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Bernard D. Newsom

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FOREWORD

This test was a collaborative effort between the Ames Research Center and the Environmental Physiology Laboratory (EPL) at University of California, Berkeley. Emphasis was placed on assessing the operation of implanted telemetry and the adequacy of the monkey pod as a general restrained animal support system to function in an operational environment. Support for maintaining the pod and the scientific apparatus required for it to function was provided by the EPL staff. The investigator team was as follows:

Principal Investigator:	Dr. Bernard D. Newsom, Biomedical Research Division, Ames Research Center.
Co-Investigator:	Dr. Donald F. Rahlmann, I.P.A. Assigned to Ames Research Center from U. C. Berkeley.
Co-Investigator:	Dr. Nello Pace, Environmental Physiology Laboratory, U. C. Berkeley.
Co-Investigator:	Dr. Ernest P. McCutcheon, Physiology Branch, Biomedical Research Division, Ames Research Center.

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CV-990 INTERFACE TEST AND PROCEDURE ANALYSIS OF THE MONKEY RESTRAINT, SUPPORT EQUIPMENT, AND TELEMETRY ELECTRONICS PROPOSED FOR SPACELAB

Bernard D. Newsom

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SUMMARY

The Airborne Science Office (ASO) has provided the scientific community with a CV-990 to perform physical, meteorological, astronomical, and geophysical research. The similarity in mission structure and objectives to that of the Shuttle Spacelab suggests that the informal mission management scheme used by the ASO may be applicable in parts to the management of Spacelab experiment development and integration. A biological system proposed to restrain a monkey in the Spacelab was tested under operational conditions using typical metabolic and telemetered cardiovascular instrumentation. Instrumentation, interface with other electronics, and data gathering during a very active operational mission were analyzed for adequacy of procedure and success of data handling by the onboard computer.

The test was completed and all systems eventually worked satisfactorily. The problems encountered, however, indicated areas requiring improved design and the need for additional interface control during experiment buildup.

With the intent to minimize documentation, reviews, and change-order distribution, a concept of a Computerized Management Program for Experiment Integration is presented that could provide a terminal as a substitute for the series of conventional documents and would assure visibility into the current integration status to provide a means of interface control.

INTRODUCTION

The Skylab program was a highly successful program that carried out numerous physical and biological experiments. One of the outstanding results of the program was qualification of man for long duration missions by a series of physiological measurements utilizing unique apparatus of highly sophisticated design. Although we know man can survive in a weightless environment for a period of at least 84 days, certain metabolic and cardiovascular changes take place which are as yet not fully understood. It is anticipated that an early Shuttle Spacelab flight using a restrained monkey or monkeys may elucidate the time course of the physiological changes in zero *g*, and further our understanding of why and how they occur. The physiological measurements incorporated into the test described in this report are those that have been proposed for such a Shuttle Spacelab experiment.

Probably the most often-heard criticism of the Skylab program and concern for future biological experimentation in space is the tremendous expense of the instrumentation and the horrendous amount of paper produced for management control, visibility into schedule, interface design problems, etc.

The Space Transportation System to be operative in the early 1980's will provide another opportunity for research in space. The Shuttle vehicle incorporates a Spacelab that is loaded into the cargo bay completely furbished for experimental missions of mixed or dedicated purposes. Because the Spacelab can be furbished apart from the vehicle, it offers an opportunity to assemble the components in one location and integrate them without the detailed interface control documentation that was necessary for the Skylab and Apollo programs. Experienced integration engineers, however, have been skeptical about just how much the control documentation can be reduced without loss of reliability. This is especially true if the philosophy is followed of using "off-the-shelf" instrumentation wherever possible, for such available apparatus usually includes many unknown components in the way of materials, functions, and stress capabilities.

At the Ames Research Center, a program has been underway for several years using a Convair 990 aircraft for in-flight experimentation. The program is conducted by the Airborne Science Office (recently renamed the Medium Altitude Missions Branch) and has been principally involved with astronomy, upper atmospheric measurements, and geological survey. A basic rule has been followed that each experiment meet the requirement of being "good science" and that meaningful data be collected. The program, however, has been conducted without a great deal of documentation and is directed largely by verbal instructions. Assembly of components are made in a single large laboratory area in the CV-990 hangar adjacent to the aircraft, under overall supervision of a mission manager.

This approach offered an alternative to the usual systems management approach used by NASA for such missions and has been under study for application to the Shuttle missions. The study has been termed ASSESS, which stands for Airborne Science/Spacelab Experiments System Simulation.

The studies have been done during actual Airborne Science missions and because collection of scientific data was an essential part of the program, no biological tests were included. The concept of using the CV-990 as a simulator to evaluate a biological experiment in terms of engineering design performance and interface compatibility with other parts of a program had not been done. Considerable concern was expressed by parts of ARC management as to why such a test should be done in the air rather than in a less expensive grounded simulator. The answer was that interfacing with a real operation, including airworthiness requirements, would provide insight into management problems and instrumentation incompatibilities applicable to biological experiments for Spacelab that would not be found in ground mock-up situations where unrealistic "fixes" could be used.

This report describes the test of a candidate biological system for the Shuttle under realistic operational circumstances. The test was an evaluation of apparatus and experiment procedures without an attempt to gather scientific data on the subjects. It was accepted as a secondary experiment to be "piggybacked" on a non-interference basis on a series of flights during the month of May 1976 to evaluate a new landing approach concept. Three flights were made each week from Ames Research Center and each lasted from three to six hours. Excerpts are included from publications by the Airborne Science Office (1,2) from results submitted by each of the co-investigators (3,4) and from the report of an engineering observer (5). Each of these reports was prepared as an individual document describing the observations, procedures, and results in much greater detail.

DESCRIPTION OF ASSESS PROGRAM

Introduction.- The Airborne Science program at NASA's Ames Research Center has provided research opportunities for the world scientific community since early 1965. Working in such aircraft as a Lear Jet, a Convair 990, and a Lockheed C-141, the airborne scientist has ranged widely over the globe at altitudes up to 15 km. These flying laboratories have provided the setting and facilities for basic research in earth and space sciences including observation of unique astronomical events, the development of earth-observation instruments for use on satellites and to supplement satellite measurements by simultaneous observations in high-altitude flight, and measurement of gaseous and particulate contamination of the atmosphere.

In managing this program, the Airborne Science Office (ASO) has evolved procedures that foster scientific research, yet are as informal and free of restrictions and documentation as possible, consistent with flight safety and the attainment of scientific objectives. A unique feature of the ASO operation is the active participation of experimenters in all aspects of the research program. The experimenters have the responsibility to construct and test their equipment, assist with installation in the aircraft, and participate in flights to obtain the scientific data. This one practice more than any other underlies the success of the Airborne Science approach. It has been enthusiastically accepted by the scientific community and is productive of research results with a minimum of preparation time, documentation and controls, and at relatively low cost.

The ASO experience in research management is a reservoir of practical knowledge available to the planners of research operations for the Shuttle Spacelab program. The potential reductions in cost and time that might result for Shuttle from such a transfer of knowledge were first suggested in 1971. Following discussions in the NASA Airborne Research Steering Committee, a two-phase program of study was sponsored by the Office of Manned Space Flight to document the form and effectiveness of the Ames program in airborne sciences. This was the start of the ASSESS program (2). The following describes the ASO approach in conducting airborne scientific research.

Management procedures.- The ASO provides the airborne platform, overall mission management, and support services, with the content and flow of activities designed to maintain a research atmosphere. Mission managers are experienced research scientists who provide a single-contact continuity of management throughout each mission. Integration facilities and support personnel are located in proximity to the management office to facilitate a close relationship between the mission manager and aircraft and research personnel.

ASO airborne missions historically have been related to one of three broad scientific categories: astronomy, meteorology and earth observations, and geophysics and space sciences. Each area is under the cognizance of an ASO program manager whose scientific background is in a relevant discipline. Specific airborne missions are directed by one of these program managers (or an immediate assistant) as part of his overall responsibility in the program area. The scientist/manager is directly involved in the preliminary stages of mission formulation. He evaluates the compatibility of proposed experiments to the aircraft, and performs preliminary flight program and logistics planning.

When a mission is approved, the ASO program manager is formally assigned responsibility for the preparation and conduct of the complete mission. His specific responsibilities as mission manager and his interactions with various support groups are depicted in Figure 1. Immediate steps are taken to integrate experimenters into the mission team. Each receives an Experimenters' Handbook (1), which defines the design requirements for flight safety, the aircraft interfaces and support utilities, and the pertinent features of the in-flight environment. Visits to Ames acquaint the experimenter with the aircraft and the mission support personnel, and mission plans and schedules are updated through periodic Experimenters' Bulletins issued by the mission manager.

The mission manager initiates and directs all local preparations for the mission, with the authority to make basic decisions relative to the scientific payload and its integration with the aircraft. During the development period, he is in frequent contact by telephone and each experimenter, working out the details of equipment integration and flight planning. Written communications are seldom necessary. In many cases, the experimenter works directly with cognizant Ames support personnel; for example, he consults with the ASO data-systems manager for the CV-990 to arrange for in-flight data recording and processing by the onboard computer; he works with shop personnel for experiment installation, and with inspectors to correct any deficiencies that have been identified.

Late in the preflight period for multiexperiment missions (on the CV-990), all flight personnel participate in a final program review, and a separate safety training session is held for experimenters. The final safety inspection with final written signoff is made prior to the initial flight — a pilot's check flight — and is followed by a full-crew, equipment checkout flight, which serves as an operational shakedown for the mission.

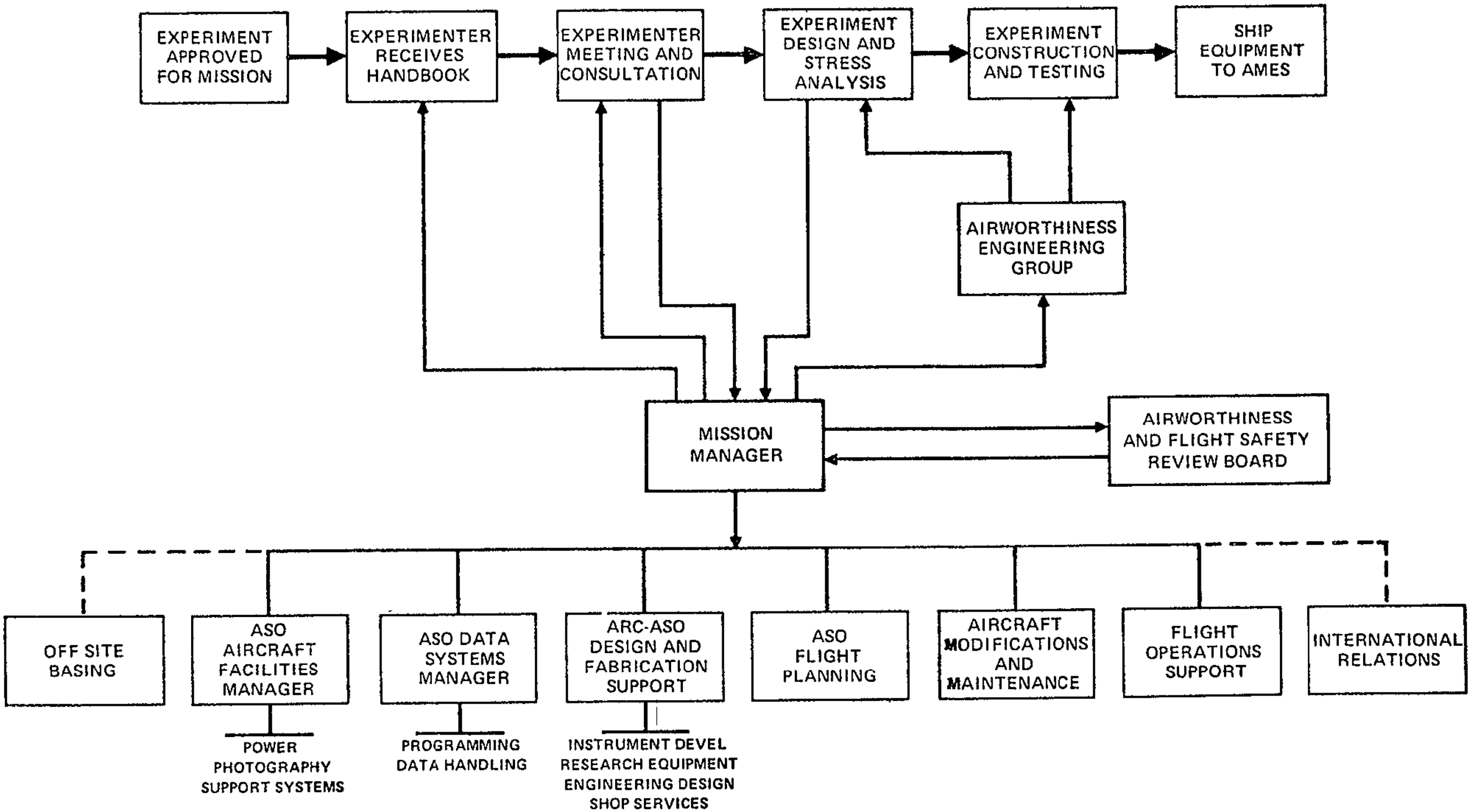


Figure 1.- ASO Mission Managers' interaction scheme.

During the flight phase, the ASO mission manager is the coordinator of pre- and in-flight research activities. In the CV-990 program, he flies with the experimenters and coordinates their activities with those of the flight/experiment support crew. In the Lear Jet program, flight and experiment operations are coordinated by the two pilots and two experimenters. In either case, the mission manager meets daily with the experimenters to review mission progress and to make revisions in schedules or specific flight plans that will enhance research opportunities.

The person-to-person informality of ASO management procedures minimizes the need for documentation, while the continuity of management and proximity of support groups allow maximum program flexibility with no compromise of personnel or equipment safety. The motivated scientist has been shown fully capable and effective in moving into this environment, with full responsibility for his experiment, to accomplish his research objectives.

Experimenter involvement.- An airborne research project begins with the interaction between the experimenter or his management and the Airborne Science Office. As an aid to early planning, the experimenter may contact the ASO for informal discussion of his experiment and its suitability as an airborne project. An Experimenters' Handbook is usually given to him at this stage. From the start, it is understood that he will have the entire responsibility to design, construct, and proof test his experiment, subject only to aircraft safety requirements, interference with other experiments, and the practical limits on size and electrical power imposed by aircraft systems.

Frequent consultation with the ASO mission manager is necessary during the development phase. The experimenter recognizes that he must do more than design a laboratory-type experiment. He must devise a relatively self-contained research operation, giving consideration to the limitations and hazards of the flight environment; to methods of experiment operation and performance monitoring; to maintenance procedures, spare parts, and equipment; to data handling and analysis; and to the selection and training of research assistants. Ready access to the mission manager and available support personnel allows quick resolution of design problems and shortens the time required for preparing an experiment.

When the design and layout of the experiment have been determined, the experimenter submits the required drawings and stress analysis to the mission manager, who refers them to the Airworthiness Engineering Group for a flight safety review. Deficiencies in design (if any) are relayed through the ASO mission manager back to the experimenter, usually by telephone. Occasionally, further direct interaction of the experimenter and the cognizant safety engineer is warranted. When all safety-related aspects of the design have been approved, the experimenter is free to complete assembly of equipment and conduct whatever testing he deems necessary. He is not required to document or report the results of his proof-testing.

The experimenter oversees and assists in installation of his equipment in the aircraft. The ASO mission manager and his support people provide assistance during this phase. The equipment must pass safety inspections both before and after installation.

During the mission, the experimenter operates and maintains his own experiment, with the support of his research assistants; ASO personnel may provide assistance, but the experimenter usually handles his own activity.

Data handling.- Prime responsibility for handling the research data rests with the experimenter. He must either provide suitable recording units as part of his own equipment or, in the case of the CV-990, arrange for recording and processing by the onboard computer system (ADDAS). Many experimenters in the CV-990 program do both, either using the ADDAS as a backup capability in the event of a local recorded malfunction, or using data scanning techniques in their own system and the ADDAS for complete data handling. The ASO is responsible for the operation (hardware) and programing (software) of the CV-990 ADDAS system, and the experimenter must match the magnitude of his data signal to the input requirements.

On the CV-990 missions, the presence of both ADDAS and experimenter on the aircraft precluded any requirement for an air-to-ground data link. No such link was ever requested by an experimenter. However, with flights lasting at most six hours, there was ample opportunity for postflight data processing on a daily basis.

Applications to Shuttle Spacelab planning.- The development of a plan for managing experiments in the Shuttle Spacelab, with maximum benefits for the user community and a minimum of controls and documentation, can proceed one of two ways: by building on relatively simple concepts and procedures such as those practiced by the Ames Airborne Science Office, adding those features judged to be absolutely necessary; or by attenuation of the complex experiment-control networks of existing manned space programs, subtracting features judged unnecessary. The ASSESS program is based on the former approach in studying Spacelab experiments management. The following sections address those features of the Ames airborne science activity believed to be pertinent to current Spacelab planning.

Mission preparation.- Development times for airborne experiments typically vary from 6 to 12 months. This condensed time scale is made possible largely by the close interdependence of the experimenter and ASO management. But it also derives from the use of standard Experimenters' Handbooks as design guides, the use of standard instrument racks to minimize mounting and interface problems, and from the relatively benign conditions in the flying laboratory, which permit the extensive use of standard commercial components and do not necessitate intensive environmental testing. Testing activities in the home laboratory averaged less than 10 man-days per experiment. Based on the performance of 66 experiments during this study period, in which scientific data were obtained in 95 percent of all experiment-flights, this relatively small amount of testing appears adequate in most cases. Obviously, experiment-preparation procedures for Shuttle cannot be as simple as for airborne experiments; nevertheless, adherence to the direct and effective guidelines described herein, together with full experimenter involvement, should lead to minimum experiment costs and development times for Spacelab payloads.

Onboard data processing.- An onboard central recorded/computer system is a valuable support to experiments in the CV-990 program. It is used for the real-time display of flight and experiment parameters, for recording research data, and for processing of raw data in support of experiments. Certain coordinated payloads would not be possible without this support, since in-flight assessments of the progress of the total research effort may require processed results from four to six separate experiments. In addition, the onboard computer has reduced the need for postflight data processing, thus increasing the self-sufficiency of the mission payload. With rare exceptions, the experiments on a Spacelab mission could be served similarly by an onboard computer facility, and its value would be enhanced if the experimenter were there to interpret results.

USE OF THE CV-990 FOR INTERFACE TESTING AND PROCEDURE ANALYSIS FOR THE BIOLOGICAL EXPERIMENT

Introduction.- The flight mission on the CV-990 was an extension of the baseline provided by previous ground tests in relation to the form, fit, and function of integrating a general type of biological payload within an aircraft to partially simulate an operational space mission. It also provided a means to identify problem areas of scheduling, manpower, pre-flight preparation, onboard maintenance, data acquisitioning, packaging, and interfacing with actual available support from aircraft sources which are very similar to "state-of-the-art" space hardware.

The study of experiment management under operational conditions where other activities are underway helps to define the man-machine interfaces requiring further development or refinement. This is particularly important for data acquisition and management. The information gained on the management of a monkey will be applicable to many other biological experiment packages. The preparation procedures for flight are equally important to study, since most biological investigators have not had the experience of scheduled development and flightworthiness requirements imposed upon their science.

The care and support of a 10 to 15 kg animal for seven days in a manner that ensures the collection of data and total comfort of the animal dictates a complex system requiring electrical, gaseous, and fluid interfaces. In addition, the experiments to be performed require a closed environment so that all metabolic products can be measured and precise monitoring of airflow, feed, and water is assured. Certain physiological activities are recorded through implanted biotelemetry that could be affected by other electronic systems in the area and could also have an effect on adjacent experimental, navigational, and operational systems using similar operating frequencies.

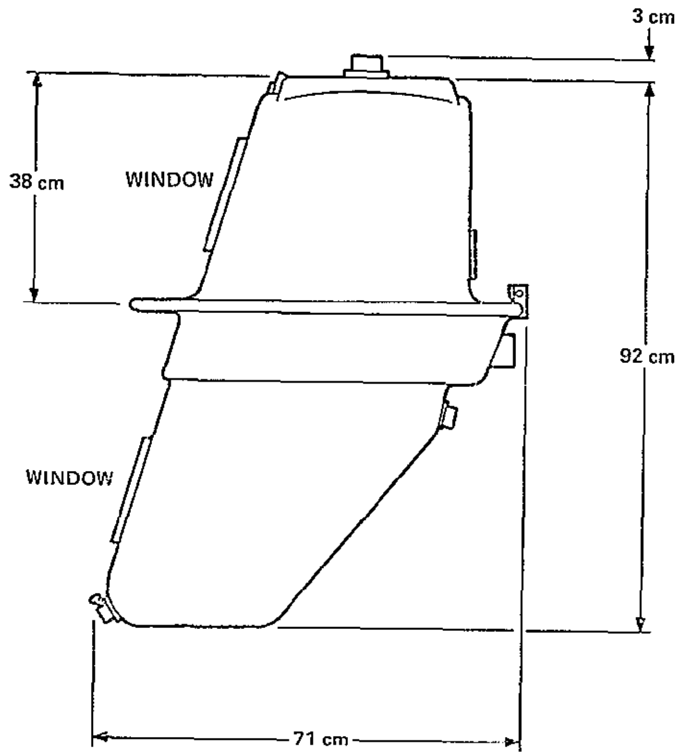
The monkey restraint.- The monkey pod that was used in this test has been under development by the Environmental Physiology Laboratory (EPL) of the University of California at Berkeley (fig. 2). This system consists of: (1) a fiberglass pod containing a comfortably restrained, instrumented, 10-12 kg monkey with feeding and watering devices and provision for excreta collection; (2) an electronics console containing the Skylab mass spectrometer with associated valving and electronic controls, sensing, regulating, recording, and monitoring units for lower body negative pressure, feeder activity, waterer activity, temperatures, and gas metabolism calibration; (3) interfacing gas flow lines and electronic cabling; and (4) an additional console, in principle representing support which could be provided from general aircraft sources. A block diagram of the system is shown in Figure 2. Additional electronic components were added to support the biotelemetry implants and to receive, record, or transfer transducer signals from the monkey's cardiovascular system. The monkey pod had undergone tests at the Environmental Physiology Laboratory for periods of up to 10 days; in addition, the system had been successfully operated as a part of the Shuttle Payload Concept Verification Tests conducted at NASA/ARC in April 1974, and at NASA/MSFC in October 1974. The pod is sized for the adult male pigtailed Monkey (*Macaca nemestrina*), but the system can be used as well with other macaques of equivalent size. With modification, it is also feasible for use with other primates. The features utilized could also apply to the development of a controlled physiological experiment package for some non-primate species such as the dog, miniature pig, or pygmy goat.

