Project MIA (Mouse-in-Able), Experiments on Physiological Response to Spaceflight[1]

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Mice carried in the nose cones of long-range ballistic missiles have successfully survived re-entry into the atmosphere. In most aspects, the environmental conditions experienced by these subjects exceeded in severity those which will be imposed on satellite passengers. This program represents an extension of the early pioneering flight experiments with mice and monkeys in relatively low performance sounding rockets. The relative success of these experiments permits a considerable degree of confidence in the ultimate successful recovery of biological payloads from future satellite vehicles. The project, known as Project MIA (Mouse-in-Able), was planned as a noninterference experiment in conjunction with the Project Able re-entry test program. The preparatory work was accomplished and the first flight occurred one month after official authorization. In each of the three Able flights, one mouse was carried in the nose cone. Although none of the nose cones was recovered, telemetered physiological records were obtained on the second and third Able flights. This report includes a description of the physical system, the preliminary tests, development of the instrumentation used in flight and the resulting signal pattern. The special problems associated with the use of living payloads in spaceflight vehicles are also discussed.

DURING April and July 1958, a series of tests of ICBM re-entry nose cones was performed, using as the launching vehicle a two-stage missile consisting of the Douglas Thor IRBM and the Aerojet 1040 liquid propellant rocket. This program, known as Project Able, was approved by the Air Force Ballistic Missile Division in December 1957, and the responsibility for assembly and instrumentation of the second stage and nose cone was given to the Space Technology Laboratories.

The nose cones used in these re-entry test flights were built by General Electric. They were encased in heat shields of various ablation materials, and provision was made for recovery of the nose cones for postflight inspection. Data were transmitted during flight from ablation gages and other instruments mounted in the nose cones. In addition to this instrumentation and the other supporting equipment, a certain amount of ballast was required to obtain the desired value of W/C_DA,[4] the parameter of critical importance in these re-entry experiments. A proposal was made by Space Technology Laboratories that a portion of this ballast be replaced by a minimum biological experiment which would be included in the vehicle as a secondary objective, on a noninterference basis.

This experiment consisted of flying a mouse in each Able nose cone in order to evaluate the effect of vehicle induced environmental parameters on a living animal. The proposal was officially approved by AFBMD on March 24, 1958, and the first MIA (Mouse-in-Able) package was flown in the first Able vehicle on April 23, 1958.

Equipment Development

Survival Equipment

The principal components of the MIA package are shown in Fig. 1. The physical system consisted of two aluminum cylinders connected end-to-end to form a closed circuit. The Mouse House cylinder housed the animal, its supporting equipment and a chemical canister containing silica gel for moisture absorption. The mouse was placed in an offset "cradle" mounted on bearings to permit automatic orientation in the optimum position for resistance to g loads.[5] The base of the cradle was filled with water which was made available to the mouse through an inserted wick. The second cylinder contained additional air purification chemicals and the circulation system used to assure continuous purification of the internal atmosphere. The ventilation system consisted of a small fan, driven by a 6-v motor powered by a pair of mercury cells. Chemical containers in this cylinder were filled with soda lime for absorption of carbon dioxide and additional silica gel.

This ventilation cylinder was connected by a hose to an oxygen regulator, which in turn was connected to a high pressure oxygen bottle. As the pressure in the closed system was reduced through chemical absorption of carbon dioxide and excess water vapor, more oxygen was admitted to the system. In this way a self-regenerating artificial atmosphere was maintained. The high pressure oxygen tank was a standard aircraft bailout bottle containing approximately 18 in.^{3} of oxygen at 2000 psi, the charged pressure. This amount of oxygen is sufficient to support a mouse for about two weeks if supplied only on demand. The oxygen regulator was a modified Alar A-2000 two-stage model.

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[1] For a more complete version of this report refer to ARS preprint 715-58.

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[3] Member of the Technical Staff, Research and Development Division.

