I. Bio-Flight 1 Old Reliable

In the development and testing of ballistic missiles, there sometimes exist small spaces within the nose cone which may be used for purposes incidental to the main objective. An opportunity arose for utilizing such space for a biologic experiment on a non-interference basis. Non-interference defined the size and weight limitations, the character of the flight, and the time dimension. The available space was 750 cubic inches; the weight limit 30 pounds, and, although the flight time was only fifteen minutes, the count-down and pickup intervals, with a safety factor, increased the operation time for the closed biologic system to twenty-four hours.

Inasmuch as the space was small and the uncertainties large, consideration was first given to sending aloft a collection of plant and animal specimens, some of which were "certain" to survive. Indeed, the project acquired the name "Noah's Ark," and only after many tests and much thought was the decision made to risk everything by sending a monkey.

The squirrel monkey *(Saimiri sciurea)* was chosen primarily because of its small size and weight. Young animals were easily procured in the weight range of 300 to 500 grams. It was soon evident that these squirrel monkeys were highly excitable and rather aggressive in the untamed state. When excited, they showed wide fluctuations in respiration, heart rate, and body temperature. In general, the squirrel monkeys were found to be rather delicate animals and difficult to handle, but have the advantage of being a sensitive biological indicator of stressful situations.

THE BIO-CAPSULE AND ASSOCIATED EQUIPMENT

EXTERNAL DESCRIPTION

The capsule resembled a box with a curved top (10 by 13.75 inches) and a curved sloping bottom plate (Fig. 2). Its depth varied from 4.75 to 7 inches, and the volume of the empty capsule was 750 cubic inches. The size and odd shape of the bio-capsule were determined by the available space in the nose cone. The capsule was constructed of aluminum sheet metal with exterior reinforcement ribs; he-

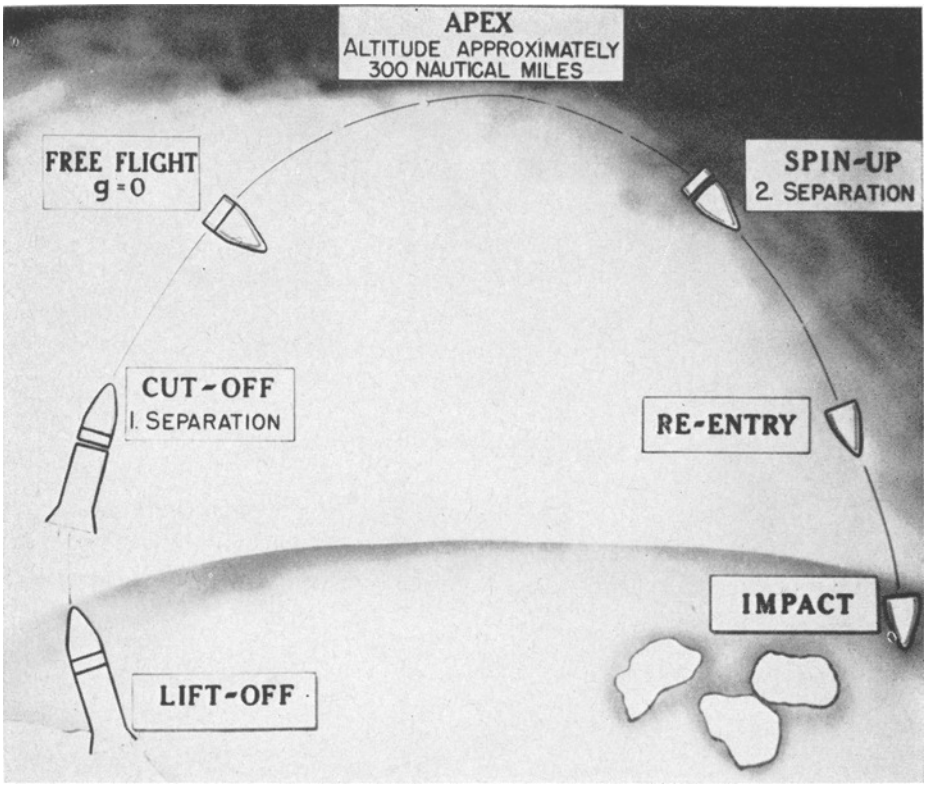

Fig. 1. Typical Jupiter trajectory. The curve describes the essential characteristics and main missile events of an IRBM flight.

liarc welding was used throughout. An elastomer coating, 0.125 inch thick covered by a layer of 0.5-inch thick glass fiber wool, held in place and protected by two layers of gummed aluminum foil, served as a water sealer and thermo-insulation of the capsule surface. An access port, 3.75 inches in diameter served as an opening on one end for the insertion of the animal support cylinder and of other equipment. A door plate and O-ring assembly sealed the capsule vacuum-tight. A second smaller opening on the same end of the capsule carried a pressure relief valve. This valve was set to relieve an over-pressure in the capsule in excess of 20 pounds per square inch. A third hole on the opposite end of the capsule carried a vacuum-tight, electrical receptacle for connection of the amplifier inside the capsule to the telemetry equipment of the nose cone. The total weight of the capsule including its contents was 30 pounds.

INTERNAL EQUIPMENT AND ARRANGEMENT

Mounted inside the capsule were three special systems: facilities for supporting and securing the animal, the life-support equipment, and electronic measuring devices.

Facilities for Support and Restraint of the Animal.—The animal was supported and secured in a cylindrical container which could be inserted in-

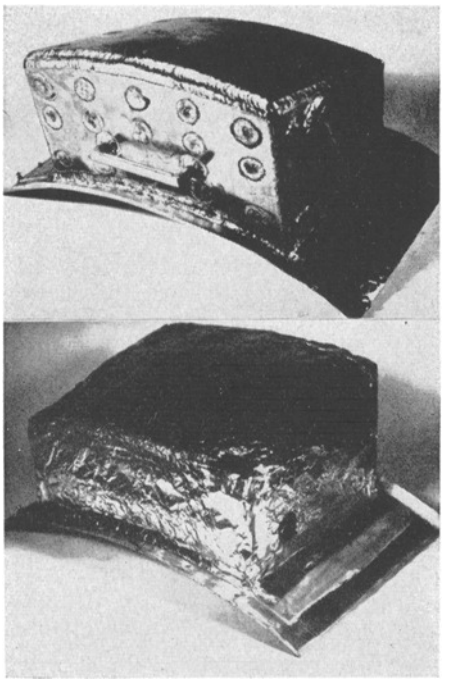

Fig. 2. Biocapsule for Bio-Flight 1. The upper photograph shows the capsule before, and the lower one after the final insulation coats have been applied.

to the capsule through the access port (Fig. 3). This container provided a rigid support and comfortable bedding for the animal against the high G forces and strong vibrations. The container consisted of two coaxial cylinders with end plates. The outer cylinder had a diameter of 3.75 inches, an over-all length of 12.75 inches, with a wall thickness of 0.125 inches. Part of the wall of this cylinder was cut out for observation of the animal, and the rest of the surface was perforated for ventilation purposes. When inserted into the capsule, the ends of the outer cylinder rested on keyed rubber pads fastened to the inside of the capsule and the inside porthole cover.

Inside the outer protective cylinder was the inner cylinder which carried the animal. The two cylinders were separated by rubber buffers. The inner cylinder had a diameter of 3 inches, a length of 11 inches, and 0.062-inch wall thickness. This cylinder was also supplied with ventilation holes. The top opening could be partly closed by a perforated cover plate fastened to the inner cylinder. This cover plate, lined with a thin layer of sponge rubber, covered the lower extremities of the animal and formed part of its restraint. The inner cylinder contained a molded, form-fitted silicone rubber bed, perforated for ventilation. Inserted in the rubber bed was a rubber strap to which the animal's helmet could be fastened. An electrical connector was also embedded in the silicone rubber connecting the physiologic transducer receptacles in the cylinder to the amplifier. Two wide nylon straps were attached to the inner cylinder. They served as belly and chest straps in restraining the animal. The latter strap also held the chest microphone mounted in a sponge rubber buffer.

