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EVALUATION OF PHONOCARDIOGRAPHIC DATA
OF ASTRONAUTS DURING ORBITAL FLIGHTS

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SUMMARY

Simultaneous electrocardiographic and phonocardiographic records were obtained from both crew members during the flights of Gemini IV and V and on the pilot of Gemini VII. Analysis of the data recorded during flight reveals: (1) wide fluctuations of the duration of the cardiac cycle within physiological limits throughout the mission; (2) fluctuations in the duration of the electromechanical systole that correlated with the changes in heart rate; (3) stable values of the electromechanical delay; (4) considerable shortening of the duration of the cardiac cycle (i.e. increase in heart rate), of the electromechanical systole and, to a lesser extent, of the electromechanical delay at lift-off, at re-entry and for the few hours that preceded re-entry. It is likely that the shortening of the cardiac cycle and of its phases occurred in response to positive chronotropic and inotropic influences (adrenergic reaction) that were observed in all the astronauts who participated in this experiment.

INTRODUCTION

The duration of the cardiac cycle and of its phases (systole and diastole) shortens when the heart rate increases in response to homeostatic demands. Variations in the time of systole and diastole occur at random according to the degree of physical or metabolic activity, emotional reactions, etc. In addition, rhythmic fluctuations of the heart rate of circadian periodicity affect also the duration of systole (including both isometric and isotonic phases) and the duration of diastole.¹

Under normal circumstances, an increase in heart rate is accompanied by some degree of shortening of the time of systole and a more pronounced shortening of diastole time. Several regression equations have been proposed to predict the normal degree of shortening of systole^{2,3,4} and of its isotonic phase.^{5,6,7} Deviations from the normal occur under the influence of different factors (increased metabolic activity, stress) or pharmacological agents (digitalis, epinephrine). Data on the effect of weightlessness are scarce, but Bayevskiy and Gzenko have reported an increase in the electromechanical delay (i.e. the lapse of time between the beginning of electrical depolarization and the onset of the first heart sound) during the Vostok orbital flights.⁸

FOREWORD

The study reported herein was conducted as a medical experiment during the Gemini flights of the USA space program. The electrocardiogram and phonocardiogram of the astronauts were recorded during their mission on a specially designed tape recorder, and the data were played back after the flights for detailed analysis.

The analysis of the data was conducted at the Texas Institute for Rehabilitation and Research under contract with the National Aeronautics and Space Administration (NAS 9-6162).

The primary purpose of the experiment was to determine under what conditions the duration of the cardiac cycle and of its phases may vary during orbital flight. It was not intended to analyze possible changes in amplitude of the sounds or to detect murmurs. Nevertheless, special attention was paid to screen the phonocardiograms at critical times of the mission (lift-off, extra-vehicular activity, and re-entry). No murmurs were detected on any astronaut at these times.

An important by-product of this study has been the analysis of the circadian rhythmicity of the heart rate, of the durations of the cardiac cycle and of its phases in an extra-terrestrial environment. This study has been conducted in collaboration with Professor Franz Halberg, M.D., Ph.D., of the School of Medicine of the University of Minnesota. The results of the study are quite revealing and will be reported in a separate publication.

The study reported here required the cooperation of the personnel of the Manned Spacecraft Center and of the Cardiopulmonary Laboratory of the Texas Institute for Rehabilitation and Research. The contributions of Messrs. Robert Lamonte and William Young of the Manned Spacecraft Center, those of Mr. Thomas O. Townsend of the Texas Institute for Rehabilitation and Research, and of Miss Becky Moore of Baylor University College of Medicine have been essential to the successful completion of the project. The collaboration of Mrs. Lois Westrich in the preparation of the manuscript is gratefully acknowledged.

The purposes of this study were (1) to record and measure the changes in various phases of the electrical and mechanical activity of the cardiac cycle during the manned orbital flights of Gemini IV, V and VII; and (2) to correlate these changes with specific circumstances or events that might have influenced the functional cardiac status of the flight crew members.

MATERIALS AND METHODS

A) Subjects

This study was conducted on six astronauts: The command pilot and pilot of Gemini IV, Gemini V, and Gemini VII. Experimental restrictions did not allow for registration of the phonocardiogram on the command pilot of Gemini VII.

B) Equipment

The experimental equipment consisted of: (a) ECG electrodes and phonocardiographic transducer, (b) and electrocardiographic signal conditioner (preamplifier and amplifier) and (c) an on-board biomedical tape recorder.

Electrodes for the detection of the ECG were applied in the usual locations for the MX lead (manubrium-xiphoid). The microphone was taped parasternally in the left fourth intercostal space of the flight crew members. It remained attached to the chest throughout the mission.

The phonocardiographic transducer incorporated a lead zirconate-lead titanate piezoelectric plate (of 7 mm on a side) encapsulated in flexible polyurethane resin and sealed in a nylon case of 1 inch diameter and 0.2 inches in thickness (Figures 1 and 2). A shielded cable of 10 inches in length connected the heart sounds transducer to the signal conditioner housed in a pocket of the astronaut's under-garment (Figure 3). The phonocardiographic signal was conducted from the signal conditioner output to the suit bioplug and thence to the biomedical recorder. The three decibel points of the microphone-signal conditioner system are 30 hertz and 100 hertz.*

C) Biomedical Recordings

The electrocardiogram and phonocardiogram were recorded simultaneously throughout the flight of Gemini IV (with the exception of the period of extra-vehicular activity and re-entry of the pilot) and of Gemini V. They were recorded intermittently in the pilot of the flight of Gemini VII. The recording procedure was entirely passive and did not require active participation on the part of the flight crew members.

* The system was designed and constructed by the Biomedical Instrumentation Section of the Crew Systems Division of the Manned Spacecraft Center, Houston, Texas.

The analog data registered on the biomedical tape recorder were played back in real time after completion of the flight on a rectilinear direct recording instrument that has a frequency response of 100 cps.** The records were digitized with a semiautomatic analog to digital converter.*** Digital readings were taken at each of the following points: (a) at the onset of the QRS complex, the beginning of the electrical systole, (b) at the onset of the first heart sound, (c) at the onset of the second heart sound which indicates the end of the mechanical systole and diastole, the interval between the onset of QRS and the first heart sound (electromechanical delay) and the interval between the first and second heart sounds. The same computer program allowed for computation of means and standard deviations of these variables after each 15 consecutive beats⁹ (Figure 5).

Digitization and computations of the Gemini IV data were made in the following periods: (a) continuously for 8 minutes from the time of lift-off until the spacecraft had reached orbit, (b) continuously from 5 minutes before the period of extra-vehicular activity (EVA), which began at 4 hours 22 minutes after lift-off, to 10 minutes following this extra-vehicular activity, (c) continuously from 5 minutes before re-entry until splashdown, (d) continuously for approximately 1 minute at 2-hour intervals for the first 24 hours and at 4-hour intervals for the second, third, and fourth day. Technical difficulties precluded recording of the phonocardiogram from the 10th through the 18th hour on the command pilot, throughout the extra-vehicular activity on the pilot and from the 93rd hour through splashdown on the pilot.

Measurements on the flight crew of Gemini V were made in the following periods: (a) continuously starting a few minutes before lift-off until the spacecraft had reached orbit, (b) continuously from 5 minutes before re-entry until splashdown and (c) continuously for 1 minute at hourly intervals for the first 24 hours of the mission and at 4-hour intervals for the rest of the flight until 5 minutes before re-entry.

Measurements on the pilot of Gemini VII were made: (a) continuously from 15 minutes before lift-off to 11 minutes into the mission, (b) continuously for 1 minute at 1, 3, and 4 hours, and (c) continuously for 1 minute at hourly intervals in periods assigned for rest (night-time at Cape Kennedy) from the 5th day through the 14th day of the mission. Limitations in the number of measurements in the pilot of the Gemini VII were imposed by the schedule of recording the phonocardiogram in magnetic tape. Measurements of the duration of the cardiac cycle (and heart rate) were made from the ECG recordings of the command pilot of Gemini VII at lift-off and re-entry.

RESULTS

A) Effect of Lift-Off

The changes in the duration of the cardiac cycle are shown in Figures 6 through 11. All the astronauts had marked acceleration of the heart rate (i.e. short cardiac cycle). This acceleration led to peak heart rate values that ranged from 132 on the pilot of Gemini IV to 159 on the pilot of Gemini V. There was rapid deceleration as soon as the spacecraft entered into orbit (approximately 7 minutes from lift-off), but steady state values comparable to those observed at rest on the ground were not reached for several hours.

** Recording System Mark 200, Model RF 1783-70, manufactured by Brush Instruments, Cleveland, Ohio.

*** Telecordex, manufactured by Benson-Lehner, Van Nuys, California.

The poor quality of the phonocardiographic records prevented accurate measurements of the electromechanical delay, but the timing of the second heart sound could be well established in the majority of the records. Thus, it was possible to measure a marked shortening of the electromechanical systole at the peak heart rates of this period. (The lowest values ranged from 205 on the command pilot of Gemini IV to 250 milliseconds on the command pilot of Gemini V.)