[4] Ratio of gross weight of nose cone to the product of drag coefficient and area normal to flightpath.

[5] A similar concept has been proposed independently by Dr. Harald von Beckh in his paper "Multi-Directional G-Protection in Space Vehicles" for manned satellite applications, with due regard for the problems of emergency escape.

The system was completely self-contained; no external connections to any part of the Project Able equipment were required, other than simple mounting brackets and, in the two final flights, telemetry connectors. The MIA package was located foward in the nose cone, near the aerodynamic center, to minimize the lateral g loads associated with possible fishtail oscillations of the nose cone during re-entry.

Instrumentation of the Mouse

The problem of determining the condition of the mouse within the survival package was solved through the instrumentation system. It was necessary to determine, first, whether the subject was alive and, if alive, his health or his reaction to the environment. There were many parameters which could be measured to obtain a history of the animal's condition, behavior and response, but because of the limited telemetry capacity available, it was necessary to select the one parameter which would be most informative. Measurement of heart rate was settled upon.

Of the several possible transducers considered, an electrocardiograph-type pickup was chosen as a feasible and effective heart rate sensor because it was almost completely insensitive to environmental stimuli and the heart output was readily recognized. Since the mouse's skin is highly resistant to electrical currents, the electrodes were placed directly into the fascia, one connected ventrally to the right pectoral muscle, the other inserted diagonally across the heart, just below and to the left of the rib cage.

Harness

The next problem was that of restraining the mouse in the package so that he would be unable to chew through or jerk loose the embedded wires.

During bench tests it became apparent that mice cannot tolerate near-total restraint under restricted sensory-input conditions for more than a few hours. This enforced immobilization frequently resulted in partial and temporary paralysis of the posterior quarters, probably accompanying a decrease in internal functions which could, in time, result in death. Apparently some less restrictive arrangement had to be developed. The ultimate solution, and the one used in the second and third flights, was a slipring assembly, restricting the motion of the mouse to single-point but unlimited rotation.

The slipring assembly was mounted on a metal saddle which was secured to the mouse with a harness made of Celastic, a special tape which provided an excellent bond to the subject's hair and skin. The harness was in two parts: A body band, with tabs for attachment of the saddle, and a metal-lined second layer used to discourage the mouse from chewing through the harness. (Fig. 2.)

After the mouse had been securely harnessed, the wires coming from the implanted electrodes were soldered to the slipring leads on the saddle. The slipring shaft was then inserted between brushes mounted on the cradle cover, thus completing the circuit to the telemetry system (see Fig. 1).