The helmet consisted of a chamois inner-lining which was individually fitted to each monkey. This lining was covered by a layer of synthetic rubber potting compound in which was imbedded nylon fabric mesh for strength. This assembly provided a strong resilient support. Two loops

on the helmet would be connected to the straps inserted in the rubber bed for immobilization of the head.

Life Support Equipment.—The components of this equipment served to assure the suitability of the environment with respect to the atmosphere (O_2, CO_2, humidity, pressure and temperature) and control of excreta throughout a period of twenty-four hours.

Oxygen Supply System and Capsule Pressure.—It appeared desirable to maintain the composition and pressure of the atmosphere at levels not far from sea level values. This necessitated replacement of the oxygen at the rate it was consumed and removal of carbon dioxide as it was produced.

Compressed oxygen from a 22 cubic inch bailout oxygen cylinder served as the oxygen supply. The cylinder could be charged by means of a modified high pressure oxygen check valve to a pressure of 1700 lb./inch^2 representing the equivalent of 42 liters of oxygen at atmospheric pressure. This furnished a supply estimated to last for sixty hours at an hourly consumption of 0.7 liter. The storage cylinder pressure was reduced to 70 lb./inch^2 by means of a small pressure reducer.

Originally, a commercial demand valve was installed for delivery of oxygen at atmospheric pressure. For the actual missile flight, this valve was replaced by a needle valve set to deliver a continuous stream of oxygen at a slightly higher rate than previously established as the average oxygen consumption for the specific animal to be used. The above mentioned pressure relief valve completed the oxygen system. It would relieve capsule pressure if the oxygen was not used as rapidly as anticipated or if the animal died during count-down.

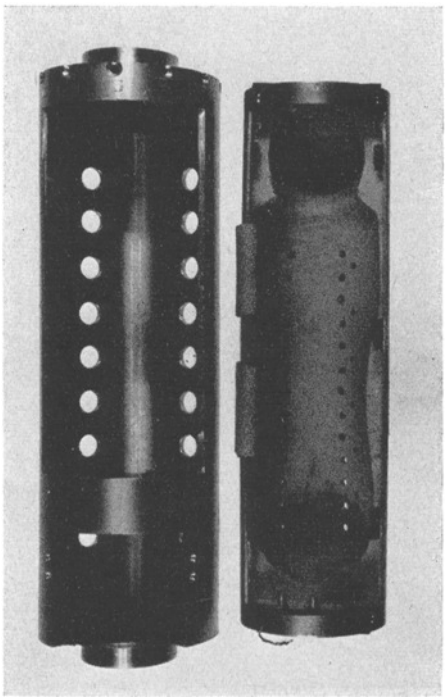

Fig. 3. Basic animal support cylinders for Bio-Flight 1. The cylinder on the right contains the ventilated, contoured support bed and is fitted into the outer protective cylinder on the left. Ventilation holes are shown clearly.

Carbon Dioxide and Water Absorbers.—Provisions were made to absorb the carbon dioxide chemically with baralyme in pellet form. The humidity in the capsule was reduced by mobilbead, a fused siliceous material in bead form. These absorbing materials were arranged in two containers fastened to the inside of the

capsule (Fig. 4). One, a flat metal box with perforated walls, contained 65 grams of baralyme and 180 grams of mobilbead. The two chemicals inside the box were enclosed in a pellon sac (a non-woven fabric of nylon, cotton, and acetate fibers). The second container was in the form of a flexible plastic screen wire blanket. The absorbing material (300 grams of baralyme and 200 grams of mobilbead) was first filled into pellon tubes of about 11.5-inch length and a diameter of about 0.5 inch. These sausage-like absorber units were then slid into the pockets of the blanket. The amount of absorber material was determined empirically to hold the concentration of carbon dioxide below one per cent and the relative humidity below 70 per cent during a twenty-four-hour period. As no fan was used, the diffusion and thermal convection rate determined the absorption rate.

Nourishment of the Animal and Waste Disposal.—The animals received no food during the twenty-four-hour test periods or during the actual missile experiment. Prior to this they were fed raw peanuts to induce slight constipation. The animals were watered shortly before placing them in the capsule and immediately after removal. Urine and feces were accumulated in diapers which had an insert of mobilbead to absorb at least part of the urine water.

Temperature Regulation. — The temperature of the capsule was primarily determined by means of five heat sources and two heat sinks. Heat sources were the metabolic heat of the animal, the heat set free by absorption of carbon dioxide and water, heat reaching the capsule through the insulation from the nose cone, and a thermostatically regulated 8 watt resistive type heater. Heat sinks for the capsule were the nose cone at a lower environmental temperature than the capsule, and cool nitrogen ventilated into the capsule area from a supply of liquid nitrogen. Only one heat source and one heat sink could be controlled. The thermostat was set to hold the temperature in the capsule above 16° C, and the nitrogen cooling could be activated at will during the count-down period.

Electronics and Measuring Devices.—Four physiologic and two environmental measures of the biologic system performance could be transmitted continuously to the telemetering receiving stations during the entire flight period as well as recorded by on-board recorders during the re-entry period. The physiologic measures were the electrocardiogram, respiration rate, chest sounds, and body temperature. The environmental measures were the ambient temperature and pressure of the closed capsule system.

Provisions were also made to record cosmic radiation on nuclear track plates, and to measure flash temperatures within the capsule by means of heat-sensitive, temperature-indicating cards. The results of these two measurements were to be analyzed upon recovery of the nose cone.

Two wide-band and four commutated channels from the missile FM-FM telemetering system were made available to the bio-project for trans-

mission of the desired data to the ground receiving stations. Each of these channels required a 5 volt, peak-to-peak input signal across a 100,000 ohm resistive load for full modulation of the voltage-controlled sub-carrier oscillator. Sufficient output was obtained from the respiration, ambient temperature, and ambient pressure transducers to drive the sub-carrier

