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FEASIBILITY STUDY FOR CONDUCTING BIOLOGICAL EXPERIMENTS ABOARD A PIONEER SPACECRAFT

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FEASIBILITY STUDY FOR CONDUCTING BIOLOGICAL EXPERIMENTS
ABOARD A PIONEER SPACECRAFT

SUMMARY

A study was conducted to determine the feasibility and practicality of conducting biological experiments aboard a Pioneer spacecraft in heliocentric orbit. Among the biological problems amenable to study on such a vehicle is the question of the stability of circadian systems divorced from geophysical cues. Seven experiments suggested by NASA supported investigators were identified as representative biological payloads. This study was undertaken in cooperation with NASA/Ames, the Principal Investigators, and TRW Systems, Incorporated, representing the Pioneer spacecraft. The study included experiment definition; conceptual design of experiment hardware; where necessary, studies of the susceptibility of biological material to simulated launch stresses; identification of requirements for monitoring devices to characterize the physical environment during biological experimentation; cost and development schedule estimates for individual experiments; and selection of representative combinations of biological and physical sciences payloads. The study was specifically directed toward engineering feasibility and not to an evaluation of the scientific merit of candidate experiments.

The results of the study demonstrated the practicality of implementing biological experiments aboard a Pioneer spacecraft and recommend a follow-on study for program definition preparatory to initiation of a BioPioneer Program.

INTRODUCTION

Purpose

This study was undertaken to determine the feasibility and practicality of conducting biological experiments in heliocentric orbit aboard a Pioneer spacecraft. It was desirable that the biological experiments take advantage of the relatively long orbital life of the Pioneer and be complemented by physical sciences experiments useful to the interpretation of the biological data.

Need

Development of space technology has provided access to "new" environments in which to study the functioning of fundamental life processes, and concurrently has introduced the question of the consequences of prolonged space residence on man. There are, however, relatively few space vehicles available for, or compatible with, biological research. At present, there are no vehicles available for biological experimentation out of earth orbit. There are important biological problems which should be studied via space probes. Among them is the question of the stability of circadian systems divorced from geophysical cues.

Biological research requires a precision of environmental control which is normally not available on spacecraft developed for other purposes. This is one reason for the special development of the earth-orbiting Biosatellite. Before design of a similar vehicle for non-orbital studies is undertaken, it is important to determine the degree to which space probes originally developed for other programs can be utilized to implement biological research. The Pioneer spacecraft is a promising candidate with proven performance and reliability and a potential experiment payload capability of 50-100 lb.

Scope

Definition of potential payloads for a "BioPioneer" was accomplished by Northrop Corporate Laboratories in cooperation with TRW Systems, Incorporated representing the Pioneer spacecraft, and various principal investigators, identified by NASA, representing specific candidate experiments. The study was specifically directed toward engineering feasibility and not to an evaluation of scientific merit of the candidate experiments. The study included conceptual design of hardware to implement candidate experiments aboard a Pioneer spacecraft; identification of required experiments and/or monitoring devices to characterize the physical environment during biological experimentation; and when necessary, determination through laboratory testing of the biological tolerances to stresses imposed by launch or spacecraft conditions. The laboratory tests supplemented data supplied by various principal investigators who were encouraged to participate in all aspects of experiment definition. Estimated cost and development plans were prepared for each experiment.

Identification of Experiments for the Feasibility Study

The purpose of this study was to demonstrate in an engineering sense the practicality of utilizing the Pioneer spacecraft as a platform on which to accommodate biological experiments. Circadian periodicity experiments were chosen to demonstrate this objective because they share common requirements for removal of geophysical influences and relatively long study periods. Candidate experiments were identified by NASA/ARC from experiments proposed by NASA sponsored investigators currently working in the field of biorhythms research (Table 1).

The study makes no attempt to establish the relative scientific merit of individual experiments. Treatment of the experiments in this study does not imply acceptance by the various NASA scientific evaluation committees, but the study does establish the feasibility of accomplishment if the program is undertaken and, using the experiments as an example, strongly endorses the Pioneer as a carrier for biological experiments.

TABLE 1. CANDIDATE EXPERIMENTS TO STUDY CIRCADIAN PERIODICITY

	EXPERIMENT	INVESTIGATOR	INSTITUTION
1.	Potato Respiration	B. W. Pince F. A. Brown	Space Defense Corporation Northwestern University
2.	Bean Leaf Movement	K. Yokoyama	NASA/ARC
3.	Fiddler Crab Activity and Metabolism	J. B. Hufham F. H. Barnwell	Space Defense Corporation University of Chicago
4.	Cockroach Activity and Metabolism	C. S. Pittendrigh R. G. Lindberg	Princeton University NCL
5.	Vinegar Gnat Eclosion	C. S. Pittendrigh R. G. Lindberg	Princeton University NCL
6.	Pocket Mouse Temperature, Heart Rate, and Activity	R. G. Lindberg C. S. Pittendrigh	NCL Princeton University
7.	C Mouse Temperature, Heart Rate, and Activity	F. Halberg G. C. Pitts L. Cooper	University of Minnesota University of Virginia General Electric Company

The Scientific Objectives of a BioPioneer Mission.- All candidate experiments share the common objective to study the stability of circadian systems when all geophysical variables are either removed or sensed by organisms at periods other than 24 hours.

Significance of Experiment Data.- The significance of the proposed BioPioneer Program is that study of the persistence and stability of circadian systems divorced from the physical environment of earth will:

- Provide insight into a most fundamental characteristic of life
- Test the dependency of circadian periodicity on the geophysical environment
- Provide data pertinent to evaluation of the risks associated with extended space flight by man
- Provide data pertinent to the design of future space biology experiments, particularly with regard to the adequacy of ground controls for flight experiments.

Rationale.- The ubiquitous nature of periodic functions in biological material suggests that rhythmicity is a fundamental quality of life. Evidence from plant research has demonstrated that upsetting the normal pattern of rhythmicity by manipulation of the photoperiod can cause serious physiological consequences. Biomedical research on humans has revealed periodicity of many clinical indicators ranging from fluctuations in body temperature to cation excretion, each of which signals changes in physiological state. Evidence is now strong that the life process involves a system of rhythmic events, likened to a system of oscillators, which couple to produce periodicities of various lengths. Thus cyclic biochemical events that account for the spontaneous discharge of neurons may couple to produce rhythmic bursts with a period of seconds, while the events associated with thermoregulation couple to produce a cycle of change in body temperature that may approximate 24 hours.

The class of biological rhythmicity which has a period of about 24 hours is referred to as diurnal, or more popularly circadian. The fact that this period approximates the length of an earth day raises the question as to whether this kind of periodicity is a manifestation of physiological processes that have evolved in an earth environment or whether there is a circadian "cue" resulting from some geophysical event that entrains the biological system. If indeed geophysical phenomena are responsible for circadian periodicity, then it is reasonable to assume their involvement in longer cyclic events such as tidal, lunar, and seasonal periodicity in biological material. Proponents of the theory that biological periodicity or "time keeping" is controlled primarily by internal or endogenous factors modified by environmental cues have demonstrated the stability of biological periodicity in spite of changing geophysical forces and argue that it is unnecessary to postulate an undefined geophysical phenomenon to interpret their data. Proponents of an external or exogenous timekeeper appear willing to accept the concept of endogenous rhythmicity but argue that the correlation of circadian, tidal, lunar and seasonal periodicity with geophysical events is prima facie evidence for an external "timekeeper."

The study of biorhythms in space will permit resolution of the question as to whether terrestrial stimuli indeed set the period or simply change its phase. The question can be partially studied in earth orbit. However, ultimate resolution of the question must be attacked in deep space probes. Both missions are important. If a circadian periodicity persists in earth orbit but decays in distant solar orbits, we would have direct evidence available from no other combination of experiments that geophysical periodicities are essential inputs for maintenance of circadian organization.

The value of the research is more than academic for if the circadian rhythms of man are in any way coupled with terrestrial cues, the probability of his satisfactory performance on prolonged space missions would be low. Within this context, studies of circadian rhythms in mammals in space must have high priority. The anticipated new knowledge is not limited to space applications. For example, it is suspected that clock mechanisms play an enormously important role in human health and disease. Scores of rhythms have been identified in the human. Some are thought to be primary, including the cyclic release of hormones and enzymes, the cyclic physiologic events such as the activity of spontaneously contractile heart and gut tissue, and the cyclic electrical discharge of nervous tissue. Others are suspected to be secondary (derived from the primary) such as rhythmic patterns of metabolism, body temperature variation and reproductive cycles, producing in turn all the hundreds of tertiary behaviorial and physiologic adjustments which allow us to successfully adapt to our environment.

It is not clear of course what role these rhythms play in health and disease; all that is known is that these cycles are profoundly disturbed during illness. Another specific problem is the loss of mental and physical effectiveness suffered by passengers and crew members when exposed to rapid geographic translocation by high speed jet aircraft. Fatigue, nausea, irritability, a feeling of dissociation and other symptoms are commonly reported and are thought to be directly related to the rephasing of primary and secondary biorhythms due to rapid movement to new time zones. These problems relate to both civilian and military effectiveness. It is clear that better understanding of clock mechanisms could have direct application to human well-being.

Experiment Descriptions

The following sections summarize the scientific objectives and experiment requirements for seven biological experiments recommended by NASA/ARC. Each principal investigator was requested to complete NASA Experiment Proposal Form 1346 as the requested information applied to execution of the experiment aboard a Pioneer spacecraft. The completed form provided a point of departure and evolved into the summary requirements that follow.

It should be noted that while all seven experiments considered were directed toward the study of the stability of circadian systems in space, none of the experiments is truly redundant, nor do they preclude identification of more definitive experiments at a later date. Each experiment looks at the phenomenon of periodicity in a different manner. It is doubtful that the results of any single experiment will satisfy the scientific community. Therefore, it is highly desirable that several experiments be done together, and preferably on more than one species on more than one space flight. The subject of experiment mixes is dealt with in the section entitled "Experiment Integration."

The seven sections on particular experiments are followed by discussions of the requirement for physical-science experiments, Pioneer spacecraft characteristics, tests and analyses for experiments, and experiment integration. General conclusions and recommendations are given in the final section.

It is apparent that in some cases several investigators can derive meaningful data from the same organism or experiment preparation. However, the short duration of the study coupled with a desire to demonstrate the variety of experiments that could be accommodated on the Pioneer spacecraft resulted in the individual treatment accorded each candidate experiment. Hopefully, a BioPioneer program will become a reality and its final objectives and implementation reflect the combined efforts of the scientific community.

CIRCADIAN PERIODICITY OF POTATO RESPIRATION

Principal Investigator: B. W. Pince, Space Defense Corporation
Co-Investigator: F. A. Brown, Jr., Northwestern University
Engineering Support: Space Defense Corporation

Technical Information

Objective. - The objective of this experiment is to determine whether the rhythmicity of oxygen consumption by a sprouting potato remains the same, is modified, or disappears in space relative to control specimens on earth. The rhythm of potato respiration is a well documented phenomenon. The data derived from this proposed deep space experiment will augment data to be gained from a similar earth orbital experiment now contemplated for 1969 (AAP). Together these data may provide either meaningful answers to biological questions of a most fundamental nature or point the way to definitive experiments for the future.

Experiment Approach. - There are two major hypotheses now current which account for timing of biological clocks. One is that these "clocks" are driven by an autonomous oscillator of some kind inside the organism. The other is that the timer is dependent upon an exogenous rhythmic input, possibly geophysical in source.

Prior to the advent of a National Space Program, no way had been found either to fully deprive an organism of all information about its rhythmic geophysical environment, or even to be reasonably assured that the organism was truly in an environment with no cues to which it was sensitive (however subtle) as to the Earth's natural periods.

In light of the two alternative hypotheses, accounting for the timing of all additional phase-labile biological rhythms, we propose to place potato sprouts with well-established biologic rhythms into deep space while maintaining a control set on Earth under identical experimental conditions of light, temperature, total pressure, and partial pressures.

A flight package consisting of six respirometers containing six sprouting potato plugs will be placed on a BioPioneer deep-space orbiting vehicle.

The oxygen consumption of each potato plug will be measured by monitoring actuation of the O_2 solenoid valve for seven days preflight and for 90 days of the BioPioneer mission, from launch onward. Measurements of the particulate and/or force field environments, as measured by the BioPioneer's on-board instrumentation, will be useful for data interpretation. Ephemeris data are required for correlation.

Simultaneously, two sets of six respirometers will be placed in operation at Space Defense, Birmingham, Michigan. Oxygen consumption will be measured for the duration of the experiment. One set will be rotated at a rate identical to the spin rate of BioPioneer; the second set will be at rest, relative to the Earth.

If space permits, it is feasible to double the number of respirometers with half located in an acceleration field of 1 G and half at 1/2 G or less. This latter option will permit study of the effect of reduced gravitational fields on the stability of the circadian system in space.

Base Line or Control Data. - The most extensive knowledge available concerning extrinsic metabolic rhythmicity is based on the sprouting potato. On the basis of a more than 11-year study in Evanston, Illinois, these rhythms have been characterized as they persist in constancy of such factors as light, temperature, humidity and ambient pressure. Among these characteristics are large seasonal changes not only in the form of the daily cycles, but also in the mean daily rate. As a consequence, there is an extensive amount of information available which can be used as a basis for comparison with data that will accrue from the relatively long-term, space-vehicle experiment proposed.

The data derived from flight and ground control experiments will be compared using computer facilities at Wayne State University, probably using University of Minnesota programs now available. We are confident that statistically significant comparisons can be made using intra-specimen data (with each subject serving as its own control). Further, six specimens allow valid statistical intragroup comparisons to be made if small sample corrections (like Yates or others) are employed. In addition, intergroup (experiment vs control) comparisons can be made with fair credibility with the sample size.

Engineering Information

Equipment Description. - A sprouting potato in the dark consumes oxygen and produces CO_2 in a well documented rhythm. The equipment described below represents a closed environmental control system designed to detect small variations in oxygen consumption (respirometer).

The respirometer (1) maintains an oxygen partial pressure of approximately 150 mm Hg at a total pressure of 760 $\pm$ mm Hg water saturated at 75°F; (2) removes carbon dioxide; (3) maintains thermal balance; (4) maintains total pressure and composition of the respiratory atmosphere; (5) provides water; and (6) maintains incident visible light below 0.1 lumens.

Temperature control can be achieved by passive techniques to maintain the specimen temperature at 23.8 $\pm$1.1°C. Depending on spacecraft temperature deviation from this value, control will be accomplished conventionally, using resistance heating and, if necessary, thermoelectric cooling.

Carbon dioxide is removed via a CO_2 selective semipermeable membrane and potassium hydroxide particles.

Makeup oxygen is provided to the "zero" leak system from a two stage 100% oxygen source.

The first-stage bottle (high pressure) contains a 90-day O_2 supply. An integral regulator controls first-stage outlet pressure of 820 mm Hg (abs). The second-stage bottle (low pressure) has an outlet pressure of 760 mm Hg (abs), nominal for specimen chamber pressure. A solenoid valve controls the flow between the bottles. A variable reluctance differential pressure transducer, between the specimen chamber anc second stage generates a 0.0 to 5.0 V dc signal representing a differential pressure range of 17.2 mm Hg. This output modulates a subcarrier oscillator (20-kHz double bandwidth at 72-kHz center frequency). The same signal triggers a switch controlling the solenoid valve when the pressure differential between the specimen chamber and the second stage approaches zero. The opened valve allows gas to flow from the first stage to the second stage until the 17.2-mm Hg differential between second stage and specimen chamber has been re-established. Thus, constant pressure is maintained in the specimen chamber, and simultaneously, the rate of pressure change in the second stage is correlated to specimen consumption. The amount of oxygen (about 0.25 ml STP) which must be metabolized to cause a full scale change in output signal permits acute discrimination, allowing differentiation at the level of about 1.25×10^{-5} ml per unit time. Signal frequency change in output signal permits acute discrimination, allowing differentiation at the level of about 1.25×10^{-5} ml per unit time. Signal frequency change is monitored by a frequency counter and can be recorded by digital or analog methods.

As presently conceived, a minimum experiment utilizes six potato sprouts. The sprouts are housed in individual respirometers. Two respirometers and the associated oxygen supply and electronics are packaged into a single assembly (Assemblies 1a, 1b, 1c). Thus the entire experiment consists of three respirometer assemblies and one experiment interface unit (Assembly 2), Figure 1. It is entirely feasible to package the respirometers in many different combinations. The described approach was selected to meet the constraints of Pioneer spacecraft dynamics and experiment platform geometry.

(a) Required equipment. An experiment unit is comprised of three assemblies (1a, 1b, 1c). Each assembly contains two potatoes. The following equipment is estimated to be required to implement the flight experiment:

Test Hardware	
Design Verification Test Assemblies	2
Qualification Test Assemblies	1
Mass Mockup Assembly	1
Flight Prototype Mockup Assembly	1
Flight Equipment Simulator Unit	1
Flight Equipment	
Flight Unit	1
Flight Backup Unit	1
Control Unit	2

The total hardware requirement is therefore estimated at four complete flight units; one simulator unit; and five assemblies (including two mockups).

At the launch site, potatoes, a few special tools, a supply of breathing oxygen, appropriate pneumatic, hydraulic and electrical gauges and assorted spare parts, both mechanical and electrical, will be provided by the contractor. A laminar flow laboratory bench, a refrigerator, and an air-conditioned laboratory with access to a regulated power supply are required as GFE.

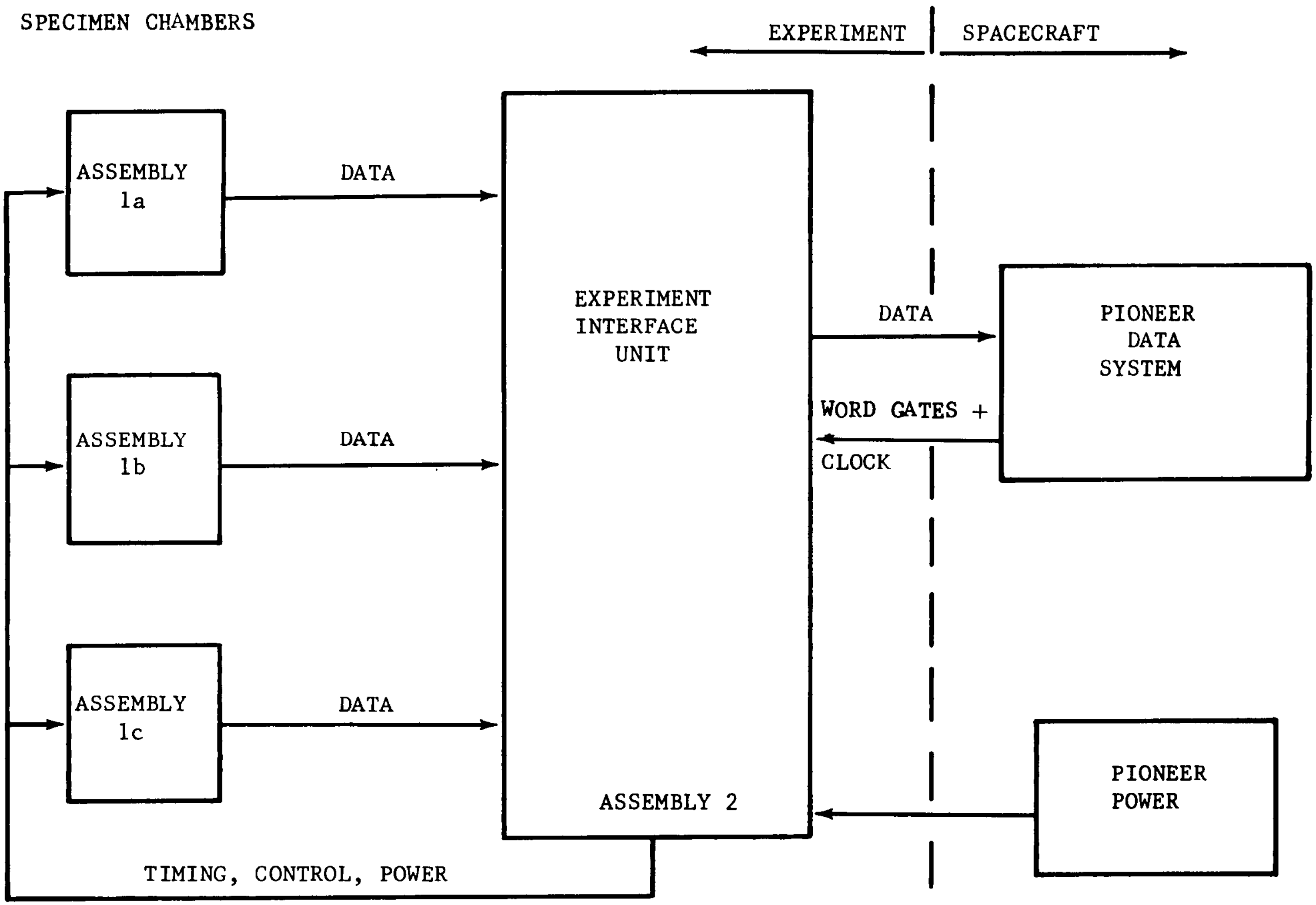

Figure 1. Electronics block diagram of Potato respiration experiment.

(b) Equipment status. The respirometer equipment is well advanced and requires only reconfiguration for adaptation to BioPioneer. Under Contract NASw-870 the basic respirometer unit was developed and has been collecting laboratory baseline data for over two years (Figure 2). In addition, under the same contract, a multicell unit (12 potatoes) was developed and is now in the final stages of checkout and test before being put into bench service (Figure 3). This unit shows great promise because of its ability to measure single potato consumption as well as the summative consumption of all the specimens. Under Contract NAS9-7172 a flight configuration for Apollo Application Program (Earth orbital) is in the Program Definition Phase. Flight hardware design employing a two-cell respirometer has been approved (September 1967) and mockups and flight equipment simulators have been delivered (December 1967).

Envelope. - The experiment hardware proposed for a Pioneer mission consists of three identical assemblies each containing two respirometers (Figure 4), and one experiment interface unit (Figure 5). The respirometer assemblies are independent in every way. Each assembly contains: one first stage oxygen supply and regulators; two interstage solenoid valves; two differential pressure transducers and appropriate electronics; and two potato chambers with scrubbers. Weight, volume and area requirements are given in Table 2.

TABLE 2. WEIGHT AND VOLUME REQUIREMENTS FOR A SIX POTATO EXPERIMENT

Assembly Description	Number	Weight (kg)	Volume (cm^3)	Dimensions (cm)	Shape	Area on S/C Floor (cm^2)
Respirometer Assembly	3					
Stored (each)		2.50	3375	15.0 x 15.0 x 15.0	Cube	na
Operational (each)		1.37	1700	10.2 x 11.8 x 14.0	Box	143
Interface Unit		2.04	2100	10.4 x 16.0 x 12.7	Box	167
Totals		6.2	7200	na	na	596

Power.- Power requirements are given in Table 3.

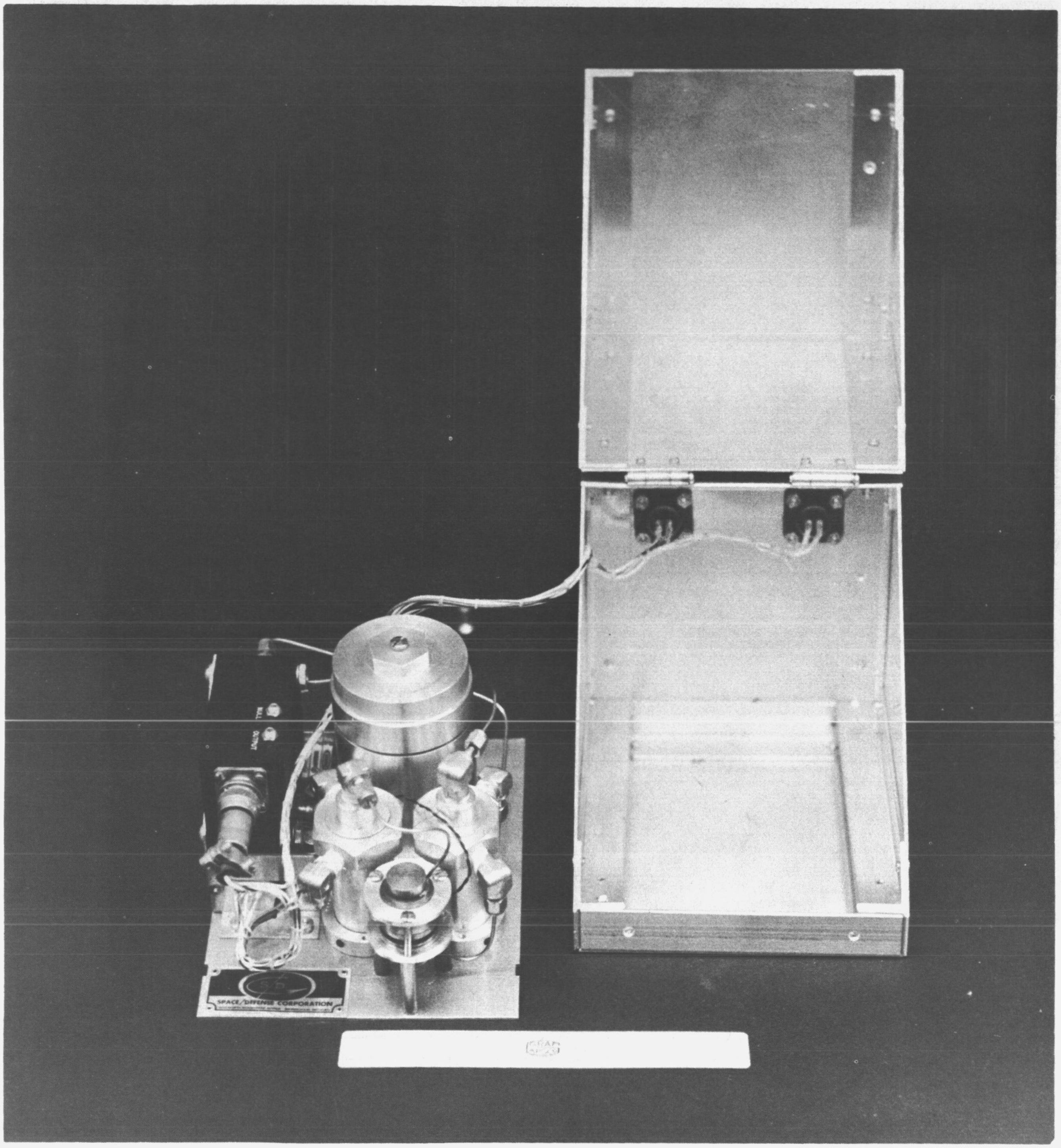

Figure 2. Potato respirometer, single specimen.

Figure 3. Potato respirometer, multiple specimen.

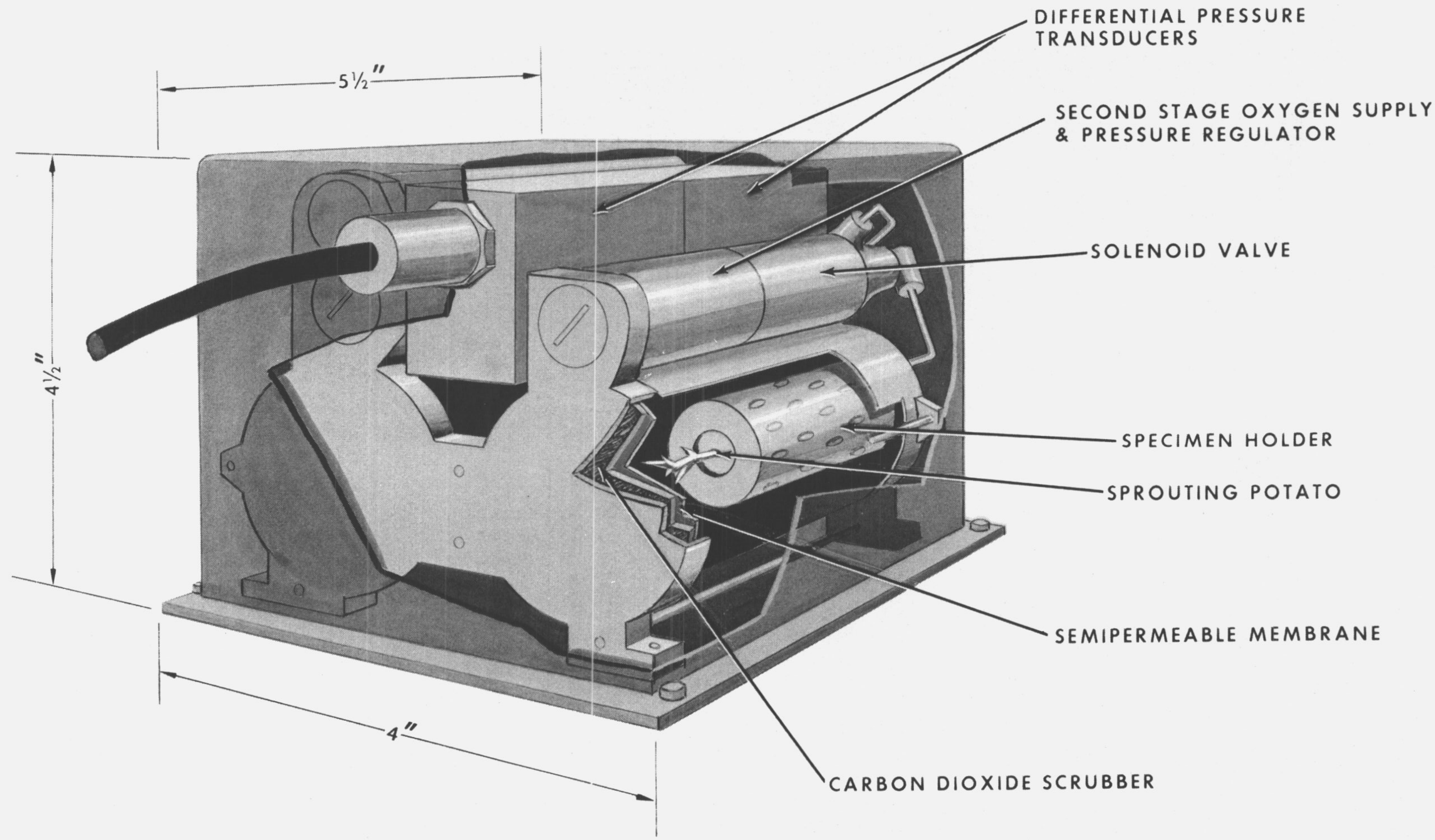

Figure 4. Experiment hardware concept for the study of circadian periodicity of potato respiration.

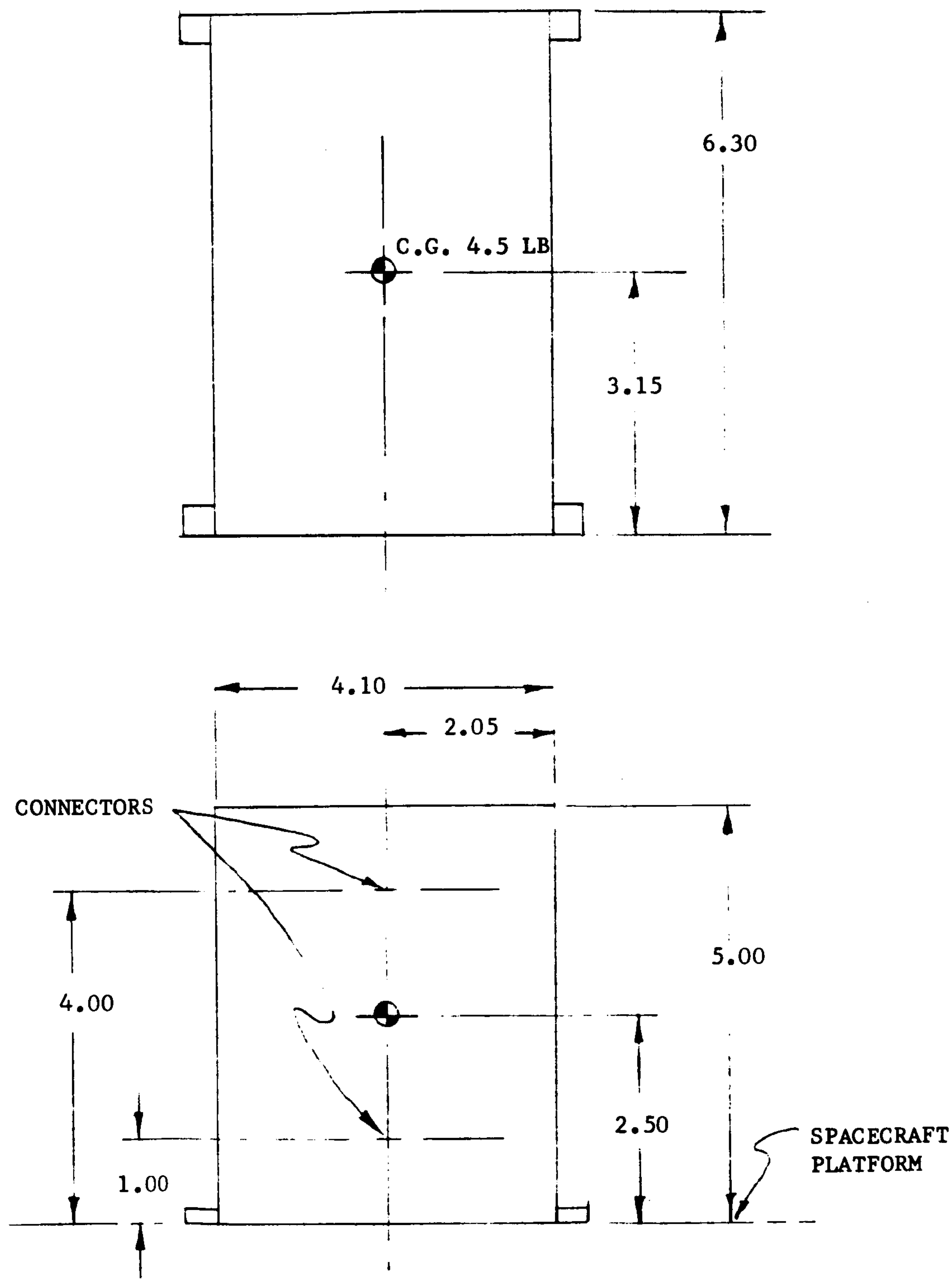

Figure 5. Potato experiment: experiment interface unit (assembly 2).

TABLE 3. POWER REQUIREMENTS FOR A SIX POTATO EXPERIMENT (W)

Instrumentation Power	Standby	Average	Maximum
Assembly 1a	0.7	0.93	3.0
Assembly 1b	0.7	0.93	3.0
Assembly 1c	0.7	0.93	3.0
Assembly 2	1.6	1.6	1.6
Total Power*	3.7	4.4	

* Assuming no power required for thermal control

Thermal control power requirement.- It is proposed that thermal control be achieved through a controlled heat path to the experiment platform. This approach is feasible but may limit the choice of mounting locations. In the event of a requirement for active temperature control, heating can be provided by a resistance and a thermoswitch. In the worst case (spacecraft ambient at -1.0°C), 0.225 W is needed. This requirement is attenuated at the expected higher spacecraft temperature. If planned passive cooling techniques are not completely successful, a thermoelectric cooling device could be utilized to maintain the specified temperature when the spacecraft temperature approaches 90°F. At this temperature, a cooling rate of 0.16 W would be required. In view of Pioneer's excellent thermal characteristics, the latter requirement is not thought to be likely.

Spacecraft Interface Requirements.-

(a) Required location. The individual respirometer assemblies (Assemblies 1a, 1b, and 1c) must be centered on a common radius which has a G load of 1.0 or less when the spacecraft is spun up. Location along the cicle described by this radius is not critical. Location of the Experiment Interface Unit is not critical.

(b) Mounting requirements. Twelve bolt holes or tapped holes on the floor plate are required. The mounting location must be such that the acceleration produced by spacecraft rotation is parallel to the long axis of the assemblies.

(c) Power and telemetry. No structural modifications are required; power, a TM lead, and an experiment interface unit are required.

(d) Plumbing. Maximum gas pressure is 165 psia. There are no mobile fluids. The only fluid is 5 g of water held in a wick at the base of each potato chamber. It does not move significantly once the atmosphere is saturated. Cabling can be arranged at the spacecraft system engineers' convenience.

(e) Dynamics. The geometric center of each assembly approximates the center of mass. The biological specimen does not move but there are slight changes in the distribution and weights of consumable supplies.

Each specimen maximally consumes 0.3 ml O_2/hr or 7.2 ml/day. The six specimens combined will use about 43.0 ml/day maximum, or about 3900 ml over the contemplated 90 day experimental period. Each dual specimen assembly will therefore utilize 1300 ml, or about 18.8 g of O_2. The potato's respiratory quotient (vol. CO_2/vol. O_2) varies from 0.45 to 1.02 but a reasonable mean is 0.8. Thus, the 18.8 g O_2 will be converted into about 20.4 g of CO_2 which in turn will react with the KOH in the CO_2 scrubber to produce K_2CO_3 and water. The latter reaction is stoichiometric. The result is the movement, over 90 days, of 18.8 of O_2 from the regulators through the potato (which loses about 2 g of weight in the metabolic process) and thence as 20.4 g of CO_2, into the scrubber, where it converts 24.3 g of KOH into the same amount of K_2CO_3 and water. Since the KOH or the reaction products don't move in the process, the net movement is the weight of the CO_2 or 20.4 g, per dual specimen assembly, incrementally, per 90 days. The distance moved is about 2 in. parallel to the spacecraft radius.

Environmental Constraints.-

(a) Constraints on the experiment package. The limiting constraints are these imposed by the biological specimens. Potato sprouts mounted in experiment hardware breadboards have survived simulated Pioneer launch stresses with no detectable change in the stability of their circadian system. (See section entitled "Environmental Tests".) The package contains an independent ECS but is dependent upon external thermal control. Without specimen it may be stored between -48°C and 70°C, with specimen -1°C -30°C.

Anticipated ambient levels of radiation, EMI, and RFI aboard the spacecraft are considered acceptable for execution of the experiment, but both their leads and periodicities must be known.

(b) Interference. This is essentially a "silent" package. With the exception of opening and closing of minute regulator valves, there is no mechanical motion and no significant resultants. The valves are actuated by tiny solenoids of low electrical energy (40 mA).

Data Measurement Requirements.- Oxygen is supplied to the potato plant by a servo system which is controlled by ambient pressure. As the potato consumes oxygen ambient pressure decreases to 14.7 psia, at which time pressurized oxygen is added to the system until pressure is increased to 15.0 psia and the cycle repeats. An estimate of the rate of oxygen consumption can be obtained from the times of limit-cycle operation; however, more precise data can be obtained if the ambient pressure is continuously monitored. A typical pressure-time curve for the highest consumption rate expected is shown in Figure 6.

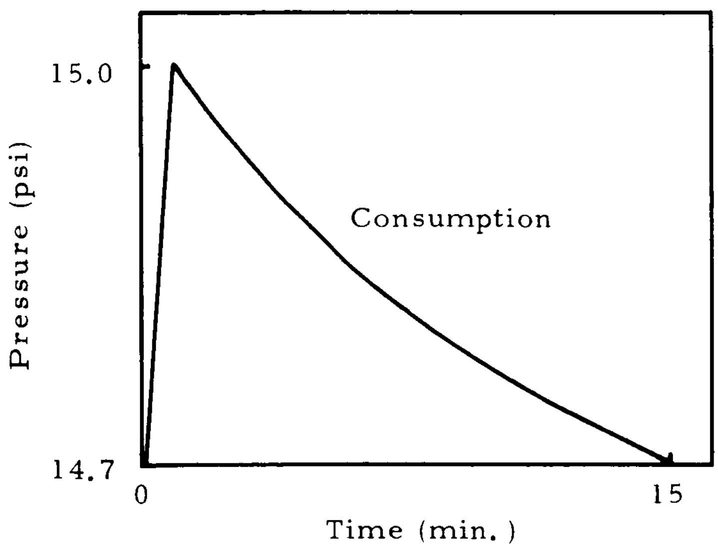

Figure 6. Typical rate of oxygen consumption by sprouting potato.

A pressure measurement is desired every minute. If pressure is sampled and digitized to six bits every minute, a total of 8.640 bits of daily data would be obtained for each potato, and the pressure at the time of each sample would be known within a resolution of approximately 1.6%. Total daily data bits for four potato plants would require 34,560 bits, which is large in comparison to the storage capacity of a Pioneer data storage unit (DSU) but would not present a problem during real-time transmission. Less data will, in general, result in reduced accuracy; however, if the change in pressure between measurements is transmitted, rather than the pressure reading itself, the quantity of data bits can be reduced without a significant reduction in accuracy. One approach is to sample pressure, A/D convert the sample, and subtract from the previous measurement. Only the most significant bits of the difference need be transmitted. These would be determined by the maximum rate of change expected. For example, assuming a maximum rate of change of 0.03 psia per minute, the slope between one minute measurements could be determined to be 0.03, 0.02, 0.01, or 0.00 psia/min using only two bits for each measurement. An alternate approach would be to use four bits per measurement and make the measurements every two minutes, or six bits every three minutes, etc. In addition to the measurements for pressure slope, the time of actuation of the recharge cycle may be desired. Assuming 24 recharges per day and 15 bits per time reading, a total of 360 bits per day would be required. Using the slope monitoring approach supplemented by time of recharge, total data bits are reduced by a factor of almost three in comparison with the pressure monitoring approach. Data requirements for the slope monitoring approach are summarized in Table 4, and engineering data requirements are summarized in Table 5.

TABLE 4. BIOLOGICAL DATA REQUIREMENTS PER POTATO

Parameter	Range	Bits per sample	Samples per day	Bits per day
Pressure Slope	0.00 - 0.03 psia/min	2	1440	2880
Recharge Time	Time of day	15	24	360
			Total	3240

TABLE 5. ENGINEERING DATA REQUIREMENTS PER POTATO

Parameter	Range	Bits per Sample	Samples per Day	Bits per Day
Ambient Temperature	-1 to 30°C	6	24	144

The data requirements as discussed above have been significantly reduced by inclusion of a large circuit in each package to perform the following function. When an interstage solenoid valve opens, signifying a second stage oxygen supply recharge (a function of the rate of oxidative metabolism), the valve event will be stored in the logic circuit if it occurs during a 6-minute period. If not, "no event" is also recorded. Thus, ten bit/hour/potato or 240 bits/day/specimen or 1440 bits/day/six specimens will be required. The data can be pulled off the logic circuit using carrier currents and time intervals most convenient to BioPioneer requirements. The temperature will be determined over each hour using a six-bit word and a range of 50 to 82°F (±0.5°F). This will require 144 bits/day per potato module. The total bit requirement for all measurements is 1872 bits/day. Total data measurement requirements for a six potato experiment are summarized in Table 6.

Operational Requirements

Pre-launch Support.- The principal investigator (PI) will deliver experiment to Kennedy Space Center 21 days prior to launch, establish a Field Laboratory, perform post-delivery acceptance tests and 15 days prior to launch will install and calibrate specimens. At the direction of the SPO, the PI will install the experiment in the spacecraft when power is established on the pad, and monitor respiration from the launch control center until a satisfactory signal is obtained. Facilities and equipment

Table 6. Summary Data Measurement Requirements for Potato Respiration Experiment

Parameter to be Measured		Respirometer Valve Event						Temperature		
Equipment Item Used		1A		1B		1C				
		Spec 1	Spec 2	Spec 3	Spec 4	Spec 5	Spec 6	1A	1B	1C
Expected Value of Parameters	Units	on/ off	→	→	→	→	→	°F	→	→
	Average	na	→	→	→	→	→	→	→	→
	Range	on/ off	→	→	→	→	→	50-82	→	→
	How Often	6 min	→	→	→	→	→	1 hr	→	→
Measurement Characteristics	Duration of Each	continuous monitoring			→	→	→	point sample	→	→
	Total Number in Mission	21,600		→	→	→	→	12,960	→	→
	Type	Digital		→	→	→	→	→	→	→
Output Signal of Instrument	Frequency Range	na		→	→	→	→	→	→	→
	Amplitude Range	0-10V		→	→	→	→	→	→	→
	Instrument Resolution	on/ off		→	→	→	→	$\pm$0.5 °F	→	→
Readout Requirements	No. of Channels	1		→	→	→	→	→	→	→
	Sampling Rate	0.003 BPS		→	→	→	→	0.0017 BPS	→	→
	Telemetry	Yes		→	→	→	→	→	→	→
	Data Storage	Yes if continuous real-time telemetry is not available					→	→	→	→
Time Identification	Method	Experiment's clock			→	→	→	→	→	→
	Accuracy	$\pm$1 min		→	→	→	→	→	→	→

previously described are required. No GFE/AGE will be required; one bottle of breathing-quality oxygen is required as service item.

Flight Operational Requirements.- Ready access by the PI to early data is desirable to determine experiment function status and to assess immediate effect of launch and orbit, if any, upon the specimens.

Data Support.- Preflight data will be collected at Kennedy Space Center 15 days prior to flight using contractor-furnished equipment. A reliable regulated power supply is needed. It may be desirable to plug into spacecraft data system to determine continued system compatibility. No real time data are required, except for "early look" (not "quick look") at data. Raw data from spacecraft should be converted from analog to digital if required, time correlated, and ephemeris correlated. The PI will treat reduced data with his own computer program. If possible, it is desirable to know of any events occurring in the spacecraft which may have cyclic characteristics.

Resources Requirements

The following material was prepared by Space Defense Corporation and represents the current best estimate of both schedule and budget requirements to accomplish the proposed experiment. A firm bid must await definition of requirements to be established by the Pioneer Project Office. Depending upon specific requirements, both the schedule and budget may be readily reduced or increased. The time and money requirements outlined below represent a realistic program optimized for attainment of scientific objectives, systems reliability, and fiscal responsibility.

Phase One, Program Definition.- The current Experiment Feasibility Study (NAS2-4526) has preempted some of the classic PDP functions. Those that remain include development of:

1. Preliminary Experiment Implementation and Program Plan
2. Reliability Program Plan
3. Design Verification Test Plan

4. Qualification Test Plan

5. Failure Mode Effect and Criticality Analysis

6. Design

   a. Design Analysis and Design

   b. Preliminary Drawings and Bill of Materials

   c. Specifications

7. Hardware

   a. Mass Mockup Assembly (one)

   b. Flight Prototype Mockup Assembly (one)

   c. Flight Equipment Simulator Unit (one)

Phase Two.- Hardware Development, Test, and Fabrication

1. Fabricate Design Verification Test Hardware. The equivalent of two respirometer assemblies in components must be provided.

2. Perform Design Verification Tests

3. Design Modification and Final Design Review

4. Fabricate Qualification Test Hardware. One assembly and selected spares are required.

5. Perform Qualification Tests

6. Prepare Production Drawings and Specifications

7. Fabricate Flight Hardware (one flight unit; one flight backup; two control units)

8. Perform Predelivery Acceptance Test

9. Deliver Flight Hardware

10. Perform Post Delivery Acceptance Test

Phase Three.- Operations

1. Prepare Operations Documentation

   a. Field Laboratory Requirements Plan

   b. Detailed Experiment Implementation Plan

c. Checkout and Count Down Document

d. Reporting Plan

2. Establish Kennedy Space Center Field Laboratory

3. Establish Flight and Backup and Control Units at KSC.

4. Assist in installation, checkout, countdown and launch of Experiment in BioPioneer.

5. Collect Flight Experiment Data

6. Reduce and Treat Data

<u>Phase Four</u>.- Reporting and Support

1. Prepare and submit monthly, annual and phase interim reports and a final report.

2. Analyze and report the experimental results to the government and the scientific community.

3. Perform baseline studies in the contractor's laboratory and at Northwestern University.

4. Provide management to assure completion of the work in a timely and cost-effective manner.

The schedule for accomplishing this program is estimated at 30 months (Figure 7). The estimated cost of accomplishing the program is $338,900 (Figure 8).

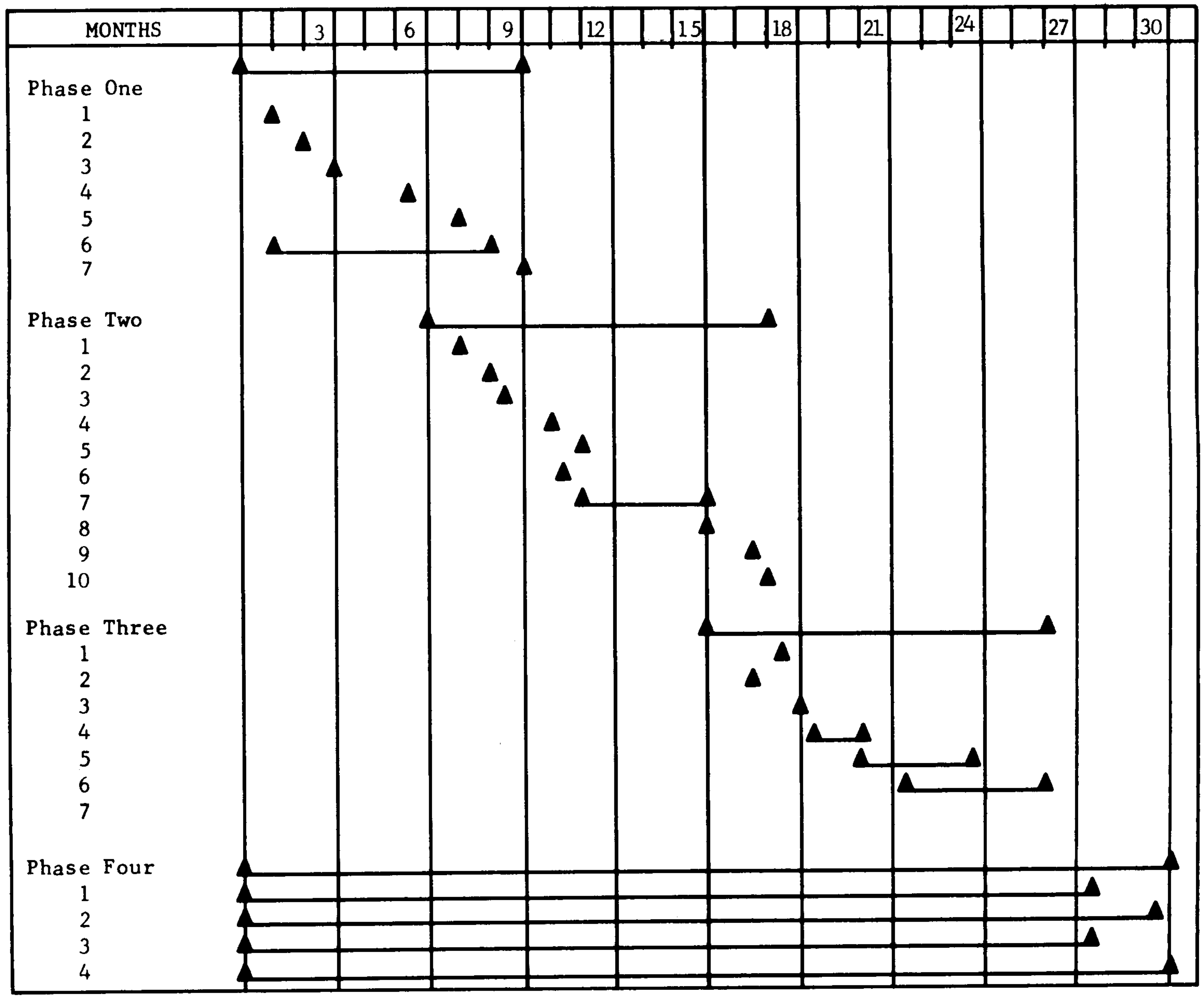

Figure 7. Estimated schedule for accomplishment of the Potato respiration experiment.

Months	3	6	9	12	15	18	21	24	27	30
Phase One		$73.1								
Phase Two				$109.0						
Phase Three							$47.3			
Phase Four					$109.5					
Quarterly Expenditure	35.31	35.3.	65.01	40.65	40.65	43.65	23.35	23.35	19.55	12.07
Cumulative Quarterly Expenditure	35.31	70.62	135.63	176.28	216.93	260.58	283.93	307.28	326.83	338.9
Annual Expenditure				176.28				131.00		
Cumulative Annual Expenditure				176.28				307.28		338.9

Figure 8. Estimated costs to accomplish Potato respiration experiment ($ x 10^3).

BIORHYTHMICITY OF BEAN LEAF MOVEMENT

Principal Investigator K. Yokoyama, NASA/ARC

Engineering Support: Northrop Corporate Laboratories

Technical Information

Objectives.- The purpose of this experiment is to observe whether or not the criteria established for normal movements of plants under controlled terrestrial environments would be different if it were possible to remove the geophysical influences of the earth. The significance of conducting an extra-terrestrial experiment to test our current interpretations has broad fundamental implications, not only on reevaluation of our experimental procedures and interpretations, but upon all future extra-terrestrial biological flight experiments.

Experiment Approach.- A self-contained package, preferably divided into several smaller modules located in different areas on the flight vehicle will be flown and the leaf movement telemetered back to earth. Sufficient oxygen, nitrogen, carbon dioxide, humidity, nutrient, light and proper sensing apparatus will be included within this package. Readings taken at regular intervals can be stored aboard the spacecraft and periodically relayed to a receiving station.

A strain gauge will be used to measure the changes in leaf position. The measurements will be converted to degrees of petiole-pulvinus-blade angle. The amplitude and the cycle of leaf movement will be plotted and compared to several ground-based controls operated simultaneously with the flight.

Loss of power, sudden drastic pressure and temperature changes are a few of the possible causes of major failures. However, subtle erroneous reading of thermisters or resistance of strain gauges are possible causes of errors which should be anticipated and compensated for by either redundant circuitry or methods to check or correct the readings.

Baseline or Control Data.- It is highly desirable to have the following controls:

(a) A complete stationary vehicle with the experiments and vehicle GMA system in operation under a controlled environment.

(b) A controlled chamber in which the modules can be placed, monitored and made to follow the flight spacecraft temperature profile.

(c) A controlled chamber with plants placed exactly as in a normal laboratory condition.

(d) A controlled chamber within which the plant modules are held under a constant condition.

(e) A controlled chamber with all conditions held constant with the modules placed on a clinostat.

All the above controls should be monitored and data recorded simultaneously as with the data from flight and plant specimens used from the same cultural stock.

Engineering Information

Equipment Description.- The minimum Bean Leaf experiment consists of one Specimen Chamber (Assembly 1) containing four individually instrumented leaves; one A/D Converter (Assembly 2); one Central Electronics Unit (Assembly 3); and an Experiment Interface Unit (Assembly 4). Assembly 2 is not required in the event of continuous real time data transmission. It is highly desirable to have up to three specimen chambers (Assemblies 1a, 1b, 1c) mounted to experience different G-levels on the experiment platform.

Four bean leaves will be rooted in a bed of nutrient media and sealed in the specimen chamber in an atmosphere of 20% oxygen, ca 80% nitrogen, ca 0.5% carbon dioxide, and normal inert gases at a pressure of 14.7 psi. Relative humidity should range between 40-70%, but 95% is acceptable. Atmosphere control will be achieved through the photosynthetic respiration functions of the plant leaves.

The leaves will be constantly illuminated by a fluorescent light (3500-8000 Å) at an intensity of approximately 100 EKG at the leaf surface. Temperatures of 77° ± 5°F will be maintained by controlled heat paths to the cold experiment platform.

A strain gauge mounted across each leaf and stem holder will be used to monitor the periodicity of leaf movement. As an optimal feature, another strain gauge may be placed adjacent to each leaf and used in a bridge circuit to compensate for changes in strain gauge resistance caused by temperature fluctuations.

The requirement for leaf illumination could be met either with "artificial" light or sunlight piped to the specimen chambers via fiber optics. A comparison of power, weight and geometry in terms of the experiment requirement beginning at the time of loading favored the use of fluorescent light (Table 7). The primary consideration was the difficulty of maintaining proper illumination prior to actuation of the spacecraft solar cells.

TABLE 7. FLUORESCENCE AND LIGHT-PIPE COMPARISON

		One 4-leaf Module		One 4-leaf Module	
		Fluores-cent	Light Pipe	Fluores-cent	Light Pipe
POWER (W)	Illumination *	3.4	--	6.8	--
	Intensity Monitor	--	0.5	--	0.5
	Central Electronics	1.3	1.3	2.3	1.3
	A/D Converter	2.5	2.5	2.5	2.5
	DSU	--	--	0.1	0.1
	Interface Unit	1.6	1.6	1.6	1.6
	Total	8.8	5.9	13.3	6.0
WEIGHT (lb.)	Specimen Chamber	9.4 **	8.4	18.8**	16.8
	Central Electronics	0.5	0.5	0.8	0.8
	Inverter (including above)		--		--
	Light Pipes		7.0		14.0
	A/D Converter	1.5	1.5	1.5	1.5
	DSU	--	--	2.2	2.2
	Interface Unit	4.5	4.5	4.5	4.5
	Total	18.9	21.9	27.8	39.8
FLOOR SPACE ($in.^2$)	Specimen Chamber	63	63	63	63
	General Electronics	4	4	6	6
	A/D Converter	8	8	8	8
	Interface Unit	--	--	26	26
	Total	75	75	103	103
REMARKS		1. Illumination conveniently controlled prior to launch. 2. Several hours of battery power required after launch.	1. High intensity light source required prior to launch. 2. Illumination available 30 min after launch.	Same as for one module with fluorescent lighting.	Same as for one module with light pipes.

* Includes inverter and ballast losses.

** Includes 1 lb for lamp and fixtures.

A block diagram for a two-chamber (8-leaf) experiment is given in Figure 9. As shown, a second DSU is required if real time telemetry is not available. Strain gauge outputs and ambient temperature* from each specimen chamber are sampled and converted by a time-shared analog-to-digital (A/D) converter, then shifted to the Experiments Interface Unit (EIU). Pressure Go/No Go signals are stored in a centrally located N-bit register and also shifted to the EIU.

Synchronization, identification, and time-of-acquisition information for the acquired data will be provided as part of the main-frame in the downlink data transmission.

Elevation of the bean plant leaf will be measured by monitoring the output of a strain gauge fixed at one end to the stem holder and attached at the other end to the mid-rib of the leaf. Leaf elevation is illustrated in Figure 10. The output from the strain gauge is small and will be amplified by electronics located in the specimen module. The leaf angle will be sampled once every 10 minutes and digitized to six bits, providing a resolution of approximately 3° over a 180° range. Three bits would probably be adequate to determine the circadian period of the leaf, but it is desirable also to be able to detect the smaller variations in movement which occur during this period.

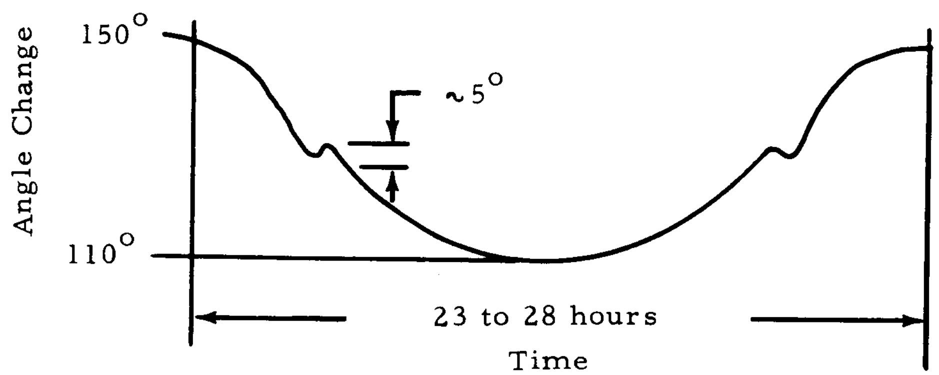

Figure 10. Typical leaf angle movement.

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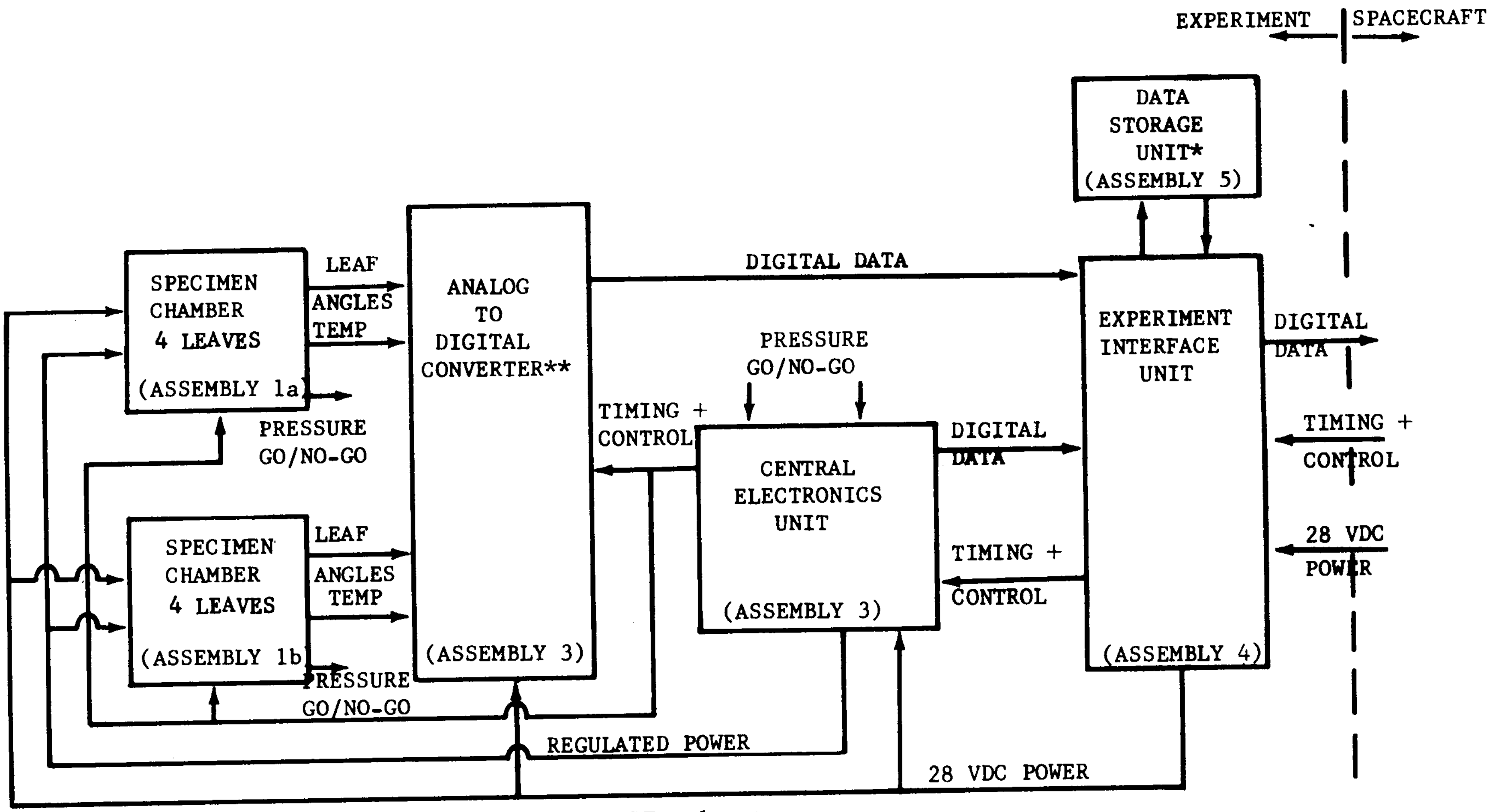
* Since the ambient temperature data rate is low, the temperature signal could bypass the experiment A/D converter. However, since the leaf angle data rate, although high enough to require an A/D converter, is low with respect to achievable conversion rates, nothing would be gained in doing so.



* Not required for 4 leaf experiment or RT telemetry

** Not required for RT telemetry

Figure 9. Electronics block diagram for Bean Leaf experiment.

(a) Required equipment.

(1) Design verification unit

(1) Prototype (also used as the laboratory control unit)

(6) Flight units

- (1) Qualification test
- (1) Backup
- (1) Flight
- (3) Control (temperature,

(1) Set of Ground Support Equipment (GSE) to be used for loading and testing of flight units, and thermal control and data monitoring of loaded units. Also required as GSE are five plant-controlled chambers and a clinostat.

(b) Equipment status. The experiment itself is well established, but the status of incorporating this experiment into a flight vehicle is by definition, in a conceptual stage. However, from our experience in the preparation and development of biological experiments for flight on the Biosatellite, we can state with confidence that this experiment is well beyond the conceptual stage.

Weight and Size.- Weight and size requirements are given in Table 8.

Power.- Power requirements are shown in Table 9.