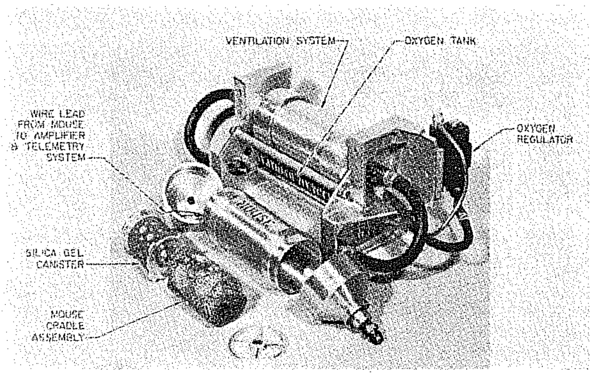


Fig. 1 Partially assembled MIA package

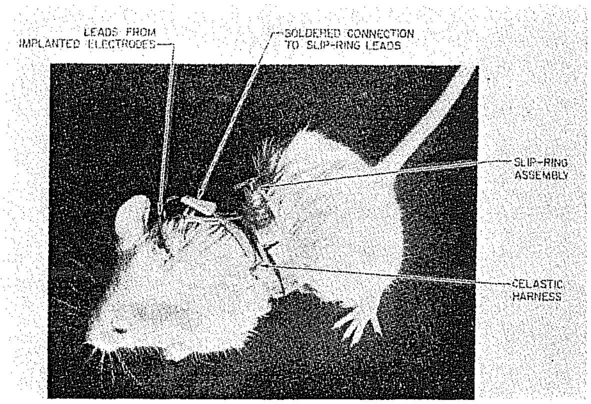


Fig. 2 Mouse in harness

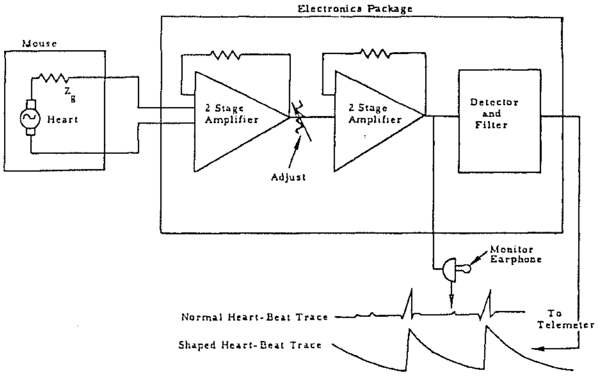


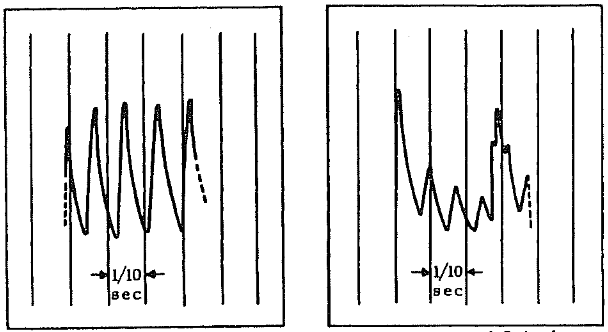
Fig. 3 Electronics unit block diagram

Electronics

The electronics unit (Fig. 3) was used to elongate the heart pulse and to amplify it by a factor of several thousand in order to produce the 5-v peak amplitude required for input to the telemeter. The pulse-elongation and filtering technique was employed to reduce the required transmission bandwidth, thus improving the system signal-to-noise ratio.

When the electronics circuit was being designed, the mouse was considered as an electrical generator with due regard for environmental stresses. The generator characteristics were found to be approximately as follows: Open circuit voltage, 1.5 mv peak-to-peak; impedance, 5000 ohms; characteristic frequency, 3 to 18 pulses per sec. A pair of two-stage transistorized amplifiers was included in the electronics unit, and an attenuator was inserted between the amplifiers in order to allow for variations in mouse output signal amplitude. Each amplifier circuit included about 10 db of negative feedback. This increased the input impedance to match the mouse impedance and stabilized the amplifier gain vs. environmental changes. Separate batteries were employed to power the two amplifiers so that only under very improbable circumstances could the amplifiers oscillate.

Initial attempts to amplify the mouse's pulse were impeded by large interference signals generated by the animal's respiration and physical motion. In order to reduce this interfer-



Normal Pattern

Superimposed Spicule

Fig. 4 Comparison of two heartbeat patterns

ence, the high frequencies were attenuated 20 db at 1000 cps by means of the feedback networks, thus making respiration noises negligible. Reducing the low frequency response about 20 db at 10 cps, by adjusting the coupling impedance values, adequately minimized motion-induced interference. Subsequent to amplification, silicon diodes rectified the heartbeat pulses and an RC filter in the output circuit elongated them to increase the low frequency component.

No evidence of adverse environmental effects on the electronics was detected in the records obtained from the flight tests. A typical section of an oscillograph record of the telemetered heartbeat is shown in Fig. 4 ("Normal Pattern").

Development Tests

The test program used in development of the MIA package consisted of testing individual components, including the mouse, under each of the anticipated stress conditions, then testing the assembled unit under the separately imposed stresses, and finally subjecting the complete system to a simulated flight by programming the tests to duplicate flight conditions. The individual stresses considered during this development test program included minimum acceptable operating duration, temperature, noise, vibration, acceleration and positive package sealing.