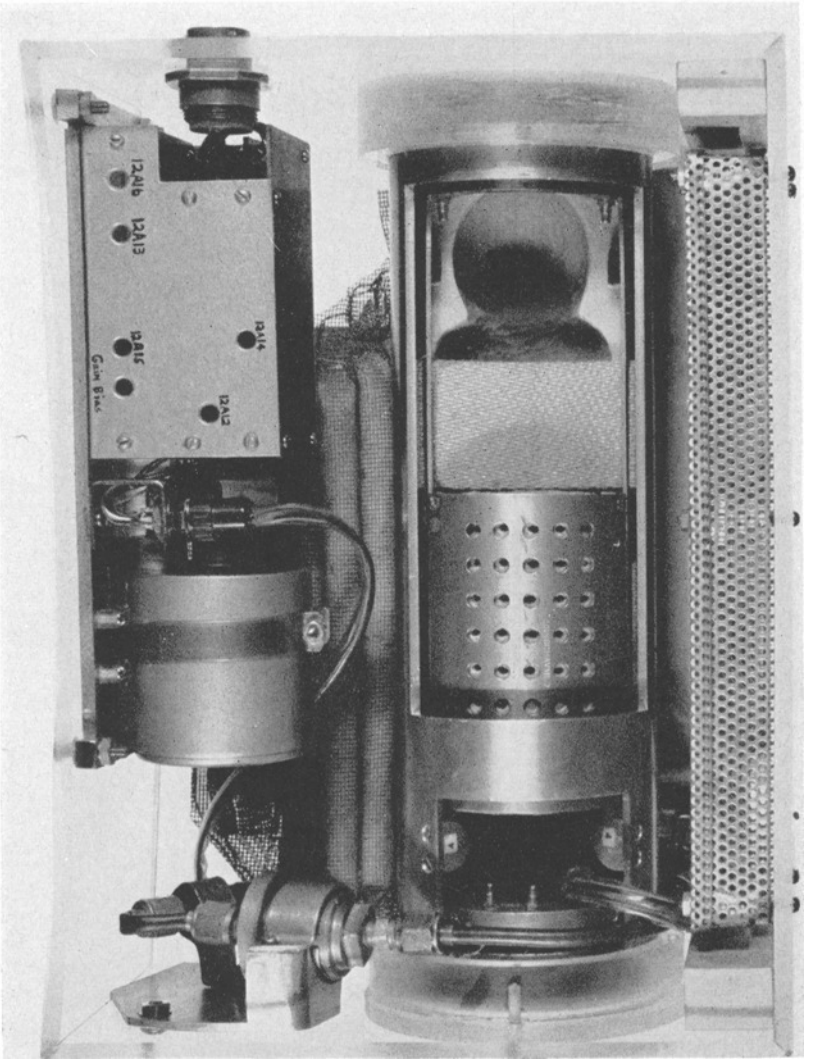

Fig. 4. Mockup of essential interior arrangements of Bio-Flight 1 capsule. The relative locations of the animal support system, the absorber tray, the absorber blanket, the electronic package, the oxygen pressure reducer and bleed valve assembly are shown. The oxygen supply bottle is located behind the absorber tray at the right.

oscillators directly without amplification. Amplifiers were provided to raise the output of the electrocardiograph, chest sounds, and body temperature measurements to the proper telemetering level. These amplifiers, constructed on printed circuit boards, and the associated environmental transducers were arranged in a single package weighing less than one pound (Fig. 5). The outputs of the electrocardiogram and the chest activity amplifiers were fed directly to the input circuitry of the two wide-band channels. The voltage-controlled sub-carrier oscillator driven by the electocardiogram amplifier operated at a frequency of 10.5 kilocycles. A 40 kc sub-carrier oscillator was driven by the chest activity amplifier. The remaining measurements were telemetered on commutated channels. Data from the missile flight were received and recorded on magnetic tape at several uprange and downrange stations. A more detailed description of the eight single measurements follows (Fig. 6).

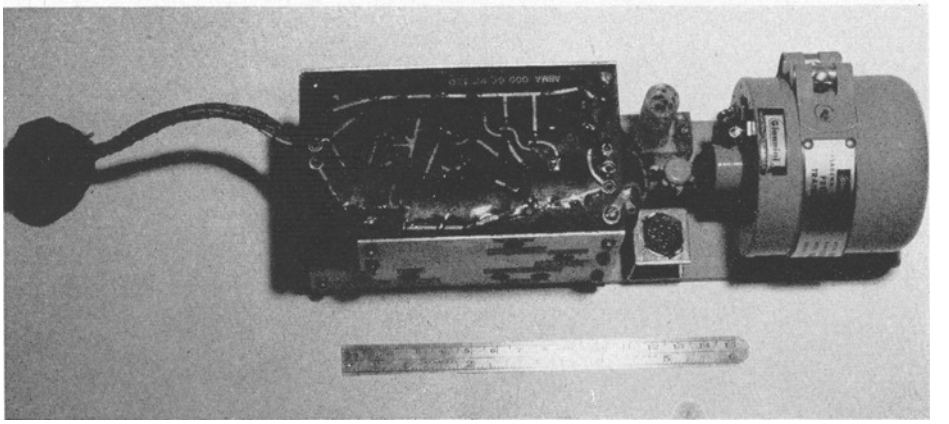

Fig. 5. Electronics package for Bio-Flight 1. The printed circuit amplifier boards, the ambient temperature and pressure transducers, and connectors are shown mounted on the base plate.

Electrocardiogram. — The positive electrode was placed on the precordium while the negative or remote electrode was placed on the right side of the back of the animal. The electrode proper consisted of a fine-mesh, platinum screen with a surface area of approximately 20 square millimeters (Fig. 6). A short length of stranded cable was soldered to the mesh, and the entire assembly was plated with bright silver. A length of polyethylene tubing was then slipped over the stranded cable to provide electrical insulation. After sterilization of the entire unit, each end of the polyethylene tubing was heat-sealed to the stranded cable. The electrodes were implanted under the skin of the animal using local anesthesia. With the cable of the electrode threaded in a needle the

mesh was inserted through a small slit in the skin. The needle guided the cable for a short distance under the skin. After healing of the incision the cable exit formed the only penetration of the skin. A cloth jacket prevented the animal from disturbing the electrode. This implantation minimized artifact due to poor subject-electrode contact and that due to high level missile vibration and acceleration.

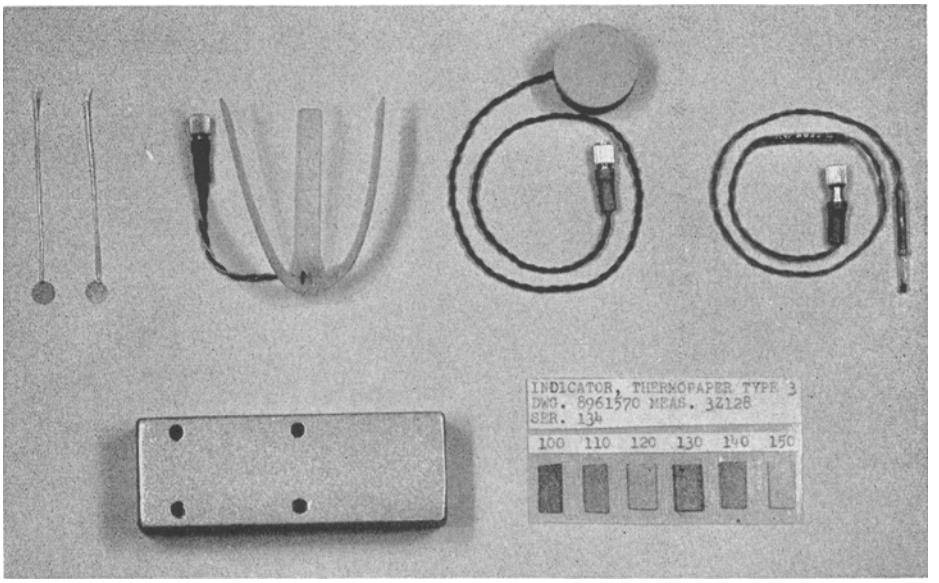

Fig. 6. Transducer assemblies for Bio-Flight 1. The top row shows the two electrocardiogram electrodes, the respiration rate transducer mounting, the chest sound microphone, and the body temperature thermistor. A nuclear track plate package and a flash temperature indicator card are shown in the bottom row.

The electrodes were connected to the input circuit of the single-ended amplifier. The voltage gain of this amplifier was 1000 at the mid-band point, and the response was down 3 decibels at 1 cps and 270 cps. The amplifier had an effective input impedance of 80,000 ohms at 100 cps.

Chest Sounds.—This measurement was obtained by placing the diaphragm of a pressure sensitive transducer in contact with the chest wall of the monkey. The mechanical activity of the heart resulted in pressure variations at the chest wall which could be used to determine the heart rate in case of failure of the ECG measurement. The sound measurement also permitted the recording of chest wall vibrations produced by such non-cardiac sources as body movement, body shivers, bronchial disturbances and voice sounds.

The basic element of the transducer assembly was a small, cylindrically shaped, variable-reluctance type magnetic pickup. This unit, used as a sound source in commercial air-conduction type headsets, was $\frac{5}{8}$-inch in diameter, $\frac{3}{8}$-inch deep, and had an

impedance of 2000 ohms at 400 cps. To minimize the coupling of undesired, air-conducted sounds (generated by missile noise sources external to the biological capsule) to the transducer diaphragm the entire assembly was coated with resilient silicone-rubber potting compound (Fig. 6).