B) Effect of Extra-Vehicular Activity

A marked increase in the instantaneous heart rate (manifested by a short duration of the cardiac cycle) occurred throughout the period of extra-vehicular activity of the pilot of Gemini IV. His instantaneous heart rate fluctuated between 140 and 155 beats per minute (Figure 7). The command pilot of Gemini IV who remained inside the spacecraft, had a smaller increase in the heart rate (decrease in duration of the cardiac cycle) with a concomitant shortening of electromechanical systole time, especially after the seventh minute of extra-vehicular activity (Figure 6).

C) Effect of Re-Entry

Figures 12 through 17 show plots of the duration of the cardiac cycle and of its phases from several hours before retrorocket firing to splashdown. All astronauts had a marked acceleration of the heart rate at re-entry with marked shortening of the time of systole. It is interesting to notice also that there was gradual increase in heart rate, shortening of systole and electromechanical delay for several hours in anticipation of the end of the mission. Inasmuch as the biomedical recorder was kept on for the period of time after splashdown, it was possible to record the rate of deceleration of the heart rate while the astronauts waited for their recovery from the ocean. It is interesting to note that deceleration occurred fairly rapidly in all the astronauts with the exception of the command pilot of Gemini IV who continued with fairly rapid heart rates until the end of the recordings.

D) Effect of Orbital Flight

Figures 18 and 19 show serial changes of the duration of the cardiac cycle (R) of the electromechanical systole (S) and of the electromechanical delay (T) on the astronauts who participated in the flight of Gemini IV. Figures 20 and 21 show the changes in the flight crew of Gemini V. Figure 22 depicts the fluctuations that occurred in the pilot of Gemini VII. All the astronauts exhibited great variability of the time intervals of the cardiac cycle throughout the mission. In general, periods of sleep or rest coincided with longer cardiac cycles (lower heart rates) and with longer duration of the electromechanical systole. A circadian rhythmicity is not clearly evident in these tracings, but processing of the data by the cosinor statistical technique of Halberg¹⁰ revealed circadian rhythmicity of the duration of the cardiac cycle, of the duration of systole and of diastole in the astronauts who participated in this experiment.^{11,12}

Table I provides a statistical summary of values obtained in all the astronauts at time of lift-off. Tables II through V indicate results at other important times.

E) Incidence of Arrhythmias

Cardiotachographic tracings were made of the entire mission on all astronauts. The tracings revealed, as expected, a normal level of fluctuation of the instantaneous heart rate. No attempt was made to correlate these fluctuations with the many events (physiological or environmental) that could have caused these fluctuations (Figure 23). A respiration heart rate response was clearly identified at certain times during the mission, especially during periods of sleep (Figure 24).

A few extrasystoles were detected in all the astronauts at some times in the mission. In general, they were detected at lift-off or re-entry, but the incidence was too small to be considered of any significance (Figure 25). An interesting disturbance of the rhythm was detected in the pilot of Gemini IV. Very few premature ventricular contractions were detected on his electrocardiogram at lift-off and re-entry, but most important, he exhibited periods of marked bradycardia (instantaneous heart rate at about 40/minute). In some of these periods, but not in all, he had first degree AV block where the PR interval measured 260 milliseconds (Figure 26). In a specific instance, at 87 hours, 47 minutes, 32 seconds into the mission, a complete AV block was suspected because a P-wave not followed by a QRS was clearly present in the electrocardiogram (Figure 27).

DISCUSSION

It had been anticipated that fluctuations of the cardiac cycle and of its phases would be recorded throughout the orbital flights of the astronauts who participated in the Gemini missions. Marked changes of the heart rate had been measured in the astronauts who participated in the Mercury flights.¹³ Stressful circumstances at times of lift-off and re-entry, during extra-vehicular activity and various performance tests imposed on the astronauts during the Gemini flights accounted for several episodes of increased heart rate and a shortening of the cardiac cycle. The results of this study showed that fluctuations of the time of systole and of the interval between the first and second heart sounds correlated with the total duration of the cardiac cycle, while the electromechanical delay (Q to first heart sound) remained fairly constant. Significantly, shorter values of electromechanical delay were observed at the times of lift-off and re-entry when the heart rates were high.

An interpretation of the significance of changes in the duration of the electromechanical systole or the electromechanical delay requires an analysis of the correlation between these measurements and those of the total duration of the cardiac cycle. Figures 28 through 32 illustrate this correlation. The regression lines shown in these figures were computed using each astronaut's average values of electromechanical systole, electromechanical delay and time interval between the first and second heart sounds for each 15 beats of the digitized records. Each one of these average values was paired with corresponding average value of the duration of the cardiac cycle for those 15 beats. Figure 33 shows a typical scattergram of all the plotted values of one of the astronauts who participated in this experiment. The duration of the cardiac cycle was used as independent variable to compute the regression equations. As predicted, the regression analyses show that the longer the total duration of the cardiac cycle (that is, the lower the heart rate) the longer is the duration of the various phases of the cardiac

cycle. With the exception of the regression lines for the command pilot of Gemini V, all the regression lines of the other astronauts followed closely the normal regression line proposed by Shah and Slodki³ derived from studies in healthy individuals. In most instances, the astronauts' regression lines depart significantly from the normal at the high heart rates of lift-off and re-entry.

Physiological circumstances and pharmacological agents that have a positive chronotropic effect on the cardiac pacemaker cause a shortening of the electromechanical systole. This is due to a greater speed of the chemical reactions that take place in the myocardium during systole as well as to an earlier closure of the semilunar valves. Physiological circumstances or pharmacological agents that cause a strong positive inotropic effect (adrenergic) will shorten the duration of systole more than predicted by the regression line.^{14,15,16,17} It is likely that the low values of systole and the shorter electromechanical delay measured at the times of high cardiac rates of the astronauts reflect the influence of strong positive chronotropic and inotropic influences on the myocardium of the astronauts.

Factors that have a negative chronotropic or inotropic effect (cholinergic) will cause a slowing of the heart rate, a longer cardiac cycle, a longer electromechanical delay. If a positive chronotropic effect on the heart is not accompanied by a strong inotropic effect, the duration of systole does not shorten as much as predicted for a physiological increase in heart rate. The significant shift to the right of the regression line of the command pilot of Gemini V may be due to a smaller preponderance of adrenergic influences than in the other astronauts, although at the faster rates produced at lift-off and re-entry he also had a shortening of the systole and of the electromechanical delay.

Several studies have provided abundant data on the relationship between the duration of the cardiac cycle and of the electromechanical systole.^{2,3,4} There is some discrepancy between the regression line proposed by Shah and Slodki³ and that of Krayenbuhl and co-workers.⁴ A possible explanation may lie in the different techniques used for recording of the heart sounds. Shah and Slodki made separate measurements at the apex and at the pulmonic area and recorded longer values of Q-T₁ in the pulmonic area than in the apex. Their regression equation is based on the values obtained at the apex. The values reported by Krayenbuhl were obtained from recordings of the second heart sound detected by a microphone placed parasternally at the third intercostal space. Thus the longer values obtained consistently by Krayenbuhl may be due to the fact that they measured the electromechanical systole of the right ventricle and not of the left. The measurements made by us in healthy individuals during bedrest¹ and in a group of 75 college students are in close agreement with the values of Shah and Slodki.

It is necessary to point out that the several equations proposed to predict normal values of time of systole are based on measurements obtained on healthy individuals whose heart rates did not exceed 120 beats per minute. It is likely that faster heart rates obtained under the strong positive chronotropic and inotropic influences would have caused a greater shortening of the electromechanical systole. In a recent publication, Hegglin¹⁴ discusses the physiological and pathological circumstances that lead to a shortening of the electromechanical systole. He acknowledges the influence of adrenergic factors, but in addition, his studies reveal

considerable shortening of systole in conditions of congestive heart failure. A short systole in the latter condition is probably due to a decreased ejection volume and early closure of the semilunar valves. It is possible that under the influence of the strong G forces of lift off and re-entry the stroke volume of the astronauts decreased significantly, but it is more likely that adrenergic factors rather than inefficiency of the cardiac muscle accounted for the short time of systole. It would be desirable to use indirect but reliable techniques for measurements of the stroke volume during lift-off and re-entry to assess the degree of efficiency of the myocardium under these stressful situations.

In an early publication, Hegglin¹⁸ had indicated that in health there was a close relationship between the Q-T interval and the interval Q-11. He had suggested that a regression equation to predict the Q-T interval¹⁹ could be used for prediction of the duration of the electromechanical systole. Although in many physiological circumstances the onset of the second heart sound does not coincide with the end of the T wave, the regression line of the Q-T equation follows closely the regression line of Shah's values for Q-11.³ Nevertheless, the measurement of Q-T interval is not recommended for assessment of the time of systole because of difficulties in establishing the end of T accurately while the onset of the second heart sound is more sharply defined.