The effluent air from the pod was vented overboard. The pod system remained closed for the full test period, so that there was no danger of aircraft contamination. An investigator provided care for the apparatus. A Life Scientist accompanied the system on every flight to gain the greatest information possible and to experience the flight problems of a participating investigator.

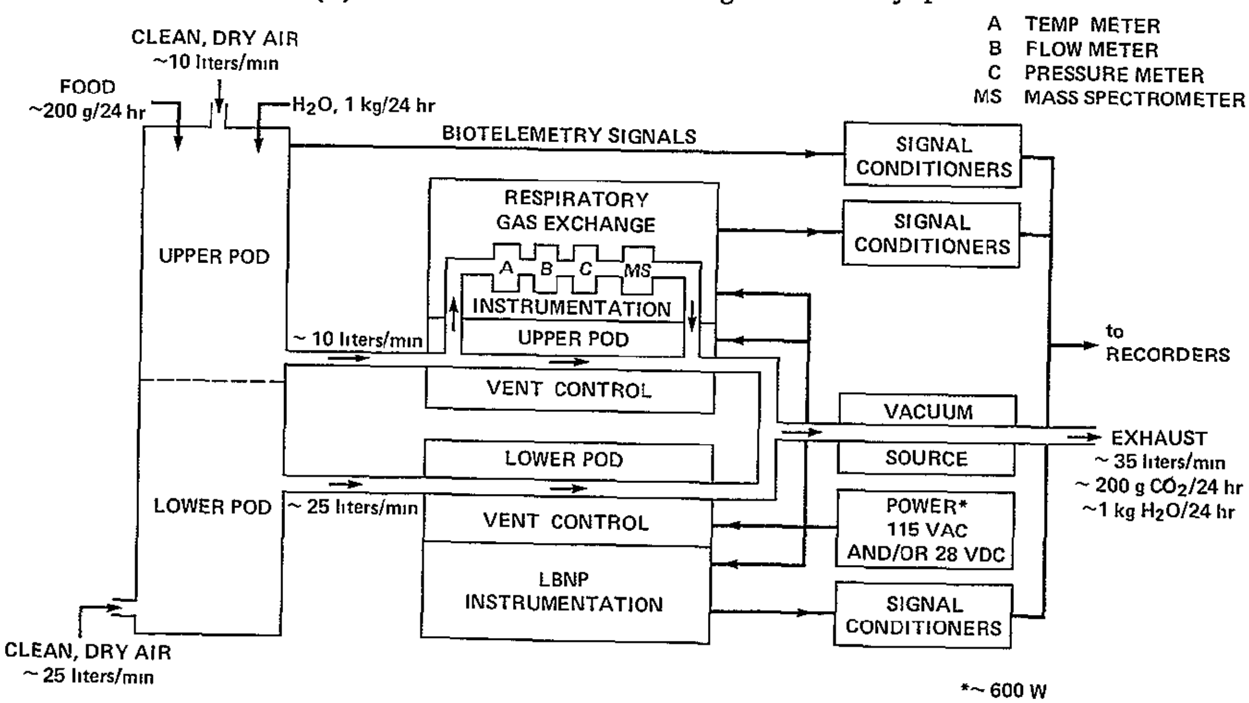
An important requirement for this test was a continuous supply of power throughout the mission. The animal remained in the pod throughout the mission, and therefore required continuous support from the environmental control system. Biotelemetry recordings of the cardiovascular system were made periodically and the application of Lower Body Negative Pressure as a challenge to the cardiovascular system was done inflight.

The implanted cardiovascular telemetry system.- Multichannel implantable systems for telemetering cardiovascular variables have been previously demonstrated in ground-based experiments (6,7). The multivariable systems were comparatively large and suitable only for animals weighing at least 20 kg, such as large dogs, baboons, or chimpanzees. Advances in miniaturized, hybrid circuit modules and use of inductively coupled power systems have made it possible to design a multichannel unit for implantation in monkeys (or dogs) as small as 10 kg. The system is shown in Figure 3

System description.- The operating principle of the implanted telemetry system is conversion of analog data to a multiplexed, pulse-width-modulated (PWM) format which frequency-modulates (FM) a radio-frequency (RF)



(a) Side view of the fiberglass monkey pod.



(b) EPL Monkey pod system.

Figure 2.- Schematic arrangement of the metabolic measurement system.

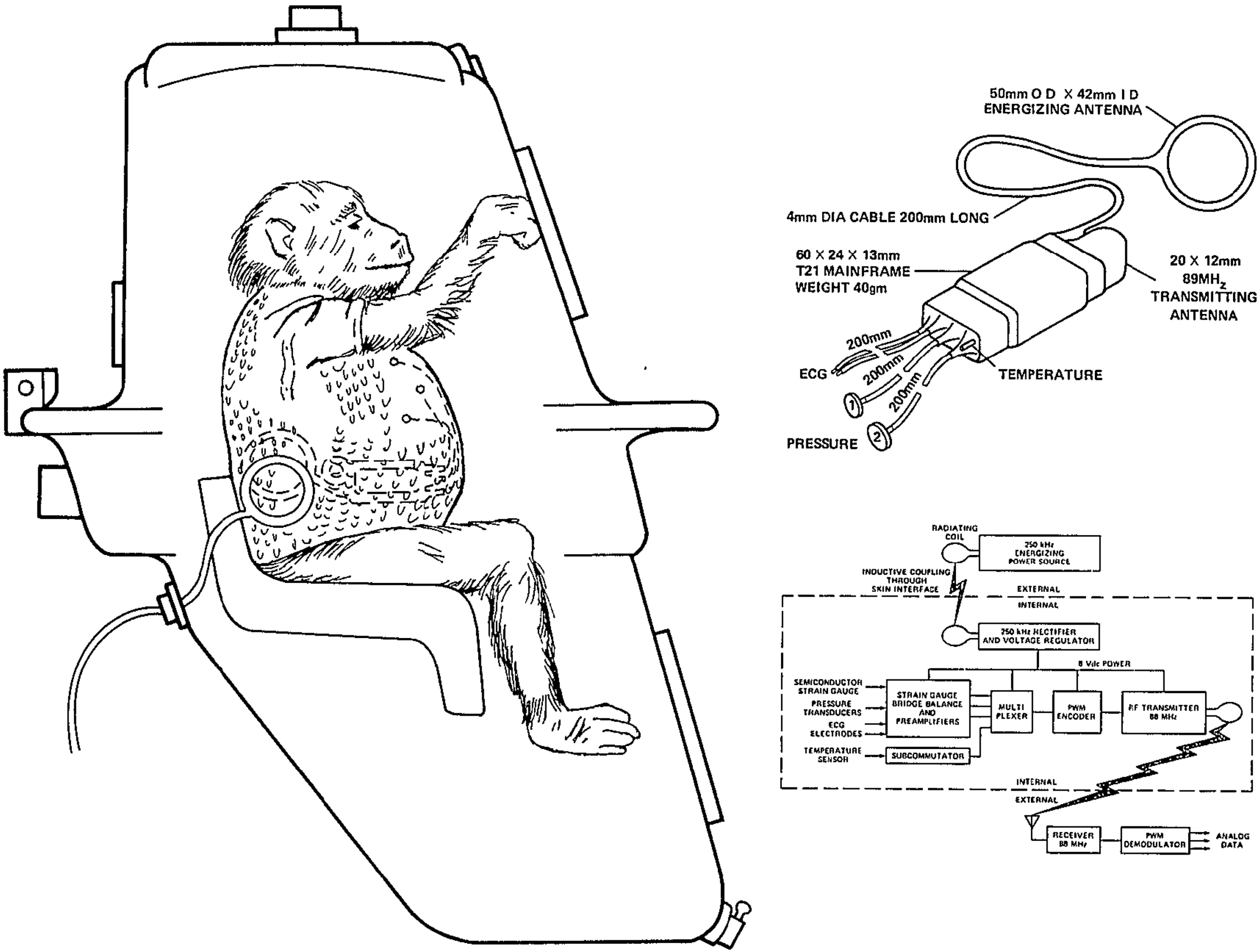


Figure 3.- Implanted cardiovascular telemetry system.

transmitter. The implanted components included two pressure transducers, a temperature sensor, and an electrocardiographic (ECG) lead. The transducers were connected to a hermetically sealed mainframe package (6 cm long, 2.4 cm wide, and 1.3 cm thick) containing power converter, signal conditioner, and 88-MHz transmitter with integral transmitting antenna. An attached Silastic-covered coil received power by inductive coupling from an external coil driven by a 250-kHz oscillator. Total weight of the implanted unit was approximately 40 g. The system was completed by an external receiver and demodulator which converted the PWM signal to the original waveforms.

No active power source was implanted. All energy for system operation was inductively coupled from an external energizing coil (7 cm o.d.) to an internal receiving coil (5 cm o.d.). The power source for the external coil supplied 250 kHz and operated at 20 V, 150 mA. A vest maintained the external coil position, and the coil power supply operated from the 115-V ac line. An alternative method would be to supply coil power from rechargeable batteries, with the entire assembly contained in the vest, to obtain data from an unrestrained animal.

The internal coil and power rectifier-regulator combined to provide an 8-V dc, 15-mA supply for operation of the internal system components. Total power consumption was approximately 150 mW.

<u>Multiplexer, transmitter, and receiver</u>.- Time-division multiplexing of the analog signals was achieved with a low-powered CMOS device. This technique converted the polarity and amplitude of the original signal into the width or duration of a pulse (PWM). The basic clock rate for system timing was 10 kHz. Time frames containing eight pulses or "words" were generated at 120 Hz. One of the eight words was a blanked pulse denoting the initiation of the sampling sequence. A second was a system zero reference. The other six words were used for the physiological and system monitoring data. The five-high-frequency channels were each sampled at 1250 Hz, providing a signal frequency response of at least 100 Hz. The sixth word sampled each of the eight subcommutated channels at 156 Hz, providing a frequency response of at least 15 Hz on each of the eight possible subchannels.

The maximum desired modulation of ±80%, altered channel pulse duration ±40 μsec. Signals exceeding the ±1-V multiplexer range would cause overmodulation with saturation and clipping; excessively low-level signals would contain noise.

The train of PWM information then frequency-modulated the 88-108-MHz RF carrier of the transmitter, which broadcasted from the internal loop through the tissue to an external antenna and telemetry receiver. The receiver bandwidth was 500 kHz to provide an acceptable rise time for the PWM signal. The transmitter operated within the maximum allowable field strength of 50 μV/m at 15 m for noncommercial applications. Despite this constraint, the transmitter easily achieved a 5-m range even in a noisy RF environment.

The encoding chain was designed to be independent of minor RF oscillator frequency drift and small variations in signal strength. Since the data were coded into the duration or width of each pulse, a highly linear frequency response in the transmitter and receiver was not required.

Demodulator, display, and recording.- The received signal was coupled to a demodulator which reversed the encoding process (1,8). The receiver output was clipped and limited to the demodulator to remove effects of amplitude variations. The individual decoded analog waveforms were then displayed on a CRT and processed in a standard manner with onboard direct-writing and analog tape recorders and a digital computer.

System accuracy.- The primary determinants of accuracy in this system were environmental RF interference, transmitter-receiver distance, percentage channel modulation, nonlinearity, and drift. At 80% modulation, 5-m range, in a relatively noisy environment, noise at the output was less than 0.1% of full scale, nonlinearity 0.25%, and zero gain instability less than 1% for a nominal accuracy of the total system of approximately ±2%, excluding transducer drift. Assessment of transducer stability required periodic calibration and comparison with a reference standard.

Implantation.- The entire unit was placed within the thoracic cavity, using surgical techniques similar to those reported previously (6,7). The pressure transducers were coated with TDMAC-heparin complex prior to implant to minimize the possibility of thrombus formation. The main unit was stabilized on the rib cage in the intrapleural space deep in the posterior thoracic gutter just above the diaphragm. The internal coil was positioned just cephalad to the main unit in an area where the chest musculature was minimal. Antibiotic coverage was begun the day of surgery and continued 5 to 7 days after surgery.

Flight test results.- On 28 January 1975, an adult male pigtailed monkey #396, was shipped from EPL/UCB to NASA/ARC as a potential surgical candidate for the chronic implantation of a cardiovascular telemetry device. The implanted device derived its power input from an exterior energizing coil, rather than batteries, thus prolonging its useful life. Following an appropriate quarantine, this monkey was successfully implanted on 23 February 1975. Through the months of March 1975 to April 1976, electronic checkouts were made on the T/M monkey system. On two occasions during this time period, the test subject was restrained within the pod and electronic signals for left ventricular pressure (LVP), aortic pressure (AP), electrocardiogram, and heart rate were recorded on strip chart.

With the experience gained from this initial non-human primate trial, some design modifications were made in the T/M device and a second monkey, #337, was shipped from EPL to NASA/ARC on 17 July 1975. This monkey was considered an excellent candidate for T/M implantation, having participated in monkey-pod trials at EPL/UCB and Shuttle Spacelab Concept Verification Tests at Ames Research Center and Marshall Space Flight Center. Parallel efforts included modifying bioinstrumentation of the monkey pod system to allow commutation of data acquisition between two pods, a method for obtaining timed urine samples uncontaminated by feces, and extending continuous pod tests to 15 and 30 days duration. The second monkey pod was delivered to EPL/UCB following fabrication at NASA/ARC, bench tested, and finally incorporated into a two-pod integration test.

System interface test.- To further investigate the changes in physiology and biochemistry that were observed in the Skylab astronauts, for many investigators the animal of choice is a monkey. The monkey restraint system that was tested consisted of the following elements:

(1) Two pods mounted in a rack on the port side of the aircraft, each holding one adult male pigtailed monkey. The inboard monkey was the one that had been surgically implanted with a telemetry device, as previously described (#396), to measure heart rate, aortic pressure, left ventricular pressure, and body temperature. Heart rate from the other monkey serving as a control was obtained by conventional body-surface ECG electrodes. Both pods were identical in all respects in that they were divided into an upper and lower portion by a rubber membrane so that excreta could be collected for subsequent analysis in the weightless state without contamination of the upper pod. The separated upper-pod section allowed the monkeys to breathe fresh cabin air. The exhaust atmosphere from the upper pods was measured continuously by a mass spectrometer for oxygen, carbon dioxide, nitrogen, and water vapor. The difference in the gas concentration between the inflowing and outflowing air stream permitted an accurate estimate of the metabolic rate of the monkeys. Food and water were accessible to the monkeys on demand. In addition, provision was made to position the pod so that the test subjects were in either a supine or a horizontal mode in order to remove the head-to-toe gravity gradient for application of lower body negative pressure as a cardiovascular challenge. (Figures 4 and 5.)

(2) Mounted to the immediate rear of the monkey-pod subsystem was a bioinstrumentation rack interfaced with appropriate gas and electronic lines. This CV-990 highboy rack contained the mass spectrometer with controls for continuous measurement of the metabolic gases, devices for measuring upper and lower pod temperatures and pressures, air flow controls, voltage regulator controls for the application of lower body negative pressure (LBNP), a water reservoir, nutrient intake indicator, and signal conditioners for interfacing with the data recording system. Data measurements were continuously commutated between the two pods. (Figure 6.)

(3) Operator and Observer were seated behind the bioinstrumentation rack and a CP 100 digital tape recorder located on a lowboy rack was immediately behind them. (Figure 7.)

(4) A highboy rack to the rear of the tape recorder housed the instrumentation for the NASA/ARC telemetry data acquisition. An oscilloscope, power supply, digital voltmeter, demodulator, F/M receiver, and strip-chart recorder were mounted in the rack. (Figure 8.)

(5) Across the aisle on the starboard side opposite the bioinstrumentation rack, a highboy rack contained the strip-chart recorder for the data

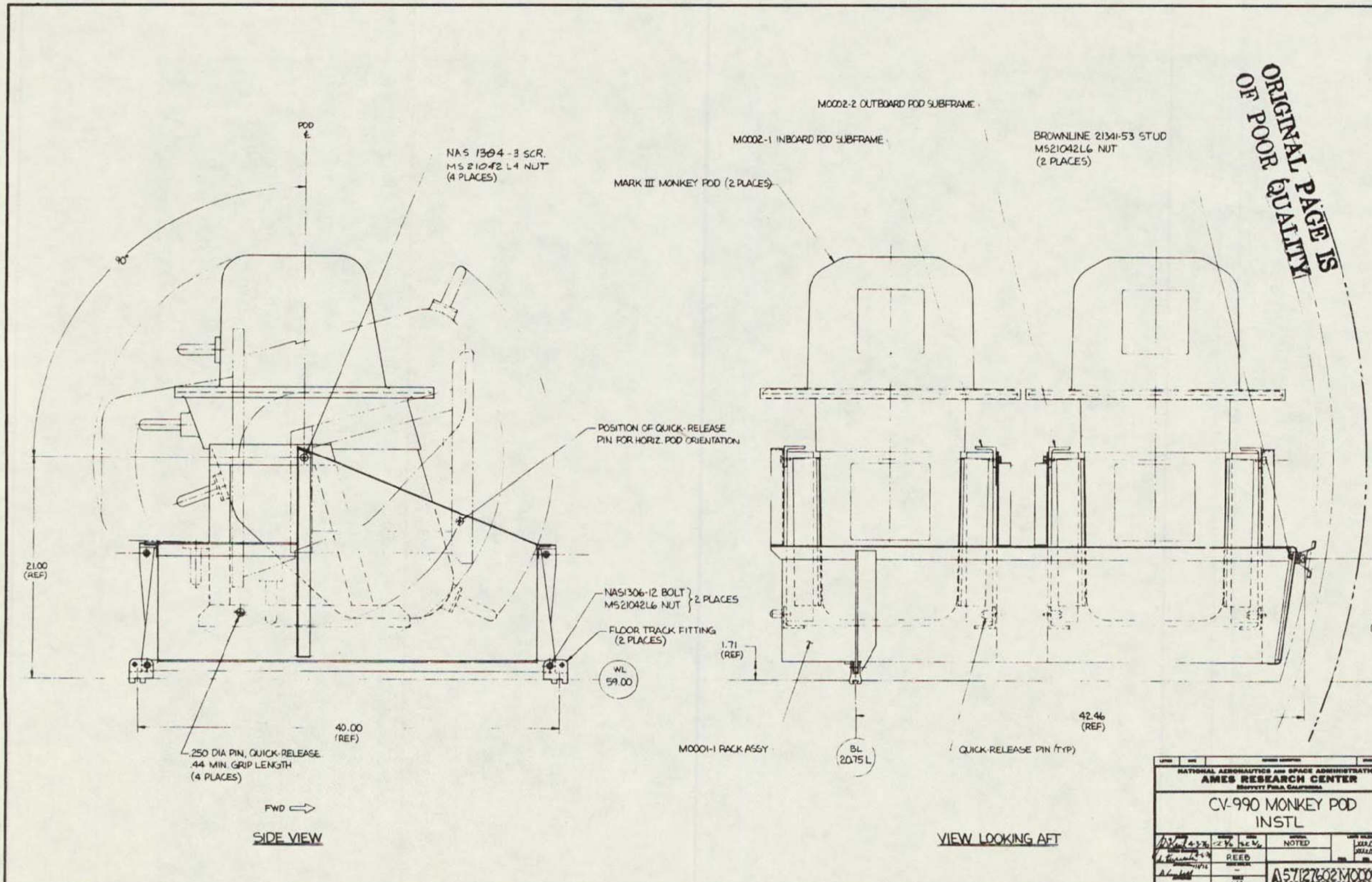


Figure 4.- The CV-990 monkey pod installation.

