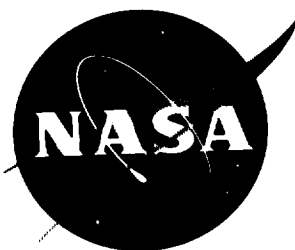


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TECHNICAL NOTE

D-351

A FLIGHT EVALUATION OF AN AIRBORNE PHYSIOLOGICAL
INSTRUMENTATION SYSTEM, INCLUDING PRELIMINARY
RESULTS UNDER CONDITIONS OF VARYING
ACCELERATIONS

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and Joseph R. Smith, Jr.

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SUMMARY

A physiological instrumentation system capable of recording the electrocardiogram, pulse rate, respiration rate, and systolic and diastolic blood pressures during flight has been developed. This instrumentation system was designed for use during control studies at varied levels of acceleration in order to monitor the well-being of the pilot and at the same time to obtain data for study of the relationships between his various physiological functions and his performance capability.

Flights, made in a T-33 aircraft, demonstrated the ability of the system to obtain the desired physiological data in flight. The data obtained in these flights, although limited in nature, indicate a slowing of the pulse rate under the subgravity conditions of brief duration. There appeared to be a proportional nearly in-phase relationship between pulse rate and acceleration. A decrease in diastolic blood pressure together with an increase in pulse pressure was noted during subgravity conditions and an elevation of the diastolic pressure together with a decrease in pulse pressure during increased accelerations. No change worthy of note was seen in the records of the systolic blood pressure, the respiration rate, or the electrocardiogram over the range of acceleration studied (0 to 3 g).

INTRODUCTION

During tests designed to provide information on the effects of vehicle acceleration on the ability of the pilot to perform meaningful control tasks, the problem of monitoring the physical well-being of the pilot is encountered. This problem is especially critical where conditions of acceleration stress approach the limits of acceptable human performance. It is important to monitor certain physiological characteristics of the pilot relating to his respiratory and circulatory systems. The recording

apparatus should be flexible in application and capable of being used in either aircraft or simulators so that direct correlation of the results can be made.

In order to meet these requirements, a compact physiological instrumentation system was designed for use in studying accelerations approaching those of space flight (weightlessness) in a modern jet fighter type aircraft. During the checkout of this instrumentation system, data were obtained on several physiological quantities over a limited range of acceleration magnitudes.

This report presents the details of the physiological instrumentation system, the flight-test results, and a brief analysis of the data obtained.

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NOMENCLATURE

g	acceleration due to gravity
A_N	acceleration factor, ratio of accelerating force to weight, positive when directed upward along spinal axis, that is, from seat to head
Systolic blood pressure	maximal pressure developed during ejection of the blood from the heart
Diastolic blood pressure	minimal pressure developed during ejection of the blood from the heart
Pulse pressure	difference between systolic and diastolic pressures
Common mode rejection ratio	ratio of the attenuation of the unwanted identical part of a signal, (which is common to both inputs - "common-mode signal") to the desired difference signal

INSTRUMENTATION

This system was designed to make physiological measurements of the cardiovascular and respiratory systems. The types of measurements, illustrated in figure 1, were the electrocardiogram, the pneumotachogram, and the blood pressure. The details as to the construction of each component are as follows:

Electrocardiograph

The voltage that the heart puts out has a very distinctive wave shape with an amplitude of about 3 millivolts peak-to-peak at the body surface. To obtain an electrocardiogram, electrodes are placed on the body to pick up a voltage differential between electrodes. The electrodes and adhesives used are similar to those used by North American Aviation in the X-15 physiological instrumentation package described in reference 1. These are illustrated in figures 2 and 3 and represent an extension of a standard medical procedure for obtaining the electrocardiogram. The location of the three electrodes on the subject with one electrode uncovered is shown in figure 4.

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Because of the relatively low resistance between electrodes, about 2000 ohms, and the fact that the system must operate at normal aircraft voltages, 28 volts d.c. and 115 volts a.c. at 400 cps, a problem in safety existed. To prevent possible electrical shock, a fuse-diode system network was inserted as is indicated in figure 1. The network is located on the pilot for maximum safety. With this device, the current is limited to 5 milliamperes which is normally the approximate threshold of sensation.

The difference amplifier used has a power gain of 38 decibels and a common-mode rejection ratio of 10,000 to 1 (see ref. 2). The frequency-response curve of the amplifier galvanometer system is shown in figure 5 and indicates a band pass between 0.25 and 84 cycles per second. The input impedance is 72,000 ohms, while the output drives a 30-ohm galvanometer. There are three amplifiers in the system, one for each of the three electrocardiograph leads.

Pneumotachograph

The present system has provisions for two pneumotachographs which are designed to measure respiration rate through a determination of oxygen mass flow. There are two because of the difficulty of placing transducers in the oxygen systems of the different types of pressure suits and oxygen breathing systems. The full-pressure suit has its oxygen regulator located on the helmet and the transducer has to be placed in the high-pressure (70 psi) oxygen line. When a face mask is used, the transducer can be placed in the low-pressure oxygen line between the regulator and the mask.

The flow transducer used in the face mask system is of the strain-gage type with a fairly linear output up to the order of 250 liters per minute flow. The other pneumotachograph, a thermopile anemometer, shown in figure 6, is sensitive enough to work at high pressures. Because of the thermopile, the transducer is compensated for both ambient temperature and rate of temperature change. A fast response time of approximately 0.1 second is achieved by using butt-welded 0.001 inch chromel-constantan wires

shown magnified in figure 7. The output of this type of pneumotachograph is inversely proportional to the square of the mass flow. Since flow volume was not measured in these tests, neither transducer was calibrated.

AutospHYgmomanometer

Indirect measurement of blood pressure in man can be accomplished by either the auscultatory method or by use of certain oscillatory criteria (determined from direct examination of time history of blood pressure). The former was selected over the latter because of its relative simplicity and greater accuracy in regard to the determination of the diastolic pressure. Blood pressure by the auscultatory method is usually measured by means of a sphygmomanometer which consists of an arm cuff, a pressure source, a manometer, and a stethoscope. The operator notes the point at which sound begins and ends, following the buildup and release of pressure in the cuff. In the present application, nothing more is done than to mechanize this procedure. The individual components are shown in figure 8. A standard 13 by 23 cm cuff is used. The pressure source is a pilot's bail-out oxygen bottle containing nitrogen; the pressure regulator is readjusted so that the output pressure will be a little over the maximum expected systolic pressure. A sequencing valve similar to that designed by the School of Aviation Medicine, USAF, Aerospace Medical Center (ATC), Brooks Air Force Base, Texas, and shown schematically in figure 9, causes the cuff to inflate in two seconds, discharge linearly for 20 seconds and then dump all remaining pressure. This sequence is repeated every 30 seconds. The cuff pressure is measured by means of a 0 to 5 pound per square inch strain-gage transducer. The stethoscope function is provided by a standard dynamic earpiece modified for better sound conduction. This microphone is connected to an amplifier which has a band pass between 150-200 cps. The stethoscope amplifier output is then added to the pressure transducer output and the points are noted where the sound pulses due to a heart beat can be identified. The accuracy of the system depends on the heart rate during the measuring sequence, the slope of the cuff discharge pressure, and the actual systolic and diastolic pressures but is normally within ± 4 mm of Hg.

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TESTS

The instrumentation system was installed in the rear seat of a T-33 aircraft for check and evaluation and the co-pilot was used as the subject. Figure 10 shows the package in its location in the test aircraft.

In all, 7 flights were made in the T-33 aircraft. Data were recorded by an on-board 11-channel oscillograph. An example of the recorded data is shown in figure 11. Base-line data at 1 g were obtained during the ascent to the altitude desired for the zero g maneuver. During each flight, several parabolic trajectories were flown.

The duration of zero gravity on each maneuver varied from 20 to 30 seconds. Reference devices provided to guide the pilot in flying a zero g path consisted of clear glass tubes partially filled with liquid, and enclosed spheres capable of "floating" at zero normal gravity. These devices supplemented the pilot's feeling of floating between the seat and seat belt. The pilot approximated the longitudinal zero-g acceleration by adjusting the engine thrust while noting the forward or aft movement of a free-floating object in the cockpit during the parabolic portion of the trajectory. The low directional-lateral stability of the aircraft in this trajectory imposed small lateral accelerations which could not be eliminated.

