III. Bio-Flight 2 Baker

The general approach to Bio-Flight 2 Baker was the same as to Bio-Flight 1. The flight record of Bio-Flight 1 had demonstrated that the squirrel monkey was in satisfactory physiologic status up to the loss of telemetered signals. This proved the technical approach to be sound. Certain changes and improvements made for Bio-Flight 2 Baker will now be described.

THE BIOCAPSULE AND ASSOCIATED EQUIPMENT

Compared with the capsule for Bio-Flight 1 the new capsule was constructed from a somewhat heavier aluminum alloy sheet to avoid the use of reinforcing ribs. Two access ports located on opposite sides of the capsule were provided to facilitate placement of equipment inside the capsule. An additional small opening was located near the one used for the pressure relief valve to serve as a gas-sampling port. It was closed with a rubber seal which could be pierced with a hypodermic needle for obtaining a sample.

FACILITIES FOR SUPPORT AND RESTRAINT OF THE ANIMAL

The facilities for support and restraint of the animal were simplified for Bio-Flight 2 Baker by eliminating the inner cylinder (Fig. 18). The single cylinder used had the dimensions of the previous outer cylinder. A new bedding compound, a flexible polyurethane foam was used as a liner. The number of ventilating holes in the cylinder and in the liner was slightly increased. A polyurethane chest pad was substituted for the chest microphone arrangement used in Bio-Flight 1 since the chest activity telemetering channel was transferred to Able.

LIFE SUPPORT EQUIPMENT

The life support equipment was modified to use lithium hydroxide instead of baralyme for absorption of carbon dioxide. A flat metal box with perforated walls contained 65 grams of lithium hydroxide and 20 grams of activated carbon as absorber materials. Activated carbon was added to absorb the ammonia from urine decomposition and was packed in two separate flat pellon sacs placed against the screen of the metal box. The lithium hydroxide in a third pellon sac was located between the carbon sacs. A second container of absorbing material formed a stainless steel wire pocket on the top wall of the capsule and held 135 grams of lithium hy-