The transducer was inserted in a contoured, foam rubber pad, and the entire assembly placed between the chest wall of the monkey and the inner cylinder chest strap. The foam rubber pad served as a holder for the transducer and as a vibration insulator between the animal's chest wall and the rigidly tightened chest strap. The monkey's chest wall was coated with a silicone grease compound to minimize sounds generated by friction with the sound transducer.

The above method of coupling the transducer to the monkey produced a peak-to-peak output signal of approximately 5 to 10 millivolts. The midband voltage gain of the amplifier was 333 and the response was down 3 decibels at 15 and 550 cps.

Respiratory Rate.—The breathing rate was recorded by measuring the flow rate of air expired from a single nostril of the monkey. This was achieved by placing a miniature glass bead thermistor of about 0.014 inches diameter directly in the path of the air flow from the naris. The beads of the thermistor were cemented to a reinforced plastic, cross-shaped visor (Fig. 6) that was rigidly fastened to the helmet. An air scoop mounted to the visor-like face shield directed the expired air over the surface of the thermistor through which sufficient current was passed to provide for a quiescent bead operating temperature of approximately 120° C. The cooling effect of the air flow on the bead produced an increase of thermistor resistance. The resultant rise in potential across the thermistor terminals was sufficient to drive the input circuitry of the missile telemetering system without amplification.

It should be noted that the flow rate, not the temperature, of the expired air from the naris was measured with this system. This technique was used to minimize the effect of changes in the capsule ambient temperature on the thermistor output voltage level. Although the flow rate was recorded, the amplitude of the change in thermistor voltage could not be used as a direct measure of respiratory volume. The inability to maintain the position of the thermistor constant over any length of time in relation to the narrow air flow prevented volume determination. In addition, the one-second time constant of the thermistor caused a decreased output voltage swing for increased respiratory rates with constant volume output. The flow of inhaled air was not directed to such an extent as to influence the thermistor temperature.

Body Temperature. — The body temperature of the monkey was measured by recording the resistance variations of a glass probe thermistor (Fig. 6) taped to the left axilla. The potential across the thermistor, derived from a compensated voltage divider circuit, was amplified by a direct current amplifier. Sufficient amplification was provided to represent axilla tem-

peratures between 95 and 110° F by the full 0 to 5 volts range required to drive the commutated channel.

Ambient Temperature.—The ambient temperature of the capsule was recorded by means of a thermistor assembly consisting of two matched thermistors mounted side-by-side in a plastic shield, which, in turn, was mounted on the electronic package base plate. The thermistors were connected in a voltage divider circuit that provided full scale telemeter output for a temperature range from 0 to 100° C.

Ambient Pressure.—The ambient pressure in the capsule was recorded by a pressure-actuated, potentiometer-type transducer. This transducer was mounted on the electronic package base plate. It provided a linear output voltage versus absolute pressure change over the pressure range of 0 to 18 psia.

Radiation Measurement.—Two sets of nuclear track plates mounted inside the capsule on opposite walls close to the animal were expected to give information on the radiation dose to which the animal was exposed during flight. Evaluation of the plates depended on recovery of the nose cone.

Each set of nuclear track plates consisted of three Ilford G.5 and three Kodak NTB plates (1 by 3 inches) with an emulsion thickness of 200 microns. The plates were wrapped in black paper and aluminum foil and the entire assembly was enclosed in an epoxy sealing compound capsule of 3.25 by 1.25 by 0.75-inch (Fig. 6). The two sets of plates were installed inside the capsule parallel to each other. An imaginary line perpendicular to the surface of one plate and intersecting it would pass through the corresponding point of the remaining eleven plates.

Flash Temperature Measurement.—Thermopaper indicator cards with a range of 100 to 150° F in steps of ten degrees were pasted to the animal cylinder and on four interior wall surfaces of the capsule (Fig. 6). This indicator paper was expected to give information on flash temperatures which might occur. The evaluation of this measurement depended on the recovery of the nose cone.

Monitoring and Recording Equipment.—Arrangements were made to monitor and record the six measurements in the laboratory during the conditioning period of the animal, as well as immediately before the launch and after recovery. Equipment for such was provided at the launching site and on the recovery ship. This equipment consisted of a monitor which allowed calibration of the power sources and connection of the six different capsule measurements to a calibrated meter, or to a single-channel, direct-writing recorder. Outlets were also provided for an optional oscilloscope monitor. Chest sounds could be made audible by a separate loudspeaker.

Additional equipment served to calibrate the body temperature transducer and to check the optimal positioning of the respiration transducer in front of the nostril of the animal. A check

was performed each time the transducer was applied.

In addition to the six measurements mentioned above for which the capsule was permanently equipped, relative humidity in the capsule was measured with an electronic hygrometer during laboratory studies.

Chemical and Related Tests.—No attempts were made to analyze for carbon dioxide content in the capsule during flight. However, during the preliminary physiologic test period the concentration of this gas was analyzed at frequent intervals using the micro-Scholander method.

The method of oxygen supply to the capsule through a continuously bleeding valve made a pre-flight determination of the oxygen consumption of each animal mandatory. It seemed advisable to perform this determination with the animal in the capsule. With the use of an outside supply of oxygen, the flow rate into the capsule was regulated to hold the pressure constant; pressure changes were determined by a water column manometer. The flow rate of oxygen represented the oxygen consumption of the animal provided the carbon dioxide absorber functioned properly. Measurements were made repeatedly for each animal during twenty-four hour exposure periods.

A capsule similar to the flight model but made of transparent plastic material was of great help during the initial period of animal testing. It allowed a clear view of the behavior of the animal and of the performance of equipment installed in the capsule. The plastic capsule served also to familiarize the animal with confinement.

DEVELOPMENTAL AND EXPLORATORY PROCEDURES IN PREPARATION FOR THE FLIGHT

The equipment described above was specially developed for this flight and required careful testing of individual parts and of the assembled capsule. All of these tests will not be described in detail here, but, a few examples may give an indication of the task involved.

TESTS OF CAPSULE AND EQUIPMENT

Pressure Tests.—The position of the capsule in the nose cone subjected the capsule at one point during flight to an explosive decompression from atmospheric pressure to a pressure close to zero. This was simulated in the satellite chamber of a large low pressure chamber. The capsule was tested by explosive decompression in 0.375 second from sea level pressure to a pressure altitude of 92,000 feet. The capsule was shaken at 40,000 feet to ensure that the pressure relief valve was tight at low outside pressure.

After the nose cone enters the water the capsule is submerged and temporarily exposed to high water pressure. To meet the water integrity requirement, the capsule was submerged in a closed, water-filled container and tested at 3 atmospheres differential pressure.

Vibration Tests.—During the powered flight, and mainly during the reentry phase of the flight, the capsule

is exposed to vibrations of varying frequency and amplitude. The main concern about the effect of vibrations centered around the carbon dioxide absorber. The absorber pads, singly and mounted in the capsule, were tested on a shaking machine at 10 to 50 vibrations per second and a maximum amplitude of 1 cm. These experiments led to the final selection of pellon as container material and baralyme and mobilbead as absorber materials. Several other absorber materials tested at this time failed to meet the requirement of minimum dusting in the capsule during the shaking test.

G Tests.—Different bedding materials were used for cushioning effect under the influence of G forces up to 100 G. The final selection for Bio-Flight 1 was a commercial silicone rubber potting compound.

The amplifier package was designed and constructed by the Army Ballistic Missile Agency to meet its standard missile specifications.

PHYSIOLOGIC REACTION OF SQUIRREL MONKEYS TO CERTAIN STRESSES

The squirrel monkey is not a laboratory animal and its physiology is not well-known. The experimental work preceding the shoot had the dual purpose of collecting basic information on the animal's reaction to some stresses characteristic to missile flight and of familiarizing it with handling and with particular environmental conditions. The experience described in the following paragraphs was collected during the preparations for Bio-Flights 1 and 2 Baker.