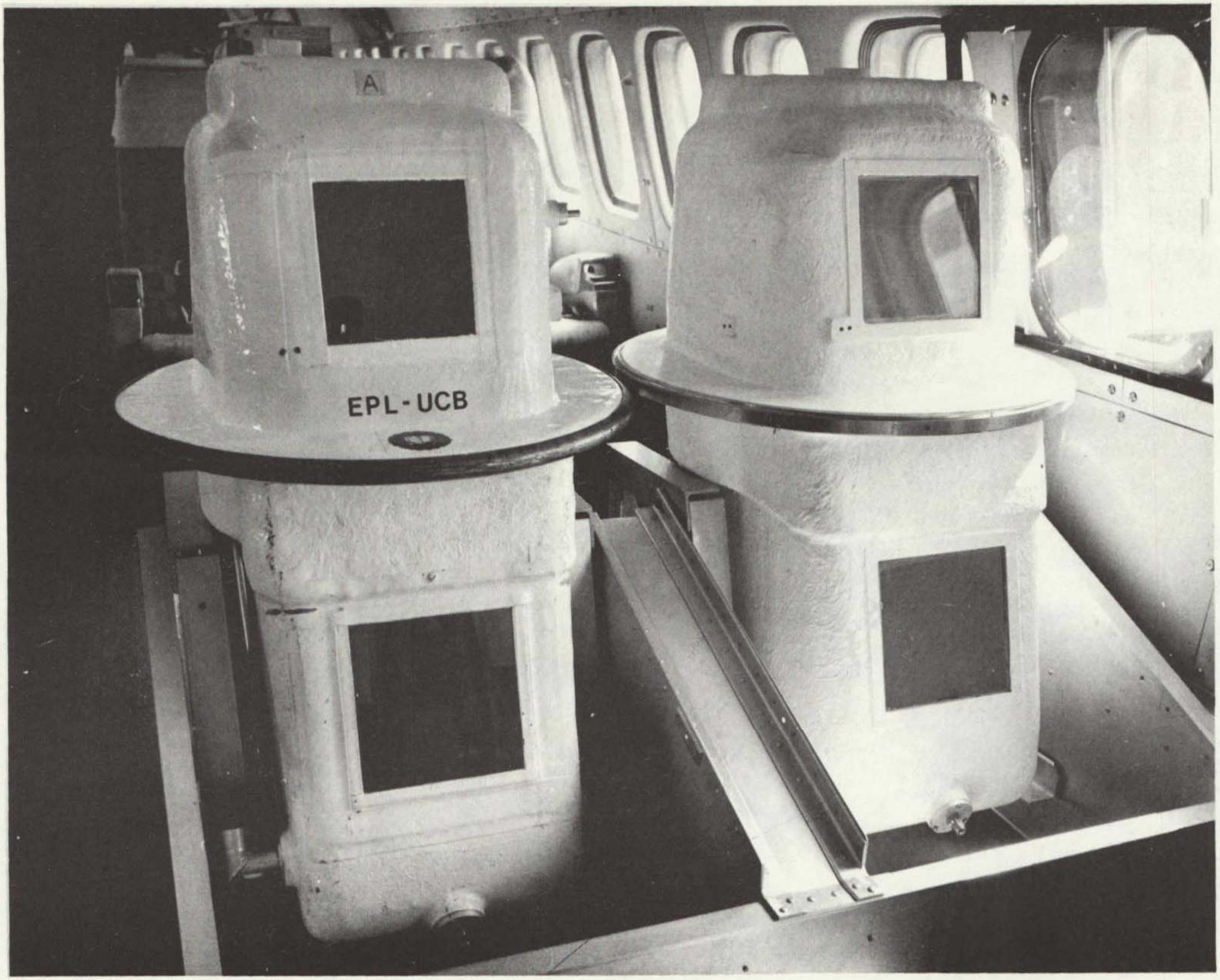


Figure 5.- Monkey pod in the CV-990

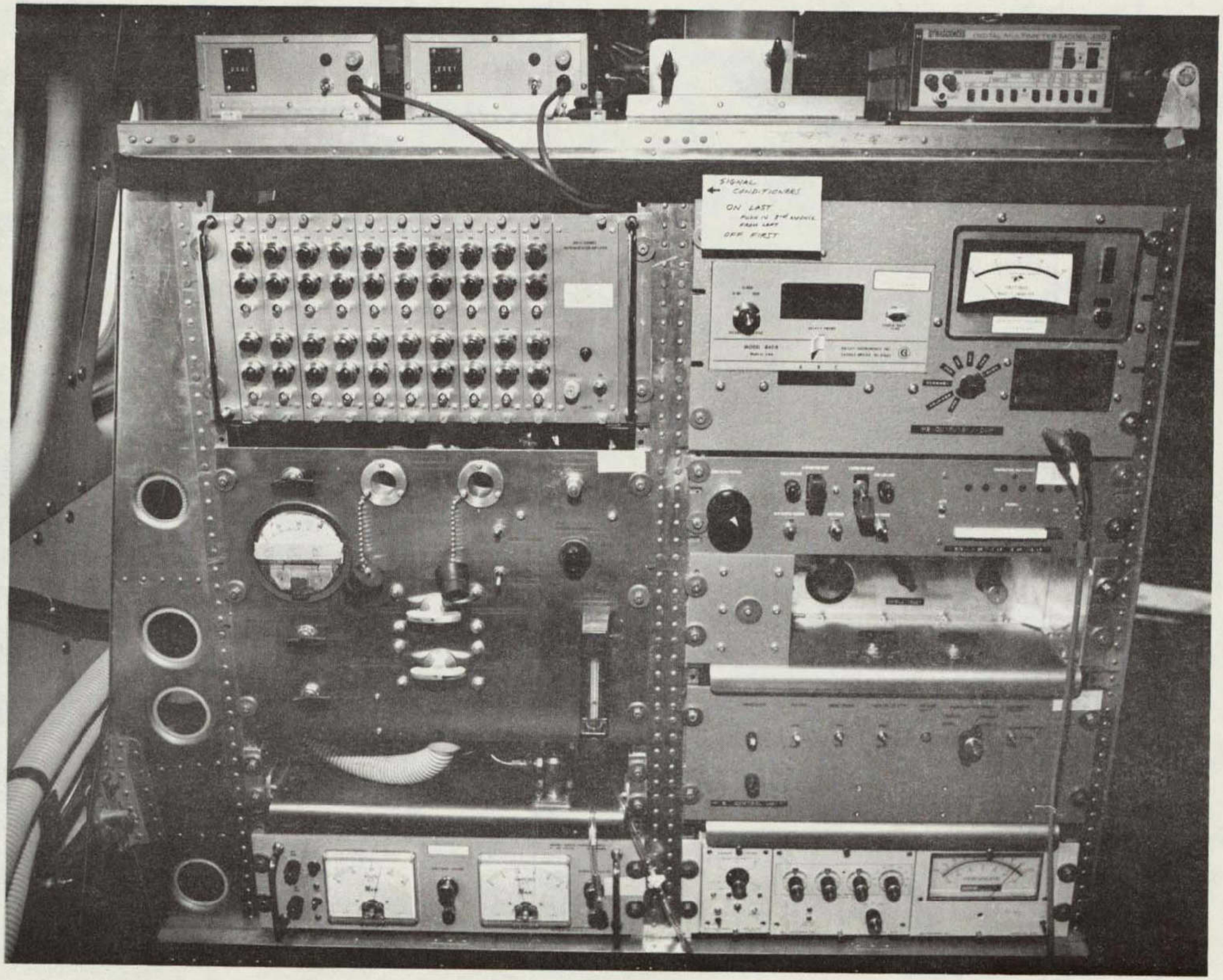


Figure 6.- Metabolic measurement instrumentation and pod support apparatus mounted in the CV-990 rack.

Figure 7.- The CP 100 digital tape recorder.

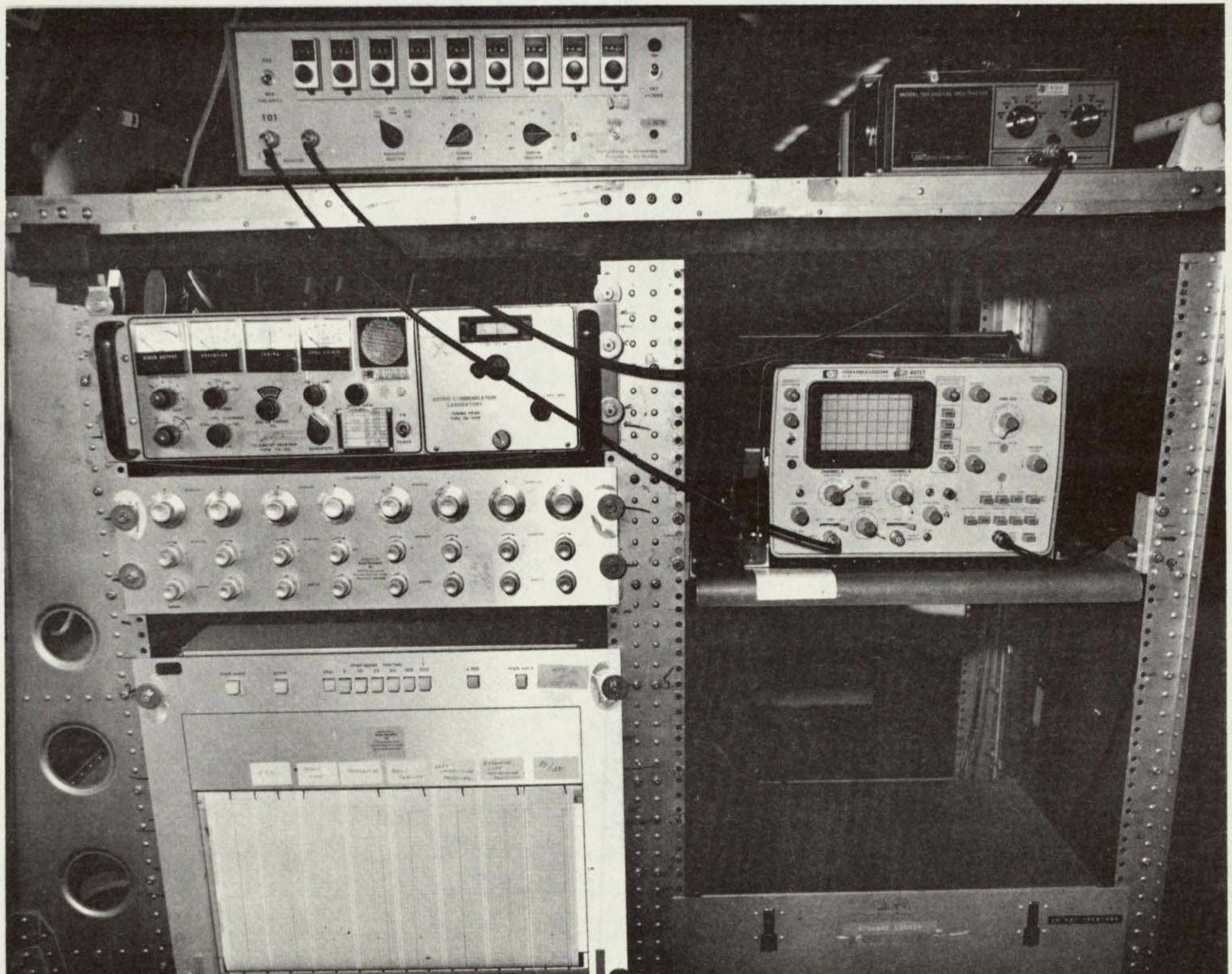


Figure 8.- Rack-mounted data acquisition instrumentation for the telemetered cardiovascular measurements.

output of gaseous metabolism and cardiovascular parameters. It also contained the interface to the ADDAS computer located in the forward section of the aircraft. (Figure 9.)

The two-pod holding rack remained in position secured to the interior of the aircraft during the entire test period. Each monkey pod with attached stand could be positioned in this rack, removed from the rack when desired, and conveniently transported to other locations on- or off-board the aircraft. While the pods were mounted within the rack, the monkey pod could be positioned either in the vertical or horizontal position by means of appropriately placed quick-release pins.

As in previous tests, the feeder was mounted within the upper pod shell. However, the constraints of the aircraft dictated a reduction in dimensions of the water reservoir and, for the purposes of this test, the reservoirs were placed on top of the bioinstrumentation rack and interfaced by connecting fluid lines to metal nipples mounted in the upper-pod sections.

Preliminary sketches were compiled for accommodating the modular components in a standard highboy rack to provide efficient access to hand controls, and to comply with airworthiness requirements, which called for mounting the heaviest components near the bottom of the rack to reduce the overturning moment. Several changes were made in the original concepts following consultation with the structural engineer. Special shelves and bracketry also had to be fabricated by the NASA/ARC Metal Fabrication Shop. Some delays were encountered in the procurement of the correct shelves and bracketry, which impacted on the electronic work and hence on the time scheduled for completion of the airworthiness tasks for this rack. Thus, it was not put in place aboard the aircraft until Saturday, 8 May 1976.

In the transfer of the instrumentation modules to the aircraft racks, all the power cabling, with the exception of the lines to the vacuum pumps located in the cargo bay, was installed as in the laboratory model. However, it was estimated that 90% of the signal cables associated with the respiratory gas instrumentation had to be replaced and all of the wiring for lower body negative pressure plumbing and controls completely redone. The vacuum pumps used in the laboratory for LBNP were considered a fire hazard on the aircraft, and considerable time and effort were consumed in attempting to provide suitable substitutes.

Approximately 2 months prior to the first scheduled flight, the ARC aircraft electrical inspector indicated that the existing LBNP pump and voltage controller would not pass aircraft electrical inspection. Both items were deemed unacceptable because of the possibility of sparking. An attempt was made to find a substitute LBNP pump, both within and outside of ARC. Three pumps were obtained for testing: a 28 Vdc axial, a 28 Vdc centrifugal, and a 110 Vac centrifugal, all supplied by ARC. All 3 pumps subjectively appeared to provide less airflow and have less capability to develop a significant pressure differential than the original LBNP pump, but this comparison was made difficult because of large differences in pump orifice sizes.

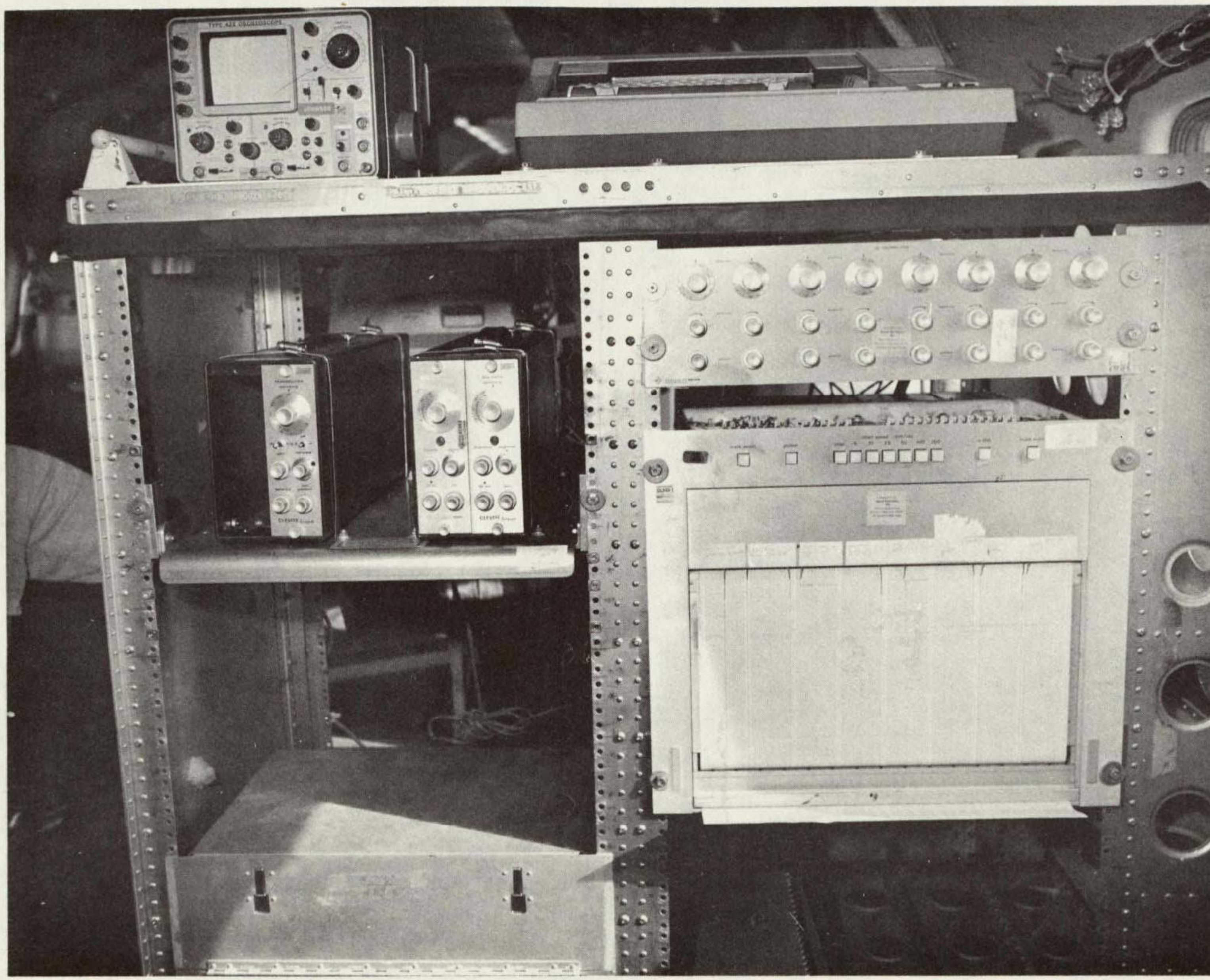


Figure 9.- Data interface with the flight computer system, ADDAS.

After consultation with ARC electrical and mechanical engineering staff, it was decided that two of the 28 Vdc axial pumps mounted in parallel might provide enough capacity to conduct the LBNP test. A manifold system which provided a single inlet and outlet was designed and fabricated at ARC. A 28 Vdc power supply was adapted so that output voltage to the pumps could be controlled from 0 to 28 Vdc. Unfortunately, this system was able to produce only about 10% of the pressure differential produced with the original LBNP pump; consequently, approval was obtained to use the original LBNP pump and voltage controller on the CV-990 for ground-based LBNP tests. The aircraft-approved 28 Vdc pumps were mounted in the UCB bioinstrumentation rack and used during flight to simulate an LBNP test and verify the adequacy of the electrical power and data interface for this subsystem. For the CV-990 flights, a new 2-pod LBNP control panel was designed and fabricated, which provided for the independent application of LBNP or fixed flow rate ventilation to the lower half of either pod as desired. These factors and the delay in delivery of appropriate shelving and bracketry caused an additional last-minute rush to complete the wiring in this rack.

An additional module not incorporated in the EPL bioinstrumentation laboratory rack contained the signal conditioners that interfaced the sensed physiological parameters with the data-acquisition system of strip-chart recorders, the CP-100 14-channel analog tape recorder, and the ADDAS. The commutation of information from two pods had previously been demonstrated at EPL, and the measurements of respiratory gases were multiplexed for one-channel input for strip-chart and tape recording, while the ADDAS received these signals separately. The signals were identified by code to indicate from which pod they originated. A 6-channel multiplexer was also incorporated for temperature measurements: (1) M/S inlet temperature, (2) upper pod #1, (3) lower pod #1, (4) upper pod #2, (5) lower pod #2, and (6) reference and calibrations.

The total number of parameters identified by the signal conditioner are listed in Table 1. Table 1 shows the distribution of the data to ADDAS, the CP-100 tape recorder, and the 2 strip-chart recorders.

Data acquisition rack.- Table 2 contains the list of modular components included in the EPL/UCB Data Acquisition Rack (standard highboy). The Tektronix R-4010-1 console, including an ADDAS teleprinter with keyboard, was mounted initially in this rack, but during the course of the flights was removed for use on another experimental aircraft. No untoward complications arose as a result of mounting this equipment. The total weight of these modules was within recommended limits. Bracketry for the recorder and strapping for the packaged strip-chart couplers were fabricated by the sheet metal shop. Although chart paper pickups were available, they were not mounted on the recorders due to time limitations. The strip-chart recorders were mounted in the outboard bay at a height where a seated experimenter could reasonably make notations on the chart paper during flight.

Cabling from the signal conditioner in the bioinstrumentation rack provided the interface with the data acquisition rack. Problems were

TABLE 1

DATA DISTRIBUTION FOR MONKEY-POD FLIGHTS ON NASA/ARC CV 990

	PARAMETER	ADDAS CHANNELS	SAMPLES/SEC	TAPE CHANNELS	STRIP-CHART #1 CHANNELS	STRIP-CHART #2 CHANNELS
1	Mass Spec. F O_2	1	1	1	1	
2	Mass Spec. F CO_2	2	1	1	1	
3	Mass Spec. F H_2O	3	1	1	1	
4	Mass Spec. F N_2	4	1	1	1	
5	Mass Flow	5	1	2	2	
6	Mass Spec. inlet pressure	6	1	-	3	
7	Upper Pod Pressure	7	1	3	4	
8	Lower Pod Pressure	8	1	-	6	
9	Mass Spec. inlet temperature	9	1	4	5	
10-13	Pod temperature	9	1	4	5	
14	Pod #1 water and feed	10	10	5	-	
15	Pod #2 water and feed	11	10	6	-	
16	TM #1 heart rate	12	1	7	7	
17	TM #2 heart rate	13	1	-	8	1
18	TM #2 aortic pressure	14	250	8		2
19	TM #2 ventricular pressure	15	250	9		3
20	TM #2 body temperature	16	1	10		4
21	TM #2 ECG	17	250	11		5
22	TM #2 left ventricular dP/dt	-		-		6
23	TM #2 left end diastolic pressure	-		-		7
24	Voice	18		12		-
25	Pod identification	19	1	13		-
26	Time code	20	1	14		8

TABLE 2

Dimensions of Modular Components Contained in the CV-990 EPL/UCB Data Acquisition Rack

INSTRUMENT	WIDTH cm	DEPTH cm	HEIGHT cm	WEIGHT kg
Tektronix R-4010-1 Console	42.5	50	28	7.3
Tektronix Signal Conditioner	48	51	22	13.6
Strip-Chart Recorder	40	36	42	47.7
Strip-Chart dc Preamplifier	44	29	14	4.5
3 Strip-Chart Couplers (2 Cardiotachometers and 1 Transducer)	20	48	15	8.0
Strip-Chart Power Supply	12	48.5	8	6.8
Strip-Chart Power Supply	12	48	8	5.9
Total Weight				93.8

encountered in the multiplexed temperature recordings, particularly the reference temperature, which drifted relative to the ambient temperature within the aircraft.

Tape Recorder CP-100.- The analog tape recorder was mounted on a lowboy rack behind the operator. This instrument weighed 97.6 kg and measured 84 × 48 × 31 cm. No pre-flight mechanical problems were experienced, as this device had a reliable history of flight aboard the CV-990. Fourteen channels of physiological data with provision for voice recording were planned as outlined in Tables 1 and 3. Provision was also made to identify portions of the tape for playback and comparison with strip-chart recordings. During the instrument assembly, several meetings were held with the contractor responsible for the operation of the CV-990 computer. There was an obvious communication gap between the investigator and the programmer. The electronics engineer maintained close liaison between the experimenters and programmers to assure the electronic integrity from signal conditioners to the data acquisition systems. Experimenters submitted detailed information in regard to their measurements and computer printout requirements for the online computation and data reduction on the following: respiratory gas exchange measurements, mass spectrometer inlet pressure and upper pod pressure, online computation of lower pod pressure, mass spectrometer inlet, upper and lower pod temperatures, heart rates, and nutrient intakes. These values were then worked into the language and form used by the programmers.

Insertion procedures.- Insertion of the test subject in the couch and pod were carried out in the Bioscience Laboratory. The restrained monkeys and pods were then transported to the Airborne Science Laboratory, where they remained ready for flight participation. Three people were required for this activity.

In general, the assembly of parts and insertion of the test subjects proceeded without major difficulty. For several weeks the available test subjects had consumed food rations in excess of maintenance requirements. As a result, monkey #337, in particular, was extremely obese in relation to his overall stature. Despite this condition, the midpiece subassembly and the restraint jacket were able to accommodate his abdominal dimensions. The placement of the external T/M energizing coil for #337 was carefully monitored electronically during the insertion procedures to provide the optimum location between the jacket and the external thorax. Thus, the T/M monkey took slightly longer to enclose completely in the pod than did the control animal with cutaneous ECG leads. (Figure 10.)

From preliminary postsurgical evaluations of all the biotelemetry implanted monkeys referred to in Table 4, #422 was considered to transmit the best quality signals. It was planned to utilize this animal in the last week of the flight series when all experiment systems would potentially be in full operation. However, on 17 May 1976, when this animal was scheduled to be inserted in the pod, an area of infection requiring clinical care was noted on the thorax near the surgical wound. It was deemed advisable to delete this animal from the experimental schedule, and monkey #337 was again placed in pod restraint for this flight period.

Figure 10.- Pig-tailed monkey during insertion into the monkey pod restraint.