Recovery

Special MIA kits, data sheets and instruction booklets were provided to each of the recovery ships to assure proper care of the recovered mouse amd maximum experimental data from each flight.

MIA Flight Tests

History

Three Able vehicles were flown, each of which carried a mouse in a MIA package mounted in the nose cone. The first of these vehicles was launched on April 23, 1958 at 1910 EST. The mouse, a female, was not instrumented, since no telemetry was available for use in that flight. The nose cone was not recovered, and, since no mouse data were transmitted, no information on the physiological state of the passenger was obtained.

The second Able vehicle was launched at 2150 on July 9, 1958. It carried as a passenger a female mouse named Laska. Laska was installed in the Mouse House at 0750 on the launch date, and the package was mounted in the nose cone at 1200. Laska was exposed to the artificial atmosphere inside the Mouse House for 14 hr prior to launch.

The third Able flight occurred at 1715 on July 23, 1958. The mouse, a male named Benji was installed in the package at 0615 hours and mounted on the missile at 0930.

Data Received

Telemetry receiving stations are located at several points along the flightpath. Heartbeat signals were recorded at Cape Canaveral, Antigua and on the search ships for both instrumented flights. The duration of the telemetry reception at these stations is shown schematically in Fig. 5.

Data Interpretation

The physiological response of the mouse during this preliminary venture in spaceflight can best be interpreted by correlation of the heartbeat record with the physical parameters of the flight environment. Some difficulty was experienced in reducing the telemetered data due to masking of the anticipated heartbeat signal by muscle voltages generated during motion of the mouse or by respiratory signals and also by electronic noise during certain portions of the flight.

A typical signal interpretation problem is illustrated in Fig. 4. The left-hand trace is typical of the regular heartbeat signal recorded in the laboratory and during both of the instrumented MIA flights. The right-hand trace is a sample of the Able no. 2 data, in which the heartbeat was regularly interrupted by a superimposed spicule, thus complicating accurate counting of the number of pulses in a given signal segment. Since this characteristic appeared only during rocket burning and was most severe at times of highest acceleration, it is possible that the signal was associated with regular gasping respiration.

Since it had not proved feasible to obtain heartbeat records

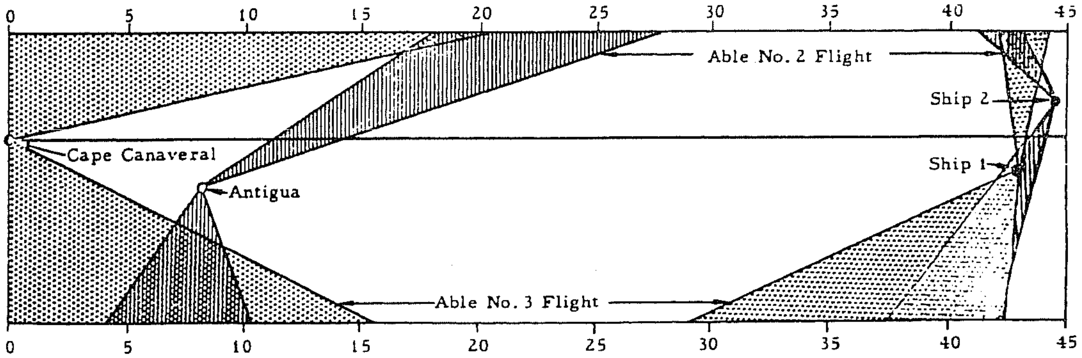


Fig. 5 Reception of physiological data

of these mice under known stress conditions in ground tests, interpretation of the flight data has been based on comparison with telemetered records obtained prior to liftoff. In Fig. 6, a plot is shown of the frequency of the heartbeat signals received from Laska and Benji at various times prior to liftoff.[6] It can be seen that Laska's "normal" heartbeat averaged about 12 impulses per sec, with variations between 11 and 13.5 per sec; the maximum spread in any continuous sample is on the order of 1 beat per sec. The mean value of Benji's heartbeat was much lower, about 5.2 impulses per sec, and the largest spread of "normal" values about the mean was only 1 beat per sec. This difference in mean values, though large, does not exceed the variation among healthy individuals as observed in bench tests.