Reduction of Data

The basic data were obtained in the form of oscillograms; a typical example is given in figure 11. The time per heart beat could be determined from the time interval between the characteristic pulses on the electrocardiogram lead I, II, or III. From this the heart rate was obtained and plotted against the time corresponding to the interval of the beat in a stepwise fashion as illustrated in figure 12. In addition to the heart rate and the variation of normal acceleration with time, the sequencing time of the blood pressure apparatus (autosphygmomanometer) is indicated by vertical lines with the systolic and diastolic blood pressures noted as a ratio. The pressure value for the first appreciable blip following elevation of the cuff pressure was taken as the systolic pressure, the diastolic being the pressure corresponding to the last noticeable blip along the cuff discharge pressure reading (see fig. 11).

The respiratory rate was determined from the time between successive inspirations.

RESULTS AND DISCUSSION

Base-line shifting caused some early difficulties in the electrocardiogram. This was attributed to temperature changes encountered during the warm up and in flight. A new amplifier was then designed that demonstrated no notable output drift between ambient temperatures of 32° F and 120° F; the temperature compensating circuit required 10 seconds to stabilize. The amplifier also had an adjustable common-mode feature which permitted common-mode rejection of noise induced in the body. The line noise was reduced by balanced lines, the fuse-diode network, and filters. It was necessary to prevent the subject from making contact with the airframe since this would change the noise balance induced in the body. This contact was prevented by proper clothing. A problem arose of proper sequencing of the autosphygmomanometer because of the short duration of the subgravity state compared with the instrument cycle time of 30 seconds.

It was necessary for the pilot to initiate operation of the valve manually in order to correlate its cycling with the appropriate period of acceleration. Acoustical noise pickup by the stethoscope was a problem only on the ground with the engine running.

The equipment has been designed to operate up to a level of 12 g and has operated up to levels of 3.5 g without any malfunction.

Discussion of the Acceleration Effects on Physiological Quantities

Inspection of the basic data of the type shown in figure 11 revealed a slowing of the heart rate as the normal acceleration was reduced from 1 g and a speeding up at normal accelerations greater than 1 g. The range of the heart rate at 1 g for 55 seconds is shown in figure 12 for comparative purposes. Typical variations of heart rate with normal acceleration for several runs are shown in figures 13, 14, and 15. The slowing of the heart rate under subgravity conditions had been previously noted in the work reported in references 3 and 4. Since the subgravity periods in the present flights were of such short duration (20 to 30 sec.), it was not expected that the pulse rate would show the tendency to return to normal during the present subgravity exposures, as was reported in reference 5.

Of interest was the observed trend in blood pressure over the range of acceleration, from 0 to 3 g as shown in figures 13, 14, and 15. It is seen that during the subgravity condition there was a drop in diastolic pressure from its 1 g level while the systolic pressure remained at approximately the 1 g level. In the transition from the 1 g to the increased g levels, there was an increase in diastolic pressure while the systolic pressure still remained at approximately the 1 g level.

Henry, et al., noted a minor blood pressure change in anesthetized monkeys during research rocket flights described in reference 6. The change was described as a gradual decrease in arterial pressure during the subgravity phase of the flight, followed by a slight increase in both systolic and diastolic pressures during the initial phases of the 1 g descent via parachute. The scatter of the systolic readings in the present study was similar to that described in reference 7 but the present study did not reveal the downward trend that was shown in reference 4.

The cause of the blood pressure changes is not readily explained. The drop in diastolic pressure may be a response to the subgravity state in which hydrostatic pressures are greatly reduced. There may be a decrease in resistance offered to the outflow of blood from the peripheral vascular bed by an increase in size or the number of active exit vessels. During the increasing acceleration phase, the rise in diastolic pressure conversely may be the result of increasing hydrostatic pressures and an increase in resistance offered to the outflow of blood from the peripheral

vascular bed due to a decrease in size as well as in number of the active vessels. As a result, the mean arterial pressure is increased. The cardiac output probably remains the same during the increase in pulse rate because of the probable concurrent decrease in stroke volume of the heart.

The respiratory data, as illustrated, shows no consistent trend in rate pattern over the range of acceleration encountered. Subjective information indicated that respiration was physically easier during the period of reduced gravity.

There were no significant changes observed in the electrocardiogram during these flights.

CONCLUDING REMARKS

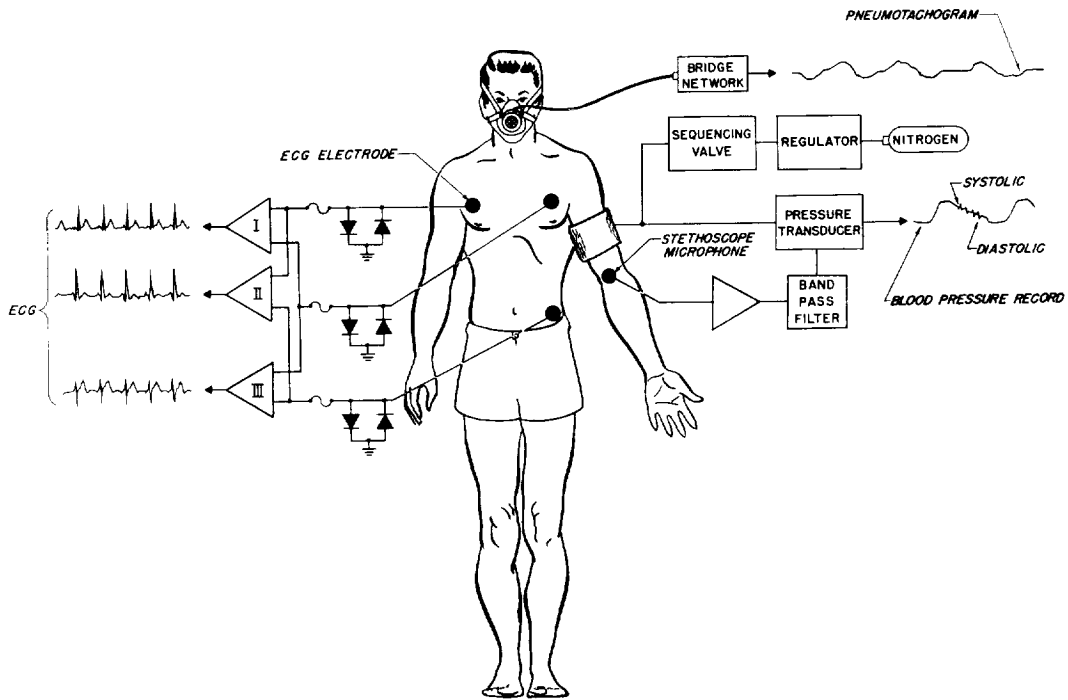
A physiological instrumentation system designed primarily for airborne use, but also adaptable for installation in ground-based simulators, has been developed. This system was able to record the electrocardiogram, pulse rate, respiration rate, and the systolic and diastolic blood pressures of a subject seated in an aircraft and experiencing a variety of acceleration stresses.

Although the amount of data obtained during the flights in the test aircraft was meager it served to demonstrate the reliability of the instrumentation as well as to yield some interesting information. The flights were designed so as to produce accelerations varying from 0 to 3 g. A relationship was demonstrated between acceleration and pulse rate over the range of 0 to 3 g during these flights. The diastolic blood pressure was seen to vary considerably showing a decrease during subgravity conditions and an increase during periods of increased accelerations up to 3 g. The systolic blood pressure, electrocardiogram, and respiration rate remained relatively unchanged during these flights. Since the diastolic pressure varied, whereas the systolic pressure was essentially unchanged, the pulse pressure increased under subgravity conditions and decreased with increased acceleration.