TABLE 3

Data recording requirements for monkey pod flights on NASA/Ames CV-990

Parameter	#1 Pod Record Interval	#1 Pod Sample Duration	#1 Pod Printout Rate	#1 Pod Sample Rate	#2 Pod Record Interval	#2 Pod Sample Duration	#2 Pod Printout Rate	#2 Pod Sample Rate	Tape Channel	Strip-Chart Channel
1. M/S F_{O_2}	15m/30m	30 sec	1/min	1/sec	15m/30m	30 sec	1/min	1/sec		
2. M/S F_{CO_2}	15m/30m	10 sec	1/min	1/sec	15m/30m	10 sec	1/min	1/sec	#1	#1
3. M/S F_{H_2O}	15m/30m	10 sec	1/min	1/sec	15m/30m	10 sec	1/min	1/sec		
4. M/S F_{N_2}	15m/30m	10 sec	1/min	1/sec	15m/30m	10 sec	1/min	1/sec		
5. Mass Flow	15m/30m	C		1/sec	15m/30m	C		1/sec	#2	#2
6. M/S Inlet P	15m/30m	C		1/sec	15m/30m	C		1/sec	#3	
7. Upper Pod P	15m/30m	C		1/sec	15m/30m	C		1/sec	#4	#3
8. Lower Pod P	15m/30m	C		1/sec	15m/30m	C		1/sec	#5	
9. M/S Inlet T	15m/30m	20 sec	1/min	1/sec	15m/30m	20 sec		1/sec		
10. #1 Up Pod T	C	10 sec	1/min	1/sec						
11. #1 Low Pod T	C	10 sec	1/min	1/sec					#6	#4
12. #2 Up Pod T					C	10 sec	1/min	1/sec		
13. #2 Low Pod T					C	10 sec	1/min	1/sec		
14. #1 Pod Water	C	C		10/sec					#7	
15. #2 Pod Water					C	C	1/min	10/sec	#8	
16. #1 Pod HR	C	C		1/sec					#9	
17. #2 Pod HR					C T/M	C			#10	#5
18. #2 Pod AP					C T/M	C	1/min	250/sec	#11	#6
19. #2 Pod LVP					C T/M	C	1/min	250/sec	#12	#7
20. #2 Pod BT					C T/M	C			#13	#8
21. #2 Pod ECG					C T/M	C	1/min	250/sec	#14	

TABLE 4

T/M implanted monkeys: summary as of 13 April 1976

No.	Weight kg		Date of Surgery	Unit No.	Last Date Checked	Status/Comments
<u>Flight Animals</u> - Pigtail (*M. nemestrina*)						
EPL #337, Simple	Pre Post	16.0 14.25	24 Mar 76	T21B-1 #116	13 Apr 76	Satisfactory; LVP = ? some trapping
EPL #422, Bushy	Pre Post	11.80 10.5	6 Apr 76	T21B-3 #120	13 Apr 76	Best signals, all excellent
<u>Test Animal - Pigtail</u>						
EPL #396, Lovel	Pre Post	13.5 14.0	26 Feb 75	T21B #101	13 Apr 76	Signals present, but low level, very poor quality

Prior to each flight, the monkey pods were separated from the ground-based laboratory environmental support apparatus in the Airborne Science Laboratory. The support consisted of water and food reservoirs and provision for air exchange in the upper pod. Air flow for the lower pod was also available, but it was not used during the experiment, since excreta odors were minimal. Urine was removed from the collection bag each morning prior to movement of the pods to the aircraft.

Although a preliminary schedule of estimated takeoff times was issued, it was not known precisely when the events would occur until the "standup" meetings were held each morning at 0815 in the Airborne Science Laboratory. It was also advantageous to move the pods onboard at a time which would minimize the possibility of prolonged environmental changes due to power outs, preflight activity of support personnel, and cabin temperature buildup while the doors were open on the aircraft. In addition, the majority of the instrument calibrations associated with the monkey pod system could be made without the pods installed onboard. Therefore, movement of the pods to the aircraft was scheduled to correspond as closely as possible to door closure which, in turn, was approximately one-half hour before takeoff.

Upon reaching this milestone, the pods were placed on platform dollies and then loaded onto a forklift vehicle and moved to the aircraft. The location of the aircraft at this time varied with each scheduled flight day, being either within the hangar or just outside on an adjacent ramp. In both situations, the time on the forklift did not exceed 5 minutes. As an emergency backup, a lightweight, foot-controlled air pump with line attachment was available for pod use at all times. The device was not used during the course of these trials, since the maximum period that air was not provided to the upper pod never exceeded 20 minutes.

Onboard loading of the pod was accomplished through the aft cabin door with the designated outboard position pod entering first, dollied forward in the aisle, and secured to the rack. The inboard pod was then secured in a similar manner. Two trained employees of the aircraft metal shop loaded and secured the monkey pods aboard the aircraft.

As a result of preliminary meetings, the biotelemetry system was checked out for aircraft electronic interference during a preliminary flight on 30 April 1976. The pods, secured in the rack without test subjects, were also subjected to an engineering checkout flight on 4 May 1976. During flight, the pods were adjusted to both the horizontal and vertical positions without difficulty, and all specifications for the pod in-flight hardware were deemed to be adequately met.

Two flights with one pod and a telemetry implanted monkey followed on 6 and 7 May. When the EPL/UCB instrumentation rack was installed aboard the aircraft, 2 monkey pods with test monkeys (one control and one T/M implanted) were flown on 11, 13, 17, 19, and 21 May 1976.

Throughout the total flight activity involving more than 50 takeoffs and landings, the monkey pod functioned well as an element of the total experiment package incorporated in an aircraft on an operational mission. A few of the specifics in relation to operation and performance are noted below:

(1) No delay in onboard loading of the pods with experimental monkeys was noted. The pods were ready for transfer without interfering with other flight operations, even though non-experiment related, last-minute schedule changes occurred each day.

(2) It was demonstrated that the monkey pods provide a comfortable and feasible restraint device for a non-human primate that can be used as a surrogate for man in investigating aerospace-related physiological phenomena.

(3) Safety aspects of the pod were evident, both with respect to the test subjects themselves, and in relation to the immediate attendant personnel. In addition, visitors to the area, either in the ground-based laboratory or onboard the aircraft with little or no knowledge of biology, were able to be in proximity to the animals with minimal impact on the experiment. Although it is realized that constraints on the presence of humans during the performance of certain aspects of a controlled physiological experiment may be necessary, it is also evident that emergency situations can arise which may involve the interaction of inexperienced personnel with the test subjects, and which could be remedied without trauma to person or animal.

(4) Troubleshooting of pod experiment-module malfunctions proved to be feasible without removal of the monkey. As an example, the feeder jammed during a portion of the test period. As presently designed, this subsystem requires the separation of the upper pod hood for installation and most major repairs. This was accomplished with both pods on several occasions in the ground laboratory area after all other approaches had been tried without corrective results.

The following notation is a record of this activity:

Date	Monkey	Time of Hood Removal	Remarks
12 May	#174	1400-1550	Mechanical malfunction feeder — removed, cleaned, air-dried, and replaced.
	#337	1500-1610	Feeder cleaned and replaced.
13 May	#174	0830-0950	Inspection of feeder mechanism. Monkey hand-fed while hood removed.
18 May	#174	0850-1205	Lightly tranquilized with Ketamine(R) HCl (60 mg) I.M. and subcutaneous ECG leads refurbished.
20 May	$337	0845-1145	Feeder electronic check.

(5) Clear, uncontaminated, 24-hour urine samples were collected from both test monkeys by a method which should function in a weightless environment.

(6) The pods were tilted within the aircraft-mounted rack without difficulty on the ground and in flight. Landings and takeoffs occurred while the pods were in either the horizontal position, which increased the $\pm G_z$ load, or vertically, which increased the $+G_x$ load. Components of the pod and interfacing electronic, gas, and water lines remained integrally sound in both these situations, as well as during short periods of weightlessness.

Bioinstrumentation rack.- During flight, single-phase 60-Hz 115V aircraft power was supplied to this rack from Station 17. An internal power supply located within the rack provided direct current for the M/S control unit, calibration gas solenoid valves, the 4-way valve and 2 heating tapes. This power supply was set at 25 Vdc. All other components operated on alternating current.

Although the 4-way valve for alternately sampling the upper pod exhaust gases vibrated considerably during takeoffs and landings, it continued to function satisfactorily throughout the test period.

During flight, the protocols were followed for operating the respiratory gas-exchange modules. The signal-conditioner system was not switched on until all the modules, including the mass spectrometer, were in an operating mode. Conversely, the signal conditioners were switched off prior to shutdown of the respiratory gas-exchange apparatus.

The signal-conditioner module carrying the transmission of the mass spectrometer inlet pressure data had to be powered after the remaining modules were switched on due to an apparent incompatibility with the mass spectrometer electronics. If this sequence was followed, no interference with other parameters was noted and reliable signals were obtained. Corrective action attempted by electronic support personnel during the course of these trials failed to alleviate the situation.

Some difficulty also arose with the commutated temperature-signal outputs. The calibration or reference temperature appeared to drift with changes in aircraft cabin environment. This, in turn, may have had some impact on the accuracy of pod temperatures recorded during the test.

Eating and drinking activity signals were not reliably recorded due to electronic incompatibility, and attempts made to correct this malfunction were not completely satisfactory. Spurious signals emanated from one feeder, whereas the other did not register feeding-lever manipulations by the monkey subject. The feeder and waterer, which had functioned satisfactorily during previous tests, were dismantled during the course of instrument preparation for the present tests. Some of the components were utilized with additional parts in fabricating a modified system which would conform to the constraints of the aircraft. With limited time and personnel involved and other facets of fabrication given higher priorities, the system was not given a substantial baseline test. However, backup provision for food and water dispensing was adequate to maintain the physiological integrity of the test subjects. During actual flights, access by the monkeys to food pellets was limited and the water allowance was controlled by a hand valve.

Data-acquisition problems arose in the interfacing of the biotachometers. The condition improved, however, with each successive flight. The cardiovascular signal input from the telemetry-implanted monkey was not of optimum quality when compared to that received from the cutaneous ECG leads. The parameters associated with respiratory gas exchange were recorded within acceptable limits. There appeared to be no other major problems specifically associated with these components. A strip-chart paper pickup would have been desirable; one was provided but not mounted on the recorder. With the recorder running at slow speed for the majority of the time, folding of the data paper was easily accomplished manually.

Fourteen data channels of respiratory gas-exchange and cardiovascular parameters (both Control and T/M) were selected for inputs to the CP-100 recorder. A voice channel identified specific locations on the tape corresponding to the direct strip-chart recordings. Post-flight playbacks to a strip-chart recorder were made to compare data output and acquisition resulting from the two methods.

NASA/ARC biotelemetry (T/M) rack.- As shown in Table 5, a preliminary flight with certain components of the biotelemetry system including an implant module were tested aboard the CV-990 for the possibility of any radio frequency interference or electromagnetic interference (EMI) between the aircraft and the system or within the system itself. When the total instrumentation package, including receiver, demodulator, strip-chart recorder, power supply, and ancillary equipment, was flown in a standard highboy rack it apparently functioned well. Data dropouts during portions of the flight were attributed to shifts in position of the externally placed energizing coil. Adjustment of the aortic pressure tracing on the strip-chart recording channel was frequently required. No doubt this was due to the design requirement of having the aortic pressure transducer ac-coupled to prevent zero drift.

ADDAS Experimental Input and Output.- The printouts obtained from the ADDAS computer were fragmentary prior to the flight of 17 May 1976. On this flight, data outputs were shown successfully as voltages. On the final two flights of 19 and 21 May, the parameters were printed in physiological units. Only two on-line problems were encountered and were partially alleviated in progressive flights. These were shifts in input calibration voltages and programming bugs. Figure 11 shows a sample of the ADDAS printout with added explanatory notes of the monkey pod experiment parameters. The "report" or printout was obtained from the ADDAS once every minute, and lists the computed mean value based on a sampling frequency of 1 per second for all parameters except water and food intake. Drinking and eating activities were sampled 10 times per second in order that the occurrence of events would not be missed.

TABLE 5

Summary of monkey pod experiment NASA CV-990 flights

Date		Experiment Elements Onboard	Number of Experiment Personnel Onboard	Remarks (Hrs = Duration from Takeoff to Return)
30 Apr 76	Fri	Checkout T/M electronics for A/C RFI or EMI problems	2	No electronic interference Moffett - StK - Moffett - 2 hrs
4 May 76	Tu	Performance of pods w/o monkeys	2	Pods secured in vertical and supine positions during flight Moffett - StK - Sac - Moffett - 3 hrs
6 May 76	Th	#337, Simple T/M monkey inboard pod	3	Cardiovascular measurements, strip-chart recording Monkey supine and vertical Moffett - EAFB - Moffett - 4 hrs
7 May 76	Fri	#337, Simple T/M monkey inboard pod	2	Cardiovascular measurements; strip-chart recording Moffett - EAFB - StK - Moffett - 4 hrs
11 May 76	Tu	#174, Exeter - control, outbd pod #337, Simple - T/M, inbd pod All instrumentation rack operational	7	Commutated 2 pod RGE and cardiovascular measurement T/M and hardware. Strip-chart recorder Moffett - EAFB - Moffett - 10 hrs
13 May 76	Thu	2 Monkey Pods as above 11 May + CP100 Tape Recorder	8	Full-up systems 1st test interface computer Moffett - LAX - StK - Moffett - 3 hrs
17 May 76	Mon	2 Monkey Pods as above 13 May	12	All systems activated Moffett - StK - San Jose - SF - Moffett 3 hrs
19 May 76	Wed	2 Monkey Pods as above 17 May	5	All systems activated Moffett - StK - Moffett - 2 hrs
21 May 76	Fri	2 Monkey Pods as above 19 May + PCM module	7	2 periods of zero-*g* in flight All systems activated Moffett - StK - Reno - Moffett - 3 hrs + post-flight LBNP in A/C on ground after return to Moffett

Summary of Monkey Hours Takeoff to Return

Subject	Simple	Exeter	
	29	21	50 Hours Total

TIME 142 19 04 01 POD ID = 5 # OF SAMPLES

FEA OXYGEN	.1962	60
FEA CARBON DIOXIDE	.0077	60
FEA WATER VAPOR	.0237	60
FEA NITROGEN	.7710	60
MASS FLOW	8137.9	60
OXYGEN CONSUMPTION	65 2	
CARBON DIOXIDE PRODUCTION	53.9	
RESPIRATORY QUOTIENT	.826	
M/S INLET PRESSURE	257.9	60
UPPER POD PRESSURE	739.4	60
LOWER POD PRESSURE	.1	60
M/S INLET TEMPERATURE	23 0	0
#1 UPPER POD TEMPERATURE	23.0	0
#1 LOWER POD TEMPERATURE	23.0	0
#2 UPPER POD TEMPERATURE	23.0	0
#2 LOWER POD TEMPERATURE	23.0	0
#1 POD HEART RATE	150 3	60
#2 POD HEART RATE	179 9	9
#1 POD WATER EVENTS	0	
RUNNING TOTAL	0	
#2 POD WATER EVENTS	0	
RUNNING TOTAL	0	
#1 POD FOOD EVENTS	0	
RUNNING TOTAL	0	
#2 POD FOOD EVENTS	0	
RUNNING TOTAL	0	

Figure 11.- Sample ADDAS printout of monkey pod experiment.

Experimental subject behavior.- In a strict experimental protocol sense, it was difficult to control all aspects of the test subjects' environment. However, this project did extend the baseline of previous ground tests of the monkey restraint system in relationship to form, fit, and function in integrating a sophisticated biological payload within an aircraft on an operational mission. Some of the factors in this exercise which were beyond experimenter control, and impacted on monkey behavior can be listed as follows:

(1) Light and dark cycles were not strictly adhered to on an 12L:12D basis with lights on at 0600 and off at 1800.

(2) Temperature and humidity in the ground-based Airborne Science Laboratory were controlled. However, the levels were different from those experienced aboard the aircraft and in transport between areas of activity.

(3) Ambient pressures within the aircraft during flight varied from the equivalent of less than 300 meters in altitude to over 2100 meters.

(4) An unscheduled extended ground situation occurred at Edwards Air Force Base on 11 May 1976, when the monkeys were subjected to elevated ambient temperatures. An auxiliary temperature and humidity control unit was not readily available, and temperatures in excess of 37°C were recorded in the upper pod. As has been demonstrated in an environmental chamber at EPL/UCB, temperatures above 35°C in conjunction with the low humidities indigenous to the Edwards Air Force Base area are known to be stressful for the pigtailed monkey. To improve the monkey environment, remedial measures, such as shading the aircraft windows with lab coats, increased allowances of water intake, and adding water to the air inlet of the upper pod were employed. Subjectively, the monkeys appeared to appreciate such action and did not make attempts to struggle against their restraint system, which would have no doubt further compromised their thermal equilibrium.

(5) The upper hood was removed on several occasions during the test period.

All of the preceding actions were accomplished as contingency measures to carry out the full experimental program. The operational versatility of the pod system in coping with emergency situations and allowing experimenters to perform tasks of obtaining physiological data without totally compromising the trial objectives was demonstrated.

Concluding remarks.- The time interval allowed for the mechanical and electronic integration of the laboratory functioning modules to an airworthiness condition within the instrumentation racks was inadequate to carry out all aspects of a controlled physiological experiment. In addition, the monkey pod experiment was essentially riding "piggy back" on the primary mission of the CV-990 flights of 3 May through 21 May 1976. Nevertheless, the opportunity to evaluate the performance of a sophisticated biological experiment on an aircraft during an operational mission proved to be a valuable learning experience for all personnel concerned and furnished the extension of previous baseline data for the monkey pod experiment system.

The total system functioned effectively under an aircraft environment with changing temperatures, altitude, vibration, and g loadings, including a short period of weightlessness. In effect, the handling procedures for interfacing pods containing monkeys with the balance of the experiment system were similar to those proposed for future Shuttle Spacelab flight experiments. All instrumentation racks, with the exception of the pods, were set up previously in the aircraft, access to which was limited. This was analogous to the Spacelab constraints, which dictate that pre-launch access might be limited for periods up to 9 days. The pods were kept at a ground-based laboratory and, when appropriate, were moved and interfaced with the instrumentation. Thus, simulation of Shuttle protocols was carried out wherein experiment organisms would be maintained at a ground laboratory or on the Orbiter prior to loading into Spacelab. Unloading procedures also were analogous to those proposed for Shuttle payloads. The procedures used permit the pods to be ready for loading at any time, regardless of holds or slips which may arise with any flight program. Furthermore, loading on the aircraft and connecting to the appropriate instrumentation was accomplished without impacting on aircraft flight preparation.

On most flights, the number of experiment-related personnel was maximized in order that they could gain full familiarization and carry out troubleshooting if needed. For the actual in-flight experiment instrument manipulation fewer people would be needed. There is every reason to believe that one well-trained payload specialist could fulfill the in-flight experimental tasks within 2 hours each day. A preliminary schedule of daily in-flight activity for a Shuttle mission would be as follows:

0600	- Lights on for monkeys
0800-0830	- Animal status checks Change 24-hr urine collector Food and water status checks
1400-1435	- LBNP tests on 2 monkeys
1435-1530	- Instrumentation calibration checks
1800	- Lights off for monkeys

In addition, the experimental racks containing all the elements used onboard the CV-990 flights reported here would be more optimally located for individual observation in the Shuttle configuration. In actuality, on the aircraft flights, the operation of the respiratory gas-exchange instrumentation was conducted step-by-step from a typed protocol by a person who had minimal training for this activity. Therefore, a qualified payload specialist could readily perform this task. After setting the respiratory gas-exchange instrumentation in an operating mode, one person would have ample time to observe the activity or make adjustments for the other racks involved in the total experiment system. In the case of a power outage while the mass spectrometer is in operation, the M/S sample inlet valve must be closed as soon as possible. Power outage did occur during flight operations and the appropriate steps were taken without damage to the instrumentation.

A wide variety of data-retrieval links, including strip-chart recording, analog and digital tape, computer printouts, telemetry, and hand-written observational notes were utilized with the monkey pod experiment. In all instances compatibility was demonstrated.

Mechanical and electronic upgrading of the experiment modules to accept aircraft standards did not cause any overall detrimental or diminutional effects in regard to data acquisition.

The collection technique for clean separation of pigtailed monkey urine from feces was satisfactorily demonstrated. Thus, excretion rates of physiologically important metabolites can be accurately evaluated under a variety of environmental conditions.

The compatibility of the airborne monkey-pod experiment system with an inductively powered, implantable, multi-channel telemetry system expanded the return of viable cardiovascular data. The implantable portion of the units are well tolerated by pigtailed monkeys, as was exemplified by #396, who was surgically implanted on 23 February 1975, and from whose signal output, heart rate could still be derived during the month of May 1976. No losses resulted from surgical implantation, and all 3 of the male pigtailed monkeys survived thoracic surgery. As a result of these studies, improvements in the design are in the offing to reduce the power requirements, improve the stability of the pressure transducers, and allow greater latitude in energizing coil placement.

For the conduct of a Spacelab flight experiment, no major obstacles appear to exist; however, several parts of the experiment system will require further development. These are:

(1) Miniaturize existing electronic instrumentation to effect savings in weight and volume for the total system.

(2) Change pod design to permit in-flight blood sampling.

(3) Incorporate a scrubbing device into the pod system if exhaust gases are not to be dumped overboard.

(4) Fabricate and test a nutrient-dispensing system capable of functioning in weightlessness. The water dispenser should be modified to simplify its function in zero-*g*.

(5) Develop an LBNP pump and vacuum control system that will satisfy aircraft safety requirements, and that could be used for both ground-control and Spacelab flight experiments.

(6) Improve implanted unit to permit continuous operation. The proper relative position must be maintained between the internal and external coils. Possible solutions to the coil positioning problem are a) inclusion of an access port in the pod enclosure, and b) provision of an external energizing

coil with a greater field strength over a larger area. The latter approach has been implemented; evaluation is continuing, but current results indicate satisfactory operation.

(7) Determine postoperative recovery time for macaques after intrathoracic implantation. It appears to be 6 to 8 weeks, approximately 4 weeks longer than for dogs. The long lead times with chronically instrumented animals must be considered in planning for flight experiments.

CRITICAL ANALYSIS OF THE APPARATUS, ASSEMBLY, EXPERIMENTAL PROCEDURES AND MANAGEMENT APPROACH

Introduction.- An initial meeting was held in January 1975, between members of NASA/ARC Airborne Science Office and Biomedical Research Division, and a representative of the University of California at Berkeley to discuss the possibility of flying the monkey pod system aboard the NASA CV-990. A preliminary proposal was submitted in March 1975, followed by a completed proposal in July 1975. Final approval for the proposed flights was given in January 1976.

During May 1976, the monkey pod with associated biotelemetry was flown as a secondary experiment aboard the NASA CV-990. The purpose of the flights was to test how well the system interfaced with the CV-990 and to analyze the procedures involved in bringing a biological laboratory experiment under the discipline imposed by flight schedules and airworthiness requirements. The primary flight mission was under the direction of the ARC Flight and Systems Research Branch and was part of a program to develop operational procedures and avionics for delayed flap landing approach. Takeoff and landing times, as well as flight profiles, were designed to support the primary experiment and strongly influenced both the system integration and operational procedures of the secondary experiment.

Mission objectives and guidelines.- For the monkey biological experiment, the overall objective of the flights was to test the interface between the CV-990 and the experimental equipment, and to analyze the in-flight preparation procedures. Other objectives were:

(1) To examine the management of the experiment under operational conditions.

(2) To determine the degree of manpower effort required to take the experiment from a laboratory to an operational environment.

(3) To test a recently designed biotelemetry implant within the monkey pod restraint system.

(4) To develop supporting electronics for the biotelemetry implant.

(5) To detect any interference to or from adjacent operational electronic systems.

