863.7
73154	-9.42	863.6
73159	-9.32	863.6
73204	-9.27	863.5
73208	-9.26	863.4
73213	-9.36	863.5
73218	-9.45	863.6
73223	-9.32	863.6
73228	-9.27	863.8
73233	-9.20	863.6
73238	-9.18	863.6
73242	-9.13	863.6
73247	-9.15	863.8
73252	-9.15	863.9
73257	-9.26	864.0
73302	-9.15	864.0
73307	-9.02	864.0
73312	-9.14	864.0
73316	-9.17	864.0
73321	-9.25	863.8
73326	-9.22	863.9
73331	-9.07	863.9
73336	-9.02	864.1
73341	-9.07	864.2
73345	-9.07	864.2
73350	-9.01	864.1
73355	-9.07	864.1
73400	-8.98	864.2
73405	-8.95	864.1
73410	-9.01	864.1
73415	-8.82	864.3
73419	-8.91	864.3
73424	-8.80	864.4
73429	-8.72	864.4
73434	-8.70	864.4
73439	-8.75	864.4
73444	-8.78	864.3
73449	-8.86	864.3
73453	-8.89	864.3
73458	-8.97	864.3
73503	-8.92	864.2
73508	-8.82	864.3
73513	-8.69	864.3
73518	-8.65	864.3
73523	-8.57	864.4
73527	-8.53	864.4
73532	-0.85	864.3
73537	-8.51	864.4
73542	-8.55	864.4
73547	-8.51	864.3
73552	-8.51	864.4
73556	-8.56	864.4
73601	-8.40	864.3
73606	-8.28	864.3
73611	-8.31	864.4
73616	-8.33	864.4
73621	-8.31	864.4
73626	-8.31	864.6
73630	-8.48	864.6
73635	-8.42	864.7
73640	-8.17	864.7
73645	-8.23	864.7
73650	-8.32	864.8
73655	-8.34	864.8
73700	-8.37	864.8
73704	-8.20	864.9
73709	-8.22	865.0
73714	-8.28	865.0
73719	-8.10	865.0
73724	-8.06	865.0
73729	-8.06	865.2
73734	-8.11	865.2
73738	-8.13	865.1
73743	-8.02	865.3
73748	-8.09	865.2
73753	-8.09	865.2
73758	-8.07	865.2
73803	-8.08	865.3
73807	-8.14	865.3
73812	-8.14	865.3
73817	-8.14	865.5
73822	-8.15	865.3
73827	-8.14	865.5
73832	-7.82	865.4
73837	-7.88	865.5
73841	-7.80	865.5
73846	-7.71	865.4
73851	-7.79	865.3
73856	-7.68	865.3
73901	-7.64	865.1
73911	-7.39	864.5
73915	-7.57	864.4
73920	-8.08	864.2
73925	-8.16	864.2
73930	-8.32	864.2
73935	-8.35	864.0
73940	-8.36	863.9
73945	-8.43	864.0
73949	-8.47	864.1
73954	-8.50	864.1
73959	-8.53	864.1
74004	-8.61	864.3
74009	-8.61	864.4
74014	-8.63	864.7
74019	-8.66	865.3
74023	-8.67	865.5
74028	-8.67	865.9
74033	-8.71	865.9
74038	-8.71	865.9
74043	-8.71	866.0
74048	-8.71	866.7
74053	-8.72	866.9
74057	-8.72	867.0
74102	-8.71	867.2
74107	-8.72	867.2
74112	-8.69	867.3
74117	-8.68	867.5
74122	-8.62	867.5
74126	-8.63	867.6
74131	-8.64	867.7
74136	-8.57	867.8
74141	-8.56	867.9
74146	-8.58	867.9
74151	-8.58	868.1
74156	-8.56	868.1
74200	-8.53	868.2
74205	-8.26	868.2
74210	-8.08	868.3
74215	-8.03	868.2
74220	-7.93	868.2
74225	-7.78	868.2
74229	-7.72	868.3
74234	-7.66	868.2
74239	-7.63	868.2
74244	-7.61	868.4
74249	-7.56	868.3
74254	-7.51	868.2
74259	-7.53	868.3
74303	-7.48	868.3
74308	-7.49	868.3
74313	-7.46	868.5
74318	-7.42	868.4
74323	-7.43	868.1
74328	-7.62	867.8
74332	-7.98	867.7
74337	-8.10	867.6
74342	-8.16	867.9
74347	-8.14	867.9
74352	-8.23	867.7
74357	-8.21	867.7