Ames Research Center
National Aeronautics and Space Administration
Moffett Field, Calif., Oct. 12, 1960

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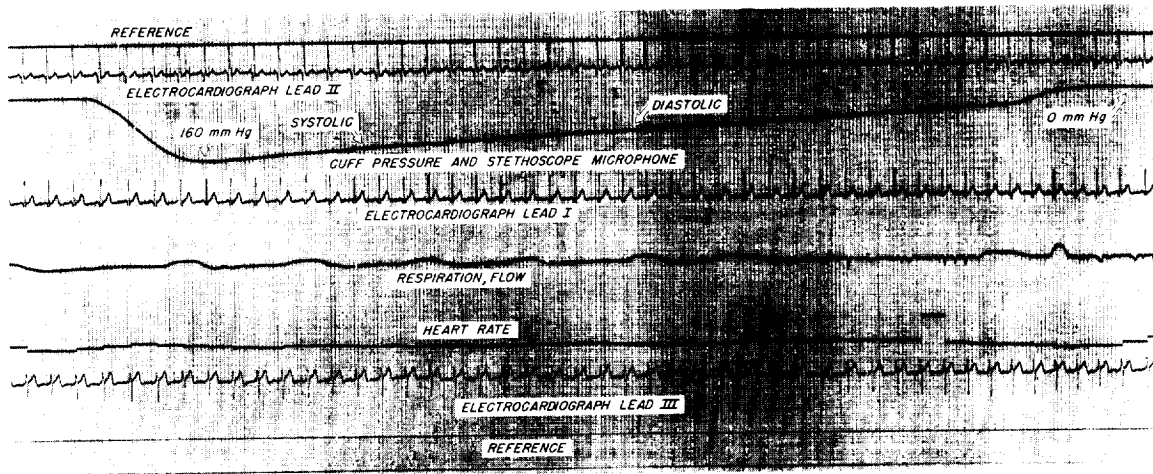


Figure 1.- Subject-system block diagram and a laboratory oscillogram.

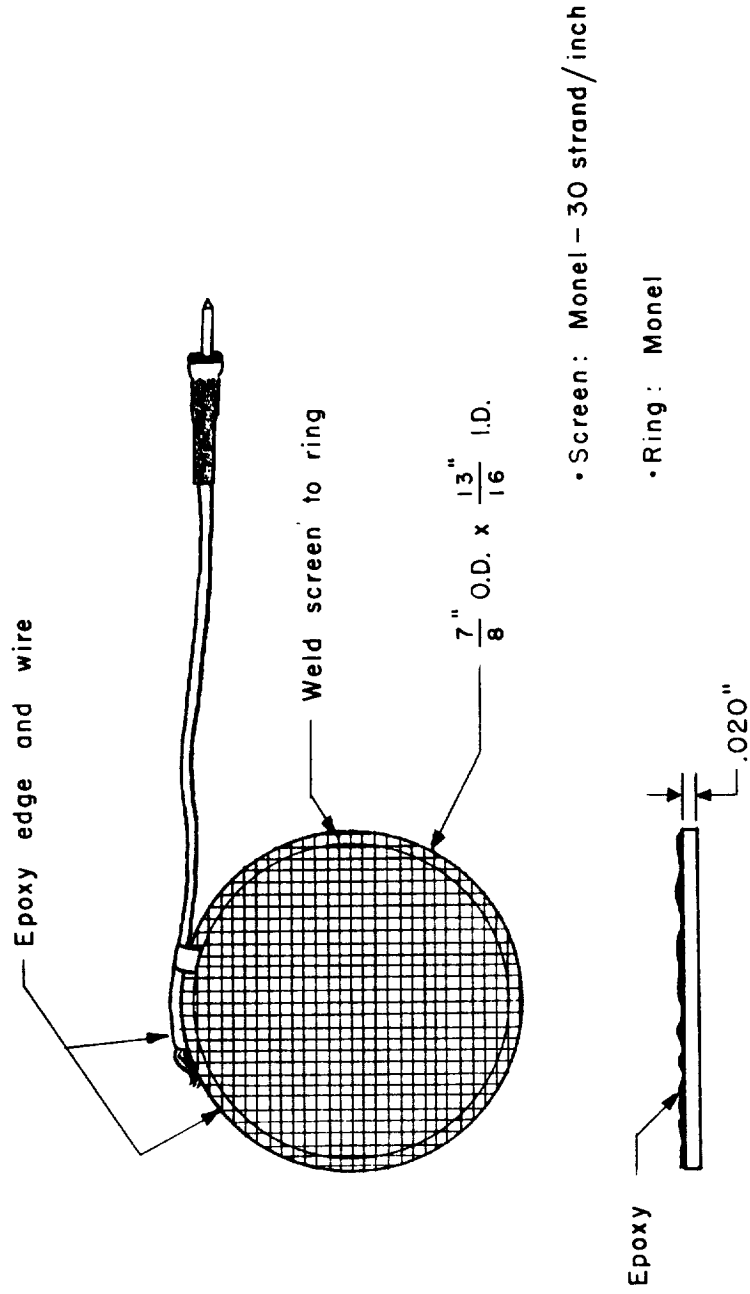
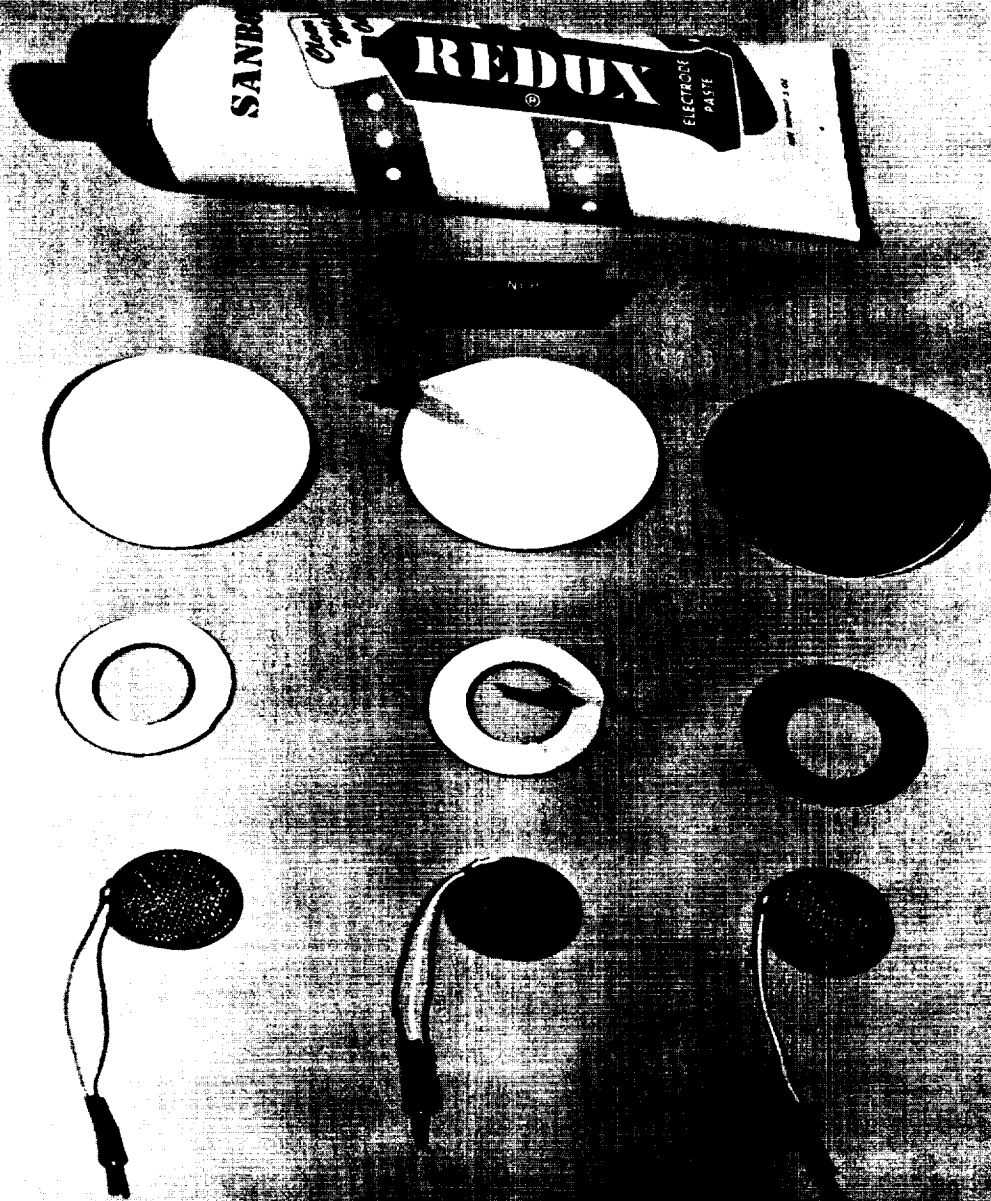


Figure 2.- Electrocardiograph electrode.