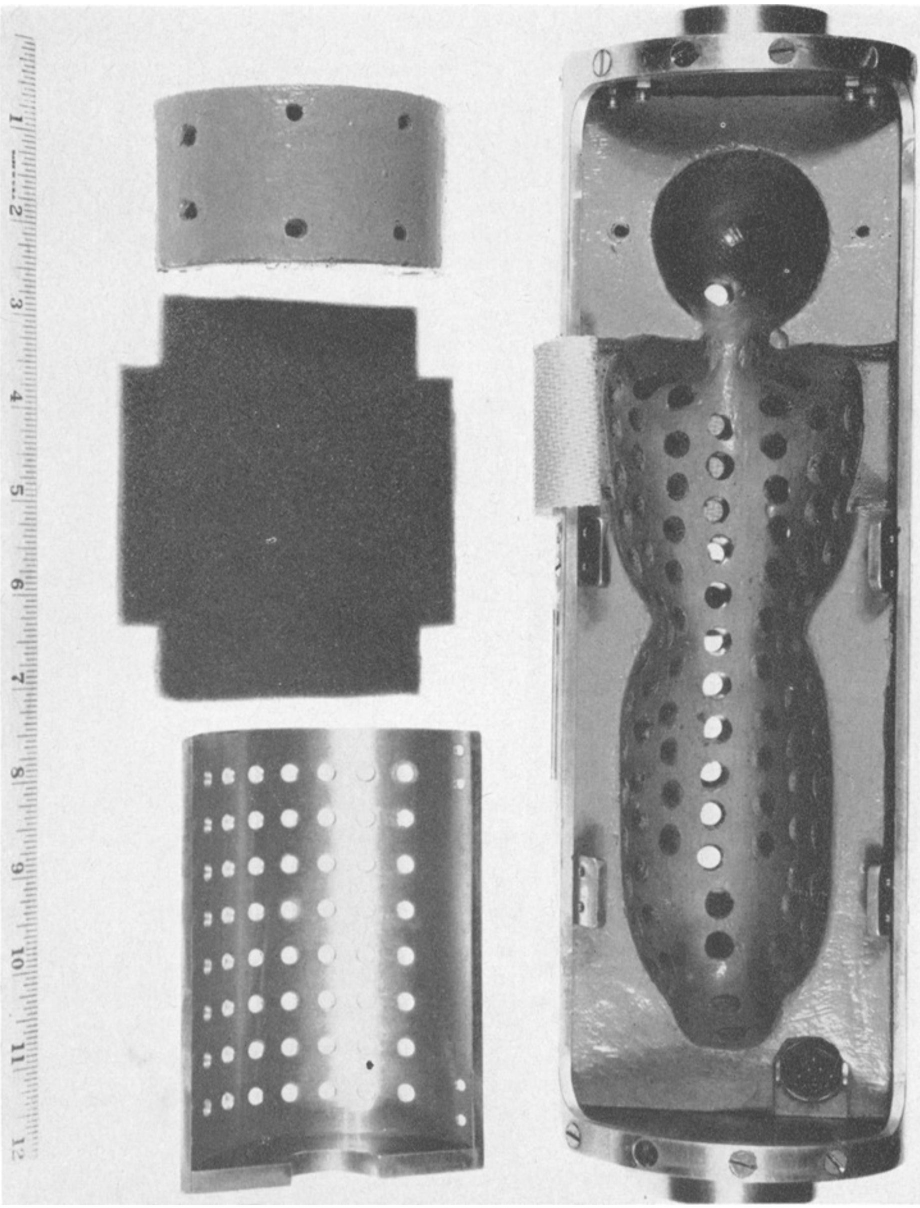

Fig. 18. Components of animal support assembly for Bio-Flight 2 Baker. The cylinder with ventilated contour bed is shown on the right. On the left from top to bottom; chest pad, cover plate liner and cover plate.

droxide and 100 grams of mobilbead. The chemicals were inserted into the wall pockets in the form of three pads each made of double thickness pellon material. The lithium hydroxide was tightly packed and held solidly in the

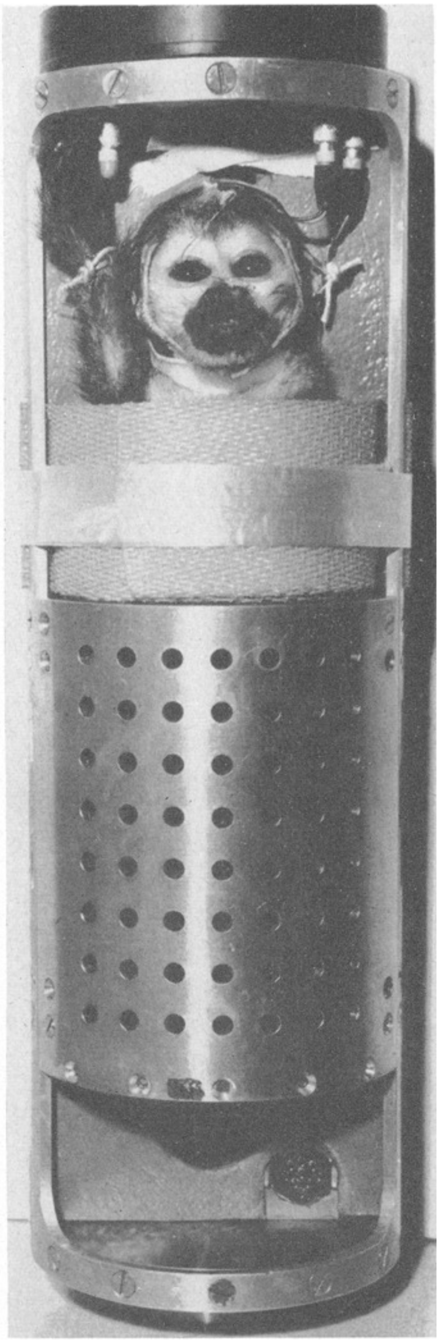

Fig. 19. Monkey No. 27 (Baker) during Bio-Flight 2 count-down. The photograph shows the animal prepared for flight shortly before final insertion into the capsule.

wall pocket to avoid formation of dust during periods of vibration of the nose cone.

PHYSIOLOGICAL MEASUREMENTS

The physiologic measurements were modified by elimination of the heart microphone. The transducer assembly used in recording of the respiratory rate was changed. The glass bead thermistor was soldered to fine wire leads which were used to position the bead in the main stream of the exhaled air. The end of the lead bearing the thermistor was then fixed to the tip of the nose by a drop of fast-drying model cement (Fig. 19). The other end was attached, allowing some slack, to the connector on the cylinder. This arrangement allowed recording of respiratory rate undisturbed by G forces of the expected magnitude. An analysis of the capsule air after the flight was added to the chemical tests provided in Bio-Flight 1.