74402	-8.27	867.2
74406	-8.27	867.0
74411	-8.26	866.7
74416	-8.23	866.5
74421	-8.22	866.5
74426	-8.25	866.3
74431	-8.25	866.3
74435	-8.27	865.9
74440	-8.26	865.9
74445	-8.23	865.7
74450	-8.20	865.8
74455	-8.09	865.7
74500	-8.15	865.8
74505	-8.12	865.9
74509	-8.06	865.8
74514	-8.03	866.0
74519	-8.04	866.0
74524	-7.93	866.1
74529	-7.89	866.1
74534	-7.82	866.3
74538	-7.80	866.3
74543	-7.80	866.4
74548	-7.76	866.5
74553	-7.74	866.6
74558	-7.66	866.6
74603	-7.68	866.7
74607	-7.70	867.0
74612	-7.68	867.0
74617	-7.58	867.1
74622	-7.57	867.2
74627	-7.48	867.2
74632	-7.43	867.3
74637	-7.39	867.5
74641	-7.39	867.5
74646	-7.38	867.6
74651	-7.35	867.8
74656	-7.34	868.0
74701	-6.92	867.9
74706	-6.69	867.8
74710	-6.58	867.7
74715	-6.46	867.4
74720	-6.42	867.2
74725	-6.39	866.9
74730	-6.24	866.7
74735	-6.03	866.5
74740	-6.19	866.1
74744	-6.49	866.0
74749	-6.66	865.7
74754	-6.65	865.4
74759	-6.79	865.1
74809	-6.82	864.5
74813	-6.80	864.1
74818	-6.78	863.9
74823	-6.43	863.7
74828	-6.19	863.5
74833	-5.93	863.3
74838	-5.83	863.2
74843	-5.69	863.0
74847	-5.61	862.7
74852	-5.55	862.4

74857	-5.57	862.2
74902	-5.56	862.1
74907	-5.52	861.9
74912	-5.51	861.5
74921	-5.49	861.1
74926	-5.41	860.8
74931	-5.33	860.7
74936	-5.27	860.5
74941	-5.21	860.4
74950	-6.32	860.3
74955	-6.56	860.2
75000	-6.72	860.2
75005	-6.87	860.1
75010	-6.96	860.1
75015	-7.00	860.1
75019	-7.04	860.0
75024	-7.00	860.1
75029	-6.95	860.0
75034	-7.01	860.1
75039	-7.02	859.9
75044	-7.03	860.0
75049	-7.07	860.0
75053	-7.03	859.9
75058	-6.94	860.1
75103	-7.05	860.0
75108	-7.01	859.8
75113	-7.07	859.8
75118	-7.09	860.0
75122	-7.10	859.9
75127	-7.10	860.0
75132	-7.04	859.8
75137	-7.00	859.8
75142	-6.98	859.6
75147	-6.98	859.9
75151	-7.02	859.9
75156	-7.05	859.5
75201	-7.09	860.1
75206	-7.10	859.7
75211	-7.15	859.6
75216	-7.12	859.4
75221	-7.17	859.5
75225	-7.20	859.4
75230	-7.19	859.2
75235	-7.30	859.7
75240	-7.20	859.1
75245	-7.24	859.3
75250	-7.33	858.9
75254	-7.34	859.2
75259	-7.35	859.1
75304	-7.40	859.2
75309	-7.42	859.2
75314	-7.48	859.5
75319	-7.50	859.2
75324	-7.55	859.2
75328	-7.60	859.0
75333	-7.68	859.3
75338	-7.67	859.5
75343	-7.70	859.2
75348	-7.67	859.7
75353	-7.74	859.2

75357	-7.75	859.5
75402	-7.76	859.2
75407	-7.77	859.5
75412	-7.76	859.2
75417	-7.78	859.5
75422	-7.78	858.8
75426	-7.79	859.2
75431	-7.74	859.0
75436	-7.73	858.5