Effects of Restraint and Confinement.—The procedure used in Bio-Flight 1 and 2 required a prolonged period of restraint and confinement of the animals. Assuming a countdown period of up to twelve hours, a recovery period of six hours, and applying a safety factor, it was estimated that a period of twenty-four hours would be maximum confinement time. For such a period of time the animals would be completely restrained in absolute darkness in the cylinder. They would rest most of this time (countdown time) in prone position.

The animals are accustomed to free movement in their natural habitat so the restriction in cages had a preliminary conditioning effect. The further restraint in capsules was started gradually with short training exposures, then increased up to twenty-four hours and more as the animals became adapted. During a later phase of experimental testing the animals were restricted in a dark room in the position they would later assume in the capsule. Body temperature, respiratory rate, and the direct observation of the movements of the animals were decisive factors in their selection. Constant struggling and a high body temperature (over 103° F) after repeated exposure were the characteristics which typically excluded animals from further training.

Animals which passed this preliminary selection were exposed for periods of increasing length of time in the cylinder placed into a plastic capsule or later on in a space flight unit. Some animals showed great restlessness, high respiration rate, and high body temperature sometimes soon

after start or later during exposure. At these indications the animals were removed immediately from the capsule. Animals which tolerated restraint well were used to establish a scale of normal values of physiological data. A typical run on Baker is presented in Figure 7.

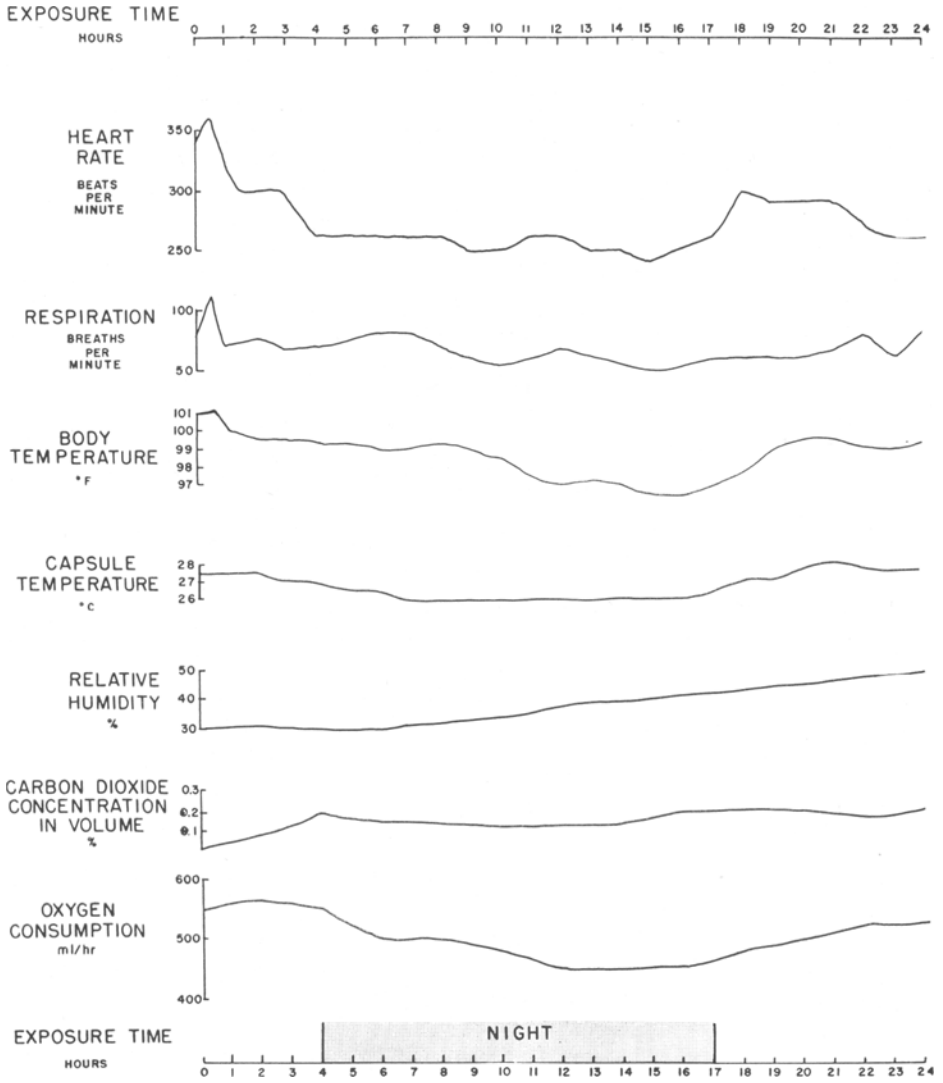

Fig. 7. The record of a twenty-four-hour training exposure of Monkey No. 27 (Baker). This experiment was performed one month before Bio-Flight 2 in the laboratory at the U. S. Naval School of Aviation Medicine.

Normal Range of Body Temperature.—The body temperature of restrained squirrel monkeys normally varied between 92° and 102° F. High

temperature values were consistently observed shortly after the onset of restraint. Daytime temperatures were generally higher than those during the nighttime. The influence of extremes in the environmental temperature on the body temperature were not studied systematically. However, some observations indicated that an environmental temperature above 27° C tends to raise the body temperature of the restrained animal. On the other hand, temperatures below 25° C seem to have a tendency to lower the body temperature. A capsule temperature between 25 and 27° C was generally well tolerated by the restrained squirrel monkeys.

Heat conductivity of bedding material also has a great influence on the body temperature of the restrained animal. Bedding materials with good qualities as mechanical shock absorbers have often low values of heat conductivity. The body temperature of animals on such bedding compounds may increase to an intolerable level unless ventilation holes in bedding materials are provided. In general, the body temperature of the squirrel monkey is a good indication of the well-being of this animal. Extremes are not tolerated very well.

Normal Range of Heart Rate.—The normal heart rate, determined from heart sound measurements or the electrocardiogram, varied in restrained animals from 120 to 375 beats per minute. The heart rate was observed to decrease noticeably with prolonged exposure of the animal to confinement. Considerable changes in the activity of the heart seem to be normal. The heart rate of the restrained animal seems to depend greatly on the emotional status. A period of increased activity of the heart due to excitement is often followed by a period of decreased heart rate.

Normal Range of Breathing Rate.—This rate varied in the restrained animal between 50 and 150 breaths per minute and was usually highest shortly after restraining, dropping to below 100 after several hours. As in the case of the heart rate, the breathing rate of these animals may vary considerably within a short period of time.

Normal Resting Oxygen Consumption.—The oxygen consumption of the resting squirrel monkey depends primarily on its size. Animals of 300 grams weight (twelve animals tested) consumed an average of 1.66 liters of oxygen per kg. per hour. Heavier and presumably older animals showed a lower oxygen consumption. Animals with a body weight of close to 500 grams (eight animals tested) consumed an average of 1.4 liters of oxygen per kg. per hour. The influence of sex on the oxygen consumption was not investigated. An increase of the oxygen consumption was observed during periods of excitement, however, during total rest and sleep at nighttime a drop of the oxygen consumption of a 300 gram animal to 0.84 liters of oxygen per kg. per hour was observed.

LAUNCH PROCEDURES

In preparation for the launch of the squirrel monkey, certain laboratory

facilities, two flight-ready capsules, and six animals were moved from Pensacola, Florida, to Cape Canaveral, Florida, four days ahead of the expected launching date. At the same time another team with monitor, recorder, and facilities to assist a recovered animal joined the down-range recovery ships.