MONITORING AND RECORDING EQUIPMENT

The monitoring and recording equipment was improved by the construction of a dual-channel biological monitor which made possible monitoring of two capsules simultaneously (Fig. 20). The monitor also had outlets for testing and calibrating individual transducers.

DEVELOPMENTAL AND EXPLORATORY PROCEDURE IN PREPARATION FOR THE FLIGHT

In this regard, little can be added to what has already been described for Bio-Flight 1. The improved equipment as described above went through the same tests for mechanical integrity. The physiologic reactions of the squirrel monkeys to certain stresses have been summarized previously for both bio-flights.

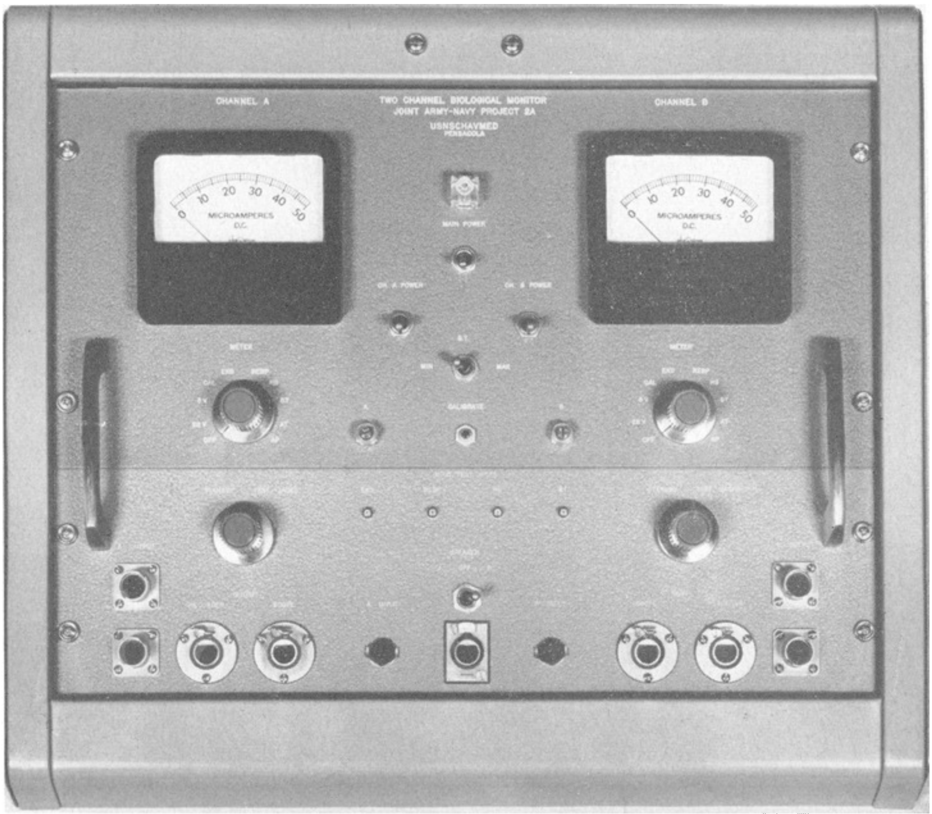

Fig. 20. Front view of biological monitor for Bio-Flight 2 Baker electronic system.

Since more time was available for experimentation the use of several different tranquilizers to assist the monkeys through the stressful period of initial instrumentation, restraint and encapsulation was investigated. It was soon apparent, however, that although these drugs were effective in quieting the animals, this procedure held no advantage over the method of simply training, or acclimatizing the animals to accept this situation. In addition the use of any premedication might conceivably mask or alter subsequent physiological responses; this would be highly undesirable in an experiment of this nature.

LAUNCH AND RECOVERY PROCEDURES

The launch procedure for Bio-Flight 2 Baker at Cape Canaveral was essentially similar to that for Bio-Flight 1 but was considerably facili-