Envelope.- Geometrical sketch of a typical Specimen Chamber (Assembly 1) containing four leaves is shown in Figure 11. A sketch of the Central Electronics Units (Assembly 3) is shown in Figure 12.

Spacecraft Interface Requirements.-

(a) Location: If one Specimen Chamber (Assembly 1) is flown, it should be mounted so that all four leaves experience approximately 1 G acceleration during flight. If more than one Specimen Chamber is flown, they should be placed to permit study of the effects of different levels of G. There are no special requirements for Assemblies 2,3 or 4.

(b) Mounting requirements should be sufficient to permit thermal control as well as mechanical support.

(c) Spacecraft subsystem support requirements include electrical power as stated above; telemetry link with or without data storage; no special guidance or uplink commands.

TABLE 8. WEIGHT AND SIZE OF A FOUR-LEAF EXPERIMENT

Assembly	Weight	Volume	Dimensions (in.)
1	9.4	545	8.25 x 7.15 x 9.25
2	1.5	16	4 x 2 x 2
3	0.5	16	2 x 2 x 4
4	4.5	130	4.1 x 6.3 x 5
Totals	15.9	701	

TABLE 9. POWER REQUIREMENTS FOR A FOUR-LEAF EXPERIMENT

Assembly	Standby	Average	Maximum
1	4.2	4.2	4.2
2	0.0	2.5	2.5
3	0.5	0.5	0.5
4	1.6	1.6	1.6
Totals	6.3	8.8	8.8

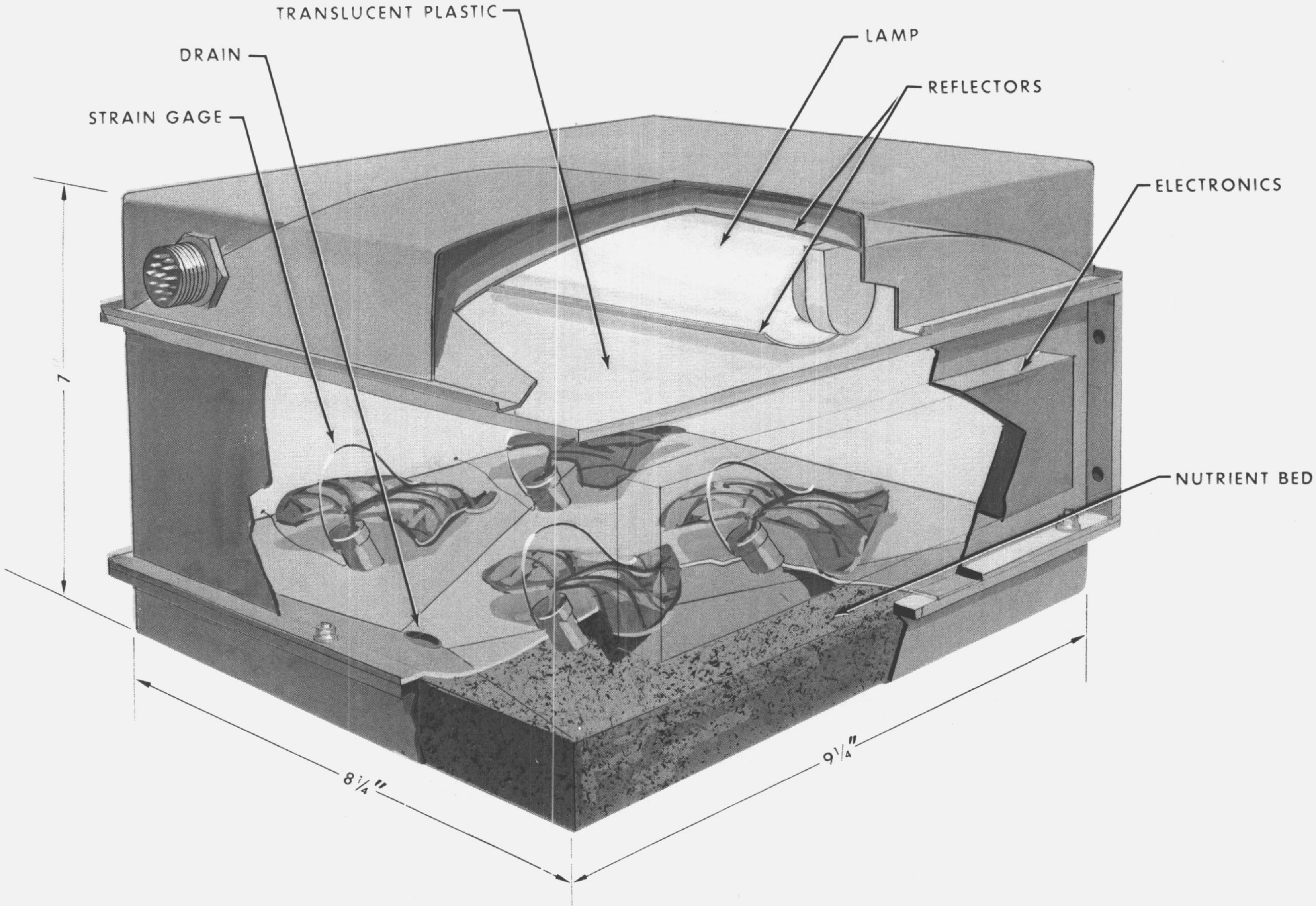
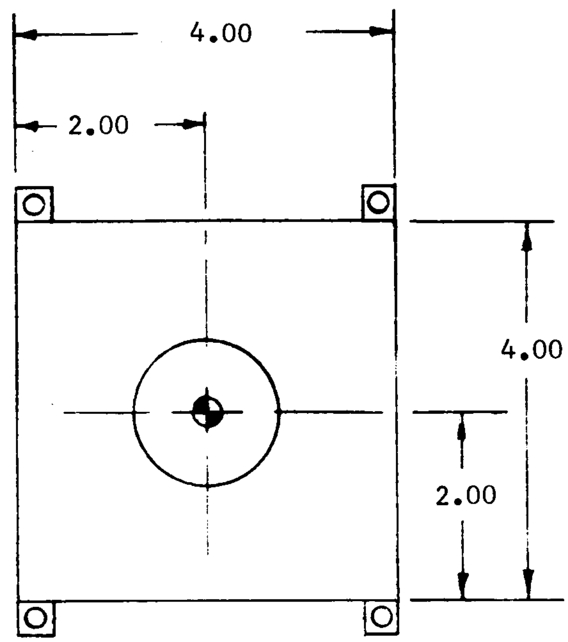


Figure 11. Experiment hardware concept for the study of circadian periodicity of bean leaf movement.



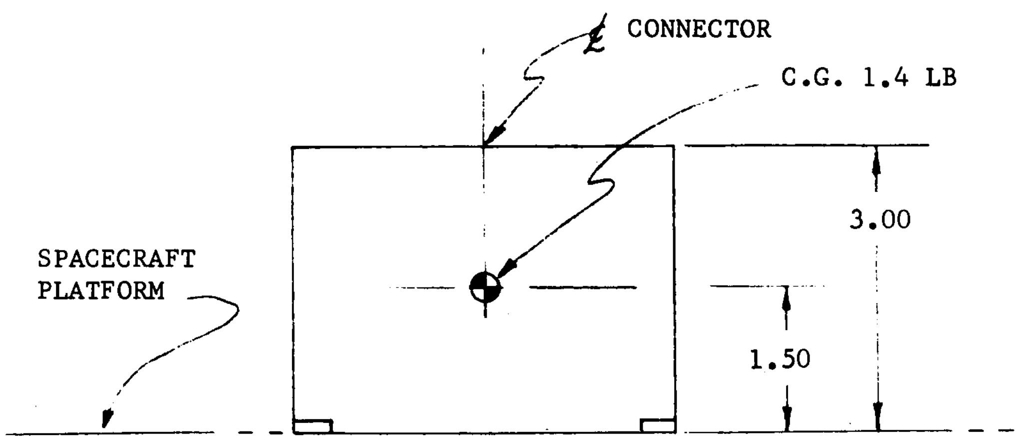


Figure 12. Bean Leaf experiment central electronics unit (assembly 3).

(d) Power switching is required.

Ambient temperature in each module will be monitored once per hour and digitized to six bits, providing a resolution of approximately 1.6%. A pressure indicator, which indicates when the pressure within the module has decreased below 13 psia, will also be monitored once per hour. Biological and engineering data requirements are summarized in Tables 10 and 11, respectively.

TABLE 10. BIOLOGICAL DATA REQUIREMENTS PER MODULE

Parameter	Range	Bits Per Sample	Samples Per Day	Bits Per Day
Leaf No. 1 Angle	90 - 180°	6	144	864
Leaf No. 2 Angle	90 - 180°	6	144	864
Leaf No. 3 Angle	90 - 180°	6	144	864
Leaf No. 4 Angle	90 - 180°	6	144	864
Totals		24		3456

TABLE 11. ENGINEERING DATA REQUIREMENTS PER MODULE

Parameter	Range	Bits Per Sample	Samples Per Day	Bits Per Day
Ambient Temperature	50 - 90°F	6	24	144
Ambient Pressure*	Go/No-Go	1	24	24
Totals		7		168

* Desirable, but not required.

Environmental Constraints.-

(a) Constraints on the experiment package. The limiting constraints are those imposed by the biological specimens. Bean leaves mounted in experiment hardware breadboards have survived simulated Pioneer launch stresses with no detectable change in the stability of their circadian system (See section entitled, "Environmental Tests"). The package contains an independent ECS, but is dependent upon external thermal control. With specimens, it should be stored at 77 ± 1.5°F, with an acceptable range of 56-90°F.

(b) The plant package is clean and self-contained with no anticipated output of contaminant, RFI or EMI.

Data Measurement Requirements.-

Requirements are shown in Table 12.

TABLE 12. DATA MEASUREMENT REQUIREMENTS FOR A FOUR-LEAF EXPERIMENT

(Monitoring of light intensity level in at least one specimen module is also required if fiber-optics approach is used to provide illumination. Vehicle spin rate is also required once per day; however, it is assumed that this will be available as part of the spacecraft engineering data.)

Parameter To Be Measured		Leaf Movement Angle				Temperature	Pressure
Equipment Item Used		Assembly 1, Leaf				Assembly 1	Assembly 1
		1	2	3	4		
Expected Value of Parameter	Units	Degrees				^{0}f	psia
	Average	40				77 ± 1.5	14.7
	Range	90-180				50 - 90	One-bit digital set if pressure falls below 13 psia.
Measurement Characteristics	How Often	10 min				once per hour	
	Duration of Each	point sample					
	Total Number in Mission*	7200				1200	
Output of Instrument	Type	Analog					
	Frequency Range	Maximum of approximately 2 cycles/hour				DC	
	Amplitude Range	0-3V					
	Instrument Resolution	approx 3°				2°F	GO/NO-GO
Read-out Requirements	No. of Channels	1					
	Sampling Rate	0.010 BPS				0.0017 BPS	0.00028 BPS
	Telemetry	yes					
	Data Storage	yes, if continuous real-time telemetry is not available.					
Time Identification	Method	Experiment's clock-time annotation once per data frame.					
	Accuracy	±1 min					

* For a maximum duration of 50 days.

Operational Requirements

Spacecraft Orientation Requirements.- The experiment as described is specifically "sized", for a "typical" Pioneer mission, the basic elements of which are acceptable to experiment execution.

There are three specific requirements, all of which appear to be achievable on a Pioneer spacecraft.

(a) The spacecraft must leave the Earth field as rapidly as possible.

(b) There must be no periodic event aboard the spacecraft, such as acceleration, noise, vibration, etc. which occurs at frequencies which entrain biological rhythm.

(c) Data must be retrieved either continuously or intermittently for 60 days.

Prelaunch Support.- Preliminary installation and checkout will be done on each module with live specimens after loading into the vehicle. During installation and checkout, all environmental parameters required by the plant material must be kept in acceptable ranges. Growth chambers and standard laboratory equipment will be required at the launch site to maintain stock cultures, maintain ground controls for the flight experiment, and to conduct post flight analysis.

Flight Operational Requirements.- Transmission of data will be via telemetry system. In-flight temperature information is required and must be returned to the launch site to allow proper settings for ground controls. All other information should be returned to the PI. With the exception of the temperature data, all other data should be processed within 60 to 90 days after launch.

Data Support Requirements.- All data are anticipated to be processed and printed out at Goddard Space Flight Center or at Ames Research Center.

Resources Requirements

Development Schedule.- The development schedule is shown in Figure 13.

Estimated Funding Requirements.- Funding requirements are shown in Figure 14.

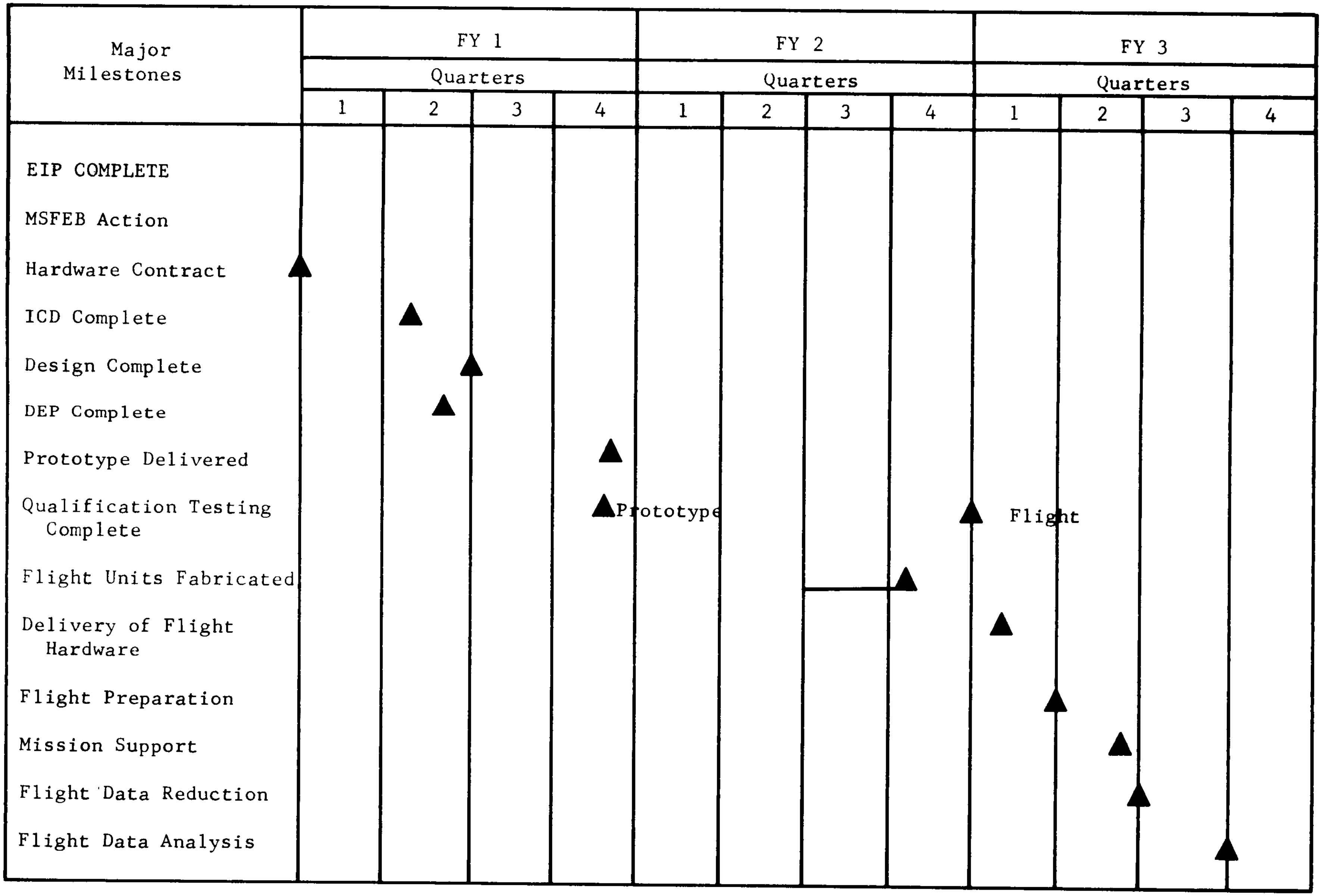


Figure 13. Estimated schedule for accomplishment of the Bean Leaf experiment.

Items	FY 1				FY 2				FY 3				
	Quarters				Quarters				Quarters				
	1	2	3	4	1	2	3	4	1	2	3	4	
Definition, Breadboard, Design, Development, Fabrication, Test (mock-ups, prototypes, and support equipment)	20	20	24	24	29	21	13	5	5				161
Fabrication, Test and Delivery (Flight units and spares)				13	20	30	56	53	5				177
Supporting Studies and Other Implementation Efforts	8	8	8	8	8	8	8	8	11	11			86
Data Analysis and Publication										3	16		19
Yearly Totals	133				259				51				
Estimated Grand Total													443

Figure 14. Estimated cost to accomplish the Bean Leaf experiment ($\$ \times 10^3$).

BIORHYTHMICITY OF FIDDLER CRAB ACTIVITY AND RESPIRATION

Principal Investigator: James Hufham, Space Defense Corporation
Co-Investigator: Frank Barnwell, University of Chicago
Engineering Support: Space Defense Corporation

Technical Information

Objectives.- The experimental objective is to determine whether removal from the earth's rhythmic geophysical environment will affect the well-known tidal rhythm and metabolic rhythm of the fiddler crab, Uca. Whether these periodicities remain the same, are modified, or completely disappear, provides insight as to whether this rhythm is timed by an autonomous, endogenous oscillator system, or whether it is dependent upon an exogenous rhythmic input.

Experiment Approach.- Until the advent of the national space program and its promised opportunity to make observations in vehicles moving out of the earth's sphere of influence, no way could be found to remove effectively the biological specimens from the cues of its geophysical environment. In light of the two diametrically opposed alternative hypotheses which could account for the timing of these biological rhythms, we propose a space flight of the fiddler crab, Uca, which has known and well-studied daily, tidal, monthly and annual biorhythms. We postulate that only if the rhythms persist essentially unaltered (from their earth-bound controls) while in the geophysical environment of space, can one be assured of the actual autonomy of the organisms rhythmicity.

The rhythmic patterns of locomotor activity and respiration in the fiddler crab, Uca, have been selected as the assay system of choice because:

(1) These activities of the fiddler crab are easily recorded.

(2) The small size (2-5 g) permits relatively large samples to be tested.

(3) The crabs may be kept for long periods of time with very little food.

(4) The activity patterns of these crabs exhibit both day-related and tide related components and would allow the study of two major natural frequencies and the interaction of the two cycles.

(5) There is already a large body of information concerning these cycles in the crab, and this information is helpful in accumulating base-line data and experiment design.

Under contract with NASA (NAS 2-4517) a highly sensitive device has been developed for recording the locomotor activity of the fiddler crab. The instrumentation is simple, sensitive, and compact. The movements of each crab are measured as digital events making interpretation direct and uncomplicated. These digital readouts would define the periods of activity and of inactivity, which are the important experimental parameters. The digital outputs obtained will be in a form suitable for transmission to ground station and programming as time series data for computer analysis at Wayne State University, or elsewhere. The structure of the activity rhythm will be examined by computer for changes in amplitude, period, rate of phase shifting, and any other effects which may become evident.

Since it will be necessary to provide regulated oxygen for the crabs, and there is little additional system penalty associated with oxygen monitoring, we will measure the integrated oxygen consumption rate of the six-crab population utilizing a respirometer developed under NASA Contracts NASw-870 and NAS9-7172. Since their oxygen consumption is a function of their activity, this measurement will allow a confirmation of the locomotor activity as determined by the actograph, as well as providing important information concerning the metabolism of the crabs during space flight.

The in-flight experiment length proposed is limited by the survival time of the biological specimens. As long as the life support needs of the crab are supplied, we expect the experiment to last at least 60 days. These life support needs consist of food, water, oxygen provision, carbon dioxide removal and thermal and barometric control. The crabs can be expected to survive for 30 to 40 days following the exhaustion of their food supply, which will probably occur in 15 to 20 days if supplied *ad libitum*. The maximum oxygen consumption is about 0.5 ml/hr/crab or approximately 75 ml per day for six crabs or a total of 4500 ml in a 60-day experiment. Supplying this quantity of oxygen presents no problem. The water will be sealed into each individual chamber and will not require changing or filtering.

Baseline or Control Data.- Two actograph-respirometers, identical to those flown in the spacecraft, will be established at Space/Defense Corporation in order to build a statistical base for comparison with the data from the spacecraft respirometer. Both the oxygen consumption and the locomotor activity will be monitored automatically. One control unit will rotate at the rate of spin of the BioPioneer spacecraft while the other will be fixed relative to the earth. These data will be compared with these obtained from the spacecraft and that obtained from other flight and control experiments.

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Engineering Information

Equipment Description.- The minimum experiment consists of three specimen chambers (Assemblies 1a, 1b, 1c); one oxygen supply unit (Assembly 2); and one Experiment Interface Unit (Assembly 3). Each specimen chamber contains two fiddler crabs individually housed and individually instrumented to monitor activity. Oxygen utilization is monitored for the population. (Figure 15).

It is significant to note that the proposed configuration was chosen to optimize integration with the Pioneer spacecraft. The modular design of the experiment package is amenable to many configurations to permit use of larger numbers of animals or to interface better with the spacecraft.

Each crab is contained in a sealed enclosure with 20% O_2, 80% N_2 atmosphere at 14.7 psi. Carbon dioxide and other gaseous contaminants are removed by chemical absorbents. Humidity is not controlled and remains close to saturation because of the presence of a small amount of sea water in each chamber. High humidity is required for the well-being of the organism. Oxygen is supplied to the animal at ambient pressure on demand. Thermal control is achieved by controlled heat paths to the cold experiment platform. The bottom of each crab enclosure is a diaphragm through which animal activity is monitored. Circuitry is provided for collecting experiment and engineering data for presentation to the Pioneer Data Handling system and relay to the ground.

A functional block diagram for a typical one crab system is shown in Figure 16.

(a) Required Equipment. An experiment unit consists of three specimen chambers (Assemblies 1a, 1b, 1c) and one Oxygen Supply Unit (Assembly 2). The following equipment is estimated to be required to implement the flight experiment:

Test Hardware	
Design Verification (Assembly 1 and Assembly 2)	1
Qualification Test (Assembly 1 and Assembly 2)	1
Mass Mock-up Unit	1
Flight Equipment Simulator Unit	1
Flight Hardware	
Flight Unit	1
Flight Unit Back-up	1
Control Unit	2

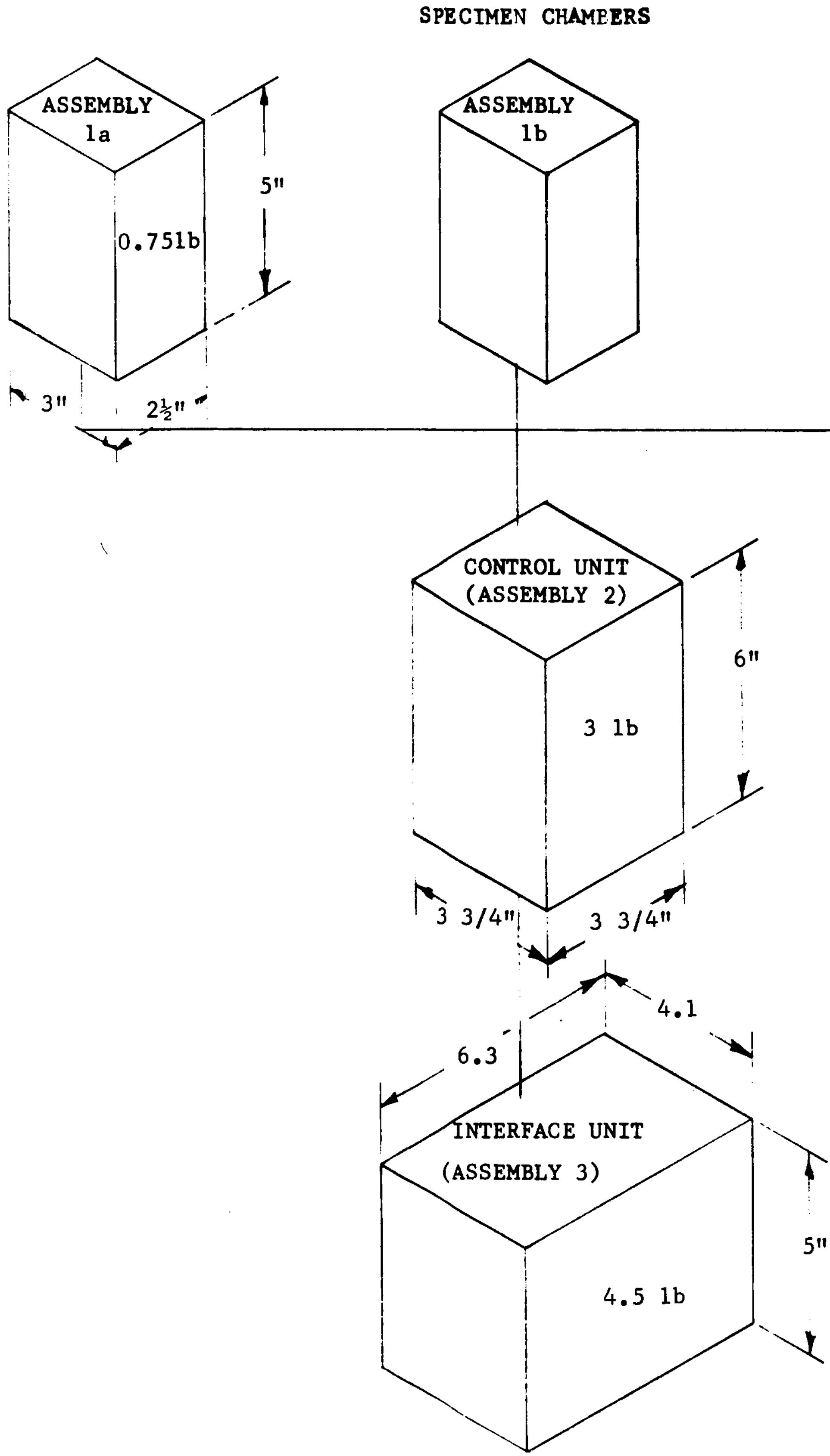


Figure 15. Assemblies for Fiddler Crab experiment.

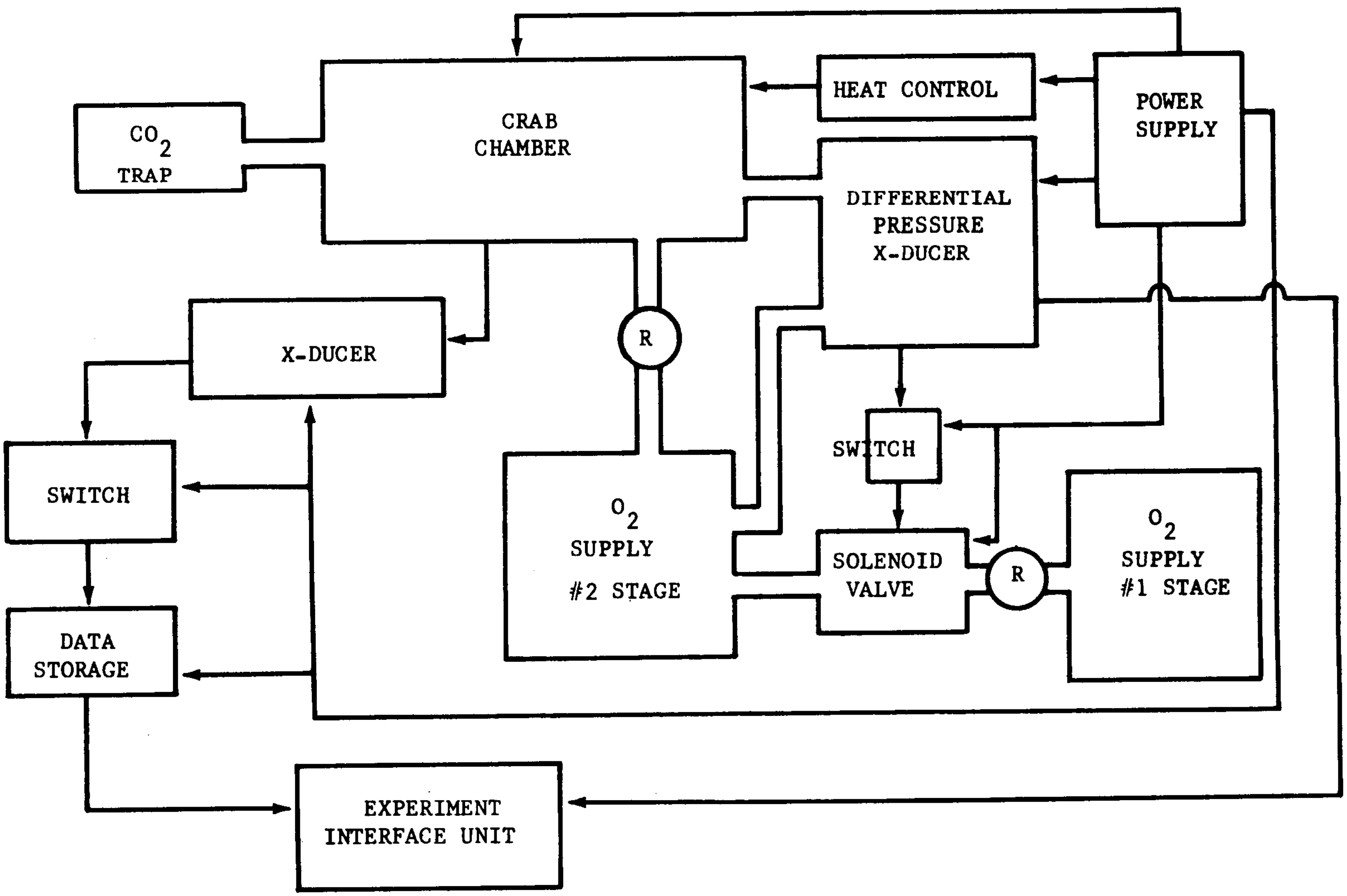


Figure 16. Block diagram of the Fiddler Crab experiment.

Crabs, a small crab vivarium, a few special tools, a supply of oxygen, appropriate pneumatic and electrical gauges and manometers, assorted mechanical and electrical spare parts, artificial sea water, and crab food will be provided by the contractor. A laminar flow laboratory bench, a regulated power 28 Vdc supply and refrigerator in an air-conditioned laboratory at Kennedy Space Center will be required.

(b) Equipment Status. Problems of actograph development have been dealt with during NASA Contract NAS2-4517, now being conducted by Space/ Defense Corporation. A breadboard configuration of the actograph unit is now being used to collect motor activity data from single specimens and a multispecimen actograph is under construction. The actograph maintains a salt-water environment, provides a food supply, maintains adequate illumination, and maintains the thermal balance. No problems are anticipated in combining the respirometer and actograph into a single experimental package. Temperature control will be achieved by a combination of active and passive techniques to maintain the specimen temperature at 24.0 ± 0.5° C.

The respirometric equipment is well advanced and only requires reconfiguration for adaptation to BioPioneer. Under Contract NASw-870 the basic respirometer unit was developed and has been collecting laboratory baseline data from potatoes for over two years. In addition, under the same contract, a multicell unit (12 potatoes) was developed and is now in the final stages of checkout and test before being put into bench service. Under Contract NAS 9-7172 a flight configuration for Apollo Applications Program Flight #3 is in the Program Definition Phase. Flight hardware design employing a two-cell respirometer has been approved (September 1967) and two mock-ups and two flight equipment simulators were delivered (December 1967).

Weight, Size, and Area.- Weight, size, and area are shown in Table 13.

Power*.- Power requirements are shown in Table 14.

Envelope.- Hardware for this experiment is illustrated in Figure 17.

*All power requirements are in the form of 28 Vdc (nominal).

TABLE 13. WEIGHT, SIZE, AND AREA REQUIREMENTS FOR A SIX-CRAB EXPERIMENT

Assembly	Number of Units	Weight (kg)	Volume (cm^3)	Dimensions (cm)	Floor Area (sq cm)	Shape
Respirometer	One					
Stored	(Each)	2.50	4500	20.0x15.0x15.0	NA	Box
Operational	(each)	1.36	1360	15.3x9.5x9.5	90	Tall Box
Actograph	Three					
Stored	(Each)	1.00	1500	15.0x10.0x10.0	NA	Box
Operational	(Each)	0.34	620	12.7x7.6x6.4	79	Long Box
Interface Unit	One	2.04	2100	10.4x16.0x12.7	167	Box
Totals						
Stored		7.54	11100	NA	NA	NA
Operational		4.42	5320	NA	495	NA

TABLE 14. POWER REQUIREMENTS FOR A SIX-CRAB EXPERIMENT

	Standby	Average	Maximum
Total Power	2.3	4.8	
Assembly 1a	0.0	0.77	1.7
Assembly 1b	0.0	0.77	1.7
Assembly 1c	0.0	0.77	1.7
Assembly 2	0.7	0.93	3.0
Assembly 3	1.6	1.6	1.6

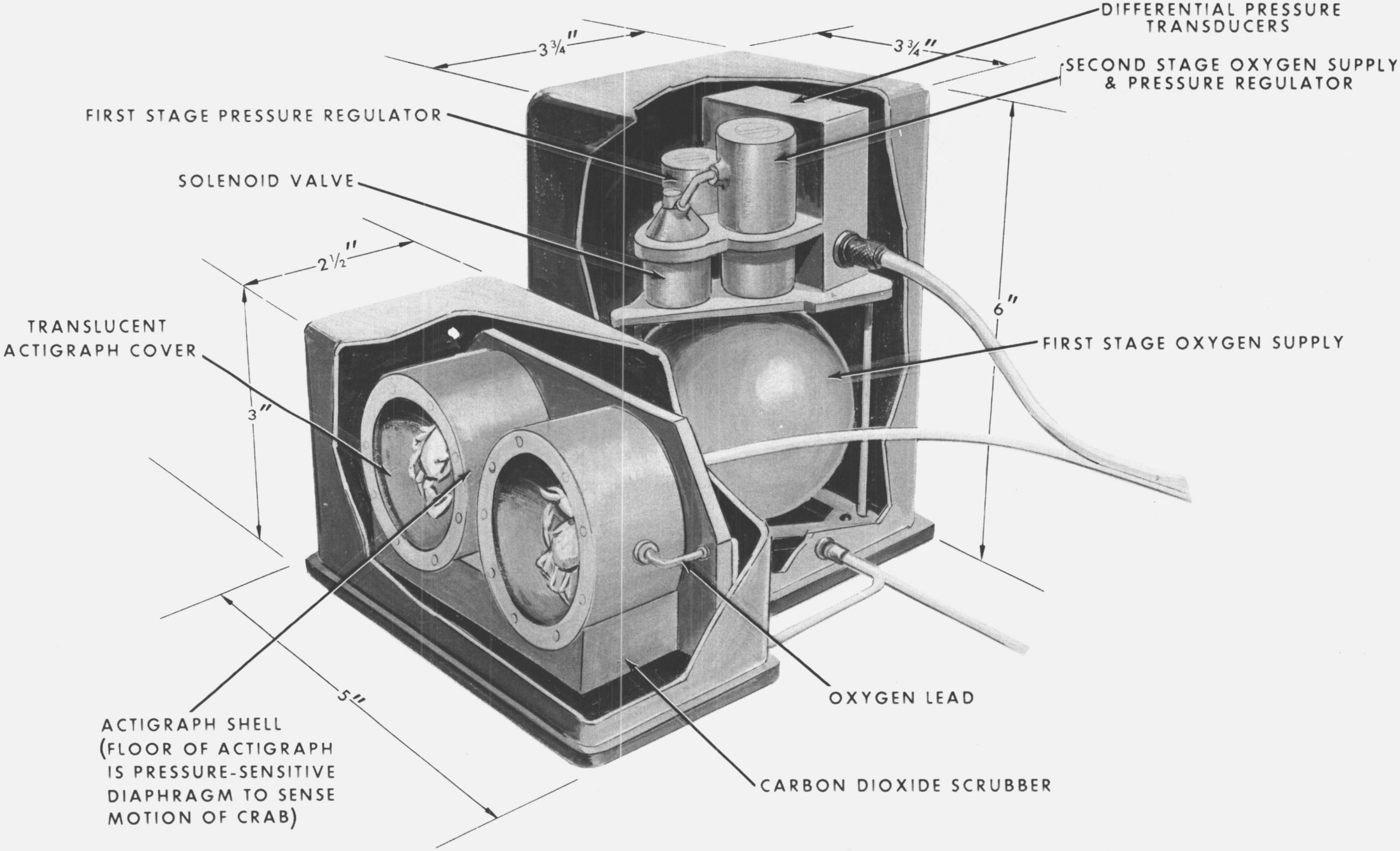


Figure 17. Experiment hardware concept for the study of circadian periodicity of fiddler crab activity and metabolism

Spacecraft Interface Requirements.-

(a) Location. The actographic assemblies must be placed at a position such that, after spinup and rotation of the unit, the floor of the individual actographs sustains a G load of not less than 0.9 nor more than 1.1. The oxygen supply unit (Assembly 2) may be placed anywhere in the spacecraft.

(b) Mounting Requirements. Fifteen bolt holes or tapped holes on the floor plate are required. No special stressing or supports are thought to be required. Smaller tapped holes to accept tiedown U-loops for wiring and oxygen lines will also be necessary.

(c) Subsystem Support Requirements. No structural modifications are required. Power and TM leads are required.

(d) Plumbing. Maximum gas pressure is 2000 psia. No fluids will be moved. Cabling requirements are not demanding. Routing of these may be by the most convenient path. Oxygen leads from the regulator assembly to the actograph assemblies should be routed as short paths as possible to minimize dead space and vibration.

(e) Dynamics. Assume geometric center of each unit to be the center of gravity. Location of moveable objects can be derived from Figure 17. The pattern of crab movement is circular, around perimeter of individual actograph. The crabs weigh 3.0 to 4.0 g. The longest possible distance separating two crabs in an actograph assembly is 4 in.; 1 in. is the least distance. The chronotropicity of movement patterns is unpredictable.

Food is located in a niche in the side of the individual actograph and weighs 2.0 g per crab. For each crab, 25 ml of water (weighing about 25 g) will be provided, for a total of 150 g. The water, before and during boost, will collect at the lower edge of the individual actographs. Upon spinup, the water will be evenly distributed over the diaphragmatic floor of the actograph. The water will not be pumped and will only be given motion by the crab.

Solid wastes are generally distributed over the "floor" of each actograph (the diaphragm serving as the floor when the spacecraft is rotating). Oxygen is converted by oxidative metabolism into carbon dioxide at a known ratio. This respiratory quotient (RQ) for the crab is

0.8 CO_2/O_2. Since each crab consumes no more than 0.5 ml O_2 (STP)/hr, total consumption for the proposed configuration is 72 ml/day or about 4320 ml O_2 at STP for a 60-day mission. This amounts to 0.103 g of O_2 per day (or 6.2 g for 60 days), or 0.113 g of CO_2 per day (or 6.8 g for 60 days). This CO_2 is, in turn, converted into potassium carbonate by reaction with potassium hydroxide. However, this reaction is stoichiometric and furthermore occurs in the CO_2 scrubber shared by both crab in an actographic assembly. Thus, the net mass movement is from the oxygen storage bottle (of 0.033 g O_2/day) to each of six individual actographs where the O_2 is converted to CO_2 (by the crabs' metabolism) and thence to K_2CO_3. However, the latter two conversions produce no major change in center of mass, occurring as they do within an inch of one another.

Environmental Constraints.-

(a) Constraints on the Experiment Package. The limiting constraints are these imposed by the biological specimens. Crabs mounted in experiment hardware breadboards have survived simulated Pioneer launch stresses with no detectable change in the stability of their circadian system. (See section entitled "Environmental Testing") The package contains an independent ECS. Without specimen it may be stored between -48°C and 70°C; with specimen -1°C to 30°C.

Anticipated ambient levels of radiation, EMI, and RFI aboard the spacecraft are considered acceptable for execution of the experiment, but both their leads and periodicities must be known.

(b) Interference. This is essentially a "silent" package. With the exception of opening and closing of minute regulator valves, there is no mechanical motion and no significant resultants. The valves are actuated by tiny solenoids of low electrical energy (40 mA).

Data Management Requirements.- The oxygen consumption of the crabs, the activity of each individual crab, and the experiment package temperature will be combined electronically so that all the data can be collected, stored and fed to the BioPioneer DSU in a compatible mode. Oxygen consumption will be monitored by sensing whether the solenoid (which recharges the second stage oxygen supply) has been activated and the event stored in a logic circuit. Every 6 minutes, the circuit will be read and fed to the BioPioneer DSU, requiring a total of 240 bits/day of DSU capacity. Crab motor activity will be monitored as the occurrence or nonoccurrence of a select number of motion events occurring in a 6-minute period and recorded on the logic circuit as a single event. This circuit also will be read and fed to the BioPioneer DSU every 6 minutes. Since there are six crabs, a total of 1440 bits/day of DSU capacity is required for activity measurement. **(See Table 15.)**

The temperature will be determined over each hour using a six-bit word and a range of 50 to 82°F (± 0.5°F). This will require 144 bits per day. The total for all three measurements is 1824 bits per day.

Operational Requirements

Spacecraft Orientation Requirements.- There are no orientation requirements.

Prelaunch Support.- The Principal Investigator (PI) will deliver the experiment to Kennedy Space Center 12 days prior to launch and 9 days prior to launch will install and calibrate specimens. At direction of the SPO, the PI will install experiment in spacecraft when power is established on the pad, and monitor respiration and activity from the control center until a satisfactory signal is obtained. Facilities and equipment as described above are required. No GSE/AGE will be required as a service item.

Flight Operational Requirements.- Ready access by the PI to early data is desirable to determine experiment function status and to assess immediate effect of launch and orbit, if any, upon the specimens.

Data Support.- Preflight data will be collected at Kennedy Space Center nine days prior to flight using contractor furnished equipment.

Table 15. Data Measurement Requirements in a Six-Crab Experiment.

Parameter to be Measured		Crab Movement Event: Ass'y	1A	Ass'y	1B	Ass'y	1C	Temperature	Respirometer Valve Event
Equipment Item Used		Spec No.1	Spec No.2	Spec No.3	Spec No.4	Spec No.5	Spec No.6	Assembly 2	Assembly 2
Expected Value of Parameters	Units	On/Off	→	→	→	→	→	°F	On/Off
	Average	N/A	→	→	→	→	→		N/A
	Range	On/Off	→	→	→	→	→	50 - 80	On/Off
Measurement Characteristics	How Often	6 min						1 hour	6 min
	Duration of Each	Continuous Monitoring	→	→	→	→	→	Point Sample	Continuous Monitoring
	Total Number in Mission	14,400	→	→	→	→	→	8,640	14,400
Output Signal of Instrument	Type	Digital	→	→	→	→	→		Digital
	Frequency Range	N/A	→	→	→	→	→		N/A
	Amplitude	0 - 10 V	→	→	→	→	→		0 - 10 V
	Instrument	On/Off	→	→	→	→	→	±0.5 °F	On/Off
Readout Requirements	No. of Channels	1	→	→	→	→	→	→	→
	Sampling Rate	0.003 BPS						0.0017 BPS	0.0003 BPS
	Telemetry	Yes	→	→	→	→	→	→	→
	Data Storage	Yes if continuous real-time telemetry is not available							
Time Identification	Method	Experiments clock	→	→	→	→	→	→	→
	Accuracy	±1 min	→	→	→	→	→	→	→

It may be desirable to plug into spacecraft data system prior to spacecraft installation to determine continued system compatibility. No real time data are required, except for "early look" (not "quick look") at data. Raw data from spacecraft should be converted from analog to digital if required, time correlated, and ephemeris correlated. The PI will treat reduced data with his own computer program. If possible, it is desirable to know of any events occurring in the spacecraft which may have cyclic characteristics.

Resources Requirements

The following material was prepared by Space Defense Corporation and represents the current best estimate of both schedule and budget requirements to accomplish the proposed experiment. A firm bid must await definition of requirements to be established by the Pioneer Project Office. Depending upon specific requirements, both the schedule and budget may be readily reduced or increased. The time and money requirements outlined below represent a realistic program optimized for attainment of scientific objectives, systems reliability, and fiscal responsibility.

Development Schedule.-

(a) Phase One, Program Definition.- The current Experiment Feasibility Study (NAS2-4526) has preempted some of the classic PDP functions. Those that remain include development of:

1. Preliminary Experiment Implementation and Program Plan.
2. Reliability Program Plan.
3. Design Verification Test Plan.
4. Qualification Test Plan.
5. Failure Mode Effect and Criticality Analysis.
6. Design.
   a. Design Analysis and Design
   b. Preliminary Drawings and Bill of Materials
   c. Specifications

7. Mockup and Simulator Hardware

a. Mass Mockup. One respirometer and one actograph assembly will be provided.

b. Flight Prototype Mockup. One respirometer assembly and one actograph assembly will be provided.

c. Flight Equipment Simulator Unit. One respirometer assembly and three actograph assemblies (comprising one "flight unit") will be provided.

(b) Phase Two.- Flight Hardware Development, Test, and Fabrication.

1. Fabricate Design Verification Test Hardware. The equivalent of two respirometer assemblies and two actograph assemblies in components must be provided.

2. Perform Design Verification Tests.

3. Design Modification and Final Design Review.

4. Fabricate Qualification Test Hardware. One respirometer assembly, one actograph assembly and selected spares are required.

5. Perform Qualification Tests.

6. Prepare Production Drawings and Specifications. The schedule for accomplishing this program is estimated to be 24 months (Figure 18). The estimated cost of accomplishing this program is estimated to be $292,800 (Figure 19).

7. Fabricate Flight Hardware. One flight unit, one flight back-up unit and two control units will be provided.

8. Perform Predelivery Acceptance Test.

9. Deliver Flight Hardware.

10. Perform Post Delivery Acceptance Test.

(c) Phase Three.- Operations.

1. Prepare Operations Documentation.

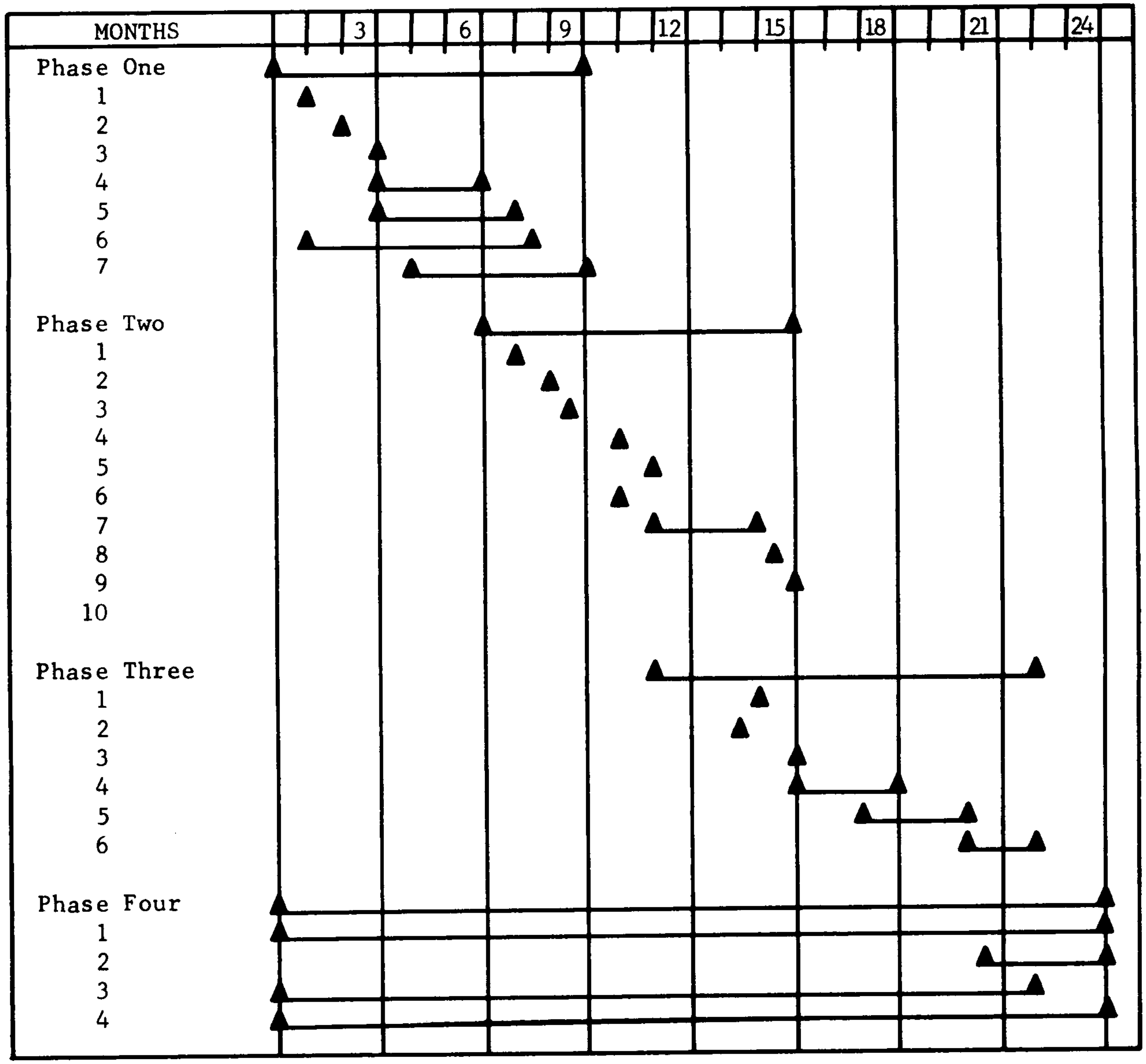


Figure 18. Estimated schedule for accomplishment of the Crab experiment.

Months	3	6	9	12	15	18	21	24
Phase One		$69.6						
Phase Two				$91.6				
Phase Three						$38.1		
Phase Four				$93.5				
Quarterly Expenditures	34.9	34.9	65.3	45.7	52.6	22.1	22.1	15.2
Cumulative Quarterly Expenditures		69.8	135.1	180.8	233.4	255.5	277.6	292.8
Annual Expenditures				180.8				112.0
Cumulative Annual Expenditures								292.8
Total Expenditures								292.8

Figure 19. Estimated cost to accomplish the Crab Experiment ($ x 10^3).

a. Field Laboratory Requirements Plan.

b. Detailed Experiment Implementation Plan.

c. Checkout and Count Down Document.

d. Reporting Plan.

2. Establish Kennedy Space Center Field Laboratory.

3. Establish Flight and Backup and Control Units at KSC.

4. Assist in installation, checkout, countdown and launch of Experiment in BioPioneer.

5. Collect Flight Experiment Data.

6. Reduce and Treat Data.

(d) <u>Phase Four</u>. Reporting and Support.

1. Prepare and submit monthly, annual and phase interim reports and a final report.

2. Analyze and report the experimental results to the government and the scientific community.

3. Perform baseline studies in the contractor's laboratory and at the University of Chicago.

4. Provide management to assure completion of the work in a timely and cost-effective manner.

CIRCADIAN PERIODICITY OF COCKROACH ACTIVITY AND RESPIRATION

Principal Investigator	Colin S. Pittendrigh, Princeton University
Coinvestigator	R. G. Lindberg, Northrop Corporate Laboratories
Engineering Support	Northrop Corporate Laboratories

Technical Information

Objectives.- The purposes of this experiment are to (1) examine the persistence and precision of the circadian period of cockroach activity and metabolic rate, and (2) examine the phenomena of temperature compensation of circadian periodicity when all geophysical variables other than light and temperature are either removed or sensed by the organism at periods other than 24 hours. The two experiment objectives strike directly at the fundamental arguments in favor of geophysical events governing the length of circadian periods. If the circadian period and the phenomenon of temperature compensation are unaffected by removal of terrestrial stimuli, the argument in favor of pervasive geophysical forces is significantly weakened.

Experiment Approach.- If both experiment objectives are undertaken simultaneously, two groups of cockroaches containing three individually monitored roaches each will be held at two different temperatures (15°C and 25°C) and the frequency of activity will be monitored at ten minute intervals. The data upon retrieval will be examined to determine the precision and persistence of the circadian period as a function of temperature. The data will be compared with ground based control data for evidence of entrainment to a precise 24-hour period. In the event that both objectives cannot be undertaken simultaneously, a minimum of three cockroaches will be flown at a constant temperature and the persistence and precision of their circadian period will be studied for approximately one year. This latter approach is not a compromise and is particularly significant in view of laboratory data which has revealed that animals maintained in a free running condition for several months will often display desynchronized periodicities.

Baseline or Control Data.- Since the objective of the experiment is to test for undefined "pervasive geophysical forces," it is essential that ground controls be run simultaneously with the flight experiment.

The use of cockroach activity to study circadian periodicity in insects is classical. Roach data are routinely collected in the laboratory in the same manner proposed for the experiment. The computer program is in operation for statistical analysis of the laboratory data. It is intended that the same computer program be used in reducing the space flight experiment.

Engineering Information

Equipment Description.-

(a) Functional description. The cockroach experiment will consist of as many as six modules, each containing one cockroach (Assemblies 1a through 1f); a Central Electronics Module (Assembly 2); and an Experiment Interface Unit (Assembly 3). Gross motor activity will be continuously monitored and read out once every ten minutes for a period of one year. Engineering data, consisting of ambient temperature and ambient pressure, will be sampled once per hour.

The environmental control system for the package requires no external power. Thermal requirements will be met passively through a controlled heat path to the spacecraft platform. Careful selection of materials for the conductive path coupled with the small change in platform temperature will yield a very stable system with change in experiment temperature following platform variation.

A "leak proof" experiment housing will contain a 14.7 psi atmosphere consisting of 20% oxygen and 80% nitrogen. The control of atmospheric composition will utilize a lithium hydroxide bed for CO_2 control and a demand O_2 regulator coupled with a high pressure O_2 source to supply make up O_2. Activated charcoal and boric acid crystals will be utilized as required for odor control.

The gross motor activity of each cockroach will be monitored by counting the number of half-revolutions of an activity wheel, which doubles as the animal holding area, during consecutive ten minute periods. The six most significant counter bits will be stored at the end of each ten minute period, thereby providing a measure of average activity during the counting period.

Illumination in each cell will be controlled by an onboard programmer which can be deactivated by ground command. A low power electrical heater will provide thermal balancing during low heat periods. As an optional feature, a respirometer can be provided and monitored as a backup activity measurement.

An electronics block diagram is shown in Figure 20. The number of activity wheel half-revolutions are counted in digital counters, and serially shifted to the Pioneer data system via the experiment interface unit every 10 minutes. Ambient pressure and temperature for each specimen chamber is sampled directly at least once per hour by the Pioneer analog multiplexer. Total activity and engineering data bits per day for a three-cockroach experiment are 2592 and 864 respectively, exclusive of timing, synchronization, and parity bits, or 3672 bits including time-of-day. This data can be handled by the existing Pioneer data system with one DSU.

(b) Equipment required.

(1) Design verification module

(1) Prototype: Mass mockup and prototype mockup are optional.

(8) Flight units

(1) Qualification test

(1) Backup

(3) Flight

(3) Control

(1) Set of Ground Support Equipment to be used for loading and testing of flight units, and thermal control and data monitoring of loaded units.

(c) Equipment status. The equipment described herein is in a stage of preliminary design. A wheel similar to one to be used in the flight configuration is currently being used in laboratory research at Princeton. No new techniques or components beyond those currently in use are required.

Envelope.- A sketch of a typical Assembly 1, which contains the specimen, is given in Figures 21 and 22. Outline dimensions for Assembly 2, the Central Electronics Module, and Assembly 3, the Experiment Interface Unit, are given in Figures 23 and 24 respectively.

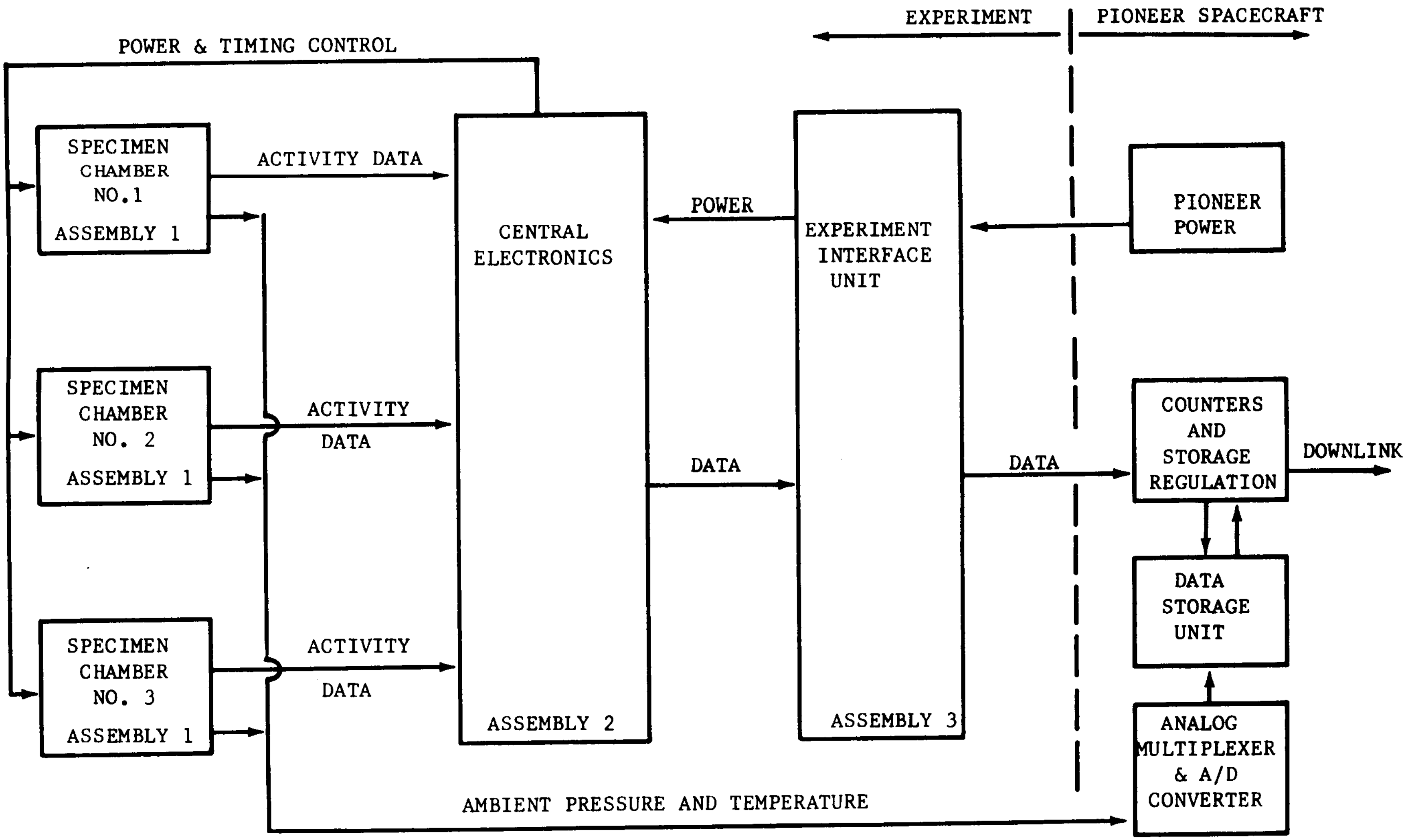


Figure 20. Electronics block diagram of Cockroach experiment.

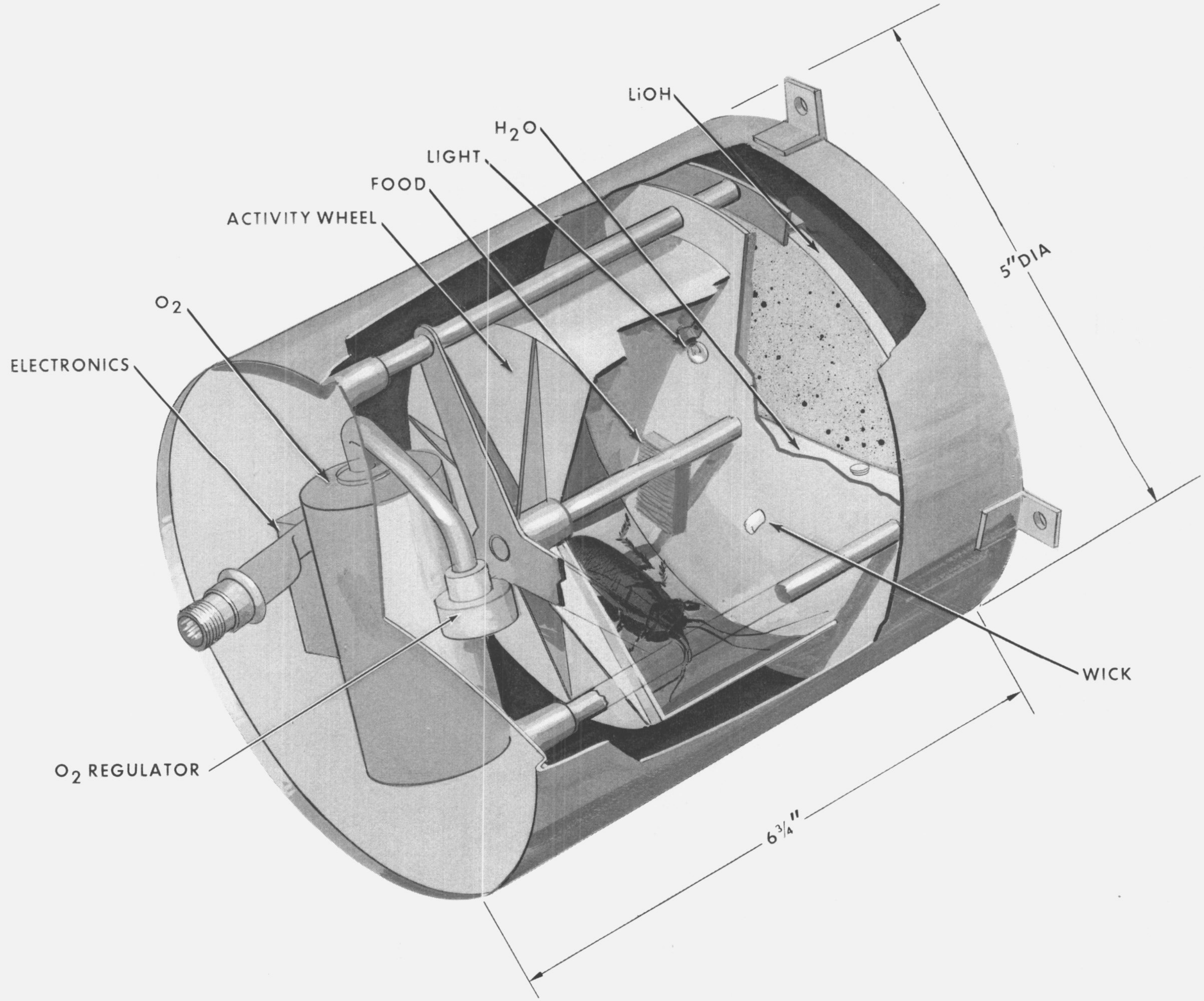


Figure 21. Experiment hardware concept for the study of circadian periodicity of cockroach activity and respiration.