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Figure 3.- Electrocardiograph electrodes, adhesives, and electrode paste.



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Figure 4.- Placement of electrocardiograph electrodes for I, II, and III lead recording with right electrode shown uncovered.

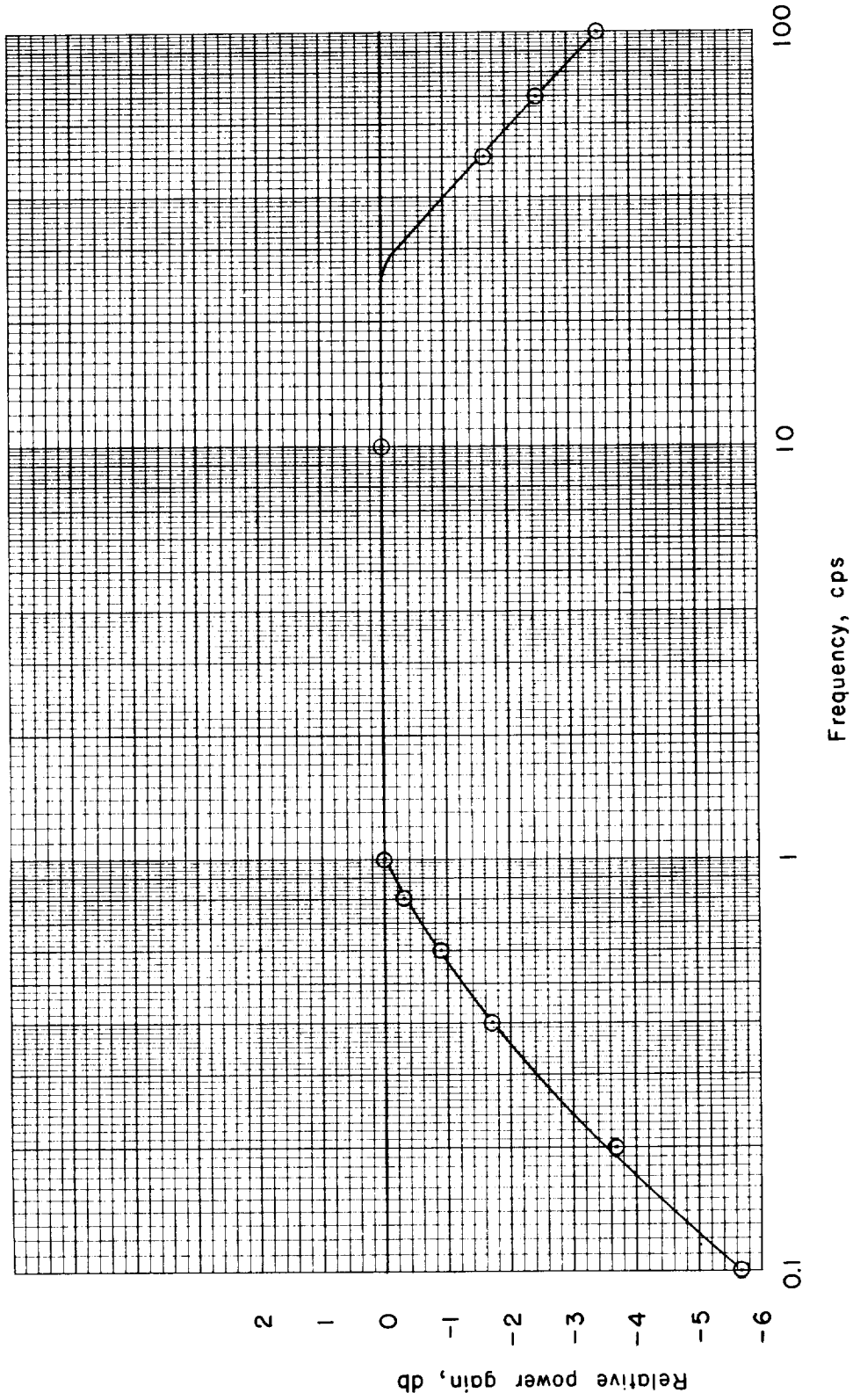
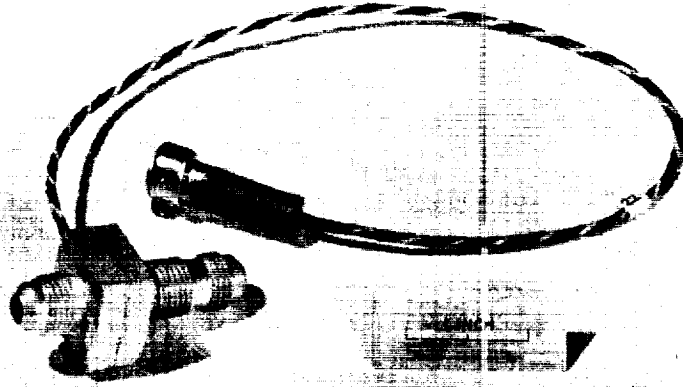


Figure 5.- Frequency response of electrocardiograph amplifier and galvanometer.



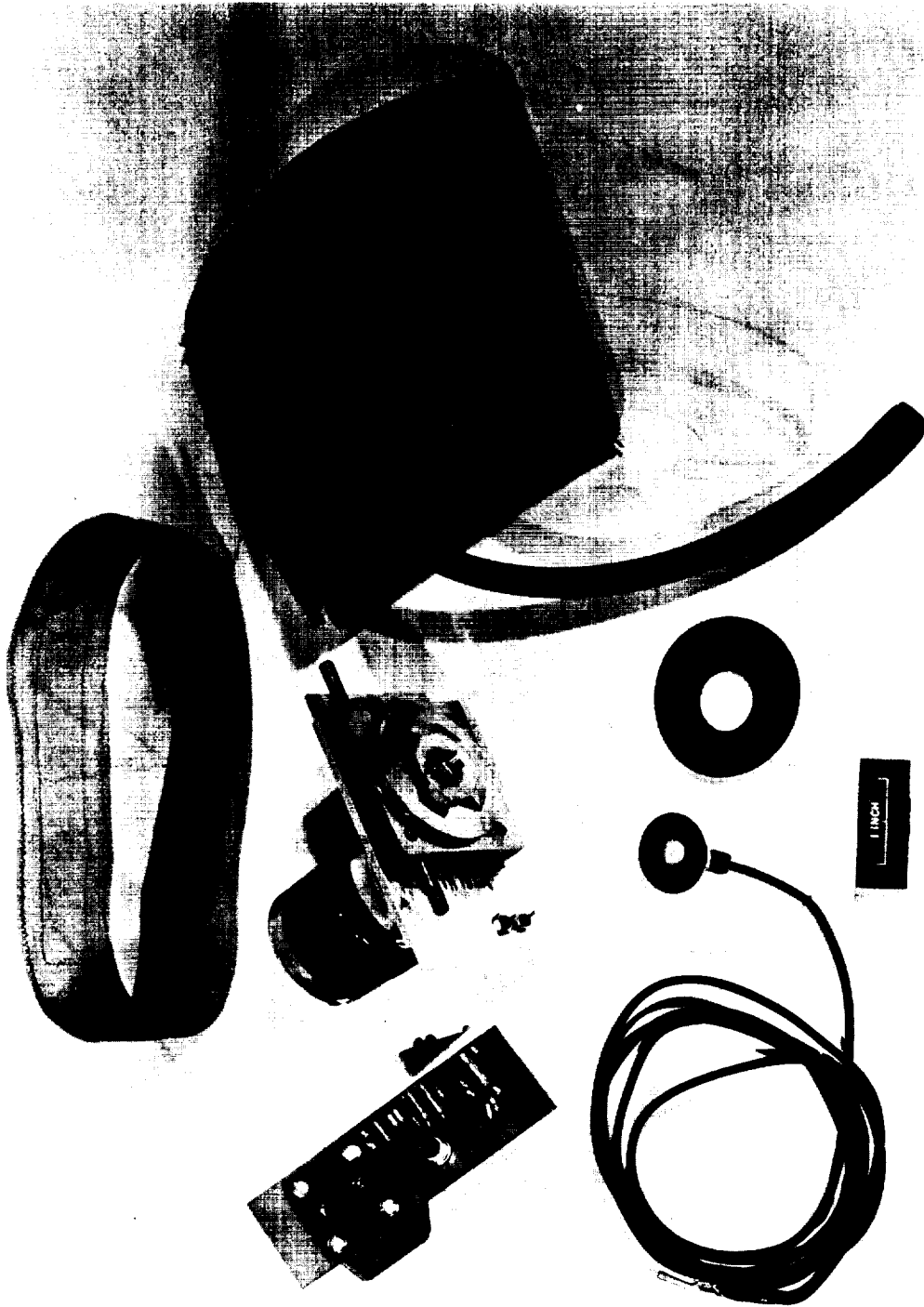
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Figure 6.- A bulkhead fitting form of pneumotachograph using the thermopile principle.