TABLE I.
INFORMATION RECEIVED DURING THE COUNT-DOWN PERIOD

Local Time	Count-Down Time (min.)	Breathing Rate (per min.)	Heart Rate (per min.)	Body Temp. °F	Capsule Temp. °C	Capsule Pressure psia
2030	390	76	275	99.2	26	14.2
2200	300	65	230	96.5	27	14.3
2230	270	74	250	97.0	25	14.3
2300	240	75	250	96.0	23	14.3
2345	195	62	240	95.0	23	14.3
0050	130	58	280	95.4	23	14.5
0220	40	68	253	94.0	23	14.6
0300	hold	61	259	95.2	23	15.0
0354	6	60	240	95.0	21	15.2

At X-12 hours the oxygen cylinder in the capsule was charged to 1400/ lb./inch^2. At the same time a newly-filled absorber pad was placed into the capsule.

At X-11 hours the packing of the animals started (Fig. 8). Two animals, selected because they had shown the best all-around performance, were prepared for the flight capsule and a spare unit by two teams. The procedure included placing the helmet, adjusting the respiration transducer, soldering the lead wires to the already implanted electrodes, and locating the thermistor in the armpit. Then the animal was restrained in the inner cylinder and the microphone placed under the chest strap. All physiological transducers were connected to receptacles located in the end pieces of the inner cylinder; this inner cylinder was inserted into the outer cylinder, and electrical contact between the two cylinders established. The fully packaged animal was then inserted into the capsule which was closed after the cable between the cylinder and the electronic package had been connected. A final monitoring of all signals concluded the laboratory preparation of the animal for flight.

At X-8 hours the flight capsule was delivered to the missile pad and immediately installed in the nose cone. Connection of the electrical cable from the capsule to the telemetering equipment of the nose cone completed the installation. The animal in the spare capsule remained in the laboratory and was removed from the capsule at X-4 hours.

The animal in the nose cone was monitored frequently from two blockhouses. The electrocardiogram and the ambient temperature were displayed on a Brush recorder at fifteen-minute intervals. All measurements were monitored on magnetic tape on a non-interference basis at hourly intervals. The heart sound was monitored audibly. The results of direct readings during the count-down period are tabulated in Table I. Part of the pre-launch period (—60 to 0

seconds) was also covered by data telemetered from the missile on the pad.

Flight 1 the telemetered record presented the necessary information concerning the physiological status of the

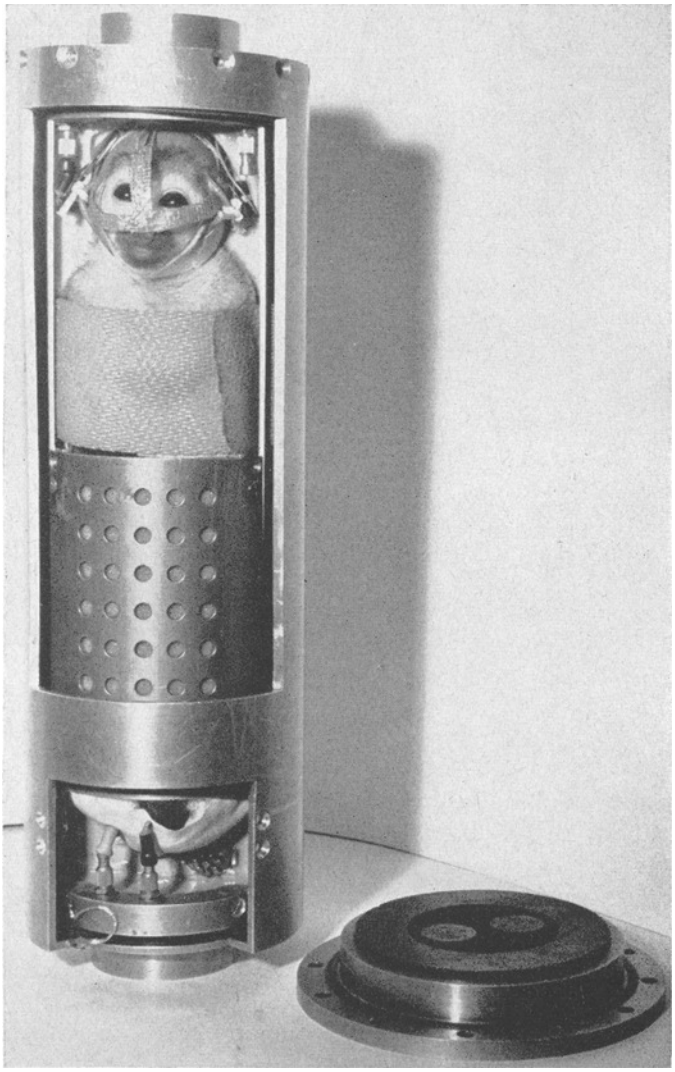

Fig. 8. Monkey No. 510 (Old Reliable) restrained in the cylinder. Photograph was taken just prior to insertion into the capsule for a laboratory experiment prior to Bio-Flight 1.

FLIGHT OF THE ANIMAL

RECORDS OF THE FLIGHT

Although the nose cone with the animal was not recovered from Bio-monkey during flight (Fig. 9). The record covers the period from lift-off to 930.5 seconds range time when all signals from the nose cone were lost.

Useful information could not be collected after 905 seconds range time when the signal became very noisy.

During the above time limits all transducers in the capsule gave valuable information with one exception. The thermistor used for measurement of the breathing rate gave no modulated signal during the greater part of the accelerated flight after lift-off. This was very likely due to a displacement of the thermistor bead in relation to the exhaled air stream. A change in the attachment of the respiration thermistor in Bio-Flight 2 resulted in a modulated signal during accelerated flight and verified the above assumption.

RESULTS OF BIO-FLIGHT 1

ENVIRONMENTAL FACTORS

Ambient Temperature in the Capsule.—In the evaluation of the ambient temperature record several technical factors had to be considered: The commutated channels are accurate to within 5 per cent and single samples may drop out to a still greater extent. Variations are canceled to a certain extent by using the average of the readings over a period of ten seconds and by omitting the drop-outs in the evaluation. The time constant (25 seconds) of the two thermistors used in this measurement should be considered in an evaluation of sudden temperature changes; however, such changes were not observed in the record of Bio-Flight 1.

Table I shows a temperature drop from 27° C to 23° C within two hours but the temperature remained constant during the next five hours. The initial decrease in capsule temperature marks an approach to equilibrium with the lower nose cone temperature. The outside air temperature at Cape Canaveral was 10° C during this particular night. A further 2:5° C decrease of the capsule temperature caused by nitrogen cooling of the nose cone was observed in the last hour before lift-off. After the temperature had dropped to 20° C at thirty seconds range time the heating effect of nose cone friction during acceleration was manifested in a gradual increase of the capsule temperature to 23° C at 600 seconds range time. From then on until the loss of signals the temperature of the capsule stayed constant. The different heat sources and heat sinks were obviously in equilibrium in this latter part of the flight. It appears unlikely that the resistor heater which was set to respond to 16° C was activated during any period of the count-down or recorded flight.

Ambient Pressure in the Capsule.—The pressure in the capsule increased gradually during the count-down period from 14.2 pounds per square inch, measured at the time the capsule was closed at atmospheric pressure, to 15.2 pounds per square inch measured at lift-off. This increase was the result of oxygen supply slightly exceeding consumption as planned. During the actual missile flight the capsule pressure stayed constant at fifteen pounds per square inch. The results confirmed the expectations held for the oxygen delivery system. The pressure reducer and the bleeder valve did not change characteristics under the influence of the different mechanical stresses of

the recorded missile flight. The bleeder valve system for oxygen supply, which has no moving parts, proved to be simple, inexpensive, and reliable in its use for the purpose.