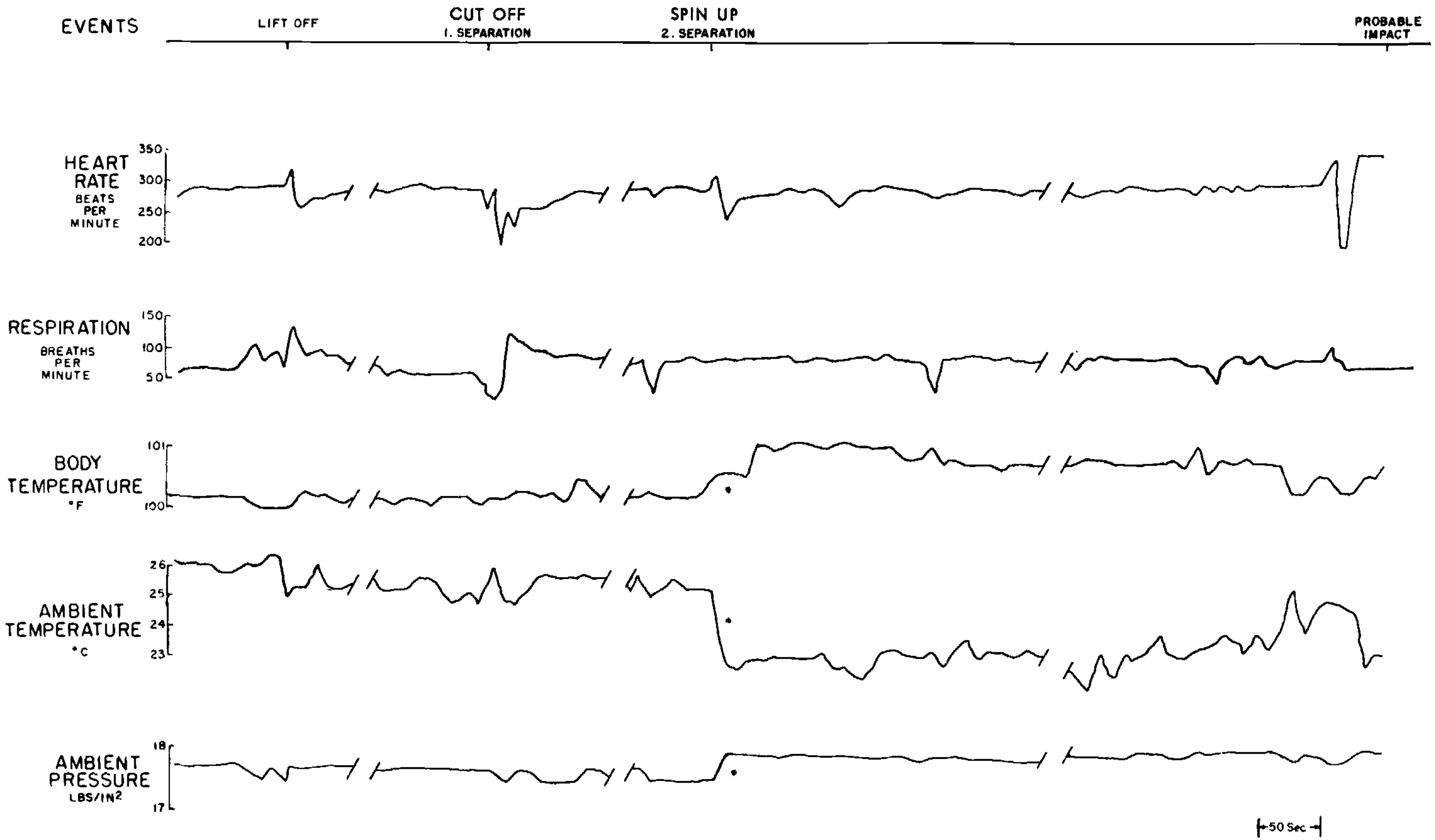

Fig. 21. Telemetered flight data from Bio-Flight 2 Baker. Physiologic and environmental data shown in relation to major events of flight. Data curves have been interrupted but time scale is accurate for portions shown. The asterisk on the three lower curves locates the base line shift at spin-up referred to in the text.

tated by the use of a laboratory trailer. This trailer (30x7x7 feet) was divided into an animal compartment and a laboratory room. It was completely equipped with regard to water supply, refrigeration, power supply (gasoline driven motor-generator set) and sewage disposal. External connections to base water and power sources as well as to base telephone and count-down communications systems were provided. The two rooms of the trailer were independently air conditioned. The animal compartment held all the facilities for caging and care of as many as thirty animals. The laboratory room was fully equipped with monitors, recorders, oscilloscope, and all equipment necessary to make two capsules (flight and spare capsule) flight-ready.