DATA FROM FLIGHT #3, DECEMBER 16,1985

HP TIME	ONBOARD TIMER	PRESSURE	AIR TEMP	HUMIDTY	POT TEMP	STRAIN	VERT ANM	PUMP	VALVE	CTRL VAL	CTRL CODE	LAST CMND
15:04:26	4.00	852.20	11.90	1.33	25.30	3.94	0.14	0	1	8400	1	0
15:04:37	24.00	852.10	10.20	1.35	23.50	3.95	7.86	0	2	8400	1	0
15:05:30	65.00	852.30	9.80	1.36	23.00	3.95	15.38	0	3	8400	1	0
15:06:01	108.00	852.50	9.10	1.43	22.20	3.95	24.92	0	4	8400	1	0
15:06:51	149.00	852.60	10.40	1.41	23.60	3.95	30.54	0	5	8400	1	0
15:07:25	192.00	852.50	8.50	1.40	21.70	3.95	32.86	0	6	8400	1	0
15:08:16	235.00	852.50	9.30	1.43	22.50	3.95	16.12	0	7	8400	1	0
15:08:49	276.00	852.50	9.70	1.41	22.90	3.95	1306.24	0	8	8400	1	0
15:09:40	319.00	852.50	8.80	1.41	22.00	3.95	1288.10	0	9	8400	1	0
15:10:12	360.00	852.50	8.40	1.38	21.50	3.95	1240.76	0	10	8400	1	0
15:11:45	443.00	852.30	7.30	1.44	20.40	3.96	1210.16	0	12	8400	1	0
15:12:19	486.00	852.30	7.30	1.45	20.50	3.96	1191.78	0	13	8400	1	0
15:13:13	527.00	852.30	7.20	1.45	20.30	3.96	1182.98	0	13	8523	1	128
15:13:46	570.00	852.30	7.60	1.50	20.80	3.95	1174.32	0	13	8523	1	0
15:14:34	613.00	852.20	7.90	1.46	21.10	3.95	1166.08	0	13	8523	1	0
15:15:06	654.00	852.20	7.80	1.47	20.90	3.96	1124.04	0	13	8523	1	0
15:15:58	697.00	852.10	8.20	1.46	21.40	3.95	1022.22	0	13	8523	1	0
15:16:30	738.00	852.10	8.30	1.45	21.40	3.95	962.32	0	13	8523	1	0
15:17:26	780.00	852.10	7.80	1.48	21.00	3.95	978.68	0	13	8523	1	2
15:17:58	821.00	852.10	8.00	1.46	21.20	3.95	993.02	0	13	8523	1	0
15:18:50	864.00	852.10	8.30	1.46	21.50	3.95	985.00	0	13	8521	1	128
15:19:21	905.00	852.10	8.20	1.46	21.40	3.95	996.14	0	13	8521	1	0
15:20:09	948.00	852.20	7.90	1.46	21.10	3.96	998.30	0	13	8521	1	0
15:20:43	991.00	852.10	8.30	1.43	21.50	3.95	994.80	0	13	8521	1	0
15:21:33	1032.00	852.00	8.30	1.45	21.50	3.95	997.28	0	13	8521	1	0
15:22:07	1075.00	852.00	7.90	1.45	21.10	3.95	976.04	0	13	8521	1	0
15:22:57	1116.00	851.90	7.70	1.43	20.80	3.95	974.60	0	13	8521	1	0
15:23:31	1158.00	851.90	7.80	1.44	21.00	3.95	970.52	0	13	8521	1	0
15:24:25	1199.00	851.90	8.20	1.46	21.40	3.95	964.00	0	13	8511	1	8
15:24:58	1242.00	852.00	8.30	1.44	21.40	3.95	954.00	0	13	8511	1	0
15:25:44	1283.00	852.40	7.90	1.46	21.00	3.96	959.22	0	14	8511	1	0
15:26:18	1326.00	852.40	7.90	1.44	21.00	3.95	959.56	0	15	8511	1	0
15:27:10	1369.00	851.80	8.40	1.44	21.60	3.96	957.52	0	15	8511	1	0
15:27:42	1410.00	852.30	7.80	1.46	20.90	3.96	968.48	0	16	8511	1	0
15:28:34	1453.00	852.40	8.20	1.46	21.40	3.95	970.88	0	17	8511	1	0
15:29:10	1493.00	852.40	8.30	1.44	21.50	3.95	964.62	0	18	8501	1	8
15:29:57	1536.00	852.40	7.90	1.45	21.10	3.96	965.06	0	19	8491	1	8
15:30:31	1579.00	852.40	7.90	1.45	21.00	3.96	966.18	0	20	8471	1	8
15:31:25	1620.00	852.50	8.00	1.46	21.20	3.95	961.66	0	21	8471	1	0
15:31:57	1661.00	852.60	8.00	1.46	21.10	3.96	968.38	0	22	8461	1	8
15:32:45	1704.00	852.50	7.70	1.46	20.80	3.96	967.18	0	23	8431	1	8
15:33:17	1745.00	852.60	7.60	1.45	20.70	3.96	961.90	0	24	8421	1	8
15:34:13	1788.00	845.60	7.00	1.46	20.80	3.95	798.04	0	25	8421	1	0
15:34:43	1830.00	840.30	7.10	1.46	21.30	3.95	626.78	1	25	8421	1	0
15:35:32	1871.00	835.40	6.80	1.46	21.50	3.95	466.08	2	25	8421	1	0
15:36:06	1914.00	832.50	6.40	1.46	21.50	3.95	332.16	3	25	8421	1	0
15:37:00	1955.00	830.40	7.10	1.46	22.40	3.95	216.40	4	25	16608	3	32
15:37:34	1998.00	828.60	5.90	1.48	21.30	3.95	126.14	5	25	16608	3	0
15:38:22	2041.00	827.70	5.20	1.51	20.70	3.95	57.84	6	25	16608	3	0
15:38:54	2082.00	827.60	4.70	1.54	20.10	3.96	27.56	7	25	16608	3	0
15:39:46	2124.00	828.70	4.70	1.58	20.00	3.95	24.44	8	25	16608	3	0
15:40:17	2165.00	830.20	4.70	1.59	19.90	3.95	47.46	9	25	16608	3	0
15:41:09	2208.00	831.20	4.80	1.59	19.90	3.95	70.90	10	25	16608	3	0
15:41:41	2249.00	832.80	5.00	1.59	19.90	3.96	78.82	11	25	16608	3	0
15:42:33	2292.00	834.70	5.80	1.55	20.60	3.96	58.84	12	25	16608	3	0