Mission management.- Decisions on flight dates, takeoff and landing times, and flight profiles were made by personnel of the Flight and Systems Research Branch at Ames who were responsible for the primary experiment. Little or no influence was exerted to alter those decisions. Thus, once the equipment was installed onboard the aircraft, the experiment was flown, whether ready or not. All flights included numerous touch-and-go computerized landings that at times were of high impact. Sometimes landings were made at ten-minute intervals over a period of more than an hour, during which time all personnel were advised to remain in their seats with seat belts fastened. At times the physical movement of the aircraft hampered attempts to work on the equipment and induced motion sickness in several of the investigators.

The monkey pod experiment was managed by a member of the NASA/ARC Biomedical Research Division who acted as principal investigator. Co-investigators included three representatives from UCB, one of whom served as test manager. Additional team members included an electronics engineer from the Electro-Systems Engineering Branch at NASA/ARC, two engineers to alternately monitor the telemetry equipment, and two electronic technicians. Personnel from the sheet metal shop and other support activities participated when required. The electronics engineer, two technicians, and the telemetry engineers, remained with the experiment through the last flight.

Mission documentation.- The mission was operated with an absolute minimum of documentation. A copy of the CV-990 Experimenters' Handbook was given to the UCB team to serve as a guide for first-time experimenters. The handbook proved useful for general orientation but, being somewhat out-of-date, lacked specific information on intrarack wiring specifications, sheet-metal shelf construction and fastenings, and airworthiness inspection criteria. As a result, one rack had to be completely rewired because wiring of the wrong specification had been used, and a metal shelf which had been sent to UCB from NASA/ARC had to be replaced by a new one custom-designed for additional strength.

The first of a series of daily experimenters' meetings was held on 27 April 1976. These meetings, which lasted an average of 20 minutes or less, were the only occasions when problems were aired before an audience representing all phases of the mission activities. The primary experiment team usually dominated these meetings. No Experimenters' Bulletins were issued, nor was any other documentation provided by the Airborne Science Office with the exception of a planned flight schedule.

The investigators began supplying NASA/ARC with sketches and specifications for work on the monkey pod and accessories starting in February 1975. Additional information specific to rack mountings was submitted intermittently. Software assistance was provided by a contractor beginning with the first joint meeting on 19 March 1976, to establish requirements.

Supporting electronics.- To integrate the metabolic and telemetry systems with the aircraft data system, interfacing electronic components had to be developed. A signal conditioner, a multiplexer, and two 8-channel strip-chart recorders were needed for processing measurements of the 26 parameters. Inevitably, delays occurred in developing the electronic components and the computer programs needed for coupling with the aircraft data system. Furthermore, delays were subsequently encountered in assembly and wiring of the components in the racks.

The completed telemetry rack was installed on the aircraft on 30 April. However, the NASA Principal Investigator decided that it would not be possible to fly as scheduled on 4 May, since the two remaining racks would not be installed aboard the aircraft by that time. Instead, the first week's flight schedule would be used to complete the installation and to test each subsystem in sequence during flight.

On 4 May the metal tub made to hold the pods was flown on the first scheduled flight for a vibration check. No problems were found, and on 6 May one pod containing a monkey was installed, connected to the telemetry rack, and flown. The results compared favorably with those obtained in the laboratory. The same results were achieved again in flight on 7 May.

The rack containing the mass spectrometer was installed on 8 May; the complete experiment was now aboard the aircraft. A system checkout had begun but was far from complete. The first flight with the system completely wired and installed on the aircraft was made on 11 May.

Telemetry unit.- The telemetry subsystem was the most thoroughly tested portion of the equipment prior to flight. Both test subjects had received implant surgery in March, and the signals from the implants had been checked after each operation using auxiliary devices. On 29 March the telemetry receiving unit was successfully flown aboard the CV-990 to determine if any RFI effects were present. Before the rack was installed on the aircraft on 30 April, signals from one of the implanted monkeys were checked out in the ASO laboratory and found to be well within acceptable limits.

Monkey pods.- The pods themselves were tested prior to flight by having the monkeys inhabit them under experimental conditions. An auxiliary pump provided adequate air flow, and food pellets and water were available on demand. During this period no apparent problems were found.

Mass spectrometer.- The mass spectrometer rack was not completely checked out before installation aboard the aircraft. Wiring within the rack was delayed until metal bracketry for mounting shelves and equipment were made and delivered. Subcontractor-developed equipment was delivered late, and since some of it was integral to the rack, wiring could not be completed until it was physically installed. Once the rack was installed on the aircraft, testing was limited to those times when access to the aircraft was allowed. In-flight testing was restricted by the necessity of remaining seated during the numerous touchdowns that occurred every flight. The coinvestigator responsible for the operation of the mass spectrometer was susceptible to motion sickness and did not make all the flights. This placed the testing burden on the NASA electronics engineer, who operated the mass spectrometer rack during several flights.

Signal conditioner unit.- The most essential supporting electronics component was the 20-channel signal-conditioning unit, which was built by a contractor. This unit did not arrive until 30 April, and since all the data were designed to pass through the signal conditioners before being recorded, it was impossible to test the operation of the total system without it. As a result, the system checkout did not begin until 6 May, two days after the first scheduled flight. Rather than keep the mass spectrometer rack on the ground until a system test was completed, the decision was made to install the rack on the aircraft and continue testing in proximity to the ADDAS system.

Another late arrival was the signal conditioner power supply for the feeder and waterer units, which were delivered on 3 May. Fortunately, there were no basic deficiencies in the units, but their late delivery put additional pressure on an already compressed schedule. The first complete system checkout was completed on 17 May during the sixth flight of the mission.

Preflight protocol.-Several weeks prior to the first flight, the UCB investigators completed a detailed protocol for preparation of the test subjects, calibration and operation of the equipment, and installation of the test subjects aboard the aircraft. The plan spanned one week's activities commencing with the removal of the monkeys from their holding cages on Monday morning to their return to the cages on Friday afternoon. There was little or no deviation from the schedule, and the entire operation moved smoothly from start to finish each week.

(1) Preparation of test subjects.- Both monkeys were kept in holding cages in a quarantine room of the animal facility at ARC, both before the conduct of the experiment and over the weekends when no flights were taking place. The insertion procedure began by injecting the implanted monkey with ketamine hydrochloride and atropine sulfate to tranquilize it sufficiently to allow it to be placed in the restraining jacket. The power oscillator and coil were then sewn into the restraining jacket and aligned adjacent to the internal coil. Fairly exact alignment of the external and internal coils was critical for proper signal reception and was always checked with a back-up telemetry receiving unit at this stage. The monkey was then fastened to the restraining couch by the restraining jacket and the couch inserted into the lower half of the pod and securely fastened in place. This procedure required at least two members of the UCB team and took approximately 1-1/4 hours to complete.

After the first monkey was secured in the pod, the control monkey was tranquilized, his chest shaved, and three silver-silver chloride ECG electrodes were fastened to his thorax. This monkey was then fitted into a restraining jacket and inserted into the lower half of the other pod. The same two members of the UCB team accomplished this in approximately 1-1/4 hours.

The upper half of each pod was then fastened to the lower, the pods placed in a truck and the monkeys transported to the Airborne Science Laboratory. When not on the aircraft, the monkeys were kept in the pods in a quiet corner of the laboratory and supplied with adequate ventilation, food, and water.

(2) Installation aboard the aircraft.- The installation of the monkeys aboard the aircraft before each flight was adversely affected both by the hot weather and the incapacity of the CV-990 air-conditioning unit. The pods did not have integral air-conditioning units, and even though power was usually available for the aircraft air conditioner, the interior temperature of the aircraft was quite high. Rather than subject the monkeys to these conditions, the pods were not inserted until about 1/2 hour before door closing, using a forklift truck to transport them from the Airborne Science Office Laboratory. As a result, the half-hour before takeoff was a frenzy of activity to get all the cabling, wiring, and hose lines connected once the pods were in place. No flights were ever delayed, but it usually took the concerted effort of four or five men, sometimes including the air-worthiness inspector, to secure everything in place.

(3) Equipment calibration.- Once the pods were installed, it was just a matter of running two cables back to the telemetry rack to begin the telemetry calibration. This calibration usually took 15-20 minutes for one man to complete. Any signal degradation was usually caused by the movement of the monkey shifting the exterior coil with respect to the interior coil.

The mass spectrometer calibration was originally planned to be performed on the aircraft with three gas cylinders of O_2, N_2, and CO_2, respectively, mounted permanently aboard. The sheet-metal work required for mounting the cylinders appeared to be extensive, so the decision was made to place the cylinders on a cart, wheel the cart to the side of the aircraft, and run hosing from the cart to the rack in the aircraft. After initial calibration was completed, the hosing would be removed and the cart wheeled away. In practice, this procedure took place about 1-1/2 hours before takeoff and involved at least two individuals. It was not until the seventh flight that exact calibration was completed, due to noisy reference signals resulting from interfacing and debugging problems with ADDAS.

Flight results.- The original flight schedule called for three flights per week for a three-week period beginning 3 May. The third flight of the second week was canceled to allow for additional work on a computer of the primary experiment. Both the flight schedule and the flight profiles were determined by the Flight and Systems Research Branch personnel at ARC and were not influenced by the monkey pod experiment. Although members of the experimental team flew on every flight, it was not until the fourth flight that all the equipment was installed aboard the aircraft.

A typical flight plan consisted of:

(1) Travel time of 3/4 - 1 hour to a particular airport.

(2) Perform 5-10 touch-and-go landings.

(3) Travel time of 3/4 hour to another airport.

(4) Perform 5-10 touch-and-go landings.

This would be repeated for a total flight duration of from 4 to 5 hours. On two flights the destination was Edwards Air Force Base, where all touch-and-go landings were performed (Table 6).

On the first flight (4 May), two experimenters flew to check the tub that would hold the two monkey pods to determine if it was subject to vibration from the aircraft. No other equipment was flown. The test proved successful.

The equipment aboard the second flight (6 May) consisted of one monkey and pod and the telemetry rack. The telemetry signals came through clearly and the only problem was a minor one of the foot restraint bar in the pod coming loose.

The same equipment was flown on the third flight (7 May) and there were no problems.

On the fourth flight (11 May) both monkeys and the total system were flown. On landing at Edwards Air Force Base, two tires blew out and the aircraft remained parked on a ramp in the hot sun at ~ 100°F for four hours. There was no air conditioning on the plane, and the total team effort was devoted to keeping the monkeys and themselves as comfortable as possible. At this time there was still no input for ADDAS to check out.

The telemetry unit was still performing well on the fifth flight (13 May) but the UCB member responsible for the mass spectrometer did not fly, so the mass spectrometer/ADDAS interface checkout did not get done.

The next scheduled flight (14 May) was canceled by ARC Flight and Systems Research Branch personnel.

On the next flight (17 May) the telemetry unit was giving erratic signals for the first half of the flight. The problem was caused by a loose cable connection to the signal conditioner, and once the connection was tightened, the unit resumed operation. The mass spectrometer functioned well except for calibration problems, with the O_2 and N_2 signals being noisy. A noisy reference signal was causing the ADDAS not to yield a temperature readout. The ADDAS printout also indicated the monkeys were eating and drinking continuously, whereas observation showed that this was not actually occurring.

The mass spectrometer calibration went well on the seventh flight (19 May) but the O_2 and N_2 channels were still noisy as was the temperature

TABLE 6

Summary of Monkey Pod Flights

Flight Date	Remarks	Problems
5/4/76	Monkey-pod tub only flown to check for vibration. No mass spec.	No problems.
5/6/76	One monkey pod and telemetry only. No mass spec.	No problems. Foot restraint bar came loose - not properly tightened.
5/7/76	One monkey pod and telemetry only No mass spec.	No problems.
5/11/76	Two monkeys and telemetry and mass spec.	Only intermittent channels on M/S working Cardiotachometer was out. No real interface yet with ADDAS - no signals to feed in. Monkeys out in hot sun 4 hrs. Nothing accomplished on M/S today - just kept alive on aircraft at Edwards in sun.
5/13/76	Two monkeys and telemetry and mass spec.	Still no input to ADDAS to checkout. T/M OK. M/S checkout still not done because coinvestigator didn't fly and engineer couldn't interpret some readings.
5/14/76	Flight canceled by Flight Research personnel.	
5/17/76	Two monkeys and telemetry and mass spec.	T/M not working properly - turned out it was a loose cable to the signal conditioner. Mass spec OK except for cal problems. ADDAS not giving a temperature readout. Engineer says this is due to his noisy reference signal. Food and H_2O signals crossed - wrong voltages indicating eating and drinking almost continuously. O_2 and N_2 signals in M/S noisy.
5/19/76	Two monkeys and telemetry and mass spec.	Mass spec cal OK but O_2 and N_2 channels still noisy. ECG on T/M varying - probably due to shifting coil in jacket. ADDAS giving wrong signals in printer for Pod #2 heart rate, O_2 and food rate (problem due to miswiring of gain in pre-amp on 3rd rack). Temperature still noisy.
5/21/76	Two monkeys and telemetry and mass spec.	T/M not working well - no signal during zero-*g* - appears coil in jacket may have shifted. Pod 2 ECG off by 30-40%. T/M working after landing at Moffett. LBNP test on ground.

reference signal. The ECG channel on the Brush recorder was fluctuating and proved to be an indication of trouble to come on the next flight. The consensus was that the signal fluctuation was caused by the movement of the monkey which in turn shifted the external coil relative to the internal coil. A lower body negative pressure test was performed on both monkeys in the supine position at three different pressure levels.

On the last flight (21 May) the telemetry unit which had been consistently working very well until the seventh flight became erratic and did not produce useful ECG data during the zero-*g* maneuvers. Except for minor fluctuations, the test of the system worked well even under two successive zero-*g* maneuvers. After landing, a lower body negative pressure test was conducted again and at this time the telemetry unit resumed proper operation.

Manpower and material estimates.- Past experience has shown that investigators flying their experiments on the CV-990 for the first time require a considerable amount of sheet metal work from ARC personnel. This is to be expected since most academic institutions have neither the personnel nor the facilities to perform the work to meet the required airworthy specifications. The monkey-pod experiment proved to be no exception to the rule. Support from NASA personnel was needed in the areas of sheet metal fabrication and electronic design and installation, and without it the experiment would never have made the scheduled flight date.

(1) Sheet metal fabrication.- The sheet metal shop at ARC provided at least the following items:

(a) A metal tub that fastened to the aircraft flooring and which held the two monkey pods.
(b) Metal brackets to fasten the pods to the tub.
(c) Custom intrarack shelving.
(d) Brackets for intrarack mounting of equipment.
(e) A special waterer container.
(f) Vacuum pump installation and adapters.

In addition, sheet metal personnel helped install and remove the monkey pods from the aircraft for each flight. The total manpower contribution from the sheet metal shop between 5 April 1976 and 22 May 1976, amounted to 354 manhours. The material cost was $227.

Electronic design and installation.- The UCB investigators who brought their experiment to ARC had little or no electronics background. They also had no personnel available at their home base to provide such support. To remedy this situation, a NASA electronics engineer was assigned full time to the project starting 1 March 1976. This individual provided design, development, installation, and moral support, and stayed with the experiment until the end of the mission. He was assisted by two electronics technicians who worked full time from 15 March to the end of the last flight. Once again, without this help the experiment would never have been able to leave the ASO Laboratory.

Support was concentrated in the areas of:

(1) Monitoring of a subcontract for a 20-channel signal conditioner and multiplexer.

(2) Fabrication of signal conditioner output terminal strips.

(3) Two feeder/waterer power-supply units.

(4) All intrarack cabling and most interrack cabling.

(5) PCM system configuration, preparation, hardware fabrication, and wiring.

(6) Fabrication of an interface to the mass spectrometer four-way valve.

(7) Modification to the signal conditioner power supply.

(8) Feeder rewiring and checkout.

The NASA manpower contribution was:

1 Electronics Engineer - 556 man-hrs.
2 Electronics Technicians - 359 man-hrs.

The signal conditioner and multiplexers cost $3,000. Cabling cost $500. The two strip-chart recorders rented for $765/mo. each. In addition to these items, numerous individuals from the Electro-Systems Engineering Branch helped out with advice and material support.

Mission problems areas.-

(1) Management.-

(a) The project team totally underestimated the complexity and magnitude of effort required to get the experiment ready.
(b) Coinvestigator for telemetry was unable to participate personally on flights until the last test.
(c) Investigators had to spend a lot of time and effort on following up requests, plans, etc.
(d) Lack of knowledge of ARC chain of command caused delays in having hardware made.
(e) The ARC/ASO mission manager was occupied with his prime mission responsibility and could not devote adequate time to assist the UCB team to work through the ARC/ASO organization. This was particularly bad for first-time experimenters.
(f) Assembly of hardware at the Airborne Science Laboratory into flight configuration began 1 March to meet a 4 May flight date. The two-month preparation time required an unreasonable effort by way of extra-time and priority requests.

(g) The investigators could not exercise any influence over flight dates or times and had to fly whether prepared or not.

(2) Preflight preparation at UCB.-

(a) Experimenters' Handbook did not provide specific enough information on intra- and interrack wiring, shelving, and fasteners. One shelf had to be discarded and a new one made up because it was not strong enough. This first shelf had been provided by ARC.

(b) Up until only three weeks before moving equipment to ARC, experimenters thought they were to be allowed only one rack.

(c) Investigators had no idea of how much manpower assistance would be available from ARC, which made planning difficult.

(3) Problems in preflight preparation and testing at ARC.-

(a) One rack had to be completely rewired because the wrong type of cabling had been used.

(b) More guidance on airworthiness requirements was needed.

(c) Wiring was delayed while awaiting bracketry that was late in fabrication.

(d) Equipment that had been put out for bid was delivered late by the contractors.

(e) The monkey pods plus the telemetry unit were the only portions of the system that were checked out in the laboratory before installation on the aircraft.

(f) The contract programmer assigned to support the experiment was not available until shortly before start of the flight period. This resulted in little interaction with the ADDAS system before flight.

(g) The lack of a supplementary air-conditioning unit for the aircraft meant that the monkeys could only be installed at the last moment, which resulted in a rush to secure rack connections before takeoff.

(h) Once the equipment was installed on the aircraft before being adequately tested, system checkout and repair became a function of when the aircraft was available, since the nature of the flights restricted repair activity while in the air.

(4) In-flight operations.-

(a) The mass spectrometer rack was not installed in the aircraft until after the third flight. Checkout of the interface with ADDAS was not completed until the sixth flight.

(b) The numerous touchdowns made during each flight meant that the investigators had to remain seated with safety belts fastened. This hampered system checkout and repairs.

(c) An unscheduled layover at Edwards Air Force Base on the fourth flight caused the aircraft to be parked in the hot sun under a 100°F temperature for approximately four hours without any air-conditioning. The investigators had to devote all their activity to keeping the monkeys alive.
(d) The telemetry unit which had functioned well during the first seven flights failed to operate properly during zero-*g* on the last flight when the rest of the system finally came up to full operation.
(e) Operation of the experimental equipment was not adversely affected by the two zero-*g* maneuvers during the last flight, nor were the test subjects.

Apparent problems areas.-

(1) Equipment design.-

(a) Moisture in air line caused H_2O to condense out, and surface of upper pod and monkeys got damp.
(b) No visible means of checking monkey's seating condition when he is slumped forward. (Can't see through back of pod to seat.)
(c) No way of checking from outside if feeder is jammed. (Caused by pellets disintegrating and jamming the opening in feeder.)
(d) Pods should have integral air-conditioning to prevent over-heating during ground preparations.
(e) Better method needed of attaching exterior coil to restraining jacket to prevent movement with respect to interior coil.

Additional support requirements.-

(1) Personnel.-

(a) Mechanical engineer for pod redesign.
(b) Electronics engineer to evaluate the present system and suggest improvements.
(c) Electronics technician as permanent addition to staff for support in field.

(2) Data processing.-

Addition of microcomputer in ASO Laboratory or integration area would allow check of total system before going on aircraft. It would also eliminate many interface problems that would otherwise develop later during flight.

(3) Management.-

A full-time experiment integration manager familiar with NASA system and technically capable would relieve investigators of burden of following through on requests and planning to meet deadlines, make flights, etc.

IMPLICATIONS OF ASO EXPERIMENT MANAGEMENT TO SPACELAB EXPERIMENT INTEGRATION

Mission management.- The primary management document used for the CV-990 missions is the "NASA CV-990 Airborne Laboratory Experimenters' Handbook." This publication described in great detail the characteristics of the aircraft, the computer system, mounting racks, and aircraft performance. The proposal for participation is submitted by the investigator and includes the protocol, experiment requirements, and engineering requirements. Once approved and assigned to a mission with a program manager, there is little more required in the way of formal reviews of design and schedule. This procedure has worked quite satisfactorily for the ASO with physical experiments. It did not suffice for the test of biological support equipment and procedures. The support of living specimens allowed less flexibility in the way of environmental control, especially when holds or unanticipated failures occurred. As a result, the animals were subjected to environmental extremes. There also was less understanding by biologists of the engineering problems.

During the period of instrumentation assembly, many changes were made in the placement of equipment on racks, and the number of racks made available to the experimenters was increased. This was all done in the laboratory to solve problems of airworthiness and to facilitate installation in the aircraft when it was available. Such alterations in plan frequently occurred between the engineers concerned with structure or electronics, and the technician or coinvestigator working in the laboratory at the time. Frequently the Principal Investigator did not become aware of the change until the next weekly meeting, and by then other decisions had been made and new designs initiated, based on the previous configuration. The number of active investigators and technicians involved in the one biological experiment — because of the many parameters being measured on the same specimens — was apparently greater than that usually involved in a single physical or astronomical experiment.

Interface control, even in the informal and small ASO Assembly Laboratory is apparently necessary for good biological experiment management. Engineering design review is also desirable, both preliminary and final, so that changes can be made visible at the time they are ordered. Such review would also make the decisions of the Airworthiness Inspector more understandable to the experimenter, who may be uninitiated in such experimental constraints. In the case of the signal conditioner that was found necessary after start of assembly, and then designed and built during a period of good communication between all members of the team, an error was still made in design voltage. The finished product had a voltage output capability that exceeded the ADDAS computer maximum. The design had not been reviewed by the ADDAS group because they were off on another mission. The test was completed without control documentation and the informality was a pleasant experience, but additional control and visibility would have alleviated some of the problems that developed.

Experiment development and integration.- The proposal for this experiment was accepted almost a year after first submittal, partially due to loss of the original ASO CV-990 in an accident. During this time, much of the original momentum had to be regenerated for all parties concerned. The approval occurred 30 January 1976, for a flight starting the first week of May. The original program plan allowed eight months of development time, which was found to be realistic. The compressed schedule to complete development in three months required an all-out effort by everyone concerned. This included considerable weekend and evening work and made procurement of unanticipated equipment extremely difficult. The test was completed successfully, and as a one-time effort was found to be a stimulating experience, but a continued program repeated at regular intervals, such as that anticipated for Level IV experiment integration for Spacelab, would not enjoy the continued enthusiasm demonstrated by the workers on this test. In conjunction with the previous section, an early completion of a final review for the engineering requirements would allow better management of shop service requests, and that would alleviate many of the fabrication problems experienced in this test.