TABLE III. INFORMATION RECEIVED ON BAKER DURING THE COUNT-DOWN PERIOD

Local Time EST	Breathing Rate (per min.)	Heart Rate (per min.)	Body Temp. °F	Capsule Temp. °C	Capsule Pressure psia
1935	—	280	96.0	26.5	—
2030	96	265	99.0	29	15.2
2130	80	270	99.0	29	15.7
2230	80	270	99.0	29	15.7
2330	85	280	99.0	29	15.8
0030	90	290	99.6	28	16.2
0130	85	290	99.0	27.5	16.8
0230	—	300	—	—	—

The count-down procedure was in general the same as described for Bio-Flight 1. The animal in the spare capsule was released in good health at X-4 hours. The recovery procedure proper began after delivery of the biocapsule to the laboratory facilities aboard the *USS Kiowa*. Post-flight monitoring of all five telemetered channels, gas sampling, and removal of the monkey were performed in that order. Complete facilities for medical treatment were available. These included a basic surgical kit, monkey plasma and provisions for administration, a portable animal resuscitator, as well as drugs and antibiotics. Fortunately none of these were required. In the event of recovery of a deceased animal, provisions were made for quick-freezing and transport of the body to the Armed Forces Institute of Pathology for evaluation.

Finally, a portable magnetic tape recorder was provided to facilitate obtaining detailed protocols of all procedures actually performed.

RESULTS

ENVIRONMENTAL FACTORS

The ambient temperature and pressure data are presented for the count-down period in Table III and for the flight in Figure 21. Ambient temperature remained constant throughout the flight at approximately 25.5° C. Ambient pressure likewise remained constant, the average pressure level being 17.7 psia. It should be noted that the discontinuity occurring at spin-up is a shift in the telemetering baseline and not a true change in magnitude of these variables.

Following recovery of the capsule, post-flight monitoring indicated an ambient pressure of 17.8 psia and an ambient temperature of 26.5° C. Both variables were well within tolerable limits. In addition to ambient pressure and temperature, it was possible to obtain a sample of the capsule atmosphere. Chemical analysis gave 0.18 per cent CO_2, 19.9 per cent O_2, and 80 per cent N_2. The thermo paper did not indicate the presence of high flash temperatures.

PHYSIOLOGICAL FACTORS

Cardiorespiratory Findings.— Most of the data were obtained from recordings of the electrocardiograms and respiration. Both were displayed on oscillograph charts made from magnetic tapes recorded at the launch site and down range. Two additional electrocardiographic records were obtained, one from an in-flight tape recording which covered the period of 97 seconds before impact, the other was a short strip obtained immediately after recovery of the capsule and before the animal was removed. The variations in cardiac and respiratory rate will be presented with the aid of Figure 21 after which the results will be described in relation to the different phases and principal events throughout the flight. The discussion will center around the electrocardiographic data inasmuch as they constitute the most detailed findings.

During the flight the animal was warm which may have accounted for the stability of the heart rate and the rather high level. The latter in turn may have accounted for the equal tendency for the heart rate to go down as well as up. In any event, at times when the conspicuous variations occur the response is bimodal. The very slow rates after cut-off and re-entry were due to the appearance of sinoatrial block, sometimes with ventricular escape.

The respiratory rate varied considerably until after cut-off following which it was unusually stable. At liftoff the conspicuous brief rise may have been due to startle and the slowing during the boost phase may have been in response to pressure on the chest. At cut-off the rate tripled but soon fell to a level which was well maintained save for occasional fluctuations.

Pre-launch Period. — The electrocardiogram showed no signficant variations during the pre-launch period except when the record was altered by artifact. During the 96.5 second period of the available pre-launch record, on six occasions the baseline was disrupted by very rapid oscillations, usually present less than one second. Wandering of the baseline, indicating movement of the animal, was sometimes present during these periods. Following the appearance of artifact, the heart rate rose slightly, but quickly fell to normal. An associated finding was a considerable but short-lived increase in the respiratory rate. These periods of artifact resembled similar events in the case of Old Reliable, although they were less frequent and less prominent. Inasmuch as the animal was warm during this period, the artifact probably represented startle reactions or spontaneous movements and not shivering.

A characteristic portion of the pre-launch record is shown in Figure 22a. The atrial and ventricular components are clearly seen. The P-waves are upright and the P-R interval about 0.02 seconds. Q, R, and S-waves are readily identified, and the RS-T junction is about 1.2 millimeters above the baseline. The RS-T segment begins with a very slight scallop, then ascends in nearly a straight line to the peak of T without demarcation. The downstroke of T is very steep, and, when the cycles are short, it is difficult to define the end of T inasmuch as the T-P interval is represented by a single scallop in the baseline. The heart rate throughout the pre-launch period averaged about 280 to 295 beats a minute and arrhythmia was present.