Contrary to observations made in the Russian cosmonauts,^{8,19} the electromechanical delay (Q-1) did not increase significantly in the astronauts who participated in the Gemini missions. From a theoretical standpoint, a lengthening of the interval between electrical depolarization of the ventricles and the first heart sound should occur at very low heart rates, in the presence of a right bundle branch block, in mitral stenosis and in systemic hypertension.^{21,22,23,24,25} Strong cholinergic factors may increase it also in contrast to the shortening produced under adrenergic influences. Since it is unlikely that the Russian cosmonauts had an organic cardiac condition, a lengthening of their Q-1 interval may have reflected a very strong vagal influence. Unfortunately, the available data do not permit clear correlation between the duration of the electromechanical delay and that of the cosmonauts' heart rate. Also differences in recording technique must be taken into account. The measurements made in the cosmonauts are based on computations of the time interval between the onset of QRS and a low frequency envelope that resulted from integrating the output signals of a phonocardiogram. Although the characteristics of the microphone used by the Russians appear suitable for faithful registration of the heart sounds, it is possible that in the process of obtaining the integral of the first heart sound a significant error could have been introduced in the measurements. The physical characteristics of the microphone used in the Gemini studies gives confidence on the validity of the results reported here. Any possible error in timing produced by the limited frequency response of our recorder (up to 100 cps) would have led to overestimation of the electromechanical delay, but we did not find significant differences of the time intervals of the same electrocardiographic and phonocardiographic data when played back on a direct writing instrument (frequency response up to 100 cps)^{****} or on an oscillograph recorder (with a frequency response up to 1000 cps)^{*****} If there was overestimation of the electromechanical delay in our study, the short values measured at lift-off and re-entry would take on greater significance as manifestations of adrenergic activity.

**** Recording System Mark 200, Model RF 1783-70, manufactured by Brush Instruments, Cleveland, Ohio.

***** Visicorder, Model 906C, manufactured by Honeywell, Inc., Denver Division, Denver, Colorado.

In a recent publication, Agress²⁶ has reported on the correlation between the duration of the isometric phase of systole (isovolumetric period) and the stroke volume. He has proposed also a regression equation to compute the stroke volume from the ratio between the isotonic (ejection period) and isometric times of systole. The measurements reported in Agress' study were made from tracings of the ECG and central arterial pressure. No such measurements were obtained in the astronauts who participated in the study, but our measurements of the electromechanical delay overestimate the duration of the isovolumetric phase of systole by the duration of cardiac excitation (usually fairly constant at about 40 milliseconds). Likewise, the duration of the isotonic phase of contraction (period of ejection) is closely approximated by the measurement of the time interval between the two heart sounds. We have not attempted to make computations of the stroke volume by these methods, but gross observation of the values of these variables during orbital flights and at critical times of their mission (lift-off and re-entry) indicate maintenance of a high ratio ejection time/isovolumetric time. If this is indeed the case, one may conclude that there was excellent cardiac contractility even in the periods of tachycardia and that in all likelihood this was made possible by the strong positive inotropic effect of adrenergic factors.

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TABLE I

VALUES OF THE DURATION OF THE CARDIAC CYCLE OF ASTRONAUTS
AT 15 MINUTES BEFORE LIFT-OFF

	HEART RATE $\bar{x} \pm \sigma$	R $\bar{x} \pm \sigma$	S $\bar{x} \pm \sigma$	T $\bar{x} \pm \sigma$	X $\bar{x} \pm \sigma$
G-IV Command Pilot	94 ± 7	640 ± 45	---	---	---
G-IV Pilot	70 ± 5	860 ± 59	390 ± 12	70 ± 6	320 ± 12
G-V Command Pilot	78 ± 4	770 ± 41	380 ± 8	50 ± 7	330 ± 12
G-V Pilot	76 ± 4	790 ± 44	340 ± 5	35 ± 3	305 ± 5
G-VII Command Pilot	78 ± 5	770 ± 50	---	---	---
G-VII Pilot	88 ± 11	681 ± 93	301 ± 4	36 ± 3	265 ± 5

Heart Rate values expressed in beats per minute

R, S, T, and X values in milliseconds.

TABLE II**VALUES OF THE DURATION OF THE CARDIAC CYCLE OF ASTRONAUTS
AT THE PEAK OF CARDIAC ACCELERATION DURING LIFT-OFF**

	TIME INTO MISSION	HIGHEST INSTANTANEOUS HEART RATE	SHORTEST R	SHORTEST S	SHORTEST T	SHORTEST X
G-IV Command Pilot	0.25	158	378	205	-	-
G-IV Pilot	2	132	453	247	-	-
G-V Command Pilot	6.4	152	394	250	40	210
G-V Pilot	5.7	159	378	220	42	178
G-VII Command Pilot	1	146	410	-	-	-
G-VII Pilot	3	134	445	225	30	195

Time into mission expressed in minutes

Heart rate in beats per minute

R, S, T, X, in milliseconds

TABLE III**RATE OF DECELERATION OF THE HEART RATE OF ASTRONAUTS AFTER LIFT-OFF**

	HIGHEST INSTANTANEOUS HEART RATE	AVERAGE RATE AT STEADY STATE	TIME CONSTANT τ .63	INSTANTANEOUS HEART RATE AT τ.63
G-IV Command Pilot	158	72	238	90
G-IV Pilot	132	66	182	81
G-V Command Pilot	152	63	129	81
G-V Pilot	159	69	148	88
G-VII Command Pilot	146	60	87	77
G-VII Pilot	134	50	62	71

Heart Rate expressed in minutes

Time Constant in minutes (τ .63: time at which the heart rate dropped 63% of the difference between the peak instantaneous rate value of lift-off and the average Steady State value)

TABLE IV

VALUES OF THE DURATION OF THE CARDIAC CYCLE
OF ASTRONAUTS WHILE IN ORBIT

	HEART RATE $\bar{x} \pm \sigma$	R $\bar{x} \pm \sigma$	S $\bar{x} \pm \sigma$	T $\bar{x} \pm \sigma$	X $\bar{x} \pm \sigma$
G-IV Command Pilot	72 ± 11	836 ± 140	347 ± 31	51 ± 4	312 ± 34
G-IV Pilot	66 ± 12	904 ± 206	362 ± 26	67 ± 5	291 ± 19
G-V Command Pilot	63 ± 10	950 ± 130	392 ± 27	50 ± 5	342 ± 25
G-V Pilot	69 ± 12	865 ± 179	365 ± 30	47 ± 4	318 ± 30
G-VII Pilot*	56 ± 10	1073 ± 217	391 ± 30	46 ± 4	344 ± 29

Heart Rate expressed in beats per minute

R, S, T, X in milliseconds

*Most of this astronaut's values were obtained during sleep periods.

TABLE V

VALUES OF THE DURATION OF THE CARDIAC CYCLE OF ASTRONAUTS AT RE-ENTRY

	HIGHEST INSTANTANEOUS HEART RATE	TIME BEFORE SPLASHDOWN	SHORTEST R	SHORTEST S	SHORTEST T	SHORTEST X
G-IV Command Pilot	146	0.25	410	213	40	173
G-IV Pilot	142	2	420	285	60	225
G-V Command Pilot	171	6	351	225	40	185
G-V Pilot	180	0	333	201	41	160
G-VII Command Pilot	190	19	315	-	-	-
G-VII Pilot	149	15	403	-	-	-