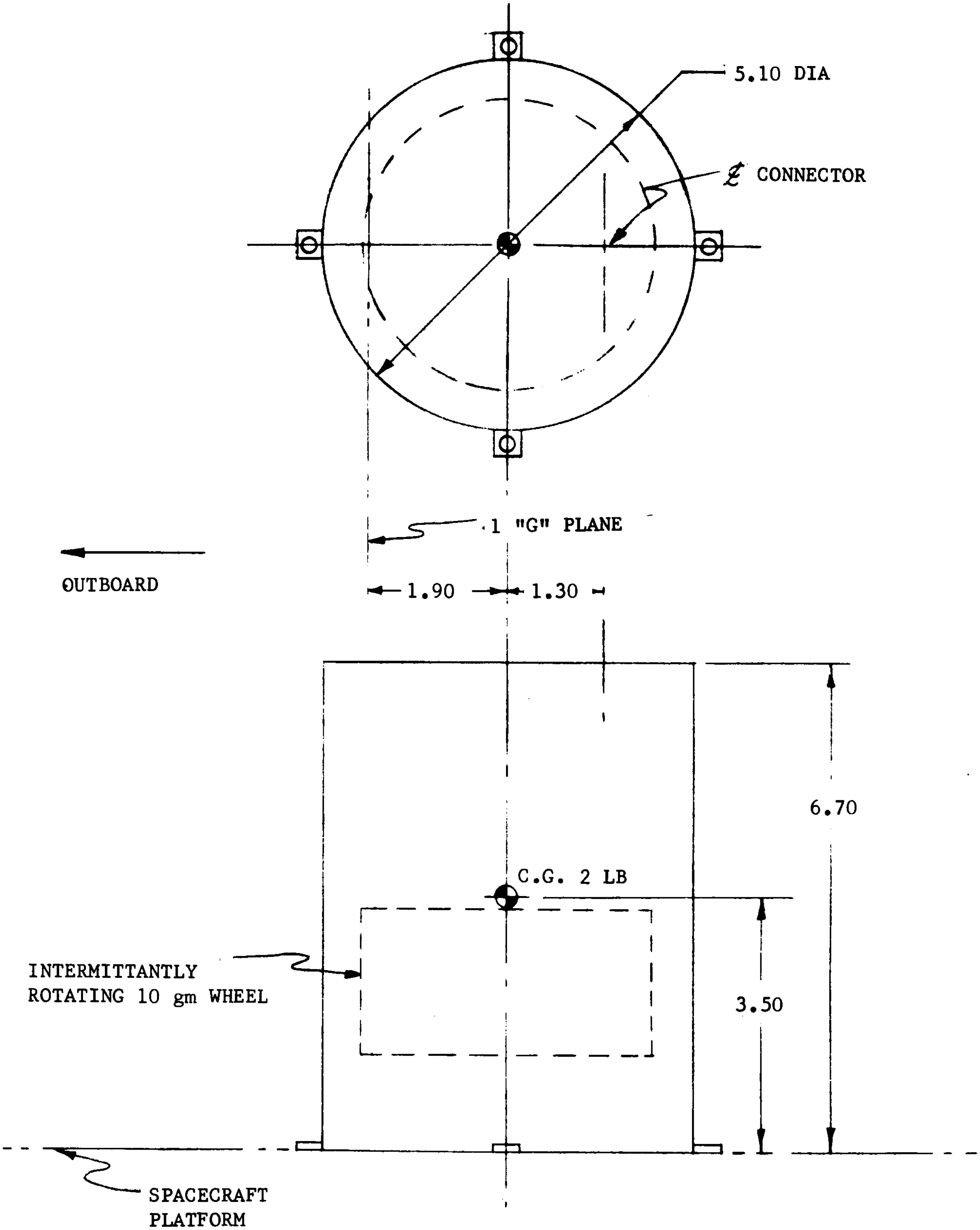


Figure 22. Cockroach experiment assembly 1.

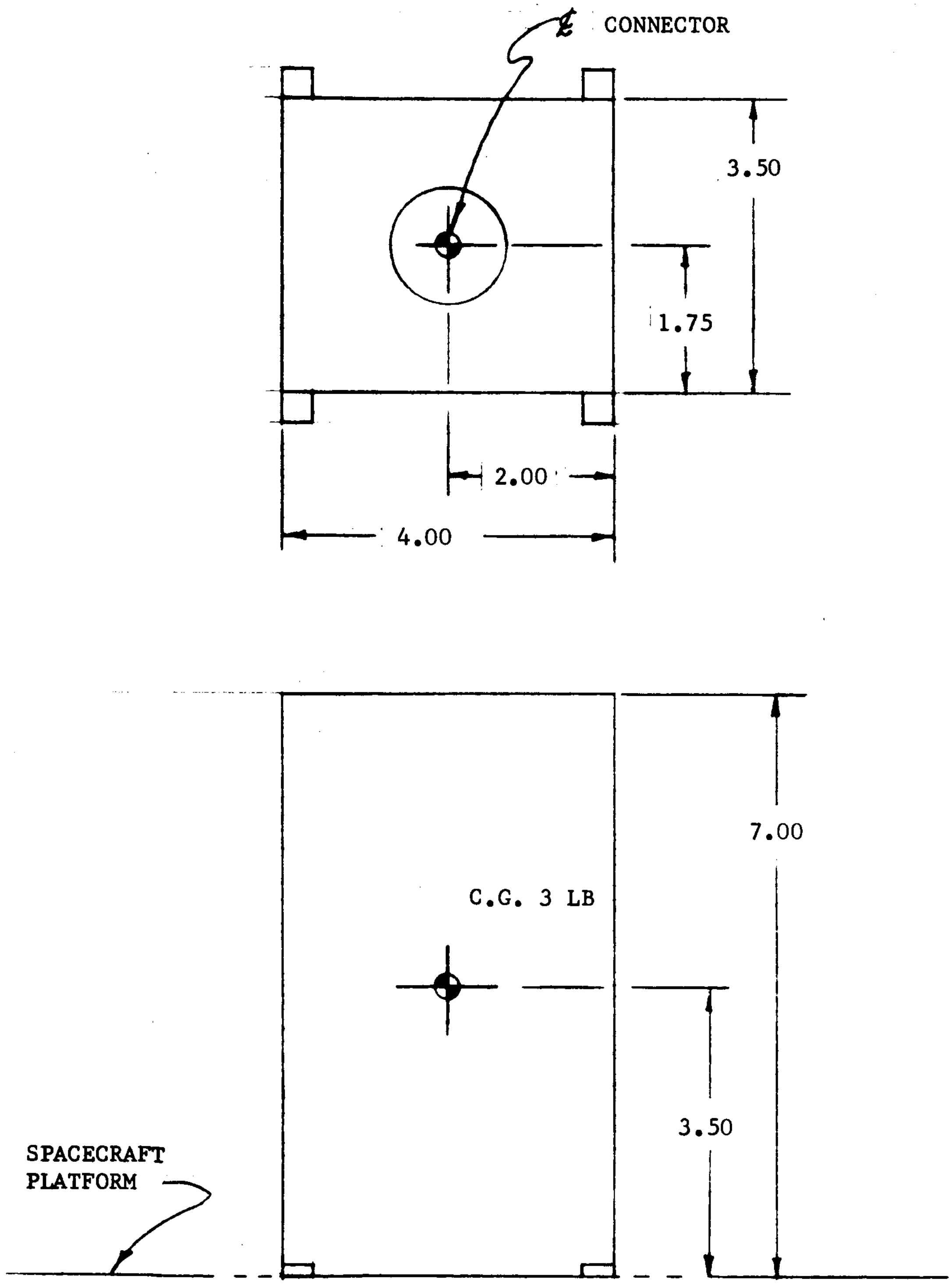


Figure 23. Cockroach experiment central electronics unit (assembly 2)

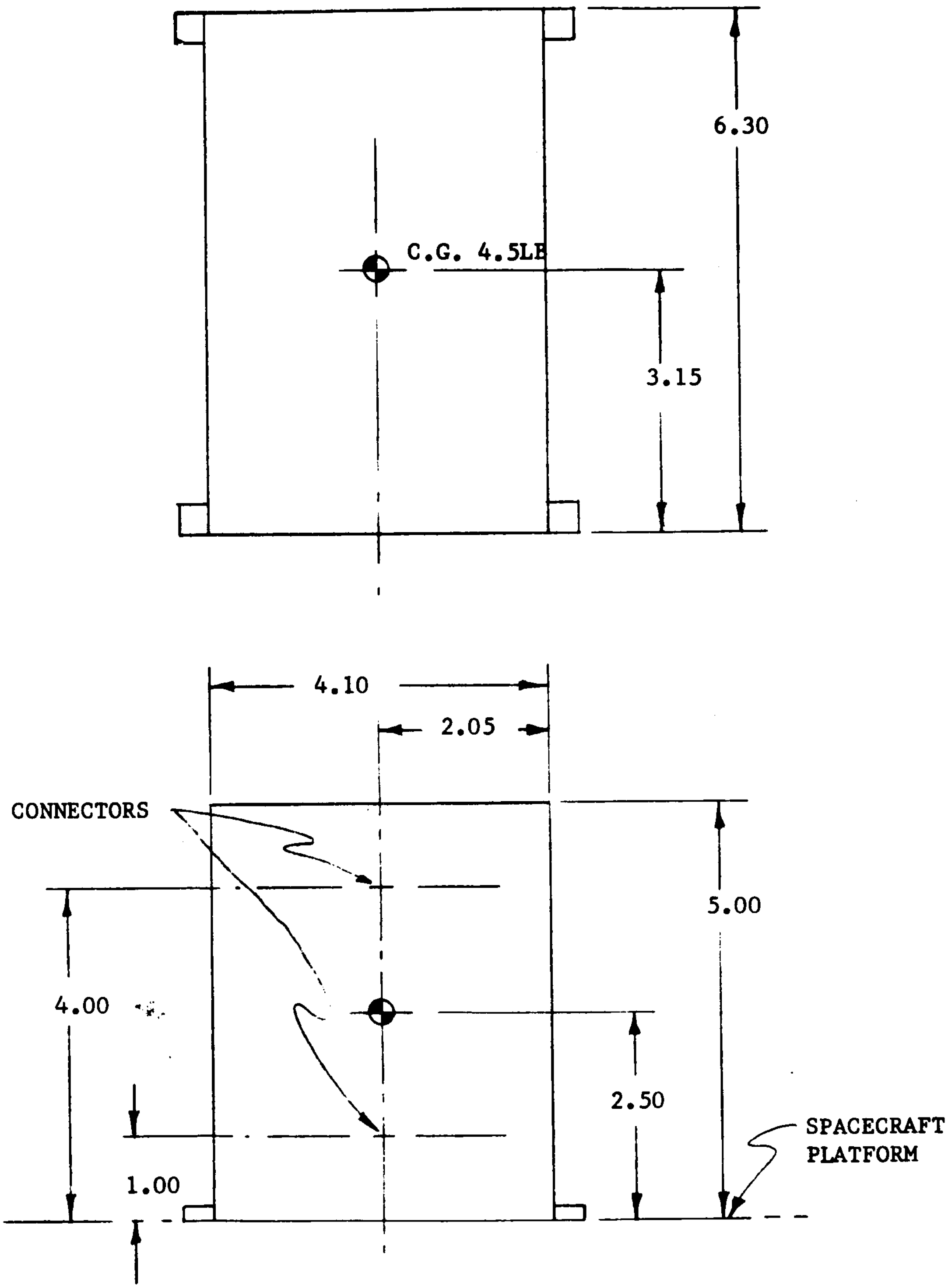


Figure 24. Cockroach experiment: experiment interface unit (assembly 3).

Weight and Size.- Weight and size are shown in Table 16.

TABLE 16. WEIGHT AND SIZE OF A THREE COCKROACH EXPERIMENT

ASSEMBLY	WEIGHT (lb)	VOLUME (in.^{3})	DIMENSIONS L" x W" x H"	SHAPE
1A	2.0	132	5.05 x 5.05 x 6.72	Cylinder
1B	2.0	132	5.05 x 5.05 x 6.72	Cylinder
1C	2.0	132	5.05 x 5.05 x 6.72	Cylinder
2	3.0	98	4 x 3½ x 7	Rectangular
3	4.5	128	6.3 x 4.1 x 5	Rectangular
Total	13.5	622		

Power.- Power requirements are shown in Table 17.

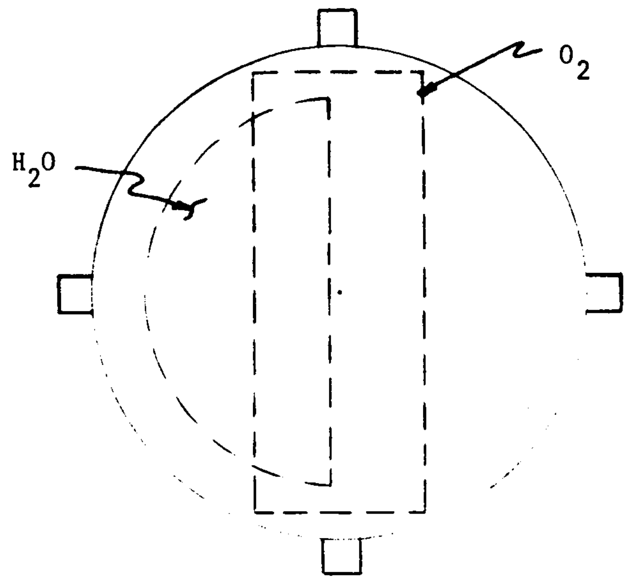
TABLE 17. POWER REQUIREMENTS FOR A THREE COCKROACH EXPERIMENT

ASSEMBLY	STANDBY	AVERAGE	MAXIMUM
1A	0.7	0.7	0.7
1B	0.7	0.7	0.7
1C	0.7	0.7	0.7
2	0.6	0.6	0.6
3	1.6	1.6	1.6
Total Power (W)	4.3	4.3	4.3

Spacecraft Interface Requirements.-

(a) Location. It is required that each of the three specimen chambers be located where the force of gravity is simulated by rotation of the spacecraft.

(b) Mounting. Mounting shall be sufficient for thermal control as well as mechanical support.



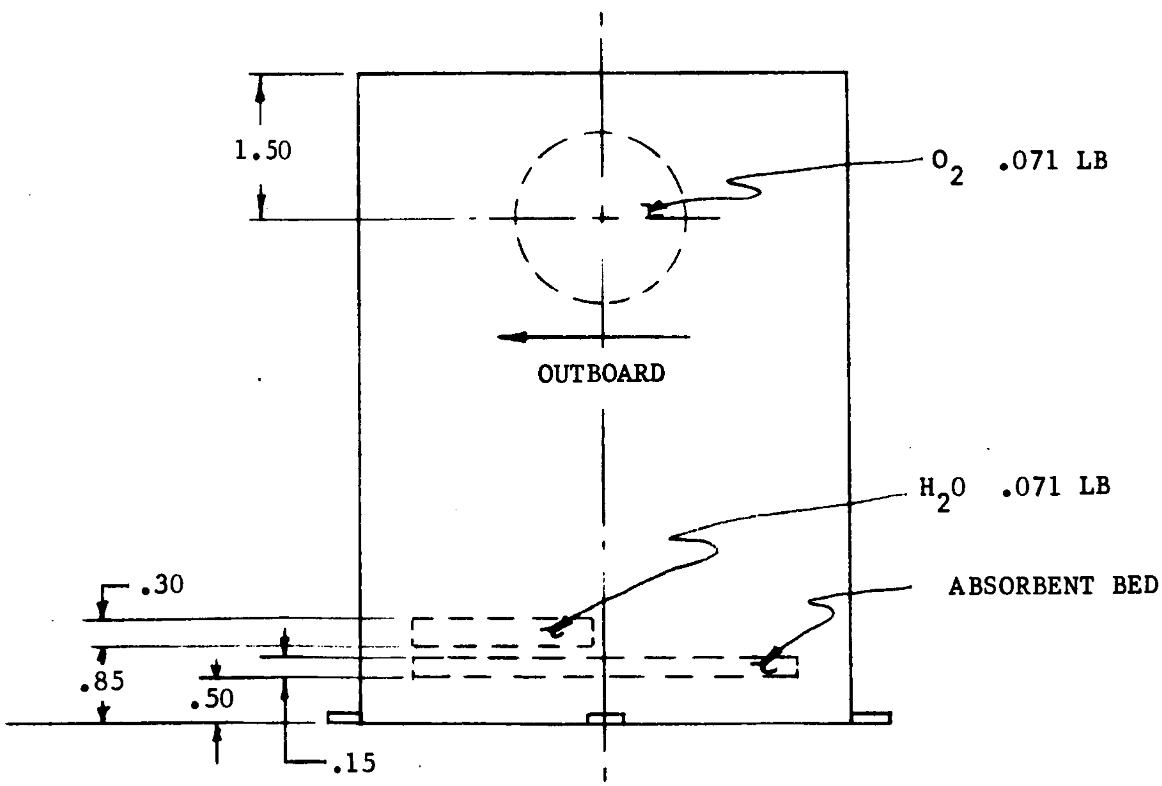


Figure 25. Shifts of consumable material in Cockroach experiment assembly 1.

(c) Support. Support requirements are 28 VDC power and switching, data storage and downlink transmission, uplink commands, and thermal control. It is required that the specimens not be subjected to thermal cycling.

(d) Linkages and control. No special mechanical linkages or controls are required except power switching.

(e) Dynamics. Shifts in location of expendable supplies is shown in Figure 25.

Environmental Constraints.-

(a) Constraints. The limiting constraints are those imposed by the biological specimens. Test specimens survived simulated Pioneer launch stresses with no apparent after effects.

The experiment does require a stable environment with no periodic stimuli capable of entraining biological rhythms.

(b) Interference. There are no known sources of interference in this experiment.

Data Measurement Requirements.- Requirements are shown in Table 18.

Operational Requirements

Spacecraft Orientation Requirements.- The experiment as described is specifically sized for a "typical" Pioneer spacecraft mission, the basic elements of which are acceptable to experiment execution.

There are three specific requirements, all of which appear to be met on Pioneer.

a) The spacecraft must leave the earth field as rapidly as possible.

b) There must be no periodic event aboard the spacecraft, such as acceleration noise, vibration, etc., which occurs at frequencies which entrain a biological rhythm.

c) Data must be retrieved either continuously or intermittently for a minimum of 120 days.

TABLE 18. DATA MEASUREMENT REQUIREMENTS FOR A THREE-COCKROACH EXPERIMENT

Parameter to be Measured		Activity			Ambient Temperature			Ambient Pressure		
Equipment Item Used (specimen chamber)		1	2	3	1	2	3	1	2	3
Expected Value of Parameter	Units	Levels	→	→	°F	→	→	psia	→	→
	Nominal Value	TBD	→	→	69	→	→	14.7	→	→
	Range	0-63	→	→	64.4-75.2	→	→	13.2-16.3	→	→
Measurement Characteristics	How Often	10 min	→	→	1 hour	→	→	→	→	→
	Duration	10 min	→	→	Point Sample	→	→	→	→	→
	Total in Mission	52,560	→	→	8,760	→	→	→	→	→
Output Signal of Instrument	Type	Pulse	→	→	Analog	→	→	→	→	→
	Frequency Range	TBD	→	→	DC	→	→	→	→	→
	Amplitude Range	0-5V	→	→	0-3V	→	→	→	→	→
	Resolution	1 count	→	→	2°F	→	→	0.03 psia	→	→
Readout Requirements	No. of Channels	1	→	→	→	→	→	→	→	→
	Sampling Rate	0.010 BPS	→	→	0.0017 BPS	→	→	→	→	→
	Telemetry Required	yes	→	→	→	→	→	→	→	→
	Storage Required	yes, if real time telemetry is not available								
Time Identification	Method	Experiments clock				→	→	→	→	→
	Accuracy	± 1 min	→	→	→	→	→	→	→	→

Prelaunch Support.- Shipping and handling procedures for the experiment hardware will follow usual procedures for equivalent flight items. Addition of oxygen, specimen food and water, and the experimental organism will be at the launch site as close to time of launch as is operationally feasible.

The assemblies containing the experimental organisms will go through all necessary checkout to insure the integrity of the package prior to installation in the spacecraft. Experiments will receive a prelaunch checkout by procedures to be defined. The principal support requirement in this category is for thermal control. The proposed experiment achieves temperature control passively through its mounting on the experiment platform. All other functions are self contained or need not become operational prior to prelaunch checkout and/or launch.

A combination office/laboratory space will be required to accommodate up to 24 experimental animals, the flight hardware and associated backups and ground controls. This is estimated to require approximately 400 square feet of air conditioned work space, a desk, an electronics bench, one or two tables and an animal rack. Both 120 V and 28 V power will be required. The space should be available continuously from 30 days prior to launch to 30 days after completion of the flight experiment. It is entirely feasible to accommodate total experiment support in a suitable trailer.

Flight Operational Requirements.- There are no special flight operational requirements.

Data Support Requirements.- Control data will be collected on magnetic tape at the launch site. Flight data will be recovered from the NASA communication net on computer compatible magnetic tape and relayed to Princeton University for analysis. Flight data may be retrieved either in real time or intermittently from a data storage unit, depending upon operational constraints.

Resources Requirements

Development Schedule.- The development schedule is shown in Figure 26.

Estimated Funding Requirements.- Funding requirements are shown in Figure 27.

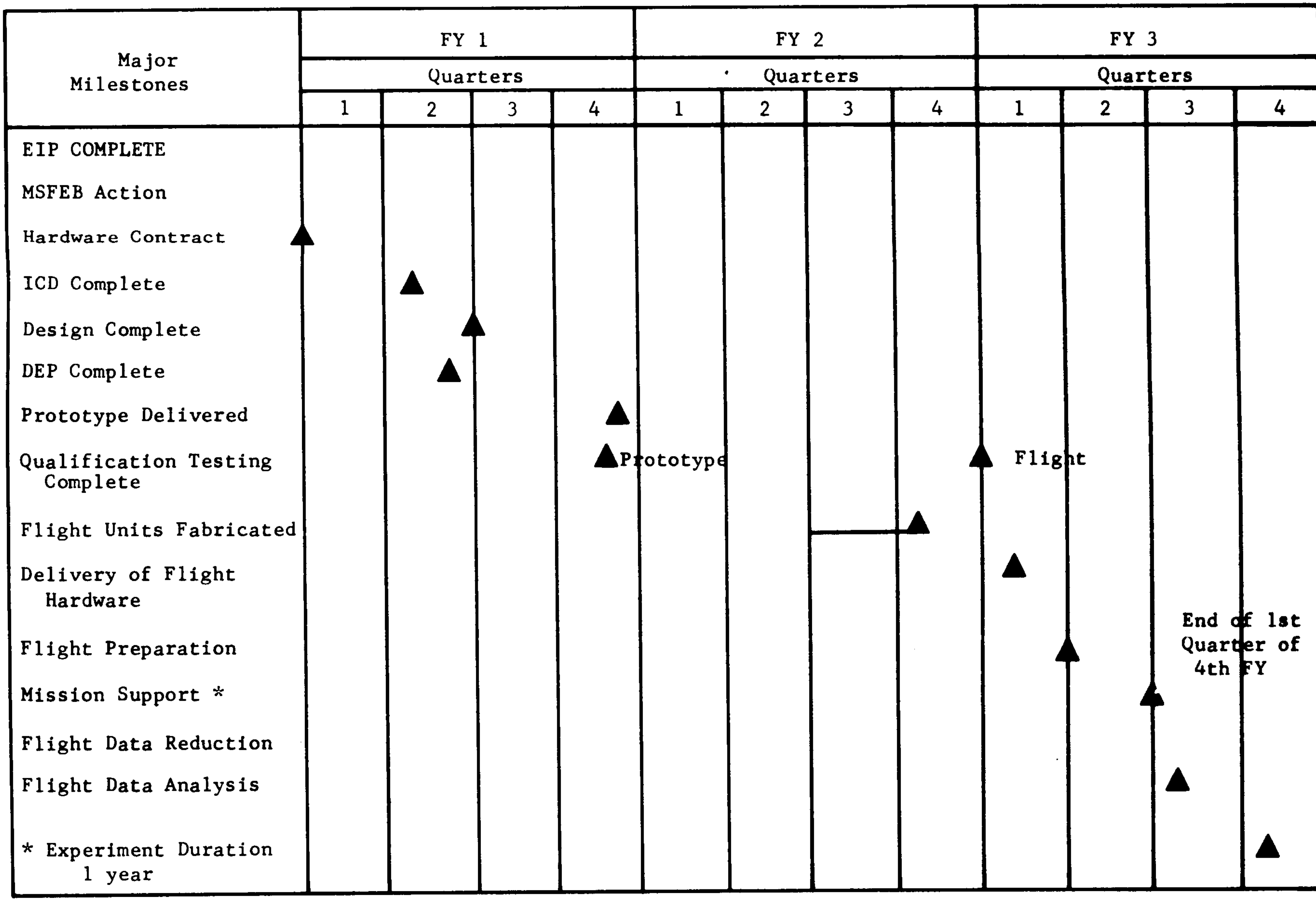


Figure 26. Estimated schedule for accomplishment of the Cockroach experiment.

Items	FY 1				FY 2				FY 3				FY 4				Totals
	Quarters				Quarters				Quarters				Quarters				
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	
Definition, Breadboard, Design, Development, Fabrication, Test (mock-ups, prototypes, and support equipment)	27	27	21	21	29	24	16	8	5								178
Fabrication, Test and Delivery (Flight units and spares)				13		30	55	53	5								156
Supporting Studies and Other Implementation Efforts	8	8	8	8	8	8	8	8	11	11	8	8	8				110
Data Analysis and Publication													3	16			19
Yearly Totals	141				247				48				27				
Estimated Grand Total																	463

Figure 27. Estimated cost to accomplish the Cockroach experiment ($\$ \times 10^3$).

CIRCADIAN PERIODICITY OF VINEGAR GNAT ECLOSION

Principal Investigator: C. S. Pittendrigh, Princeton University
Coinvestigator: R. G. Lindberg, Northrop Corporate Laboratories
Engineering Support: Northrop Corporate Laboratories

Technical Information

Objectives.- The purpose of this experiment is to examine the phenomenon of "temperature compensation" of the circadian periodicity of an insect during spaceflight. Specifically the question being asked is whether the circadian rhythm of eclosion of Drosophila pupae is changed when all geophysical variables other than light or temperature are either removed or sensed by the organisms at periods other than 24 hours.

The experiment strikes directly at one of the fundamental arguments in favor of geophysical events governing the length of the circadian period. If the circadian period and temperature compensation are unaffected by removal of terrestrial stimuli, the argument in favor of "pervasive geophysical forces" is significantly weakened.

Experiment Approach.-

(a) Premise. The proposed experiment will test the premise that some "pervasive geophysical force" does entrain the circadian periodicity of organisms and that as a consequence circadian systems removed from terrestrial stimuli will degrade. The proposed experiment will study both the precision of the circadian period in space and temperature compensation of the period in space. (In case of power or weight restrictions it is not essential that both questions be attacked simultaneously.) The end point to be monitored is the frequency of Drosophila eclosion.

(b) Experiment. Development of a Drosophila pupa is precisely controlled by its circadian system. After the system has been held in constant dark, a light flash is sufficient to entrain the circadian system and the time of hatching following the light flash can be predicted with great precision. However, there are periods during the organism's subjective day when the pupa is refractory and does not entrain to the light flash but continues its development according to the prevailing circadian period. By subjecting newly formed pupae to light flashes at different times of its subjective day the circadian period stays constant but the phase shifts to varying degrees depending upon the time at which the light flash is administered. These phase shifts have been intensively studied and reported in the literature. The proposed experiment is therefore an application of a very thoroughly studied phenomenon and technique.

The experiment consists of two populations of pupae developing at different ambient temperatures with each population further divided into sub-populations of 500 pupae each. The chambers once loaded will be held in constant dark under 100% nitrogen at 14.7 psi. This treatment will hold the pupae dormant until initiation of the experiment in space ten to twenty days later. At initiation of the experiment the ambient temperature of one pair of pupal populations will be gradually raised to approximately 26°C and the other pair of populations will be gradually lowered to 17°C. When the temperature has stabilized, oxygen will be added to the experiment chambers to reconstitute a 20% oxygen 80% nitrogen atmosphere at 1 psi. One population of pupae at the high temperature and one population of pupae at the low temperature will receive a flash of white light at this time. Twelve hours later the remaining population at the high temperature and the low temperature will receive a similar flash of white light. The rate of eclosion will be monitored by optical scanning of the pupae chambers. Upon retrieval the data will be examined in terms of the precision of the circadian period, phase shifts as functions of ambient temperature and/or time of white light stimulus. The results will be compared with ground controls and previous laboratory data in an effort to resolve degradation of the circadian period and changes in the anticipated temperature compensation of the circadian period.

It is proposed that one ground control experiment be run concurrently at the launch site with the flight experiment. Housekeeping data (ambient temperature, atmospheric pressure) will be required to document the consistency of the environment which the experiment requires.

(c) Validity of technique. Drosophila eclosion rhythm is the best studied circadian system of any organism. Techniques fully developed at Princeton University permit the selection of a pupal population that would emerge in, e.g., three or four successive peaks of activity separated by a precise circadian period. The pupae can be stored in a dormant state under nitrogen and only released into activity long after the system had entered either solar orbit. Experimental studies are presently underway at Princeton to determine more precisely how long and at what temperatures the pupae can be kept dormant. Vibration is known to influence the rate of eclosion. Studies to determine the threshold of this effect are underway.

Baseline or Control Data.- Since the objective of the experiment is to test for unknown "pervasive geophysical forces," it is essential that ground controls be run at the launch site simultaneously with the flight experiment. Baseline data from which to design the proposed experiment are well in hand. Drosophila eclosion is the most intensively studied circadian system in the literature. A key reference is Pittendrigh, C.S., "On the Mechanism of the Engrainment of a Circadian Rhythm by Light Cycles," in Circadian Clocks, pp 277-297. North Holland Pub. Co., Amsterdam 1965.

Engineering Information

Equipment Description.-

(a) Functional description. The fruit fly experiment will consist of four populations of 500 pupae each housed in two separate compartments of two populations each (Assembly 1), and an Experiment Interface Unit (Assembly 2). Prior to activation of the experiment the pupae will be held dormant in 100% nitrogen in constant dark. The experiment will be initiated by reestablishing a 20% oxygen 80% nitrogen atmosphere and establishing an 8 to 10°C temperature differential between compartments. The modules will be individually strobed with white light at different times and the hatching rate will be observed. Infrared light, to which the flies are insensitive, will be used at 15-minute intervals for monitoring. These data, along with engineering data sampled once per hour, will be transferred to the Pioneer spacecraft data system.

Thermal control will be via a conductive path to the thermally regulated spacecraft platform, and a low-power electrical heater. The two packages will be stacked with the lower package the coolest. Prior to activation of the experiment the packages will be essentially at platform temperature. Upon activation, with resulting power input, the package temperatures will rise until equilibrium is reached through the heat flow paths. Since the two packages are at different temperatures and are sealed, a pressure difference will occur. This has been eliminated by the incorporation of a small bleed port between the two packages. The O_2 required for activation of the experiment is stored at the same pressure as the N_2 in the package (14.7 psi) in a container equal to approximately 20% of the combined volumes. Upon activation a solenoid is activated to puncture a diaphragm between the containers, thus allowing the gases to mix. The relative humidity will be established at the time of package closure. Absorbents are not required.

Each pupa will be mounted on a fiber optic "light pipe." When the pupae hatch, the pupa will become transparent and can be sensed by a photodiode. The cells will be illuminated in groups by gallium arsenide light sources at the time of counting. The gallium arsenide light requires approximately 65 milliwatts of power and produces light in a frequency which the developing pupae cannot sense.

Each module of 500 pupae will be scanned once every 15 minutes. The total number of pupae which have hatched will be counted in a binary counter. After the count has been made the contents of the counter will be shifted to the experiment interface unit (EIU). The counter will then be used to count hatched pupae in the next module, etc., until all four modules have been scanned. Engineering data will also be periodically monitored. A block diagram of the electronics is shown in Figure 28. A section view of a typical cell is shown in Figure 29.

Several electronic monitoring approaches were considered: (1) "fuses" which are broken by the fly upon hatching, thereby providing an electrical indication, (2) a weak opaque film which is broken upon hatching, thereby

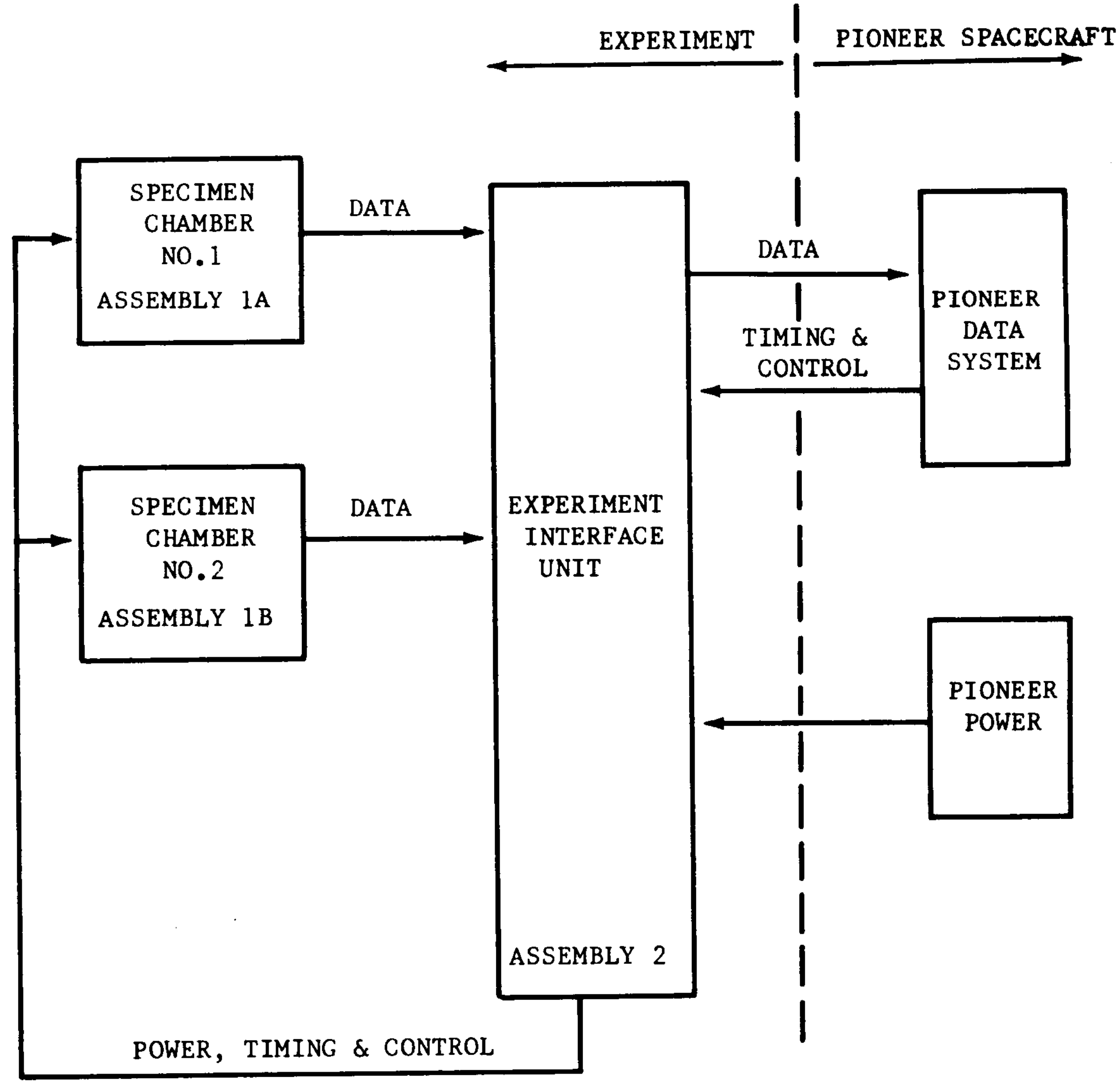


Figure 28. Electronics block diagram of the Drosophila eclosion experiment.

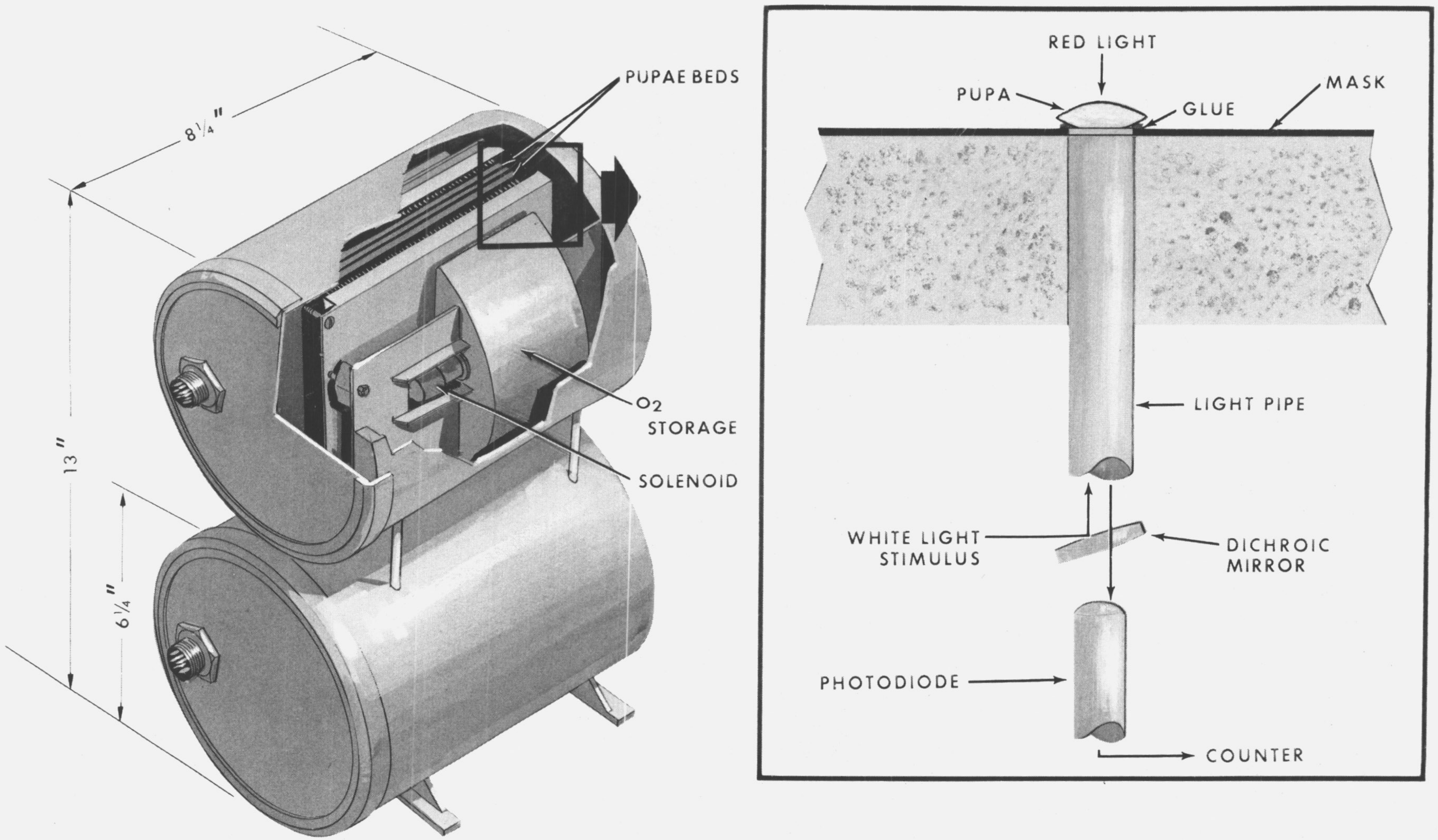


Figure 29. Experiment hardware concept for the study of circadian periodicity of Drosophila eclosion.

providing an optical indication, (3) an electronic memory device or counter which is triggered when the fly interrupts, or fails to interrupt, a photodiode-sensed light beam, and (4) a carbon black film which is eaten by the fly and photodiode-sensed.

The broken fuse and opaque film approaches do not appear to be as dependable as the photodiode-sensed approaches since they require that the fly be strong enough to break the indicating material. Any of the photodiode-sensed approaches would provide reliable indications of hatching; the principal investigator has had favorable experience with the carbon black and Northrop has performed informal tests which established the feasibility of photodiode sensing.

Monitoring of hatched pupae can be accomplished with several different combinations of lamp and diode scanning. Any of these approaches is usable with or without carbon black, where the approach without the carbon black would be that of (3) above.

These approaches are compared in Table 19. The combination lamp-diode scanning approach seems to offer the best features of either lamp or diode scanning and is the recommended mechanization. Included in the estimates of Table 19 are power regulation and all electronics except timing and control common to all approaches.

For a 2000 pupae experiment, 3744 bits of daily storage would be required for biological, timing, and engineering data. Assuming only one downlink dump per day, it is feasible to use the existing capability available for biological experiments on a Pioneer spacecraft with one DSU and physical experiments.

(b) Equipment required.

(1) Design verification module

(1) Prototype - Mass mockup and prototype mockup are optional.

(6) Flight Units

(1) Qualification test

TABLE 19 COMPARISON OF MONITORING APPROACHES (2000 PUPAE EXPERIMENT)

APPROACH	Maximum Power (W)	Weight (lb)	Volume (in.^{3})	Component Cost ($)	Relative Complexity (Parts)	Remarks
Photodiode with Individual Lamps	1.8	3.3	108	14,710	4164	
Fiber Optics with Individual Lamps	1.8	3.6	119	10,190	2188	Optic fibers can be used in strobing pupae with white light.
Photodiode with Common Lamp	5.6	5.2	172	6,520	2198	
Combination Lamp-Diode Scanning	1.8	4.7	156	3,210	381	Optic fibers can be used in strobing pupae with white light.

(1) Backup

(2) Flight

(2) Control

(1) Set of Ground Support Equipment to be used for loading and testing of flight units, and thermal control and data monitoring of loaded units.

(c) Equipment status. The equipment status is conceptual design, except that a breadboard of the photodiode-sensing circuit has been successfully tested by Northrop.

Envelope.- A sketch of Assemblies 1A and 1B is shown in Figure 29. Outline dimensions for Assembly 2, the experiment interface unit, are shown in Figure 30.

Weight and Size.- Weight and size are shown in Table 20.

TABLE 20. WEIGHT AND SIZE OF VINEGAR GNAT EXPERIMENT

ASSEMBLY	WEIGHT (lb)	VOLUME (in.^{3})	DIMENSIONS L" x W" x H"	SHAPE
1A	10.3 for both	247	8.2 x 6.2 x 6.2	Cylindrical
1B		247		
2	4.5	128	6.3 x 4.1 x 5	Rectangular
Total	15.0	622		

Power.- Power requirements are shown in Table 21.

TABLE 21. POWER REQUIREMENTS FOR VINEGAR GNAT EXPERIMENT

ASSEMBLY	STANDBY	AVERAGE	MAXIMUM
1A	0.6*	2.5	6.5**
1B	0.3*	1.1	5.1**
2	0.5*	1.6	1.6
Total	1.4*	5.2	9.2**

* Allows continuous temperature sensing and 0.3 duty cycle for heater.
** 4 watts activated once per mission for approximately 50 ms.

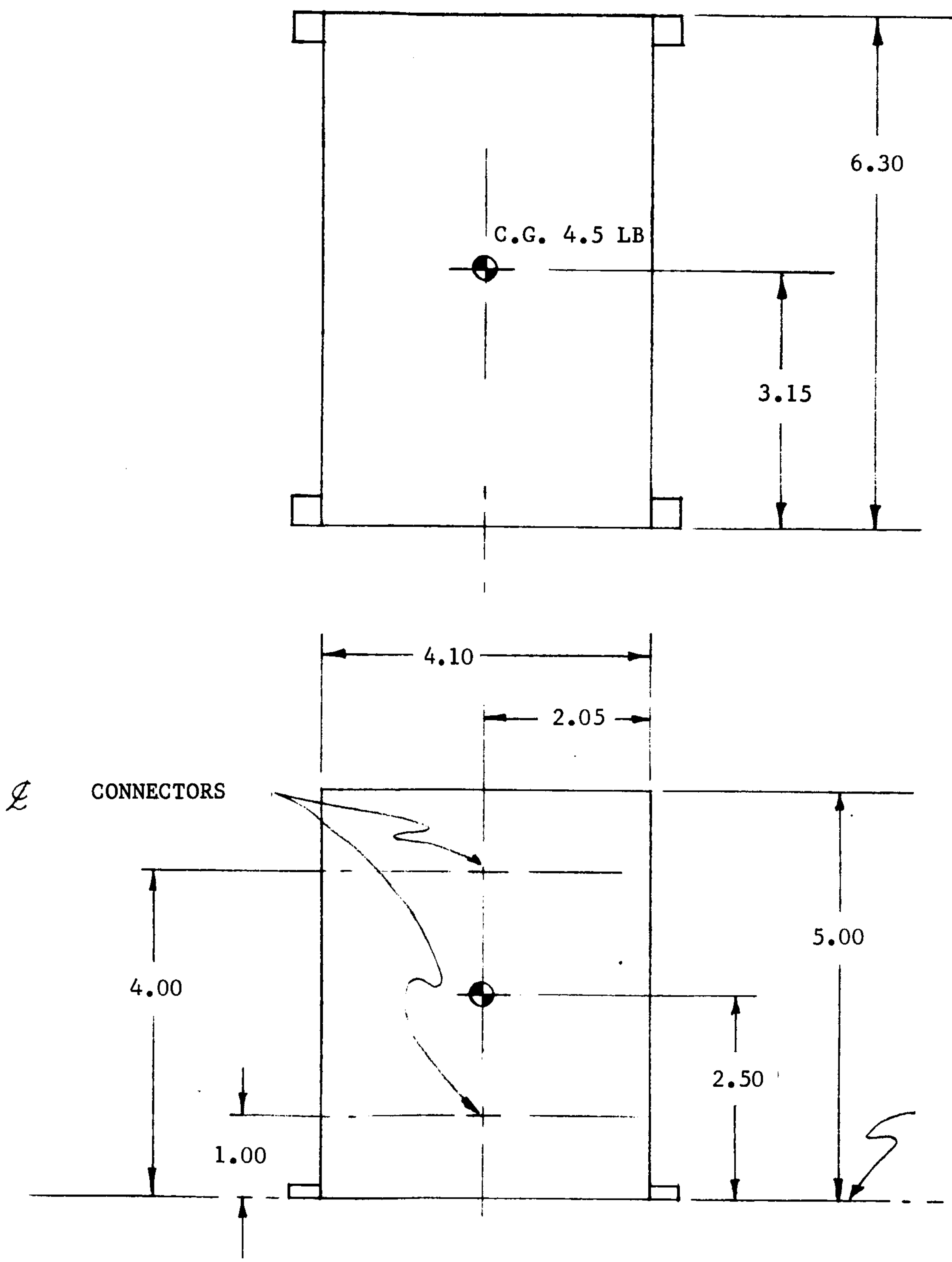


Figure 30. Drosophila eclosion experiment: experiment interface unit (assembly 2).

Spacecraft Interface Requirements.-

(a) Location. It is required that the two specimen chambers be mounted in a location which simulates the force of 1-G by spacecraft rotation.

(b) Mounting. Mounting shall be sufficient for thermal control as well as mechanical support.

(c) Support. Support requirements are 28 V dc power and switching, data storage and downlink transmission, uplink commands, and thermal control. It is required that the specimens not be subjected to thermal cycling.

(d) Linkages and Control. No special mechanical linkages or controls are required except power switching.

(e) Dynamics. The package center of gravity is estimated at the geometrical center of the stacked configuration. (See Figure 29.) There are no movable components.

Environmental Constraints.-

(a) Constraints. The limiting constraints are those imposed by the biological specimens. Test specimens in experiment hardware configuration have been subjected to simulated Pioneer launch stresses. (See section "Environmental Test.") The package will require vibration dampening.

(b) Interference. There are no known sources of interference in this experiment.

Data Measurement Requirements.- In addition to the periodic data requirements shown in the following table, time of activation of the following events is required.

1) Release of O_2 into both specimen chambers.

2) Application of white light to Chamber 1.

3) Application of white light to Chamber 2.

General requirements are shown in Table 22.

TABLE 22. DATA MEASUREMENT REQUIREMENTS FOR VINEGAR GNAT EXPERIMENT

Parameter To Be Measured		Number of Pupae Hatched				Ambient Temperature	
Equipment Item Used (specimen chamber)		1		2		1	2
		Module A	Module B	Module C	Module D	Modules A&B	Modules C&D
Expected Value of Parameter	Units	Count	→	→	→	°F	→
	Nominal Value	Not Applicable	→	→	→	~77	~64
	Range	0-500	→	→	→	~75-78.8	~62.6-66
Measurement Characteristics	How Often	15 min	→	→	→	1 hour	→
	Duration	Paint Sample	→	→	→	→	→
	Total in Mission	450	→	→	→	120	→
Output Signal of Instrument	Type	Pulse	→	→	→	Analog	→
	Frequency Range	Not Applicable	→	→	→	DC	→
	Amplitude Range	0-5V	→	→	→	0-34	→
	Resolution	1 count	→	→	→	2°F	→
Readout Requirements	No. of Channels	1	→	→	→	→	→
	Sampling Rate	5.010 BPS	→	→	→	0.0017 BPS	→
	Telemetry Required	yes	→	→	→	→	→
	Storage Required	yes, if continuous real time telemetry is not available					
Time Identification	Method	Experiments Clock				→	→
	Accuracy	± 1 min	→	→	→	→	→

Operational Requirements

Spacecraft Orientation Requirements.- The experiment as described is specifically sized for a "typical" Pioneer spacecraft mission, the basic elements of which are acceptable to experiment execution. There are three specific requirements, all of which appear to be met on Pioneer.

a) The spacecraft must leave the earth field as rapidly as possible.

b) There must be no periodic event aboard the spacecraft, such as acceleration noise, vibration, etc., which occurs at frequencies which entrain a biological rhythm.

c) Data must be retrieved either continuously or intermittently for a minimum of 30 days.

Prelaunch Support.- Shipping and handling procedures for the experiment hardware will follow usual procedures for equivalent flight items. Culture of the experimental organism will be at the launch site and loading of experiment hardware will occur as close to time of launch as is operationally feasible.

The assemblies containing the experimental organisms will go through all necessary checkout to insure the integrity of the package prior to installation in the spacecraft. Experiments will receive a prelaunch checkout by procedures to be defined. The principal support requirement in this category is for thermal control. The proposed experiment achieves temperature control passively through its mounting on the experiment platform. All other functions are self-contained or need not become operational prior to prelaunch checkout and/or launch.

A combination office/laboratory space will be required to accommodate the flight hardware and associated backups and ground controls. This is estimated to require approximately 400 square feet of air conditioned work space, a desk, an electronics bench, and one or two tables. Both 120 V ac and 28 V dc power will be required. The space should be available continuously from 30 days prior to launch to 30 days after completion of the flight experiment. It is entirely feasible to accommodate total experiment support in a suitable trailer.

Flight Operational Requirements.- There are no special flight operational requirements.

Data Support Requirements.- Control data will be collected on magnetic tape at the launch site. Flight data will be recovered from the NASA communication net on computer compatible magnetic tape and relayed to Princeton University for analysis. Flight data may be retrieved either in real time or intermittently from a data storage unit depending upon operational constraints.

Resources Requirements

Development Schedule.- The schedule is shown in Figure 31.

Estimated Funding Requirements.- Funding requirements are shown in Figure 32.

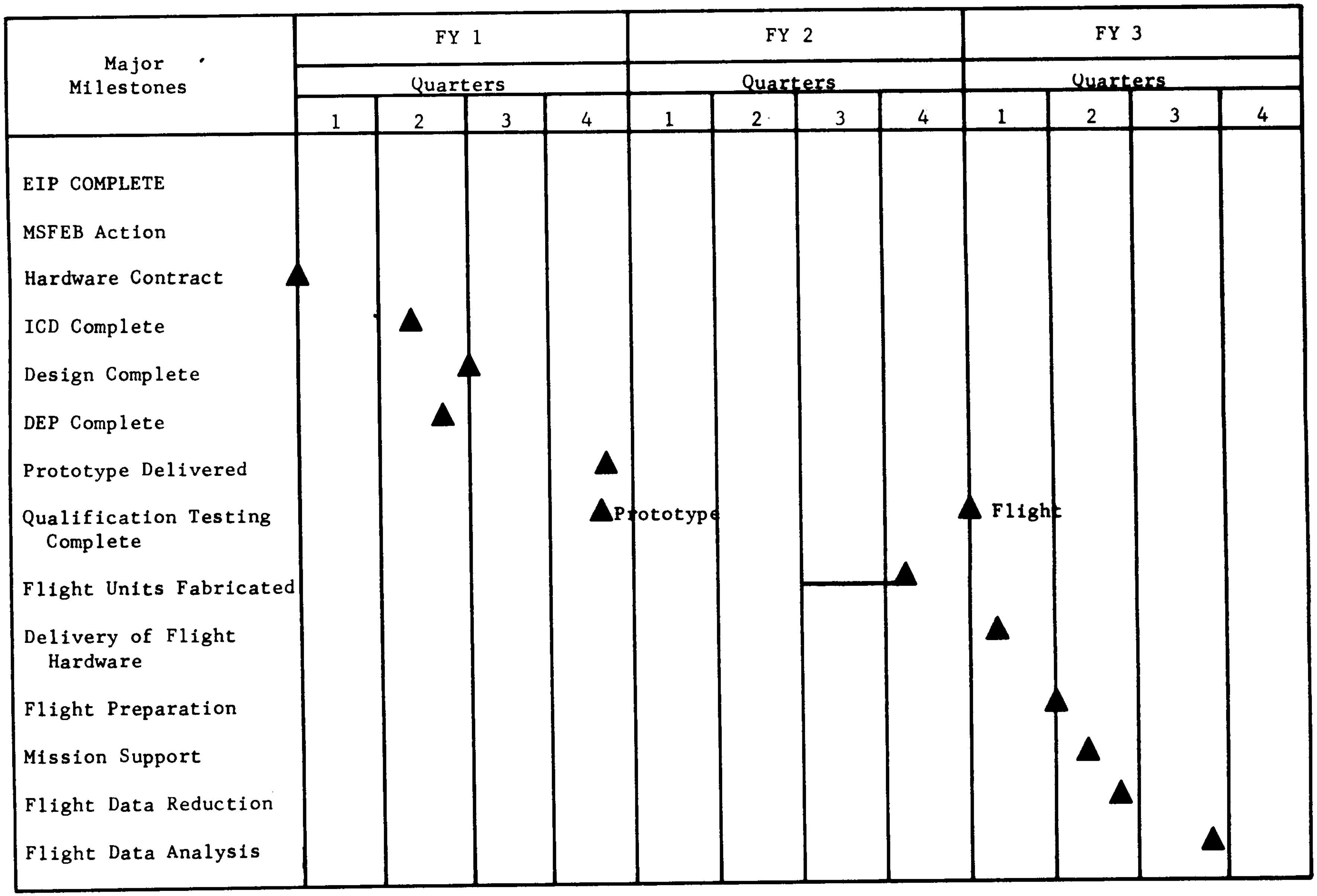


Figure 31. Estimated schedule for accomplishment of the Drosophila eclosion experiment.

Items	FY 1				FY 2				FY 3				Totals
	Quarters				Quarters				Quarters				
	1	2	3	4	1	2	3	4	1	2	3	4	
Definition, Breadboard, Design, Development, Fabrication, Test (mock-ups, prototypes, and support equipment)	22	24	25	22	27	22	13	5	5				165
Fabrication, Test and Delivery (Flight units and spares)					33	35	59	54	11				192
Supporting Studies and Other Implementation Efforts	16	16	16	16	8	8	8	8	11	5			112
Data Analysis and Publication										3	16		19
Yearly Totals	157				280				51				
Estimated Grand Total													488

Figure 32. Estimated cost to accomplish the Drosophila eclosion experiment ($\$ \times 10^3$)

CIRCADIAN PERIODICITY OF POCKET MOUSE TEMPERATURE, HEART RATE AND ACTIVITY

Principal Investigator: R.G. Lindberg, Northrop Corporate Laboratories

Coinvestigator: C.S. Pittendrigh, Princeton University

Engineering Support: Northrop Corporate Laboratories

Technical Information

Objectives.- The purpose of the experiment is to determine whether prolonged space flight will affect the circadian periodicity of a mammalian system. Specifically, the question to be asked is: whether the circadian rhythm of body temperature, heart rate and activity in pocket mice changes when all geophysical variables other than light or temperature are either removed or sensed by the animals with periods other than 24 hours.

Experiment Approach.-

(a) Premise. The proposed experiment will test the premise that some "pervasive geophysical force" does entrain the circadian periodicity of organisms and that, as a consequence, circadian systems removed from terrestrial stimuli will degrade. The experiment studies the persistence and precision of the circadian period in a mammal. Specifically, the question to be asked is whether the circadian rhythm of body temperature, heart rate, or activity changes when all geophysical variables are either removed or sensed by the animals with a period other than 24 hours. The only impressive evidence of control of circadian organization by an unknown periodic variable will come from the observation of an animal's free-running self-sustaining oscillation (circadian period) equal to 24 hours, after the animal has been entrained to periods not equal to 24 hours. Statistical constraints in determining significant shifts in circadian periods and the presence of precise 24-hour components in the data point to the desirability of an experiment lasting for as long as possible (2 to 3 weeks minimum). This, coupled with the need to place the experiment away from any residual coupling to the earth's cycles, points to the desirability of a spacecraft placed in solar and/or lunar orbit as well as earth orbit. If a circadian periodicity persists in earth orbit but decays in distant solar orbits, we would have direct evidence, available from no other combination of experiments, that geophysical periodicities are essential inputs for maintenance of circadian organization.

(b) Experiment. A minimum of three pocket mice individually housed will be flown in conditions of constant darkness and temperature (21°C) for a minimum of 100 days, after having been entrained to a period of 22.5 hours in the laboratory. Their body temperature, heart rate and activity will be monitored at 10-minute intervals continuously for the duration of the experiment.

Digital data will be collected and stored, broadcast to earth on command, recollected on magnetic tape and the tape, after some degree of manipulation, will be processed by an existing computer program for data reduction.

The resulting length and precision of the circadian period of each end point from each animal will be compared with the period of that same animal established prior to space flight. The data will be examined for evidence of entrainment to a precise 24-hour period by a sophisticated frequency spectral analysis. The computer program is presently written for high statistical confidence and dictates a minimum requirement for 21 days of continuous data.

It is proposed that two ground "control" groups be run concurrently with the flight experiment. One group would be in-flight hardware, and the second group in an animal holding facility.

Housekeeping data (ambient temperature, atmospheric pressure and partial pressure of oxygen) will be required to document the consistency of the environment which the experiment requires.

(c) Validity of Technique. The techniques of monitoring changes in body temperature in small mammals via implanted transmitters, and the reduction of these data to meaningful studies of circadian rhythm phenomenon via computer analysis, have been well proven in the laboratory by both coinvestigators. The pocket mouse has been demonstrated to be a suitable experimental subject by both investigators.

Baseline or Control Data.- The precision and length of the circadian period must be established with high statistical confidence for each animal selected for this study. This requires a minimum study of 30 days pre-launch. Since the objective of the experiment is to test for unknown "pervasive geophysical forces," it is essential that ground controls be run simultaneously with the flight experiment. However, it should be understood that because of the variation in periodicity between individuals, any changes that should occur will in all probability be of different magnitudes and possibly different direction. The controls may therefore provide more qualitative than quantitative data.

Two control groups are anticipated. The first is a handling control with three to six pocket mice in flight hardware modules; the second will be six mice undisturbed in the animal holding facility.

Baseline circadian rhythm data for pocket mice as well as their life support requirements have been intensively studied both at Northrop Corporate Laboratories and Princeton University. The data are summarized in the following contract reports and publications.

(a) Contract Reports.

1. "Investigation of Perognathus as an Experimental Organism for Research in Space Biology," NASr-91 Final Report, Aug 1963
NASw-812 Progress Report, Dec 1964
Dec 1965
Dec 1966

2. "Development and Flight Qualification of a Biosatellite Experiment Package to Study Circadian Rhythems in Pocket Mice," MASw-1191 (June 1966)

3. Contract NASr-223 between NASA and Princeton Univ. No title, Annual Report 1 February 1965 - 31 January 1966 and 1 February 1966 - 31 January 1967.

(b) Publications.

1. "Circadian Rhythm of Metabolic Rate in Pocket Mice," R.M. Chew, R. G. Lindberg and P. Hayden, J. Mammalogy 46:477-494, 1965.

2. "Temperature Regulation, Hibernation and Aestivation in the Little Pocket Mouse Perognathus longimembris," G. A. Bartholomew and T. J. Cade, J. Mammology 38:60-71, 1957.

3. "Diurnal Torpidity in the California Pocket Mouse," V.A. Tucker, Science 136:380-381, 4 May 1962.

Engineering Information

Equipment Description.-

(a) Functional Description. The pocket mouse experiment will consist of three pocket mice in separate modules (Assembly 1a, 1b, 1c), a Central Electronics Module (Assembly 2), and an Experiment Interface Unit (Assembly 3). Biological data will be sampled every 10 minutes and engineering data will be sampled every hour for the duration of the experiment, which is expected to be between 90 and 120 days.

The environmental control system for the package requires no external power. Thermal requirements will be met passively through a controlled heat path to the spacecraft platform. Careful selection of materials for the conductive path, coupled with the small change in platform temperature will yield a very stable system with change in experiment temperature following platform variation. Illumination will be controlled by an on-board programmer which can be deactivated by ground command.

A "leak proof" experiment housing will contain a 14.7-psi atmosphere consisting of 20% oxygen and 80% nitrogen. The control of atmospheric composition will utilize a lithium hydroxide bed for CO_2 control and a demand O_2 regulator coupled with a high pressure O_2 source to supply make up O_2. Activated charcoal and boric acid crystals will be utilized as required for odor control. As an optional feature, activation of the O_2 regulator, may be monitored to document changes in respiratory rate of the mouse.

(b) Monitoring Approach.- It is desirable to retrieve data which are essentially identical to the raw data transmitted by implanted telemeters. The telemetered data consist of short bursts of RF. The average repetition rate of the bursts is a function of mouse body temperature, periodic jitter of a burst provides an indication of a heart beat, and abrupt changes in RF signal strength indicate activity. This approach has been proven in tests conducted by Northrop and is currently being used in laboratory research.

Idealized telemeter pulse rate output as a function of body temperature is shown in Figure 33.

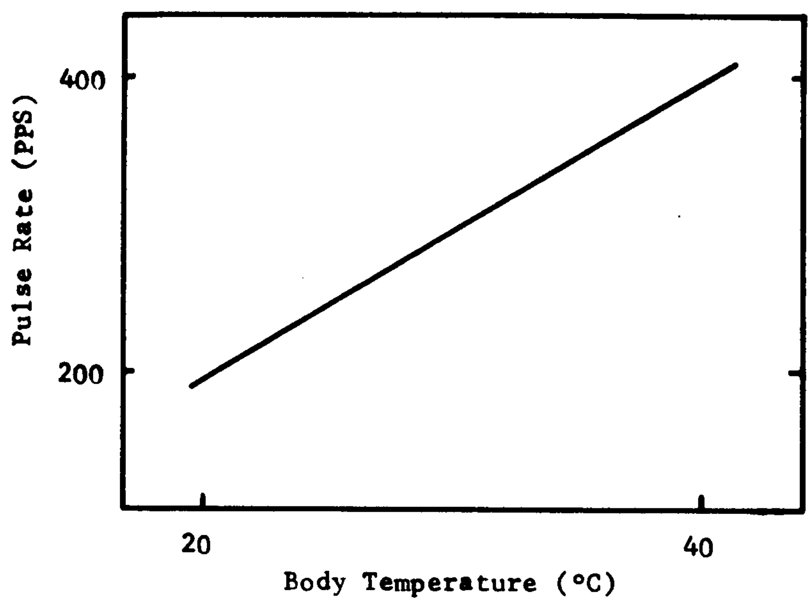


Figure 33 Idealized telemeter output.

Using a ten-bit counter and counting for a period of 2.56 seconds limits the maximum monitoring error to $+0.039°C$. Assuming this to be an acceptable error, the bits required for downlink data transmission can be reduced to nine since the temperature range of interest is approximately 20°C to 40°C. This will be accomplished by resetting a nine-bit counter to zero after a count of 511 is reached and counting for a period of 2.56 seconds.

The approach to monitoring heart rate will be essentially the same as that for monitoring body temperature: pulses will be counted for a given period of time. The heart rate of interest is between 40 and 500 beats per minute (BPM). Since the lower limit to the range of interest is low with respect to the upper limit, not much is gained by resetting the counter; therefore, this complexity is not recommended. The approach will be to count heart beats for a 1-minute period. This will require nine bits per sample, the maximum error will be $\pm$ one BPM, and the range covered will be 0 to 511 BPM.

Activity will be monitored continuously by accumulating an activity count in a binary counter. The counter contents will be periodically shifted out and the count reset to zero prior to the next counting period. The count accumulated during each period will provide an indication of relative activity during that period.

Since body temperature and heart rate each require nine bits, and the standard Pioneer data word is six bits, the activity count will be allocated six bits. If more than six bits are required to count activity during the monitoring period, only the six most significant bits will be sent down-link. Six bits will provide 63 discrete levels of relative activity.

(c) Electronics Functional. Body temperature, heart rate, and activity will be sampled once every ten minutes and transferred to the Pioneer data system via the Experimental Interface Unit (ETU). Engineering data consisting of ambient temperature, ambient pressure, and partial oxygen pressure will be sampled every hour and transferred to the Pioneer data system via the EIU. An electronics block diagram is shown in Figure 34. Each cell has an independent antenna and receiver system.