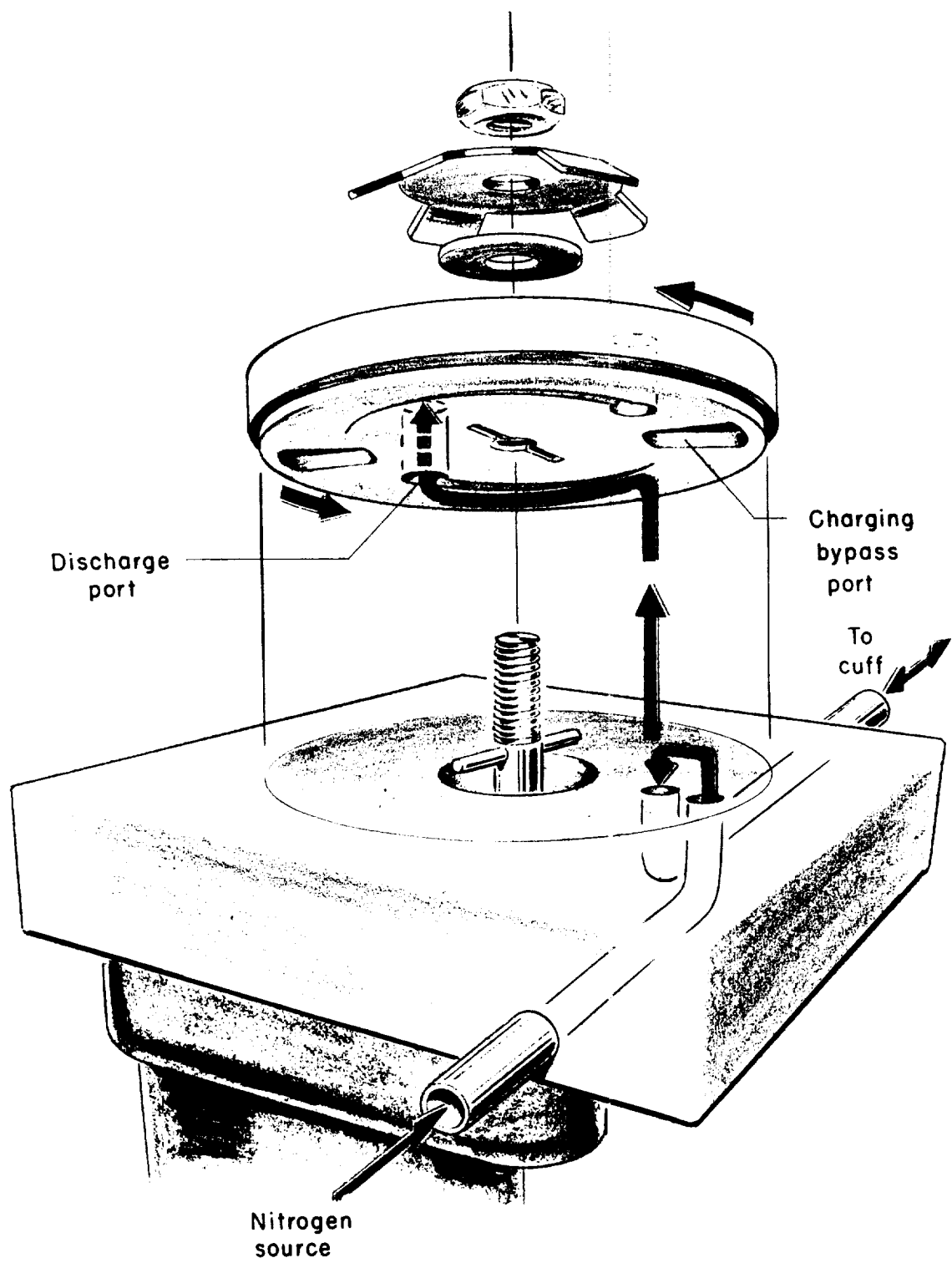
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Figure 7.- Pneumotachograph thermopile showing three butt-welded thermocouples enlarged 16 times.



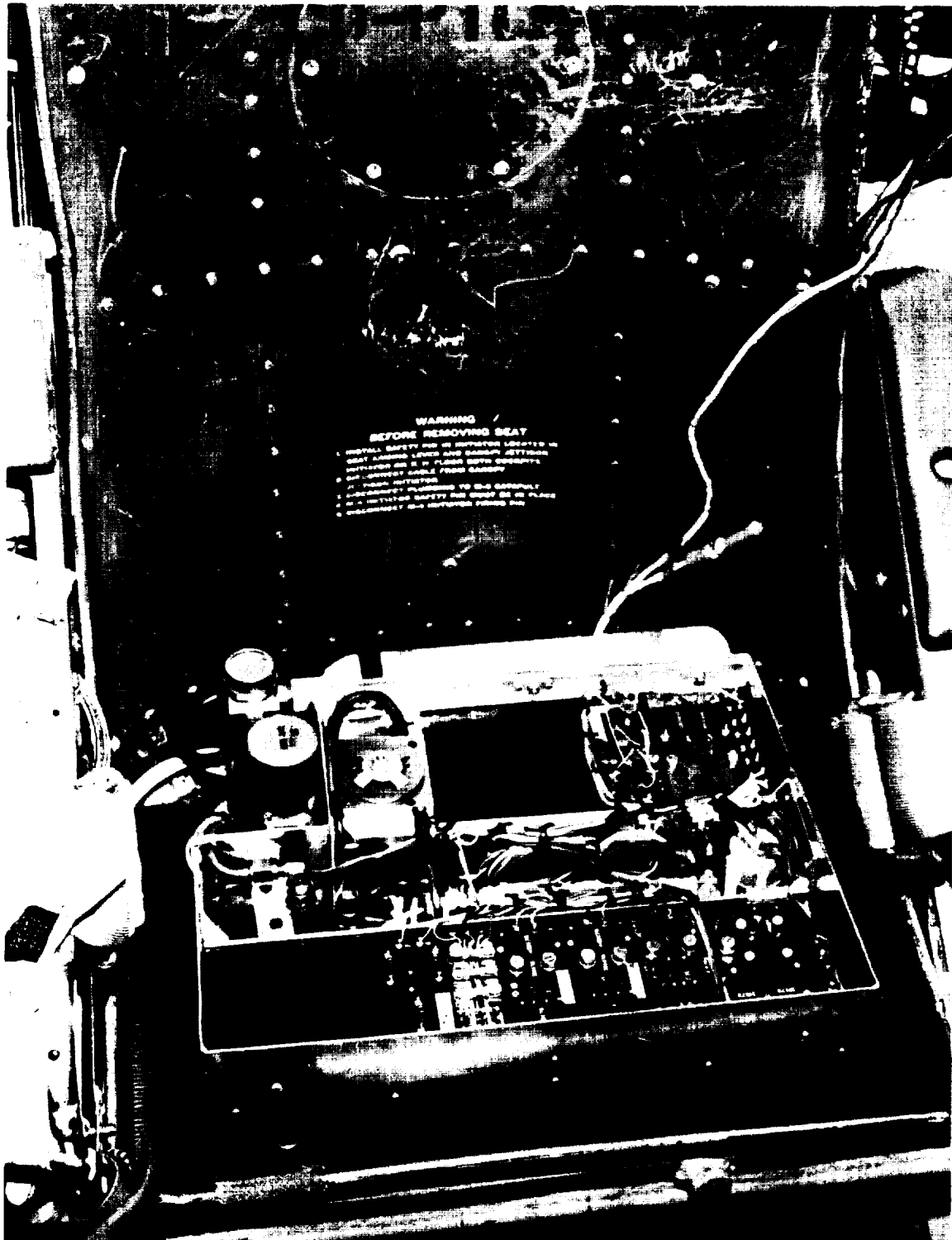
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Figure 3.- Components of the autospHYgmomanometer with cuff, sequencing valve, stethoscope microphone, amplifier, and microphone holding pieces.