15:43:07	2335.00	838.00	5.80	1.52	20.30	3.96	56.28	13	25	16608	3	0
15:43:57	2376.00	839.80	5.80	1.52	20.00	3.96	31.34	14	25	16608	3	0
15:44:30	2419.00	840.30	6.40	1.52	20.70	3.95	1283.76	14	26	16608	3	0
15:45:21	2459.00	841.30	7.00	1.49	21.20	3.95	1216.78	14	27	16608	3	0
15:45:54	2502.00	840.80	7.70	1.48	22.00	3.95	1121.32	14	28	16608	3	0
15:46:44	2543.00	839.50	7.10	1.48	21.50	3.95	1028.44	14	29	16608	3	0
15:47:18	2586.00	836.90	6.40	1.50	21.00	3.95	908.28	14	30	16608	3	0
15:48:08	2627.00	835.60	6.70	1.48	21.50	3.95	829.12	14	31	16608	3	0
15:48:41	2670.00	835.30	6.40	1.50	21.20	3.95	741.96	14	32	16608	3	0
15:49:34	2713.00	833.20	7.00	1.50	22.00	3.95	668.58	14	33	16608	3	0
15:50:05	2753.00	829.30	6.20	1.50	21.50	3.95	613.90	14	34	16608	3	0
15:50:57	2796.00	827.00	6.70	1.51	22.30	3.95	545.70	14	35	16608	3	0
15:51:29	2837.00	829.20	6.00	1.51	21.30	3.95	475.40	14	36	16608	3	0
15:52:21	2880.00	830.30	6.70	1.51	22.00	3.95	377.72	14	37	16608	3	0
15:52:53	2921.00	829.90	6.70	1.50	22.00	3.95	272.40	15	37	16608	3	0
15:53:45	2964.00	828.70	6.10	1.50	21.50	3.95	170.48	16	37	16608	3	0
15:54:18	3007.00	827.00	5.30	1.54	20.80	3.95	97.44	17	37	16608	3	0
15:55:08	3047.00	826.70	4.80	1.56	20.30	3.95	39.36	18	37	16608	3	0
15:55:46	3090.00	826.50	4.60	1.59	20.10	3.95	6.94	19	37	16608	3	2
15:56:36	3131.00	827.30	4.40	1.61	19.80	3.95	6.92	20	37	16608	3	0
15:57:06	3174.00	828.90	4.60	1.62	19.90	3.95	31.46	21	37	16608	3	0
15:57:55	3215.00	829.80	4.80	1.61	20.00	3.95	42.50	22	37	16608	3	0
15:58:29	3258.00	832.70	4.90	1.61	19.80	3.95	34.52	23	37	16608	3	0
15:59:21	3301.00	834.40	5.20	1.60	19.90	3.95	35.70	24	37	16608	3	0
16:00:36	3384.00	834.90	5.10	1.59	19.90	3.95	1282.24	25	38	16608	3	0
16:01:26	3425.00	833.90	5.20	1.59	20.00	3.95	1253.52	25	39	16608	3	0
16:01:59	3468.00	832.80	5.00	1.59	19.90	3.95	1250.50	25	40	16608	3	0
16:02:50	3509.00	830.60	4.90	1.60	20.00	3.95	1254.14	25	41	16608	3	0
16:03:23	3552.00	828.90	4.70	1.61	20.00	3.95	1261.60	25	42	16608	3	0
16:04:15	3595.00	829.80	4.80	1.61	20.00	3.95	33.54	26	42	16608	3	0
16:04:47	3635.00	832.80	5.20	1.61	20.20	3.95	139.30	27	42	16608	3	0
16:05:39	3678.00	836.00	5.40	1.59	20.10	3.95	262.98	28	42	16608	3	0
16:06:53	3762.00	838.60	5.90	1.56	20.20	3.95	531.88	28	44	16608	3	0
16:07:43	3803.00	836.80	5.80	1.56	20.30	3.95	655.84	28	45	16608	3	0
16:08:17	3846.00	836.30	5.40	1.56	20.00	3.95	759.72	28	46	16608	3	0
16:09:09	3889.00	839.70	5.80	1.56	20.00	3.95	913.90	28	47	16608	3	0