The Pioneer data system provides 9 six-bit main frame words for biological data. The Pioneer data system with physical experiments aboard is capable of sampling each of these words every 8.5 minutes for a period of 9.5 hours each day. This provides a total storage capacity of approximately 3600 bits, which is only adequate for storage of biological data for one mouse. A second DSU will therefore be required for a three-mouse experiment unless continuous real-time telemetry is available.

The Pioneer data system with physical experiments aboard provides six submultiplexed analog words for engineering data. This system is capable

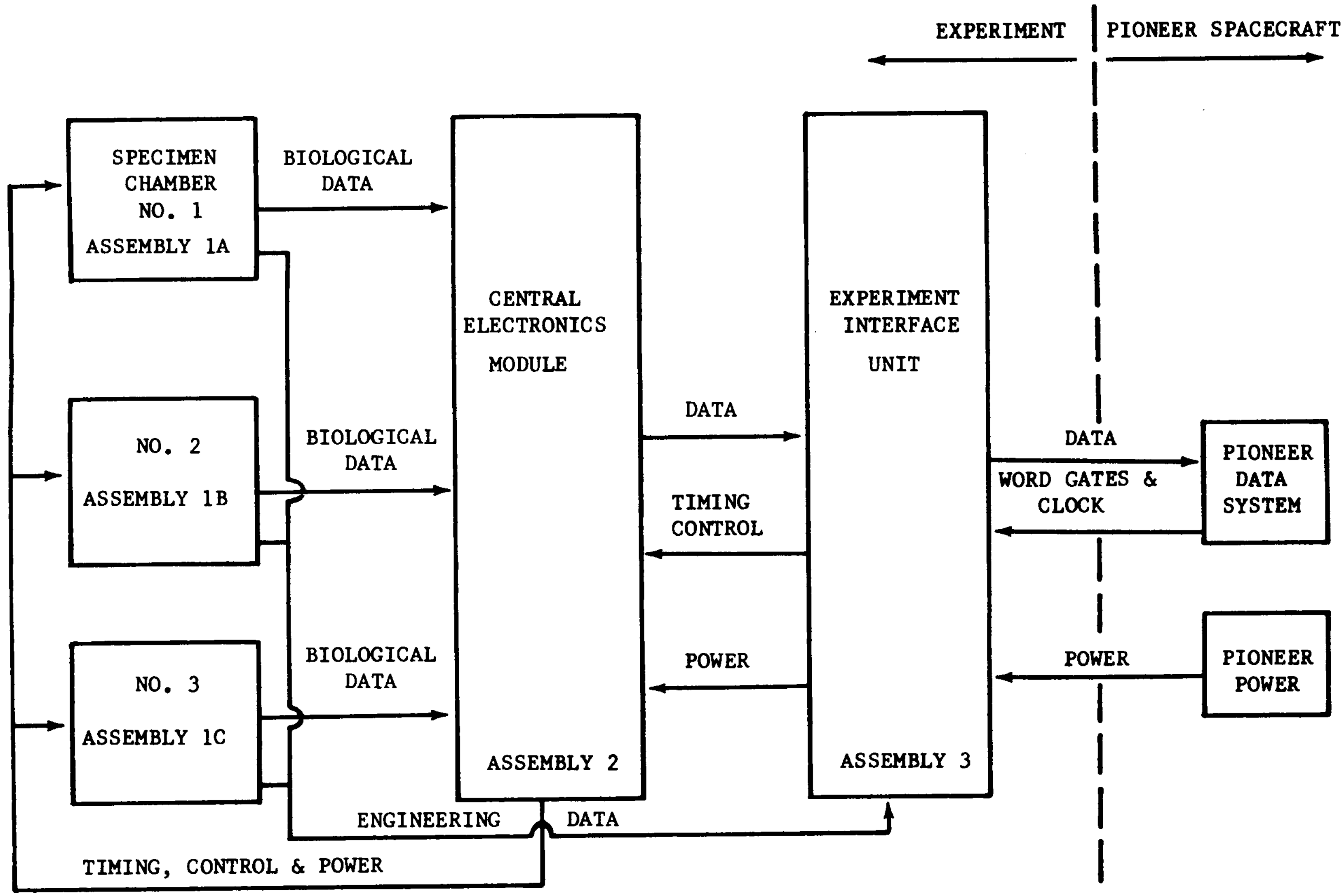


Figure 34. Electronics block diagram of Pocket Mouse experiment.

of sampling each of these words every 15 minutes during realtime telemetry operation. Values of three engineering data parameters will be sampled every hour. Assuming six bits per sample, which would provide a resolution of approximately 1.6% 432 bits of storage per mouse, or a total of 1296 bits for a three-mouse experiment, would be required to buffer-store engineering data until downlink transmission.

Biological data must be time-tagged with sufficient accuracy to allow time-of-acquisition correlation within ± 1 minute. Timing and control signals for data acquisition are also required from the EIU.

Assuming a three-mouse experiment and noncontinuous telemetry, a total DSU storage of 12,636 bits would be required for biological, timing and engineering data. The remaining bits in the second DSU would be available for use by other experiments, or to obtain additional data (e.g. events) on the pocket mouse experiment. This storage estimate is exclusive of parity bits and synchronization words to be supplied by the Pioneer data system, which brings the daily bit total to 18,144.

(d) Equipment Required.

(1) Design verification test unit

(1) Prototype - Mass mockup and prototype mockup are optional

(8) Flight units

- (1) Qualification test
- (1) Backup
- (3) Flight
- (3) Control - modified to interface with Ground Support Equipment

(1) Set of Ground Support Equipment to be used for loading and testing of flight units, thermal control of loaded units, and data monitoring.

(e) Equipment Status. The equipment status is conceptual design, by definition. However, Northrop's previous experience under contracts NASr-91, NASw-812 and NASw-1191 provides confidence beyond that of the conceptual design stage. The biotelemetry proposed is now a standard monitoring system both at Northrop Corporate Laboratories and at Princeton University.

The circadian periodicity of pocket mice has been studied in a demand type oxygen system similar to the one proposed herein with good success. In addition, the periodicity of pocket mice has been monitored for 30 days while the gaseous environment of the animals has been maintained with a superoxide system. Despite good biological data, this promising approach to environmental control was abandoned in favor of the demand-type oxygen system because the variations in atmospheric constituents observed in the superoxide system were not acceptable to the Principal Investigator.

Envelope.- Figures 35 and 36 summarize the conceptual design of Assembly 1, which contains the specimen. Outlined dimensions for Assembly 2, Central Electronics Module, and Assembly 3, the Experiment Interface Unit, are given in Figures 37 and 38 respectively.

Weight and Size.- Weight and size are given in Table 23.

TABLE 23. WEIGHT AND SIZE OF A THREE POCKET MOUSE EXPERIMENT

Assembly	Weight lb	Volume in^3	Dimensions L" x W" x H"	Shape
1A	8.7	407	5.25 x 8.50 x 9.12	rectangular
1B	8.7	407		
1C	8.7	407		
2	4.0	126	4 x 3 x 10½	
3	6.7*	208	6.3 x 4.1 x 8	
Total	34.8	1555		

*Assumes inclusion of a supplementary core memory for buffer data storage (2.2 lb; 78 in^3; D.1.W)

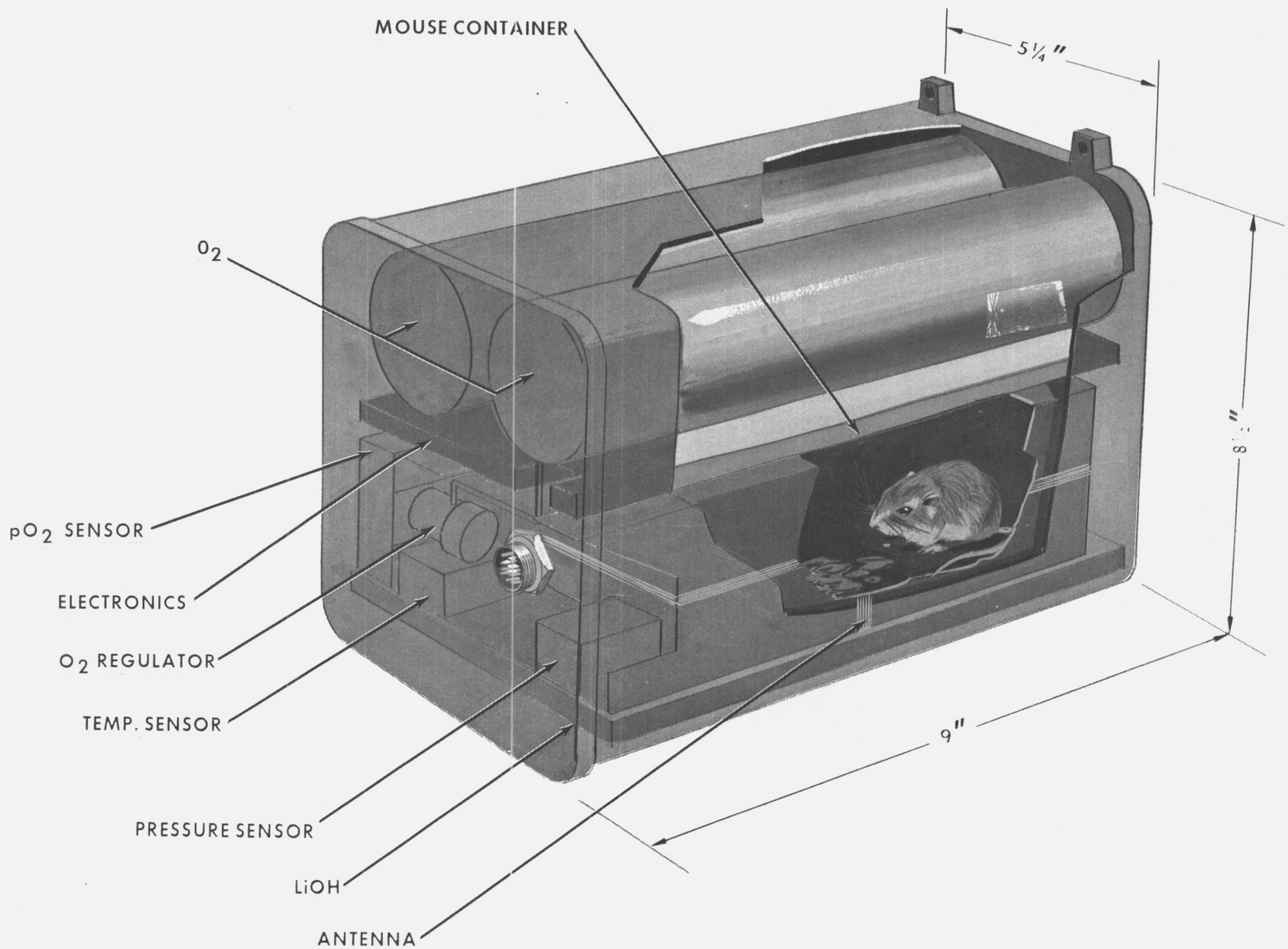


Figure 35. Experiment hardware concept for the study of circadian periodicity of Pocket Mouse body temperature, heart rate, and activity.

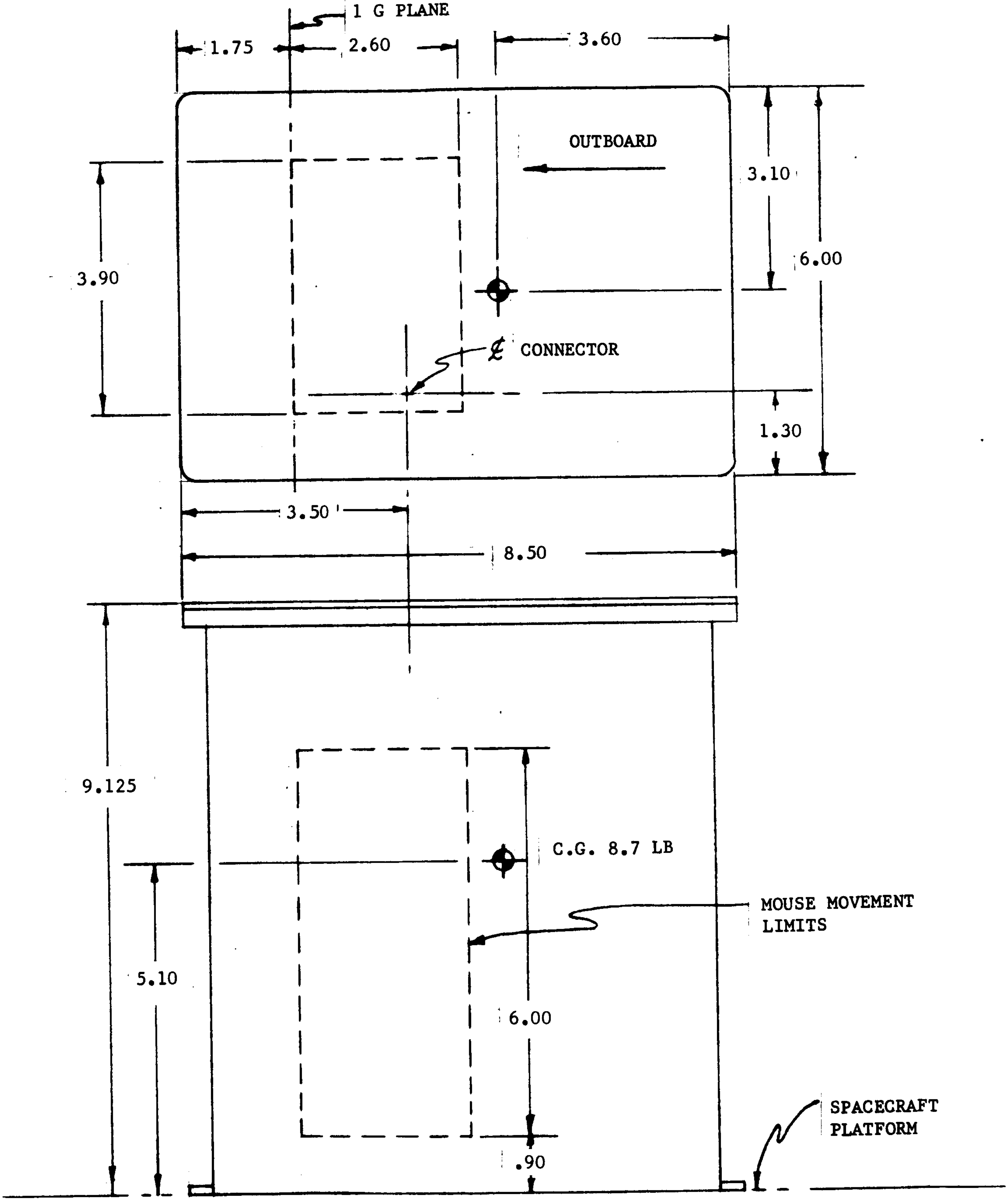


Figure 36. Pocket Mouse experiment assembly 1.

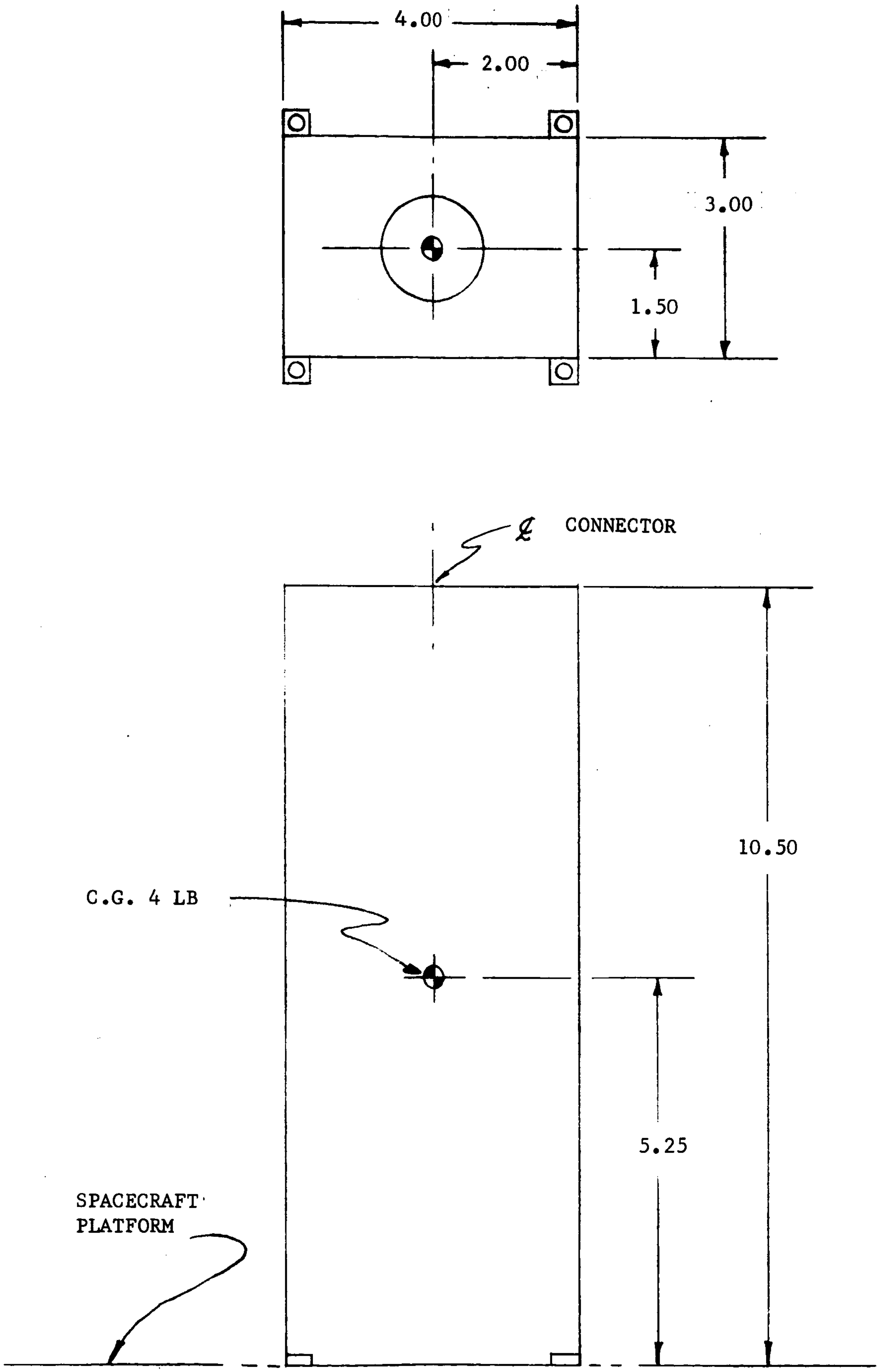


Figure 37. Pocket Mouse experiment central electronics unit (assembly 2).

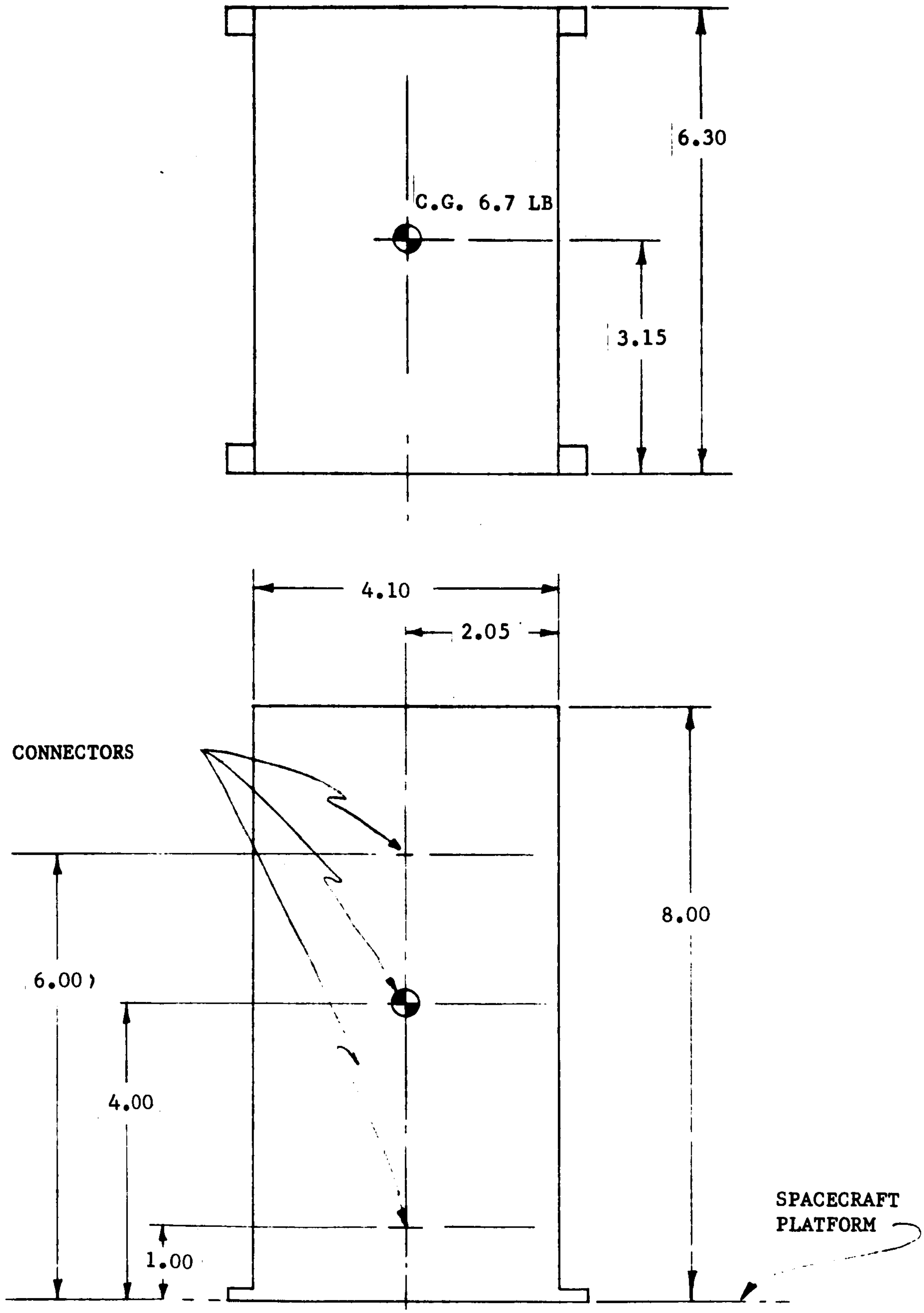


Figure 38. Pocket Mouse experiment interface unit (assembly 3).

Power.- Power requirements are shown in Table 24.

TABLE 24. POWER REQUIREMENTS FOR A THREE POCKET MOUSE EXPERIMENT

Assembly	Standby	Average	Maximum
1A	1.4	1.4	1.4
1B	1.4	1.4	1.4
1C	1.4	1.4	1.4
2	1.3	1.3	1.3
3	1.7	1.7	1.7
Total Power(W)	7.2	7.2	7.2

Spacecraft Interface Requirements.-

(a) Location. It is required that each of three specimen chambers be mounted in a location such that the specimen be subjected to a 1 g acceleration force.

(b) Mounting. Mounting must meet the requirements for thermal control and mechanical support.

(c) Support. Support requirements are 28 Vdc power and switching, data storage and downlink transmission, uplink commands, and thermal control. It is required that the specimens not be subjected to thermal cycling.

(d) Linkages and Control. No special mechanical linkages or controls are required.

(e) Dynamic. Shifts in location of expendable material is summarized in Figure 39.

Environmental Constraints.-

(a) Constraints. The limiting constraints are those imposed by the biological specimens. Test specimens have survived simulated Pioneer launch stresses with no detectable change in the stability of their circadian system (See section entitled "Environmental Tests").

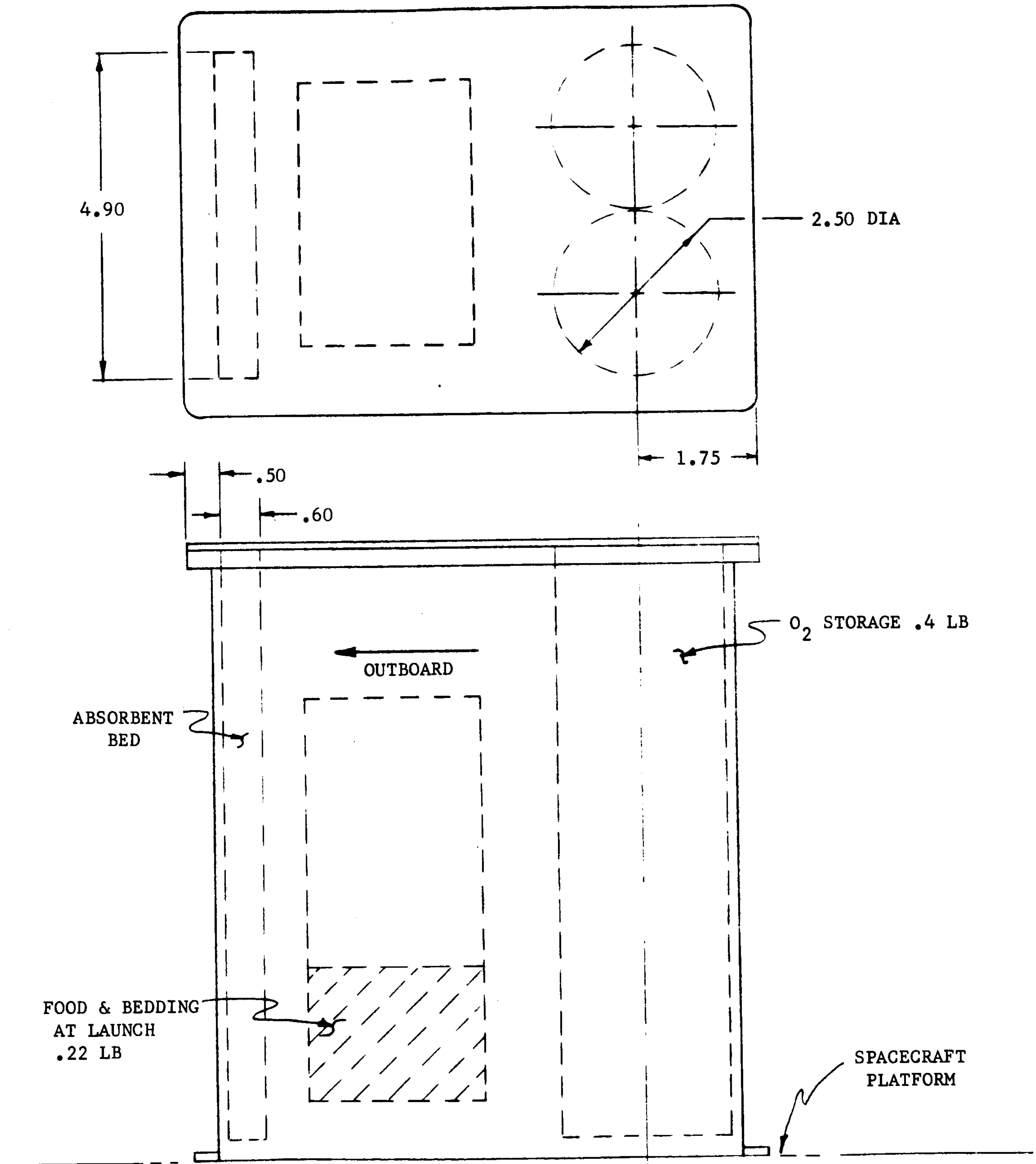


Figure 39. Shift of consumable materials in Pocket Mouse experiment assembly 1.

(b) Interference. The implanted biotelemeters produce a weak magnetic field. Interference from the telemeters will be prevented by shielding of the specimen chambers. Vibration, noise, light, and radiation will present no problems. The specimen chamber will be shielded against RFI, and against EMI and grounding will be controlled.

Data Measurement Requirements.- Data measurement requirements are given in Table 25.

Operational Requirements

Spacecraft Orientation Requirements.- The experiment as described is specifically sized for a "typical" Pioneer spacecraft mission, the basic elements of which are acceptable to experiment execution. There are three specific requirements, all of which appear to be met on Pioneer.

a) The spacecraft must leave the earth field as rapidly as possible.

b) There must be no periodic event aboard the spacecraft, such as acceleration noise, vibration, etc., which occurs at frequencies which entrain a biological rhythm.

c) Data must be retrieved either continuously or intermittnetly for 120 days.

Astronaut Training and/or Participation.- Special training or participation are not required.

Prelaunch Support.- Shipping and handling procedures for the experiment hardware will follow usual procedures for equivalent flight items. Addition of oxygen, chemical absorbents, specimen food, and the experimental organism will be at the launch site as close to time of launch as is operationally feasible.

The assemblies containing the experimental organisms will go through all necessary checkout to insure the integrity of the package prior to installation in the spacecraft. Experiments will receive a prelaunch checkout by procedures to be defined. The principal support requirement in this category is for thermal control. The proposed experiment achieves temperature control passively through its mounting on the experiment

TABLE 25. DATA MEASUREMENTS REQUIREMENTS FOR A THREE-POCKET MOUSE EXPERIMENT

Parameter to Measured		Body Temperature			Heart Rate			Activity			Ambient Temperature			Ambient Pressure			Partial O_2 Pressure		
Equipment Item Used (specimen chamber)		1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Expected Value of Parameter	Units	°C →			BPM →			Levels →			°F →			PSIA →			%O_2 →		
	Nominal Value	Not APFL →			480 →			TBD →			70 →			14.7 →			21 →		
	Range	20-40 →			30-500 →			0-63 →						13.2 16.2 →			10-30 →		
Measurement Characteristics	How Often	10 min →									1 hour →								
	Duration	2.46 sec →			1 min →			10 min →			Point Smpl. →								
	Total in Mission	17,280 →									2,280 →								
Output Signal of Instrument	Type	Pulse Rate →						Pulse →			Analog →								
	Frequency Range	200-400pps →						TBD →			DC →								
	Amplitude Range	mv →									0-3v →								
	Resolution	0.039 °C →			1 BPM →			1 Level →			2°F →			0.03 PSIA →			0.3 %O_2 →		
Read-Out Requirements	No. of Channels	1 →																	
	Sampling Rate	0.015 BPS →						0.010 BPS →			0.0017 BPS →								
	Telemetry Required	Yes →																	
	Storage Required	Yes if continuous real time telemetry is not available →																	
Time Identification	Method	Experiment's Clock →																	
	Accuracy	± 1 min →																	

platform. All other functions are self contained or need not become operational prior to prelaunch checkout and/or launch.

A combination office/laboratory space will be required to accommodate up to 24 experimental animals, the flight hardware and associated backups and ground controls. This is estimated to require approximately 400 square feet of air conditioned work space, a desk, an electronics bench, one or two tables and an animal rack. Both 120 V and 28 V power will be required. The space should be available continuously from 30 days prior to launch to 30 days after completion of the flight experiment. It is entirely feasible to accommodate total experiment support in a suitable trailer.

Data Support Requirements.- Control data will be collected on magnetic tape at the launch site. Flight data will be recovered from the NASA communication net on computer compatible magnetic tape and relayed to Princeton University for analysis. Flight data may be retrieved either in real time or intermittently from a data storage unit depending upon operational constraints.

Resources Requirements

Development Schedule.- The schedule is shown in Figure 40.

Estimated Funding Requirements.- Requirements are shown in Figure 41.

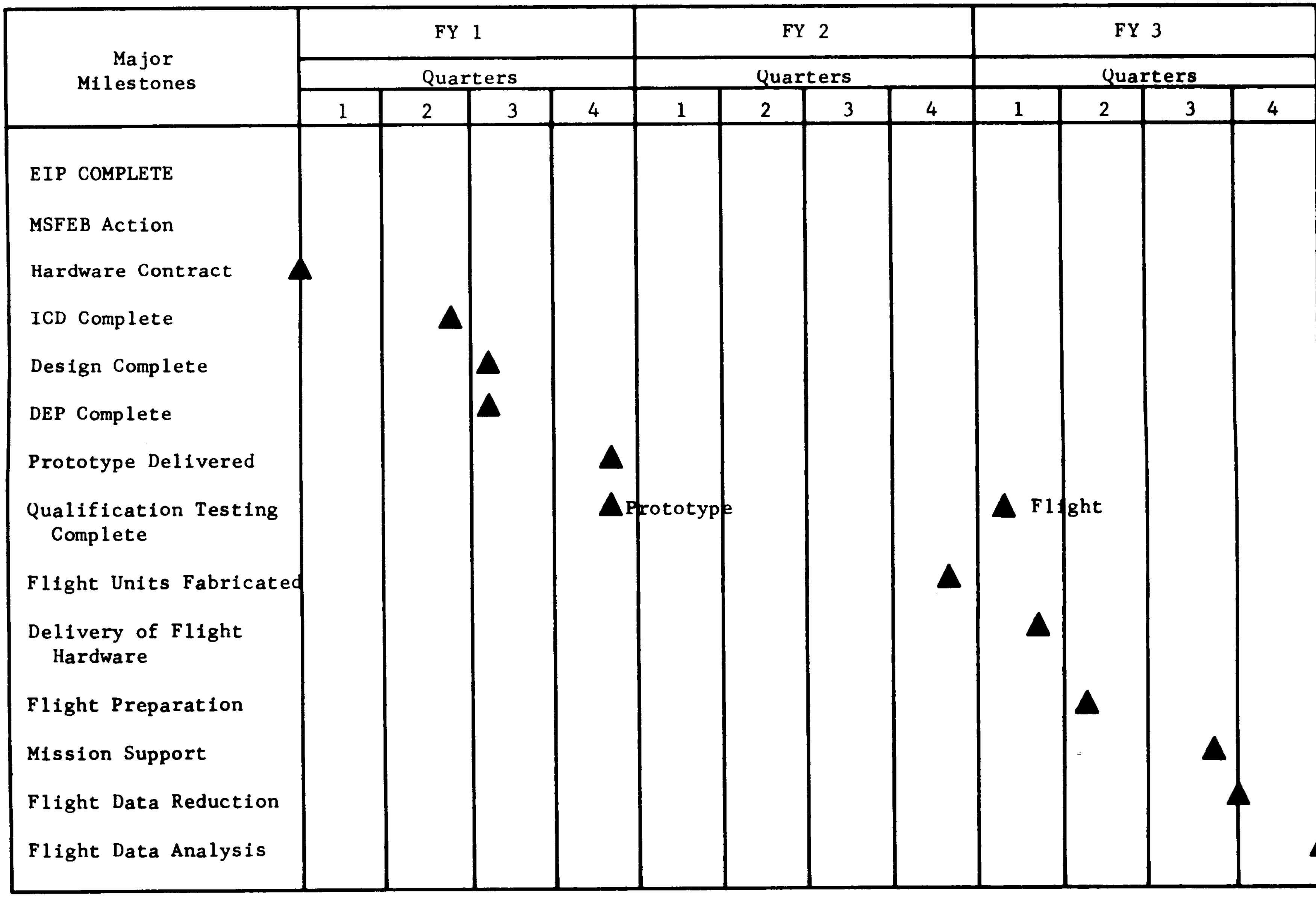


Figure 40. Estimated schedule for accomplishment of the Pocket Mouse experiment.

Items	FY 1				FY 2				FY 3				Totals
	Quarters				Quarters				Quarters				
	1	2	3	4	1	2	3	4	1	2	3	4	
Definition, Breadboard, Design, Development, Fabrication, Test (mock-ups, prototypes, and support equipment)	22	22	30	24	30	32	19	29	5				213
Fabrication, Test and Delivery (Flight units and spares)			13	30		30	56	78	16				223
Supporting Studies and Other Implementation Efforts	8	8	8	8	8	8	8	8	5	16	11		96
Data Analysis and Publication											3	16	19
Yearly Totals	173				306				72				
Estimated Grand Total													551

Figure 41. Estimated cost to accomplish the Pocket Mouse experiment ($ x 10^3).

CIRCADIAN PERIODICITY OF C-MOUSE TEMPERATURE, HEART RATE AND ACTIVITY

Principal Investigator: F. Halberg, University of Minnesota
Coinvestigator: G. Pitts, University of Virginia
Engineering Support: General Electric Company

Technical Information

Objective.- The objective of this experiment is to assess any systematic terrestrial and/or lunar influences upon circadian rhythms in telemetered body core temperature, gross motor activity, and in heart rate, of a small homeothermic mammal with objectively quantified rhythms.

Experimental Approach.- Since we predict neither the abolition of rhythms nor their unaltered persistence, i.e., since we anticipate small effects, we believe it is essential to test each of several endpoints of rhythms in more than one circumstance. Since the effects are anticipated to be subtle, it is particularly important that the biological rhythmicity of the experimental organisms be well documented. We believe the inbred strain of C-mouse meets this criterion best. It is intended that the flight experiment consist of four C-mice implanted with suitable instrumentation to permit monitoring core body temperature, activity, and heart rate at 10-minute intervals continuously for approximately 120 days. The animals will be maintained at 1 g on various light regimes in space and, when suitably entrained, the light regimes will be changed. The time and the pattern demonstrated by the animal in adjusting to the new regime will be used to assess the effects of space residence. (By accepting serious compromises in the experimental design, the number of flight subjects could be reduced to three and under some circumstances the duration of the experiment could be reduced.) The experiment plan that follows assumes four experimental animals flown for 120 days and consists of four types of experiments to be undertaken in the given sequence.

1) The mean amplitude (C), mean level (C_0), and the so-called acrophases (φ and Φ) as gauges of both the external (φ) and internal (Φ) phase relations

of the 24-hour-synchronized circadian rhythms will be measured in C-mice kept on a 24-hour cyclic lighting regimen (LD 12:12, the synchronizer).

2) The shift-time of circadian rhythms (the number of transient cycles) following a delay of the synchronizer ($-90°\Delta\phi$LD) as well as the C, C_o, φ, and Φ of the phase-shifting rhythmic variables will be tested. If, and only if, daily analyses of the data telemetered from extraterrestrial space and those telemetered from controls on earth fail to reveal differences in any one endpoint, the effects of an advance of the synchronizer ($+90°\Delta\phi$LD) also will be tested.

3) The rhythms' period (τ), as well as C, C_o, φ and Φ will be studied under conditions associated on earth with desynchronization from lunar (24.8 hour), solar (24.0 hour), and other planetary periods. The appropriate condition at the outset will be continuous darkness (DD). Tests in continuous light (LL) will be added if, and only if, as-you-go analyses of the data in DD have failed to indicate any difference between the flyers and the controls.

4) Time in orbit permitting, endpoints of both circadian and ultradian spectral components will be tested under conditions of a cycle of six hours of light alternating with six hours of darkness.

Apart from the manipulations of the lighting regimen indicated above, the flyers placed into orbit, as well as control animals, should be effectively isolated, as far as possible, from all known periodic stimuli external and internal to the spacecraft (or control housing unit) with relatively constant environmental temperature and humidity and with food and water available ad libitum.

The data received through spacecraft communication from animals in flight will be analyzed using inferential statistical methods. Appropriate computer programs are available in the investigators' laboratory.

Control Data.- Control data will be obtained on several groups of "support" mice and "mission-controls."

a. Support. The support data are to be collected as soon as the decision to fly the C-mouse mission is implemented by the availability of at least six sets of developmental hardwares to be used with separate and mobile digital data acquisition systems. With these systems available, the "liftoff" simulation will have to be repeated with (1) exposure to all liftoff transients as concomitantly as possible, and (2) with different groups being exposed at different phases of their circadian system. If possible, physiologic functions should be monitored during this simulated liftoff and the test period for each group after exposure should extend to > 100 days. Such support data will validate the anticipated ground control parameters for the actual flight. The 24 animals used in this group will be selected from a larger pool of 160 telemeter-implanted C-mice using the procedures discussed below for "mission controls." At least 128 liftoff controls will be maintained under environmental and spatial conditions resembling those of the BioPioneer mouse package as closely as is practical at this stage. Liftoff transients to be simulated concomitantly as far as possible are vibration, acceleration, and noise, as they are anticipated to occur during launch and orbital injection. These transients will be tested only at the levels expected for the chosen trajectory and only for the 24 liftoff mice.

b) Mission control data will be obtained (1) for two months before actual liftoff; and (2) on earth while mission mice fly. At the time of weaning at 21 days of age, 450 inbred male C-mice will be implanted with transensors. Telemetry will be carried out up to the actual launching of the space probe about 2 months later. Rhythms will be investigated for the preflight endpoints. Body weight also will be measured whenever a change in lighting condition is instituted. One week prior to the mission, histograms will be prepared of the distribution of the mice by gain in weight, by level of body temperature, and by other rhythmometric criteria. The 5% on the extremes of body weight and rhythmometric distributions will be omitted from study. The remaining animals up to 360 will serve as concurrent ground controls during the mission. They will be maintained under conditions as nearly identical with those in the BioPioneer as is practical.

Compromises.-

a) Adherence to 1 g level. The effect of weightlessness per se upon metabolic rhythms in a rodent presumably will have been tested by the time of the BioPioneer mission. The influence of altered gravity upon rodent rhythms will have been studied by us in 1968. Current plans call for studying rats exposed to two levels higher than 1 g (presumably 1.75 and 2.50 g). Nonetheless, the interaction of altered gravity with any geoselenic influences constitutes an important problem of basic and applied biology, if indeed such an interaction can be detected. Eventually, this problem should be studied in a non-earth orbit by exposing C-mice to several g levels. Onboard variations in a first BioPioneer mission are not feasible because spatial and other logistic limitations to the BioPioneer package prevent increasing sample size. Against this background it is definitely preferred to maintain the mice at 1 g with compromises being acceptable only to the extent to which they are unavoidable.

b) Reduction in number of experimental animals. Four C-mice represent the minimum required to obtain the study conditions outlined above. Three animals will permit achievement of some mission objectives. A reduction in sample size can be advocated only as a "last resort" for two reasons.

First, in flying only three C-mice, several of the test conditions to be applied sequentially may have to be omitted from study in order to compensate for the reduced number of mice by longer observation spans during any one given test situation.

Second, any losses of data during transmission or otherwise will weigh more heavily when the total number of mice monitored at a given time is reduced by one-fourth, particularly when this number is initially as small as four. Thus the relatively small logistic saving realized by omitting an animal will result in a large loss of information or it may altogether jeopardize achieving many of the rhythmometric aims of the mission.

c) Omission of heart rate telemetry. Valuable physiologic information can be obtained without telemetry of heart rate but only with a very severe reduction in the scope of the mission. In support of this omission, savings in cost and effort may be cited, as well as the fact that information on the heart rate of the mouse as yet is limited. However, in the near future we definitely intend to collect and to quantify by inferential statistical methods the heart rate rhythms of the C-mouse. The electronic task on hand appears to be within the state of the art, and it may represent a reasonable expense, as compared to total mission cost. It should be emphasized against this background that the omission of heart rate measurements may entail partial loss of the applied objective and may drastically reduce the scope of invaluable applied and basic information. Thus, as to information on rhythms, the inclusion of heart rate measurements permits quantification of internal timing of metabolism and circulation (by any phase difference between temperature and pulse) as an important feature of circadian system structure. It seems pertinent that the phase relations of heart rate and rectal temperature rhythms have been found to be maintained in human beings during prolonged isolation in a cave. In any event, to monitor the heart rate of the C-mice would also be an additional and, perhaps, the most pertinent way to ask whether this orbiting mammal is still alive, a dividend that seems non-trivial and a problem that indeed should be explored in a small mammal for three to four months, under conditions permitting extrapolation to the behavior of human beings in extraterrestrial space, in lieu of initial studies on man himself.

d) Reduction of flight duration. As a "worst case" only, the minimal span of 90 days or the preferred longer span of 120 days could be reduced to the extent that only one or a few conditions of study are tested. Such a reduction is not advocated, since the time spans visualized for the testing of a given condition are already minimal. Despite the very sensitive available "microscopic" procedures for data analysis, the time necessary to derive definitive data from a given experimental condition may well take much longer than anticipated. If certain scheduled conditions have to be maintained for longer spans, some other conditions will be excluded from study. Under such circumstances a short duration mission represents a limitation to the scope of the mission.

Engineering Information

Equipment Description.- As originally conceived (Basic Plan) the entire experiment is contained in a sealed enclosure with a 20% O_2, 80% N_2 atmosphere at 14.7 psi. Only electrical connections pass through the walls. Carbon dioxide and other gaseous contaminants are removed by chemical absorbants. Humidity is controlled between 40-80% RH by a thermo-electric cooler which condenses water from the airstream to provide drinking water for the animals. Oxygen is supplied to the animals at ambient pressure on demand. Thermal control is achieved by controlled heat paths to the cold experiment platform. Dry food is provided ad libitum.

Within the sealed enclosure each mouse is visually isolated from every other mouse but will share a common air circulation system. Waste materials are carried out of the cage area by gravity and air circulation into an absorbent debris trap. (See Figure 42.)

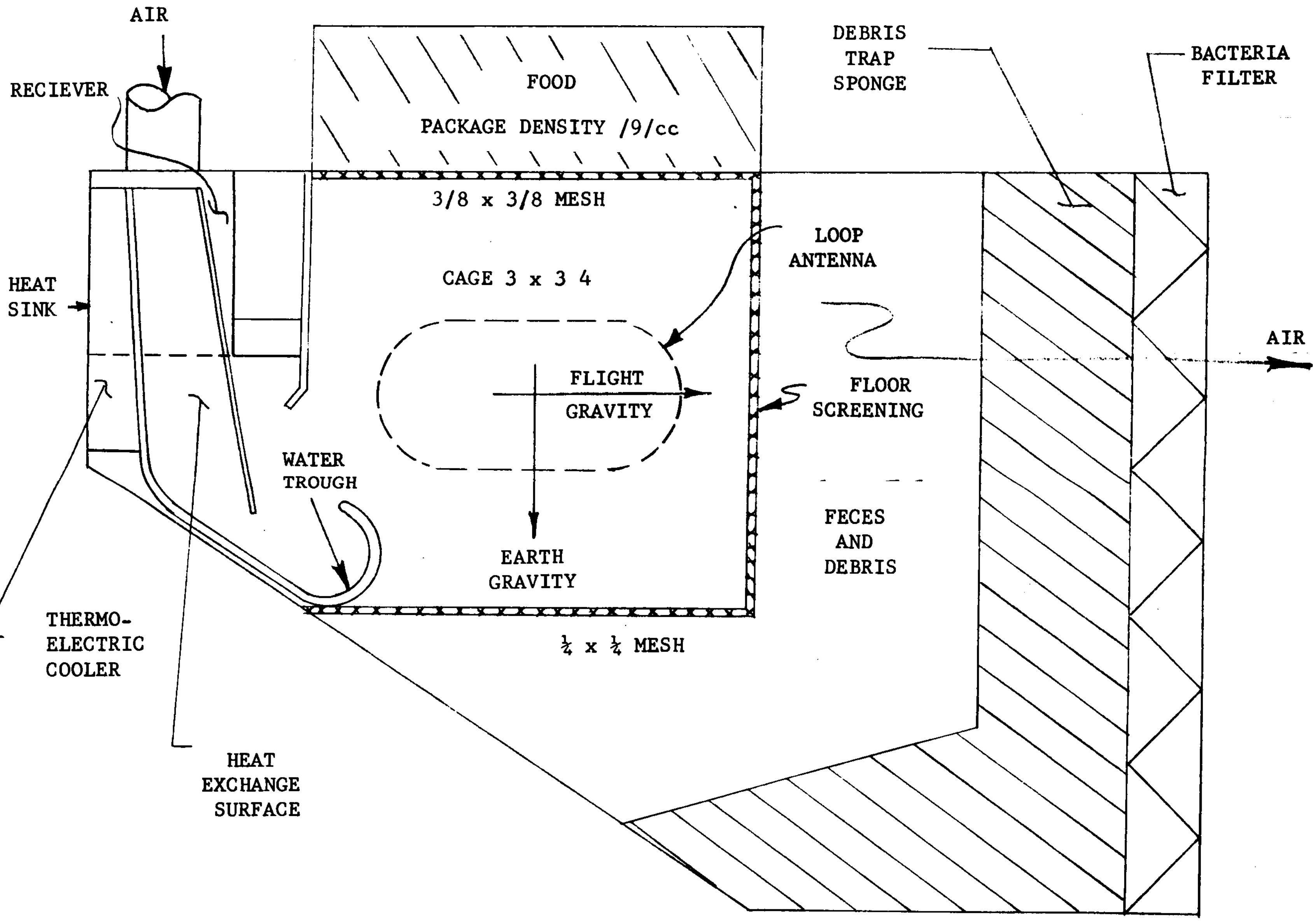


Figure 42. C-Mouse experiment cage assembly.

The walls of each mouse container contain antennae with which to monitor signals from the telemeter implanted in the mice. Programmed lighting is provided in each mouse cage. Circuitry is provided for collecting experimental and engineering data for presentation to the Pioneer Data Handling system and relay to the ground.

The basic plan, however, was too massive and could not be accommodated on the Pioneer experiment platform. Consequently, two alternative plans were evolved by separating functional components of the basic package into separate assemblies. It should be noted that many alternate configurations can be developed, depending upon defined spacecraft constraints.

Alternate Plan A consists of one specimen chamber containing three mice (Assembly 1); one oxygen supply with regulators (Assembly 2); one blower and trace contaminant unit (Assembly 3); and one electronics unit (Assembly 4). This configuration is compatible with the Pioneer spacecraft. Alternate Plan D consists of one specimen chamber (Assembly 1); one oxygen supply, regulator, blower and gas contaminant control unit (Assembly 2); and one electronics unit (Assembly 3). This configuration is also compatible with the Pioneer spacecraft and is preferred by the Principal Investigator because of the increase in number of experimental animals. Regardless of the configuration, the mechanical, electrical, and electronic aspects of the experiment package are the same and provide for life support and data acauisition from up to four animals for a period of approximately 100 days.

a. Structure. The experiment enclosure is of lightweight aluminum construction of sufficient strength and rigidity to withstand the anticipated physical environments and pressure differential. Hermetic seals are utilized for all access openings and electrical connectors to provide a gas-tight assembly. A pressure relief valve safeguards the assembly from overpressurization in the event of leakage from the oxygen source. Insulation is placed between the mouse cage assemblies for isolation. The cages are rectangular in configuration and fabricated from nonferous material with the approximate dimensions of 3 in. by 4 in. by 3 in. high. The mice stand on a screen floor. The cages are oriented so that rotation of the vehicle produces an artificial gravity, forcing loose material and wastes to fall through the screen into the debris trap. A photoluminescent light source provides overhead illumination to each cage. Dry food held in a screen bin is accessible to the mouse ad libitum.

b. Water supply and humidity control. Water is available from a small trough located in each cage area. This water is the condensate runoff from the cold surface of a thermoelectric element located near the air inlet to each cage. As the air enters the cage and passes over the cooling elements' finned surface, a portion of the air is chilled below its dew point, producing liquid condensate. As the liquid layer increases in thickness, the gravity force induced by the vehicle's rotation will cause the liquid to flow into the trough where it may be consumed on a continuous basis. The temperature of the cooling element cold surface (T_c) is a function of the imposed thermal load and the temperature of the hot side (T_c) of the element. T_h can be expected to be relatively stable since it will be connected directly to the outer skin of the experiment package, which in turn is fastened to the temperature-controlled Pioneer platform. A bimetal switch attached to the cooling element cold surface senses T_c and stop operation of the cooling process if the surface becomes too cold under low load conditions. Because, generally speaking, the absolute humidity in a system is determined by the coldest point in the system, the cold surface of the cooling element must be maintained near a dewpoint representing 76°F and 40% RH.

Urine and overflow water from the trough enter the debris trap under the influence of gravity and are evaporated by the air flowing through the sponge and filter. If necessary, excess water produced by the metabolic processes and the reaction of CO_2 with LiOH will be retained in a sponge in the high gravity end of the enclosure.

By condensing and reusing metabolic water, the need for a separate water supply is eliminated, as is the need for chemicals to absorb water to retain desired humidity levels. This results in a weight saving of 12 lb which is offset in part by the cooling elements.

c. Gas system. Oxygen is stored in a pressure bottle at a pressure between 2000 to 7500 psi. As the mice consume oxygen and CO_2 is absorbed by LiOH chemical packs, the total pressure in the sealed enclosure will fall. When this pressure drop equals a predetermined magnitude (e.g., 0.5 psi), the pressure regulator automatically releases oxygen from the tank until the desired total pressure in the sealed enclosure is re-established. It is intended to provide a leak-tight enclosure so that it is not necessary to provide stored nitrogen. (Since this is an extended mission, sufficient time can be taken during count-down to assure that the container is airtight.)

As shown in Figure 42, air enters the cage near the ceiling, passes over a cooling element and then through the cage area. Exit air is forced through a coarse debris-type filter and a bacterial filter similar to the system used by General Electric on the Rat Experiment in the Biosatellite. This filter is made by the Pall Corporation.

A single blower delivers air through parallel ducts to the mouse cages. Air leaving the cages returns to the blower inlet by migration through the LiOH chemical packs and through and around the partitions between the subjects. A backup fan will be considered if reliability figures indicate this need for a 100-day mission.

d. CO_2 control. Carbon dioxide level is controlled by the placement of containers filled with LiOH in the enclosure. The LiOH is held behind a fine mesh screening or in porous paper bags (similar to Biosatellite) to prevent the spread of LiOH dust. It is not planned to duct air directly through the LiOH since General Electric's previous experience on project Spurt has indicated that natural convection and diffusion will do an adequate job in a gravity field. In the proposed design, air moving from the cages is directed toward the chemical package; if needed, additional forced circulation will be provided. Permeable membranes and molecular sieves were considered for CO_2 control, but the oxygen and nitrogen losses in the former case and complexity in the latter case preclude the usage of either technique for this program.

e. Trace contaminants. In closed systems with living subjects there is generally a slow buildup of carbon monoxide in the chamber. If tests indicate control is required, a canister of Hopcalite preceded by a LiCl dryer will be used. Similarly, ammonia levels can be controlled by the use of Amberlyst and odor can be minimized by the use of activated charcoal.

f. Thermal control. Information from NASA/ARC indicates that the Pioneer platform can be maintained relatively stable (thermally) at a selected temperature between 60 and 80°F while dissipating as much as 80 W of energy. On this basis it will be advantageous to provide a good thermal linkage between the experiment envelope and the Pioneer platform. Additionally, heat-producing devices will be attached wherever possible so that they dissipate their heat directly into the experiment housing. With such an arrangement, it will not be necessary to provide independent means for heating and cooling within the experiment package.

g. Instrumentation. Figure 43 is a block diagram for instrumenting four mouse cages. This diagram shows the method proposed for monitoring cage temperature, illumination level, and "in vivo" temperature for the mouse. Consideration has also been given to the possibility of obtaining mouse average heart rate from the existing instrumentation system.

h. Method for obtaining average mouse heart rate. General Electric has conducted some limited tests on a mouse implanted with a temperature transmitter in an attempt to determine the feasibility of obtaining mouse average heart rate from the existing telemetered signal. The transmitted signal consists of a pulsed carrier of approximately 500 kHz, with the separation between bursts being proportional to mouse body temperature. The testing by GE has consisted of examining oscilloscope traces and multispeed recordings of the transmitted pattern to determine if there is a measurable amplitude modulation of the carrier. The recordings show considerable amplitude variations even for a resting mouse with a fixed rf path length. At least part of the amplitude modulation can be identified as being caused by respiration rate, occurring approximately 3 times per second. Various portions of the recordings also show a very small modulation at a rate of approximately 10 per second, and this is suspected to be due to heart rate. However, the modulation is not always present or is sometimes indistinguishable from "noise." The conclusion is that since the "naked eye" cannot discern a definite heart rate pattern, some electronic data processing will be required in order to suppress background noise (respiration, body motion, electronic noise, etc.) and enhance that portion of the frequency spectrum which contains heart rate.

Figure 44 shows one possible scheme for accomplishing this. The received signal is first amplified and then fed to a gain-controlled amplifier which automatically adjusts the gain of the amplifier to maintain the long term signal voltage at point "a" constant. The time constant for the AGC loop is chosen to be about 1 second, so that it can follow relatively slow variations in signal strength (such as body motion and respiration) and adjust the gain accordingly. However, for rapid changes in signal strength such as produced by the 10-bps heart rate, the AGC loop will be unable to follow, and a threshold detector can be made to trigger at the peaks in signal strength.

This concept is shown in Figure 45 for an assumed set of signal conditions. Each time the threshold detector triggers, it sends a pulse to a counter which

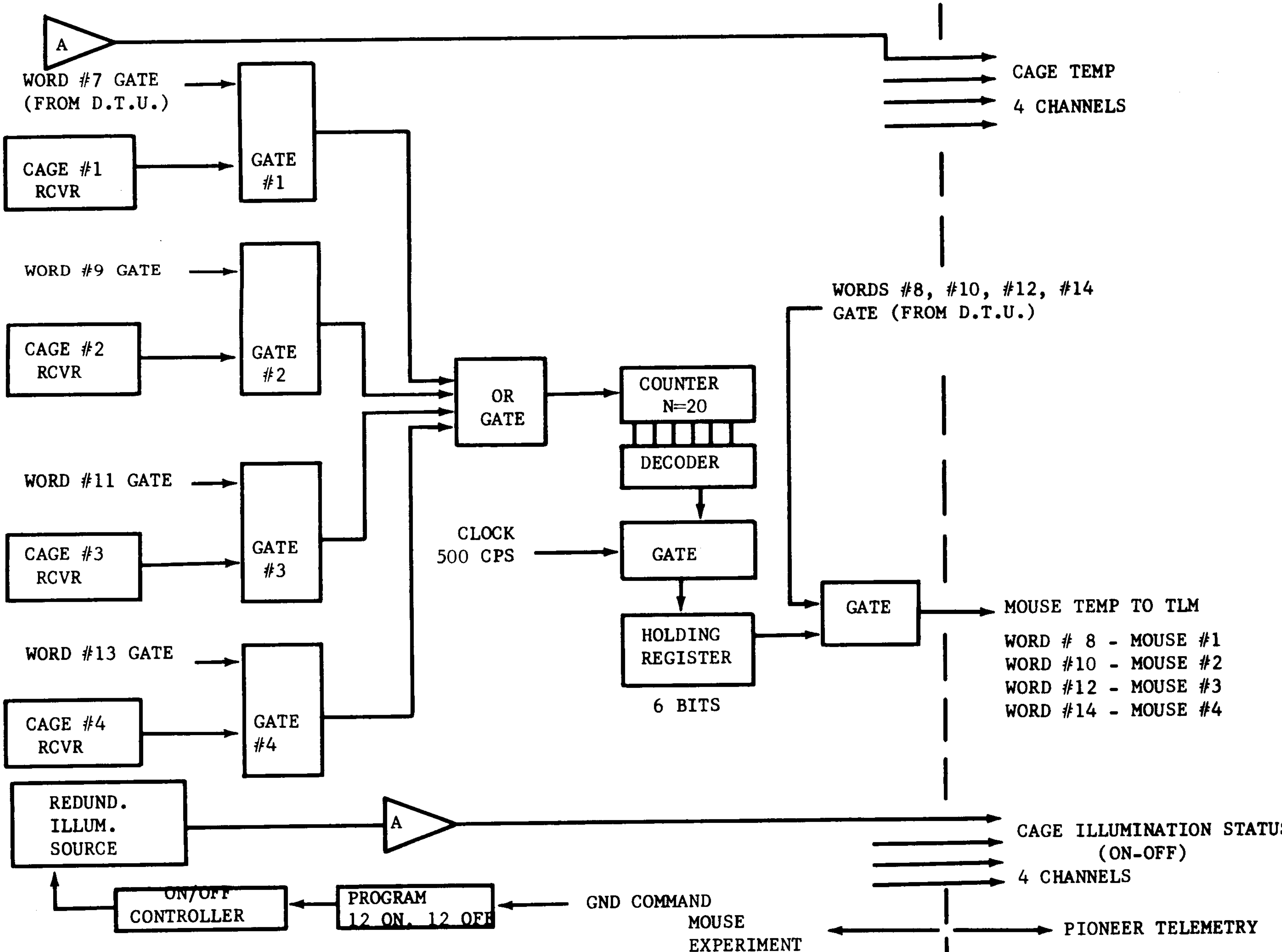


Figure 43. Block diagram for C-Mouse experiment.

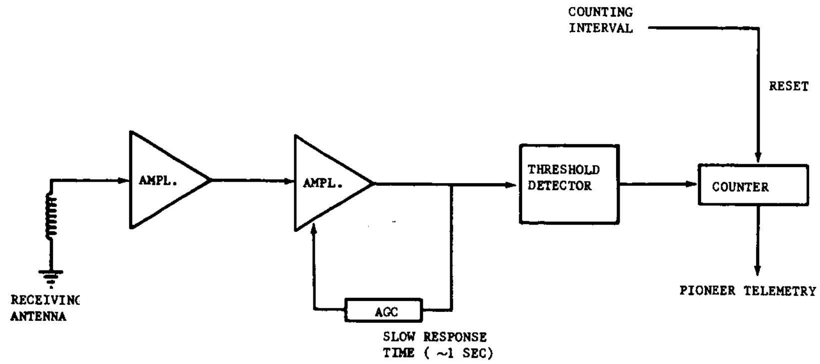


Figure 44. Proposed method for extracting mouse heart rate from transmitted temperature signal.

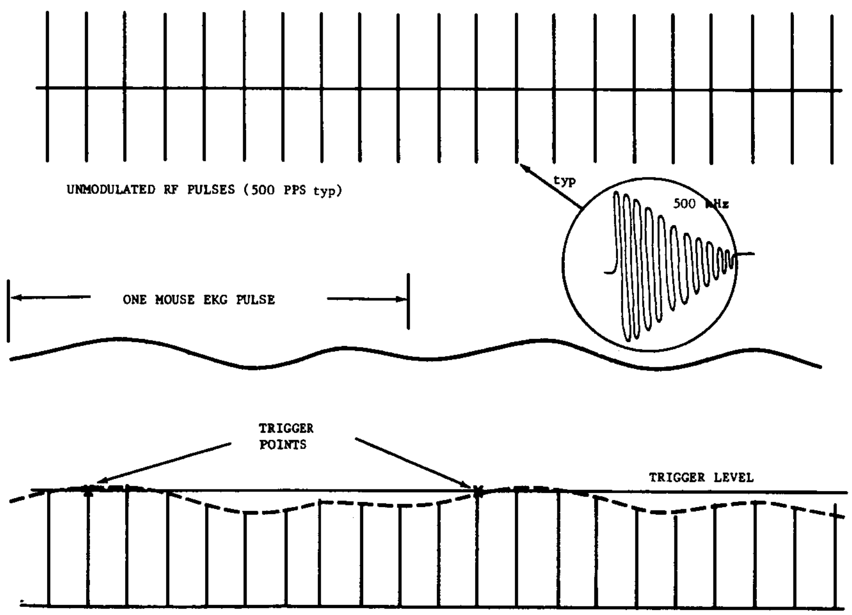


Figure 45. Signal from receiver, RF bursts plus EKG modulation.

counts the total number of pulses occurring within a given time interval. The time interval could typically be selected as one hour, thus registering the total number of heart beats which occur in the 1-hour interval. For telemetry back to the ground, the number of heart beats to the nearest 1000 (requiring 6 bits) may be sufficient.

$$3600 \text{ sec} \times \frac{10 \text{ beats}}{\text{sec}} = 36000 \text{ beats/hr}$$

Register contains 36 at end of 1 hour.

i. Cage temperature. The cage temperature is measured by a thermistor bridge and amplifier, thus providing an analog voltage proportional to temperature, with a voltage and impedance level compatible with the Pioneer telemetry system.

j. Illumination level. Each mouse cage is illuminated to approximately 5 ft-C with a redundant set of electroluminescent lamps as shown in Figure 46. The "on-board" programmer cycles the lamps through a nominal cycle of 12 hours "on" followed by 12 hours "off." This basic cycle can be modified by a ground command signal as shown.

Electroluminescent lamps have been chosen for this application because of their rugged construction. Figure 47 shows the illumination for a 10-in.^{2} lamp operating with 120 V ac at 400 Hz. It is seen that a rather severe decrease in illumination takes place over the first 1000 hours, followed by a more gradual decline in output. It is proposed to "burn in" the lamps for approximately 1000 hours to "burn off" this initial slope and then operate the lamps at a somewhat higher voltage in the Pioneer experiment package. In this way, as shown in Figure 47, the illumination should decrease less than 20% over the 100-day mission time.

Figure 48 shows the variation in illumination as a function of the voltage applied at 400 Hz for the three common color phosphors which are available in electroluminescent lamps. The green phosphor, peaking at 5300 Å, is by far the most efficient lamp, and fortunately this spectrum of energy is compatible with the mice.