Heart rate expressed in beats per minute

Time in minutes

R, S, T, and X in milliseconds

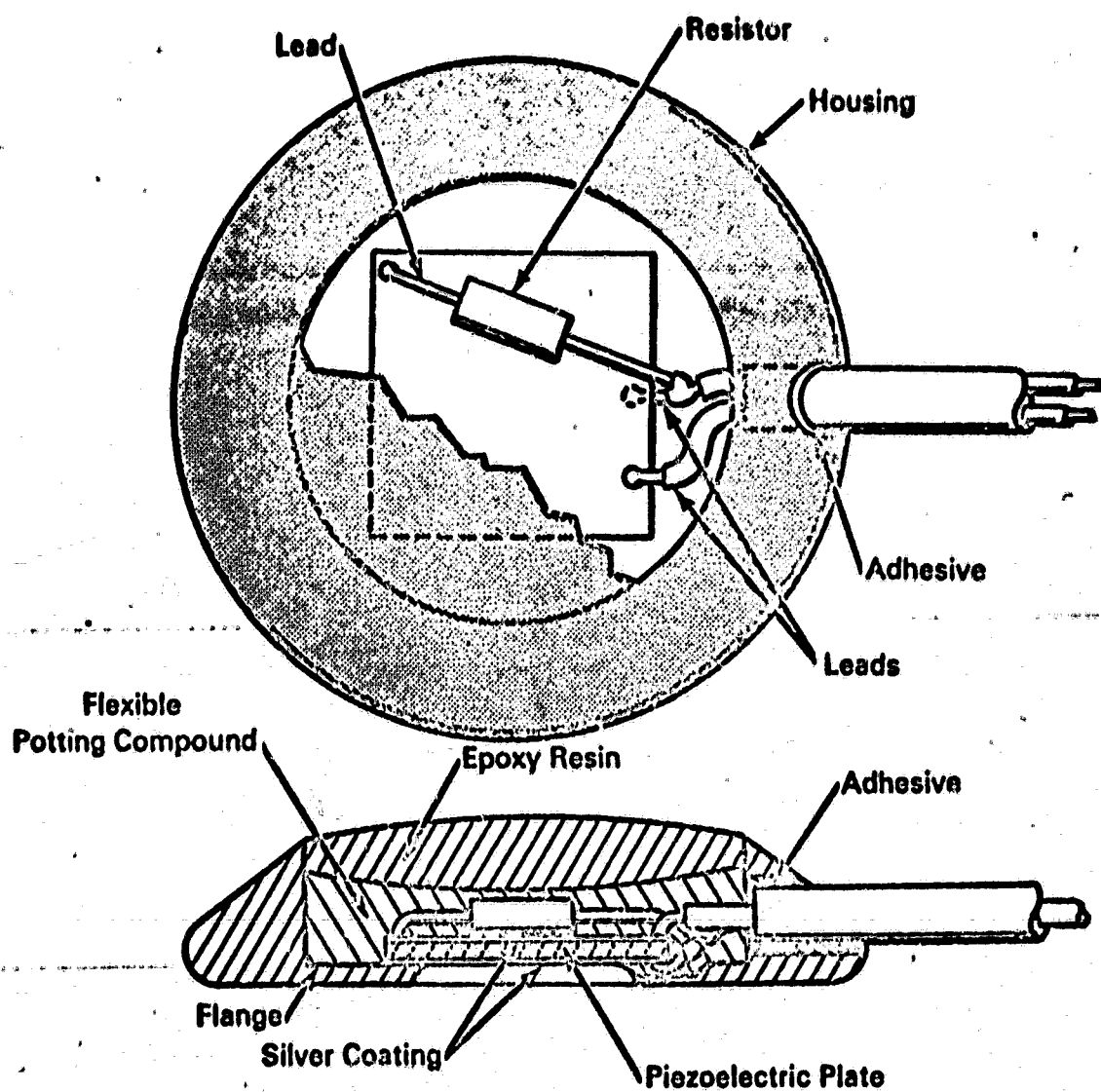


FIGURE 2

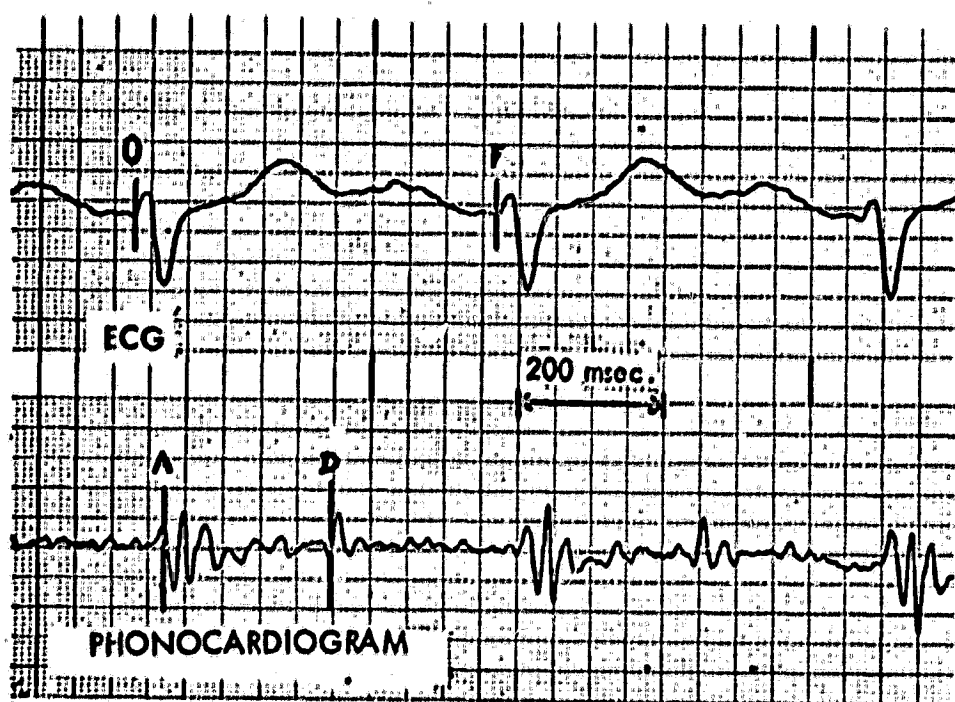
Detailed view of the components of the microphone used in the M-4 experiment. The dimensions of the microphone are the following: the piezoelectric plate measures 7 millimeters on a side, the nylon case is 1 inch in diameter and 0.2 inches in thickness.



FIGURE 3

Placement of the microphone for the M-4 experiment of the Gemini Program. The microphone is taped parasternally in the left fourth intercostal space. A shielded cable of 10 inches in length connects the transducer to the signal conditioner housed in a pocket of the astronaut's undergarment. The suit bioplug is shown on the left side of the chest of this subject.

G-V PILOT (190 hours, 36 minutes)



- O to F = Cardiac Cycle (R)
- O to D = Electromechanical Systole (S)
- D to F = Diastole (D)
- O to A = Electromechanical Delay (T)
- A to D = 1st to 2nd Sound (X)

FIGURE 4

Simultaneous tracing of the phonocardiogram and electrocardiogram of the pilot of Gemini V. The points identified in the figure are those where digital readings of time intervals were taken.

```

***** J. A. McDIVITT ST-0 ***** PAGE 1361
000 00 00 J. A. McDIVITT 70000 /70511 3 /TIME 0100 /DATE 0066 CALIB. 0101 0100
OBSERVATION 11
00.00 000.00 000.00 000.00
OBSERVATION 12
00.00 000.00 000.00 000.00
OBSERVATION 13
00.00 000.00 000.00 000.00
OBSERVATION 14
00.00 000.00 000.00 000.00
OBSERVATION 15
00.00 000.00 000.00 000.00
OBSERVATION 16
00.00 000.00 000.00 000.00
OBSERVATION 17
00.00 000.00 000.00 000.00
OBSERVATION 18
00.00 000.00 000.00 000.00
OBSERVATION 19
00.00 000.00 000.00 000.00
OBSERVATION 20
00.00 000.00 000.00 000.00
***** J. A. McDIVITT ST-0 ***** PAGE 1362
000 00 00 J. A. McDIVITT 70000 /70511 3 /TIME 0100 /DATE 0066 CALIB. 0101 0100
AVERAGE FOR BEAT 1 TO 15
AVERAGE T AVERAGE S AVERAGE X AVERAGE R AVERAGE S'
00.00 000.00 000.00 000.00 000.00
STD. DEV. T STD. DEV. S STD. DEV. X STD. DEV. R STD. DEV. S'
0.00 0.00 0.00 0.00 0.00
RATIO S/S'
0.00000
RANGE OF S RANGE OF R
MIN MAX MIN MAX
CALCULATED 072.00 340.00 000.00 100.00
ACTUAL 001.00 002.00 000.00 000.00

```

FIGURE 5

Example of a print-out of the computer report of measurements of the time intervals of the cardiac cycle on the command pilot of Gemini IV. The average values for the first 15 beats recorded at this point in time of their mission are presented at the bottom. The values of T, S, X, R correspond to the time intervals illustrated in Figure 4. The value of S' was computed using a regression equation to predict S as a function of R in healthy subjects.