PHYSIOLOGICAL FACTORS

Body Temperature of the Animal.—The body temperature fell during the count-down period, at first rapidly and then gradually from 101° F, measured shortly after closing of the capsule, to 95° F at zero time. This decrease is normal for an animal restrained in a capsule at nighttime. During most of the flight an axillary temperature of 95.5° F was measured. A small increase of 0.5° F during accelerated flight was indicated. However, this increase is well within error limits and may be disregarded on that account. The absence of any noticeable increase of body temperature in an animal which demonstrates such increases under stress was considered a very favorable sign and suggested that the stresses in flight were well tolerated.

Cardiorespiratory Data.—In the following presentation of cardiorespiratory data, it is well to remember that the information is based upon the raw telemetry record. As such, it was expected that some artifacts would be observed, but, in fact, so little real difficulty was experienced in this regard that preliminary interpretation of the data even from the untreated recording is quite feasible.

The electrocardiogram shows a number of disturbances which, from the usual clinical viewpoint would be considered artifacts. These are primarily baseline movements and extraneous muscle potentials. The respiration record, on the other hand, exhibited no real artifacts except during the acceleration phase when loss of signal occurred. The chest sound, or preferably chest activity record showed no artifacts other than external nose cone and missile noise. It should be recalled here that the chest sound transducer was not designed to obtain a classical phonocardiogram, but rather a general picture of activity including not only crude heart sounds, but body movement, vocalizations, and bronchial and respiratory noises. As will be evident, these signals proved to be helpful indicators not only of events in flight but also of physiological status.

A highly characteristic "artifact" kept recurring at frequent intervals throughout the entire recording and will be briefly described. The first indication was in the record of the chest activity, the usual pattern of heart sounds being interrupted by high frequency waves of varying amplitude and various wave lengths. Within one-tenth of a second it was declared in the electrocardiogram by oscillations of low amplitude and low frequency which distorted the T-complex and the P-wave. Sometimes there was conspicuous movement of the baseline. Within one second there was an increase in heart rate with loss of sinus arrhythmia and an increase in respiratory rate. The event was shortlived, usually two or three seconds, and the return of the heart rate to normal marked the end. The artifact occurred at intervals, varying from five to thirty seconds. In most instances it

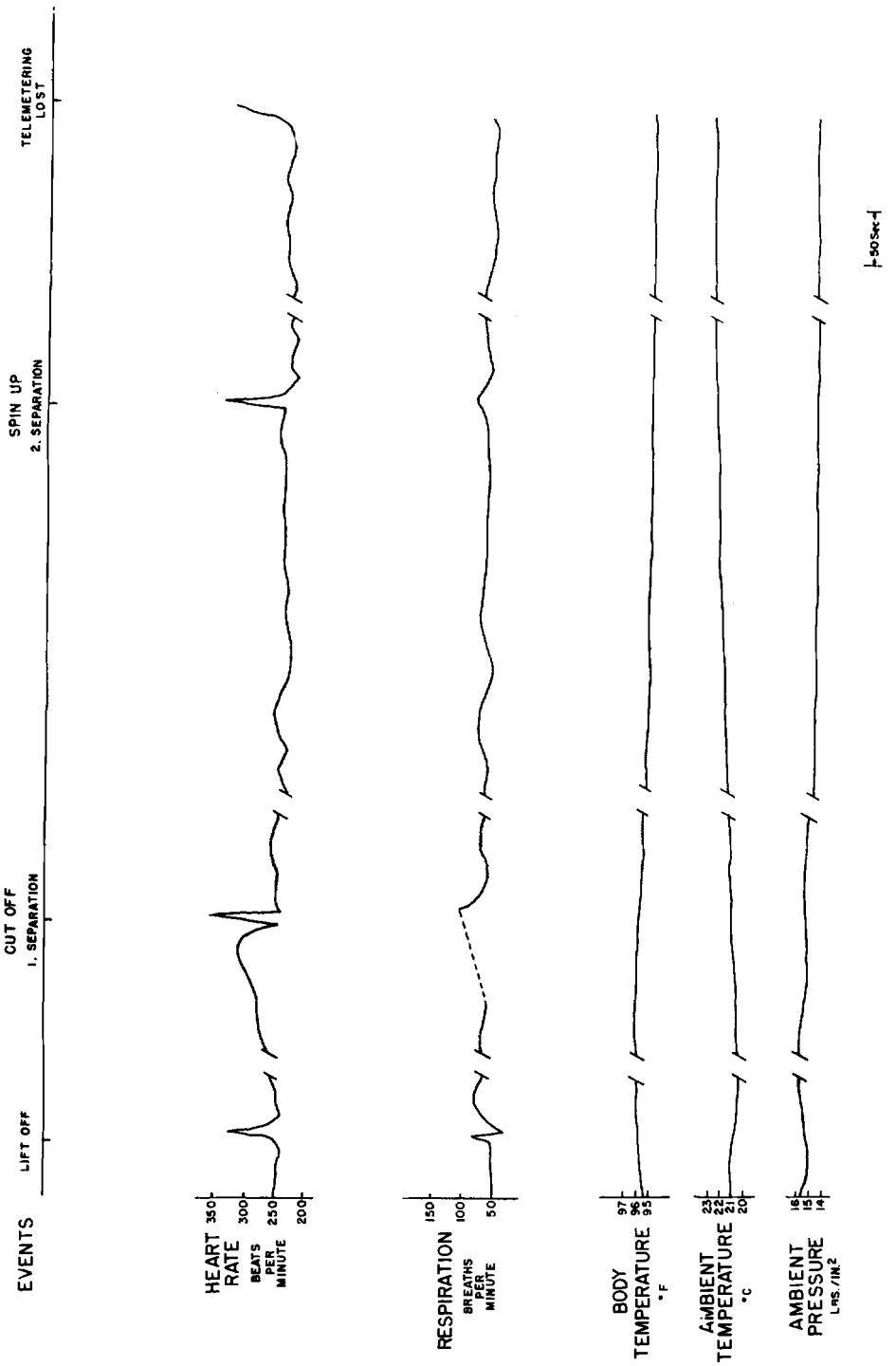

Fig. 9. Telemetered flight data from Bio-Flight 1 Old Reliable.

was probably due to shivering, in some to startle.

The variations in heart rate and respiratory rate caused by the major events in flight are shown in Figure 9. In constructing the curve depicting changes in heart rate, variations due to extraneous events were omitted. Average respiratory and heart rates were around 70 and 250 per minute except during special events of the flight. After lift-off the respiratory rate fluctuated above and below the average values before the signal was lost during the last half of the boost phase. When the signal was recaptured shortly after cut-off the rate was falling and may have been preceded by an even higher rate than the observed 115. Thereafter there was little variation except at spin-up when a slight rise occurred.

The variations in the heart rate in association with the major events stood out clearly. After an initial sharp rise and fall at lift-off, the rate gradually rose during the boost phase until just before cut-off when it fell to the average value. This sharp fall represented either a response to the peak acceleration or to the abrupt cessation of acceleration. The latter is more likely, which points up the delicate nature of this response when used as an indicator of flight events. This fall was followed by a brief sharp rise. During the period of zero G or near zero G the heart rate remained at the prelaunch level. Spin-up was indicated by a brief sharp rise following which there was a slight fall. There was no marked change in rate at re-entry time, arbitrarily chosen as the moment when the nose cone had fallen to within 100 km. of the earth. Shortly thereafter, the rate rose precipitously as the signal was lost.

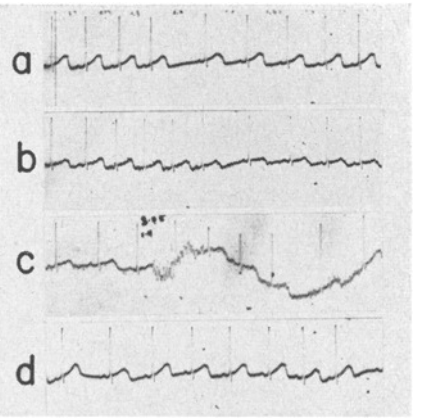

Fig. 10. Sample electrocardiograms from Bio-Flight 1 Old Reliable. (a) three to five seconds before lift-off; (b) eleven to thirteen seconds after lift-off; (c) at cut-off; and (d) during free flight before spin-up (near G=O condition).