Each mouse cage has a "prime" lamp and an auxiliary lamp to take over should a failure of the prime lamp occur. The logic for this circuitry and

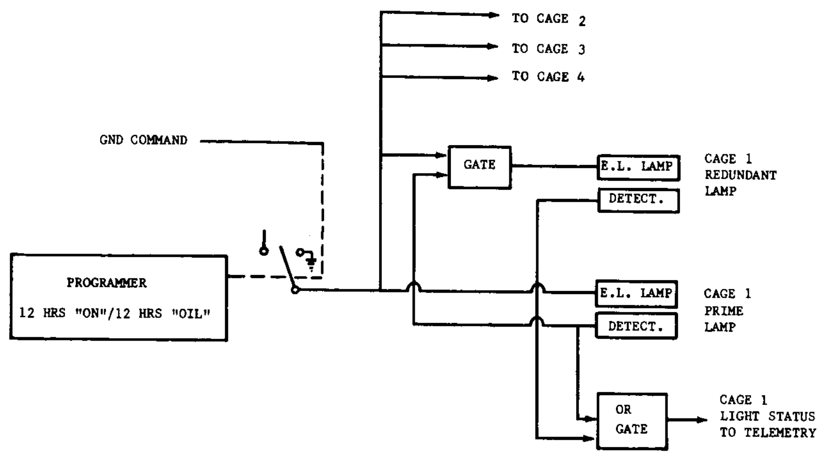


Figure 46. Illumination method for C-mouse experiment.

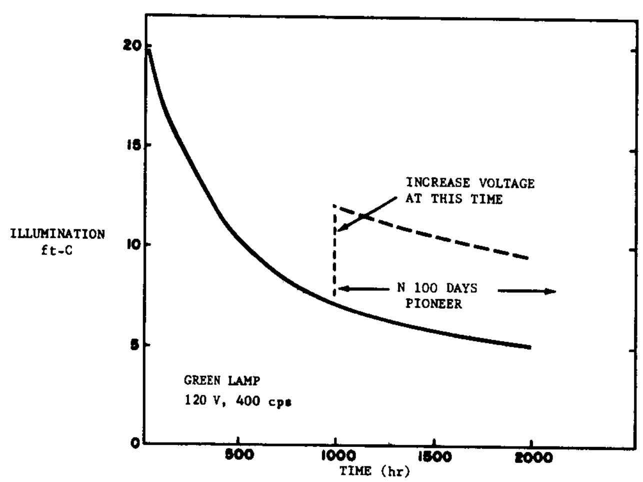


Figure 47. Illumination vs time for electroluminescent lamp.

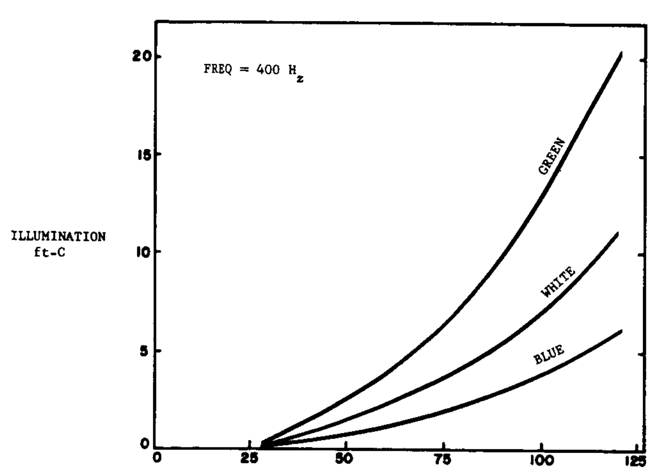


Figure 48. Variation in illumination as a function of voltage and phosphor.

for the "illumination present" signal to telemetry is shown in Figure 46. When either lamp is illuminated, the telemetry signal indicates presence of light. Some consideration will be given to the possibility of combining the illumination signal from each cage (a digital signal) with the corresponding cage temperature signal (analog) in order to reduce the number of telemetry channels required.

k. Mouse temperature measurement. The method proposed for measuring the mouse temperature is based on the successful development of an implanted temperature telemeter and its application to the Biosatellite program. The output of this telemeter is a burst of rf pulses (approximately 500 kHz) with a repetition between these bursts of between 330 and 670 pps, depending on mouse temperature. The induction field created by the transmitter is picked up by one or both of the orthogonal antennas mounted on the mouse cage. Each antenna coil is connected to an amplifier, and the largest signal is further processed to a constant amplitude signal. The digital data processing of this signal (see Figure 43) is designed to provide a digital number proportional to the amount of time it takes to receive 20 input pulses from the receiving antennas. This time is about 30 ms for a high-temperature mouse transmitting 670 rf bps, and is about 60 ms for a low-temperature mouse transmitting 330 rf bps. The gate shown in Figure 43 permits the holding register to count the 500-Hz clock pulses for the duration of this time. Thus for a high-temperature mouse, the holding register will record a count of approximately $\frac{30 \text{ ms}}{2.0 \text{ ms}} = 15$, and for a low-temperature mouse, a count of about $\frac{60 \text{ ms}}{2.0 \text{ ms}} = 30$. This permits a 0.33°F resolution of the expected 5°F mouse temperature range. The digital word resulting from this operation will be 5 bits long and allowing one bit for cage identification, the Pioneer telemetry system must process a six-bit word for each mouse.

The telemetering of the four mouse temperatures is synchronized with the Pioneer telemetry system format by the "word gate" pulses which are provided by the "Digital Telemetry Unit" (DTU) within the spacecraft. The data processing is arranged so that the four mouse cage receivers time-share one digital processor as shown in Figure 43.

During the Pioneer telemetry frame, a "word gate" signal ("word 7 gate" has been chosen as an example) energizes gate 1, permitting the computation of the mouse 1 temperature. When the next "word gate" signal occurs ("word 8 gate" in this example) the six-bit digital number corresponding to mouse 1 temperature, is shifted from the holding register to the Pioneer telemetry system for playback to the earth. At the completion of the eighth word, the digital processing counters are reset to zero. During the ninth "word gate," the mouse 2 temperature is computed and stored in the holding register. During the tenth "word gate," this digital number is shifted out to the telemetry system. This sequence is repeated for all four cages, alternately computing the mouse temperature during one "word gate" signal, and reading this out during the next "word gate" pulse.

In the final application of this method, it may be necessary to actually space the temperature "words" by more than two words in order to permit sufficient time (60 ms) to compute each mouse temperature during one "word gate" interval. For the present Pioneer telemetry system design with a maximum bit rate of 512 bps, a spacing of five words would be required.

If weight, power and data channels are available, additional instrumentation should be considered for the flight hardware. Of considerable value in measuring performance of the experiment would be cage ambient, total pressure, and stored oxygen pressure. Ambient pressure would indicate performance of the oxygen regulator, and stored O_2 pressure would indicate leakage of the experiment enclosure. (Over the longer period a measure of average O_2 consumption of the mice would also be provided.) Temperature of the cold surface of the thermo-electric elements would provide an indication of humidity levels. Should the mice die prior to completion of the 100-day mission, these additional data would assist measurably in identification of possible equipment failure as cause of death.

1. Equipment required. Minimum requirements are estimated to be:

Test	
Design Verification Test Unit	1
Prototype	1
Qualification Test Unit	1
Flight	
Flight Unit	1
Flight Unit Backup	1
Control Unit	2
GSE (To be defined.)	

m. Equipment status. The experiment hardware summarized above is at the level of conceptual design. Breadboards have been fabricated to determine the feasibility and practicality of the proposed life support system. These breadboards have been operated with experimental animals at the Valley Forge Division of General Electric under the scrutiny of both the Principal and Coinvestigators. A summary report is attached.

Breadboard tests have confirmed the adequacy of the proposed method of water management and life support. Methods of instrumenting mice to study changes in body temperature and activity are currently in use at the University of Minnesota and have been adapted for use on the planned NASA Biosatellite 21-day mission. Methods of monitoring heart rate are under development.

GENERAL ELECTRIC COMPANY SUMMARY REPORT

PIONEER MOUSE FEASIBILITY TESTS-CLOSED CYCLE WATER CONCEPT

SUMMARY.- Four separate tests were conducted with a "C" mouse in a closed environment. These tests were conducted for 5, 12, 16 and 24 days and proved the feasibility of closing the water ecology with the mouse drinking water condensed from the atmosphere. Also, the tests demonstrated the reliability and design adequacy of the thermoelectric cooler and the brushless blower which are similar to those which may be required for the flight experiment. Results to-date do not indicate the existence of any major technical obstacles which would prevent the successful development of this experiment for flight.

PURPOSE.- The purpose of the tests was to prove the feasibility of closing the water loop, i.e., re-use of the water in a simulated Pioneer Mouse Experiment enclosure. Re-use of the water will minimize the launch weight of the experiment by eliminating a large amount of stored water and chemicals required for humidity control.

TEST SETUP.- The test setup consisted of a wire mesh mouse cage placed in a Plexiglas enclosure which, in turn, was placed in a sealed belljar. Air was circulated through the cage, Plexiglas enclosure and belljar via a brushless DC blower. A thermoelectric cooling unit was used to cool the air flow and also to condense drinking water from the atmosphere. A normal atmosphere gas composition was used with carbon dioxide control by lithium hydroxide absorption. In the last test, carbon monoxide control was provided by Hopcalite catalytic oxidation, ammonia control by Amberlyst absorption and odor control by activated charcoal. Food was placed at the top of the cage, and debris was collected in a tray below the cage. Temperature and humidity were monitored at several points in the test setup, and gas analyses were provided by mass spectrograph and specific gas analyzers.

RESULTS.- The first test was used to check out the equipment. The test volume was then reduced to better simulate the available vehicle volume. The second and third test mice died apparently of malnutrition (35 - 40% weight loss) when all the readily available food was consumed. There was also the possible problem of toxic gas buildup, since the mass spectrograph could not distinguish between carbon monoxide and nitrogen because of their equal molecular weights. The fourth test provided carbon monoxide control and gas analysis by specific gas analyzers. This test confirmed the buildup of carbon monoxide and the suspicion that carbon monoxide caused or contributed to the death of the two previous test mice. This test was terminated after 24 days when the mouse squeezed through the food retaining mesh at the top of the cage. This mouse was quite active, looked healthy and had lost only 7% of his weight, possibly through dehydration after escaping from the cage. During all tests, a good level of water was maintained in the drinking trough by the thermoelectric condensing technique, and the mouse was observed to drink from the source.

Envelope.- The basic approach, illustrated in Figure 49, is for a four-mouse experiment and is a single platform-mounted unit. Alternate plans A (Figure 50) and D (Figure 51), for three and four mice respectively, consist of individual assemblies which can be separately mounted to make better use of available platform space. Figures 52 and 53 represent configurations of Alternate Plan D.

Weight and Size.- Weight and size requirements are shown in Table 26.

Power.- Power requirements are shown in Table 27.

Spacecraft Interface Requirements.- Requirements are as follows:

Location: On equipment platform.

Mounting: Good thermal contact between experiment and platform.

Spacecraft Support: Electrical, data storage and telemetry.

Special Control: Thermal control and spin rate.

Environment Constraints.-

a) Constraints. The limiting constraints are those imposed by the biological specimens. Mice mounted in a manner proposed for the experiment hardware have survived simulated Pioneer launch stresses with no detectable change in their circadian system. (See section entitled "Environmental Tests.")

b) Interference.

Vibration	-	None
Noise	-	None
Light	-	None
Radiation	-	None
RFI	-	To be studied
EMI	-	To be studied

Data Measurements Requirements.- Data requirements given in Table 28 are for a three-mouse experiment. For a four-mouse experiment an additional channel would be required for each parameter.

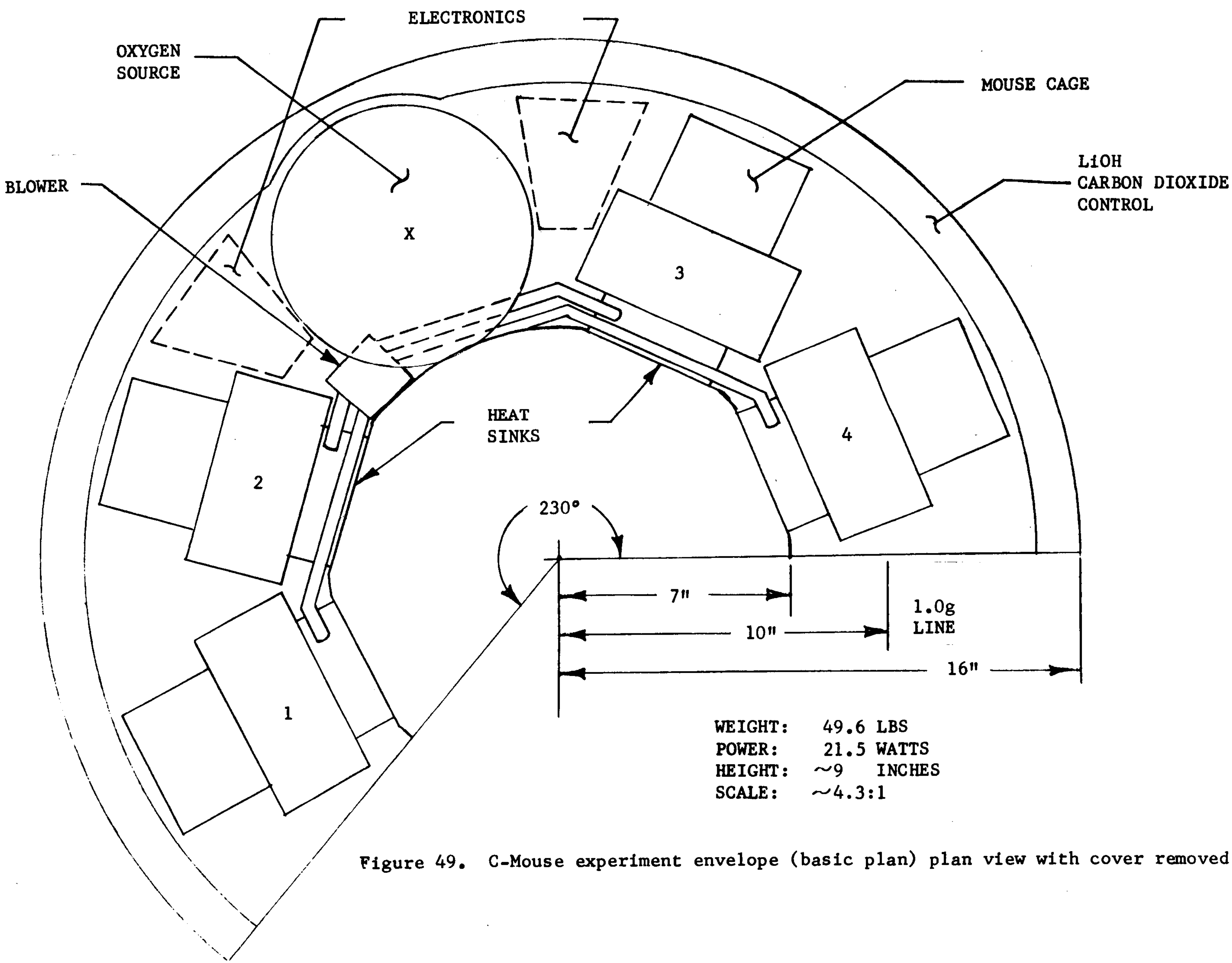


Figure 49. C-Mouse experiment envelope (basic plan) plan view with cover removed.

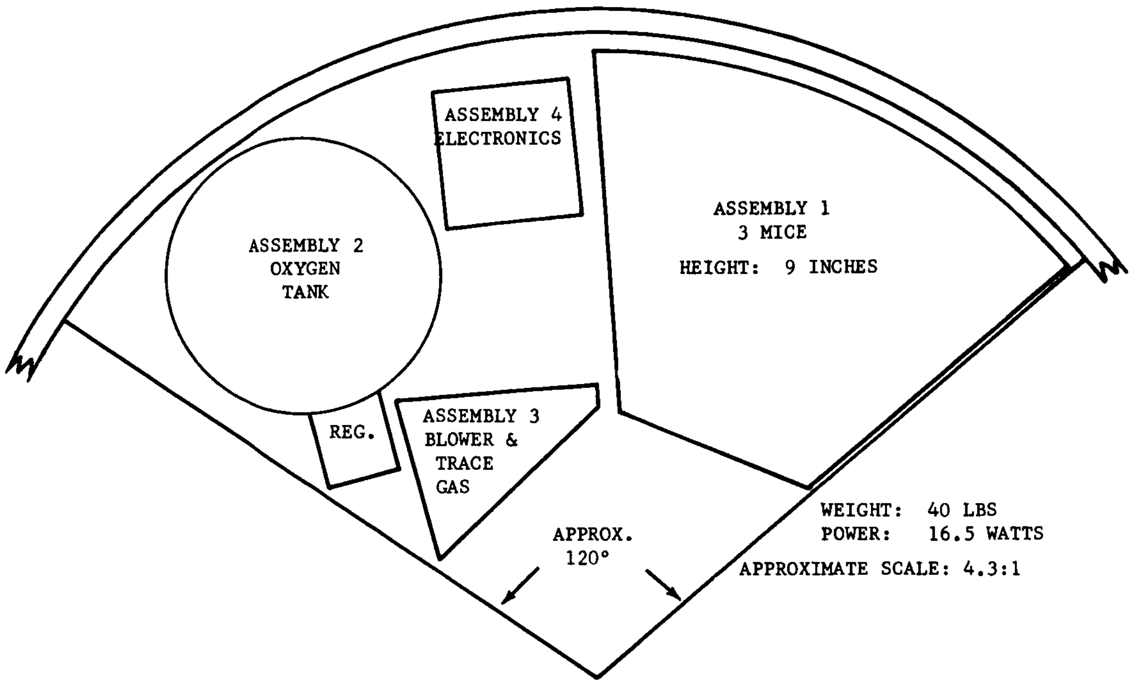


Figure 50. Experiment envelope for C-Mouse experiment (alternate plan A).

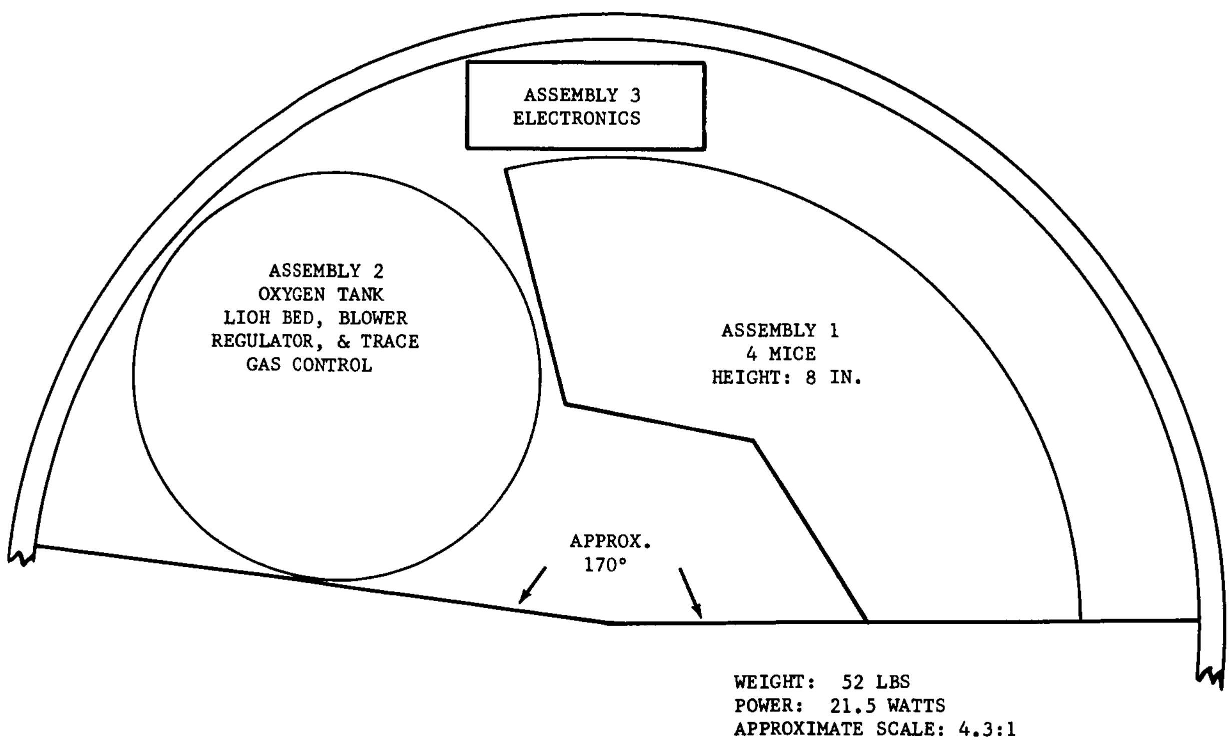


Figure 51. Experiment envelope for C-Mouse experiment (alternate plan D).

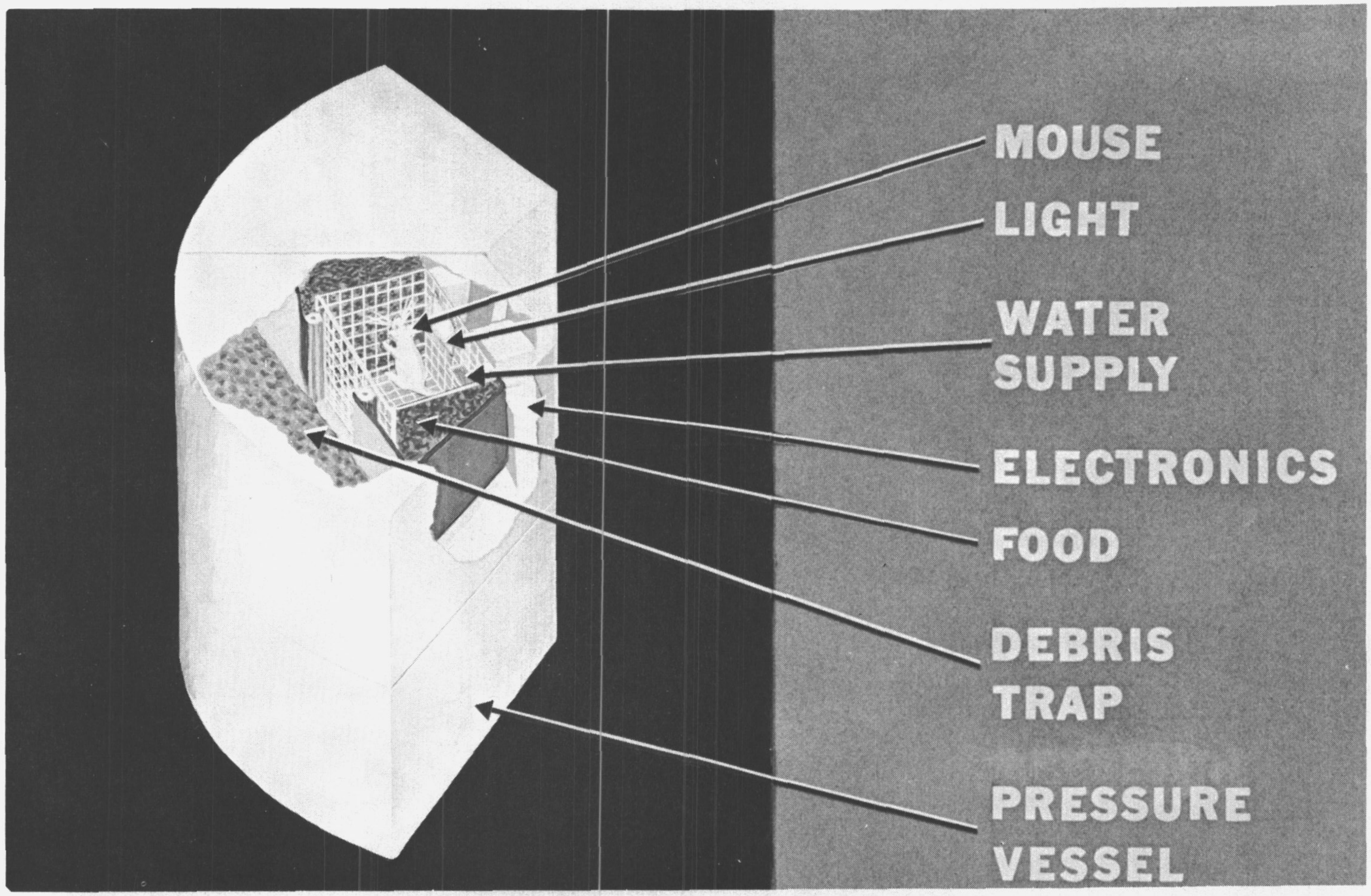


Figure 52. C-Mouse experiment hardware concept for the study of circadian periodicity of body temperature, heart rate, and activity.

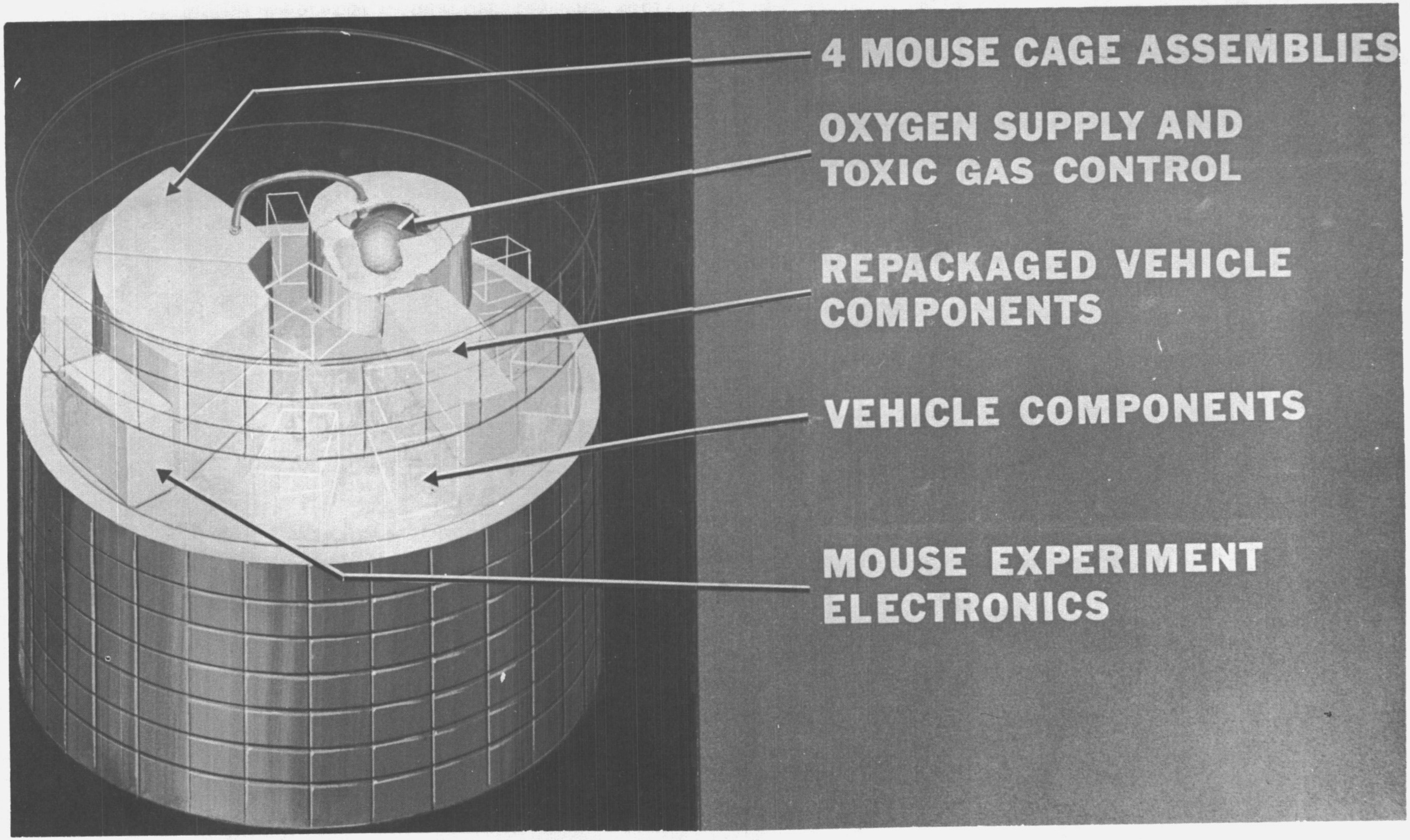


Figure 53. C-Mouse experiment hardware concept as it might appear on a Pioneer experiment platform.

TABLE 26. WEIGHT AND SIZE REQUIREMENTS FOR THREE DIFFERENT CONFIGURATIONS OF C-MOUSE EXPERIMENT

Equipment Item	Weight (lb)	Volume (ft^3)	Dimensions	Shape
Basic Plan			Minor diameter, 7 in	230° of spacecraft annulus
Assembly 1	49.6	2.8	Major diameter, 16 in	
Total	49.6	2.8		
Alternate Plan A				
Assembly				
1	14	-	Height, 9 in	-
2	15	-	-	-
3	6	-	-	-
4	5	-	-	-
Total	40			Approximately 120° of spacecraft annulus
Alternate Plan D				
Assembly				
1	10	-	Height, 8 in	-
2	36	-	-	-
3	6	-	-	-
Total	52			Approximately 170° of spacecraft annulus

TABLE 27. POWER REQUIREMENTS FOR THREE DIFFERENT CONFIGURATIONS OF C-MOUSE EXPERIMENT

Equipment	Standby	Average (W)	Maximum
Basic Plan			
Assembly 1	-	21.5	-
Total	-	21.5	-
Alternate Plan A			
Assembly 1	-	10.3	-
2	-	0.0	-
3	-	1.5	-
4	-	4.7	-
Total	-	16.5	-
Alternate Plan D			
Assembly 1	-	13.5	-
2	-	1.5	-
3	-	6.5	-
Total	-	21.5	-

TABLE 28. DATA MEASUREMENT REQUIREMENTS FOR A THREE C-MOUSE EXPERIMENT

Parameter to be Measured		Body Temperature	Heart Rate	Activity	Ambient Temperature	Ambient Pressure	Cell Illumination
Equipment Item Used		Cage 1 | 2 | 3	Cage 1 | 2 | 3	1 | 2 | 3	Cage 1 | 2 | 3	Pressure Shell 1 | 2 | 3 (1 channel)	Cage 1 | 2 | 3
Expected Value of Parameter	Units	0_f →	BPM →	Levels →	0_f →	psia →	Photo Level →
	Nominal Value	Not Appl. →	600 →	TBD →	76 →	14.7 →	5 ft Candles →
	Range	95-100 →	317- →	0-63 →	60-1100 →	14.2-15.2 →	ON/OFF →
Measurement Characteristics	How Often	10 min →				1 hour →	
	Duration	15-some →	10 min →	→	Point Sample →		
	Total in Mission	14,400 →				2,400 →	
Output Signal of Instrument	Type	Pulse Rate →		Pulse →	Analog →		ON/OFF →
	Frequency Range	200-400 pps →			OC →		Once per Day →
	Amplitude Range	mv →			0-2V →		0-5V →
	Resolution	$\pm$0.5 °F →	17 BPM →	1 Level →	2°F →	0.03% psia →	ON/OFF →
Read-out Requirements	No. of Channels	1 →					
	Sampling Rate	0.0015 BPS →		0.010 BPS →	0.0017 →	0.0017 BPS →	0.0003 BPS →
	Telemetry Req'd.	Yes →					
	Storage Req'd.	Yes, if continuous real-time telemetry is not available →					
Time Identification	Method	Self-controlled clock →					
	Accuracy	$\pm$ 1 min →					

Missing information or data available mostly at unequal intervals can be tolerated. An undesirable blackout of communication with the spacecraft for spans up to five days would not jeopardize the mission, notably if the information could be retrieved whenever communication is reestablished. If, in turn, the capacity of onboard data storage allows coverage only for spans shorter than the duration of the blackout, and thus some information is necessarily lost, the flexibility of the sequential design here proposed will allow for replications of the exposure to certain conditions, e.g., of the execution of a phase shift. In case of a failure of the entire mission, say, at 45 days, enough data will have been accumulated to draw valid inferences about the τ, C_o, C, φ and Φ of the metabolic rhythms under several conditions of study; and if failure occurs yet earlier, at least one or a few conditions of study can be documented by objective data. The worst case of uncertainty would be generated by reception of an undue proportion of mutilated or missing data, but so long as 3 or 4, more or less evenly-spaced reliable data points per animal per day are available, useful rhythm estimates can be obtained.

Operational Requirements

Spacecraft Orientation Requirements.- The experiment as described is specifically sized for a "typical" Pioneer spacecraft mission, the basic elements of which are acceptable to experiment execution.

Specific requirements which appear to be met on Pioneer are:

a) The spacecraft must leave the earth and lunar fields as rapidly as possible.

b) There should be no change in distance between the vehicle and the sun.

c) There must be no periodic event aboard the spacecraft, such as acceleration noise, vibration, etc, which occurs at frequencies which entrain a biological rhythm.

d) There should be minimal variation in possible effect of other planets--notably Venus and Mars.

e) Data must be retrieved either continuously or intermittently for approximately 120 days.

Prelaunch Support.- Shipping and handling procedures for the experiment hardware will follow usual procedures for equivalent flight items. Addition of oxygen, chemical absorbents, specimen food, and the experimental organism will be at the launch site as close to time of launch as is operationally feasible.

The assemblies containing the experimental organisms will go through all necessary checkout to insure the integrity of the package prior to installation in the spacecraft. Experiments will receive a prelaunch checkout by procedures to be defined. The principal support requirement in this category is for thermal control and electrical power. The proposed experiment achieves temperature control passively through its mounting on the experiment platform. All other functions are self-contained or need not become operational prior to prelaunch checkout and/or launch.

A combination office/laboratory space will be required to accommodate up to 24 experimental animals, the flight hardware, and associated backups and ground controls. This is estimated to require approximately 400 square feet of air-conditioned work space, a desk, an electronics bench, one or two tables and an animal rack. Both 120 V ac and 28 V dc power will be required. The space should be available continuously from 30 days prior to launch to 30 days after completion of the flight experiment. It is entirely feasible to accommodate total experiment support in a suitable trailer.

Data Support Requirements.- Control data will be collected on magnetic tape at the launch site. Flight data will be recovered from the NASA communication net on computer compatible magnetic tape and relayed to University of Minnesota for analysis. Flight data may be retrieved either in real time or intermittently from a data storage unit, depending upon operational constraints.

Resources Requirements

Development Schedule.- The schedule is shown in Figure 54.

Estimated Funding Requirements.- In the opinion of the principal investigator and his engineering support (General Electric Co.) estimations of costs through program completion are misleading at this point in time. The costs presented in Figure 55 represent best estimates based on the prior experience of both parties in developing flight hardware for the NASA Biosatellite and related programs. While supporting documentation is not available, an estimated rate of expenditure can be derived from Figure 54.

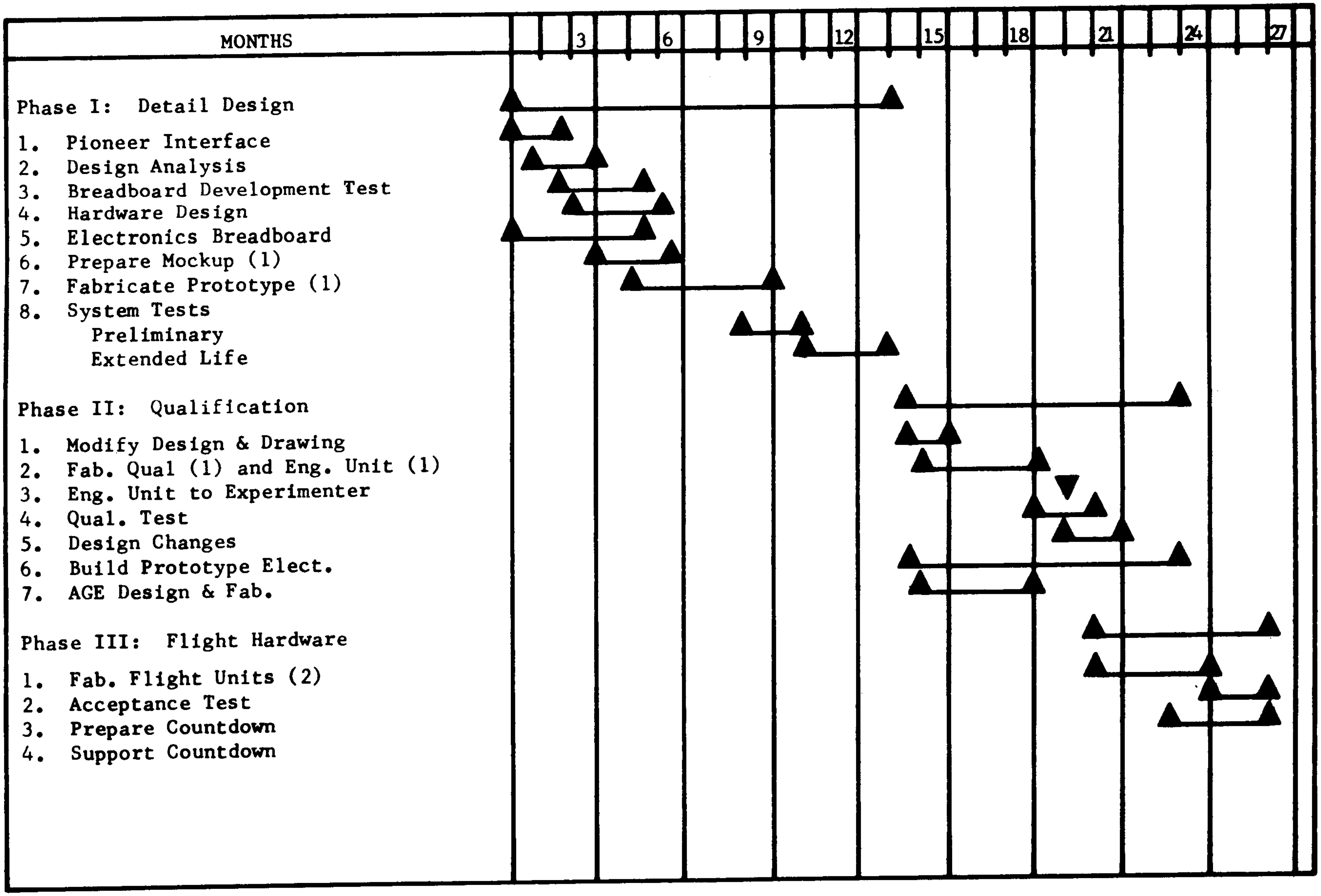


Figure 54. Estimated schedule for accomplishment of the C-Mouse experiment.

Experiment hardware development cost estimated by General Electric Co. to include:

Engineering
Liaison
Fabrication
Laboratory Breadboard
Spatial Mockup
Development Engineering Unit
Test Support Equipment
Qualification Unit

Estimated Cost	$550,000 *

Supporting activities at the University of Minnesota and/or University of Virginia to include:

Scientific Support
Development of Biotelemetry

Estimated Cost	$300,000 *
Estimated Total Development Cost	$850,000

FIGURE 55. Estimated costs for preliminary development of C-Mouse experiment.

(* Breakdown and quarterly funding requirements not available)

REQUIREMENTS FOR PHYSICAL SCIENCES EXPERIMENTS

Philosophy

The biological experiments treated in this study are designed to test the premise that some geophysical phenomenon is responsible for maintaining the integrity of the circadian system. Execution of the experiment in space many millions of miles from the earth should either result in the removal of geophysical cues or result in the cues being "sensed" by the biological material at intervals which should disrupt the circadian system.

A reasonably well documented hypothesis subscribed to by many biologists is that in a "stimulus free" environment the addition of any stimulus which an organism can sense is capable of entraining a biological rhythm. In practice the most effective stimuli have been shown to be photoperiod and temperature. The proposed biological experiments are directed toward packaging the experimental material in a constant environment aboard a spacecraft in an effort to achieve a near "stimulus free" condition and to determine whether the biological periodicity remains stable or changes; and whether changes if they occur can be related to some aspect of the space environment.

Complete analysis of the biological data therefore is dependent upon characterization of the physical environment in which the experiment is conducted. Paradoxically, biological material cannot survive unprotected from the space environment and indeed requires a simulated terrestrial environment for definitive studies. Physical characterization of the experiment environment therefore relates to the environment as the specimens "sense" it within the experiment hardware.

Requirements

Each Principal Investigator was requested to identify his <u>requirements</u> for monitoring devices to characterize the physical environment during biological experimentation. Their requirements fell into three categories.

First, all investigators required adequate monitoring of the experiment hardware to insure its proper performance. For the most part, this kind of monitoring is designed into the experiment package itself.

Second, it was required that there be no periodic event aboard the spacecraft, such as acceleration, noise vibration, etc., occurring at a frequency or intensity capable of entraining a biological rhythm. This area requires further study but at first analysis it appears that such events will not occur. The problem of transient magnetic fields remains controversial.

Third, it was required that events associated with the space environment be documented. This requirement was least well defined and the priority varied with different investigators. In order of importance, a requirement was expressed for the spacecraft ephemeris; documentation of the ionizing radiation inside the experiment hardware; and documentation of the magnetic fields inside the experiment hardware. Measurement of changes in the levels of ionizing radiation in space and magnetic fields in space was requested but could only be justified to the extent that such a measurement related to the immediate environment of the experimental organism.

Existing Pioneer Physical Sciences Experiments

Three physical sciences experiments currently being flown on the Pioneer spacecraft have been "suggested" as both contributing to the interpretation of biological data and extending the useful life of BioPioneer by continuing to operate for many months after cessation of biological experimentation. One experiment is a Magnetometer designed to measure the magnetic fields in space. The sensor is located at the end of a boom approximately 5½ feet from the edge of the experiment platform on which the biological experiments will be mounted. "The interplanetary magnetic field is only of the order of 4 to 10 gammas (one gamma = 10^{-5} gauss). At the earth's surface the field is approximately 500 milligauss (50,000 gammas). Inside the Pioneer spacecraft the field will exceed the interplanetary field because of internal magnetic sources such as the traveling-wave tubes. At the experiment platform, in the probable locations of biological experiments, the field will be 2 to 3 milligauss (200 to 300 gammas). The platform field is nonperiodic and its variation from point to point is unpredictable."

The second experiment is a plasma probe designed to measure low energy emissions associated with the solar wind. In the opinion of the Pioneer Program Office, NASA/ARC, "The experiment platform is sufficiently shielded from the low-energy solar wind that there will be no appreciable radiation effects on the biological specimens from this source."

The third experiment is designed to measure cosmic rays. "The true cosmic or galactic rays originate outside the solar system. Although they cover a wide spectrum of energies, the flux is so extremely low that no appreciable effects on biological experiments are anticipated."

Data on high-energy particulate radiation associated with solar flares are in the process of summary. The information supplied thus far from NASA/ARC is as follows: "The sun emits protons at irregular intervals. These high-energy particles, called "solar cosmic rays" by some, originate primarily from solar flares. Solar-flare activity waxes and wanes in an approximately 11-year cycle, but so far no one has developed a method of predicting the time of an occurrence. The last peak of solar activity was in 1958 and the next will be in the 1968-1970 period. Thus, Pioneer VI (launched December 15, 1965) and Pioneer VII (launched August 17, 1966) are flying in a time of increasing activity. A launch year of 1971 for the first BioPioneer would be at a time of decreasing solar activity, at approximately the same time interval beyond the peak as Pioneers VI and VII precede the peak."

It was specifically recommended that before specific requirements are defined by the biologists that the physical sciences data presently on hand be examined by some form of time series analysis in an attempt to identify periodicities of biological importance.

Assumptions for BioPioneer Feasibility Study

It is assumed that physical monitoring of the space environment will be required either to document biological experiments or to take advantage of the orbital life of the satellite after the biological experiments have been completed. It appears feasible to design monitoring devices such as dosimeters which could have one sensor either mounted in the biological experiment hardware or shielded to provide data which could be extrapolated to conditions within the experiment hardware; and one sensor mounted in a manner to monitor ambient space radiation. One sensor would be activated to monitor biological experiments.

The system could then be switched to the alternate sensor for physical sciences studies when the biology was completed. Design of such a system was beyond the scope of this study.

Since it was assumed that physical sciences experiments would be accommodated, the existing Magnetometer, Plasma Probe, and Cosmic Ray experiments were used to develop representative payloads for a BioPioneer Mission.

PIONEER SPACECRAFT CHARACTERISTICS

The purpose of this section is to provide design information with respect to the Pioneer Block II Spacecraft currently being fabricated and launched as a continuing program for NASA/ARC. The spacecraft is designed to operate in solar orbit to provide data on solar wind, interplanetary magnetic field, solar physics and basic interactions of high-energy charged particles and magnetic fields (Figure 56). The purpose of the present study is to determine the usefulness of a Pioneer spacecraft as a platform for biological experiments. General spacecraft characteristics are provided, including acoustic, vibration, acceleration and thermal aspects of a typical Pioneer mission. These data are based on the use of the McDonnell-Douglas DSV-3E booster with a FW-4 third stage and an assumed 150-pound payload. However, the present booster combination can accommodate significantly heavier payloads. Figure 57 shows the launch-vehicle third-stage, fairing, and spacecraft interface.

Pioneer 6 was launched December 16, 1965, from Cape Kennedy on a six-month interplanetary mission. Final earth-sun orientation was achieved as scheduled 44 hours after launch at 230,000 miles from Earth. Spacecraft systems and experiments have performed their required functions as designed over the past 21 months. Pioneer 7 was launched August 17, 1966, and has been operating as required for the past year. On December 13, 1967, a third Pioneer spacecraft was launched and all systems are operating flawlessly. Figure 58 depicts the heliocentric orbits of Pioneers 6 and 7 and the Earth.

Spacecraft Description.- The basic spacecraft body is a cylinder 37 in. diameter and 35 in. high. Three 64-in. booms deploy from the midsection, with a magnetometer, wobble damper and orientation nozzle mounted on the ends of their respective booms. A 52-in. mast containing high-gain and two low-gain antennas projects from one end of the spacecraft. A dual-frequency antenna used in a radio propagation experiment deploys from the other end. The sides of the cylinder are covered with solar cells, except for the experiment view band at the midsection. The present Pioneer system characteristics are given in Table 29. Figure 59 is an exploded view of the basic spacecraft, and Figure 60 shows plan and side views of the spacecraft in launch and flight configurations. Spacecraft systems include an S-band communication system

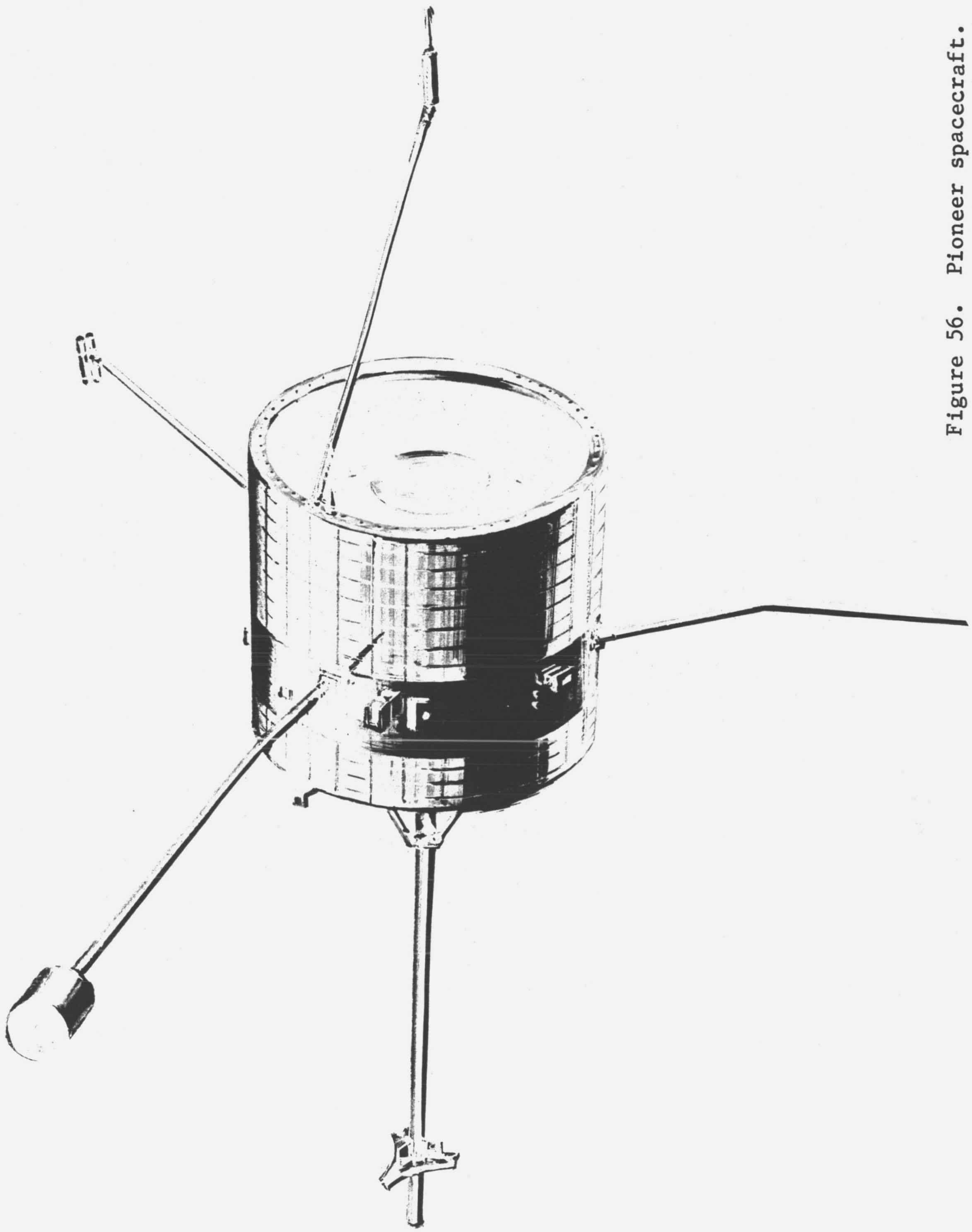


Figure 56. Pioneer spacecraft.

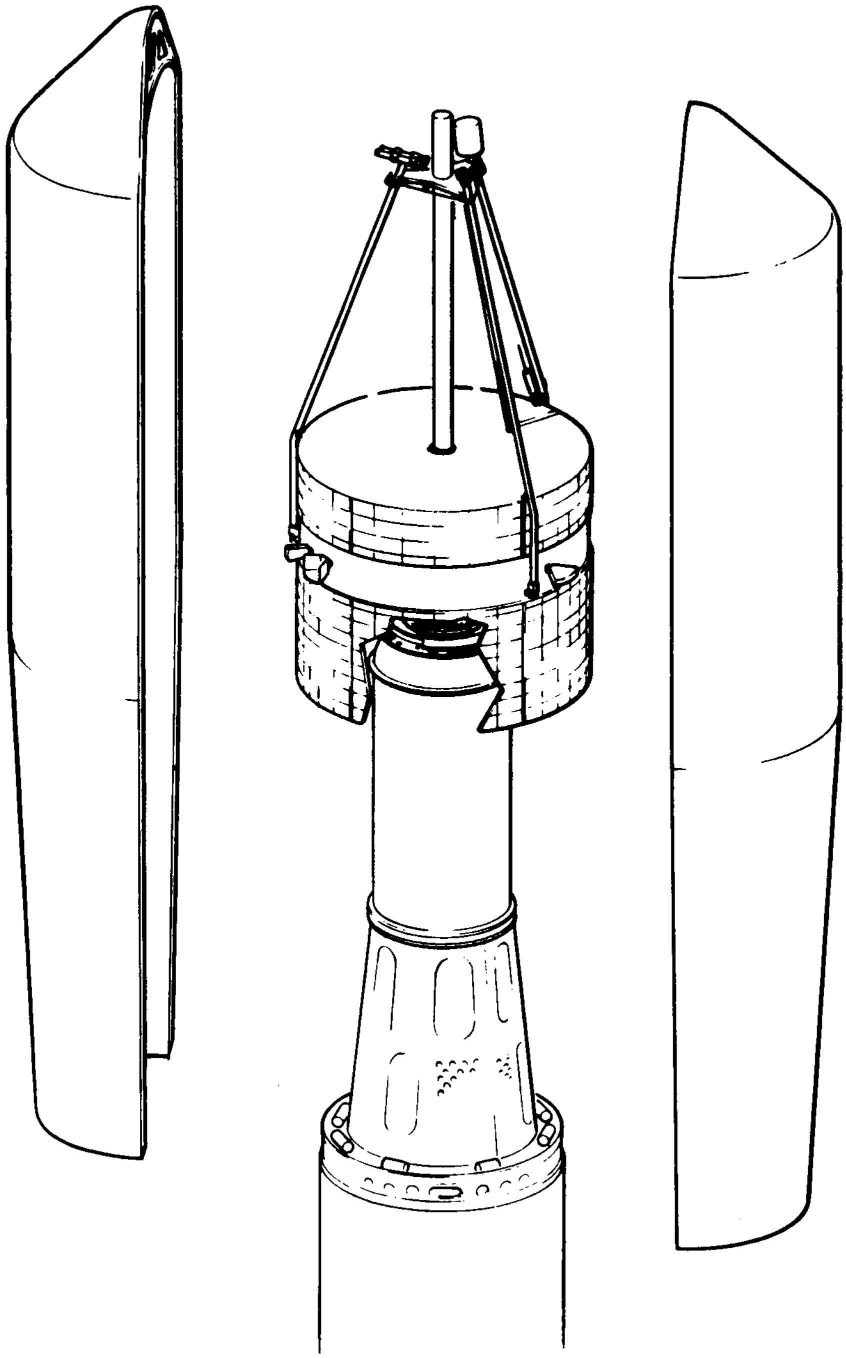


Figure 57. Launch vehicle.

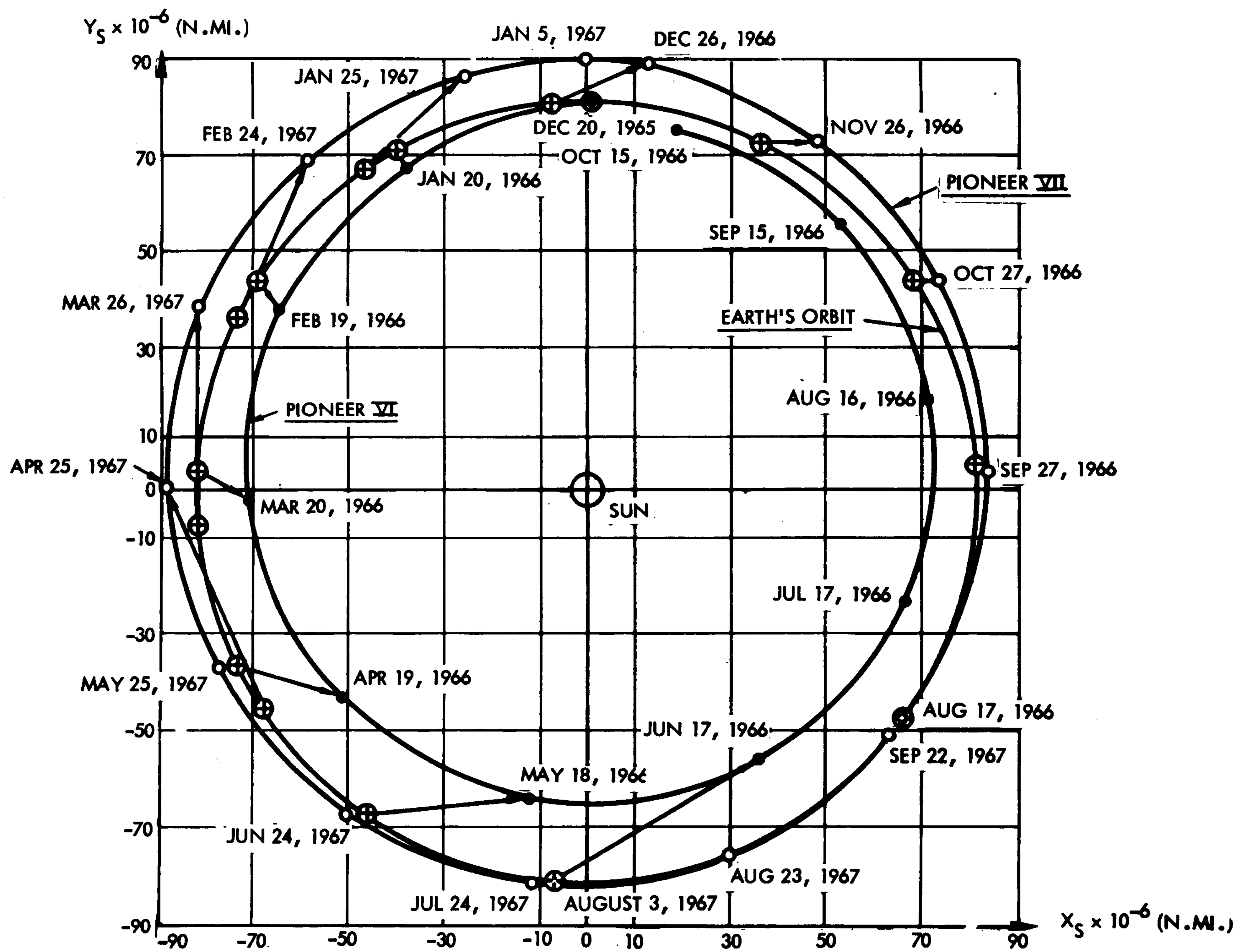


Figure 58. Heoliocentric Orbits of Pioneer VI, VII, and Earth

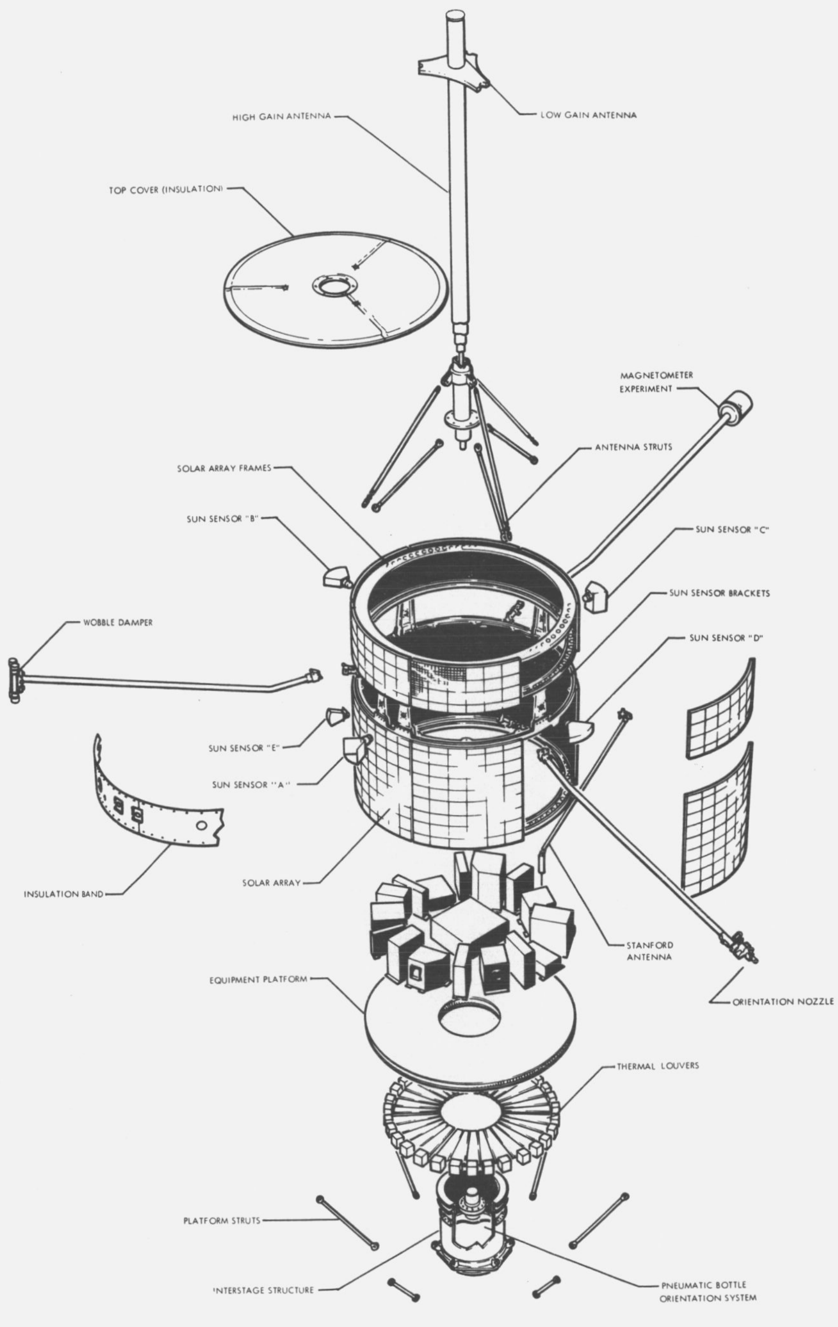


Figure 59. Spacecraft Exploded view

TABLE 29 PRESENT PIONEER SYSTEM CHARACTERISTICS

Pioneer C total spacecraft and experimenter weight: 144 lb

Pioneer C experiment weight: 38 lb

Spacecraft trajectory constraint: Aphelion - 1.2 AU (electrical power); Perihelion - 0.7 AU (thermal).

Present experiment volume: 2,000 $in.^3$; Experiment window area in plane of ecliptic - 750 $in.^2$.

Watts available to experiments: 12 at 1.2 AU; 22 at 1 AU; 43 at 0.7 AU.

Experiment viewing direction during spin cycle provided.

Reliability: 0.88 for 6 months: MTBF, 48 months.

Lifetime: More than 1 year.

Communication range: 8 BPS to 0.5 AU (85 ft ground antenna) or 1.82 AU (210 ft ground antenna).

Variable bit rate: 512, 256, 64, 16, 8 BPS.

Commands: 80 (57 presently in use).

Variable experiment sampling formats: Analog to Digital conversion.

Data storage: 15,232 bits.

Spacecraft magnetic field at 6 ft: Less than 0.2 gamma at 6 ft.

Spacecraft thermal environment: 40-90°F over 0.8 to 1.2 AU.

No electromagnetic interference detected in prototype spacecraft test.

Broad range of housekeeping data telemetered to the ground.

Four spacecraft funded: Two launched; Subsequent launches, one at approximate 12-month intervals.