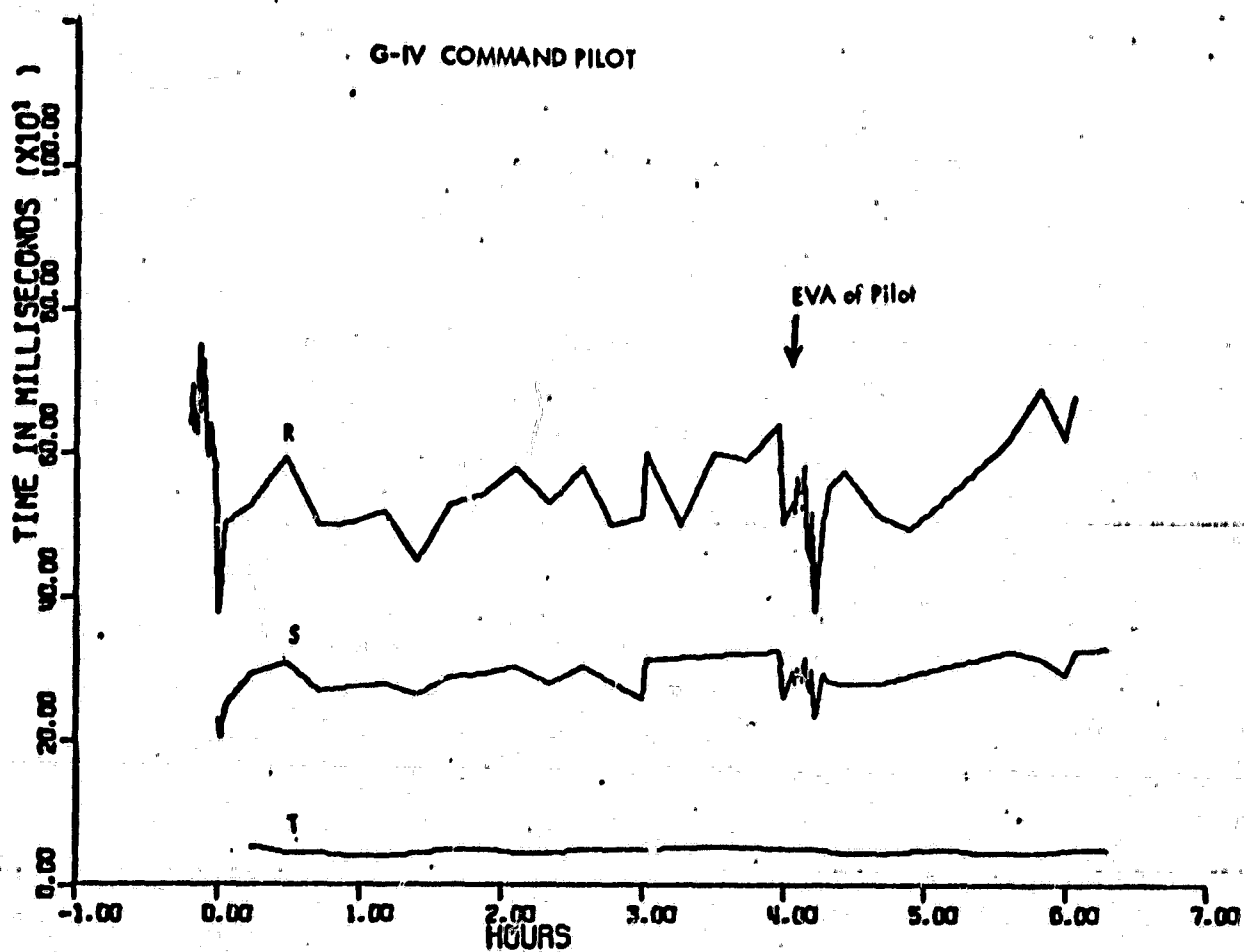


FIGURE 6

Effect of lift-off on the duration of the cardiac cycle and of its phases on the command pilot of Gemini IV. Time in hours is shown in the abscissa. The O indicates lift-off. Values plotted on the minus side of the scale were measured for a few minutes before lift-off. The ordinate shows time in milliseconds for easy reference of the duration of the cardiac cycle (R) of the time of systole (S) and of the electromechanical delay (T). Notice the increase in heart rate and shortening of the diastole during the period of extra-vehicular activity (EVA) of the pilot of the Gemini IV.

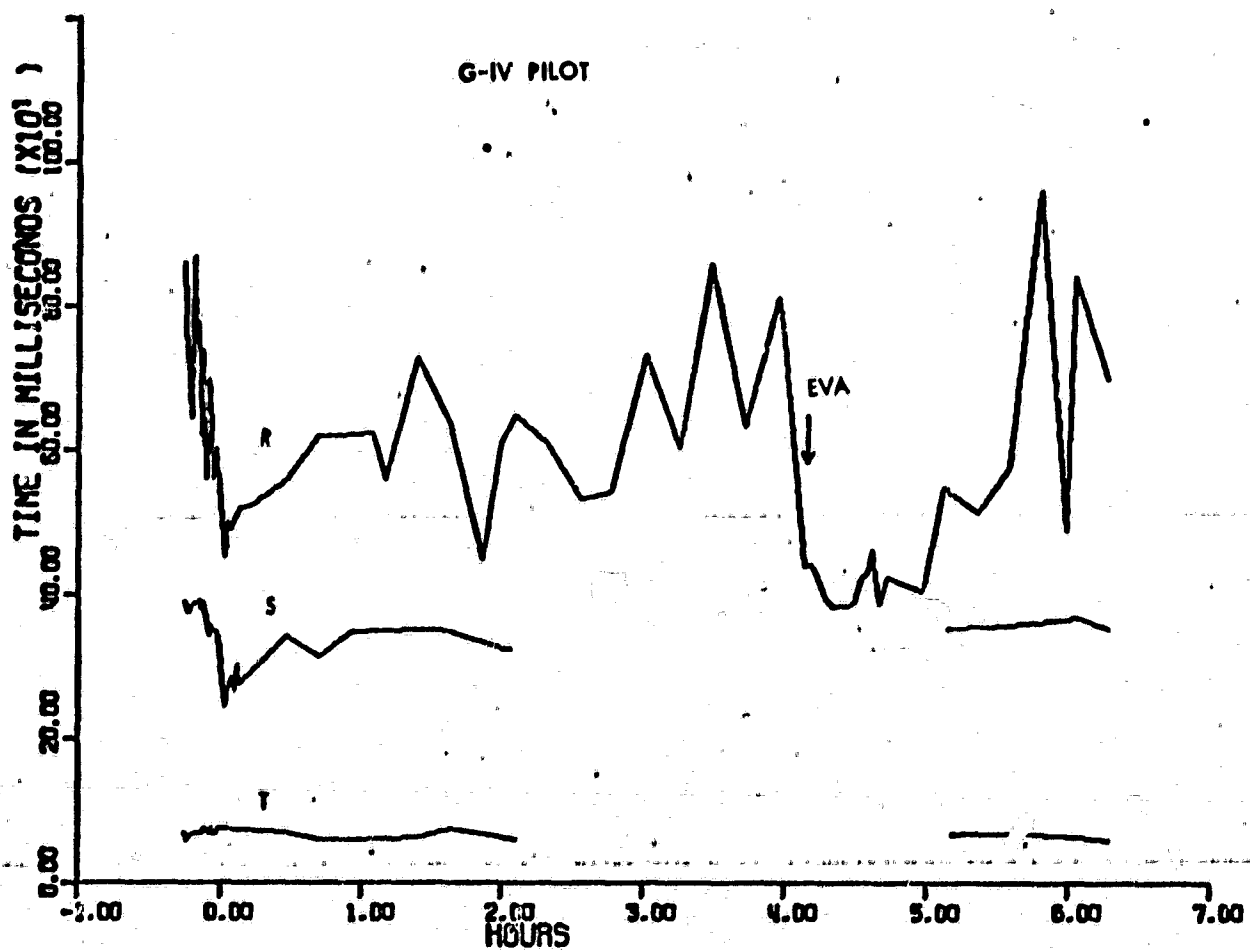


FIGURE 7

Effect of lift-off on the duration of the cardiac cycle and of its phases on the pilot of Gemini IV. Coordinates are the same as in Figure 6. Notice the marked shortening of the duration of the cardiac cycle during the period of extra-vehicular activity (EVA). This increase in heart rate lasted considerably longer than the 20 minutes of activity outside of the spacecraft. The phonocardiogram was not recorded during this period of extra-vehicular activity.