The detailed considerations of the cardiorespiratory changes in relation to the major phases and principal events of the flight will center around the electrocardiographic findings.

Pre-launch.—A typical portion of the electrocardiogram obtained five to three seconds before lift-off (Fig. 10a) shows sinus arrhythmia, the rate varying between 169* and 293. The arrhythmia was phasic with respiration and the atrial and ventricular components of the electrocardiogram are clearly shown. The P-wave is upright, symmetrical, and without a notch. The P-R interval averages 0.048 second. The PR segment slopes upward, is slightly concave, and leads

*Rates based on length of single cycles unless otherwise stated.

directly into the RS complex. The RS-T junction is about one mm. above the baseline, and the RS-T segment is slightly concave and merges into the upstroke of T without demarcation. The apex of the T-wave is slightly notched, probably due to the superimposition of a U wave. The downstroke of T is very steep. When the cycle is short, the TR segment is represented by a light concavity between the end of the T and the upstroke of P. In the longer cycles it is seen that the T wave ends abruptly and the TR segment is nearly straight with a slight slope upward. The Q-T interval is 0.1 second.

Transition at Lift-off.—This period covers the cardiorespiratory changes between the relatively stable pre-launch patterns and the acceleration phase. It started 1.4 seconds before zero time with the appearance of missile disturbances in the chest sound record and the electrocardiogram. The heart rate rose precipitously from 190 to 320 at the time of lift-off with disappearance of sinus arrhythmia. It reached in the fourth second a maximum of 350 but soon fell to 240 and sinus arrhythmia returned. Concurrently the respiration rate rose to 90, fell to 17, then returned to the pre-launch value.

About five seconds after lift-off, there was a significant lowering of the RS-T segments and T waves, reaching a maximum between twelve and twenty seconds when the amplitude of T was less than half normal. These changes are illustrated in Figure 10b which represents the period from nine to thirteen seconds. Compared with the pre-launch trace, it is seen that the RS-T junction has fallen to or nearly to the level of the PR segment and that the first portion of the T complex is at times nearly flat. The terminal portion of T is characterized by a more gentle downstroke than in Figure 10a and the Q-T interval has become prolonged. There was no marked change in the P-wave, the P-R interval, or in the QRS complex.

Period of Accelerated Flight.—During this phase there was a progressively greater increase in acceleration which reached a peak of about 10 G at cut-off. The heart rate gradually rose until just before cut-off but the respiratory signal was lost due to displacement of the thermistor in relation to the nostril. This was verified by the fact that phasic changes in the electrocardiogram undoubtedly due to respiration not only remained but were exaggerated indicating an increase in depth of respiration. During this period the T-waves gradually became more upright, and after thirty seconds there was very little change in pattern throughout the remainder of the boost phase except for phasic variation associated with change in heart rate.

Transition at Cut-off.—It is worth noting that the time of cut-off was revealed only in the electrocardiogram; the heart sound recording showed little change until 1.5 seconds after cut-off and the respiratory signal was not recaptured until 7.0 seconds afterward. Shortly before cut-off, there was a fall in heart rate from values which had ranged from be-

tween 300 and 330 to approximately 225. The sharpest decrease occurred in the last four seconds, and sinus arrhythmia again became prominent. Considerable shifting of the baseline of the electrocardiogram in all likelihood indicated bodily movement at cut-off (Fig. 10c). Within two seconds after cut-off, the heart rate rose momentarily to 360 at which time there may have occurred an auricular premature beat, but the presence of artifact leaves the matter in doubt. In addition to the changes in rate and rhythm there were also changes in the RS-T segment and the T waves. These changes were very similar to those observed following lift-off but were of shorter duration.

Period of Free Flight.—During the period of free flight, a number of events deserve mention. First separation was clearly indicated in the electrocardiogram. During free flight (Fig. 10d) the vehicle tumbled very slowly imposing 0.03 G on the animal. The onset of spin-up was indicated in the electrocardiogram, but the extent of the disturbance was masked by the periodic artifact which supervened. Following spin-up, because of the eccentric location of the biocapsule, the animal was subjected to 0.27 G. Second separation occurred at a time when there was much noise in the record and could not be identified. During periods in which the trace was free from artifact, the electrocardiographic pattern was similar to that observed in the pre-launch period. The heart rate averaged about 250, and sinus arrhythmia was present. The body movement, judged from changes in the ECG baseline, increased in frequency during this period to about one movement every ten seconds. The respiration rate during free flight was normal at 60 to 75 breaths per minute except during periods of tachycardia where peaks of 150 breaths per minute were observed.

Period of Re-entry.—Re-entry was not a success, and the last cycle which could be clearly identified in the electrocardiographic record was about 900 seconds range time. With proper allowance for the very considerable amount of telemetry noise present, there was no indication of significant electrocardiographic alterations during this brief period.

SUMMARY AND DISCUSSION

However careful the preparations, however complete the testing under simulated flight conditions, a big uncertainty remains until the actual flight decides success or failure. Until the mishap to the nose cone on re-entry, there was no indication of failure of the biotechnical aspects of this experiment and every indication that the animal was in a satisfactory condition. The life support system functioned satisfactorily during the long countdown period and the stresses of telemetered flight. The provisions for obtaining physiologic measurements were adequate save for the thermistor measuring respiratory rate which became displaced during high acceleration. Admittedly only a few measurements were made but to have attempted more, under the existing restrictions, might have compromised all.

The telemetry represented an outstanding example of professional skill and ingenuity. Immediate display of the signal permitted monitoring throughout the experiment and the graphic recordings could be analyzed in detail. During the count-down period, aside from periods of shivering and possibly startle, the relatively slow respiratory rate and the slow cardiac rate with sinus arrhythmia indicated that the animal was not under mental or physical stress.

At lift-off the noise and vibration startled the animal and resulted in brief but conspicuous changes in heart rate and respiration. Startle is also one explanation for the electrocardiographic changes which followed. These were maximal between twelve and twenty seconds, a period during which humoral factors of neurogenic origin, possibly by way of the sympathoadrenal system, might have been exhibited. An alternative or additional explanation involves the redistribution of blood: a reduction in central blood volume with decrease in cardiac output. Inasmuch as the acceleration during this period was less than 0.5 G the direct effect of this force on the heart was not a likely explanation.

At cut-off, the cardiorespiratory changes were similar to those at lift-off. Within a period of fifteen seconds there was lowering of RS-T and T, followed by unusually tall T waves, then a lowering again. How much the animal was startled is unknown but gross movements of the baseline suggest struggling. The sudden change from a peak acceleration of about 10G to near-zero G must have led to redistribution of the blood mass which must have affected many integrative functions of the circulatory system.

It should be emphasized that the changes in heart and respiratory rate were not extreme and the electrocardiographic changes were short-lived and not severe. The absence of arrhythmias having pathologic significance, conduction defects or indications of serious injury to pericardium or myocardium is also significant.

From cut-off time to spin-up the animal was almost weightless. It is noteworthy that save for changes related to shivering and struggling there was no marked difference in heart rate, respiratory rate and electrocardiographic findings compared with the pre-launch period. Beginning at the second third of this period, body movements occurred at increasingly frequent intervals. If they were related to weightlessness, and this is a possibility, the onset of spin-up with its attendant 0.27 G loading on the animal did reduce movement. In any case, all other evidence indicates the animal was in satisfactory condition until the loss of signal at re-entry.