AIRSONDE DATA FOR FLIGHT #3, DECEMBER 16, 1985

ADAS TIME	TEMP	PRESSURE
152507	11.08	886.7
152512	11.15	886.7
152516	11.28	886.7
152521	11.11	886.8
152526	10.92	886.7
152531	11.21	886.8
152535	11.13	886.7
152540	11.24	886.7
152545	11.23	886.8
152550	11.03	886.7
152554	10.07	886.6
152559	10.03	886.6
152604	9.76	886.4
152609	9.63	886.3
152613	9.33	886.1
152618	8.98	886.0
152623	8.92	885.9
152628	9.04	885.8
152632	8.90	885.7
152637	8.72	885.5
152642	8.79	885.5
152647	8.86	885.4
152651	8.70	885.3
152656	8.70	885.2
152701	8.68	885.1
152706	8.67	884.9
152710	8.67	884.9
152715	8.61	884.9
152720	8.92	884.9
152725	9.40	884.8
152729	9.66	885.0
152734	9.61	885.0
152739	10.06	884.9
152744	9.83	884.9
152748	10.05	884.9
152753	9.74	885.0
152758	9.93	884.8
152803	9.31	884.8
152807	8.95	884.7
152812	8.83	884.5
152817	8.64	884.4
152822	8.62	884.2
152826	8.61	884.1
152831	8.61	883.9
152836	8.60	883.8
152841	8.60	883.8
152845	8.57	883.6
152850	8.41	883.5
152855	8.37	883.5
152900	8.41	883.3
152904	8.38	883.2
152909	8.21	883.0
152914	8.39	882.9
152919	8.60	882.8
152923	8.58	882.7
152928	8.52	882.6
152933	8.58	882.6
152938	8.42	882.6
152942	8.52	882.5
152947	8.40	882.4
152952	8.28	882.3
152957	8.54	882.2
153001	8.39	882.1
153006	8.41	882.0
153011	8.57	881.9
153016	8.39	881.9
153020	8.57	881.7
153025	8.58	881.7
153030	8.35	881.6
153035	8.17	881.5
153039	8.10	881.4
153044	8.15	881.3
153049	8.14	881.2
153054	8.10	881.0
153058	8.12	881.0
153103	8.04	880.9
153108	8.14	880.7
153113	8.23	880.6
153117	8.14	880.6
153122	8.05	880.3
153127	7.96	880.3
153132	7.98	880.1
153136	7.98	880.0
153141	8.07	880.0
153146	8.02	879.8
153151	8.00	879.7
153155	8.37	879.7
153200	8.30	879.7
153205	8.37	879.5
153210	8.14	879.4
153214	8.55	879.4
153219	8.13	879.4
153224	8.20	879.3
153229	8.09	879.2
153233	8.14	879.1
153238	8.12	879.1
153243	8.08	879.0
153248	8.03	878.8
153252	8.00	878.7
153257	8.13	878.6
153302	8.04	878.6
153307	8.25	878.5
153311	8.19	878.4
153316	8.18	878.4
153321	8.11	878.3
153326	8.20	878.1
153330	8.21	878.0
153335	8.19	878.0
153340	8.23	877.7
153345	8.22	877.3
153349	8.28	876.8
153354	8.04	876.4
153359	8.03	876.0
153404	7.96	875.5
153408	7.90	875.0
153413	7.80	874.6
153418	7.74	874.2
153423	7.87	873.8
153427	7.81	873.5
153432	7.82	873.2
153437	7.87	872.7
153442	7.91	872.4
153446	7.68	871.9
153451	7.47	871.5
153456	7.27	871.2
153501	7.13	871.2
153505	6.99	870.9
153510	6.94	870.8
153515	6.78	870.7
153520	6.79	870.4
153524	6.65	870.2
153529	6.50	870.1
153534	6.48	870.0
153539	6.77	869.8
153543	6.50	869.8
153548	6.31	869.6
153553	6.15	869.5
153558	6.14	869.4
153602	6.02	869.3
153607	5.98	869.3
153612	6.01	869.1
153617	5.94	869.0
153621	5.90	868.9
153626	5.90	868.7
153631	5.83	868.7
153636	5.86	868.6
153640	5.83	868.5
153645	5.86	868.4
153650	5.90	868.3
153655	5.83	868.2
153659	5.81	868.0
153704	5.77	868.0
153709	5.72	868.0
153714	5.66	868.0
153718	5.64	867.9
153723	5.61	867.9
153728	5.47	867.8
153733	5.41	867.7
153737	5.31	867.8
153742	5.31	867.8
153747	5.26	867.7
153752	5.26	867.7
153756	5.29	867.7
153801	5.25	867.7
153806	5.27	867.4
153811	5.17	867.7
153815	5.04	867.7
153820	4.97	867.7
153825	4.93	867.6
153830	4.87	867.5
153834	4.85	867.5
153839	4.81	867.4
153844	4.81	867.4
153849	4.81	867.4
153853	4.82	867.4