G-V COMMAND PILOT

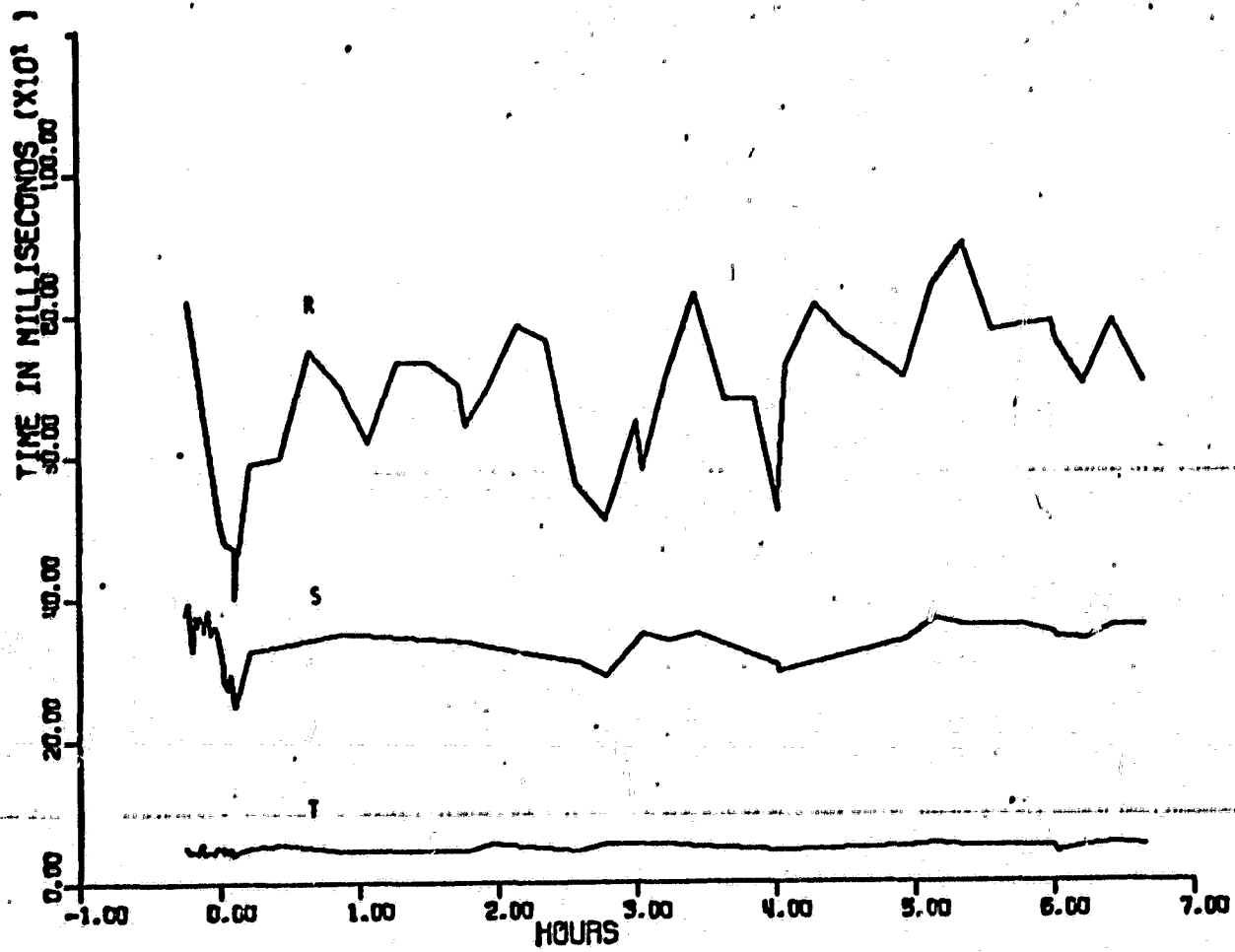


FIGURE 8

Effect of lift-off on the duration of the cardiac cycle and of its phases on the command pilot of Gemini V. The coordinates are the same as in Figures 6 and 7.

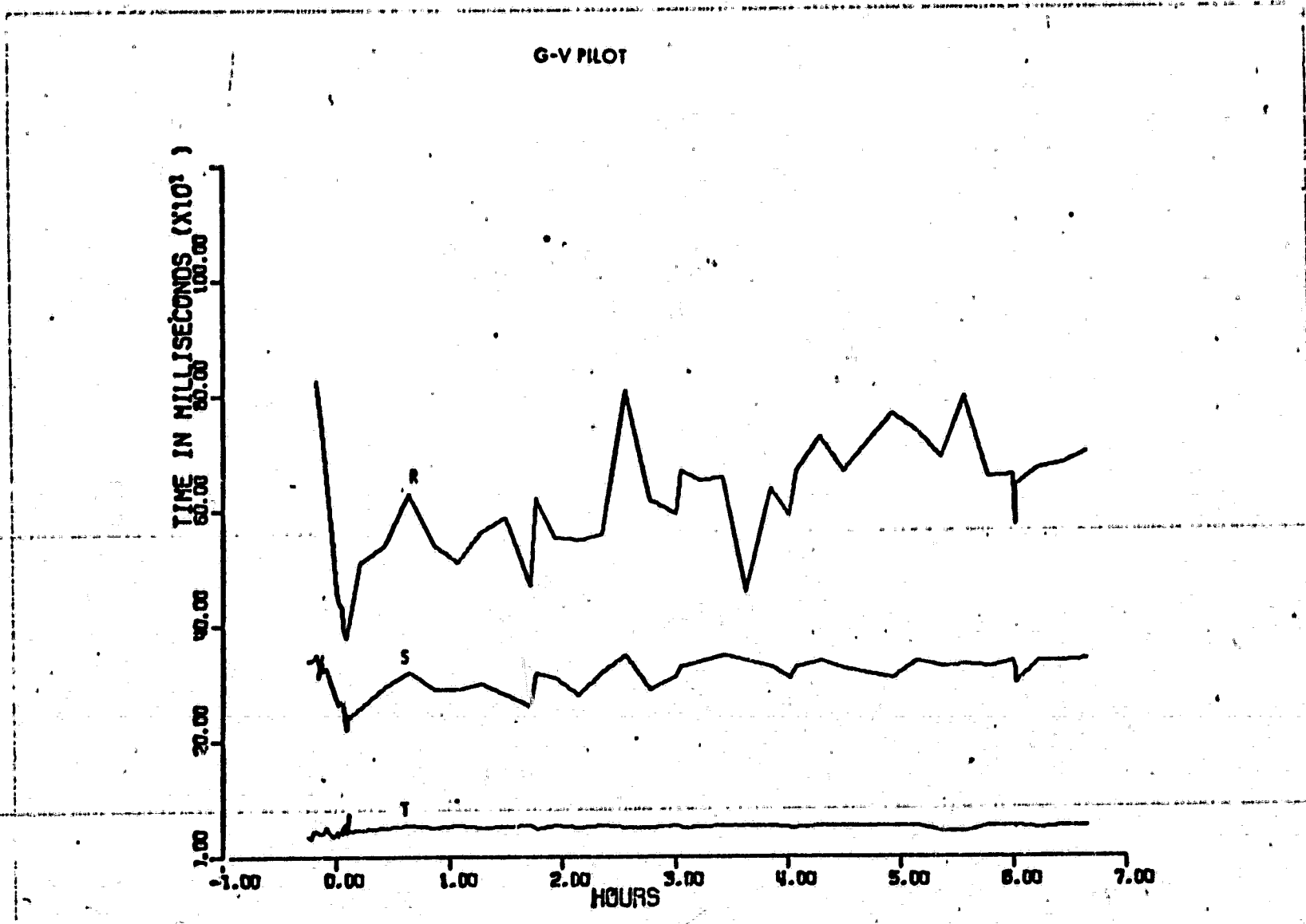


FIGURE 9

Effect of lift-off on the duration of the cardiac cycle and of its phases on the pilot of Gemini V. The coordinates are the same as in Figures 6 through 8.

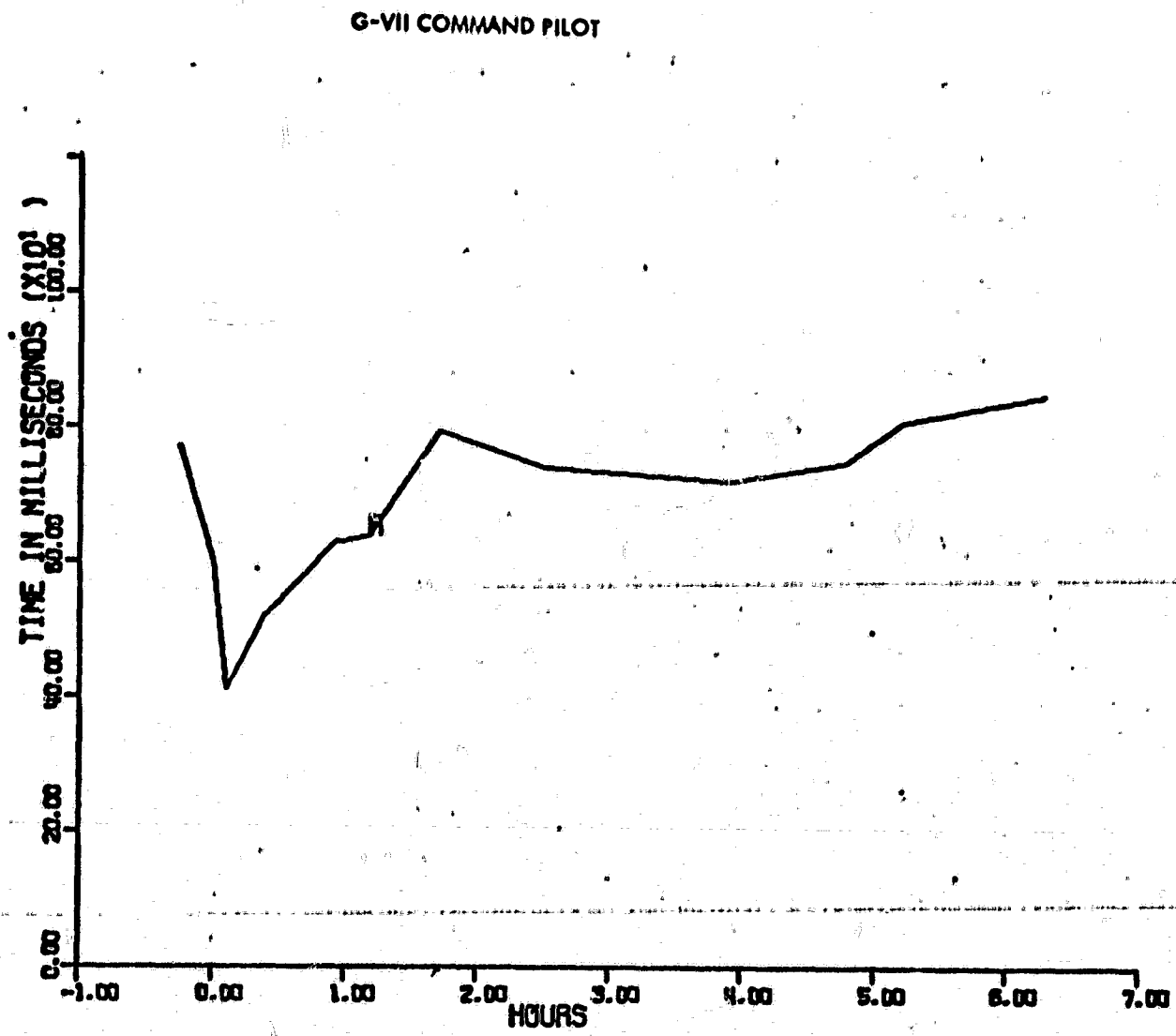


FIGURE 10

Effect of lift-off on the duration of the cardiac cycle of the command pilot of Gemini VII. The coordinates are the same as in Figures 6 through 9.