In Fig. 7 are shown time-correlated plots of acceleration for Able no. 2 and heartbeat frequency for the mouse passenger Laska. There was a momentary sharp increase in heartbeat rate at liftoff. This settled immediately to a value equal to that recorded prior to liftoff, then increased fairly steadily with the increasing acceleration loads to a peak of 21.6 per sec just prior to first-stage burnout. The heart rate then began to drop slowly, but fluctuating; very high rates were maintained for about 35 sec. This relatively slow decrease to "normal" from maximum heart rate at maximum g is similar to the trend reported by the Russians for Laika the satellite dog when she entered the weightless state. Since Laska was not weightless at this time, however, one would instead expect a sharper decrease, such as had been observed in laboratory tests where the acceleration has been reduced suddenly from some high value to the normal 1 g.

During second-stage burning, the heart rate increased again, to a lower maximum (16.3 beats per sec), almost proportional to the g load. At second-stage burnout, when the vehicle and Laska became weightless, the rate dropped suddenly to the preflight value and remained quite steady.

As indicated in Fig. 5, no heartbeat signals were received in the time period from 28 to 41 min after liftoff of Able no. 2. This is also shown in Fig. 8, where Laska's heart rate during the weightless portion of the trajectory is presented with a time-correlated plot of vehicle altitude. When the down-range signal was picked up by the recovery ships at this later time, Laska's apparent heart rate had become very irregular, and the mean had dropped to less than half the earlier zero gravity mean of 12 beats per sec. Since the animal had already experienced 23 min of weightlessness prior to loss of the signal at Antigua without evidence of any distress, it seems unlikely that this decrease was in response to exposure to zero g. No conclusive explanation of this irregularity can be given at the present time for lack of supporting laboratory investigations or more comprehensive flight data.

An expanded plot of the down-range ship data is shown in Fig. 9. During high speed re-entry into the atmosphere, air particles near the nose cone are ionized due to the high temperature generated by friction. This ionized layer effectively blacks out transmission of signals from the nose cone telemetry, until the vehicle has slowed down considerably. The period during which signals are lost is approximately 30 sec long, and is shown by the break in recorded ship data indicated in Fig. 9. The mouse was experiencing about 60-g deceleration, following a higher peak value, when the heartbeat signal was regained. Values of deceleration during this re-entry phase were computed on the basis of known burnout conditions, followed by a ballistic trajectory. Because of uncertainties in predicting re-entry flight parameters from burnout conditions, a time error of perhaps 3 sec may exist in correlation of the trajectory characteristics with telemetered data. The quality of the data used in preparing Fig. 9 was severely compromised by the high noise level on the ship tapes; therefore, it would be quite unrealistic to attempt to