153858	4.81	867.3	154343	4 68	874.0	154828	5.03	867.2
153903	4.79	867.4	154347	4.67	873.5	154832	5.02	867.1
153908	4.69	867.4	154352	4.67	873.6	154837	4.78	867.0
153912	4.62	867.4	154357	4.67	873.6	154842	4.63	866.9
153917	4.62	867.5	154402	4.67	873.6	154847	4.59	866.7
153922	4.64	867.5	154406	4.79	873.7	154851	4.58	866.5
153927	4.55	867.6	154411	4.87	873.9	154856	4.51	866.3
153931	4.56	867.7	154416	4.90	873.9	154901	4.48	866.2
153936	4.49	867.8	154421	4.92	874.0	154906	4.45	865.9
153941	4.46	867.9	154425	5.05	874.1	154910	4.39	865.7
153946	4.47	867.9	154430	5.15	874.3	154915	4.46	865.6
153950	4.49	867.7	154435	5.28	874.3	154920	4.50	865.4
153955	4.47	868.2	154440	5.31	874.3	154925	4.59	865.2
154000	4.43	868.5	154444	5.23	874.5	154929	4.62	865.0
154005	4.43	868.5	154449	5.37	874.3	154934	4.95	864.8
154009	4.43	868.7	154454	5.36	874.2	154939	5.01	864.6
154014	4.45	868.8	154459	5.35	874.1	154944	5.21	864.5
154019	4.46	868.7	154503	5.34	874.0	154949	5.00	864.2
154023	4.45	868.4	154508	5.33	873.9	154953	5.15	864.0
154028	4.46	868.7	154513	5.38	873.8	154958	5.29	863.7
154033	4.43	868.9	154518	5.49	873.6	155003	5.25	863.4
154038	4.41	868.7	154522	5.43	873.5	155008	4.98	863.2
154042	4.39	868.7	154527	5.37	873.3	155012	5.20	862.9
154047	4.41	868.5	154532	5.38	873.1	155017	5.23	862.6
154052	4.39	868.2	154537	5.30	873.1	155022	5.01	862.3
154057	4.36	868.2	154541	5.31	872.9	155027	4.95	862.0
154101	4.38	868.3	154546	5.28	872.8	155031	4.97	861.8
154106	4.37	868.4	154551	5.24	872.7	155036	4.99	861.7
154111	4.36	868.3	154556	5.27	872.5	155041	4.73	861.5
154116	4.45	868.4	154600	5.26	872.4	155046	4.70	861.4
154120	4.42	868.4	154605	5.29	872.2	155050	4.56	861.3
154125	4.41	868.4	154610	5.25	872.1	155055	4.55	861.2
154130	4.47	868.6	154615	5.23	871.9	155100	4.54	861.0
154135	4.53	868.6	154619	5.26	871.8	155105	4.59	861.0
154139	4.54	868.7	154624	5.20	871.5	155109	4.44	860.9
154144	4.60	868.9	154629	5.19	871.4	155114	4.50	861.0
154149	4.57	869.0	154634	5.19	871.3	155119	4.50	860.9
154154	4.68	869.2	154638	5.17	871.1	155124	4.48	860.8
154158	4.85	869.4	154643	5.17	870.9	155128	4.47	860.7
154203	4.82	869.4	154648	5.16	870.8	155133	4.46	860.7
154208	4.86	869.6	154653	5.23	870.6	155138	4.66	860.7
154213	4.87	869.7	154657	5.19	870.5	155143	4.52	860.7
154217	4.95	869.9	154702	5.14	870.3	155147	4.89	860.6
154222	5.01	870.0	154707	5.14	870.1	155152	4.88	860.5
154227	5.00	870.1	154712	5.13	869.8	155157	4.87	860.4
154231	4.96	870.4	154716	5.12	869.8	155202	4.86	860.4
154236	4.93	870.4	154721	5.12	869.5	155206	4.90	860.3
154241	4.88	870.7	154726	5.11	869.3	155211	4.98	860.3
154246	4.86	871.0	154731	5.11	869.1	155216	5.04	860.2
154250	4.84	871.2	154735	5.10	868.9	155221	4.86	860.1
154255	4.79	871.3	154740	5.13	868.8	155225	4.87	860.1
154300	4.77	871.8	154745	5.13	868.5	155230	4.93	860.1
154305	4.72	872.1	154750	5.09	868.5	155235	4.84	860.1
154309	4.64	872.3	154754	5.08	868.3	155240	4.80	860.0
154314	4.60	872.5	154759	5.08	868.2	155245	4.79	859.8
154319	4.60	872.9	154804	5.09	868.0	155249	4.83	859.8
154324	4.59	873.3	154809	5.06	867.8	155254	4.80	859.6
154328	4.60	873.7	154813	5.07	867.7	155259	4.83	859.5
154333	4.61	874.1	154818	5.09	867.5	155304	4.78	859.5
154338	4.61	874.0	154823	5.07	867.4	155308	4.79	859.5