G-VII PILOT

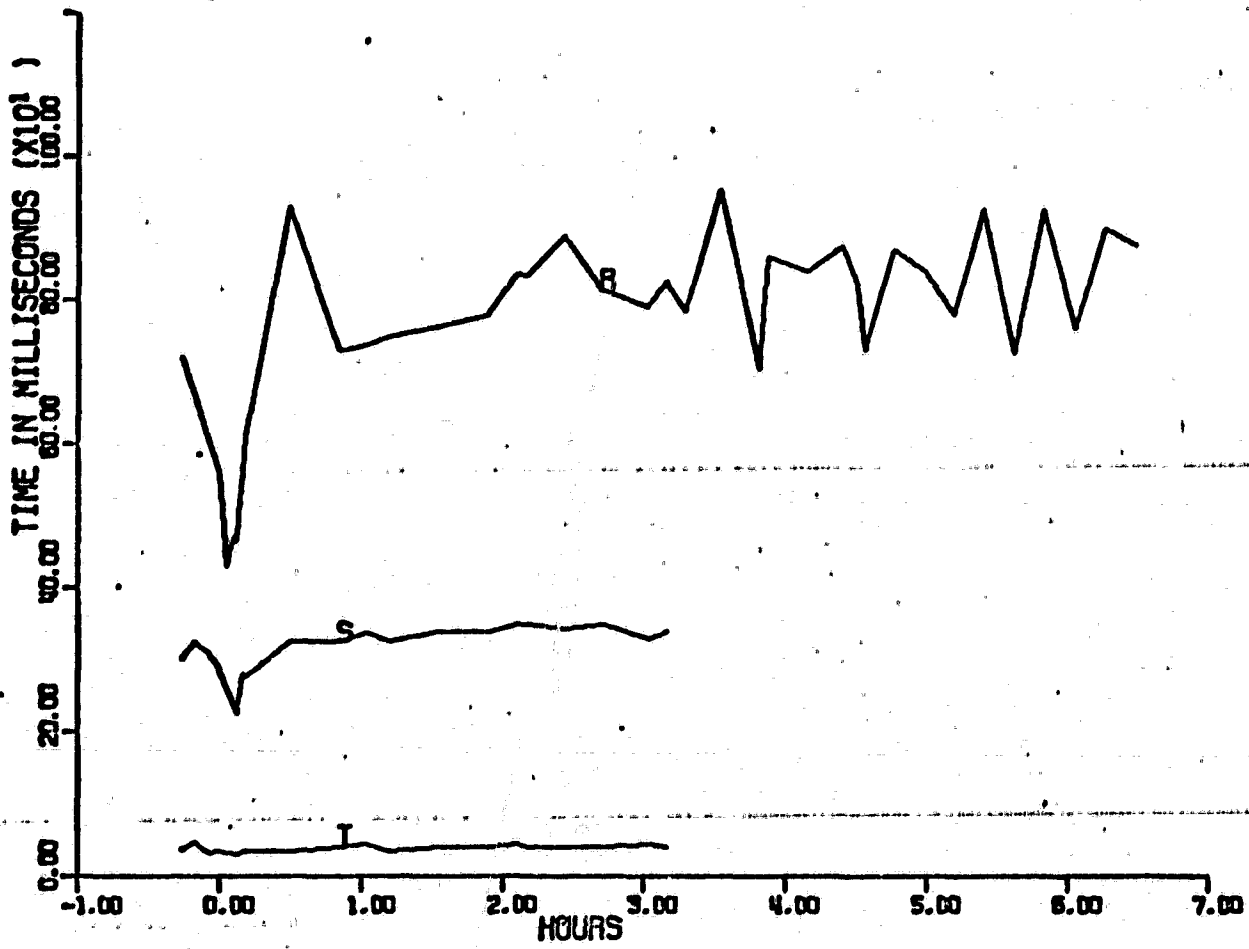


FIGURE 11

Effect of lift-off on the duration of the cardiac cycle and of its phases on the pilot of Gemini VII. The coordinates are the same as in Figures 6 through 10.

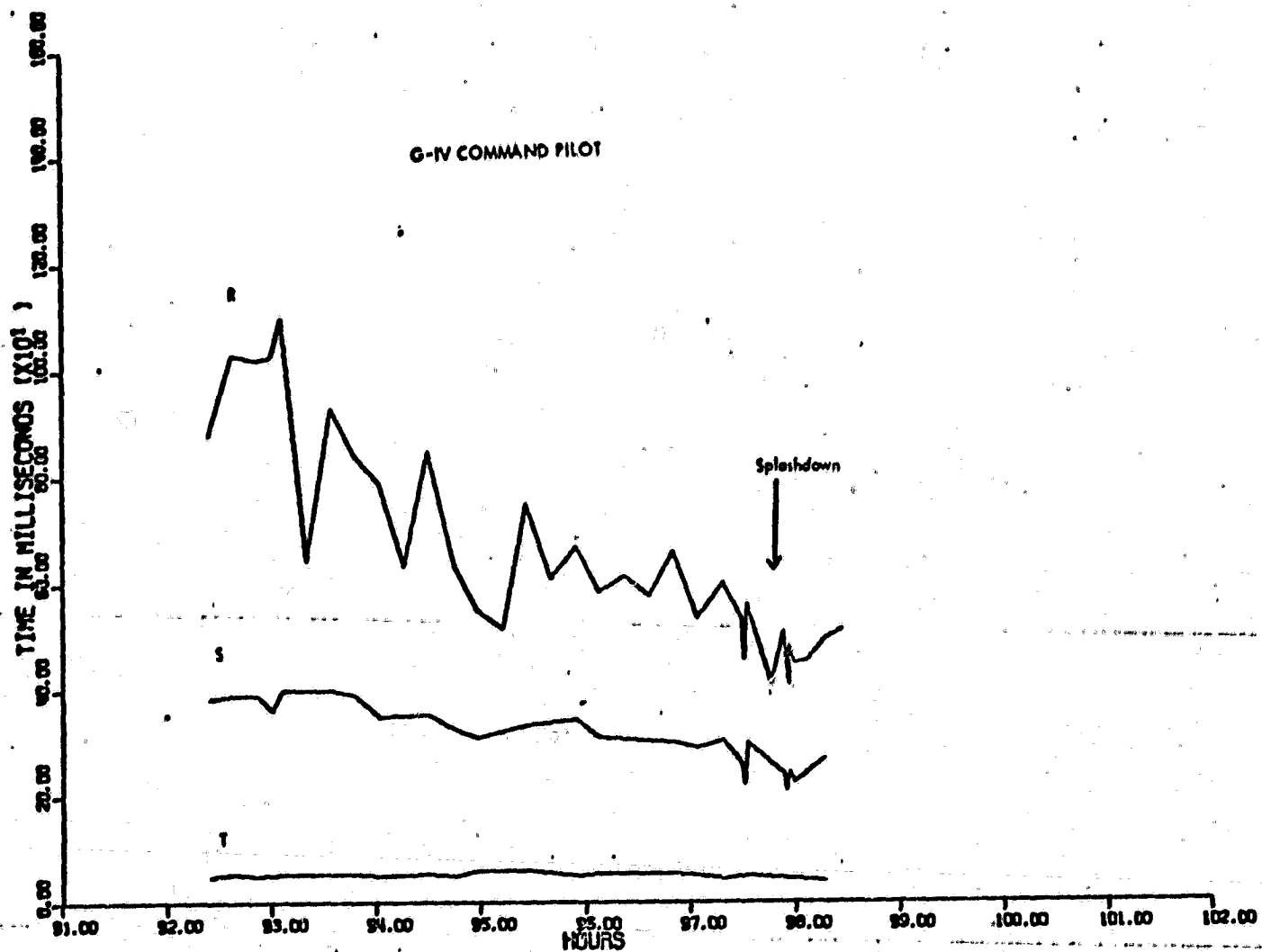


FIGURE 12

Effect of re-entry of the duration of the cardiac cycle and of its phases on the command pilot of Gemini IV. The abscissa indicates the hours into the mission. The ordinate indicates time in milliseconds for easy reference of the duration of the cardiac cycle (R) of the time of systole (S) and of the electromechanical delay (T). Surface contact (splashdown) occurred at 97 hours, 56 minutes, 12 seconds after lift-off.