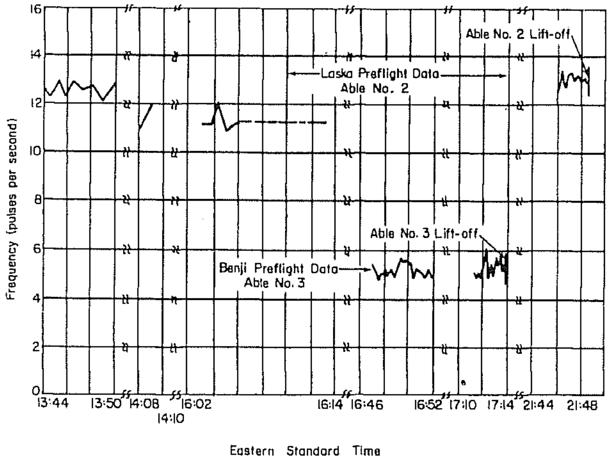


Fig. 6 Preflight heartbeat data

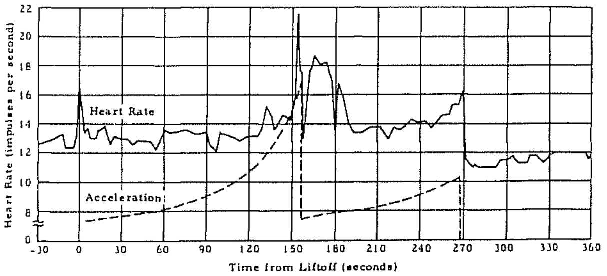


Fig. 7 Heart rate and acceleration during burning period, Able no. 2 (Laska)

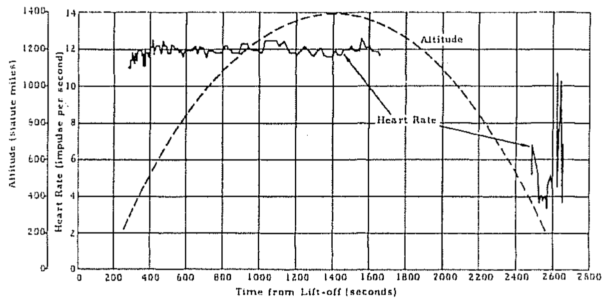


Fig. 8 Heart rate and altitude during weightlessness, Able no. 2 (Laska)

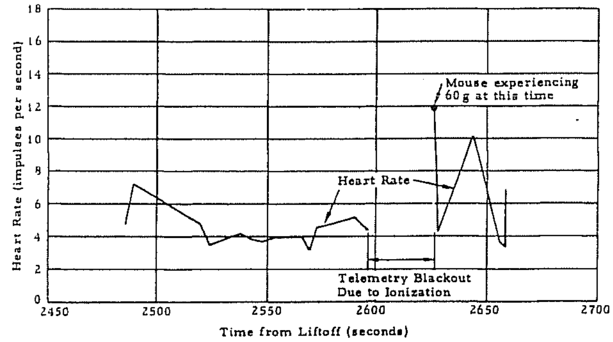


Fig. 9 Heart rate during re-entry, Able no. 2 (Laska)

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[6] In the following graphs, the heart rate data plots represent straightline connections between discrete points and have not been smoothed.

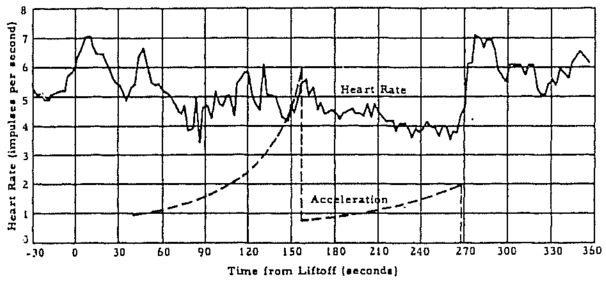

Fig. 10 Heart rate and acceleration during burning period, Able no. 3 (Benji)

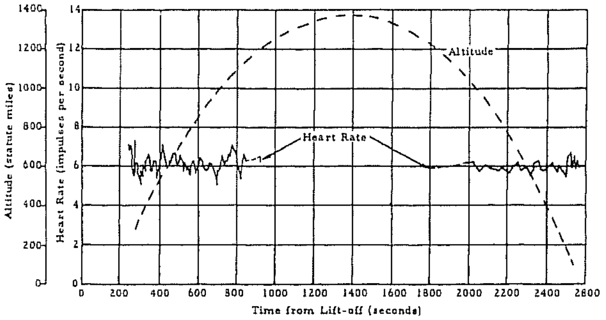

Fig. 11 Heart rate and altitude during weightlessness, Able no. 3 (Benji)

find meaningful trends in this fluctuating signal.