Experimenter operator requirements.- The ASO approach to airborne experimentation has been to simplify procedures by minimizing automation and maximizing experimenter participation. This is contrary to the proposed Spacelab concept, in which a payload specialist will be running the experiments of several ground-based Principal Investigators. In the biological experiment system being evaluated here, it was necessary to have experts representing each phase of the system. An electrical engineer who had been associated with the telemetry was required for those operations. Biologists flew on each flight, one each for animal handling, metabolic measurements, and Lower Body Negative Pressure testing. An additional engineer, and on some flights a technician, flew for data conditioning. Much of this manpower was required because it was necessary to do the system checkout during flight rather than in the laboratory or on the ground because of schedule constraints. It was apparent, however, that if one person were to handle all the operations, he would have to be exceptionally well trained in a very high fidelity simulator, since most of the in-flight problems that occurred had never been experienced by investigators in their home laboratories using the same equipment.

RECOMMENDATIONS FOR SPACELAB LEVEL IV INTEGRATION

Management Requirements for Experiment Integration

Integration of experiments into the Spacelab are to be managed by a series of steps designated by Levels IV to I. Following the experiment selection and the development of those experiments to the point where they can begin integration, Level IV integration is the first step. This is where experiments are organized into the racks to be flown, and may consist of entire racks to be fitted together in the experiment module, or as parts of such a rack, to be shared with other disciplines. Level IV integration of

Life Science animal experiments are to be performed at Ames Research Center, and medical experiments are to be so integrated at Johnson Space Center. Level III is the installation of racks into an experiment module for rack-to-rack checkout and is now designated to take place at JSC. After the module interface testing is completed and approved, the module is to be sent to Kennedy Space Center for installation into the Spacelab, and this is the Level II operation. The final step — Level I — is placement of the Spacelab into the Shuttle Bay.

With three centers involved, it is difficult to see how the operation could be reduced to the simplistic management scheme that ASO has been able to employ for the CV-990. This will be even more true for the Life Science packages where "upstream-downstream" interface control is so necessary. In addition, many of the "Principal Investigator - Integration Engineer" problems prevalent in Skylab will again surface. Visibility and change control will have to be maintained, but the proposed time schedule calls for a management scheme that may obviate the documentation and change-order management previously used by JSC.

From the exercise performed on the CV-990, it was obvious that more control is required, even for placement of experiments into the racks to assure proper interface. That simple test, however, could not have been completed in the time frame had preliminary and final reviews been attempted at every stage as it was for Skylab. Principal Investigator participation and control over his experiment will be more important in the Spacelab than it was in Skylab, so he must be made aware of all engineering changes in the event it vitiates his experimental approach in a way not recognized by the integration and design engineers. At the same time, it is important to avoid retrofits, as they are not only expensive when they impact "upstream-downstream" components, but are a chief source of program delay.

Computerized Experiment Management Control and Visibility Concept

During the CV-990 test, the concept of a Computerized Experiment Management Control and Visibility developed. Documentation for such a management tool would be limited to program inputs for purpose of approval only. Once approved, the input would be part of the computer data bank and all users would derive information from the current updated information bank.

The program can be started with the Experimenters' Handbook, but more complete engineering details of hard-points, electronics, etc., must be provided. Accepted protocols, experiment implementation, experiment requirements, engineering requirements, and subsequent control documents would then be incorporated. By having access to a terminal, all persons involved should then be able to quickly determine current status or interface compatibility of any element, as well as potential "upstream-downstream" problems.

This is only a concept and requires development to evaluate its utility. ARC has the capability to develop and test such a program scheme in several planning areas. The CV-990 ASSESS program is one such tool for developing a rudimentary approach. The SMD simulations (10) being performed by ARC in cooperation with JSC is another potential source for debugging such a program.

It is proposed that such a management program be initiated for a single typical rack and tested for practicability. A computer-programmed management scheme such as shown in Figure 12 would require the Level IV Integration Program Office to direct the activities of only three individuals for each approved experiment. Each person would then respond by producing procedures, designs (or a program), hardware or installations, and tests. A description of each item would be entered in the computer information bank. The Integration Office would then monitor the progress of those directives through the computer review. All persons would derive their design and assembly information from the computer to ensure obtaining currently valid data. Management authority would be maintained by the Integration Office controlling 1) Action Directives, 2) Rack-space Allocations, 3) Change Orders, and 4) Budget.

The elements within the scheme are similar in some respects to the way ASO conducts its program, but are also the basic management documents that were used to initiate the "M" flight experiments for Skylab. The "scheduled computer reviews" can replace weekly Program Director reviews and may suffice for Preliminary and Final design reviews. An important aspect of the concept is that no documents would be produced but that only a dated display or printout would be used. Each item in the computer can be labeled as to whether it has been approved or is waiting approval by the next review. This allows a generalized RID (response in discrepancy) response by anyone with access to a terminal.

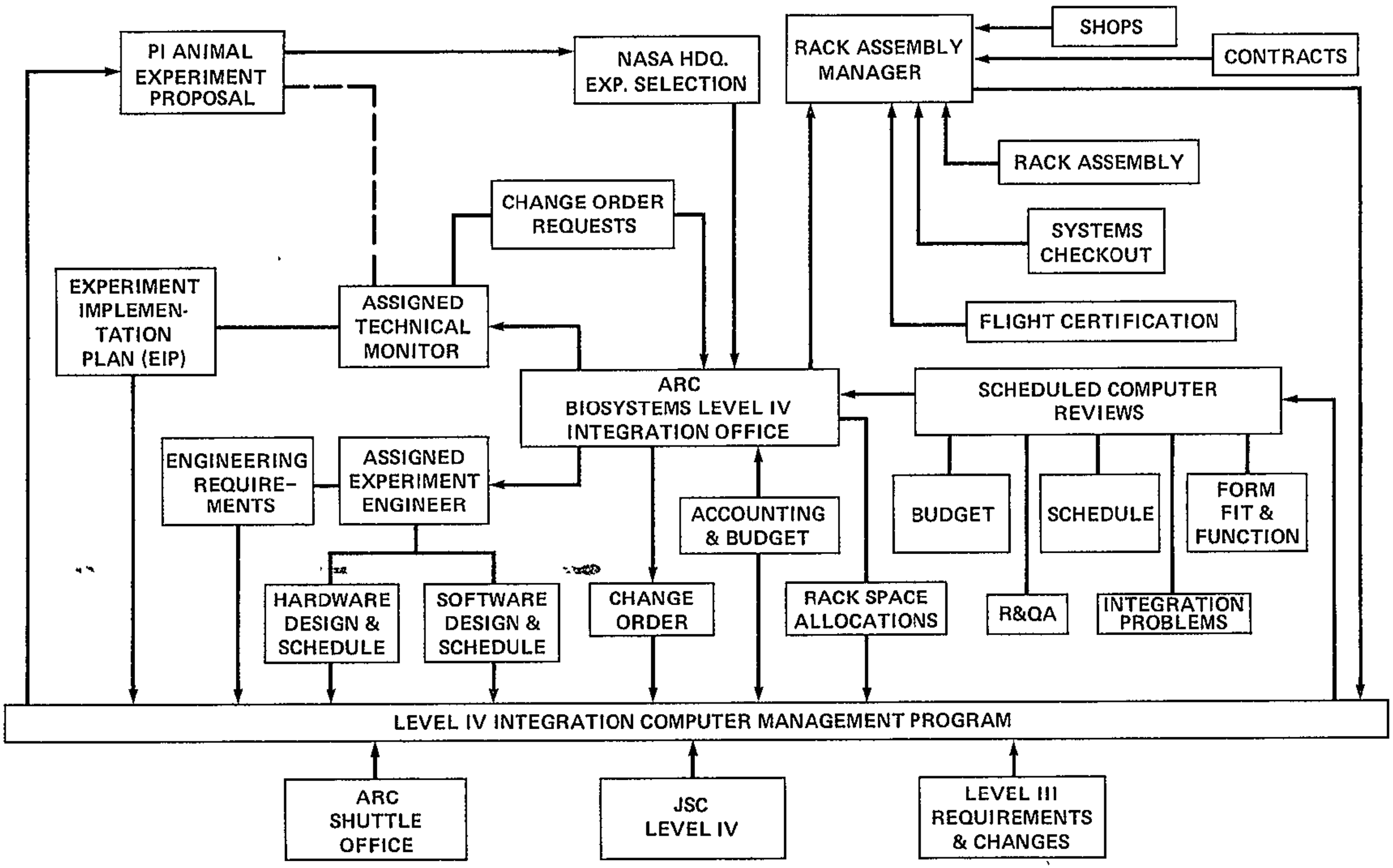


Figure 12.- Conceptual scheme to computerize management of experiment assembly for level IV Spacelab integration.

ABBREVIATIONS AND ACRONYMS

ADDAS	Airborne Digital Data Acquisition System
AP	aortic pressure
ARC	Ames Research Center (NASA)
ASO	Airborne Science Office (at ARC)
ASSESS	Airborne Science/Spacelab Experiments System Simulation
CMOS	complementary metal oxide semiconductor
CRT	cathode ray tube
ECG	electrocardiograph
EMI	electromagnetic interference
EPL	Environmental Physiology Laboratory (at UCB)
FM	frequency modulation
I.P.A.	Intergovernment Personnel Act
JSC	Johnson Space Center (NASA)
LBNP	lower body negative pressure
LVP	left ventricular pressure
M/S	mass spectrometry
MSFC	Marshall Space Flight Center (NASA)
PCM	pulse-code modulation
PWM	pulse-width modulation
RF	radio frequency
RFI	radio-frequency interference
R.Q.	respiratory quotient
T/M	telemetry
UCB	University of California at Berkeley

APPENDIX

SUMMARY OF BIOLOGICAL DATA

Respiratory gas exchange.- Respiratory gas-exchange measurements were carried out in flight on the two test animals, monkeys #174 and #337, by alternate sampling of the upper-pod exhaust air streams every 15 min for respiratory gas analysis by a mass spectrometer. As indicated earlier, the Bioinstrumentation Rack, including the mass spectrometer, was placed onboard the CV-990 for a "shakedown" flight on 11 May 1976. Respiratory gas-exchange data were recorded on strip charts starting with the flight of 13 May 1976, and including the flights of 17, 19, and 21 May 1976. Simultaneous recordings of the data on analog tape and elements of ADDAS were progressively incorporated into the test system during the final weeks of flights.

Inasmuch as strip charts were the only recorders previously available for use with the EPL/UCB monkey pod, this recording system, albeit with its limitations, was considered the primary source of physiological data for the CV-990 flights. The strip chart data also served as a frame of reference for the new experience of analog tape recording and computer-processed data acquisition. As mentioned above, the analog tape recorder and ADDAS were introduced stepwise into the data-collection scheme during successive flights, and near-completion of a fully operational data system was not realized until the final flight on 21 May 1976. Accordingly, most of the test results for respiratory gas exchange reported herein were derived from postflight analysis of strip-chart records. Opportunity for comparisons between recording systems was provided by the data yield from the flight of 21 May 1976.

Respiratory gas-exchange data are typically collected in the laboratory over a period of 3 to 30 days and reported on an hourly basis as liters/hr. However, because the CV-990 flights were only of 2 to 3 hours duration, the results were computed instead on a minute-by-minute basis in cm^3/min. Figures 13 and 14 show such records of respiratory gas exchange for the flights of 13 and 17 and 19 and 21 May 1976, respectively. Since the principal aeronautics objective of the flights concerned new landing techniques, the minute-by-minute values of cabin pressure (upper-pod pressure) were also included in the figures to indicate the most obvious environmental variable during the course of the measurements.

As can be seen from the results, there was a fairly large variability in respiratory gas-exchange rates; however, some relationship with the flight profiles may be discerned. The response time of the gas analysis system is of the order of several minutes, whereas the notable events in the flight profiles were relatively transient, lasting perhaps no longer than a minute. The Kepplerian maneuvers resulted in a zero-*g* condition of a few seconds, as shown in Figure 15. As judged by the continuous strip-chart records of cabin pressure, most of the landing and takeoff maneuvers were

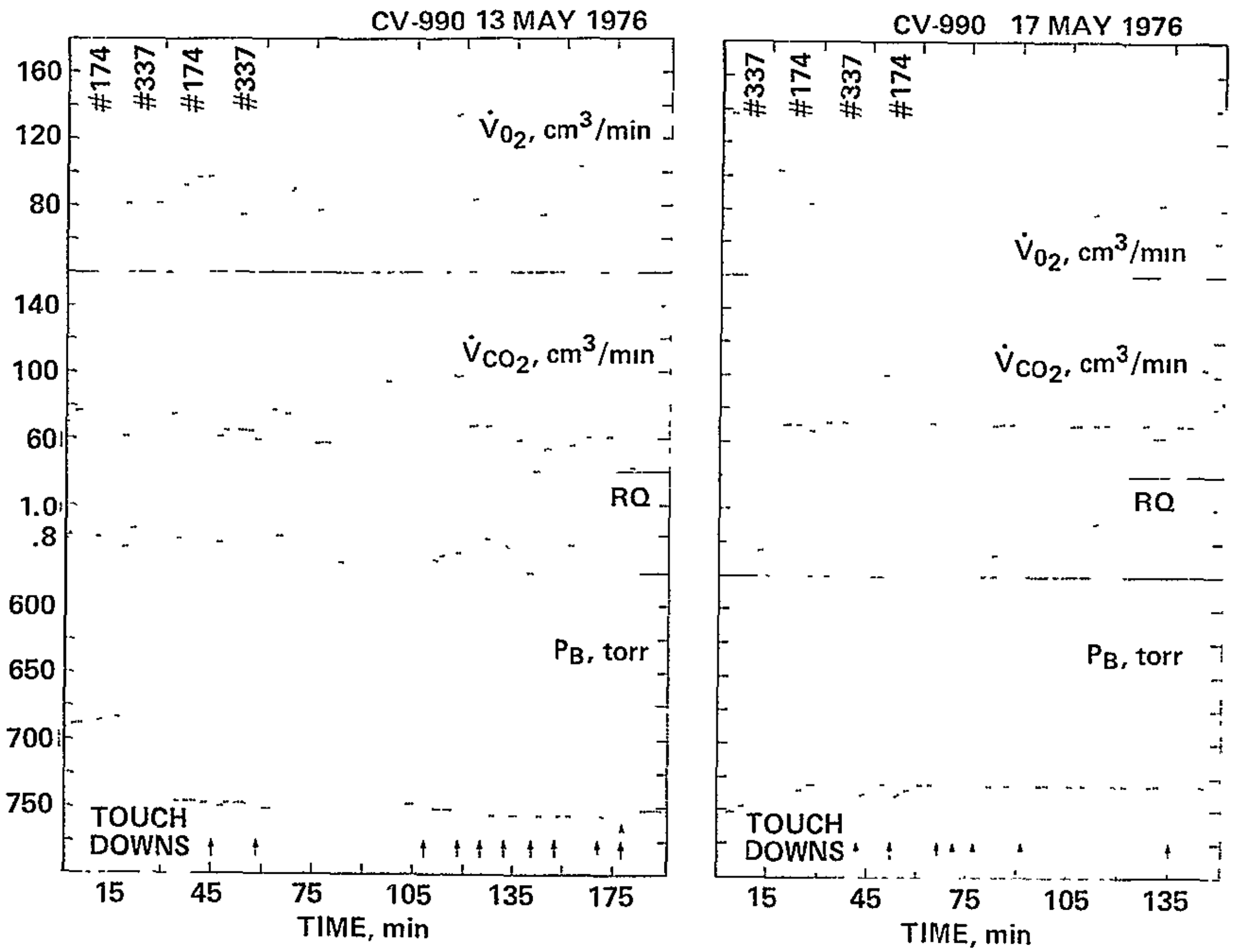


Figure 13.- Monkey oxygen consumption (V_{O_2}) carbon dioxide production (V_{CO_2}) and respiratory quotient (RQ), and cabin air pressure (P_B) during CV 990 flights of 13 and 17 May, 1976. Monkey #176 and monkey #337 data are shown during alternate 15 min periods.

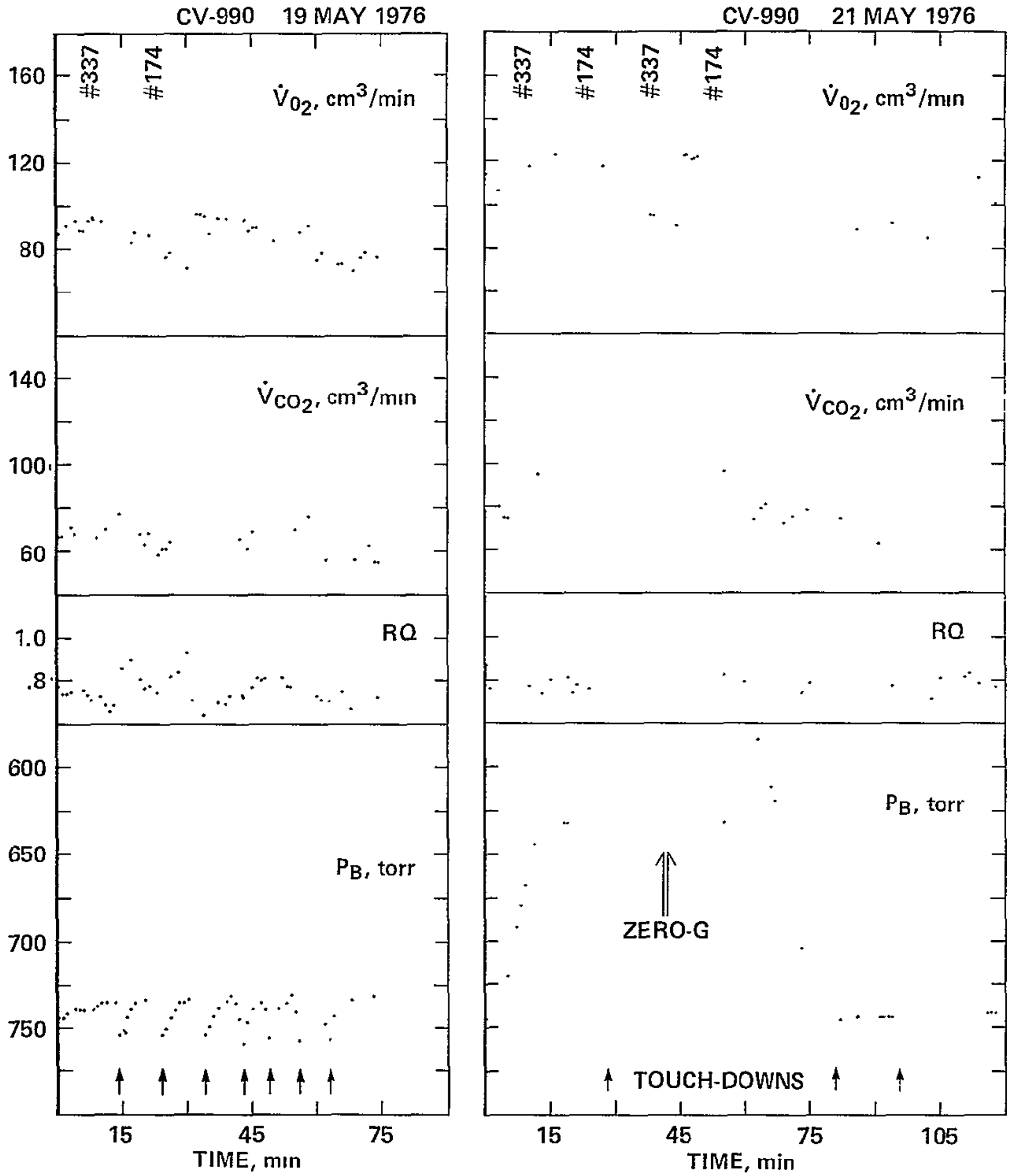


Figure 14.- Monkey oxygen consumption (V_{O_2}), carbon dioxide production (V_{CO_2}) and respiratory quotient (RQ), and cabin pressure (P_B) during CV 990 flights of 19 and 21 May, 1976. Monkey #176 and monkey #337 data are shown during alternate 15 min periods.

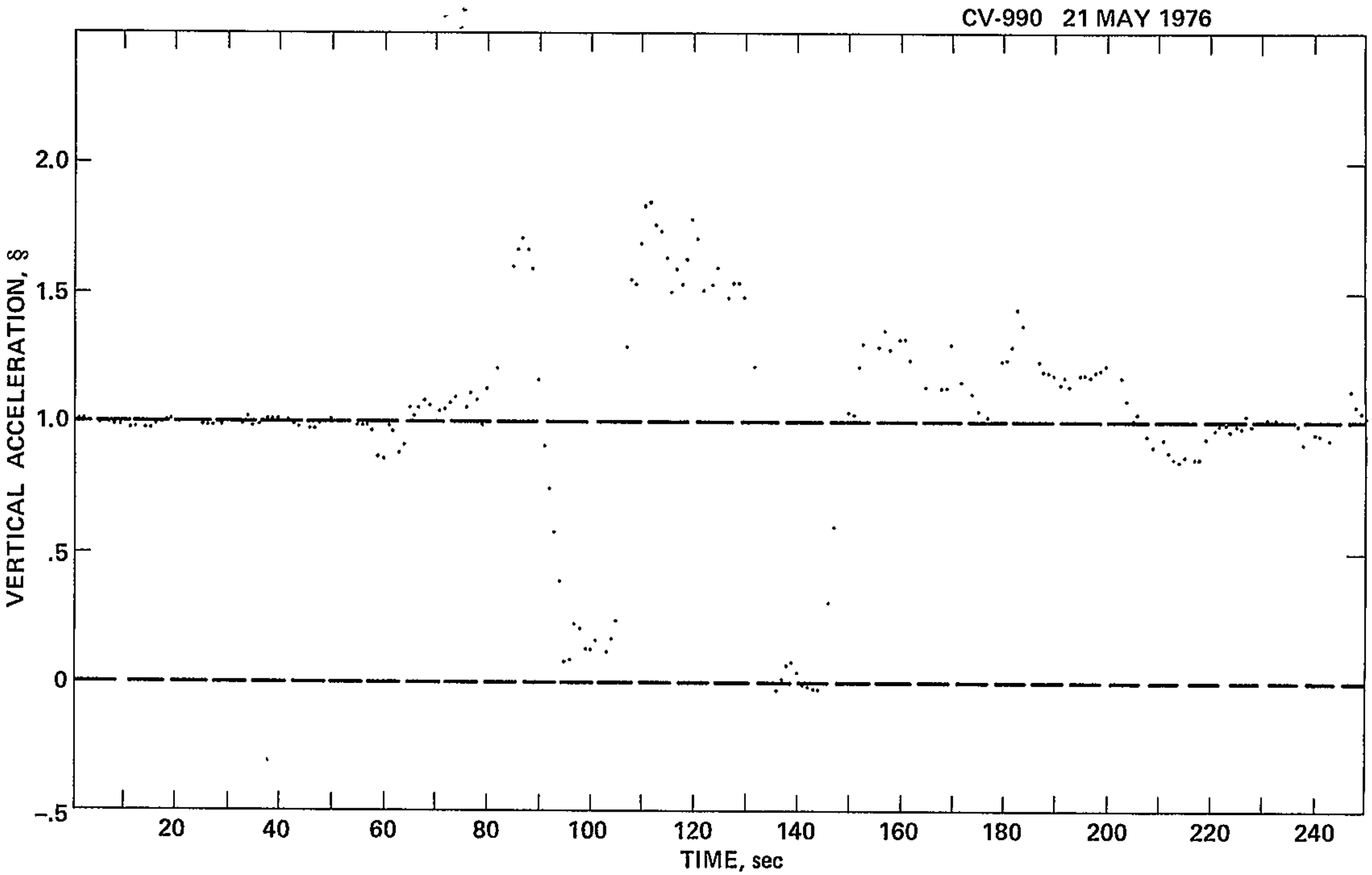


Figure 15.- Vertical acceleration of CV 990 aircraft during the portion of the flight of 21 May, 1976, when "zero-G" was achieved for several seconds.

initiated from level flight at low altitudes and were completed in approximately one minute. Hence, anything less than major responses of the animals to the aircraft maneuvers tended to be damped out by the buffering effect of the response time of the system.