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Figure 9.- Schematic diagram of autosphygmomanometer sequencing valve demonstrating cuff charge and discharge.

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Figure 10.- Installation of amplifiers and blood pressure sequencing valve assembly in co-pilot's seat of T-33 with cover removed.

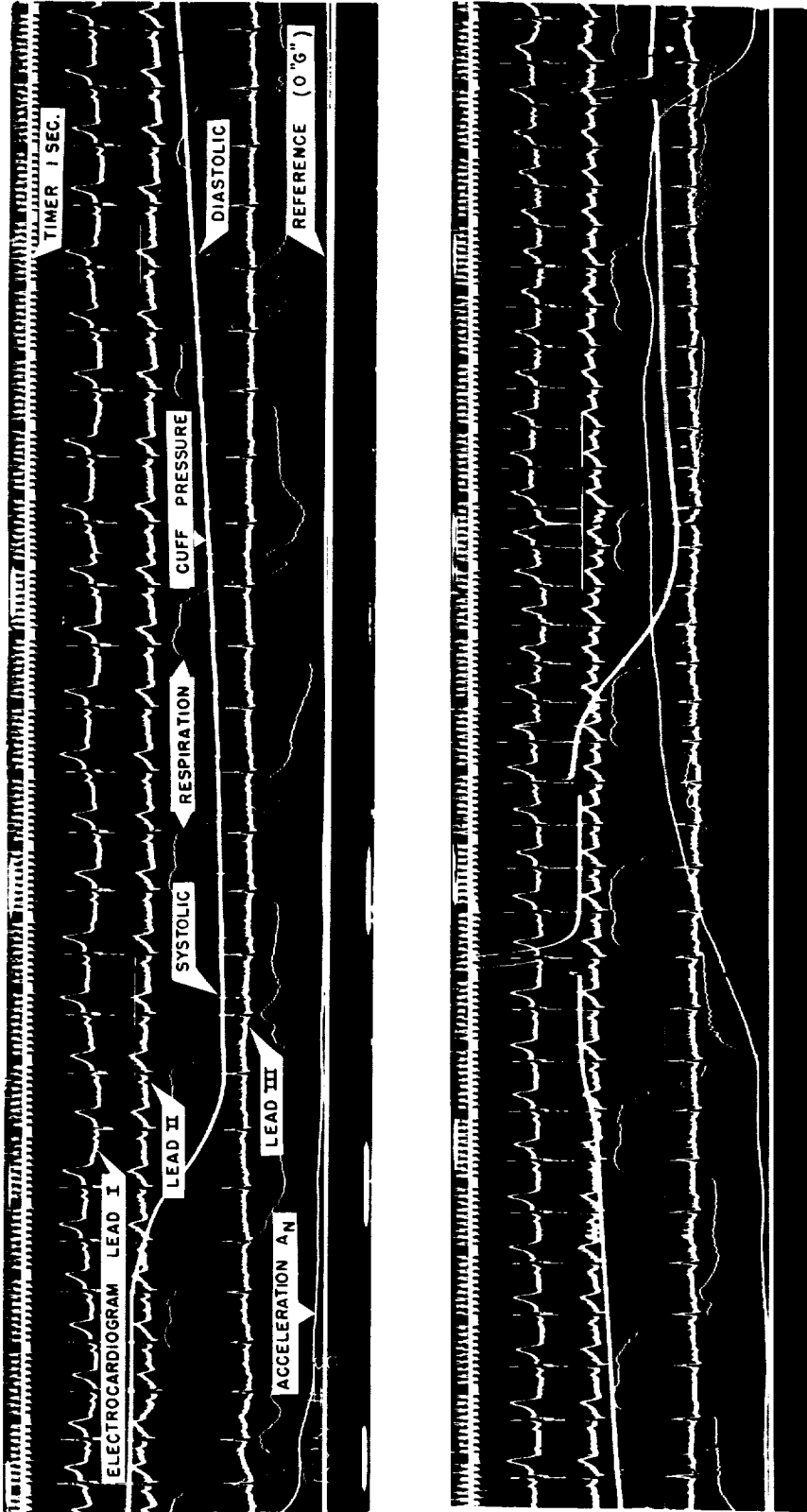


Figure 11.- Airborne oscillograph tracing of Ames physiological instrumentation system.