155313	4.85	859.5	155759	3.22	863.9	160243	2.84	863.9
155318	4.69	859.6	155803	3.26	864.2	160248	2.77	863.6
155323	4.52	859.5	155808	3.26	864.2	160253	2.77	863.4
155327	4.68	859.6	155813	3.28	864.8	160258	2.76	863.0
155332	4.50	859.6	155818	3.34	865.1	160302	2.67	861.6
155337	4.43	859.6	155822	3.41	865.3	160307	2.65	857.9
155342	4.31	859.7	155827	3.35	865.6	160312	2.69	854.6
155346	4.41	859.7	155832	3.33	865.8	160317	2.51	851.3
155351	4.42	859.7	155837	3.36	865.8	160321	2.48	848.5
155356	4.44	859.7	155841	3.37	866.1	160326	2.32	845.6
155401	4.29	859.7	155846	3.44	866.1	160331	2.17	843.2
155405	4.25	859.7	155851	3.41	866.2	160336	2.05	841.2
155410	4.24	859.8	155856	3.39	866.2	160340	1.93	839.3
155415	4.17	859.8	155900	3.38	866.4	160345	1.92	837.6
155420	4.16	859.8	155905	3.38	866.3	160350	2.00	836.0
155424	3.98	859.8	155910	3.40	866.4	160355	1.98	834.8
155429	3.89	859.9	155915	3.37	866.2	160359	2.04	834.0
155434	3.80	860.0	155919	3.38	866.5	160404	2.03	833.3
155439	3.76	860.1	155924	3.37	866.7	160409	1.87	832.6
155444	3.74	860.2	155929	3.38	866.8	160413	1.88	832.4
155448	3.70	860.2	155934	3.38	866.8	160418	1.86	832.3
155453	3.67	860.2	155938	3.38	866.8	160423	1.83	832.4
155458	3.66	860.2	155943	3.38	867.0	160428	1.52	832.7
155503	3.66	860.2	155948	3.39	866.9	160432	1.47	833.0
155507	3.67	860.2	155953	3.42	866.8	160437	1.35	833.3
155512	3.68	860.3	155957	3.40	867.1	160442	1.51	833.5
155517	3.64	860.4	160002	3.37	867.2	160447	1.52	833.7
155522	3.58	860.4	160007	3.42	867.2	160451	1.51	834.0
155526	3.56	860.6	160012	3.47	867.4	160456	1.59	834.4
155531	3.64	860.8	160016	3.45	867.5	160501	1.60	834.7
155536	3.62	860.9	160021	3.42	867.6	160506	1.65	835.1
155541	3.55	861.2	160026	3.43	867.5	160510	1.71	835.4
155545	3.49	861.4	160031	3.41	867.4	160515	1.92	835.8
155550	3.49	861.5	160035	3.48	867.6	160520	1.91	836.1
155555	3.40	861.6	160040	3.43	867.8	160525	1.95	836.4
155600	3.35	861.6	160045	3.45	868.0	160529	2.07	836.6
155604	3.37	861.1	160049	3.42	867.9	160534	2.21	836.9
155609	3.39	861.6	160054	3.54	867.8	160539	2.30	837.2
155614	3.36	862.1	160059	3.43	867.6	160544	2.47	837.4
155619	3.28	862.2	160104	3.33	867.1	160548	2.59	837.6
155623	3.26	862.2	160108	3.47	867.4	160553	2.74	837.9
155628	3.24	862.2	160113	3.42	867.2	160558	2.65	838.3
155633	3.29	862.4	160118	3.41	867.1	160603	2.71	838.6
155638	3.32	862.3	160123	3.34	867.1	160607	2.77	838.8
155643	3.30	862.5	160127	3.25	866.8	160612	2.98	839.1
155647	3.34	862.2	160132	3.19	866.7	160617	3.01	839.2
155652	3.26	862.2	160137	3.07	866.6	160622	2.98	839.4
155657	3.26	862.5	160142	3.01	866.2	160626	2.98	839.6
155702	3.26	862.6	160146	3.08	865.3	160631	3.96	839.6
155706	3.27	862.9	160151	3.13	865.5	160636	4.40	839.8
155711	3.22	862.9	160156	3.07	865.5	160641	4.61	840.0
155716	3.20	862.8	160201	3.13	865.4	160645	4.54	840.2
155721	3.19	862.7	160205	3.09	865.1	160650	4.79	840.3
155725	3.16	862.9	160210	2.98	864.9	160655	4.60	840.0
155730	3.15	863.0	160215	2.99	864.8	160700	4.58	839.9
155735	3.18	863.2	160220	3.02	864.5	160704	4.56	840.1
155740	3.19	863.3	160224	2.90	864.4	160709	4.77	839.9
155744	3.25	863.5	160229	2.88	863.7	160714	5.10	839.8
155749	3.22	863.5	160234	2.89	863.7	160719	5.25	839.8
155754	3.24	863.8	160239	2.91	864.0	160723	5.23	839.5