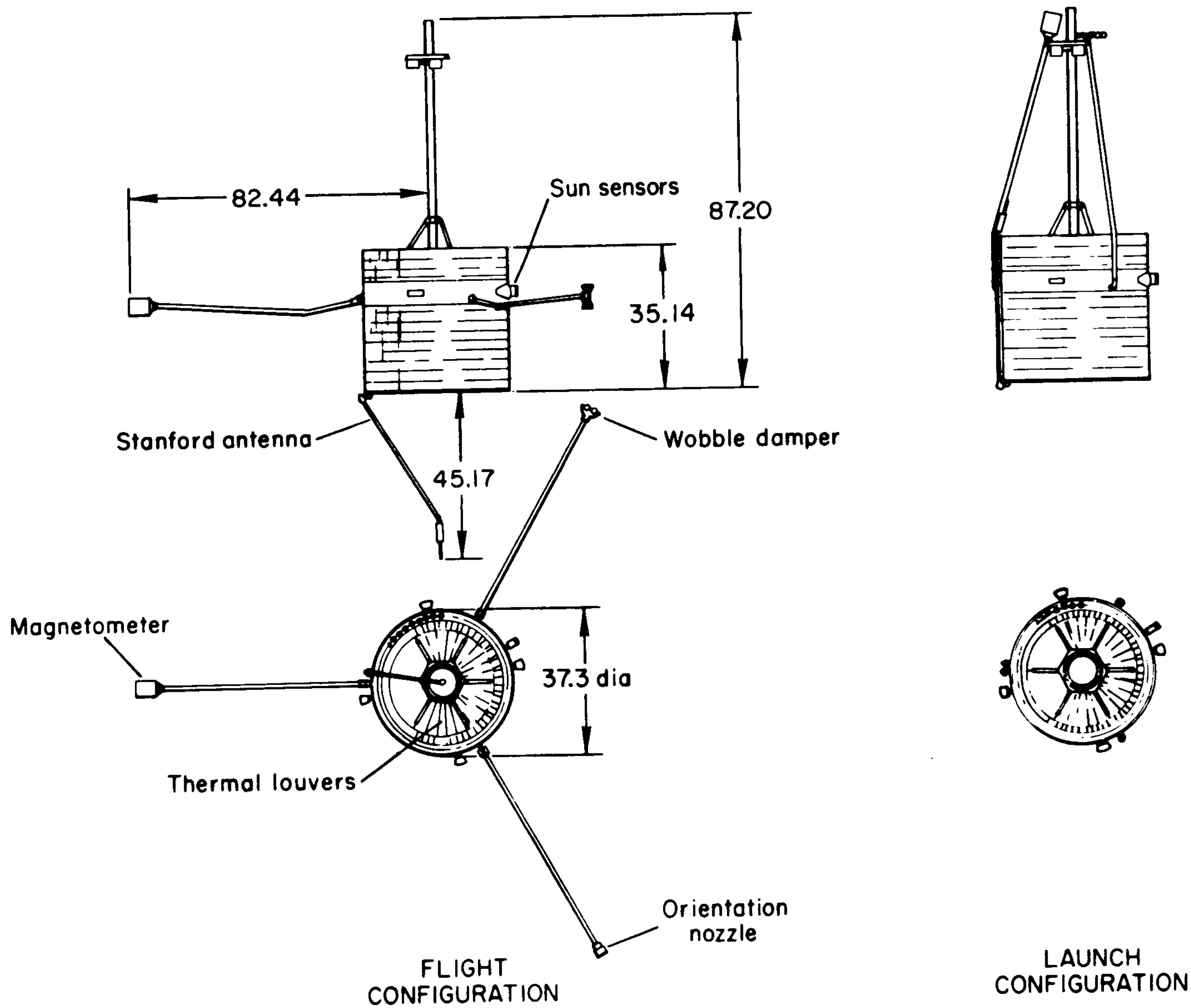


Figure 60. Spacecraft In Launch And Flight Configurations

with redundant 8-W TWTs for transmission range in excess of 40 million nautical miles (85-ft DSIF antenna). Transmission rates vary from 512 bits per second near earth to 8 bits per second at maximum range. Data storage capacity is approximately 15,000 bits. The nitrogen gas attitude control system is actuated by input from four sun sensors. The spacecraft is spin stabilized (60 rpm) and oriented normal to the ecliptic plane. Experiments are designed to sweep the ecliptic plane. Sun sensors define the direction of experiment sensors with respect to the spacecraft/sun line. Power is supplied by 10,368 n-on-p solar cells, providing 80 W at earth distance and about 90 W at 0.8 AU. Vehicle design minimizes and controls spacecraft magnetic fields; materials and currents were selected to assure high accuracy measurements of low magnetic fields in space. Pioneers 6 and 7 have magnetic fields significantly smaller than that of any previous spacecraft.

Scientific Payload.- The total weight of the seven physical sciences experiments flown to date on Pioneer is 38 lb, the highest ratio of scientific instrument weight to overall vehicle weight of any interplanetary spacecraft. Experiments are divided into four groups: (a) single-axis fluxgate magnetometer for magnetic field data; (b) detector for solar wind studies; (c) cosmic ray anistrophy detector and cosmic ray telescope for cosmic ray measurements, and (d) radio propagation measurements.

Spacecraft Environment.-

(a) Acoustics. The period of high acoustic noise levels begins with the ignition of the main engine (launch minus approximately 1 sec) and extends to the point in the ascent trajectory where maximum dynamic pressure occurs (launch plus approximately 31 sec).

The acoustic noise environment outside the spacecraft and inside the shroud is illustrated in Figure 61. The noise field will be reverberant, i.e., there will be very little deviation in the overall sound pressure levels over the spacecraft, and any point in the sound field is considered a source in which noise is generated in all directions. Transmission of sound into the spacecraft can occur in a number of ways with the most crucial being through the different leakage paths, such as the openings around the boom damper attachment brackets, around the sun sensor and antenna strut openings, between adjacent solar panels and through the top cover insulation interfaces. Acoustically induced resonance of the spacecraft structure results in the

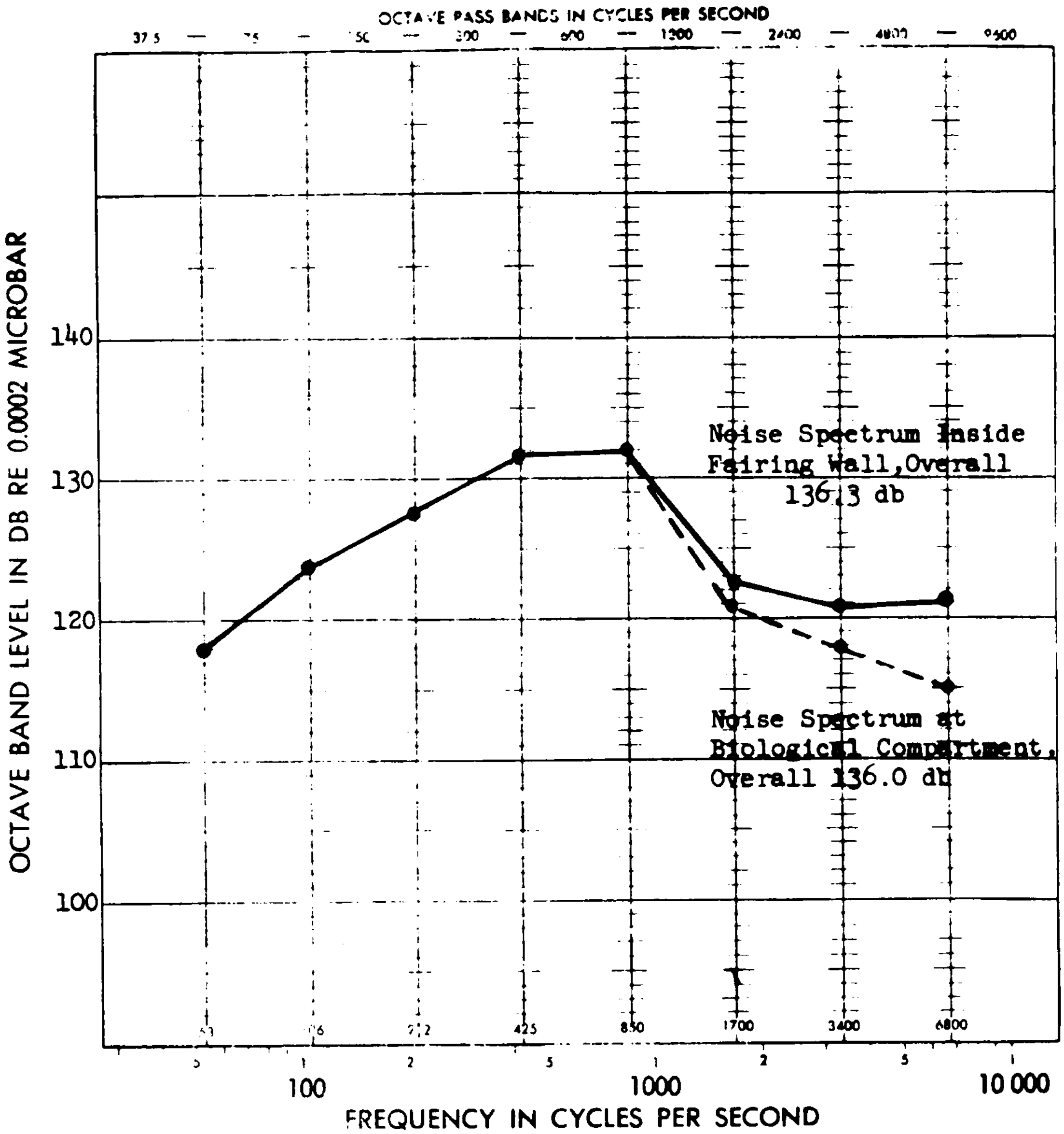


Figure 61. Acoustic noise environment outside S/C and inside shroud.

structure appearing transparent to the impinging sound at the particular resonant frequency, with the amount of sound transmission being a function of the structural damping. Significant structural resonance will occur in the low frequency range below 500 Hz. Transmission of sound through a wall obviously depends on the absorbtion characteristics of the wall material. The spacecraft structure, especially the solar array substrates, is a porous solid in which the dissipation of acoustic energy results from the severe forces that are set up by the flow of air through the small capillary pores in the material. Typical performance of this type of material allows transmission of low frequency energy and attenuates energy above 1000 Hz. The thermal insulation attached to the spacecraft is loosely packed and does not provide much attenuation except at very high frequencies.

The sound distribution within the spacecraft enclosure will not be uniform and differences in the overall sound pressure levels over the volume will be in the order of ± 3 db. The differences in the overall sound pressure levels are due primarily to standing waves set up between the parallel walls of the enclosure.

We can conclude from this discussion that the incident sound energy will be affected by the spacecraft structure primarily in the high frequency region. An estimate of the acoustic environment inside the spacecraft enclosure is illustrated in Figure 61.

The solution to a sound level problem would be to construct acoustically insulated enclosures for the experiment subjects. Any design must take into consideration vibration damping, noise absorbtion inside the enclosure and sound transmission reduction through the enclosure walls, such as, double-wall construction with acoustical lining between the walls.

(b) Vibration. Vibration data applicable to presently envisioned Bio-Pioneer experiments are given in Tables 30 and 31. These data were derived from Block 1 Pioneer test data. The peak transmissibility figures for the Pioneer spacecraft are given in Table 32. These figures were derived from qualification and acceptance tests performed on the prototype and Pioneers 6 and 7. The application of the Table 32 transmissibility data to the vibration levels mentioned above provided the acceptance levels for experiment assemblies to be installed on Pioneer. The qualification levels are derived by multiplying the acceptance levels by 1.5 and by multiplying the duration at

TABLE 30 ASSEMBLY FLIGHT SINUSOIDAL VIBRATION

ACCEPTANCE

AXIS	FREQUENCY CPS	DURATION MINUTES	LEVEL G, 0-PEAK	SWEEP RATE
THRUST	10-19 19-25 25-50 50-150 150-250 250-400 400-2000	0.23 0.10 0.25 0.40 0.20 0.17 0.58	3 4.5 3 8 4 4.8 5	4 OCTAVES PER MINUTE
LATERAL (EACH AXIS)	10-250 250-400 400-2000	1.42 0.17 0.58	6 2 4.5	4 OCTAVES PER MINUTE

QUALIFICATION

AXIS	FREQUENCY CPS	DURATION MINUTES	LEVEL G, 0-PEAK	SWEEP RATE
THRUST	10-19 19-25 25-50 50-150 150-250 250-400 400-2000	0.46 0.20 0.5 0.8 0.4 0.34 1.17	4.5 6.8 4.5 15 6 7.2 7.5	2 OCTAVES PER MINUTE
LATERAL (EACH AXIS)	10-250 250-400 400-2000	2.83 0.35 1.16	9 3 6.8	2 OCTAVES PER MINUTE

TABLE 31. RANDOM VIBRATION

LEVEL	AXIS	FREQUENCY CPS	PSD LEVEL G^2/CPS	ACCEL G-RMS	DURATION
ACCEP	THRUST AND LATERAL	20-150 150-300 300-2000	0.01 increasing from 150 cps at constant rate of 3DB/octave. 0.02	6.15 6.15 6.15	2 Minutes each axis
QUAL	THRUST AND LATERAL	20-150 150-300 300-2000	0.023 increasing from 150 cps at constant rate of 3DB/octave. 0.045	9.23 9.23 9.23	4 Minutes each axis

TABLE 32. PIONEER VIBRATION TRANSMISSIBILITY

AXIS	FREQUENCY CPS	QUALIFICATION PEAK TRANSMISSIBILITY	ACCEPTANCE PEAK TRANSMISSIBILITY
THRUST	10-19	1.5	1.5
	19-25	1.5	1.5
	25-50	1.5	1.5
	50-150	5	4
	150-250	2	2
	250-400	1.6	1.6
	400-2000	1	1
LATERAL	10-250	4	4
	250-400	1	1
	400-2000	0.9	0.9

each level by 2. The random vibration requirements for the assemblies are given without amplification to the spacecraft levels.

Acceleration.- Axial acceleration data for each of the three stages is shown in Figure 62. The maximum axial acceleration is approximately 25 G which occurs at the end of the third-stage burn. A maximum onset acceleration of approximately 280 G per second occurs at the termination of the first stage firing. Just prior to igniting the third stage, the payload and third stage are spun up to approximately 120 rpm. Maximum transient angular acceleration resulting from peak spin-up thrust occurring at ignition is approximately 27 rad/s^2. The nominal sequence of events for Pioneer is given in Table 33. This sequence is appropriate for preliminary planning purposes.

Thermal.- The emissivity requirement placed on the experiments is important in regard to providing thermal control for the spacecraft subsystems and experiments. Particular experiments not meeting the emissivity requirements must be considered in light of the total spacecraft requirements. These cases will be considered in more detail in followon studies.

The temperature levels at various positions vs time are given in Table 34. The sun-spacecraft distance vs time from launch were supplied by NASA/ARC as an approximation of the type mission to be flown. The temperatures given in this table for the mission indicated were derived from the orbital data taken from Pioneers 6 and 7. Measurement 236 is a temperature measurement located on the spacecraft platform in the experiment area. (See Figure 63.) The primary reason for these measurements changing is the distance from the sun is changing. Therefore, it can be seen that the rate-of-change is small and there are no minor fluctuations; that is, the temperature is steady and not fluctuating. Figure 64 presents thermal data for the first 40 days.

The temperature of an experiment assembly is primarily a function of the heat generated internal to the box and the platform mounting area of the experiment. In order for the spacecraft to maintain experiment temperature within specified levels, the experiment must meet several spacecraft requirements:

1) Experiment power dissipation must be no more than 0.2 $W/in.^2$ of mounting area for a spacecraft temperature of 60°F.

2) The mounting base must be bare metal with a surface finish of 32 μ in. rms or better and must be flat within 8 mil in an 8-in. length (or proportional value for actual base dimensions).

TABLE 33. NOMINAL PIONEER SEQUENCE OF EVENTS

TIME FROM LIFTOFF	EVENT
OM 01S	MAIN ENGINE IGNITION
0	LIFTOFF
OM 31S	MAXIMUM G
IM 10S	THRUST AUGMENTATION ROCKET JETTISONED
2M 29S	MAIN ENGINE CUTOFF (MECO)
2M 33S	STAGE II IGNITION
2M 48S	FAIRING JETTISONED
8M 49S	SECOND ENGINE CUTOFF (SECO)
24M 35S	THIRD STAGE SPIN-UP
24M 50S	THIRD STAGE IGNITION
25M 21S	THIRD STAGE BURNOUT
26M 20S	SPACECRAFT SEPARATION
26M 21S	SPACECRAFT BOOMS DEPLOYED AND SPIN RATE REDUCED TO APPROXIMATELY 60 RPM
30M	STEP 1 ORIENTATION COMPLETE
38 HOURS	START STEP 2 ORIENTATION
43 HOURS	STEP 2 ORIENTATION COMPLETE AND BEGIN CRUISE PHASE

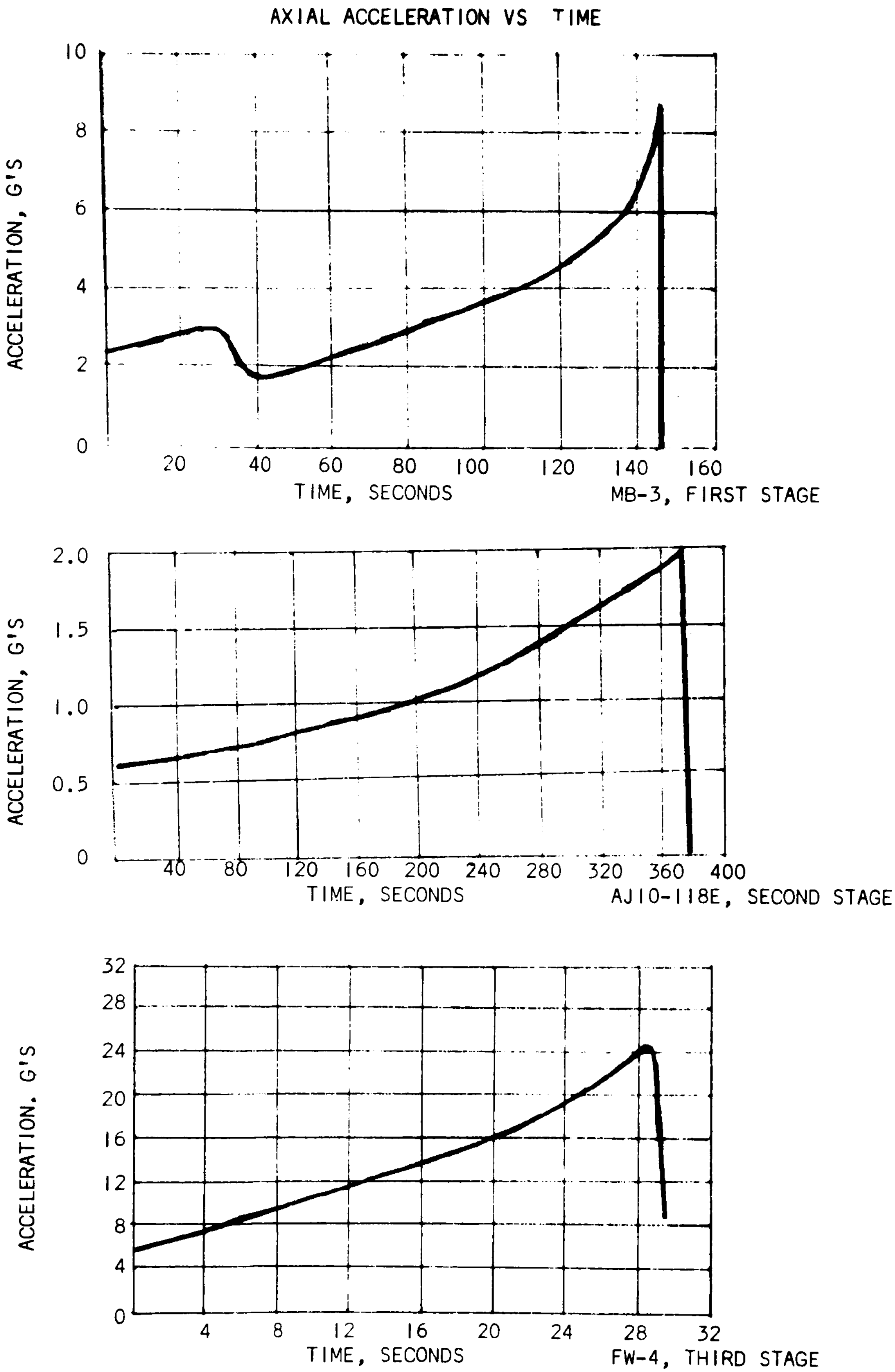


Figure 62. Axial acceleration data.

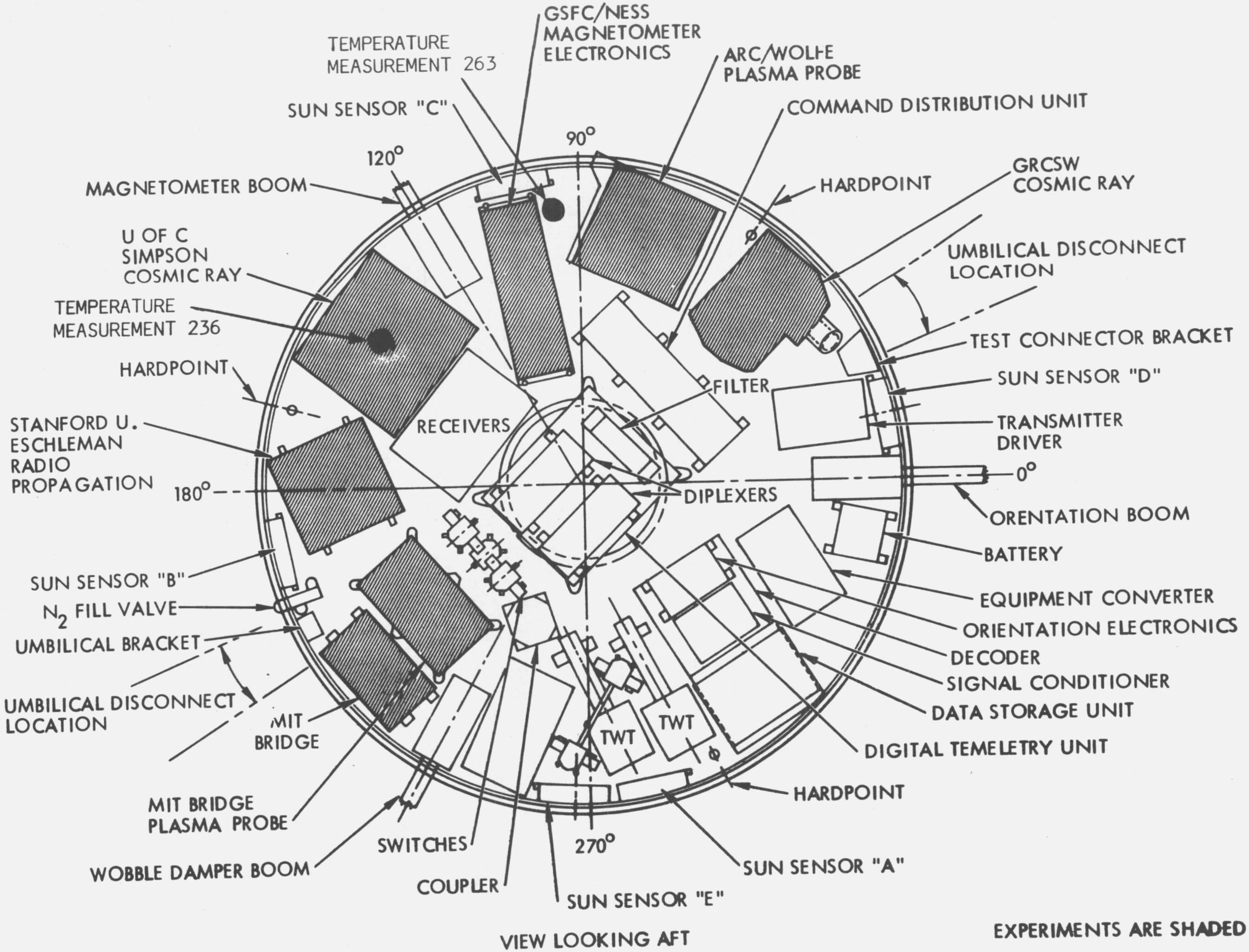


Figure 63. Spacecraft platform.

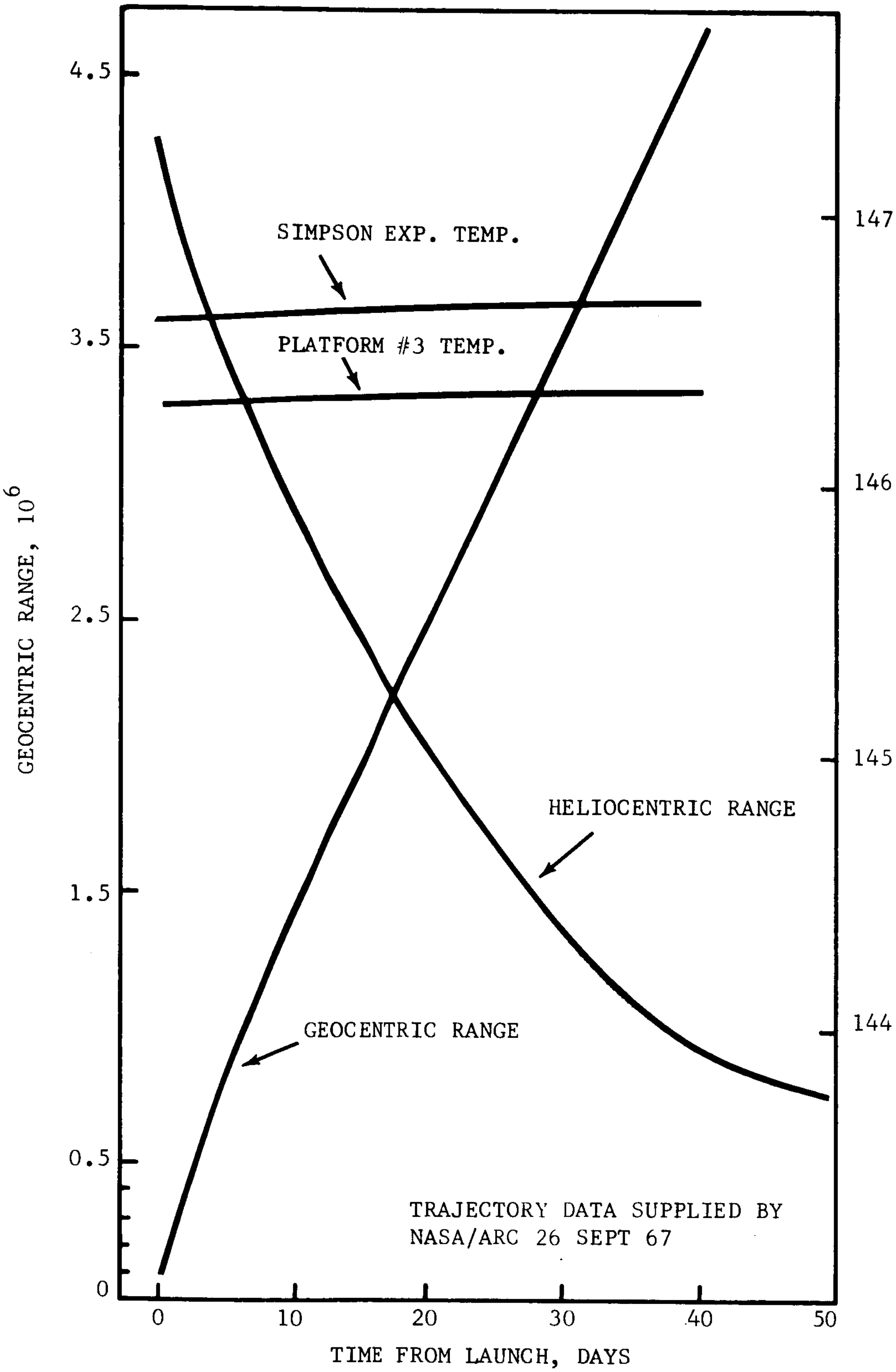


Figure 64. Thermal data vs time and position of the Pioneer spacecraft.

3) External surfaces, except the mounting base, must be treated or coated to have an infrared emittance not less than 0.72 at a temperature of 60°F.

TABLE 34. TEMPERATURE LEVELS VS TIME

Time From Launch	Spacecraft		Temperature	
	Earth Range	Sun Range	Simp. Exp. (M #236)	Plat. #3 (M #263)
Days	10^6 KM	10^6 KM	°F	°F
0	0.01	147.28	64	52
20	2.43	145.02	66	54
40	4.72	143.93	67	54
60	7.28	143.72	67	54
80	9.94	144.37	66	54
100	12.37	145.76	65	53
120	14.27	147.69	64	52
140	15.42	149.89	62	50
160	15.69	152.09	60	49
180	15.07	154.05	59	48
200	13.63	155.56	58	47
220	11.57	156.47	57	46
240	9.13	156.68	57	46
260	6.68	156.17	57	46
280	4.80	154.96	58	47
300	4.12	153.14	60	48

ENGINEERING TESTS AND ANALYSES OF BIOLOGICAL EXPERIMENTS

This section contains data common to many experiments resulting from various tests and analyses performed to establish the feasibility of accomplishing meaningful biological research aboard a Pioneer spacecraft. The tests deal specifically with determining the survivability of organisms and/or the stability of their circadian systems following exposure to simulated launch forces. The analyses deal with problems of spacecraft dynamics; analytical tests of the effectiveness of "passive" thermal control; and determination of the adequacy of data handling as a function of data requirements and spacecraft trajectories.

Environmental Tests

Biological material was instrumented and mounted in the manner proposed for the experiment hardware and exposed to the simulated launch forces of vibration, acoustics and acceleration (Table 35). Test subjects were returned to the laboratory for study of survivability and/or stability of the circadian system. With one exception, the principal investigators reported that all specimens survived a simulated launch and/or that there was no degradation of the circadian system attributable to the test program.

The one exception was experienced in populations of vinegar gnat pupae. One vibration test was run with the pupae in a standard oxygen nitrogen atmosphere at 14.7 psi; one vibration test was run in 100% nitrogen atmosphere at 14.7 psi; and one population held in 100% nitrogen was exposed to all three launch stresses. Vibration accelerated the rate of eclosion, and storing the pupae in 100% nitrogen produced an unacceptable level of mortality. The effects of vibration can probably be damped out with suitable mounting of the experiment package, but time did not permit further study. Laboratory studies have shown that the stage of pupal development at which atmospheric oxygen is replaced by nitrogen is critical to survival. Subsequent laboratory testing endorsed the practicality of using nitrogen but further study is required. The following paragraphs describe the mechanics of the environmental tests performed on the biological material.

TABLE 35. REPLICATION OF ORGANISMS USED TO DETERMINE SUSCEPTIBILITY TO SIMULATED LAUNCH FORCES

SPECIES	CONTROL	VIBRATION	ACOUSTIC	ACCELERATION	SEQUENTIALLY** VIBRATION, ACOUSTIC AND ACCELERATION
Potato Sprout	1	1	1	1*	-
Bean Leaf	2	2	2	2	2
Fiddler Crab	1	1	1	1*	-
Cockroach	3	-	-	-	3
Vinegar Gnat Pupae (O_2)	500	500	-	-	-
(N_2)	332	332	-	-	332
Pocket Mouse	3	-	-	-	3
C-Mouse	6	6	6	6	6

* Acceleration tests on Potato and Crab were done at Space Defense Corporation. In addition, single specimens were maintained on a centrifuge rotating at 60 rpm continuously for several weeks with no ill effects.

** All three stresses delivered within a two-hour period.

Acoustics.- Specimens were suspended by resilient mounting systems within the Norair Reverberant Chamber. A microphone located within the test volumn was used to monitor the sound field. A Noraircoustic Generator MK V-H-20 was used to provide the random sound energy directed at the specimens (Figures 65 and 66).

Sound field exposure was for 2 1/2 minutes at an overall sound pressure level of 136 db. Sound spectra typical of the acoustic environment are tabulated below with the test specification.

TABLE 36. ACOUSTIC ENVIRONMENT TO WHICH BIOLOGICAL MATERIAL WAS SUBJECTED

Octave Band (Hz)	Sound Pressure Level (db re: .0002 dynes/cm^2)	
	Specification	Run 1
37.5 - 75	118	118
75 - 150	124	124
150 - 300	128	129
300 - 600	131.5	131
600 - 1200	132	130
1200 - 2400	121	121
2400 - 4800	118	114
4800 - 9600	115	113
Overall	136 db	136 db

The following test equipment was used to provide and monitor the acoustic environment:

1 - Noraircoustic Generator MK V-H-20

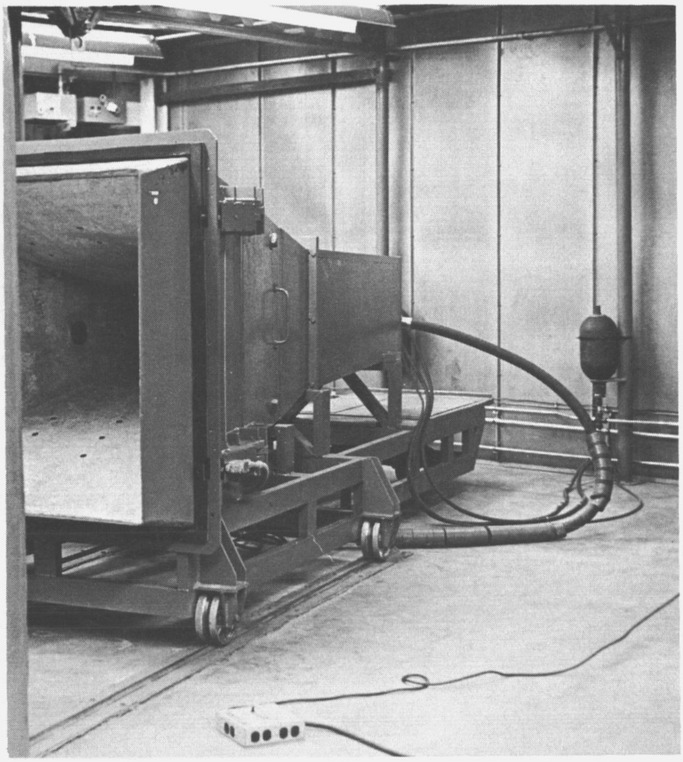
1 - Photocon Model 524 Microphone

1 - B & K Type 2409 Electronic Voltmeter

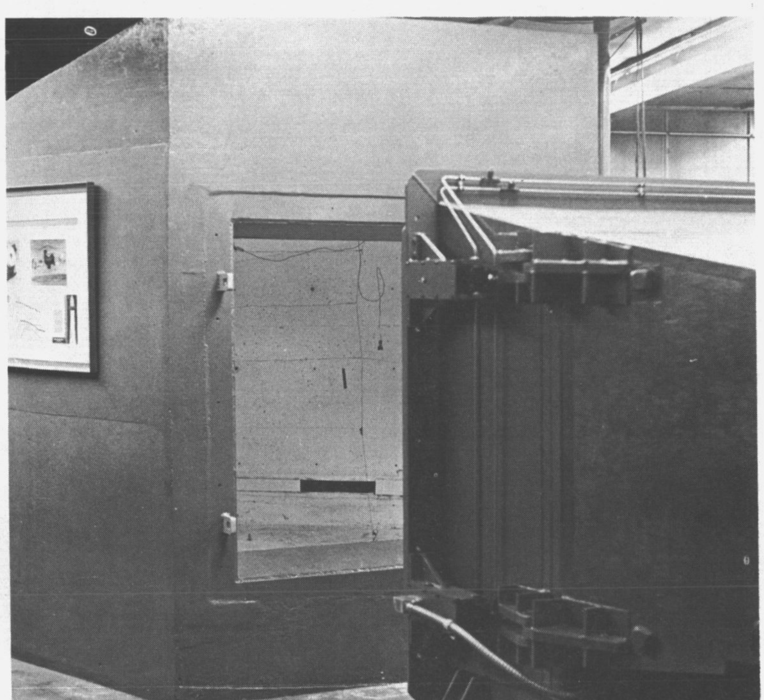
1 - B & K Type 2111 Audio Frequency Spectrometer

1 - B & K Type 2305C Level Recorder

3 - Special test setups within the Norair 170 cubic foot Reverberant Chamber



Acoustic Generator



Test Chamber

Figure 65. Acoustic generator used to provide random sound energy during a study of the biological effects of noise anticipated during the launch of a Pioneer spacecraft.

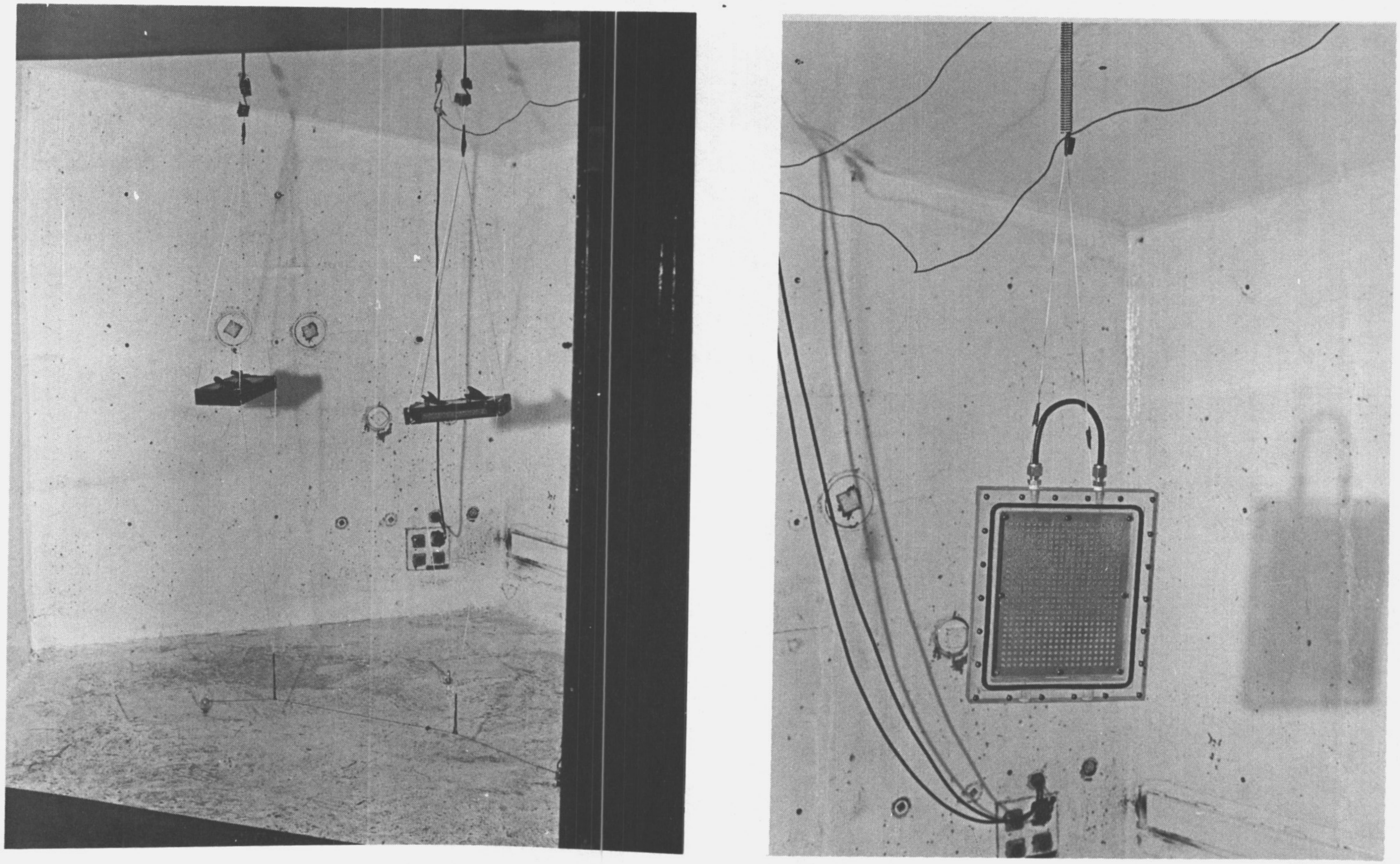


Figure 66. Biological specimens mounted in acoustic test chamber. Left: Two bean leaf modules. Right: _Drosophila_ pupae bed.

Vibration.- Specimens housed in simulated experiment hardware were mounted normal to the exciter head. The specimens and containers were subjected to random excitation in the thrust or vertical axis for a period of two minutes. The exciter head was then rotated 90 degrees and the specimens subjected to a 4-minute random vibration test. The 4-minute exposure period was divided into two 2-minute runs separated by 2 minutes (Figures 67 and 68).

The shaker was equalized with bare table at full test level. A plot of the equalized spectrum is shown in Figure 69 along with a plot of the test specification. The specimens were mounted on the exciter head after equalization was complete for the test runs.

The following test equipment was used to provide and monitor the vibration environment:

1 - Ling A-249 Vibration Exciter System

1 - Endevco Model 2213 Accelerometer

1 - SD 101A Tracking Filter w/20 cps Filter

1 - Moseley Model 7035 X-Y Plotter

1 - Ballantine Model 320 True RMS Voltmeter

Acceleration.- Test specimens were subjected to acceleration forces that varied from 5.5 g's to 25.0 g's in 28 seconds then back to 9.0 g's in 1 second. Acceleration forces were varied by changing the position of the specimens on a constant speed centrifuge. The specimens were placed on a movable carriage 0.92 ft from the centrifuge axis. The centrifuge was brought up to a speed of 2.22 rps. At this speed the carriage was moved to a position 4.2 ft from the axis in one second (Figures 70 and 71). The centrifuge was then stopped. The time from startup to complete stop was approximately 5 minutes. Radial position of the carriage was determined by a linear potentiometer attached to the carriage drive and recorded on an oscillograph. Tracings of these positions vs time plots are presented as acceleration vs time in Figure 72.

The following items of test equipment were used to provide and monitor the acceleration environment:

1 - Centrifuge ETF: 10 (USAF 9574)

2 - CEC Oscillograph EP 10701

3 - Waldale Potentiometer ET 9273

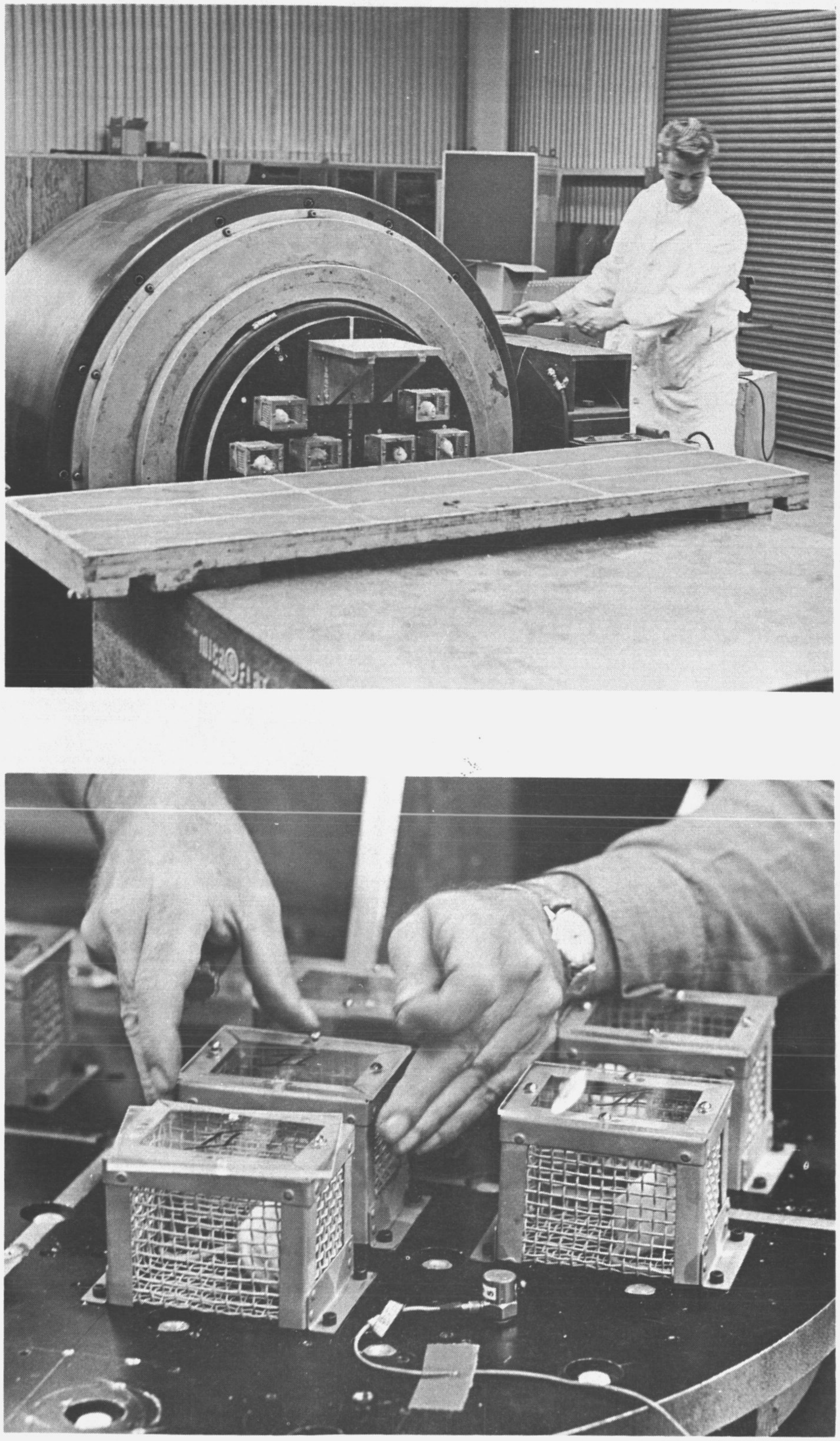
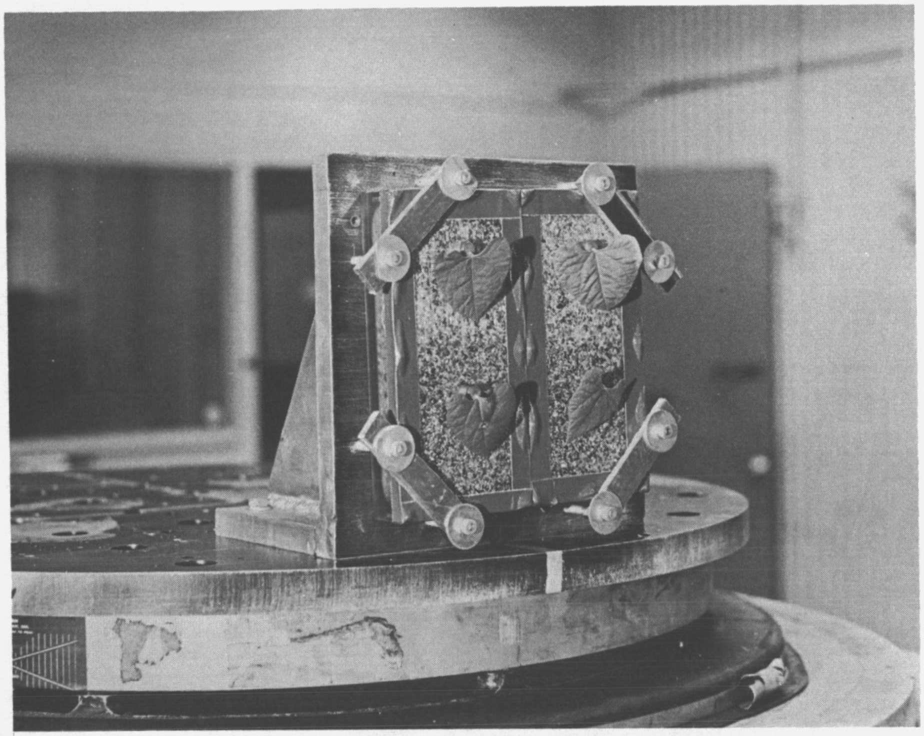


Figure 67. C-mice mounted on an electromagnetic shaker to study the biological effects of vibrations anticipated during the launch of a Pioneer spacecraft.



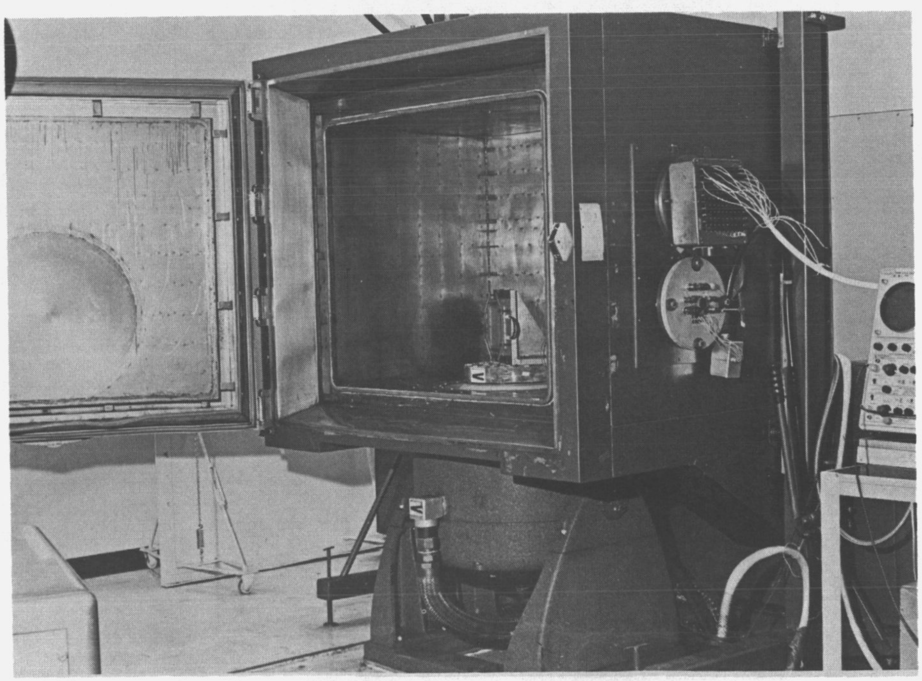


Figure 68. Biological specimens mounted on electromagnetic shakers to study the biological effects of vibrations anticipated during the launch of a Pioneer spacecraft. Upper: Bean leaves. Lower: *Drosophila* pupae bed.

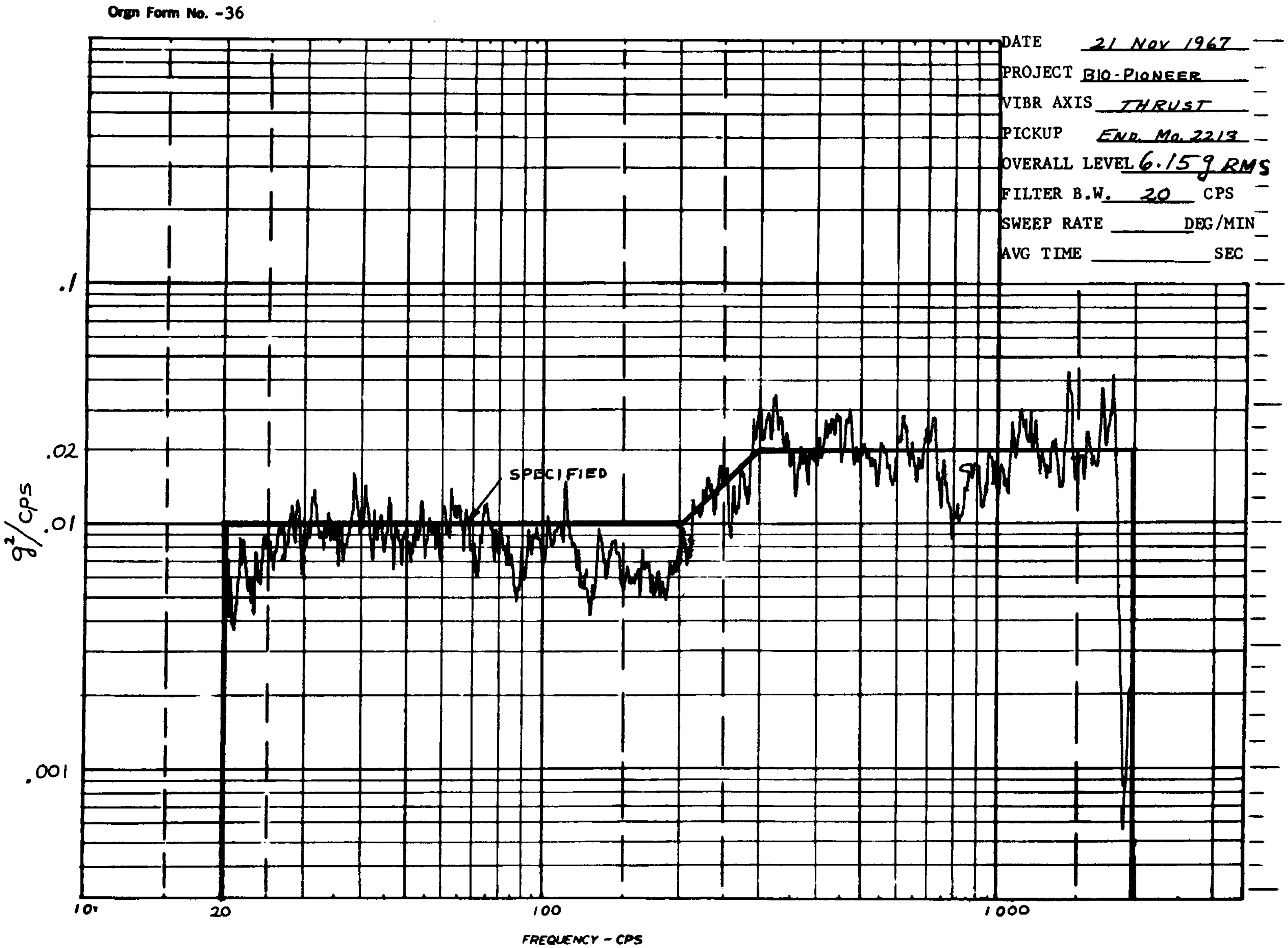
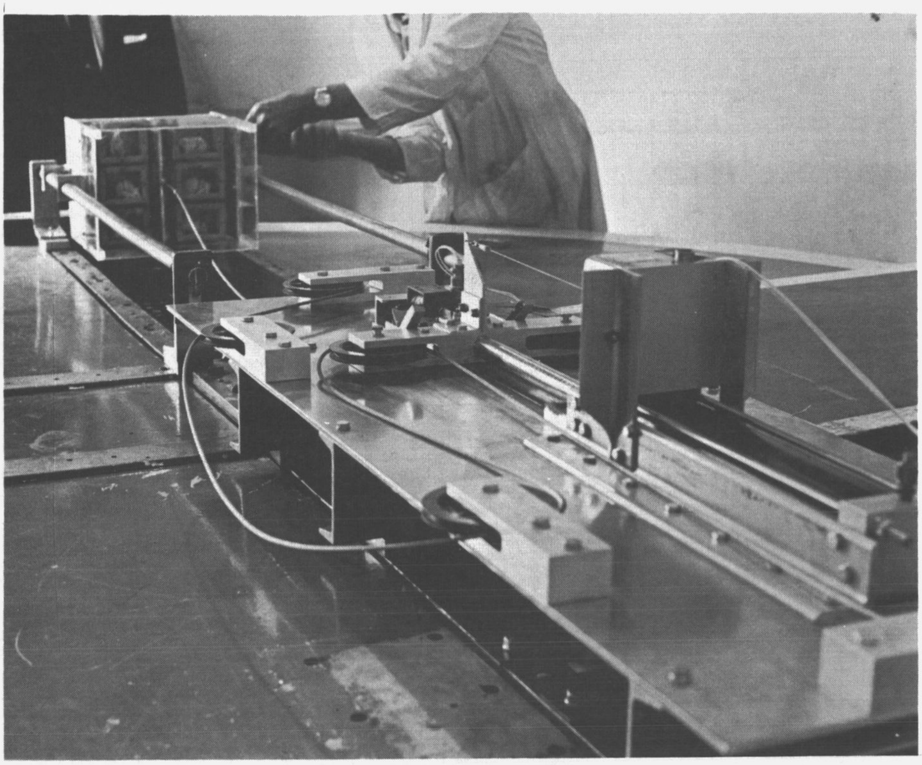


Figure 69. Typical recording of accoustical environment during tests of biological effects of noise anticipated during the launch of a Pioneer spacecraft.



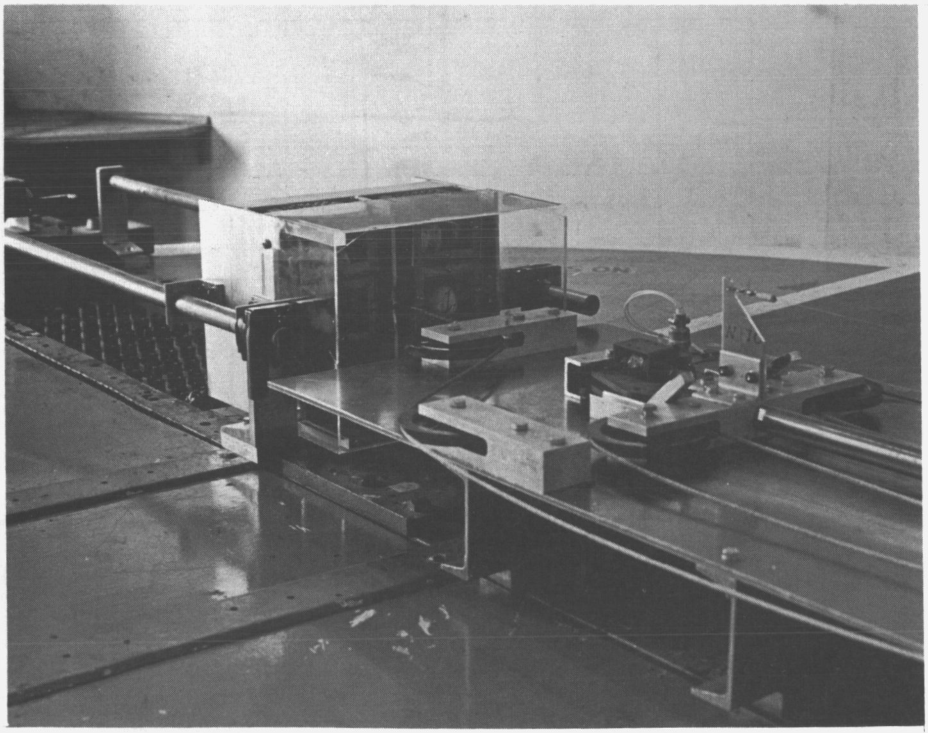


Figure 70. C-Mice mounted on a centrifuge to study the biological effects of accelerations anticipated during the launch of a Pioneer Spacecraft. Top: At the long radius position. Bottom: At the short radius position.

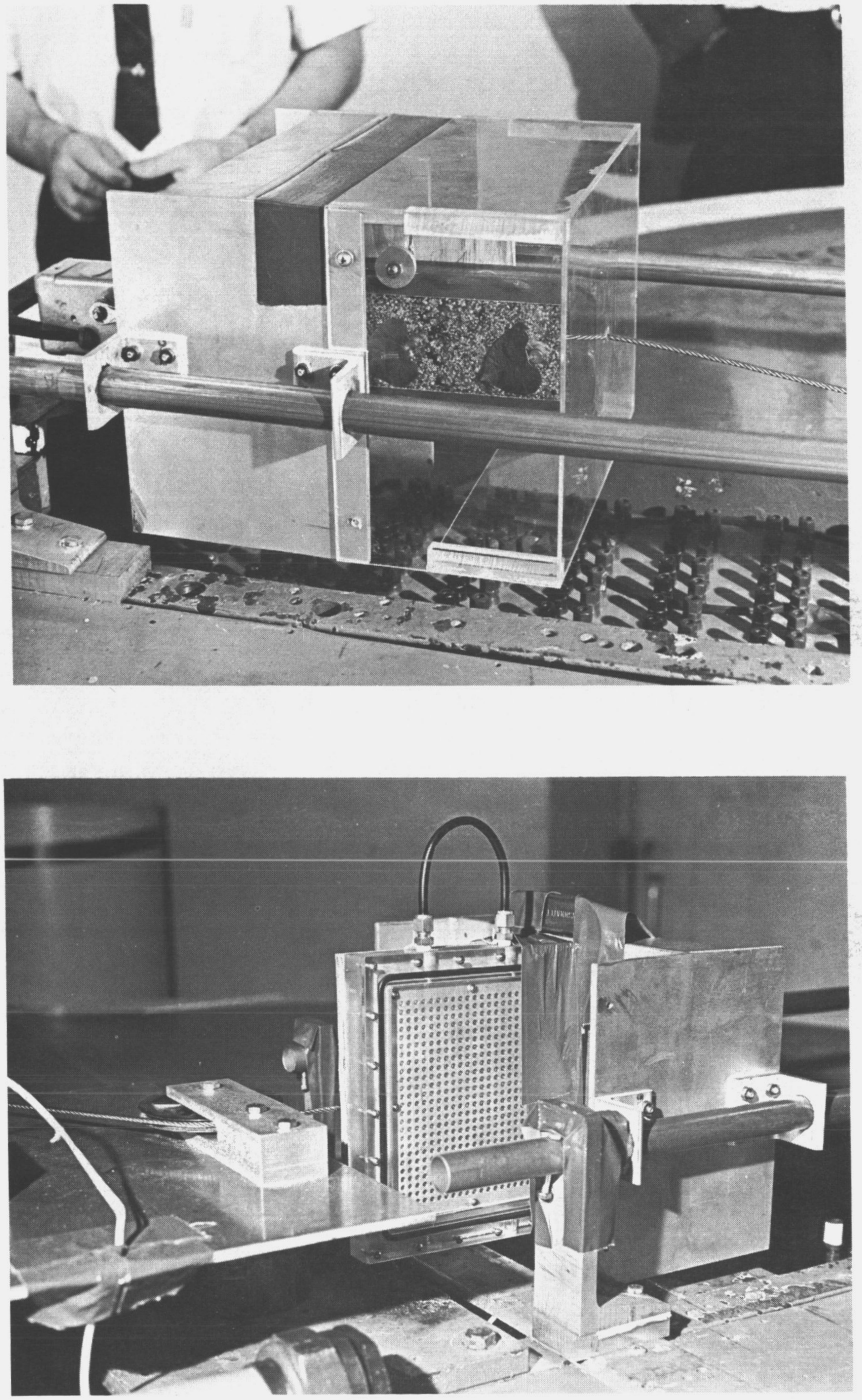


Figure 71. Biological material mounted on a centrifuge to study the biological effects of accelerations anticipated during the launch of a Pioneer spacecraft. Top: Bean leaves. Bottom: Drosophila pupae bed.

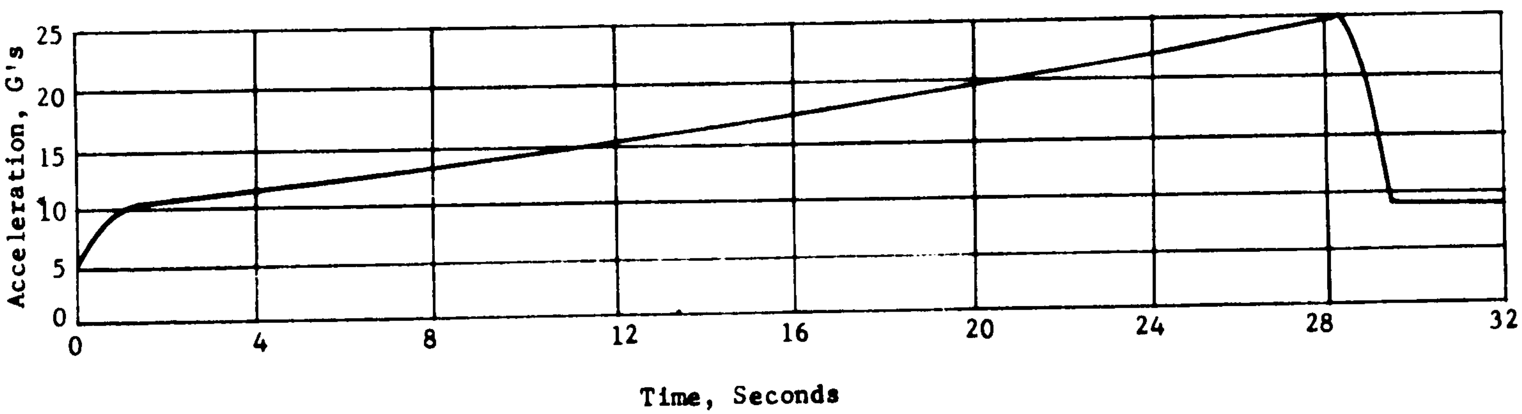


Figure 72. Typical recording of acceleration profile during tests of the biological affects of accelerations anticipated during the launch of a Pioneer spacecraft.

The effects of the acceleration on the potato and fiddler crab were studied at Space Defense Corporation using their Space Flight Acceleration Profile Simulator (SFAPS-Mark I). The profile duplicated was that supplied to Space Defense as indicative of the characteristics of the Pioneer spacecraft. Both a sprouting potato plug and a Fiddler Crab (Uca) were studied and the timing and staging were adjusted to simulate the Pioneer 7 sequence of events. While no long-term studies have been made upon the specimens subjected to the acceleration tests, short term studies show that there were no detrimental effects and that no difficulties are anticipated in the BioPioneer spaceflight.

The possibility of angular rotation inducing disorientation or an aberrant behavior pattern in the mice is judged remote. Laboratory studies of this phenomenon in man have been performed in mixed force fields in which centrifugal force was acting at right angles to gravitational force and disorientation was experienced. The reaction was further complicated by visual cues depicting a static environment. In the spinning spacecraft, however, there will be negligible cross field forces and no visual cues since the experiments are to be done in constant dark. Further assurance that the mice will be unaffected is provided by results of animal experiments at University of California at Davis, University of Minnesota and University of Kentucky, in which animals kept on centrifuges for long periods of time quickly adapted. Indeed the experiment at Davis reportedly includes maintenance of breeding colonies of small animals on a centrifuge.

Effect of Biological Experiments on Spacecraft Dynamics

Assumptions.- The dynamic effects of adding any of seven different bio-experiments to the Pioneer spacecraft were investigated. Preliminary layouts and verbal information supplied by Northrop Corporate Laboratories form the basis for the dynamic studies. The primary areas of investigation were spacecraft balance and spin stability.