Transition at Lift-off.—This period began with rapid oscillation of the baseline about one-tenth of a second before zero time and ended, twenty-five to thirty seconds later, when a stable electrocardiographic pattern had been established. During this interval, the animal was subjected to noise, vibration, and acceleration. The noise was maximum initially because of the slow velocity at lift-off and reflection of sound from the ground.

At lift-off, the respiratory rate rose sharply and fell nearly as abruptly. The heart rate suddenly increased, averaging 321 during the first four seconds, but fell quickly below pre-launch values with a return of sinus arrhythmia. Some of these events are shown in Figure 22b. Note the displacement of the baseline indicating body movement; the R waves are "clipped." The T waves appear taller after cut-off.

With the onset of flight there was a

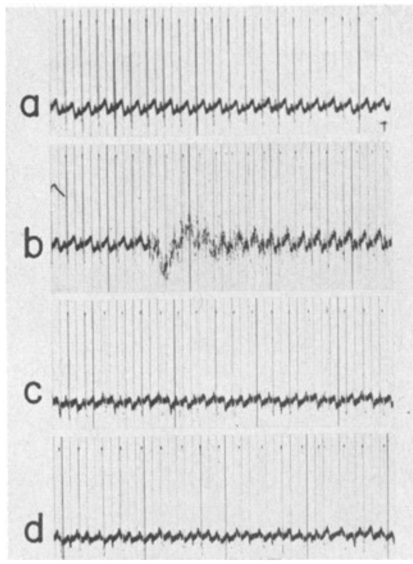

Fig. 22. Sample electrocardiograms for Bio-Flight 2 Baker (a) four to eight seconds before lift-off; (b) at lift-off; (c) 12-16 seconds after lift-off; and (d) transition at cut-off.

gradual decrease in the amplitude of the T waves which continued until about 6½ seconds after lift-off. Thereafter, the T waves gradually became more upright, almost reaching their prelaunch amplitude at thirty seconds after lift-off. The maximum change is illustrated in Figure 22c. There is lowering of the RS-T junction but not below the baseline. The T complex shows phasic changes with respiration; movement of the thorax undoubtedly affecting the position of the heart. The upstroke of T has flattened out and its diphasic character has become exaggerated.

Middle Period of Powered Flight. —From thirty seconds after lift-off until twenty seconds before cut-off, very little variation occurred in the electrocardiogram except on two occasions when the record was slightly distorted by artifact for very brief periods. During the first three-quarters of this middle period, there was a gradual increase in heart rate of about twenty beats a minute and thereafter little change.

Final Boost Period. — During the final twenty seconds of the boost phase, acceleration increased to approximately 10 G. The reason for this sudden increase was the escape of the missile from atmospheric drag. The onset of this final period was heralded by two distinct kinds of artifacts. One consisted of rapid, high-frequency waves which progressively interfered more and more with the P waves and the T complex until they were defined mainly as a moving blur of the baseline. The second artifact consisted of a change in the phasic variation with respiration. At first, this was declared mainly by an exaggeration of the normal phasic variations without any significant change in rate. However, during the last nine seconds the movement of the baseline became less, and it appeared as though respirations became slower and more irregular. During the last four seconds before cut-off, there was a decrease in heart rate from 298 to 270, based on four one-second counts. Concomitantly there appeared to be significant lowering of the T complex with an increase in sinus arrhythmia although the artifact produced so much distortion that close interpretation was impossible. At no time were there any abnormalities of arrhythmia.

Transition at Cut-off.—Within four tenths seconds after cut-off, an increase in high frequency noise lasted about seven and one-half seconds. Interpretation of the electrocardiogram for this interval was limited to identification of the R waves and the rise and fall of the baseline. During this period, the respiratory record was lost except for one small deflection, but phasic variations of the baseline of the electrocardiogram indicated in all probability that there was a loss of respiratory signal rather than a period of apnea. The "first separation" was clearly indicated by an artifact in the electrocardiogram, but the effect of the vernier engine could not be positively identified.

There were significant changes in heart rate and rhythm during the transition period at cut-off (Fig. 22d). It has already been mentioned that during the last four to five seconds before cut-off, there was a fall in heart rate from 300 to 270 with increase in sinus arrhythmia. Following cut-off, the heart rate went back to 300, and four seconds after cut-off a sudden slowing in heart rate with gross arrhythmia occurred. It probably represented an exaggerated sinus arrhythmia with sino-atrial block, although artifact made interpretation difficult. The heart rate during this four-second period of arrhythmia averaged 142 beats per minute. Following the arrhythmia, the heart rate slowly rose to reach 291 in just under a minute.