160728	5.25	839.2
160733	5.43	838.8
160738	5.23	838.5
160742	5.28	838.2
160747	5.26	838.0
160752	5.26	837.5
160757	5.23	837.2
160801	5.44	837.0
160806	5.59	836.8
160811	5.61	836.9
160816	5.65	837.1
160821	5.73	837.2
160825	5.67	837.4
160830	5.82	837.6
160835	6.11	837.8
160840	6.13	838.1
160844	6.07	838.5
160849	5.94	839.0
160854	5.93	839.4
160859	5.99	840.1
160903	5.99	840.6
160908	5.93	841.3
160913	5.94	842.0
160918	6.06	842.7
160922	6.23	843.1
160927	6.13	843.5
160932	6.13	844.0
160937	6.09	844.4
160941	6.22	845.0
160946	6.39	845.6
160951	6.69	846.4
160956	6.70	847.0
161000	6.66	847.6
161005	6.69	848.2
161010	6.82	848.6
161015	6.84	849.2
161019	7.04	849.9
161024	7.13	850.8
161029	7.17	851.1
161034	7.32	851.6
161038	7.26	851.5
161043	7.50	851.8
161048	7.50	851.2
161053	7.49	851.7
161058	7.49	852.0
161102	7.59	852.1
161107	7.70	851.2
161112	7.71	851.3
161117	7.89	851.6
161121	7.80	851.6
161126	7.96	852.6
161131	8.11	851.4
161136	8.16	852.2
161140	8.36	852.0
161145	8.40	853.4
161150	8.48	851.3
161155	8.47	850.5
161159	8.56	851.2
161204	8.61	849.0
161209	8.55	851.8
161214	8.54	852.4
161218	8.52	851.5
161223	8.49	852.2

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE DEVELOPMENT OF AN ADJUSTABLE BUOYANCY BALLOON TRACER OF ATMOSPHERIC MOTION Phase II. Development of an Operational Prototype		5. REPORT DATE 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) B.D. Zak, H.W. Church, E.W. Lichfield, and M.D. Ivey		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Sandia National Laboratories Albuquerque, NM 87185		10. PROGRAM ELEMENT NO. CDTA1D/08-3005 (FY-86) 11. CONTRACT/GRANT NO IAG DW89930214
12. SPONSORING AGENCY NAME AND ADDRESS Atmospheric Sciences Research Laboratory - RTP, NC Office of Research and Development U. S. Environmental Protection Agency Research Triangle Park, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED Interim 14. SPONSORING AGENCY CODE EPA/600/09

15. SUPPLEMENTARY NOTES

Phase I report: EPA/600/3-85/027, April 1985

16. ABSTRACT

An Adjustable Buoyancy Balloon Tracer of Atmospheric Motion is a research tool which allows one to follow horizontal and vertical atmospheric flows, including the weak sustained vertical motion of meso- and synoptic-scale atmospheric disturbances. The design goals for the Tracer Balloon being developed here specify a lifetime $\geq$ 3 days, tracking range $\geq$ 1000 km, a ceiling altitude $\geq$ 5.5 km (500 mb), and the capability to respond to mean vertical flows as low as 1 cm/s. The Tracer Balloon is also to measure and telemeter selected meteorological variables, to be sufficiently inexpensive to permit use in significant numbers, and to be serviced by a ground system capable of handling several Tracers at a time. While the Tracer has applications throughout the atmospheric sciences, the immediate need for this effort is to evaluate the accuracies of air pollution transport models, to establish source-receptor relationships out to 1000 km, and to assess the limits on the predictability of source impacts at long distances. In Phase I of this project, the authors proposed a generic design. In Phase II, the authors have developed an operational prototype. Three test flights of the operational prototype were conducted near Albuquerque, New Mexico. Analysis of the data indicated that the control algorithms performed properly. Further improvements in the balloon design and additional flight tests are planned for Phase III.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT RELEASE TO PUBLIC	19. SECURITY CLASS *(This Report)* UNCLASSIFIED	21. NO. OF PAGES
	20. SECURITY CLASS *(This page)* UNCLASSIFIED	22. PRICE