The basic Pioneer 6-7 spacecraft without the Stanford antenna and solar sail was assumed. In order to arrive at approximate quantitative results for the study, the following spacecraft properties (typical of previous Pioneer spacecraft) were assumed:

Spacecraft Weight	140 lb
Deployed Spacecraft Transverse Inertia, A	6.75 slug ft^2
Deployed Spacecraft Spin Inertia, A	8.85 slug ft^2
Stowed Spacecraft Transverse Inertia, A	6.5 slug ft^2
Stowed Spacecraft Spin Inertia, C	5.1 slug ft^2

The dynamic effects of each of the experiments were considered separately although several of the experiments may ultimately be combined in a single space launch. The experiments, most of which are designed for a 4-month in-orbit life, which were considered are:

a. "C" Mouse Experiment (Four layouts, Plans A,B,C, and D were considered.)

b. Pocket Mouse Experiment

c. Cockroach Experiment

d. Fiddler Crab Experiment

e. Pupae Fruit Fly Experiment

f. Potato Experiment

g. Bean Leaf Experiment

The experiments will all be positioned on the equipment platform at a radius where they will have close to a one "g" environment. Currently the worst case spin rate planned is 45 rpm which places the experiments about 17 in. from the spacecraft spin axis. However, as shown in "Experiment Integration" section of this report, the majority of the individual experiments or experiment combinations were placed nearer to the spacecraft spin axis with resultant higher spacecraft spin rates. The lesser radii used for certain experiments somewhat alleviate the dynamics problem but the spacecraft balancing problem remains the most formidable one to solve in followon studies.

The most serious dynamics problem associated with the bioexperiments is static and dynamic balance when mammals are on-board. The transfer in location of the food and oxygen for the proposed "C" mouse layouts will result in high static and dynamic unbalances. The study indicates that a careful layout of these experiments will be required to maintain acceptable static and dynamic balance limits. Arrangements where oxygen and food are transferred symmetrically with respect to the equipment platform is minimized would be preferred. Balancing problems for the remainder of the experiments will be much less serious. Figure 73 compares the predicted dynamic unbalances for the BioPioneer experiments with previous Pioneer balancing requirements.

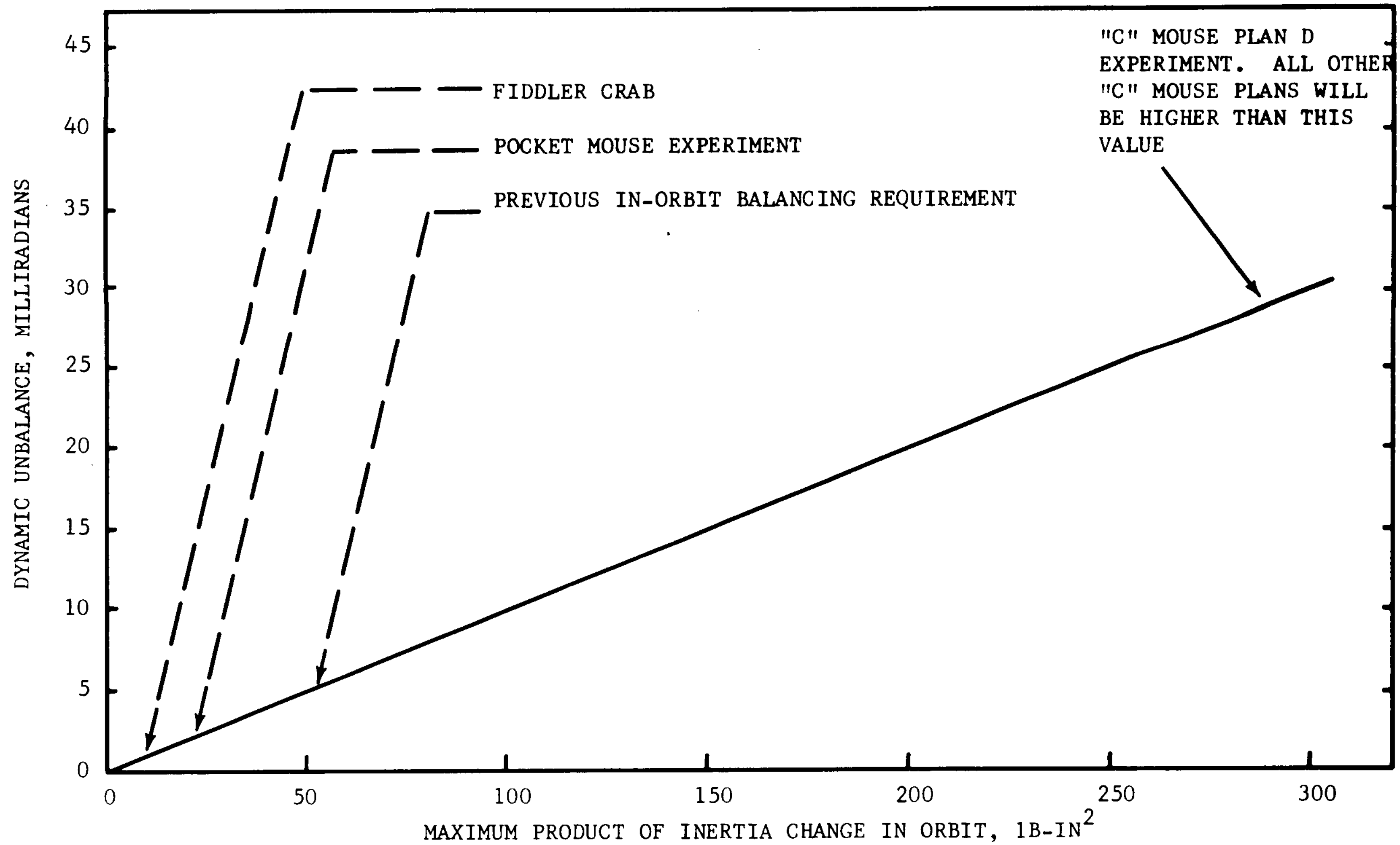


Figure 73. Dynamic unbalance caused by mass transfer of the experiments during in-orbit operation.

The effects of spacecraft wobble were evaluated. The existing Pioneer wobble damper will keep the spacecraft wobble angle within a 2 degree half cone angle after initial wobble due to spacecraft separation and boom deployment has been damped out. Solar radiation pressure is not expected to produce attitude drift above 0.015 degree/day.

Balance Requirements.- Static and dynamic balance of the spacecraft are important since the allowable center of mass offset and principal axis misalignment are very small. The problem is compounded by the motion of passengers, food and oxygen. The Douglas report, SM-48897, "Improved Delta Spacecraft Design Restraints," revised January 1966, specifies the spacecraft balance requirements at launch. These are:

a) Static unbalance (center of mass offset from the nominal geometrical centerline), 15 mil.

b) Dynamic unbalance (angular misalignment between the longitudinal principal axis and the geometrical centerline), 2 mrads (or about 15 lb-in.^{2}).

The in-orbit balancing requirements, which are based on subsystem requirements on board the spacecraft (especially the communication antenna) are:

a) Static balance, 0.03 in.

b) Dynamic balance, 5 mrads (or about 50 lb-in.^{2}).

These in-orbit balancing requirements will need re-evaluation for the Bio-Pioneer but may be typical of the final requirements, depending on which of the original Pioneer physical experiments are left on the spacecraft for the BioPioneer.

Of all the experiments, the "C" mouse experiment represents the most formidable balance problem. Unrestricted motion of the "C" mice in their cages can produce a maximum statis unbalance of about 3 mils and a maximum dynamic unbalance of about 1 mrad (the totals are for three "C" mice in Plan A and four "C" mice in Plan D). However, the pocket mice will cause less imbalance as can be seen in Figure 65. It therefore appears that balancing to meet the launch requirements would be difficult but achievable for launches with mice experiments on board.

Imbalances induced during orbit are caused primarily by food and oxygen transfer. None of the proposed "C" mouse layouts appear feasible for meeting the present in-orbit balancing requirements and would require relaxation of balance requirements. The best of the four from this standpoint, Plan D, results in a change in spacecraft center of mass of about 0.1 inch and a change in product of inertia of over 300 lb-in.^{2}. The estimated maximum changes in mass center and product of inertia for the remaining experiments are shown in Table 37.

TABLE 37. ESTIMATED MAXIMUM CHANGES IN MASS CENTER AND PRODUCT OF INERTIA FOR BIOLOGICAL EXPERIMENTS

Experiment	Lateral Change in Mass Center (in.)	Product of Inertia Change (lb-in.^{2})
Pocket Mouse (3)	0.043	20
Cockroach	Negligible	6
Fiddler Crab	.01	10
Fruit Fly	Negligible	Negligible
Potato	Negligible	2
Bean Leaf	Negligible	Negligible
C-Mouse	(see discussion)	

As mentioned previously, experiment layouts where food and oxygen transfer can be made symmetrically with respect to the spacecraft spin axis and at relatively the same "height" from the equipment platform will help alleviate the balance problem.

Spacecraft Wobble.- Transverse torques can cause wobble (coning motion of the spacecraft spin axis about the spacecraft angular momentum vector). Major contributors to the wobble angle will be:

a) Booster errors.
b) Spinup
c) Separation
d) Boom Deployment
e) Attitude Control
f) Motion of Passengers

Previous Pioneer results indicate that the maximum wobble angle will exist just after the booms are deployed. This estimate will not change appreciably for the BioPioneer. A worst case value of about six degrees can be expected. The continuous rolling motion of the cage floors caused by wobble will make the mice think they are on-board a ship. A six-degree wobble angle, for example, would correspond to a peak-to-peak floor motion of about 3.5 in. and a frequency of about 0.25 Hz. It is shown in the analyses to follow that the wobble damper will reduce the wobble angle from six degrees to one degree in about 10 minutes.

The existing Pioneer 6-7 wobble damper is expected to be adequate for the BioPioneer. The damper consists of two ball-in-tube impact dampers located at the end of one of the deployed booms. Energy is dissipated as the balls inelastically impact the ends of the tubes.

The damper analysis previously made for the Pioneer spacecraft was used to evaluate damper performance. The rate of spacecraft wobble angle decay is related to the energy dissipation in the impact damper by:

$$\frac{d\theta}{dt} = \frac{\frac{dT}{dn}}{Cs^2 \lambda \theta}$$

where

$\frac{d\theta}{dt}$ = Rate of change of wobble angle (angle between momentum vector and the axis of symmetry)

$\frac{dT}{dn}$ = Energy dissipation per cycle

λ = Inertia ratio, $\frac{I_{spin} - I_{transverse}}{I_{transverse}} = 0.31$

s = Spin rate, rad/sec

The damper threshold of about one degree wobble angle is reached when rolling friction of the balls causes them to stop impacting the tubes. (The threshold would be reached in about 10 minutes for the proposed configuration and an initial 6-degree wobble angle.) Thereafter, damping continues, but at a much clower rate as the booms flex. Figure 74 shows the damping characteristics.

Previous analyses were used to evaluate wobble which could be induced by motion of the mice. The rate of energy increase which the mice would conceivably cause was compared with the rate of energy dissipation which is provided by the wobble damper. The mice can efficiently produce spacecraft wobble if their axial impulsive motion (a continuous back and forth cycling within their cages) is synchronized with the spacecraft body precession rate. The induced wobble angle was shown to equal the principal axis shift due to this motion:

$$\Delta\Theta = \frac{mr\delta}{C-A}$$

where

m = Mouse mass, slug

r = Radial mouse location, ft

δ = Axial shift in mouse position, ft

C = Spacecraft spin inertia, slug-ft^2

A = Spacecraft transverse inertia, slug-ft^2

The time interval between shifts from one end of the cage to the other which will produce a maximum wobble buildup is the half period of the body precession cycle:

$$\Delta t = \frac{\pi}{Cs}$$ (equals about 2 seconds for the proposed configuration)

where $\lambda = \frac{C-A}{A}$

s = Spin rate

The rate of wobble increase is:

$$\theta = \frac{\Delta\Theta}{\Delta t} = \frac{mr\delta\lambda s}{\pi(C-A)}$$

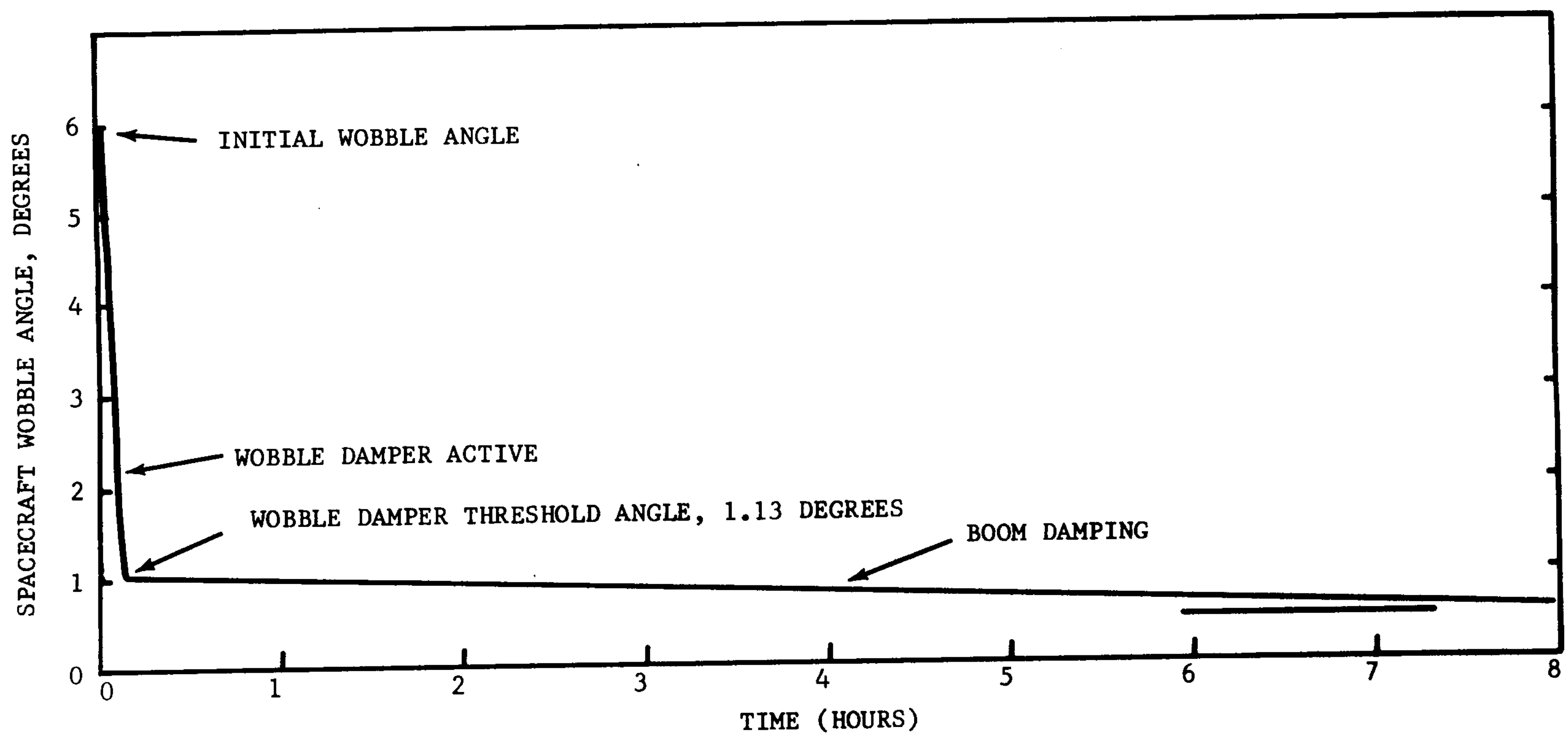


Figure 74. Pioneer wobble angle decay for 6° of initial wobble.

For $\Theta << 1$, the wobble energy is approximately:

$$E_w \cong \lambda \Theta^2 \frac{Cs^2}{2}$$

and the rate of wobble increase is:

$$\dot{E}_w = \lambda \Theta \dot{\Theta} Cs^2$$

Substituting,

$$\dot{E}_w = \frac{mr\delta\lambda^2 Cs^3 \Theta}{\pi(C-A)}$$

where

m = 25 grams each (C - mice)

r = 1.41 ft (for 45 rpm spin rate)

δ = 0.17 ft

λ = 0.31

C = 8.85 slug ft^2

A = 6.75 slug ft^2

s = 4.72 rad/sec

The rate of wobble energy increase is:

$$\dot{E}_w = .005\ \theta \text{ ft-lb/sec}$$

The energy dissipation rate for the Pioneer damper is:

$$\dot{T} = 10^{-6} s^3 f\left(\frac{q}{L\Omega^2}\right)$$

where

$\dot{T}$ - Energy dissipation rate, ft-lb/sec

s - Spin rate, rad/sec

$f\left(\frac{q}{L\Omega^2}\right)$ - Abscissa of Figure 75

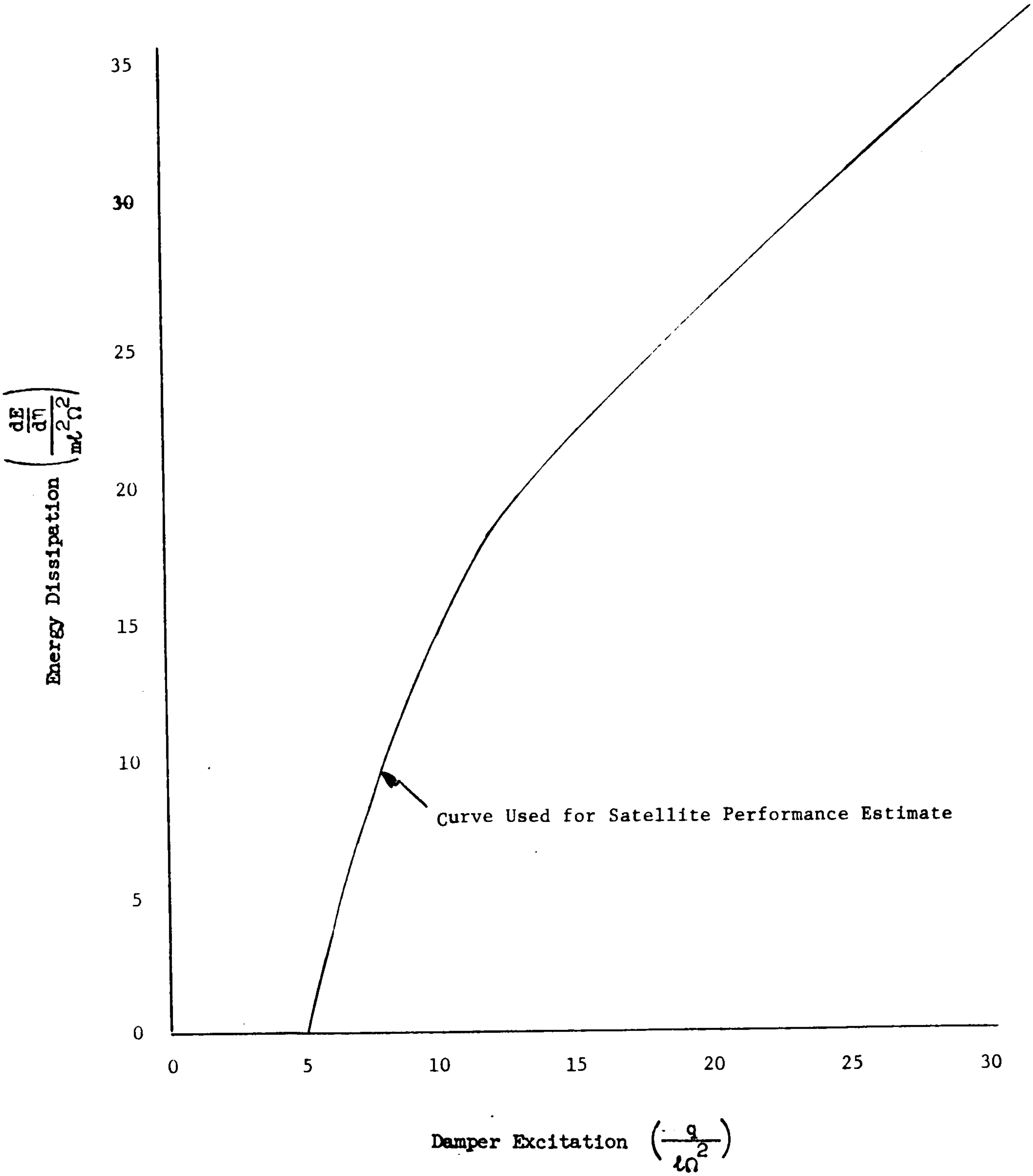


Figure 75 Impact wobble damper energy dissipation.

Figure 76 compares the "C" mouse induced energy increase with the damper energy dissipation rate. The bound on wobble angle is obtained when the damper energy dissipation rate exceeds the energy increase rate due to motion of the mice. It can be seen that wobble is bounded at approximately 2 degrees.

The "C" mouse experimenter should determine whether mouse motion as prescribed above is likely to occur. In addition, the probability of more than one mouse moving in unison with other mice on board will need to be determined. If it can be determined that the "C" mice will be fairly dormant during in-orbit operation, the probability of producing the above wobble angle is remote.

Attitude Drift Due to Solar Pressure.- Solar radiation pressures will cause a long-term attitude drift of the spacecraft if the center of radiation pressure is offset from the satellite center of mass. For this study, the basic Pioneer 6-7 configuration was changed as follows:

a) The Stanford experimental antenna was removed.

b) The solar sail was removed.

Removal of these items has a compensating effect for solar pressure torque calculations.

The attitude drift due to solar pressure torque is:

$$\alpha = \frac{P(c.p. - c.m.)\,\Delta t}{Cs}$$

where

α	- Attitude change, rad
P	- Solar pressure $\cong$ 12 x 10^{-7} lb
c.p. - c.m.	- Distance between center of pressure and center of mass $\cong$ 0.1 ft
Δt	- Time increment, 1.05 x 10^{+7} sec
C	- Spin inertia, 8.85 slug ft^2
s	- Spin rate, 4.72 rad/sec

The attitude drift after four months due to solar pressure is 1.7 degrees.

Effects of Cockroach "Running Wheel".- The cockroach capsule contains a small rotor which has a spin axis aligned but laterally displaced from the spacecraft spin axis. The cockroach uses the rotor to exercise and reportedly

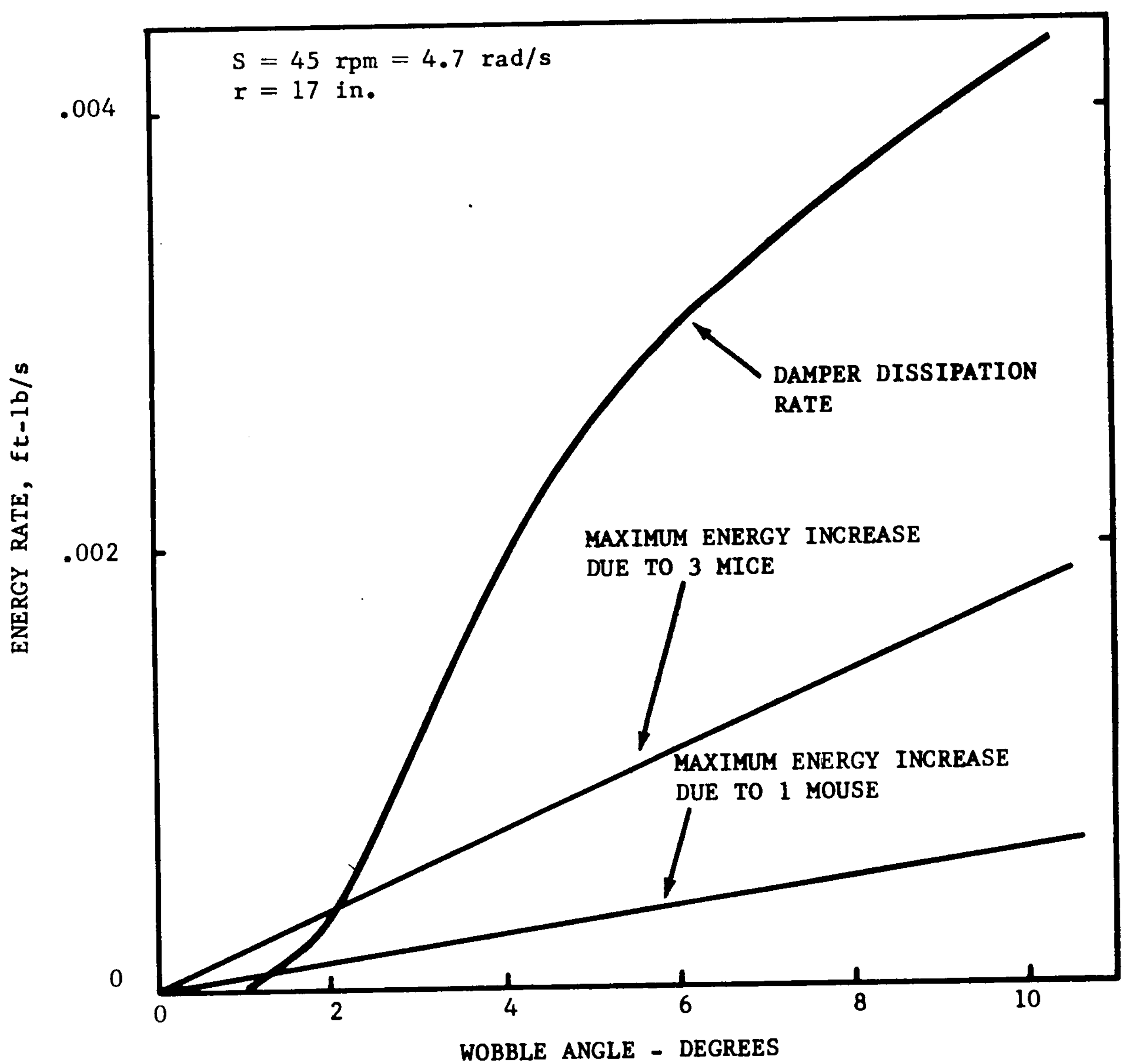


Figure 76. Comparison of damper energy dissipation rate to energy increase due to motion of "C" mice.

can cause it to spin up to as high as 100 rpm. This effect on spacecraft spin stability was investigated. The criteria for spacecraft spin stability for the proposed configuration are:

$$\lambda_1 \cdot \lambda_2 > 0$$

$$\lambda_1 h > 0$$

where

$$\lambda_1 = \quad C_1 - B_1 - B_2 \quad s_1 + C_2 s_2 \quad / A_1 + A_2$$

$$\lambda_2 = \quad C_1 - A_1 - A_2 \quad s_1 + C_2 s_2 \quad / B_1 + B_2$$

$$h = C_1 s_1 + C_2 s_2$$

A_1 = Spacecraft transverse inertia, 3.1 x 10^4 lb-in^2

B_1 = Spacecraft transverse inertia, 3.1 x 10^4 lb-in^2

C_1 = Spacecraft spin inertia, 4.1 x 10^4 lb-in^2

s_1 = Spacecraft spin rate, 45 rpm

A_2 = Rotor transverse inertia, .029 lb-in^2

B_2 = Rotor transverse inertia, .029 lb-in^2

C_2 = Rotor spin inertia, .044 lb-in^2

s_2 = Rotor spin rate - this quantity was determined for the instability condition

h = Angular momentum

It was found that the cockroach would have to spin the rotor to about 10^6 rad/sec (in a direction which opposes the spacecraft spin direction) to create spacecraft instability.

Feasibility of "Passive" Thermal Control of Biological Experiments

A thermal analysis for a typical experiment was performed by Northrop to determine the practicality of passive thermal control for organism environment. The Vinegar Gnat (Drosophila) experiment was chosen for this analysis since it represented one of the more difficult thermal control problems and required both steady-state and transient analysis.

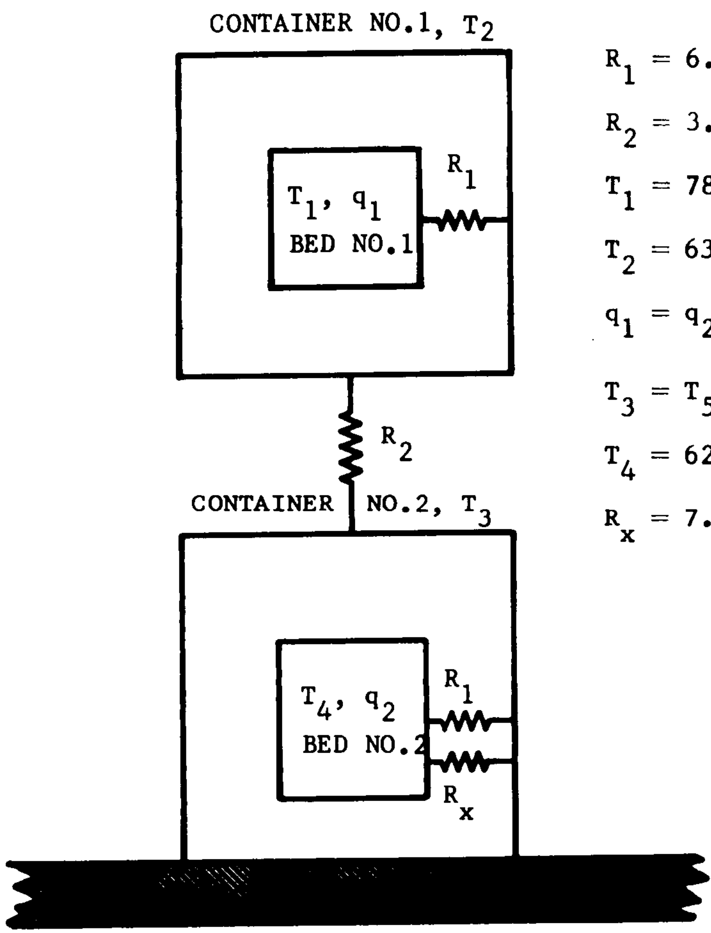
Steady State Thermal System.- Results of the steady-state analysis confirmed that the desired temperature equilibrium could be achieved by proper selection of heat paths to the spacecraft platform. Results of the transient analysis indicated that approximately 24 hours would be required to reach the desired temperature states unless a heater was added to the system. The addition of a one watt electrical heater allows the desired state to be reached in approximately six hours.

The steady-state analysis was performed assuming the thermal configuration of Figure 77. Each container is insulated to eliminate radiation and isolated except for the selected thermal paths represented by R_1, R_x, and R_2. R_1 represents heat transfer through the air from the pupae beds to the container walls. R_x is a metal conduction strap which was added as a result of the analysis, and R_2 is the thermal path of the structure between the upper and lower containers. The structure between the lower container and the spacecraft platform is sufficient to maintain the lower container approximately at platform temperature.

Transient Thermal System.- The transient analysis was performed assuming the thermal system of Figure 78. The thermal masses of the upper and lower pupae beds are represented by C_1 and C_3, and the thermal mass of the upper container is represented by C_2. The parallel resistance of R_1 and R_x if R_3. The analysis was performed by a digital computer and the results are given in Figure 79.

Trajectory and Data Handling

BioPioneer Trajectory.- A trajectory which would be suitable for a BioPioneer mission was developed by NASA/ARC. A plot of this trajectory for 500 days is illustrated in Figure 80. The Sun and Earth are fixed in this coordinate system and the Earth is at the center. Each point is 20 days from



$R_1 = 6.1 \frac{\text{hr °F}}{\text{BTU}}$

$R_2 = 3.6 \frac{\text{hr °F}}{\text{BTU}}$

$T_1 = 78.8$ °F

$T_2 = 63.2$ °F

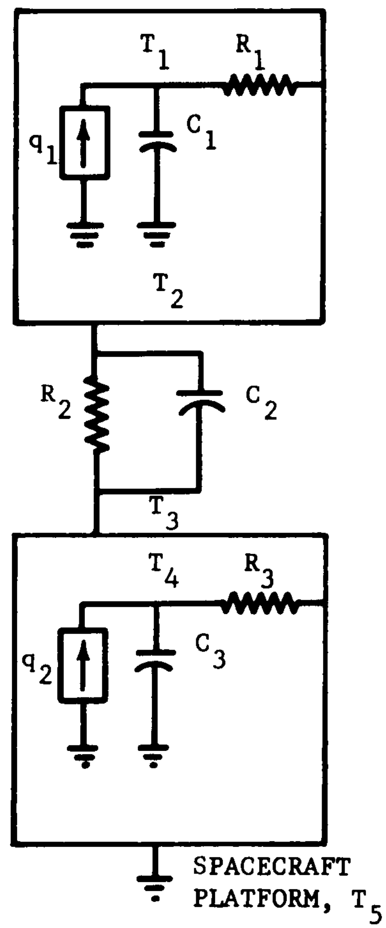
$q_1 = q_2 = 2.56 \frac{\text{BTU}}{\text{hr}}$

$T_3 = T_5 = 54$ °F

$T_4 = 62.6$ °F

$R_x = 7.46 \frac{\text{hr °F}}{\text{BTU}}$

Figure 77. Steady-state thermal system Drosophila eclosion experiment.



$C_1 = C_3 = 1.03 \frac{\text{BTU}}{\text{°F}}$

$C_2 = 0.36 \frac{\text{BTU}}{\text{°F}}$

$R_3 = 3.35 \frac{\text{hr °F}}{\text{BTU}}$

Figure 78. Transient thermal system-Drosophila eclosion experiment.

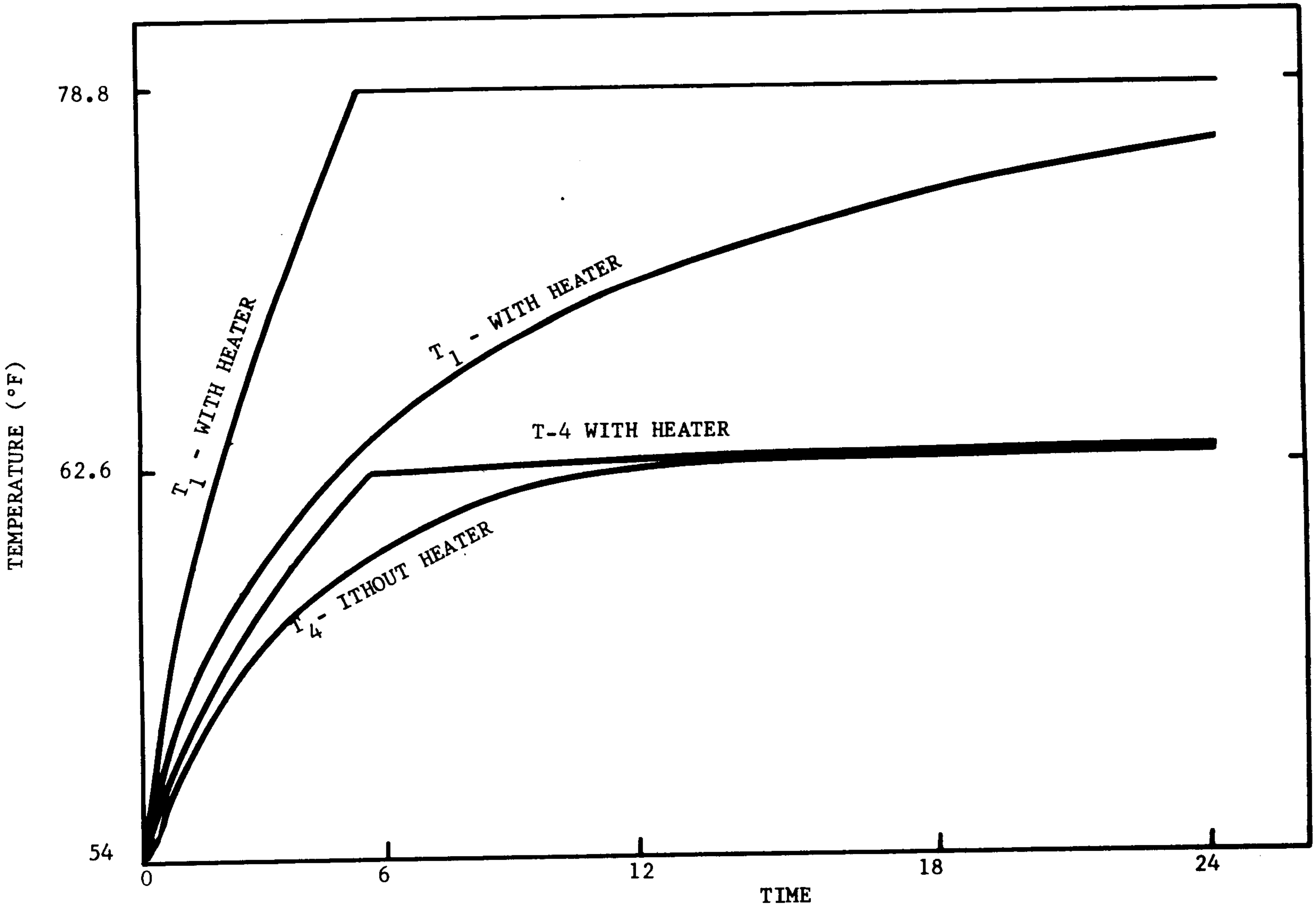
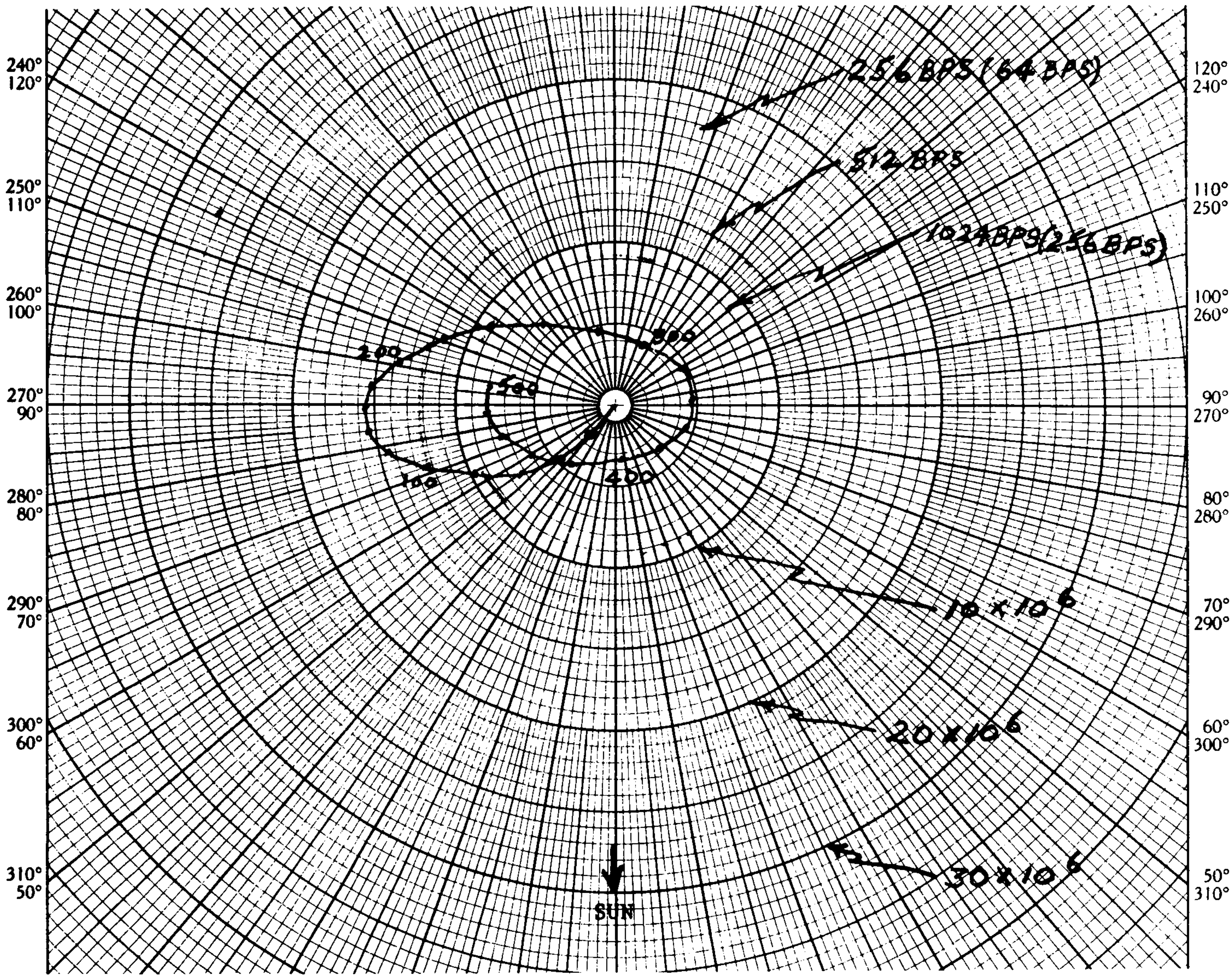


Figure 79. Relative value of using a supplemental heater to bring the Drosophila eclosion experiment to operating temperature.



NOTE:
1. Numbers opposite points indicate time in days from the launch day.
2. The smallest radial division represents one million kilometers.
3. Bit rates in parenthesis refer to 2 watt transmitter. Other bit rates refer to present Pioneer TWT's.

Figure 80. Spacecraft position from earth in a fixed earth-sun coordinate system.

adjacent points, and each point representing position at 100-day intervals is so noted beside its respective point. The trajectory plot shows that the most distant point which the spacecraft would travel from Earth is approximately 16×10^6 km or 9.95 million miles. This point would occur approximately 150 days after launch.

The ranges of the spacecraft from both the Earth and the Sun have been calculated for specific time intervals from launch to 300 days after launch. These data were then converted to actual temperature data derived from Pioneers 6 and 7 at two platform positions as shown in Table 36. Measurement 236 is a measurement located within an experiment mounted on this spacecraft platform and Measurement 263 is a temperature measurement located on the spacecraft platform in the existing experiment area. As noted, the rate of temperature change is small and there are no minor fluctuations, thereby providing a benign temperature environment for biological specimens.

The proposed trajectory has an insignificant effect on total available power. The power budget at 1.0 AU is outlined below:

Total power at 1 AU	80 W
Spacecraft power	-45
	35
Nominal power for 3 physical experiments	-10
	25
Nominal power for biological experiments	-25
	0 W

Telemetry and Commands.-

(a) Commands. The total number of commands available for experiments is 23. These commands result in the generation of pulse signals to be applied to the experiments. Three representative physical experiments (Cosmic Ray, Plasma Probe, and Magnetometer) required eight of these commands. Seven more commands are available for applying power to individual experiments. Three of these would be required by the above mentioned physical experiments. One additional command is used to remove power from all experiments simultaneously. Typically, power is removed from the experiments just prior to launch until several hours after launch. This has been necessary to minimize the requirements on the

TABLE 38. THERMAL DATA

Time From Launch Days	Spacecraft		Temperature	
	Earth Range 10^6KM	Sun Range 10^6KM	Simp. Exp. (M #236) °F	Plat. #3 (M #263) °F
0	0.01	147.28	64	52
20	2.43	145.02	66	54
40	4.72	143.93	67	54
60	7.28	143.72	67	54
80	9.94	144.37	66	54
100	12.37	145.76	65	53
120	14.27	147.69	64	52
140	15.42	149.89	62	50
160	15.69	152.09	60	49
180	15.07	154.05	59	48
200	13.63	155.56	58	47
220	11.57	156.47	57	46
240	9.13	156.68	57	46
260	6.68	156.17	57	46
280	4.80	154.96	58	47
300	4.12	153.14	60	48

battery which provides power until the solar array is able to supply the total power requirements. Figure 81 shows a typical Pioneer Command Matrix (Pioneer 6) and indicates spacecraft commands, experiment commands, and unusable commands.

(b) Telemetry. The communication data rate for the BioPioneer mission utilizing the 8-W TWT's used in the present Pioneer system would be no less than 256 bits per second. Most of the mission would be at 512 bits per second as can be seen in Figure 80.

The possibility of removing TWT's and their converters for significant savings in weight, power, and space has been examined. The transmitter driver presently installed on Pioneer has a 50 mW output and does not provide sufficient power even for 8 bps to provide communications much beyond 1 million km which is reached within 10 days after launch. Replacement of the 50-mW driver with one having a 2-W output would still provide significant savings in available platform space and would allow for complete mission coverage via the present Pioneer system with a bit rate no lower than 64 bps. (See Figure 80.) A 2-W transmitter and its associated converter is currently under development at TRW for use on another space program. This transmitter used in a redundant mode was considered in developing various Pioneer Spacecraft layouts discussed in later sections.

(c) Data Storage.- In regard to additional data storage, several possibilities exist. An additional Pioneer DSU could be installed serially with the present DSU, thereby doubling the existing storage of 15,232 bits. An alternative is to replace the present DSU by a larger DSU now in production for the Vela Project which has a 130,000 bit capability. Other techniques can be examined in a followon study that may better match particular requirements. For the purpose of this study, it was assumed that an additional Pioneer DSU would be used where necessary to accommodate certain experiments or experiment combinations. This unit could be mounted on top of the Experiment Interface Unit (EIU) required for most biological experiments and therby save spacecraft platform space.

(d) Experiment Interface Unit.- The Experiments Interface Unit contains a time of day clock, experiment timing and control signal generators, buffer storage, and amplifiers required for experiment outputs to interface with the Pioneer data system. In general, these electronics can be shared by more than one biological experiment; however, most of the functions provided by this unit would be required even if only one experiment were on the spacecraft.

S UV Simulate 000	S TWT 1 On 001	* 002	S Rcvr. to Lo Gain Ant. 003	S 512 Bit Rate 004	S 256 Bit Rate 005	S 64 Bit Rate 006	S One Shot 007
S TWT's Off 010	S TWT 2 On 011	* 012	Bridge Pwr On 013	* 014	S TWT 1 to Antenna 015	S 16 Bit Rate 016	S Battery On 017
S Exp's Off 020	S Orient. Step 1 Start 021	S TWT 2 to Ant 022	* 023	S DTU Redun.B 024	S TWT to Lo Gain Ant. 025	S One Shot 026	S 8 Bit Rate 027
S Non Coherent Off 030	S Orient. Step 2 CW 031	* 032	S Rcvr. to Hi Gain Ant. 033	S Format A 034	S Format B 035	S Battery Off 036	S Format C 037
S Orient. Step 2 CCW 040	S Orient. Pwr On 041	S Orient Pwr Off 042	S Non Coherent On 043	S DTU Redun.A 044	S Boom Deploy 045	S Drvr to Lo Gain 046	S TWT's to Hi Gain Ant. 047
S Format D 050	S TLM Storage 051	S Memory Readout 052	S Duty Cycle Store 053	Wolfe Pwr On 054	Ness Pwr On 055	S * 056	S * 057
S Real Time Readout 060	Ness Calibr. 061	Ness Flip 062	Simpson Calibr. 063	Pulse CMD 064	Pulse CMD 065	S 066	S * 067
Simpson Normal 070	Stanford Calibr. 071	Wolfe Calibr. 072	McCracken Dynamic 073	Pulse CMD 074	Pulse CMD 075	Simpson Pwr On 076	Stanford Pwr On 077
McCracken Dynamic Range Off 100	McCracken Calibr. 101	Pulse CMD 102	Pulse CMD 103	Pulse CMD 104	Pulse CMD 105	Exp. Pwr On 106	S UV Override On 107
S UV Override Off 110	Bridge Mode 1 111	Bridge Mode 2 112	Wolfe Mode Change 113	Pulse CMD 114	Pulse CMD 115	McCrack. Pwr On 116	* 117

* CMDS without electronics - not useable.
S Spacecraft CMDS
Note: All exp. CMDS are pulse CMDS except the Pwr On CMDS which provide 28 VDC PWR to experiments.

Figure 81. Pioneer 6 command matrix.

EXPERIMENT INTEGRATION

It is specifically beyond the charter of this study to rank experiments in terms of scientific merit. The problem of experiment platform layout and experiment integration has been approached with the following assumptions:

1. All experiments are of equivalent technical merit.

2. Integration of biological payloads must be accomplished with a minimum change to the proven Pioneer spacecraft system.

3. It is highly desirable to include physical sciences experiments to fully utilize the orbital life of the spacecraft.

The first series of platform layouts treats the problem of accommodating individual biological experiments and several physical sciences experiments. A second series shows several feasible combinations of biological and physical sciences experiments but makes an additional assumption that an improved data system presently under development for future Pioneer missions will be available. The assumption is reasonable.

Combinations of biological experiments attempt to utilize different classes of organisms with the assumption that phenomena occurring over a broad phylogenetic spectra are better evidence of an effect or lack of an effect on a fundamental process than if the same phenomena occurred in only one species. Thus, an optimal payload derived from the experiments considered in this study would include at least one mammal, one arthropod, and one plant experiment, plus two or three physical sciences experiments to study particles and fields.

There are obviously a very large number of possible combinations. In all cases the biological experiments represent the minimum replication of experimental material that will permit meaningful data to be obtained. A summary of the biological experiment requirements compared to the Pioneer spacecraft capability is shown in Table 39.

Pioneer capability is that available for use by both biological and physical experiments and is an approximation subject to geometrical constraints. Comparison of experiment requirements with spacecraft capability, however, indicates that the spacecraft is more than adequate to accommodate biological as well as physical science experiments.

TABLE 39. SUMMARY OF EXPERIMENT REQUIREMENTS VS PIONEER SPACECRAFT CAPABILITY

	EXPERIMENT REQUIREMENT							PIONEER CAPABILITY[1]	
EXPERIMENT	C-Mouse	P-Mouse	Drosophila	Cockroach	Bean Leaf	Potato	Crab	PRESENT	IN DEVELOPMENT
Minimum Replication[2]	3	3	4 x 500	3	4	6	6		
Average Power (watts)	16.5	7.2	5.2	4.3	8.8	4.4	4.8	20	30
Weight (pounds)	40.0	34.8	15.0	13.5	15.9	13.7	9.8	75	84
Volume (cubic inches)	1600	1555	622	622	707	440	325	2790[3]	3330[3]
Surface Area (square inches)	178	156	80	120	97	92	77	310[3]	370[2]
Real-Time Data Rate (bits per second)	0.11	0.14	0.05	0.04	0.05	0.02	0.02	176 to 352	44 to 176
Uplink Commands (discrete signals)	6	1	4	1	0	1	1	8 on-off 23 pulse	no change
Maximum Flight[2] Duration (days)	100	120	20	365	60	90	60	365	no change

1 Available for experiment payload. Data rates, etc., are exclusive of synchronization and housekeeping requirements of the spacecraft.

2 Minimum replication for definitive experiment.

3 Subject to geometrical constraints.

Approach.- The existing Pioneer Spacecraft platform was examined for the purpose of investigating various platform layouts for several proposed biological experiments. Figure 82 is a diagram of the Pioneer 6 Spacecraft platform showing the layout of Pioneer components and physical experiments. In the investigation of various biological experiments and combinations of experiments, the biological experiments were, whenever possible, located in the same general areas now occupied by physical type experiments. When considering the many different types of biological and physical experiment combinations, it becomes quite evident that a large variety of possible experiment combinations exist. Therefore, only what appeared to be the most logical and feasible combinations were considered. However, it is entirely possible that after review of this report certain other logical combinations may look feasible enough for study or more detailed examinations. Table 40 is a summary of the various experiment combinations studied.

Some discrepancy will be noted between the number of experimental organisms accommodated in the various platform layouts and the minimum replication of organisms required by the experimenter (Table 39). In most cases the discrepancy is attributable to changes in the experiment design made after the platform analysis was completed. It is the feeling of both the study contractor and the spacecraft contractor that where such discrepancies occur there are simply solutions and that the discrepancies in no way reflect on the feasibility of accommodating experiments to the satisfaction of the respective Principal Investigators.

The platform layout investigations are considered to be feasible from a conceptual design standpoint. It is here noted that the artist concepts shown in this section were derived from scaled layouts of each experiment on approved engineering prints. Where individual experiments rather than experiment mixes were considered the layouts incorporated existing Pioneer components. The layouts dealing with experiment mixes, however, considered certain modifications of Pioneer spacecraft components. These modifications were the incorporation of a convolutional coder (CCU) presently under development; a miniaturized digital telemetry unit (DTU); replacement of the existing Pioneer transmitter driver, transmitter converter and TWT's with redundant two watt transmitter and transmitter converters currently under development at TRW. Incorporation of these modified spacecraft equipments provides additional platform space which can be utilized for both biological and physical sciences experiments.

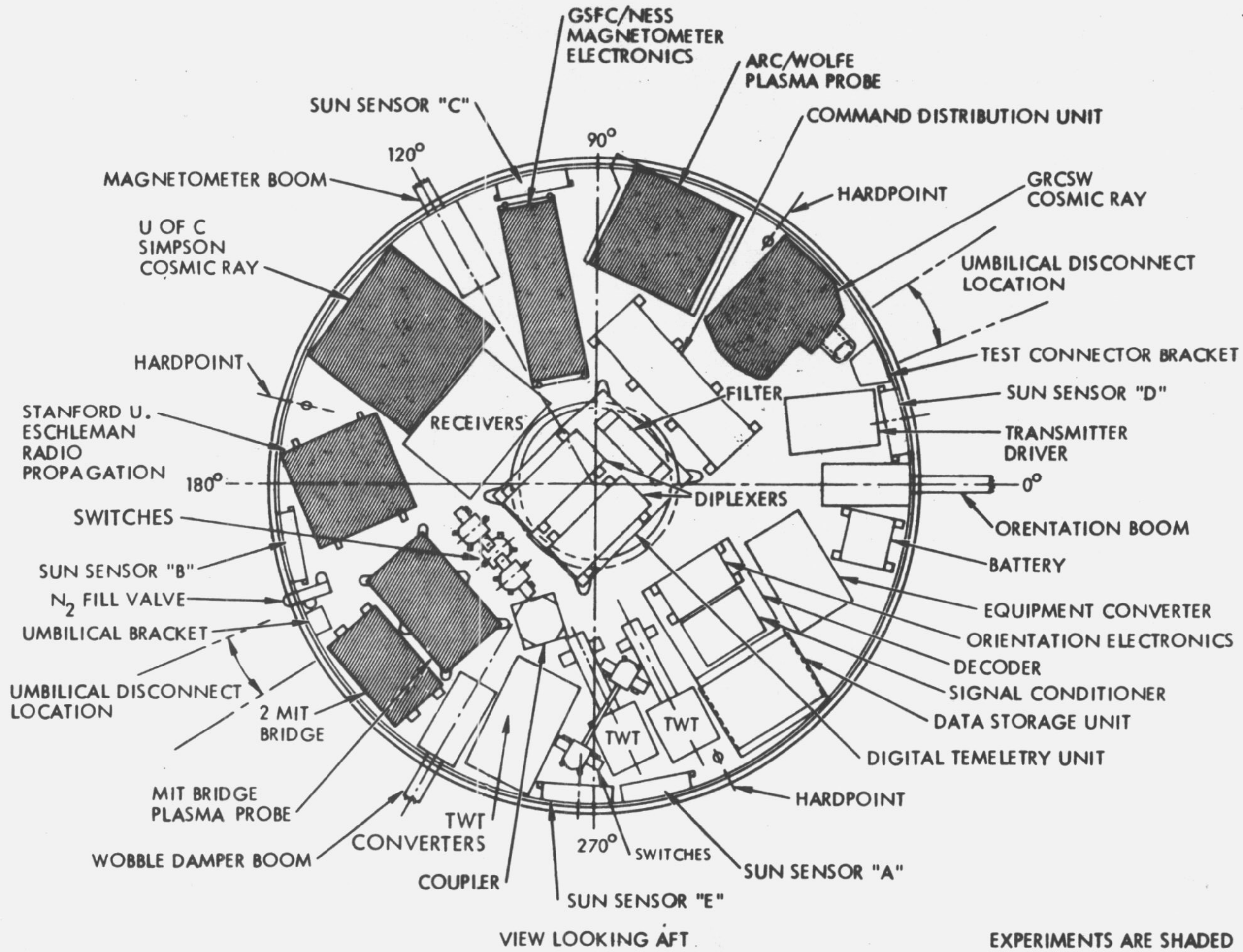


Figure 82. Pioneer 6 platform layout.

TABLE 40. SUMMARY OF EXPERIMENT COMBINATION

Combination No.	Biological Experiments	Gravity Environment (g's)	Spacecraft Spin Rate (RPM)	Physical Sciences Experiments (3)
1. (1)	3 "C" Mice (Plan A)	1	57	Cosmic Ray Plasma Probe
2. (1)	4 "C" Mice (Plan D)	1	57	None
3. (1)	3 Pocket Mice (3 containers)	1	54	Magnetometer Plasma Probe
4. (1)	6 Cockroaches (1 per container)	1	45	Magnetometer Cosmic Ray
5. (1)	4 Fiddler Crabs (2 containers) 4 Fiddler Crabs (2 containers)	1 0.5	45	Cosmic Ray Plasma Probe
6. (1)	4 Bean Leaves (1 container) 4 Bean Leaves (1 container)	1 0.8	49	Cosmic Ray Cosmic Dust
7. (1)	4 Potato Plants (2 containers) 4 Potato Plants (2 containers)	1 0.55	45	Magnetometer Plasma Probe Cosmic Ray
8. (1)	4000 Pupae Fruit Fly Specimens (4 containers - 2 each in tandem)	1	54	Magnetometer Plasma Probe

TABLE 40. SUMMARY OF EXPERIMENT COMBINATION (cont.)

Combination No.	Biological Experiments	Gravity Environment (g's)	Spacecraft Spin Rate (RPM)	Physical Sciences Experiments (3)
9. (2)	4 Potato Plants (2 containers)	1	46	Cosmic Ray
	4 Fiddler Crabs (2 containers)	1		Magnetometer
	4 Bean Leaves (1 container)	0.9		
	4 Fiddler Crabs (2 containers)	0.5		
	4 Potato Plants (1 container)	0.5		
10. (2)	3 Pocket Mice	1	53	Magnetometer
	2000 Pupae Fruit Fly Specimens (2 containers in tandem)	1		Plasma Probe
11. (2)	3 Pocket Mice (3 containers)	1	49	Cosmic Ray
	3 Cockroaches (3 containers)	1		
12. (2)	3 Cockroaches (3 containers)	1	53	Magnetometer
	2 Fiddler Crabs (1 container)	1		Cosmic Dust
	2000 Pupae Fruit Fly Specimens (2 containers - 2 ea. in tandem)	1		Cosmic Ray
	4 Fiddler Crabs (2 containers)	0.5		
13. (2)	3 Pocket Mice (3 containers)	1	54	Magnetometer
	2 Fiddler Crabs (1 container)	1		
	2 Potato Plants (1 container)	1		
	2 Fiddler Crabs (1 container)	0.58		
	2 Potato Plants (1 container)	0.58		

Notes:

(1) Existing spacecraft components.

(2) Modified spacecraft components (redundant 2 watt transmitters, convolutional coder, miniaturized DTU).

(3) Other experiments could be substituted.

Platform Considerations

Figure 83 is a photograph of the existing Pioneer Spacecraft showing spacecraft components, structural members and experiments. This illustrates the need to observe certain constraints in laying out the various experiment combinations. These constraints included:

a) No box above 6 3/4 in. in height could extend closer than 2 in. from the platform circumference.

b) Equipments could not be located over certain platform flanges and brackets.

c) Spacing of boxes could not violate the envelope required for the 3 boom mounts or the 3 sets of antenna mounting struts.

d) No box could be placed in a manner requiring platform mounting within 4 in. of the spacecraft center because of the circular cutout required for the pneumatics bottle and lines, and the existing spacecraft equipment occupying this centralized area.

e) Sufficient platform space must be reserved for cabling, particularly from the digital telemetry unit (DTU), command distribution unit (CDU) and the decoder.

f) Where possible, spacecraft equipments were not relocated from their existing positions to minimize spacecraft modifications.

The nominal spin rate specified for Pioneers 6 and 7 prior to separation from the third stage is 110 rpm. After separation from the third stage and deployment of the spacecraft booms, the spin rate is reduced to approximately 60 rpm. Assuming the orbital injection and spacecraft attitude stability requirements may be relaxed, it would be possible to proportionately reduce the spin rate if required by the biological experiments. The Earth's gravitational field can be simulated by selecting an appropriate spin rate for a particular location of an experiment on the spacecraft platform.

Individual Experiments

"C" Mouse Experiment (Plan A).- Four alternate plans for the "C" mouse installation were submitted. Two were selected for further consideration. As noted in the section entitled "Spacecraft Dynamics," the "C" mouse experiments

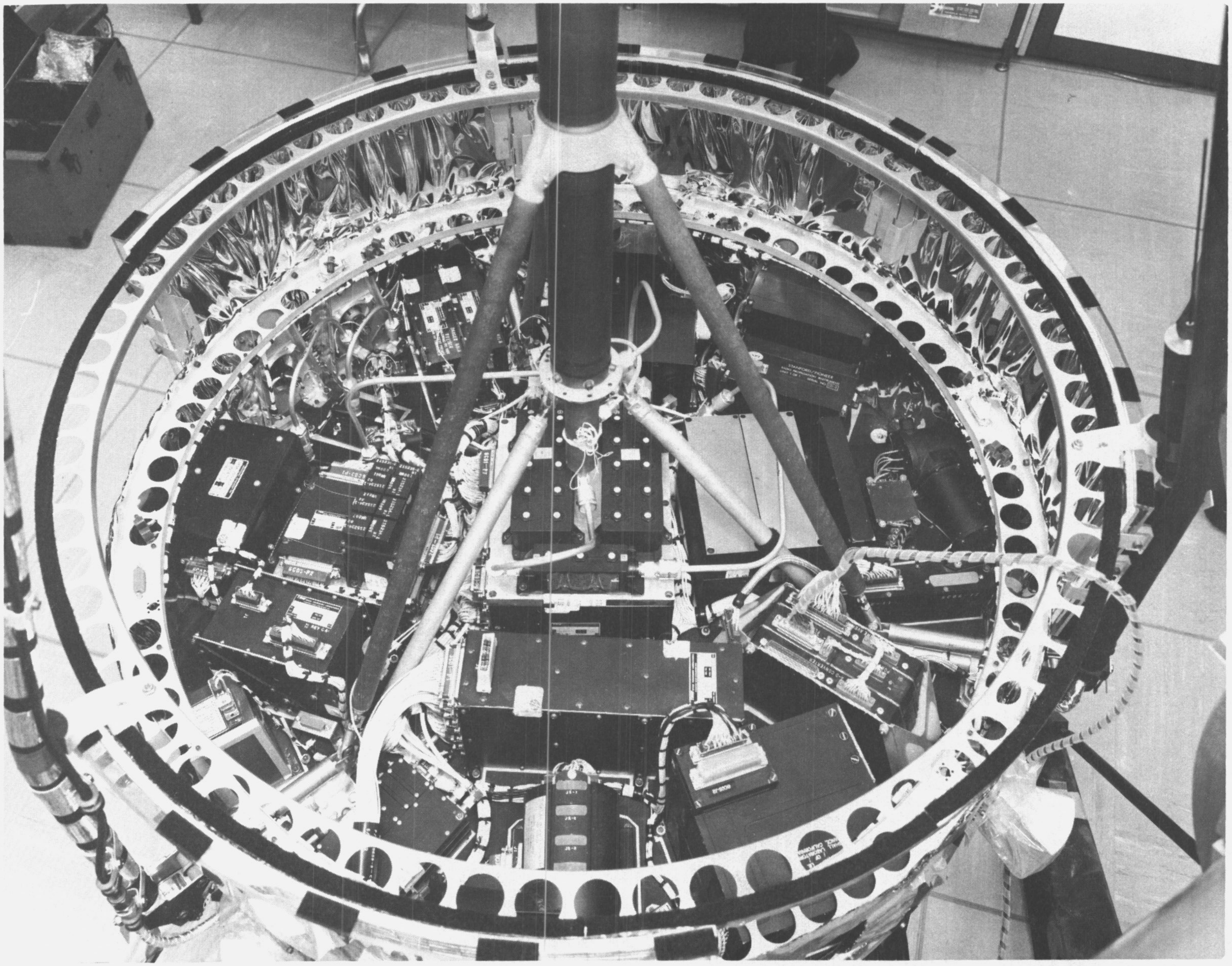


Figure 83. Present Pioneer spacecraft platform layout.

represent the most formidable balance problem of all the experiments which were examined. The first plan, (A), consisting of three mice in a container, was selected because of the relatively small spacecraft platform area required. This experiment consists of a container, an electronics box, a blower and trace gas control, an oxygen tank and an oxygen regulator. It was determined that this "C" mouse experiment could be incorporated on the Pioneer Spacecraft in addition to two physical sciences experiments. In this instance, cosmic ray and plasma probe experiments were selected, although other experiment combinations could possibly be incorporated. This layout, shown in Figure 84, requires minimum reorientation of the existing spacecraft equipments on the platform. The requirement for placement of the mouse container at least 2 in. from the spacecraft periphery results in a spacecraft radius to the floor of the container of 11 in. (This assumes the floor to be located approximately 6 in. from the end of the container nearest the spacecraft centerline.) To maintain a 1 g environment at the floor of the container, the spacecraft would be rotated at 57 rpm.