Changes in the RS-T segment and T waves were also observed. For about twelve seconds after cut-off, the record was obscured, but after that it was seen that the T complex was much lower than usual and the phasic variations with respiration were slightly exaggerated. Very gradually, over an interval of about forty-five seconds, there was a gradual return to the prelaunch pattern.

Period of Free Flight.—This period of near zero G began after cut-off, and, except for the slight forces at the "first separation" and "vernier corrections," continued until spin-up, a total period of about 4½ minutes. The long period of transition lasting nearly a minute has already been considered. During the remaining 3½ minutes, the heart rate was extraordinarily regular at a rate just under 300, and there was very little sinus arrhythmia. The baseline was unusually level and stable except for short periods of artifact at rare intervals.

Period after Spin-up.—This period lasted about seven and three-fourths minutes and, inasmuch as the monkey was near the periphery of the nose cone, it was subjected to approximately 0.27 G. The actual period of spin-up was declared in the electrocardiogram by the sudden appearance of high frequency artifact. For a few seconds the heart rate rose slightly to values above 300 and the T complex became more prominent. This was quickly followed by a slowing of the heart rate to an average of 255, accompanied by a considerable reduction in amplitude of the T complex and an exaggeration of the phasic variations with respiration. Then there was a gradual rise in heart rate over a period of one minute, to an average rate of 294. Concomitantly with this increase in heart rate, there was a gradual return to the normal pattern over a period of about thirty seconds.

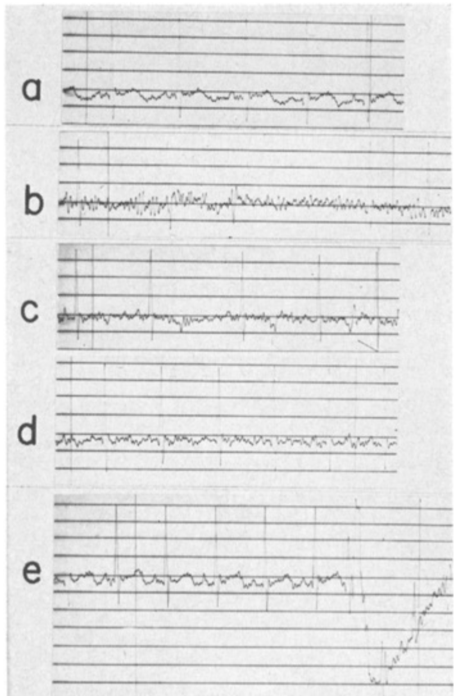

Fig. 23. Sample electrocardiograms from Bio-Flight 2 Baker. All times are related to the time of maximum deceleration at reentry. (a) Twenty seconds before; (b) at maximum deceleration; (c) five seconds after; (d) ten seconds after; and (e) near impact.

Throughout the remainder of this period, no significant changes in the rate, rhythm, or pattern of the electrocardiogram occurred save on rare occasions when artifact intervened for short intervals.

Period of Re-entry.—Re-entry was arbitrarily considered to begin when the nose cone had reached an altitude of 100 kilometers above the earth; it ended at impact. The period twenty seconds before maximum deceleration serves as a reference for interpretation of the remainder of the record. A typical portion of the trace is shown in Figure 23a. Despite the obvious artifact, the P waves and T complex are clearly shown. The QRS complexes can be exceptionally well defined. During this period the rhythm was very regular, averaging about 290 to 295. Five seconds before re-entry, there appeared two interpolated ventricular beats in consecutive cycles. They occurred late in the cycle, masking the P waves, and the basic rhythm was unaltered.

There was nothing in the record to indicate the moment of re-entry. The first definite change occurred seven seconds after re-entry time and consisted of an increase in the amount of artifact distorting the P waves and T complex. About twelve seconds after re-entry, there was lowering of the T complex. This was followed by slight slowing of the heart rate for a period of five seconds, after which there was a gradual rise. With the increase in rate, the T waves again became slightly taller but the record was increasingly noisy as re-entry progressed.