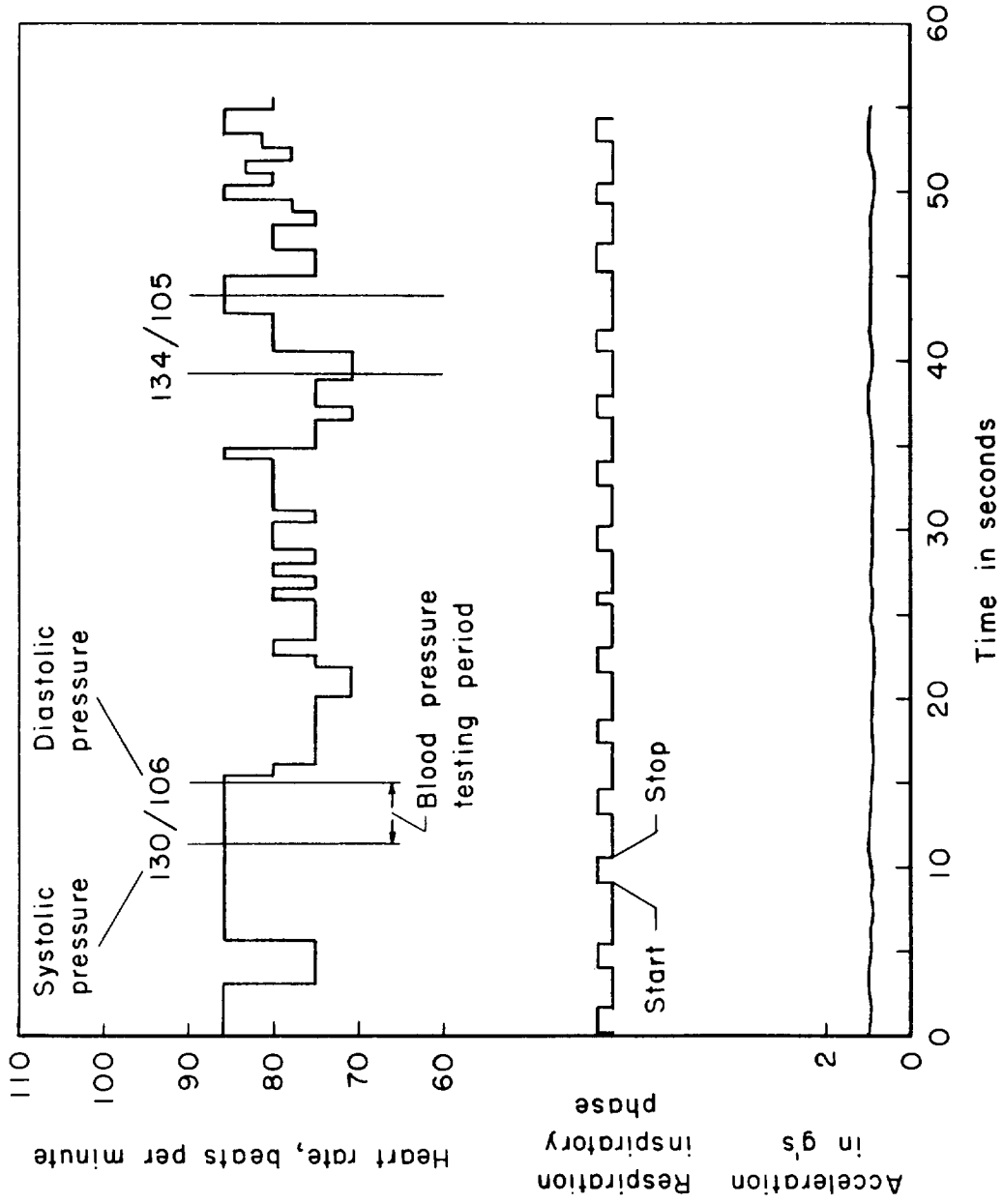


Figure 12.-- Time history of aircraft acceleration and subject's heart rate, blood pressure, and respiration.

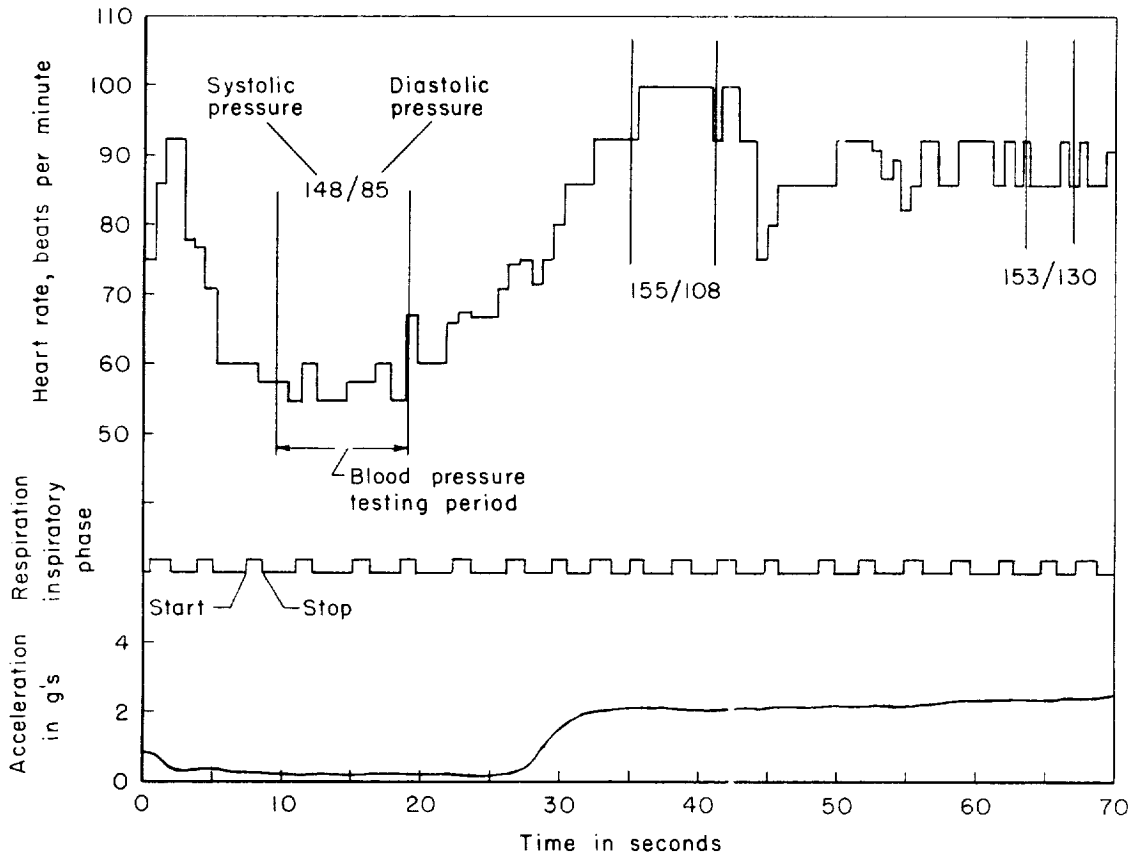


Figure 13.- Time history of aircraft acceleration and subject's heart rate, blood pressure, and respiration.

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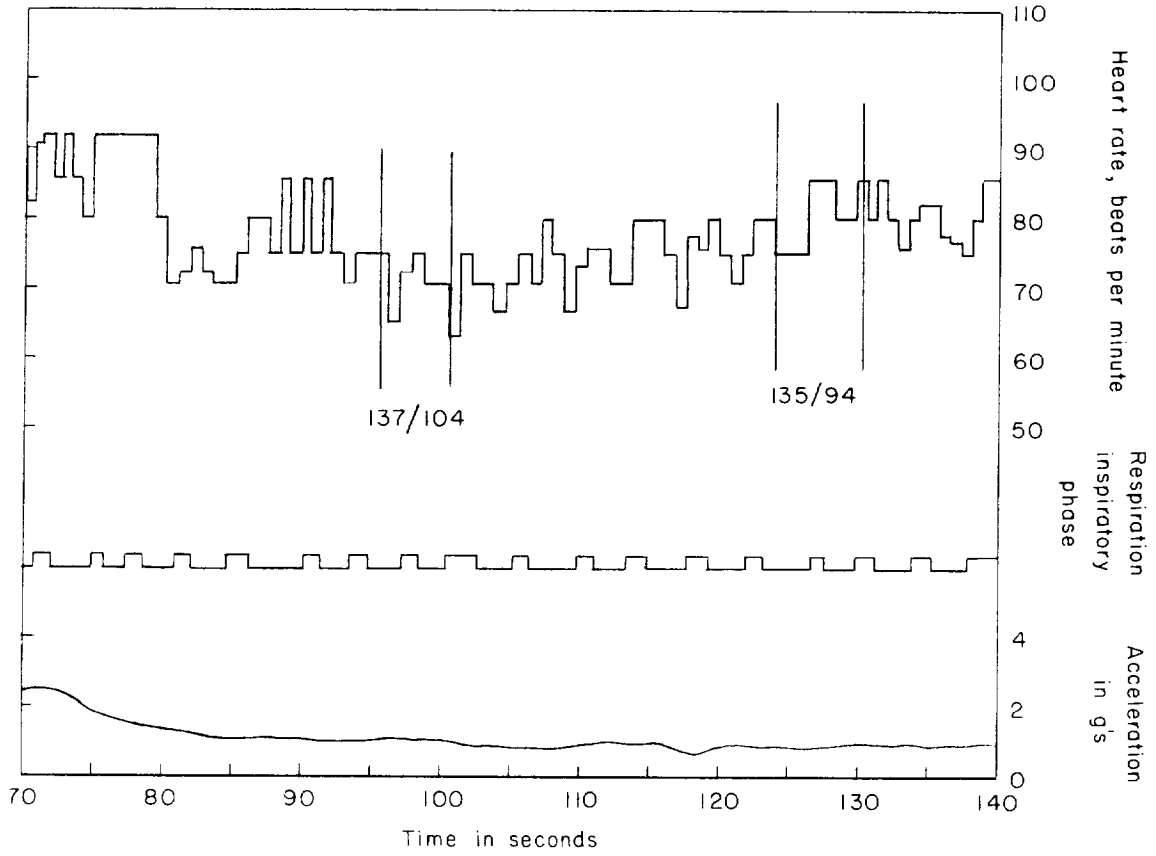


Figure 13.- Concluded.