"C" Mouse Experiment (Plan D).- The other "C" mouse experiment selected was that preferred by the experimenter (Plan D). This plan requires considerably more spacecraft platform area than Plan A, but provides for four mice instead of three, as in Plan A. This experiment requires a relatively large oxygen tank, LiOH bed, blower regulator and trace gas control occupying a sphere of 12 in. in diameter. The additional containers are required: (1) a container to house the four mice, and (2) an associated electronics box. Because of the large platform area required for this experiment, it was not possible to incorporate any physical experiments. (See Figure 85.) Assuming the floor of the container to be approximately 4 in. from the top of the container (inbound), the position of the "C" mouse container is such that it requires the spacecraft to be spun up to approximately 57 rpm to maintain a 1 g environment at the container floor.

Pocket Mouse Experiment.- The pocket mouse experiment layout consists of three pocket mouse containers, a central electronics box and an experiment interface unit with an additional data storage unit (DSU) mounted on top. It is possible in this arrangement to incorporate two physical experiments in addition to the pocket mouse experiment. These are the Magnetometer and Plasma Probe experiments. It is noted that due to the size of the pocket mouse container and the requirements for mounting the container, it is not possible to

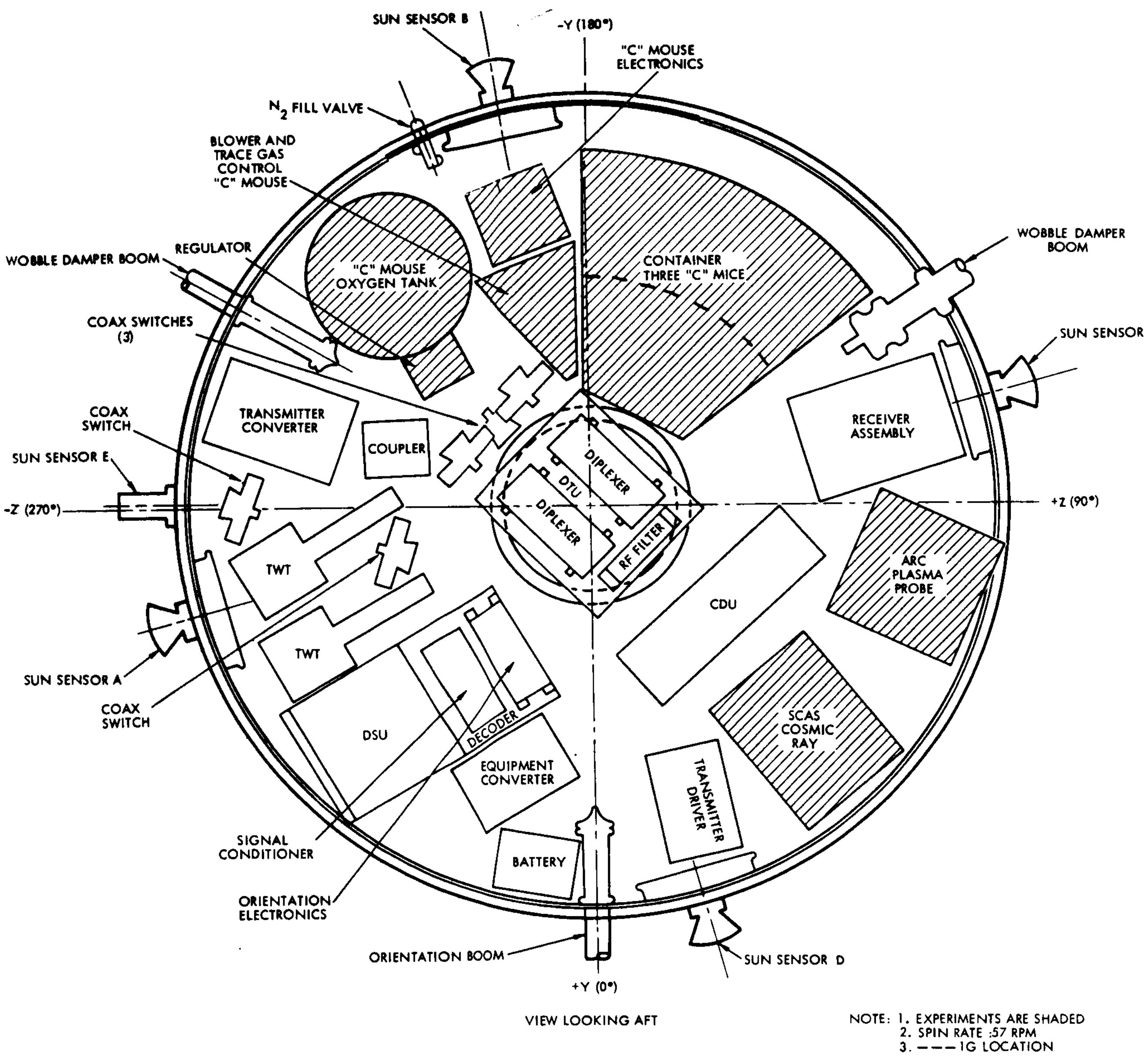


Figure 84. Pioneer spacecraft equipment and experiment installation "C" Mouse experiment (3 mice - plan A) & two physical experiments.

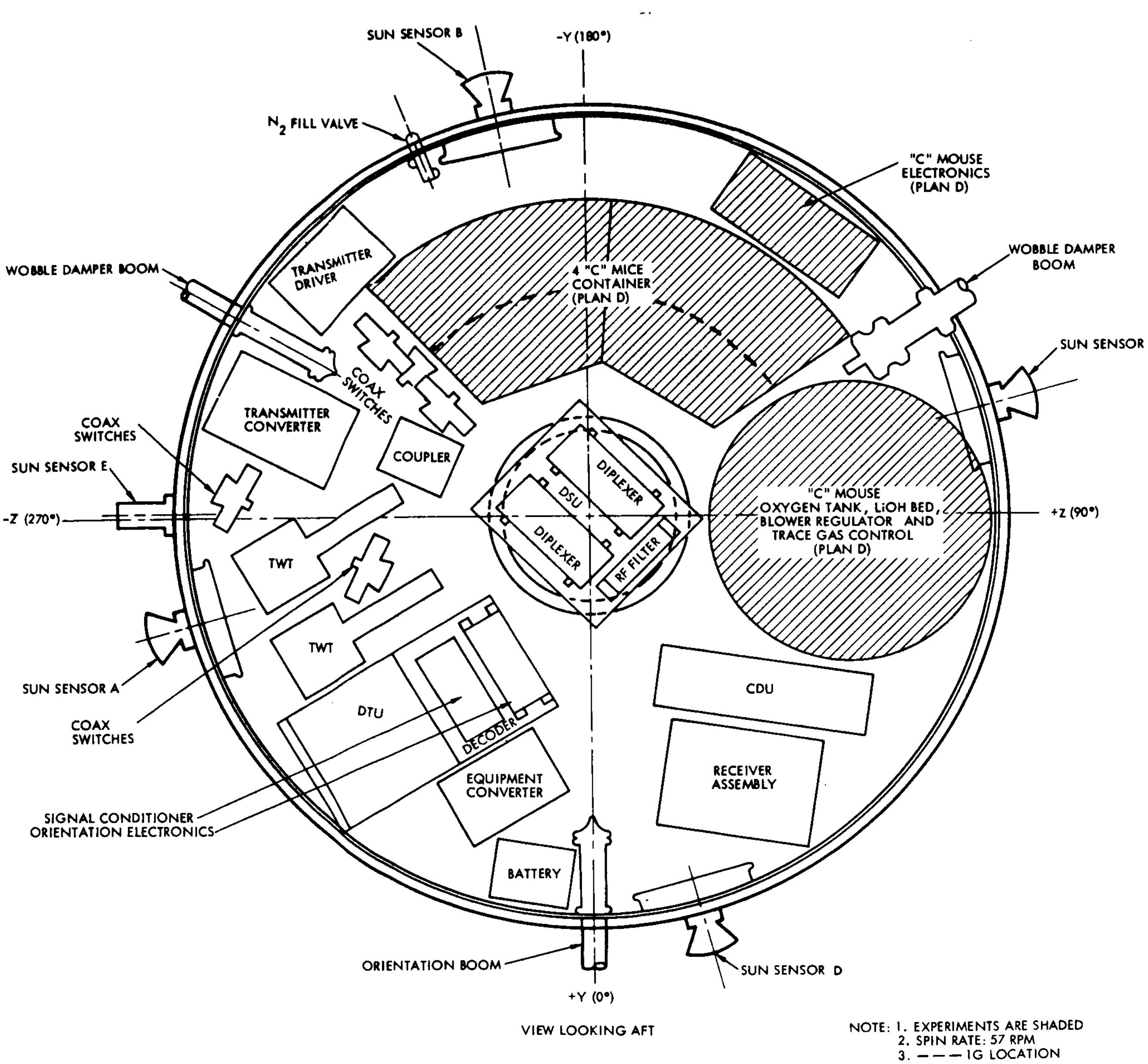


Figure 85. Pioneer spacecraft equipment and experiment installation "C" Mouse experiment (4mice - Plan D).

incorporate four mouse containers on the existing Pioneer platform together with required spacecraft components without reconfiguring the experiment package. The radius from the center of the spacecraft platform to the floor of the container was selected at 12 in. due to the requirement that the container be located at least 2 in. from the periphery of the spacecraft platform. This requires that the spacecraft revolve at 54 rpm to maintain 1 g at the floor of the container. The layout of this experiment combination is shown in Figure 86.

Cockroach Experiment.- Six cockroach experiments (1 cockroach per container) were considered at the request of the experimenter. Since these spherical containers could be placed near the periphery of the spacecraft due to the relatively low height of 6.7 in., it was possible to place six of these containers around the periphery of the spacecraft platform and still incorporate two additional physical experiments. In this instance a cosmic ray and magnetometer experiment were the selected physical experiments although other physical experiment combinations could probably be accommodated, if desired. Minimum changes to the existing spacecraft equipments layout were necessary to incorporate this combination of experiments. The radius to the 1 g position of all the containers is 17 in. requiring a 45-rpm spacecraft rotation to maintain the 1 g environment. Figure 87 shows the platform layout selected for this experiment combination.

Crab Experiment.- This experiment consists of crab containers (2 crabs per container), a crab controller unit and an experiment interface unit (EIU). (With respect to the experiment interface unit, an additional DSU could, if desired, be placed on top because of the position selected for the EIU.) This experiment would have the objective of placing these containers so that the specimen is subjected to 1 g, 1/2 g and 0 g, if possible. However, it is apparent that a 0 g environment is not possible to attain since this would require location of the specimen container on the spin axis of the spacecraft which is presently occupied by the spacecraft, diplexers and RF filter. Therefore, development of the platform layout concentrated on the objective of placing an equal number of containers at the 1 g and 1/2 g locations. As shown in Figure 88, due to the relatively small size of the crab containers, a workable platform layout was accomplished while still maintaining adequate space for location of four physical experiments in addition to the crab experiment. The physical

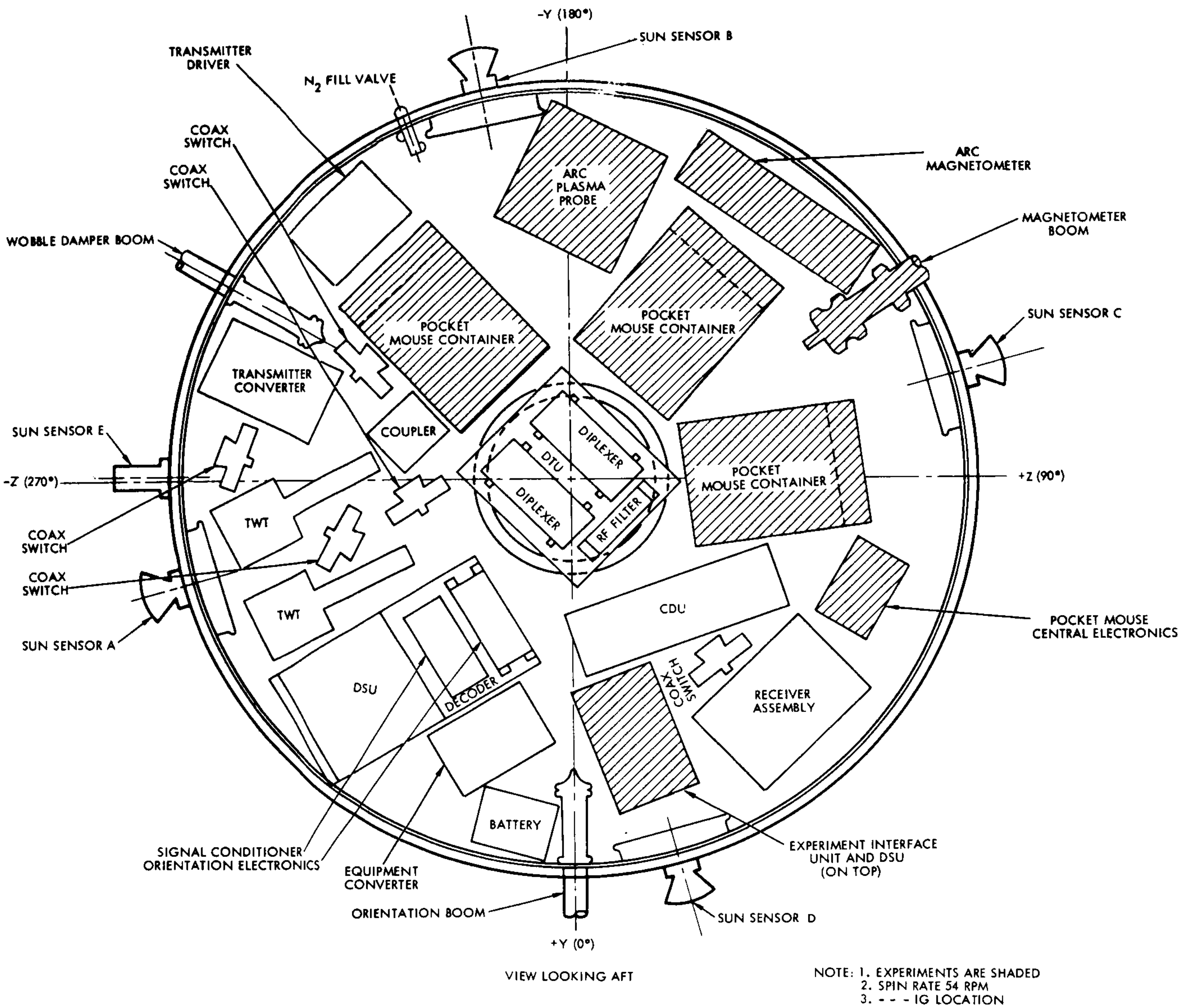


Figure 86. Pioneer spacecraft equipment and experiment installation Pocket Mouse experiment & two physical experiments.

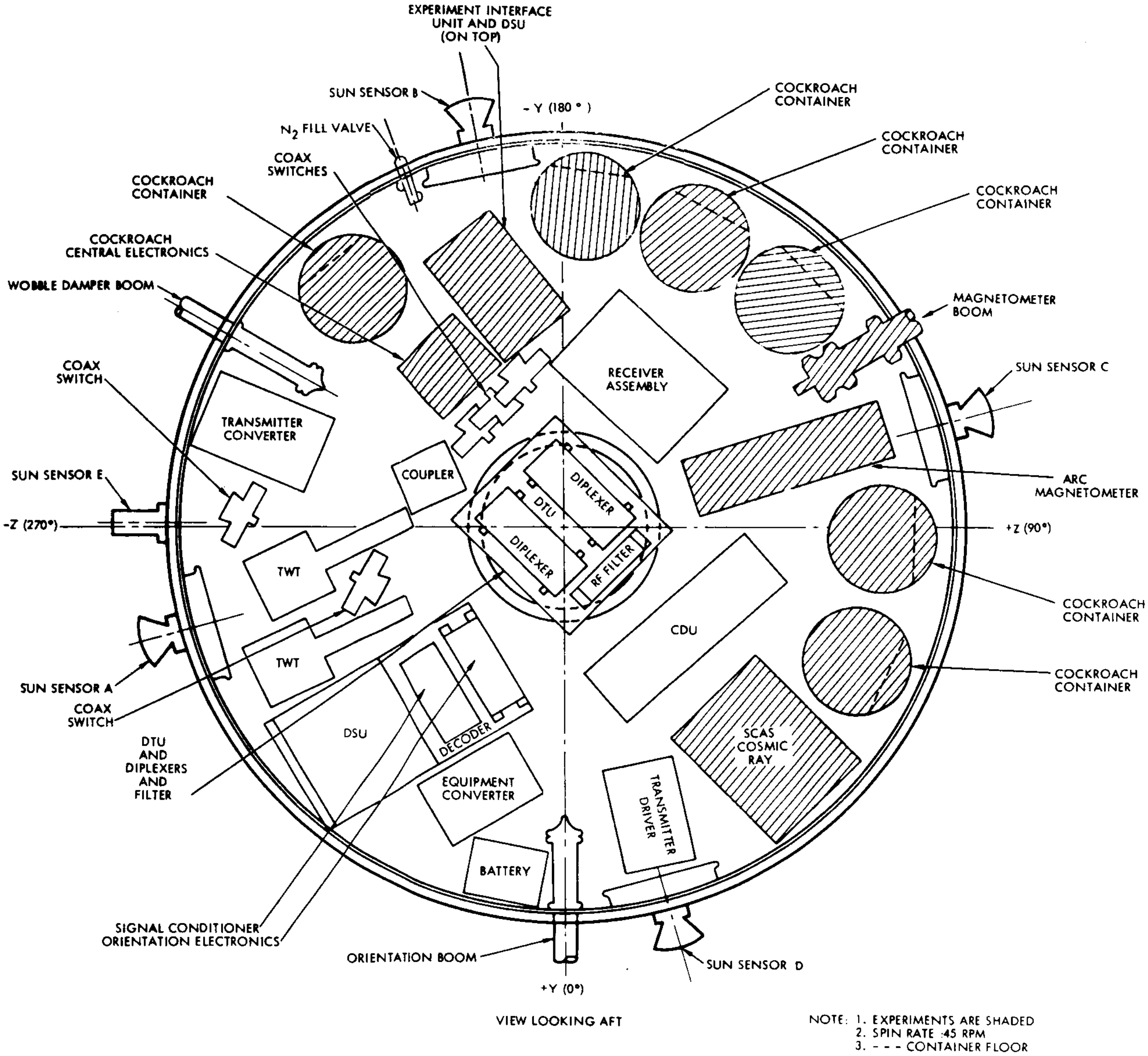


Figure 87. Pioneer spacecraft equipment and experiment installation Cockroach experiment (6 cockroaches) and two physical experiments.

experiments shown are the cosmic ray, plasma probe, magnetometer and cosmic dust. Spacecraft spin rate would be adjusted to 45 rpm so as to provide a 1 g environment to the 2 crab containers placed at a 17 in. radius from the platform center and a 1/2 g environment for the 2 crab containers located at 8.5-in. radius from the center. With the exception of relocating the receiver assembly, no changes were necessary to the existing locations of the Pioneer Spacecraft equipments.

Bean Leaf Experiment.- This experiment consists of bean leaf containers with four leaves in each, an A/D converter (required for more than one container), and a central electronics box in addition to the experiment interface unit and an additional data storage unit required for the experiment. The experimenter desired that one bean leaf container be located in a 1 g environment and the second container at less than 1 g environment. Due to the size of the bean leaf container and the constraint of the spacecraft DTU and other boxes located at the platform center, it was determined that one container located at a radius of 15 inches from spacecraft centerline would experience a 1 g environment with spacecraft spin rate at 49 rpm. The other bean leaf container with its floor located at 12-in. radius from the centerline would experience a 0.8 g environment. With this layout shown in Figure 89, it was also possible to incorporate two physical experiments which could be cosmic ray and cosmic dust experiment. In this layout it may be necessary to change the present location of the N_2 fill valve, but this should pose no problem.

Potato Plant Experiment.- Due to the relatively small volume of the potato plant experiment containers, it is possible to locate four potato plant experiment containers (2 plants per container) and their associated electronic boxes and, in addition, to accommodate three physical experiments. In addition to the 4 containers, the total experiment requires an experiment interface unit. No data storage unit is required for this experiment; however, the experiment interface unit has been placed on the platform so that if a DSU is desired, it could be accommodated within the specified volume. The outboard floors of two of the potato plant containers are located approximately 17-in. from the spacecraft centerline, while the floors of the other two containers are located 9 1/2 in. from the spacecraft centerline. A spacecraft spin rate of 45 rpm will maintain a 1 g environment for the outboard containers and 0.55 g environment for the two inboard containers. The physical experiments selected for this case

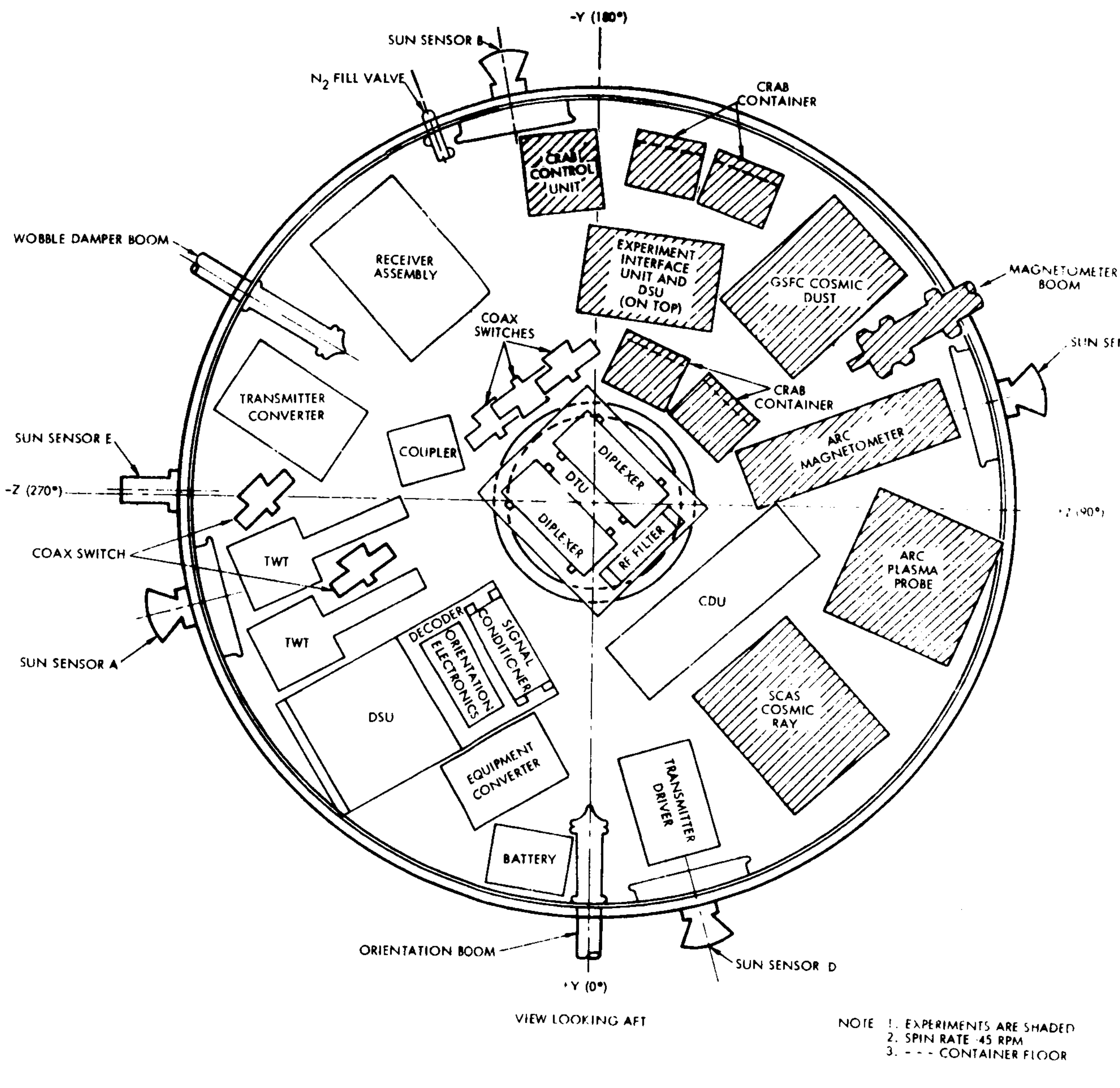


Figure 88. Pioneer spacecraft equipment and experiment installation Crab experiment (8 crabs) & four physical experiments.

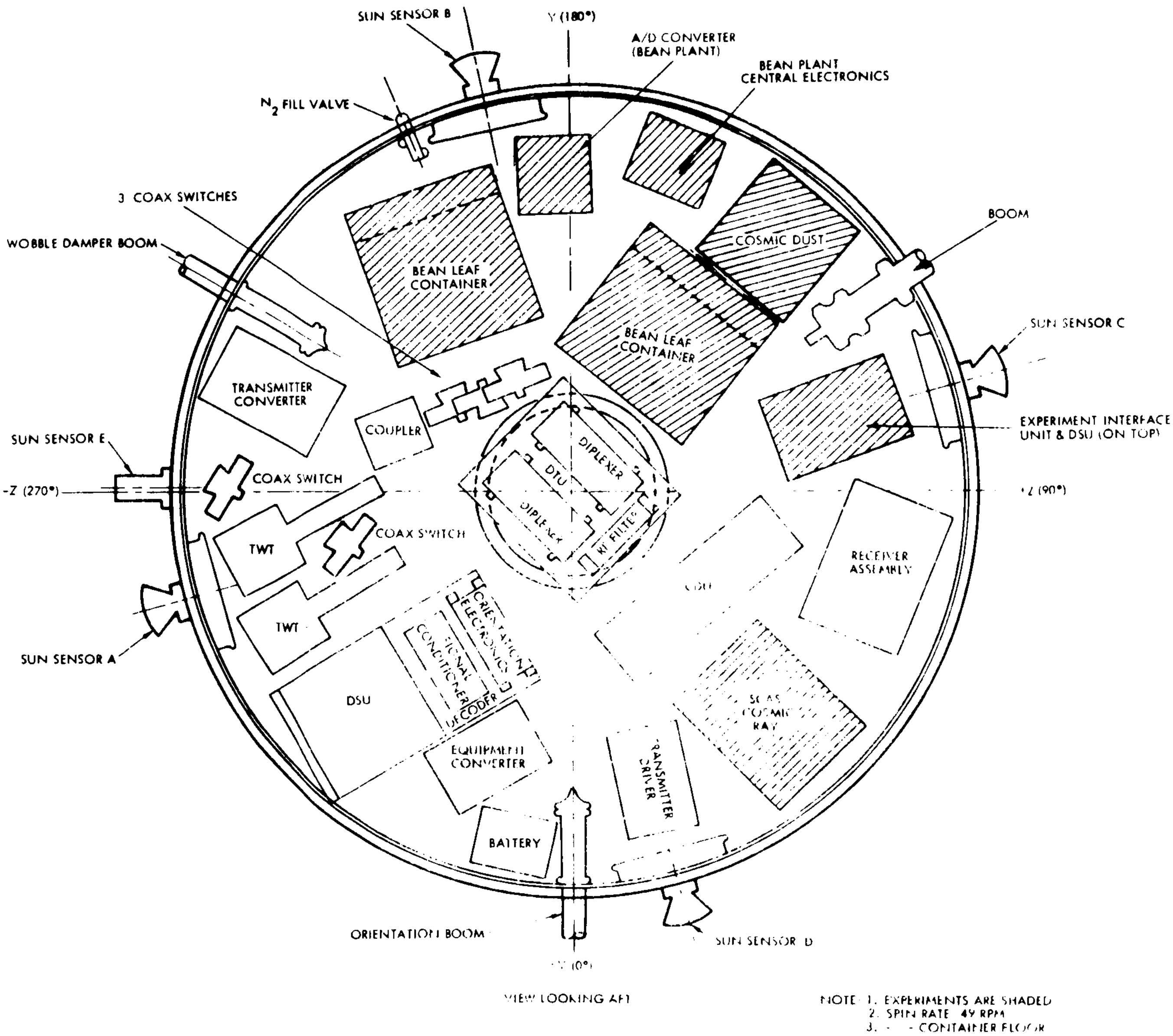


Figure 89. Pioneer spacecraft equipment and experiment installation Bean Leaf experiment (8 leaves) & two physical experiments.

are: a magnetometer experiment, a plasma probe experiment and a cosmic ray experiment. Figure 90 shows the layout of this experiment combination.

Pupae Fruit Fly Experiment.- This experiment consists of fruit fly containers with 1,000 specimens in each, and an experiment interface unit. There is no requirement for an additional DSU. In this case, four fruit fly containers (two each in tandem) were selected for placement on the spacecraft platform. The overall dimensions specified for the fruit fly tandem containers necessitate their being placed at least 2 in. from the spacecraft circumference. The centerline of the two cylindrical containers mounted in tandem is specified as the 1 g location. Therefore, under these conditions the radius from the spacecraft spin axis to the container centerline is approximately 12 in., which will require a spacecraft spin rate of 54 rpm. With four containers (two each mounted in tandem) it is possible to also locate three physical experiments with only minimal modification to the existing spacecraft platform layout (see Figure 91). The physical sciences experiments selected are the Magnetometer, Plasma Probe, and Cosmic Ray. If it were decided that one fruit fly container were sufficient for this experiment, an addition, or fourth, physical experiment could be incorporated.

Representative Combinations of Experiments with Spacecraft Modifications

Recommended Spacecraft Modifications.- As mentioned earlier, after investigation of individual biological experiments with combinations of physical sciences experiments, a selection of optimum combinations of experiments was made and platform layouts for each were prepared. In order to accommodate a larger number of variety of both biological and physical sciences experiments, a platform layout was prepared which incorporates certain spacecraft component modifications. These are:

1) Substitute the existing digital telemetry unit (DTU) for a miniaturized (new design) and a convolutional coder presently under development by the Pioneer Project. These two components would be stacked together on the spacecraft platform.

2) Substitute the existing redundant TWT's and their associated transmitter converters and transmitter drivers for redundant two-watt transmitters and transmitter converters presently under development for use by another TRW Spacecraft Project. These transmitters and their associated converters are

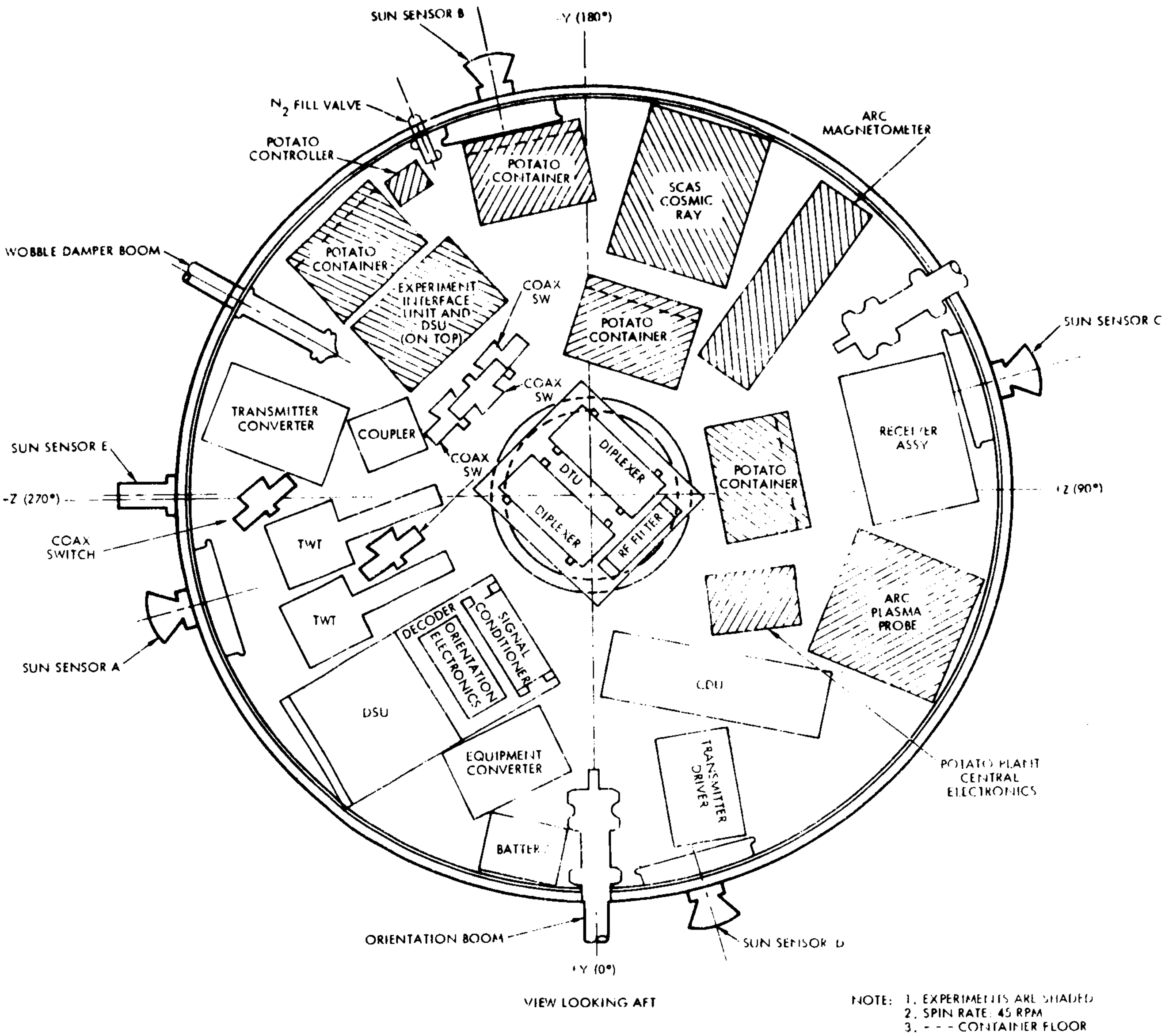


Figure 80. Equipment and experiment installation Potato plant experiment (4 containers) and three physical experiments.

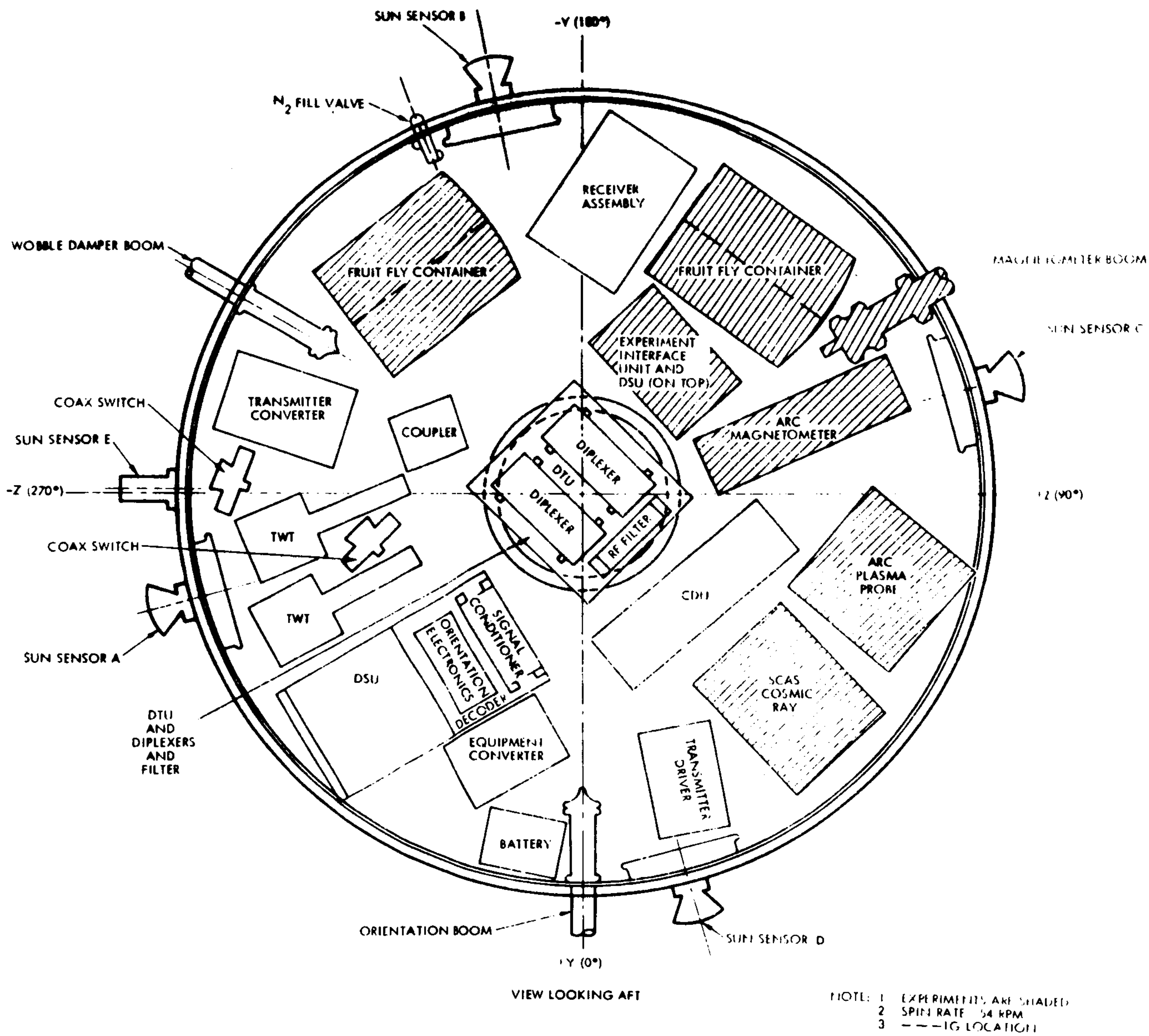


Figure 91. Pioneer spacecraft equipment and experiment installation
Fruit Fly experiment & three physical experiments.

capable of being mounted side by side on the platform and this configuration was used for conservation of platform space.

3) Delete the present coupler unit and two of the five coaxial switches as a result of the above modifications. The results of investigations of various experiment combinations are discussed below.

Combined Potato, Fiddler Crab and Bean Leaf Experiments.- An attempt was made to incorporate two different plant experiments and one arthropod experiment utilizing modified spacecraft equipments. In this case, the potato plant, fiddler crab and bean leaf experiments were selected. Figure 92 shows the layout for this combination, which includes three potato containers (six plants) and their associated electronic units, four crab containers (eight crabs) and one bean leaf container (four leaves) with associated support equipment. Provision was also made for an experiment interface unit with an added data storage unit in a stacked configuration. The two potato containers, the bean leaf container and two of the four crab containers were placed near the periphery of the spacecraft platform with the container floors located 16 in. from the spacecraft centerline. This permits the outboard floor of the two potato containers and the two crab containers to see a 1 g environment at 46 rpm spin rate while the bean leaf container, due to its height, was placed slightly inboard such that its floor would be in a 0.9 g environment. The other two crab containers and one potato container were placed so that their floors are 8 in. from the spacecraft centerline, thereby permitting their environment to be 1/2 g. This arrangement was made to accommodate the request of the experimenter to have different crab modules at 1 g and 1/2 g positions. This platform layout permits incorporation of two physical sciences experiments (cosmic ray and magnetometer). A plasma experiment could be substituted for the cosmic ray experiment, if desired.

Combination Pocket Mouse and Fruit Fly Experiments.- An attempt was made to prepare a platform layout which would include a mammal experiment (three pocket mice containers) and an arthropod experiment (one fruit fly container). This combination of experiments was determined to be feasible. An experiment interface unit (EIU) with an additional DSU on top was provided to accommodate the needs of the pocket mouse experiment. Due to the size of the experiment containers it was necessary to place them not closer than 2 in. from the periphery of the spacecraft platform. This resulted in a radius to the container floors

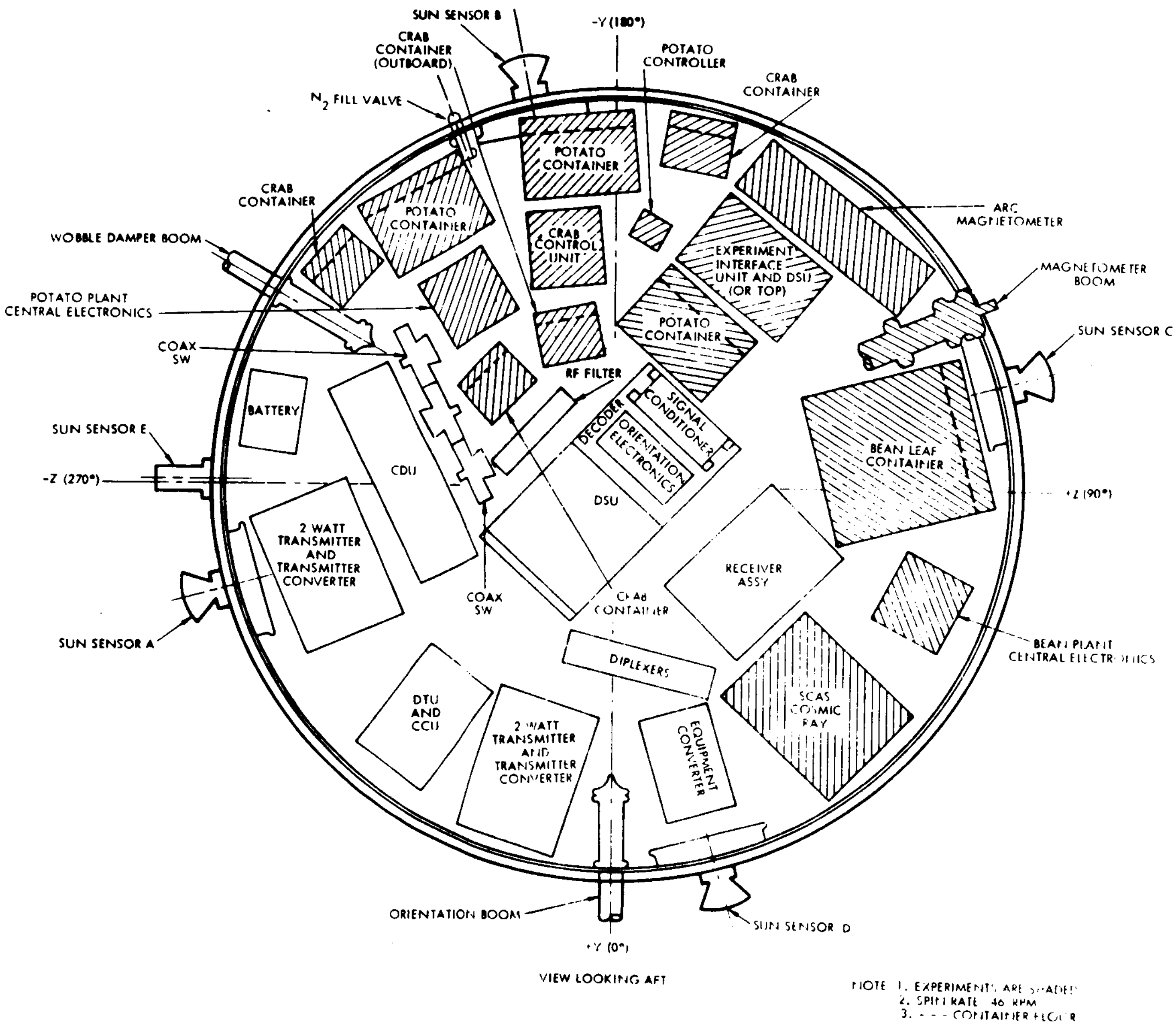


Figure 92. Equipment and experiment installation - three Potato, four Crab and one Bean Leaf experiments and two physical experiments.

of 12.5 in. and a spacecraft spin rate of 53 rpm to maintain a 1 g environment at the 1 g location of each container. It was also possible in this layout (see Figure 93) to incorporate two physical sciences experiments. Those selected were the magnetometer and plasma probe experiments.

Combined Pocket Mouse and Cockroach Experiments.- The next layout considered was a mammal (pocket mouse) experiment and a different arthropod (cockroach) experiment. This experiment combination includes three pocket mice containers and three cockroach containers and their associated supporting electronic boxes. Figure 94 shows the platform arrangement selected which places the three pocket mouse containers and the three cockroach containers with their respective floors located at 14-in. radius from the spacecraft centerline. A spacecraft spin rate of 49 rpm is necessary to provide a 1 g environment at the floor of each of the five containers. It was possible in this experiment combination to also include a physical experiment on the platform. The experiment selected is a cosmic ray instrument although another experiment selection could be made, if desired.

Cockroach, Fiddler Crab and Fruit Fly Experiments.- A platform layout was prepared for the three arthropod experiments and it was determined feasible that three cockroach containers, three crab containers and one fruit fly container and associated experiment support boxes could be placed on the Pioneer platform in addition to incorporating a magnetometer experiment. Due to the size and 1 g location of the fruit fly container, it was necessary to place 3 cockroach, 1 fruit fly and 1 crab container in positions so that the 1 g location is at a radius of 12.5 in. from the spacecraft centerline. To maintain the 1 g environment at this location, it is necessary that the spacecraft spin rate be maintained at 53 rpm. Two crab containers were placed in position so that they would experience a 1/2 g environment, as desired by the experimenter. The experiment interface unit is placed in a position that, if desired, an additional DSU can be placed on top. Three physical experiments are incorporated in this platform layout. They are a magnetometer, a cosmic dust experiment and a cosmic ray experiment. Figure 95 illustrates the platform layout for this experiment combination.

Pocket Mouse, Fiddler Crab and Potato Experiments.- This experiment combination consists of:

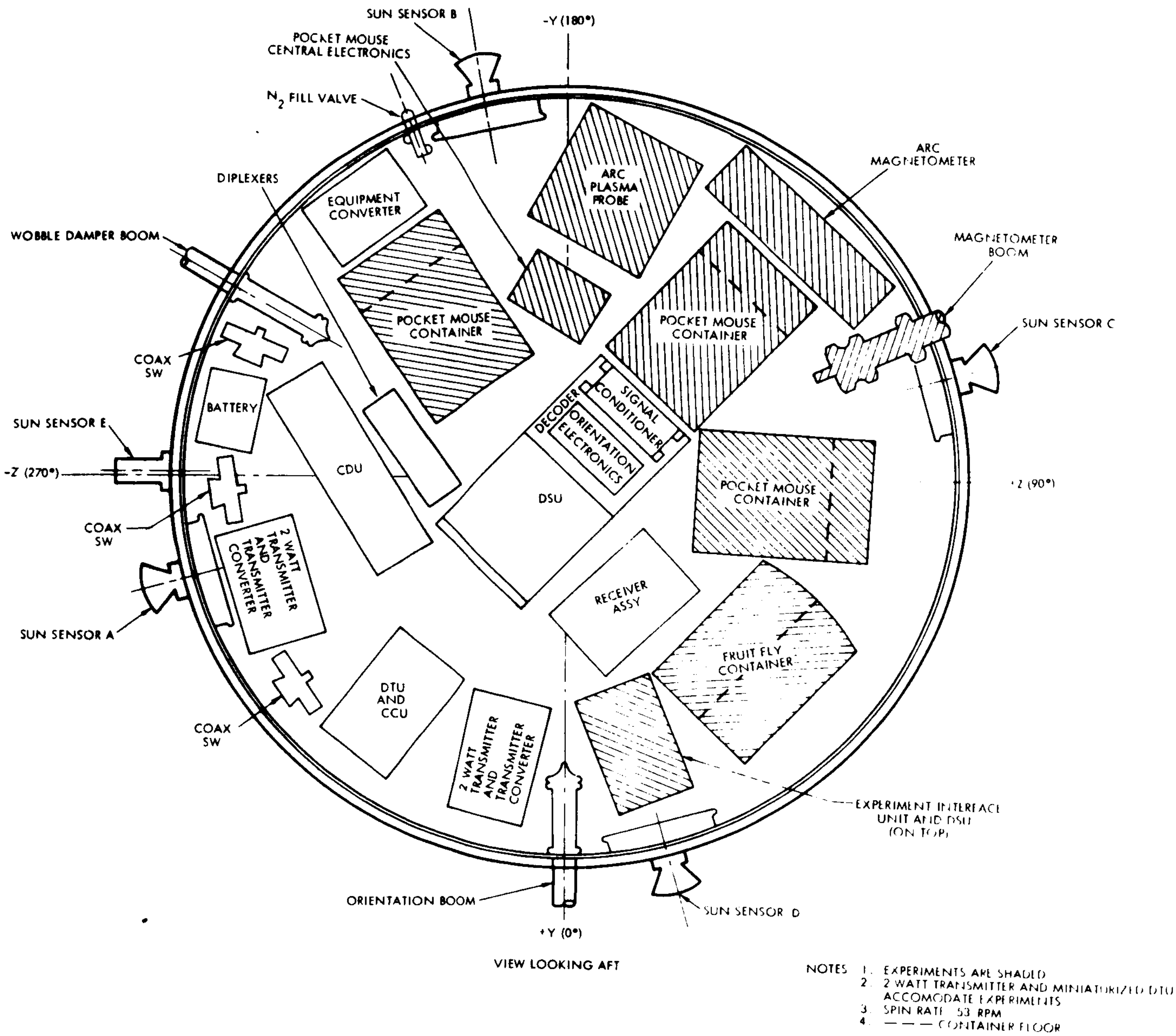


Figure 93. Equipment & experiment installation: Pocket Mouse experiment (3 containers) and one Fruit Fly experiment (1 container) and two physical experiments.

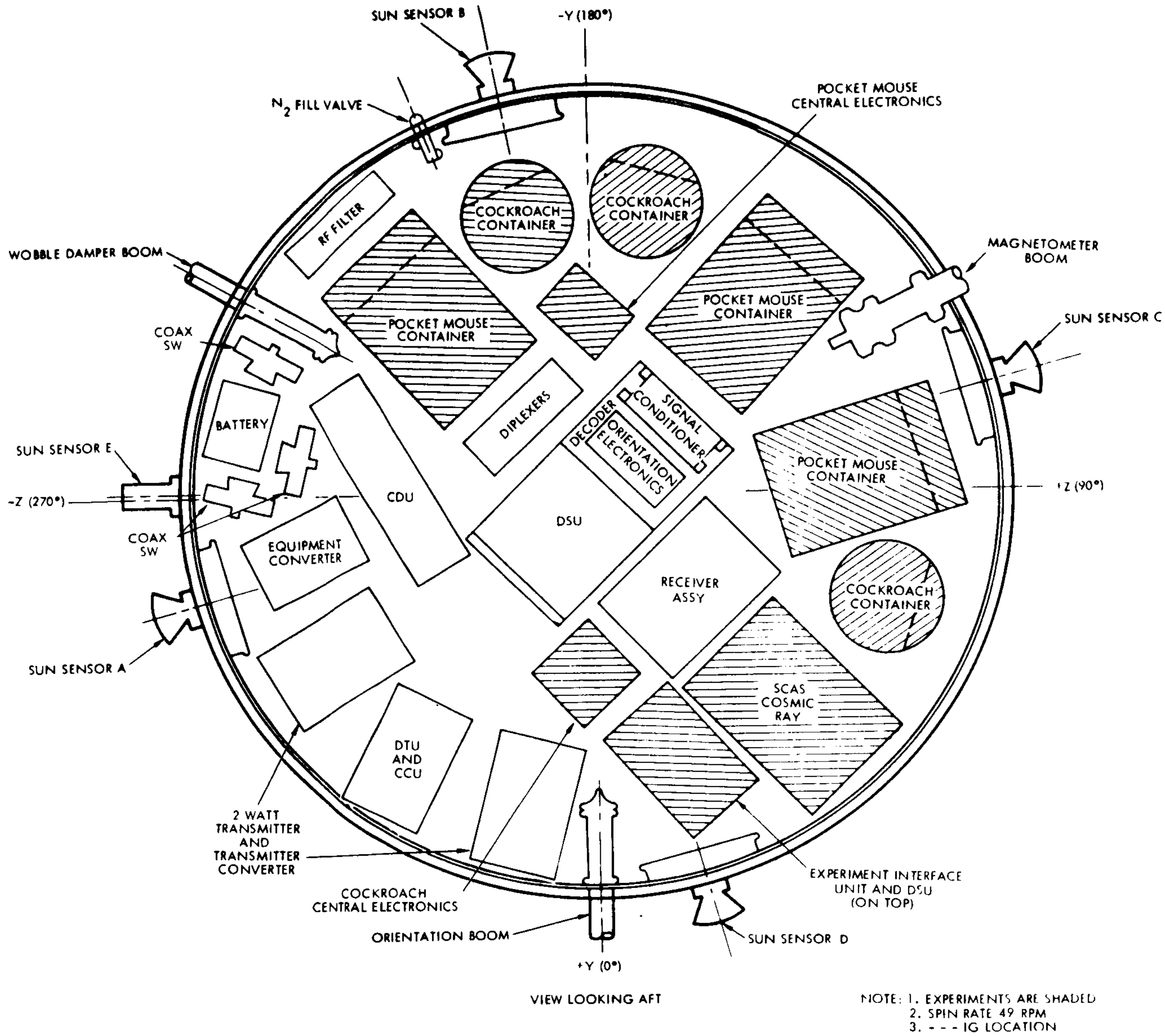


Figure 94. Equipment & experiment installation: Pocket Mouse (3 containers) and Cockroach (3 containers) experiments and one physical experiment.

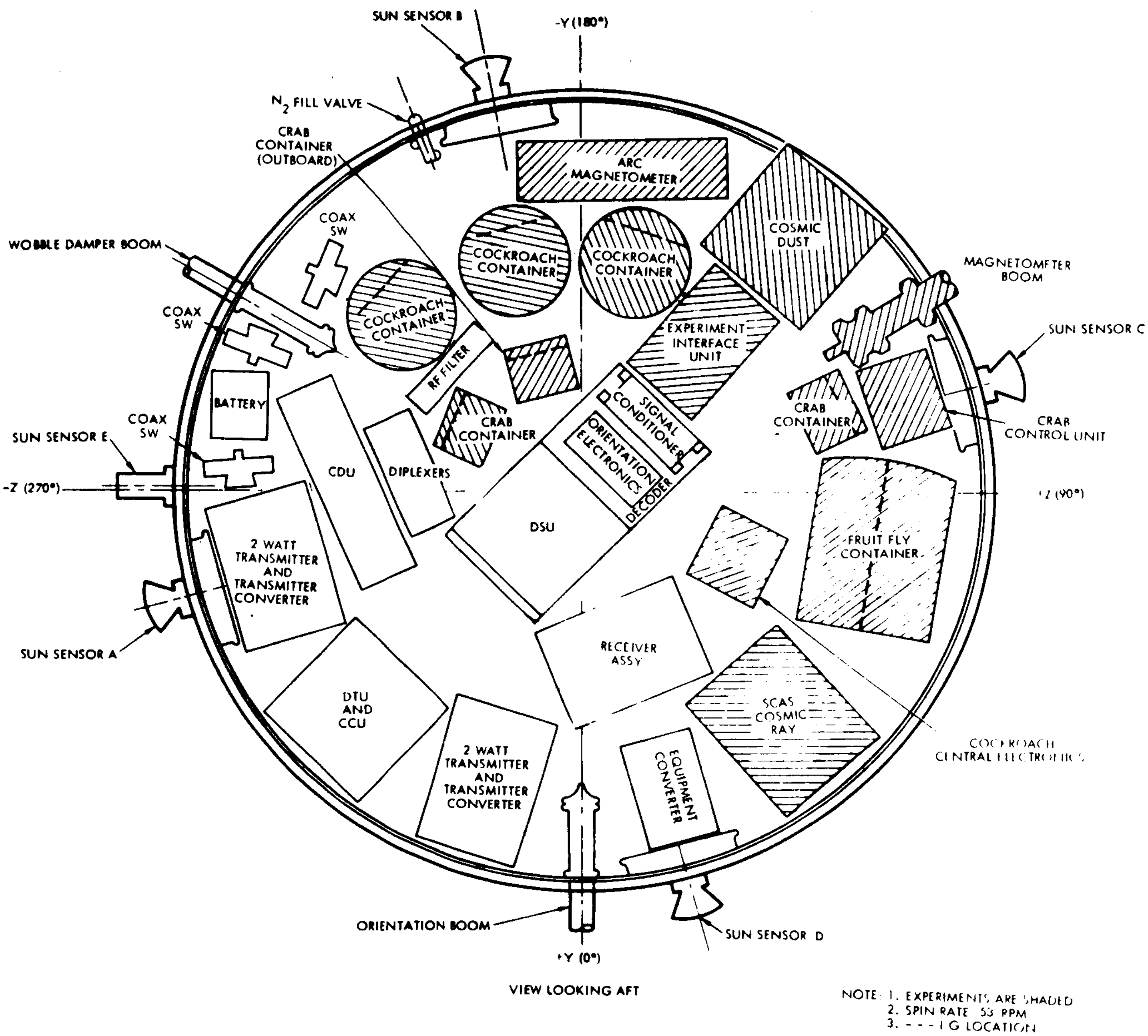


Figure 95. Equipment & experiment installation: Cockroach (3 containers), Crab (3 containers) and Fruit Fly experiments and three physical experiments.

1. A mammal experiment (pocket mouse).

2. An arthropod experiment (fiddler crab).

3. A plant experiment (potato).

Three pocket mouse containers were selected with their associated electronic box (central electronics), two crab containers with require support equipment, and two potato containers with their associated central electronics and controller box. Also included in the platform layout is an equipment interface unit with an additional DSU to accommodate the Pocket Mouse Experiment. The platform layout selected permits a 1 g environment for all specimen containers which are located at approximately a 12-in. radius from spacecraft centerline at a 54-rpm spacecraft spin rate. One of the two potato containers and one of the two crab containers are located inboard of the other experiment containers at a distance of 7 in. from the spacecraft centerline. At a 54-rpm spin rate these experiments would experience a 0.58 g environment. With the arrangement shown in Figure 96, a magnetometer (physical) experiment could also be incorporated in addition to the three different biological experiments.

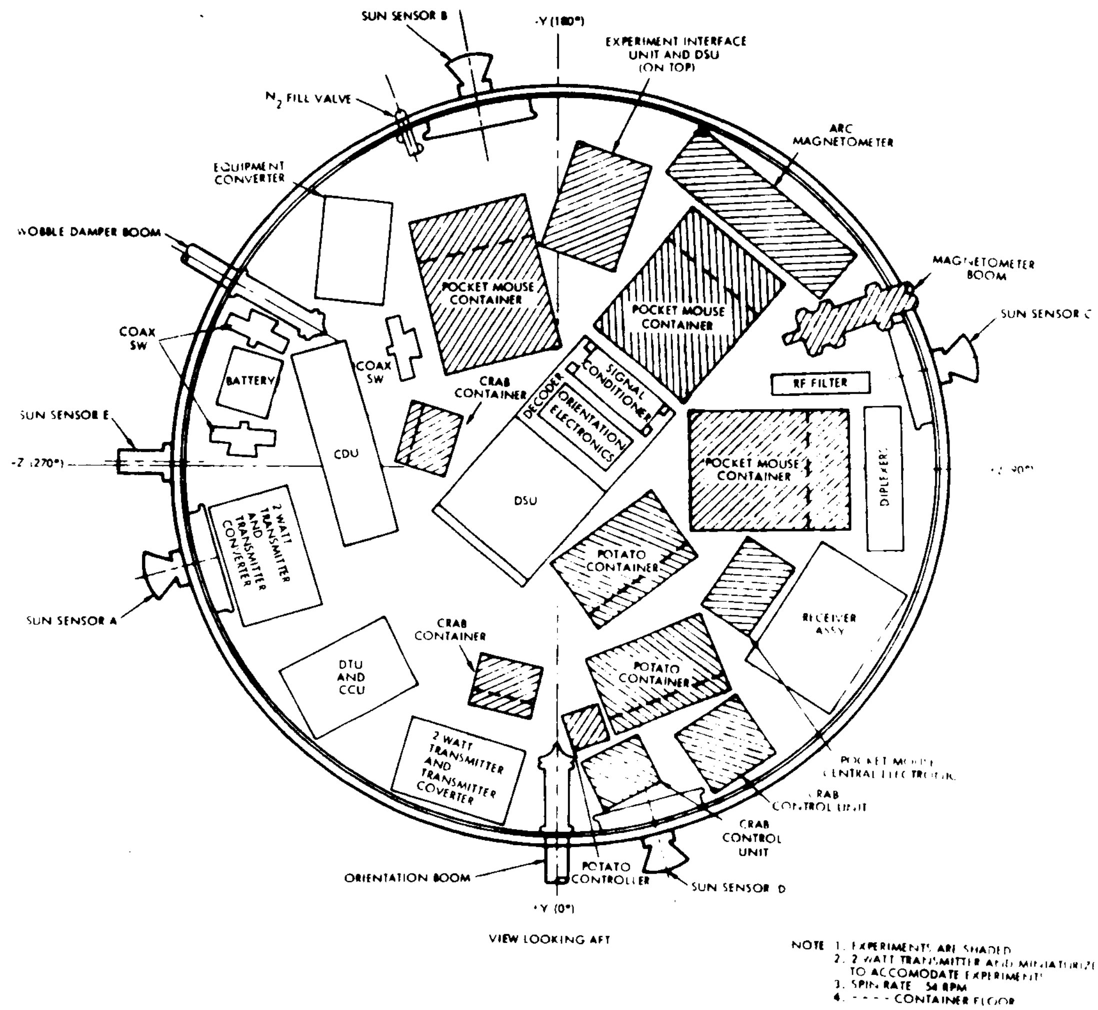


Figure 96. Equipment & experiment installation: three Pocket Mouse, two Crab and two Potato Plant experiments, one physical experiment.

CONCLUSIONS AND RECOMMENDATIONS

The results of this study clearly establish the feasibility of conducting biological experiments aboard a Pioneer spacecraft. Seven biological and three physical sciences experiments were analyzed in the course of this study. The fact that each experiment can be accommodated and in most instances meaningful experiment combinations established clearly attests to the versatility of the Pioneer experiment platform. While beyond the scope of this study, endorsement of the scientific merit of the BioPioneer is strongly implied. The feasibility of combining both physical and biological experiments also implies a cost effective mission fully utilizing the operational orbital life of the Pioneer spacecraft.

It is recommended that the feasibility study now completed be followed by a more detailed Program Definition Phase leading to detailed design, fabrication, spacecraft integration, test, and launch. Tasks which would be performed include:

1. Identification of the most likely biological and physical sciences experiment combinations to be studied in detail. It is essential that candidate experiments endorsed by NASA receive support in the immediate future to permit prototyping of experiment hardware and adequate liaison between principal investigators and the spacecraft contractor.

2. Determine general feasibility of incorporating the experiment combination(s) defined in 1. above if different from those presented in this report.

3. In conjunction with the experimenters, investigate the feasibility of making certain modifications to the experiment packages so that the capability of the Pioneer spacecraft could be better utilized for specified experiment combinations.

4. Perform more detailed investigations of the integration of selected experiment combinations on the Pioneer spacecraft. Such studies and analyses would include:

a. Thermal analysis of the spacecraft and the experiment components and the emmissivity requirements thereof.

b. Detailed platform layouts of experiments and spacecraft components to include cabling requirements and incorporating a miniaturized Digital Telemetry Unit (DTU), redundant 2 W transmitters and a Convolutional Coder.

c. Detailed dynamics analysis of the selected experiment configuration(s). Determine, if necessary, additional requirements for restraining food and/or mice to maintain balance within allowable limits. Study methods of preventing and/or damping out the wobble induced by the motion of mice or other moving specimens, if such methods are required to maintain spacecraft stability.

d. Optimized utilization of data formats and modes to best accomplish the mission. Determine method of implementing these changes.

e. Analysis of the performance of the orientation subsystem with modified dynamic characteristics and define characteristics and requirements for new spin rates, if required.

5. Determine requirements for and perform detailed design of a miniaturized Pioneer DTU to include fabrication of an engineering model, unit testing and engineering prints.

6. Determine detailed characteristics of redundant 2 W transmitters for the BioPioneer mission and study the integration and interface requirements of these components on a BioPioneer spacecraft.

7. Perform an overall system analysis, including investigation of all interfaces.

8. Develop a BioPioneer Program Plan to define (1) the remaining detailed design, (2) fabrication and unit test, (3) spacecraft integration and test and (4) launch of a BioPioneer spacecraft. Cost per launch and milestone schedules would be included in the Plan.