Gross artifact appeared at maximum deceleration heralding the onset of vibration and for a period of one minute there was conspicuous arrhythmia. There was an exaggeration of the normal sinus arrhythmia and sino-atrial block, sometimes with ventricular escape (Fig. 23b). In addition to sino-atrial block, there were interpolated ectopic beats and premature beats. The latter might or might not show abnormal QRS waves and were always followed by a fully compensatory pause. Due to artifact, the P waves were not well identified. Coincident with the arrhythmia there was lowering of the entire T complex sometimes with terminal inversion of the T waves (Fig. 23c). These significant alterations in rhythm and pattern occurred shortly after the period of vibration and maximal deceleration. About ten seconds after maximum deceleration sinus arrhythmia was slight, but the T complex remained nearly flat (Fig. 23d).

Separation of the rear cover was declared by the appearance of artifact. Very shortly thereafter, there was a return toward the normal pattern, which was still however distorted very much by artifact. Subsequently the electrocardiogram became more normal in appearance, and the P waves and T complex could be clearly identified. Near impact gross artifact appeared in the record and within one half second the electrocardiographic waves could no longer be identified and the signal lost. These terminal events are shown in Figure 23e and it is apparent that immediately prior to loss of signal, the electrocardiogram had returned to a configuration which did not greatly differ from the reference record prior to re-entry.

Without doubt, the stresses incidental to re-entry produced the most marked effects in the electrocardiogram. The slowing of the heart rate with exaggerated sinus arrhythmia and sino-atrial block may well have been the result of vagal inhibition. The sino-atrial block was not regarded as having pathologic significance. Cardiac irritability was indicated by the occurrence of premature and interpolated beats at times when the heart rate did not show any slowing. The lowering of the RS-T segment to the baseline, the flattening of the T complex, sometimes with slight terminal inversion, persisted over a relatively long period.

Post-recovery Period. — A record was obtained about 135 minutes after impact and before the animal had been taken out of the capsule. Interpretation of this record was not easy. An apparent fall-off in sensitivity of the electrocardiograph channel resulted in all of the waves appearing to be miniaturized. The heart rate averaged about 280 with very slight sinus arrhythmia.

Post-flight Events.—On release from the capsule Baker was alert and active and apparently unharmed by the experience. She reacted normally to attention and readily accepted food and water. During the succeeding five days, which included considerable excitement and extensive ship and air travel the animal became very tame. It has remained well since, intestinal parasites constituting the only health problem.

DISCUSSION

The squirrel monkey is a delicate creature; yet Baker, without medication, exhibited only moderate reactions to the stresses imposed during flight and was unharmed by the experience. This is the strongest testimonial to the care taken in selecting and training the animal, the preparation of a life support system, and the efficiency of launch and recovery procedures.

The equipment functioned well and the difficulty experienced with the respiratory thermistor in Bio-Flight 1 was rectified by an improvement which favored continuity of signal. Only one wide band channel was available for telemetry and this was used in obtaining the electrocardiogram. In retrospect this was probably a good choice because it furnished much information in addition to heart rate. It was a useful indicator of the major events throughout flight; it provided supplementary information on thoracic movements; it indicated muscular activity and whether accompanied by bodily movement; it defined the nature of the heart block and other arrhythmias; and it disclosed changes in the T complex which was a delicate though non-specific indicator of the effects of stress.

Although cooler pre-launch capsule temperatures had been programmed, the warm temperatures which were actually experienced made possible comparison of the slight "heat response" in Baker with the "cold response" in Old Reliable. Avoiding the cold response got rid of shivering, a great nuisance in Bio-Flight 1, it could have been a factor in preventing the bodily movements exhibited by Old Reliable. The heat response may well have accounted for the high "resting" heart rate and this in turn for the situation in which the heart was "poised" to respond with a conspicuous decrease in rate.

There was much similarity in the cardiac response to all major events during flight, namely, a slight increase in rate followed by cardiac inhibition. The initial response was characteristic of a startle reaction, but the prolonged after-phase suggested something more. One possible explanation is that which has been used to explain vasodepressor attacks.[11,12,13] If mobilization for "fight or flight" results in fright without flight, it may provoke a curious but ineffectual autonomic display characterized among other things by reflex cardiac inhibition and peripheral vasodilation. This in turn leads to a reduction in central blood volume for which the heart cannot compensate. This could result in T wave changes through several possible mechanisms including myocardial ischemia. Stresses other than fright could produce cardiac inhibition by way of endovascular reflexes and changes in the T waves by any one of several mechanisms, but the fact remains that these changes occurred immediately after lift-off when the physical stresses were minimal.

Post-flight history to date tends to bear out the statement that Baker did not suffer injury in flight.