Table 7 shows the overall mean values of respiratory gas exchange for the two animals during each of the flights of 13, 17, 19, and 21 May 1976. In apparent contrast to the heart-rate data, there was no clear trend in the results to suggest an adaptation by the monkeys to the experience of aircraft flight. In fact, the mean values of O_2 consumption and CO_2 production rates were highest in both animals during the last flight of 21 May 1976. However, as mentioned previously, a variety of extraneous stimuli were operative throughout the course of the flights, and may be expected to have contributed to a variability in the results, particularly considering the short duration of the flights.

The one systematic finding in the respiratory gas-exchange data was the consistently higher respiratory quotient of monkey #174 compared to that of monkey #337. Monkey #337 consumed less food during the flights, and as noted earlier, was clearly overweight. The low R.Q. observed for #337 would seem to suggest he was drawing heavily on his fat reserves to meet his energy requirements during this time.

At the conclusion of the series of CV-990 flights, the analog tape of the data from 21 May 1976 was replayed in the laboratory and recorded on strip charts to evaluate the quality of transcription. A representative 20-min segment of the playback was selected for comparison with the corresponding segment in the original direct strip-chart recording. As can be seen in Table 8, the values obtained from reading the original and transcribed strip-chart records were quite comparable. Some 60-Hz noise detracted somewhat from the aesthetic quality of the tape transcription in a few of the channels, but had no impact on the reading of the records which were otherwise very faithfully reproduced.

The reduction of strip-chart data for respiratory gas-exchange measurements involved a laborious and highly subjective procedure of reading the records and converting the readings to physiological units, followed by a series of simple yet time-consuming arithmetic operations. For the CV-990 flights, the Airborne Digital Data Acquisition System was available not only to digitize and log the signal outputs from all of the instrumentation, but also to automatically average and convert the raw voltages to physiological or engineering units. Furthermore, the system was programmed to take the respiratory gas-exchange parameters in physiological units and carry out the several secondary arithmetic operations to yield the final results; i.e., the O_2 consumption and CO_2 production rates in flight on essentially a real-time, minute-by-minute basis.

Table 9 shows a comparison of O_2 consumption and CO_2 production rates of the two test animals for the flight of 21 May 1976, computed on the one hand from postflight analysis of strip-chart records, and, on the other, by ADDAS on a real-time basis during flight. The mean values of O_2 consumption

TABLE 7

SUMMARY OF RESPIRATORY GAS EXCHANGE MEASUREMENTS ON 2 PIG-TAILED MONKEYS DURING CV 990 FLIGHT

		13 May 1976		17 May 1976		19 May 1976		21 May 1976	
		(#174)	(#337)	(#174)	(#337)	(#174)	(#337)	(#174)	(#337)
	Mean	90.1	91.3	84.3	87.7	95.6	97.0	109.6	102.2
O_2 Consumption	Range	59-130	50-167	76-91	69-108	71-148	83-138	86-155	82-132
(cm^3/min, STP)	S. D.	12.3	32.1	4.4	10.1	17.2	12.1	14.3	12.3
	n	81	85	28	45	68	68	75	73
	Mean	73.5	67.4	68.6	62.9	81.7	71.0	91.0	75.2
CO_2 Production	Range	53-114	38-115	58-76	50-77	66-143	63-106	74-135	62-120
(cm^3/min, STP	S. D.	11.5	19.7	4.8	6.7	16.6	8.7	12.6	11.9
	n	81	85	28	45	68	68	75	73
	Mean	0.815	0.754	0.814	0.719	0.857	0.733	0.831	0.732
Respiratory	Range	0.689-1.034	0.644-0.889	0.753-0.904	0.651-0.930	0.680-1.040	0.663-0.845	0.730-1.011	0.654-0.909
Quotient	S. D.	0.046	0.071	0.044	0.044	0.100	0.026	0.054	0.045
	n	81	85	28	45	68	68	75	73

TABLE 8

Comparison of values* for some selected respiratory gas exchange parameters derived from (a) a direct strip chart recording and (b) a strip chart transcription or replay of an analog tape recording obtained during CV-990 flight of 21 May 1976.

G.M.T.	Monkey No.	Exhaust Air F_{O_2}		Exhaust Air F_{CO_2}		Mass Flow (cm^3/min)		Upper Pod Pressure (torr)		M/S Inlet Temperature (°C)	
		(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
19:47	Simple (#337	0.1878	0.1881	0.0110	0.0114	7000	7000	632	631	26.0	26.2
:48		0.1878	0.1876	0.0110	0.0114	7000	7000	632	631	25.8	26.0
:49		0.1884	0.1881	0.0110	0.0109	7000	7000	632	631	25.8	26.0
:50		0.1889	0.1887	0.0110	0.0109	7000	7000	632	631	25.6	26.0
:51		0.1889	0.1887	0.0110	0.0109	7000	7000	632	631	25.6	26.0
:52		0.1894	0.1892	0.0099	0.0103	7000	7000	632	631	25.6	26.0
:53		0.1900	0.1897	0.0099	0.0098	6900	7000	622	621	25.6	26.0
:54		0.1889	0.1887	0.0110	0.0109	6700	6700	601	604	25.6	26.0
:55		0.1889	0.1887	0.0104	0.0109	6800	6700	610	612	25.6	26.0
:56		0.1894	0.1892	0.0104	0.0109	6900	6800	618	618	25.8	26.2
:57	Exeter (#174)	0.1836	0.1840	0.0163	0.0162	7100	7100	620	622	26.0	26.4
:58		0.1847	0.1845	0.0157	0.0156	7100	7100	622	622	25.3	26.0
:59		0.1857	0.1855	0.0152	0.0151	7100	7100	624	624	25.1	25.6
20:00		0.1852	0.1851	0.0157	0.0156	7100	7100	624	624	24.7	25.3
:01		0.1852	0.1851	0.0152	0.0151	7200	7100	628	628	24.3	25.1
:02		0.1852	0.1851	0.0152	0.0151	7200	7100	628	628	24.2	24.9
:03		0.1852	0.1851	0.0163	0.0162	6900	6900	612	613	24.2	24.9
:04		0.1857	0.1855	0.0152	0.0151	7000	7000	620	622	24.0	24.7
:05		0.1868	0.1871	0.0141	0.0140	7200	7100	626	627	23.8	24.7
:06		0.1873	0.1871	0.0141	0.0140	7400	7300	634	632	24.0	24.7
Mean		0.1872	0.1870	0.0130	0.0130	7030	7005	624	624	25.1	25.6

* Results normalized with respect to amplification on strip chart recorder.

TABLE 9

Comparison of O_2 CONSUMPTION RATES (cm^3/min, STP) of 2 pig-tailed monkeys during CV-990 flight of 21 May 1976, computed (a) from post-flight analysis of strip chart records and (b) by ADDAS on a real-time basis in flight.

		(a)	(b)
Exeter (#174)	Mean	109.6	106.3
	Range	86-155	86-132
	S.D.	14.3	11.6
	n	75	71
Simple (#337)	Mean	102.2	100.2
	Range	82-132	82-124
	S.D.	12.3	10.5
	n	73	70

Comparison of CO_2 PRODUCTION RATES (cm^3/min, STP) of 2 pig-tailed monkeys during CV-990 flight of 21 May 1976, computed (a) from post-flight analysis of strip chart records and (b) by ADDAS on a real-time basis in flight.

		(a)	(b)
Exeter (#174)	Mean	91.0	81.4
	Range	74-135	65-119
	S.D.	12.6	11.5
	n	75	71
Simple (#337)	Mean	75.2	65.3
	Range	62-120	53-91
	S.D.	11.9	8.9
	n	73	70

rate were reasonably close. The CO_2 production rates, however, were surprisingly dissimilar, with those computed by ADDAS some 10-15% lower than calculated from the strip charts. Inasmuch as the respiratory quotients obtained from the strip-chart data appear to be within reasonable limits, whereas those computed by ADDAS seem low, one is inclined to attribute the discrepancy to an underestimate of CO_2 production rate by ADDAS. It is clear, however, that the problem is experimenter induced, and not associated with the soft- or hardware.

Following verification of input/output voltages and debugging of programs during earlier flights, the on-line computation of respiratory gas exchange was given a final checkout just prior to the last flight on 21 May 1976, using sample calculations. The signal conditioner was used as a multichannel, constant-voltage source to simulate the simultaneous signal inputs from the mass spectrometer and mass flowmeter to ADDAS. After the calibration factors were entered, cabin air composition was entered as voltages, converted to gas fractions, and stored as constants. The computer was then placed in the "run" mode and a set of voltages representing the mass spectrometer signal outputs for the gas fractions of pod exhaust air and the mass flow of air through the pod were generated by the signal conditioner. At the same time, the signal outputs were monitored and recorded from a digital voltmeter for manual calculations.

Owing to a limitation in the number of channels available, the signal outputs for the respiratory gas fractions from the mass spectrometer were multiplexed and recorded on a single channel of the strip-chart recorder. Each of the 4 gas fractions was measured for 15 sec out of each minute. ADDAS, on the other hand, had no limitation on the number of channels and recorded the gas fractions individually and continuously. Thus, the 2 sets of data are, in fact, not really identical. The difference in CO_2 production rates, however, would appear to be much larger than could be accounted for by a difference in sampling duration.

It is possible that the calibration factors, units/volt for ADDAS and units/chart division from the strip charts, were not exactly equivalent for the gas fraction F_{CO_2}, with that of ADDAS erring on the low side. For example, the voltage readings taken during the pre-flight calibration period for the full-scale value of CO_2 may not have been sufficiently representative, with the result that the calibration factor entered and stored in ADDAS may have been inaccurate. "Representativeness" is more obvious on a continuous tract of a strip chart record.

Even more suspect, however, is another constant entered in the computer, namely, the gas fraction F_{CO_2} for cabin air. Again, the voltage reading from which the CO_2 content of cabin air is derived and stored was taken during the pre-flight calibration period and may not have been appropriate for use during flight. In addition to the ever-present spectre of operator error, there is the distinct possibility that the cabin air composition was actually different before and during flight. The experiment area on the aircraft was typically congested with traffic and activity during the pre-flight period. Given the relatively small and unventilated cabin space of the parked aircraft, the F_{CO_2} may well be expected to have been somewhat high. The strip chart record for cabin air composition was obtained while the aircraft was taxiing and during the first few minutes of flight before the gas sampling system was switched over to monitor the gas outflows from the pods. With the aircraft now on its own power and air conditioners in operation, the cabin air composition may then have been more typical. In fact, the F_{CO_2} of cabin air used by ADDAS was 0.0012, whereas that for the calculations from the strip charts was 0.0005. For an F_{CO_2} of 0.0090-0.0100 in the exhaust air from the monkey pods, the difference in cabin air F_{CO_2} would introduce a discrepancy of nearly 10% in the ΔF_{CO_2} and hence in the CO_2 production rate.

In less unusual circumstances, under more controlled conditions — free of the distractions attending power interruptions, without the operational constraint requiring completion of calibration procedures before aircraft door closure, etc. — greater care could be taken to ensure reliable calibration factors and constants for the onboard computer. Given accurate information, a system such as ADDAS is clearly a far superior data system than strip-chart records. In addition to the obvious advantage of obtaining processed and finished physiological data on a real-time basis, its fidelity may be as much as 2 orders of magnitude better than that of a multi-channel strip-chart recorder, which necessarily will result in better data. In any case, the above problems notwithstanding, useful information was gained from the CV-990/ADDAS experience and the evaluation of these test results.

Cardiovascular measurements.- Heart rate was obtained from monkey #174 by the application of bi-polar silver/silver chloride ECG leads to the thorax just prior to insertion into the pod. Heart rate from monkey #337 was obtained from the telemetry ECG output signal. Both ECG signals served as inputs to Brush biotachometers which gave heart rate as output signals to a strip-chart recorder.

A variety of minor electronic and mechanical interference problems during the flights resulted in spotty heart-rate data return. The usable minute-by-minute heart rates from the two animals during the four flights on 13-21 May are plotted in Figure 16. While the results are far from being totally satisfactory, nonetheless they are sufficient to demonstrate that the physiological condition of the animals was generally stable during the flights. It may also be concluded that with more time and attention in system preparation than was available in the present circumstances, totally satisfactory in-flight heart-rate recording could have been achieved readily.

The online computation of both heart rates and the upper/lower pod differential pressure was accomplished by the ADDAS system. Sixty samples per second of signal voltage outputs were read by the ADDAS system and used to compute minute averages for each of the 3 parameters. These averages were initially printed out on a CRT display and later in the flight as hard copy on a line printer located on the EPL/UCB Data Acquisition Rack.

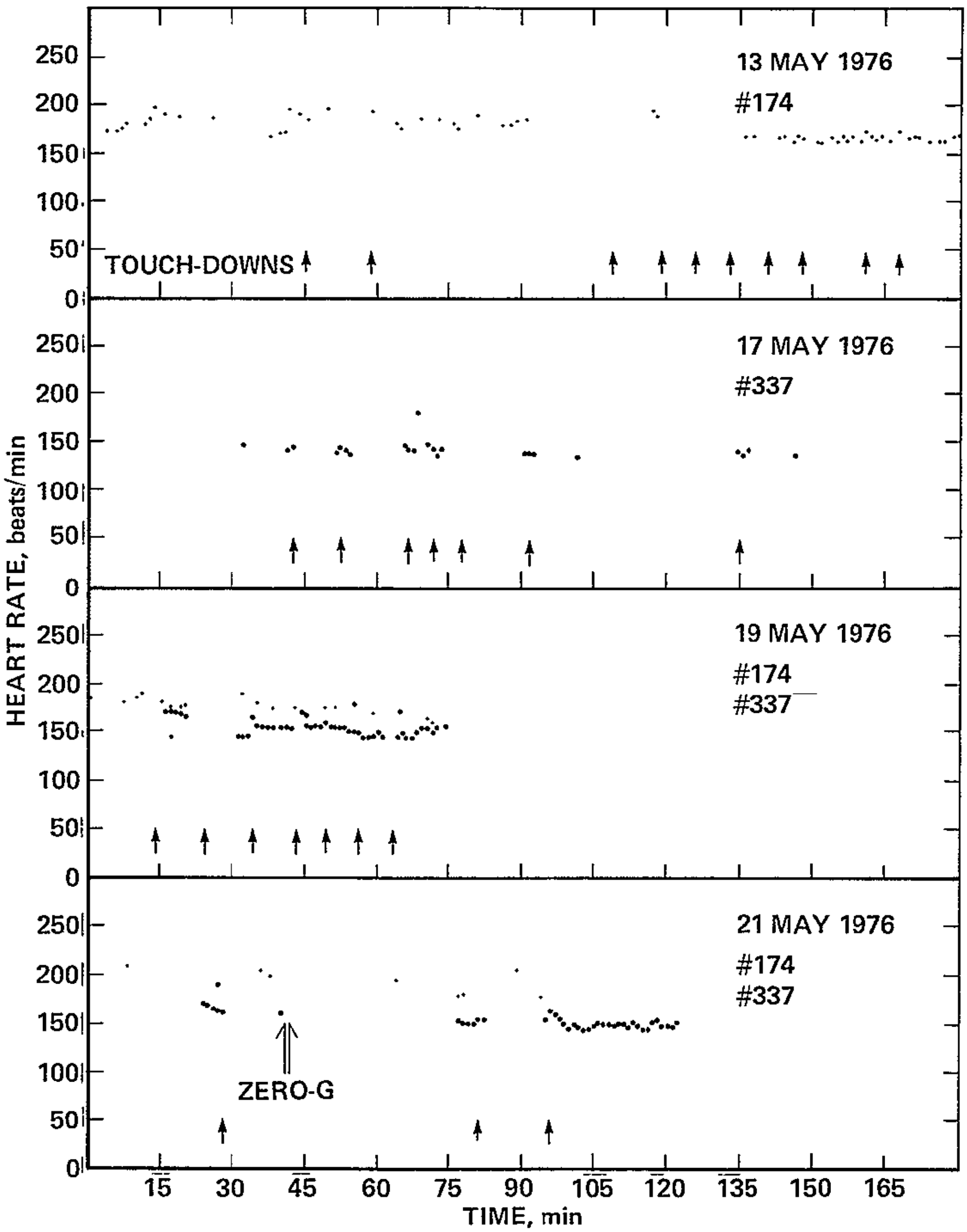


Figure 16.- Heart rates of monkey #174 (skin electrodes) and monkey #337 (implanted biotelemetry) during CV 990 flights of 13-21 May 1976).

The program for the computation of heart rate was to have included high and low heart rate limits selected by the experimenter, beyond which values would not be included in the computation of the minute rate. The number of values used in the computation (60 or less) of the average was to be printed also. The final program included only a high heart rate limit, and this was selected to be 250 beats/min (full scale) throughout the flights. The program for heart rate worked well during the flights, as shown in Table 10. Mean heart rates from the ADDAS and the strip chart records differed on the average by only 3 beats/min for both pods, with the ADDAS values usually lower than the estimates from strip chart records. The high-limit cutoff on heart rate helped to prevent ECG artifacts from being included in the heart rate computation. A similar low-limit cutoff at about 100 beats/min would have helped eliminate the inclusion of values in the computation when the cardiotachometer was not able to count R waves due to a poor ECG signal input.

From the biotelemetry data, an interpretation of the cardiovascular responses can be made for heart rate, left ventricular and aortic pressures. Assuming that the nadir of the ventricular pulse represented zero torr and that the extent of the zero-cal span represented 100 and 180 torr, respectively, regardless of the sensitivity setting on the recorder channel, a peak left-ventricular pressure could be determined. This peak pressure would in turn be the same as the aortic systolic pressure, and by calibration with the indicated zero-cal span on the aortic pulse-wave channel, aortic pulse pressure and diastolic pressure were estimated. Heart rates were determined by counting the number of pulses per unit time during the identical period that the pressures were calculated.

Some data on all parameters were derived at various stages of flight activity. Heart rates ranged from a low of 129 to 216 beats per minute, peak left-ventricular pressure from 118 to 200 torr, aortic diastolic pressure from 81 to 127 torr, and aortic pulse pressure from 32 to 55 torr. The higher levels of these observations were obtained either during the first week of the flights, or when the monkey struggled against his restraint following initial placement in the supine position and the application of lower body negative pressure. These extremes were of a transient nature.

A summary of telemetered cardiovascular measurements for a series of observations on 11, 17, 19, and 21 May made under similar conditions of level flight while the pod was positioned upright with the monkey relatively undisturbed is shown in Table 11. It would appear that the test subject became more accustomed to the environment with successive flights. Table 12 contains a summary of observations obtained during delayed flap maneuvers of the CV-990. Although initially there seemed to be some differences in cardiovascular performance during the 3 aspects of this maneuver, that is, the descent, touchdown, and subsequent ascent, the mean values for 10 observations showed very slight or no change. On the other hand, the levels of these measurements did decrease with each succeeding flight day, as did those observed during level flight. However, they tended to be higher on the average than those observed during level flight.

TABLE 10

Comparison of 1 min average heart rates (beats/min) from sample ADDAS and Brush strip chart records during the 21 May 1976 CV-990 flight.

	Greenwich Mean Time (hours:min)		ADDAS Computation	Strip Chart Estimate	ADDAS Strip Chart
Pod #1	18:44		216	220	- 4
	18:45		212	214	- 2
	18:46		215	214	+ 1
	18:47		208	210	- 2
	18:48		214	217	- 3
	18:45		214	217	- 3
	18:50		211	215	- 4
	18:51		206	213	- 7
	18:52		201	205	- 4
	18:53		202	200	+ 2
		Mean	210	213	- 3
Pod #2	18:52		186	190	- 4
	18:53		181	187	- 6
	18:54		180	185	- 5
	18:55		178	180	- 2
	20:57		146	149	- 3
	20:58		150	152	- 2
	20:59		150	152	- 2
	21:00		147	150	- 3
	21:01		146	148	- 2
	21:02		151	152	- 1
		Mean	162	165	- 3

TABLE 11

Biotelemetric cardiovascular data from the pig-tailed monkey #337, Simple, during level flight with the pod in the upright position.

Date		Heart Rate (beats/min)	Peak Left Ventricular Pressure (torr)	Aortic Diastolic (torr)	Pressures Pulse (torr)
11 May 76	Mean (6)*	154	147	108	39
	Range	(150-156)	(133-156)	(94-118)	(37-42)
17 May 76	Mean (4)*	136	136	98	38
	Range	(129-144)	(133-141)	(95-100)	(36-41)
19 May 76	Mean (4)*	137	127	87	39
	Range	(126-144)	(123-131)	(81-93)	(35-42)
21 May 76	Mean (9)*	132	122	88	34
	Range	(129-138)	(118-130)	(84-96)	(32-34)

( )* Number of observations included in the mean.

TABLE 12

Biotelemetric cardiovascular data from the pig-tailed monkey #337, Simple during delayed flap maneuvers of the CV-990.