Two significant conclusions can, however, be drawn from this graph. First, Laska lived through the high deceleration and the external heating associated with re-entry without a catastrophic change in the recorded heart rate mean from the value observed just prior to re-entry. Indeed, the fluctuations noted after re-entry do not differ in magnitude from those measured just after the high g loads at first-stage burnout. Second, there is considerable evidence that the last data points were received when the nose cone was suspended from the recovery parachute. If this is so, the mouse survived all the major stresses associated with the re-entry and recovery operation, and one may state with some assurance that Laska returned to sea level alive after some 40 min of weightlessness.

In Fig. 10, a plot is shown of the heart rate of Benji, the male mouse flown in Able no. 3, with a time-correlated trace of acceleration during the burning period. It is immediately clear that the nature of these data is markedly different from data shown for Laska (Fig. 7), so that no generalizations regarding reaction to acceleration loads may be made from the results of these two instrumented tests. For the Able no. 3 flight, the heart rate just prior to liftoff was of the same order as the preflight mean, 5.2 beats per sec. The heart rate rose at liftoff, then dropped, then rose again. This erratic behavior continued throughout the entire burning period, with no detectable trends. The maximum excursion of values was from 3.4 to 7.1 beats per sec—3.7 beats total variation as compared to 9.5 for Laska. (It may be noted that the total excursion of measured heart rate about the "normal" value for each animal was about 75 per cent of the rate measured prior to the flight.)

No significant reaction occurred at first-stage burnout. At second-stage burnout, the heart rate rose sharply to 7.1 beats per sec as Benji was exposed to zero gravity, then settled down to a ±1-beat fluctuation about a mean of 6 beats per sec, slightly higher than the preflight mean. This increase is not consistent with the sharp decrease in Laska's heart rate at the beginning of weightlessness, though both animals returned to near preflight "normal" almost immediately after the weightless period began.

The heart rate data for Benji during the entire weightless period, with a corresponding altitude trace, is presented in Fig. 11. As shown, the mean value of the heart rate did not shift during the loss of signal in the middle of the flight, and Benji appears to have been in very good shape throughout the duration of the record. In this flight, no telemetry signals were received following the ionization blackout at re-entry.

Summary of Results

Project MIA was a minimum biological experiment of secondary importance to the principal objective of the Able program, namely, the testing of ballistic re-entry nose cones. Consequently, the amount and nature of the data available were extremely limited, and certainly no generalized conclusions regarding the behavior of space mice may be drawn. However, some interesting observations were made, and may be summarized as follows:

1 Takeoff conditions were not severe enough to produce any evidence of violent or continuing response from the mice.

2 The acceleration loads during burning were essentially paralleled by Laska's heart rate, though this characteristic was not displayed by Benji under similar load conditions.

3 The observed decrease in Laska's heart rate at first-stage burnout was gradual; at second-stage burnout it was sharp. This is in opposition to the heart rate behavior reported for Laika the Russian satellite dog. No trend was detectable in Benji's heart rate at first-stage burnout, but a distinct increase to slightly above his preflight "normal" was apparent at the beginning of weightlessness.

4 Since both mice flew to a maximum altitude of 1400 statute miles (as compared to Laika's apogee of 1050 miles), they returned to Earth from a higher altitude than that reached by any other living organism.

5 Laska, and probably Benji, returned to sea level alive after experiencing re-entry conditions approaching those associated with satellite re-entry.

6 No evidence of distress due to weightlessness was noted in either flight. The mice were weightless for longer periods than any animal other than Laika.

7 There is every reason to believe that both Laska and Benji would have been recovered alive after their flights if the nose cones had been retrieved.

Acknowledgments

We would like to express our thanks to the entire Project Able staff, in particular to Dr. R. B. Morrison, Program Director, and Lt. Col. D. R. Latham, AFBMD Project Officer, for their interest, enthusiasm and cooperation. Project MIA could never have gotten off the ground, in several ways, without their help and support.