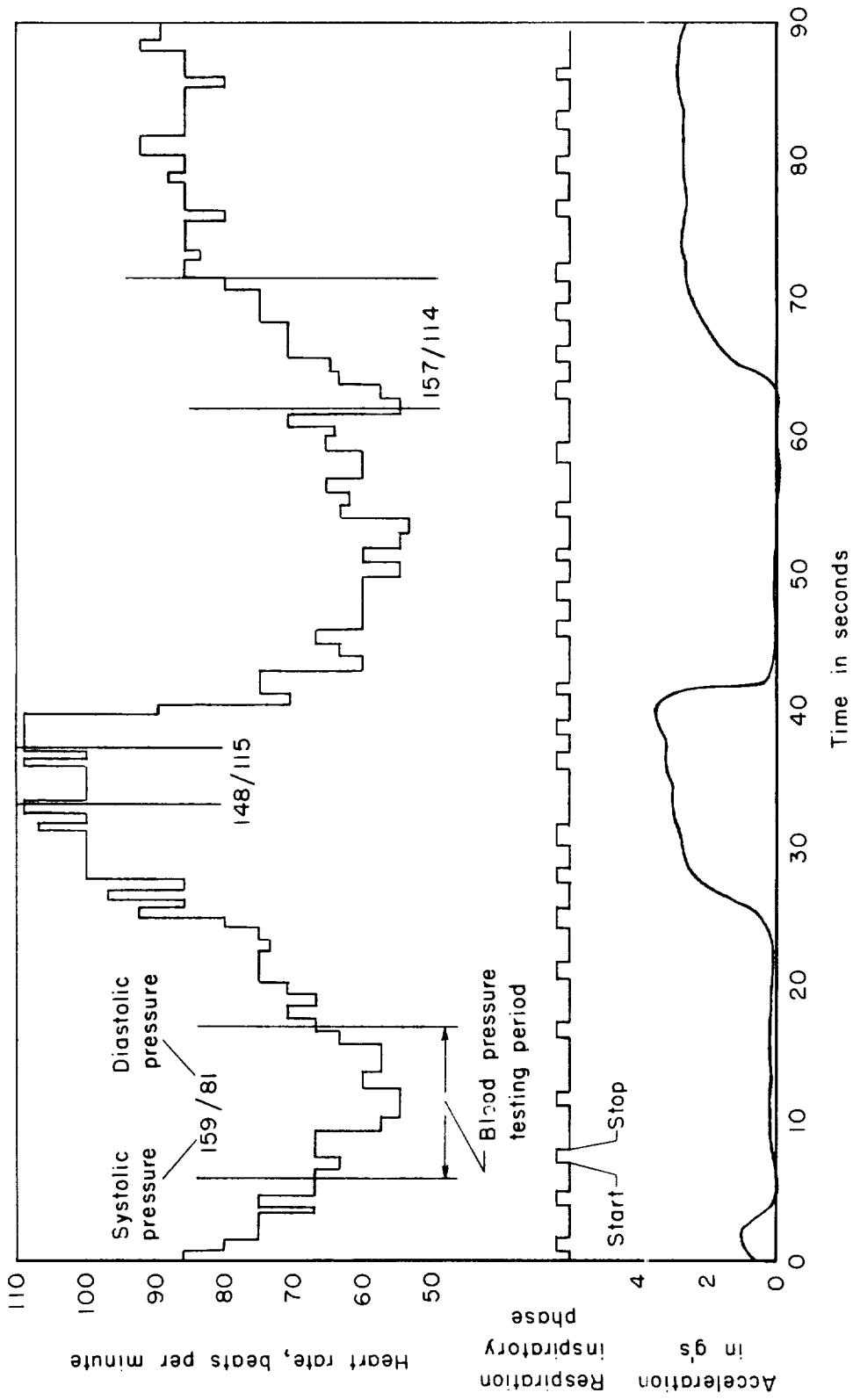


Figure 14.- Time history of aircraft acceleration and subject's heart rate, blood pressure, and respiration.

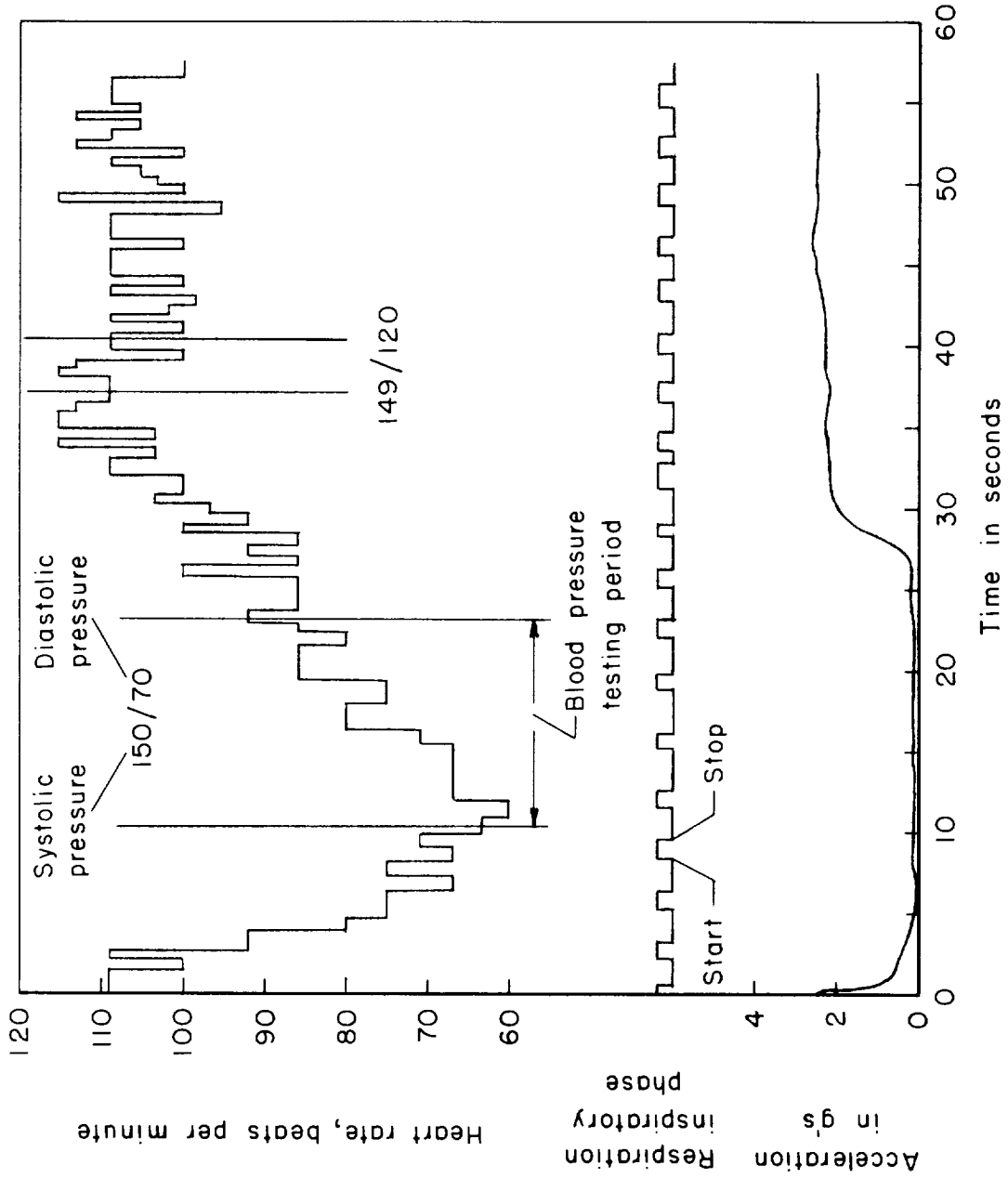


Figure 15.-- Time history of aircraft acceleration and subject's heart rate, blood pressure, and respiration.