		Heart Rate (beats/min)	Peak Left Ventricular Pressure (torr)	Aortic Pressures Diastolic (torr)	Aortic Pressures Pulse (torr)
Descent	Mean (10)*	143	141	103	38
	Range	138-156	126-165	92-127	34-42
Landing (10 sec period before and after touchdown)	Mean	144	140	101	38
	Range	135-159	122-151	88-113	34-42
Ascent	Mean (10)*	144	139	100	39
	Range	135-159	122-151	88-113	34-44

( )* = number of observations included in the mean

2 on 11 May 76
6 on 17 May 76
1 on 19 May 76
1 on 21 May 76

10 Total

Monkey condition and nutritional intake.- The procedures for monkey insertion and removal have been discussed in previous sections. In considering monkey behavior, it was noted that both monkeys were subjected to environments that would not usually occur in the conduct of an optimum experiment without the constraint of time encountered. These situations were reflected to some extent in the physical condition of the monkeys, particularly in their body weight when compared to previous trials. Both animals were over-conditioned prior to initial insertion in the pods. Rates of weight loss were greater from 5-14 May than during the last week of the flight schedule, as shown in Table 13. However, recovery periods in the cage following removal were within normal limits, and no leg edema or loss of kinesthetic activity was evident.

On 7 May 1976, upon removal from the pod, a mid-dorsal skin lesion (5 cm × 5 cm) was noted on #337. The abrasion was treated with Furacin(R) ointment. The causative factor was believed to have been mechanical or thermal, resulting from the placement of the external energizing coil or the power oscillator module of the biotelemetry subsystem. For the next insertion of this monkey, the power oscillator was mounted in a more posterior position on the couch. The energizing coil terminal to connecting electronic wiring had several abrasive areas. As a palliant, this junction was wrapped with several layers of tape. In addition, the application of power input in activation of the system was minimized to prevent overheating. No further decrement of the skin lesion occurred during the balance of the period when he was placed within a pod from 10-14 May and again from 17-21 May. On 17 May, #422, who was originally scheduled for the final week of flights, required clinical attention and was deemed unsuitable for pod insertion.

Excreta collection and handling.- As a part of the monkey insertion procedures, a silicone tube was placed over the penis and secured distally to a urine collection bag (Curity(R) 2,000 ml bag Code No. 3057) mounted on the back of the lower leg section of the couch. A drainage tube with spring-clip occluder led from the bag and connected with a fitting on the lower-pod anterior central aperture. To collect a clean, timed, uncontaminated urine sample, the fitting was removed, the drainage tube occluder released, and the urine removed. In an attempt to utilize a system which should function in zero-*g*, a syringe was used to evaluate the urine sample. Observations were made daily through the lower-pod window, and upon monkey removal from the pods there was no evidence that leakage occurred. In addition, this separation of the urine from feces tended to reduce the production of obnoxious odors. When the silicone tube was detached, no irritation to the penis was apparent. The silicone tubes following use from 10 to 14 May were cleaned and replaced on the same monkeys for collections of 17 to 21 May.

Biotelemetry.- The postoperative course following implanation was generally smooth except for late breakdown of the skin at the incision site in the two flight animals. Detailed hematological and related data on the two Macaca nemestrina animals prepared for the flight test are contained in Table 14. The most consistent changes were decreased weight, subsequently remaining stable, and anemia, resulting from blood loss during surgery.

TABLE 13

Monkey body weights at insertion into and removal from the pods during the periods in which CV-990 flights were made.

Monkey	Date	Action	Body Weight (kg)	Body Weight Change (kg)	(%)
#337, Simple	5 May 76	Insertion	14.45		
	7 May 76	Removal	13.85	- 0.60	- 4.2
#337, Simple	10 May 76	Insertion	13.95		
	14 May 76	Removal	13.15	- 0.80	- 5.7
#174, Exeter	10 May 76	Insertion	11.50		
	14 May 76	Removal	10.72	- 0.78	- 6.8
#337, Simple	17 May 76	Insertion	13.30		
	21 May 76	Removal	13.20	- 0.10	- 0.8
#174, Exeter	17 May 76	Insertion	10.70		
	21 May 76	Removal	10.60	- 0.10	- 1.0

TABLE 14

History of the Experimental Monkeys
M. nemestrina

Animal no.	Date, 1976	Year acquired	Est. age, yr	Weight, kg	Hct, %	Hgb, g%	RBC, $\times 10^6$	WBC, $\times 10^3$	Plasma protein, g%	BUN, mg%	Comment
337	3/23	1969	15	16	44	15.0	5.5	8.9	7.4		Flight animal
	3/24										Surgery
	3/31			14.25	32	10.5	4.0	13.3	6.9	13	
	4/2				33	11.5	5.5	19.1	7.7		
	4/8				34	9.8	4.8	11.4	7.4		
	4/27			14.5	39	13.4	5.0	11.9	7.8		Begin flights (5/6)
	5/5			14.5							
	5/10			14.4							
	5/17			14.5							
	5/24				38	12.7	5.7	10.6	7.5		End flights (5/21)
	7/26			14.4	47	13.1	6.1	6.9	7.0	13	
	8/9			13.8	42	11.8	6.2	14.9	8.2	15	Healthy, unit working
442	3/31	1974	9	11.8	42	13.0	5.9	6.7	7.2		Backup animal
	4/6										Surgery
	4/15			10.5	(42)[a]	10.6	5.0	21.0	7.9		
	4/27			10.5	32	10.4	4.2	11.6	8.3		
	5/24				34	11.6	5.0	11.6	8.1		
	7/9										Sacrificed

[a]Accuracy questionable.

Progressive recovery and return to normal is apparent. X-ray examination showed a left lower lobe infiltrate which gradually cleared. The time to recovery with normal hematology and X-ray findings was 6 to 8 weeks. The tissue changes were those expected with thoracic surgery and placement of an implanted device, and the unit was satisfactorily tolerated.

Failure modes of the telemetry system have been variable and of the type likely to occur with any instrumentation inside the body for a long period. In three cases, transducer leads eroded at a tie-down point. Occasionally, internal electronic components have failed. In general, the implant experience indicates the type of improvements needed in future units. Overall, the system operated as designed.

In the airborne simulation of a space flight experimental environment, eight flights with over 50 takeoffs and landings were conducted over a 16-day period. The five initial flights were made primarily to check out the onboard recording system. The implanted unit always produced signals. For the final week (three flights), monkey #337 was fitted with a vest containing the energizing coil and sealed into the pod. Data were obtained and recorded on each of the three flights.

Application of lower body negative pressure (LBNP).- As part of the objective of making cardiovascular measurements during the CV-990 flights, it was planned to record the heart-rate response to lower body negative pressure on both monkey subjects during flight. LBNP produces a redistribution of blood from central to peripheral reservoirs and thereby serves as a provocative stress to the cardiovascular system under both 1- and zero-*g* conditions. LBNP is typically applied with the subject in the supine position at 1-*g* so as to induce a postural redistribution of blood. At zero-*g* the response to LBNP is independent of body position and is an effective and simple technique for assessing the state of the reserve capacity of the cardiovascular system. During previous studies, it has been determined that an incremental LBNP test consisting of 5 min each of 40, 50, and 60 torr was sufficient to produce a significant heart-rate increase during at least one pressure level for any individual monkey. It was also determined that a 15-min control and recovery period was necessary to define the baseline heart rate and to allow return to that baseline after LBNP. After tilting each subject to the supine position, a 30-min period prior to beginning the collection of control data was allowed for stabilization of cardiovascular parameters, since the tilt process itself is a stressful event for some subjects.

The capability of tilting each pod to the horizontal position for conducting the LBNP test was included in the design requirements for the monkey pod rack. The maneuver was accomplished simply by removing a holding pin, tilting the pod, and replacing the pin in another hole. This system worked very well throughout the flight. Even though the urine-collection system was designed to collect all the urine, the possibility existed of some urine leakage at the monkey/catheter interface with the pod in the horizontal position. To prevent any extreta from entering the lower pod air inlet port during tilt, polyvinyl chloride tubes were inserted into the ports from inside of each pod during pod assembly to act as standpipes. No excreta entered the ports during the flights.

In-flight LBNP tests were performed during two flights of the series. On 13 May a preliminary 5-min test was completed with the control monkey, #174. During this test it was determined that the 28 Vdc LBNP pump was able to generate a maximum upper/lower pod differential pressure of only 6 torr. On 21 May, 5 min of 5-torr LBNP was applied to both monkeys during flight to test the data interface with the ADDAS system.

Ground-based LBNP tests on board the CV-990 were conducted on both monkey subjects on two occasions. The incremental LBNP test was performed preflight on 19 May following the protocol. Several 2- to 3-min tests at 60 torr LBNP were conducted postflight on 21 May.

A summary of the heart-rate responses to LBNP during ground-based tests on the two monkeys is shown in Table 15. These data appear similar to test results typically obtained at EPL/UCB from monkeys only minimally conditioned to supine LBNP and/or under circumstances where environmental disturbances (noise, proximity to humans) produce behavioral effects on heart rate. Control heart rates recorded previously on these two subjects during 3-5 day pod tests in the upright position, but under less disturbing conditions, were 35-40 beats/min lower than those seen during the supine LBNP test control period or in the upright position on the CV-990. Both monkeys exhibited signs of being stressed (struggling, chewing on feeder handle, etc.) during the supine control and LBNP periods.

The incremental LBNP test conducted preflight on 19 May was conducted under conditions unfavorable for obtaining good data. During the LBNP tests several persons were actively involved in calibrating portions of the instrumentation directly adjacent to the pods. The rather erratic and minimal heart rate response to increasing negative pressure levels seen during this test may have been partially due to the effect of leg muscle contraction during struggling, which would lessen the quantity of blood pooled.

The postflight LBNP tests conducted on 21 May took place with the CV-990 nearly empty and relatively quiet, and the quality of the heart rate data was improved. On this final flight day there was not enough time postflight to conduct the full 100 min two-pod LBNP protocol as planned because of the CV-990 schedule requirements. Also, the monkey with implanted biotelemetry, #337, was providing cardiovascular data output only intermittently because of positioning problems with the external energizing coil. A series consisting of four 60-torr LBNP tests of 2-min duration was conducted on this subject in an attempt to gather control and LBNP data during the short periods of adequate data output. It was hoped that the higher pressure level would give a significant cardiovascular response during the shorter duration.

Sequential applications of LBNP at 60 torr produced heart-rate increases in monkey #337 of 65, 50, 35, and 50 beats/min, for an average

TABLE 15

Effect of supine LBNP on heart rate in 2 monkeys during ground-based tests during the CV-990 flight experiment.

		Heart Rate (beats/min)*				
			LBNP (torr)			
Date	Monkey	Control	40	50	60	Recovery
19 May **						
	#337	162	168	162	216	156
	#174	185	195	195	195	140
21 May***						
	#337	175	--	--	225	178
	#174	175	--	--	225	180

* All data obtained during last minute of control, LBNP and recovery periods.

** LBNP tests on this day consisted of 5 min at each of three pressures.

*** LBNP tests on this day consisted of 2 min at 60 torr only. Data for subject #337 is mean of 4 tests.

increase of 50 beats/min. Monkey #174, during a single identical test, had the same heart rate increase. Previous studies at EPL/UCB with a group of five normal pigtailed monkeys tested three times each showed a mean heart rate increase during 5 min of 60-torr LBNP of about 50 beats/min (range of 30-75).

The in-flight LBNP tests at 6 torr conducted on two occasions did not produce any significant cardiovascular changes due to the low pressure differential. These tests, however, were useful in testing the ADDAS online computation of upper/lower pod differential pressure during flight, as part of the planned LBNP-ADDAS program checkout.

A preliminary look at the telemetry cardiovascular data from monkey #337 on 19 May suggested decreases in aortic systolic and pulse pressures proportional to the level of LBNP applied.

A typical in-flight record is shown in Figure 17, and the effect of lower body negative pressure (LBNP) in Figure 18. In-flight heart rates averaged 135 beats/min, and arterial blood pressures averaged 135/90 mm Hg.

Distance between the coplanar external and internal coils could vary about 2.5 to 4 cm, with a small degree of relative motion tolerated without loss of signal. Larger variations in these relationships caused transient signal loss.

During the prolonged period of confinement, the jacket and oscillator supply for the energizing coil within the pod caused skin irritation, and on one occasion a pressure point over a vertebral process produced a slough of skin 2 cm in diameter. This cleared without complications.

Discussion.- The results indicate that the simulation was successful. The telemetry system operated within the design limits, there were no radio-frequency interference problems, and valuable experience was gained which will aid future planning for flight experiments.

A major improvement for future development of the telemetry system would be circuitry with less power consumption. Decreased power requirements would decrease the amount of energy to be transferred and would permit greater latitude in placement of external energizing coil. Increasing the energizing coil size and the power supplied to it is also important, as well as providing a longer cable length so that the energizing oscillator could be located outside the pod. These changes are relatively easy to implement.

Other refinements needed in future units include increased stability of the oscillator frequency with less susceptibility to failure at low power levels, improved transducers with decreased zero drift, reinforcement at stress points, and smaller overall size of the implanted electronics package. Frequency stability would reduce the need for receiver tuning and would simplify operation. More stable miniature transducers would remove the need for capacitive coupling and the associated long time constant following power interruption. Smaller overall package size would reduce the extent and duration of the intrathoracic changes.

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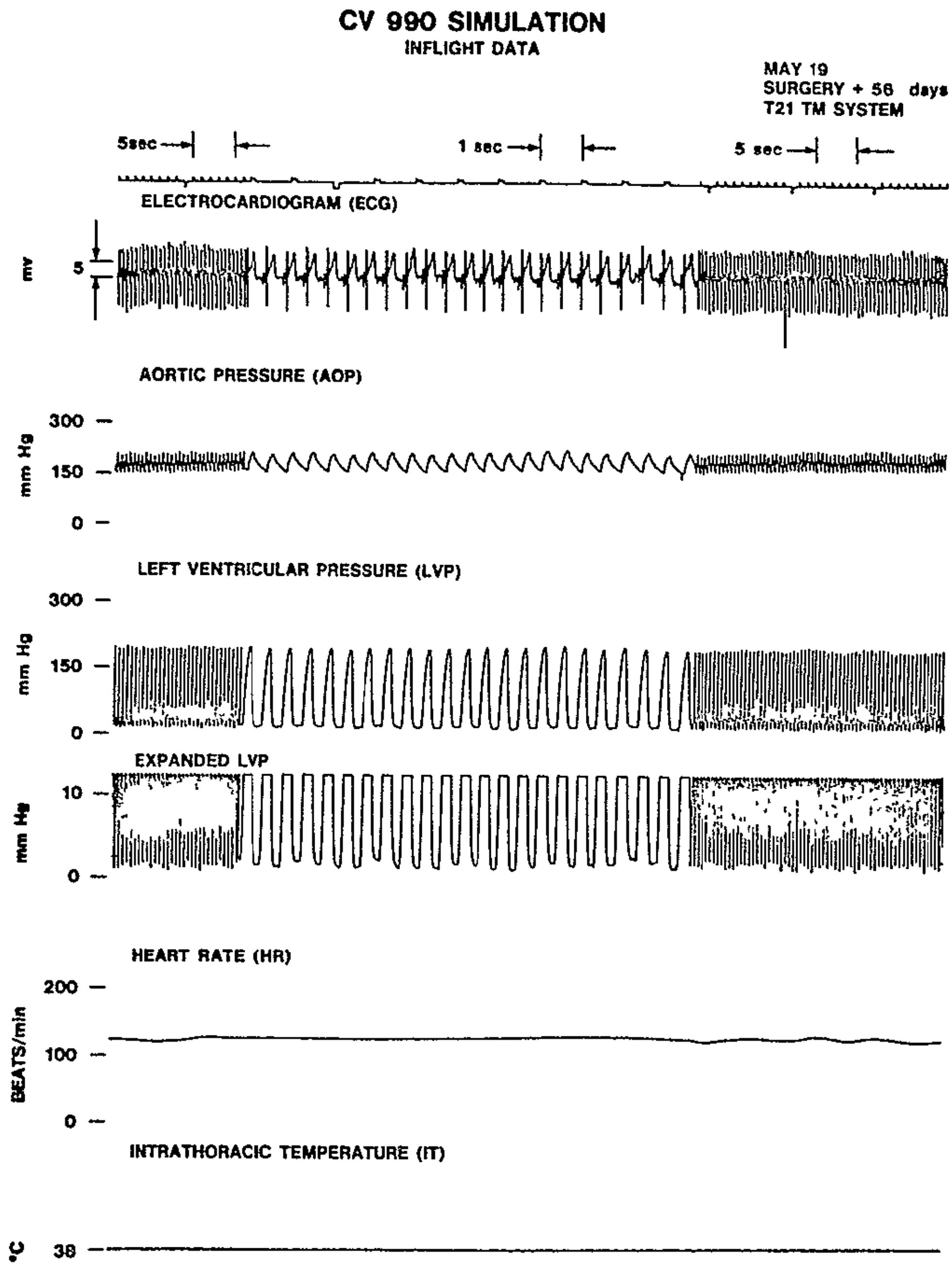

Figure 17.- Typical in-flight data from a 14.5-kg MACACA NEMESTRINA confined within the pod (#337).

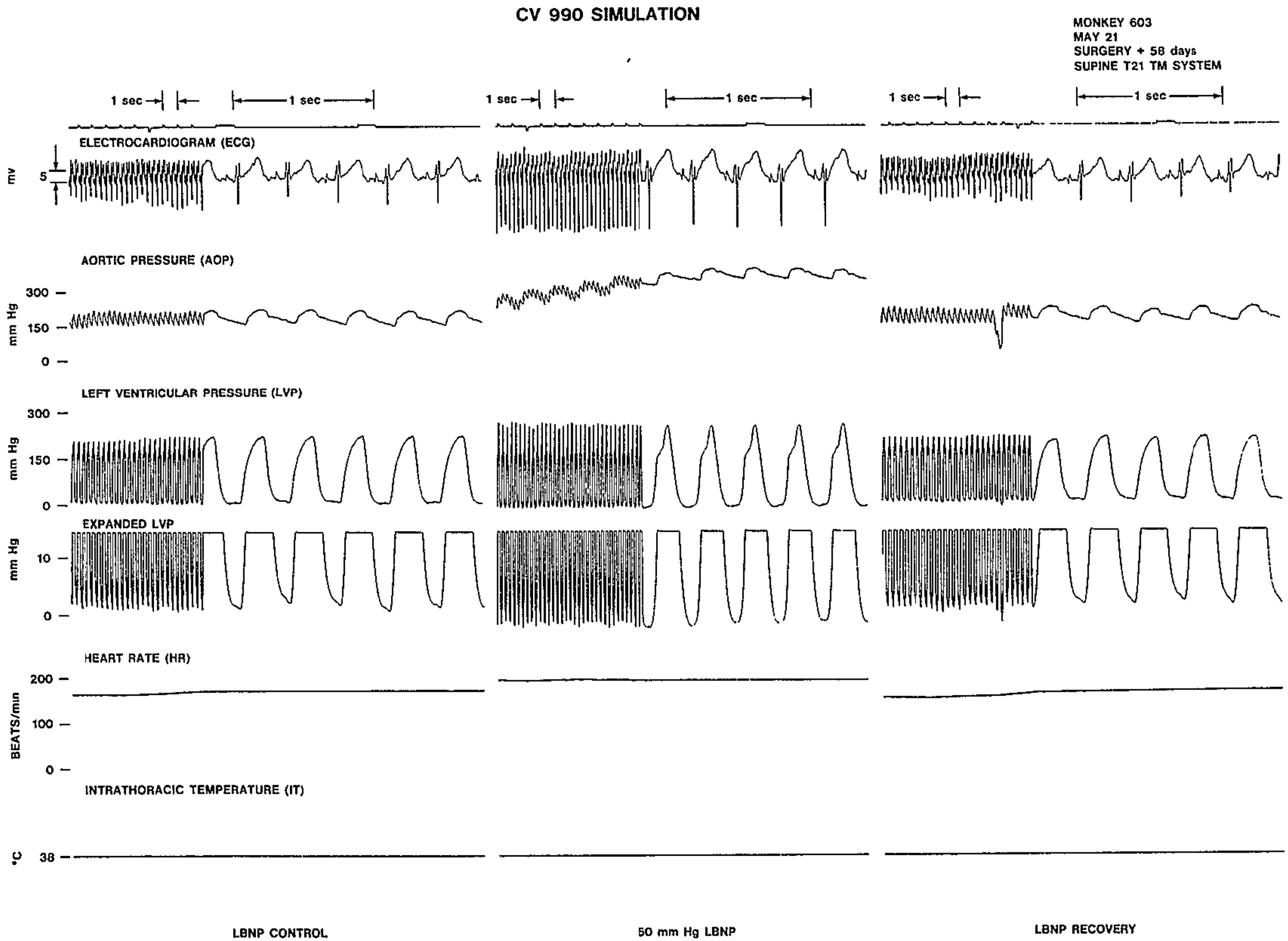

Figure 18.- Changes with lower body negative pressure recorded onboard the aircraft from the pod with the test MACACA NEMESTRINA (#337).

Monkey skin does not tolerate trauma nearly as well as dog skin. At least 2 months should be allowed for surgical recovery before pod insertion to reduce susceptibility to skin irritation from jackets or other items placed on the animal. Foreign materials over the skin should be minimized, and a protective layer should be provided with extensive padding coupled with careful skin hygiene. An access port in the monkey pod restraint system must be provided to permit this care. A suitable approach could be the arrangement used in the glove-box or germ-free animal enclosure.

Some other details regarding the working environment should be noted. In the confined quarters of an aircraft or similar situation, device controls, recorder displays, and similar items directly related to the specific experiment must be clustered with minimal distance between them, and such items must be located at a convenient work height.

The technologic advances permitting the miniaturization needed for the implanted telemetry unit and its successful operation without an implanted power source forecast similar units for even smaller animals, with energy received from coils located in the wall of the cage (9). Alternatively, for larger animals, a selection of modules with a range of transducer types could be made available. The necessity of changing experimental designs could then be met by implanting various combinations of modules without requiring a completely new multichannel system for each type of experiment.

This system expands the capability of obtaining the more meaningful data provided by study of awake animals in a wide variety of conditions, particularly onboard future space flights and in similar stressful environments.

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16 Abstract

The Airborne Science Office (ASO) has provided the scientific community with a CV-990 to perform physical, meteorological, astronomical, and geophysical research. The similarity in mission structure and objectives to that of the Shuttle Spacelab suggests that the informal mission management scheme used by the ASO may be applicable in parts to the management of Spacelab experiment development and integration. A biological system proposed to restrain a monkey in the Spacelab was tested under operational conditions using typical metabolic and telemetered cardiovascular instrumentation. Instrumentation, interface with other electronics, and data gathering during a very active operational mission were analyzed for adequacy of procedure and success of data handling by the onboard computer.

The test was completed and all systems eventually worked satisfactorily. The problems encountered, however, indicated areas requiring improved design and the need for additional interface control during experiment buildup.

With the intent to minimize documentation, reviews, and change-order distribution, a concept of a Computerized Management Program for Experiment Integration is presented that could provide a terminal as a substitute for the series of conventional documents and would assure visibility into the current integration status to provide a means of interface control.

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