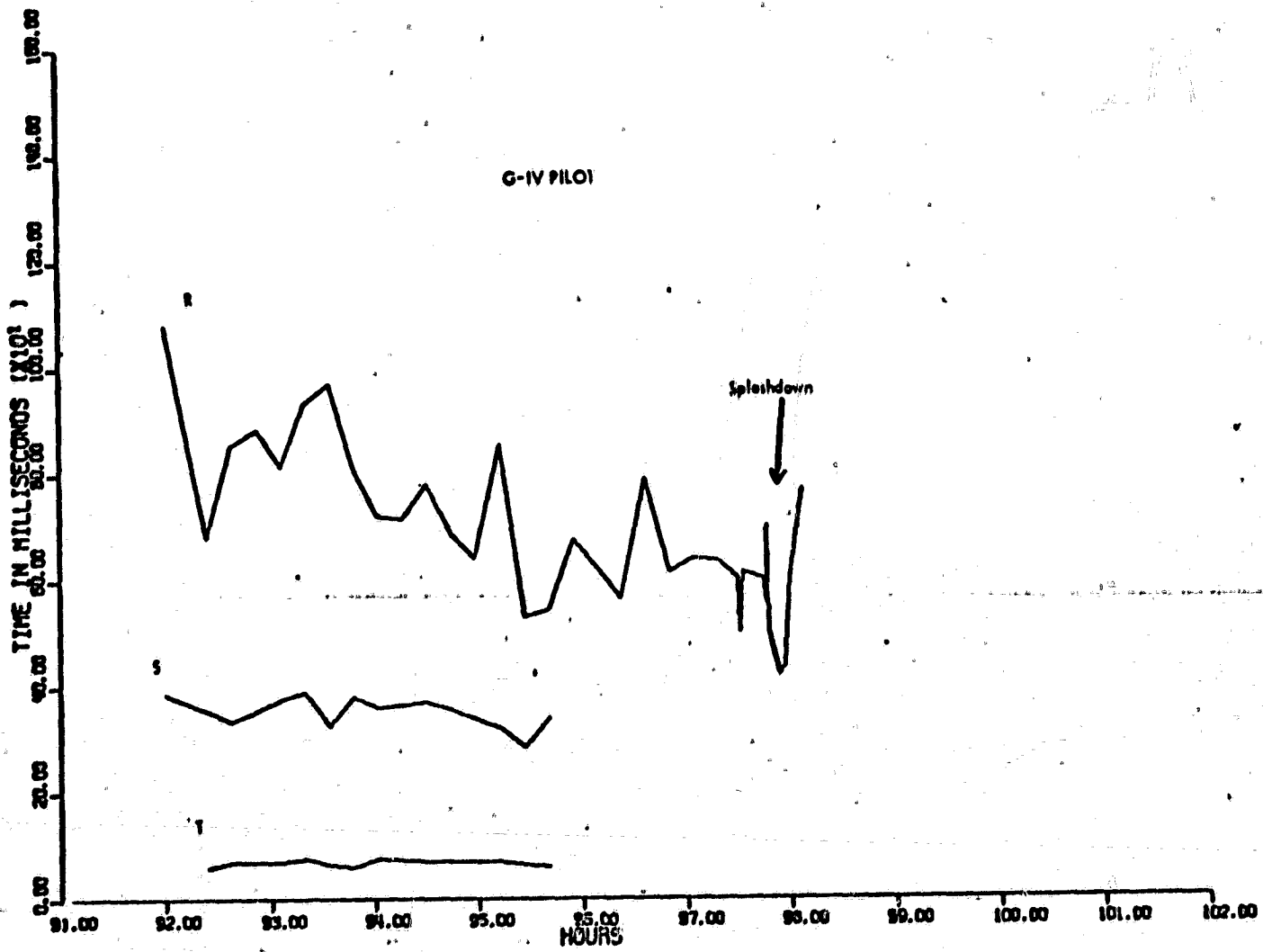


FIGURE 13

Effect of re-entry and the duration of the cardiac cycle and of its phases on the pilot of Gemini IV. The coordinates are the same as in Figure 12. Surface contact (splashdown) occurred at 97 hours, 56 minutes, and 12 seconds after lif(-)off.

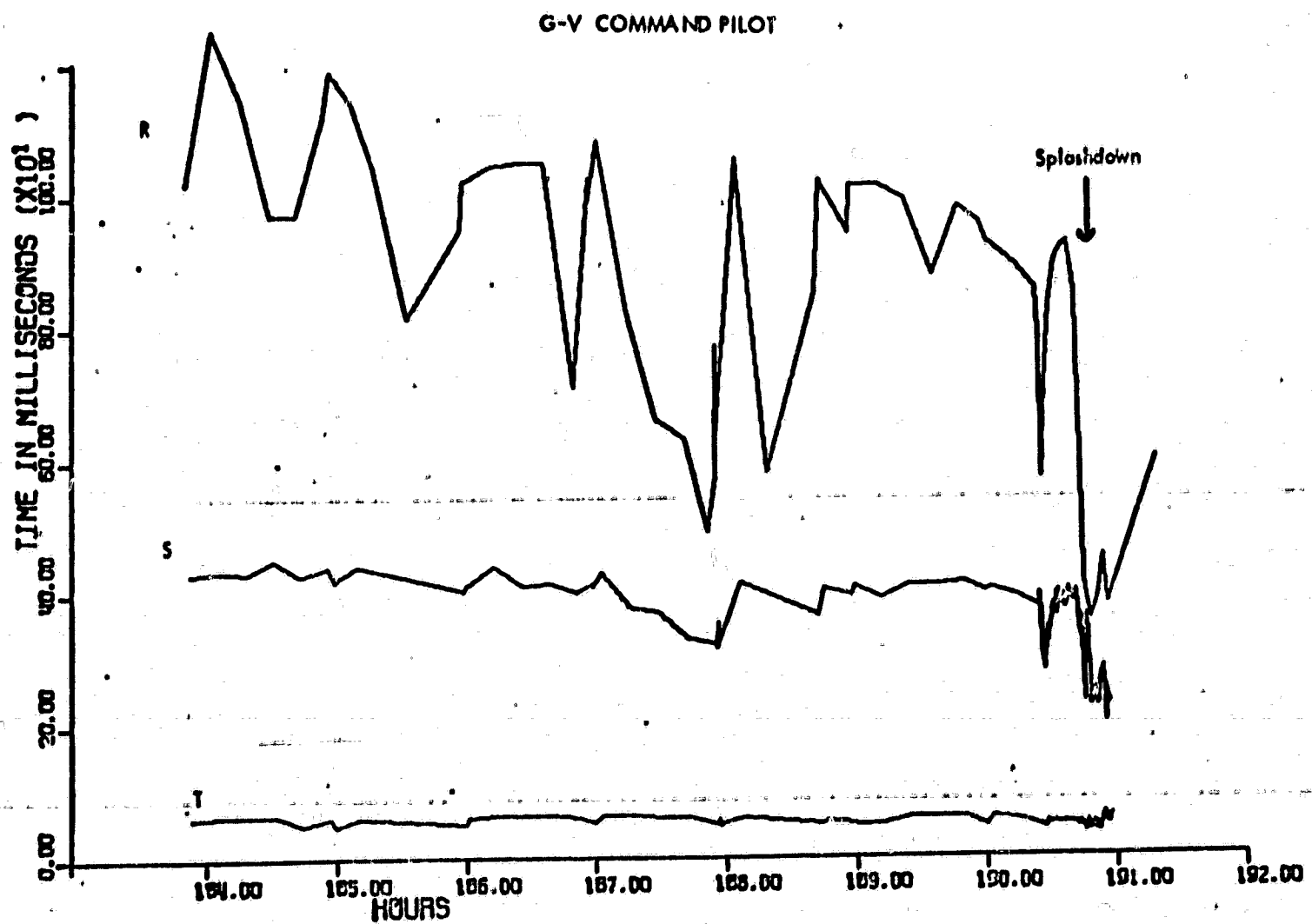


FIGURE 14

Effect of re-entry and the duration of the cardiac cycle and of its phases on the command pilot of Gemini V. The abscissa shows the hours into the mission. The ordinate is as in Figures 12 and 13. Splashdown occurred at 190 hours, 55 minutes, and 14 seconds after lift-off. Technical difficulties precluded accurate measurements of the electromechanical delay for most of this period except the critical time of re-entry.

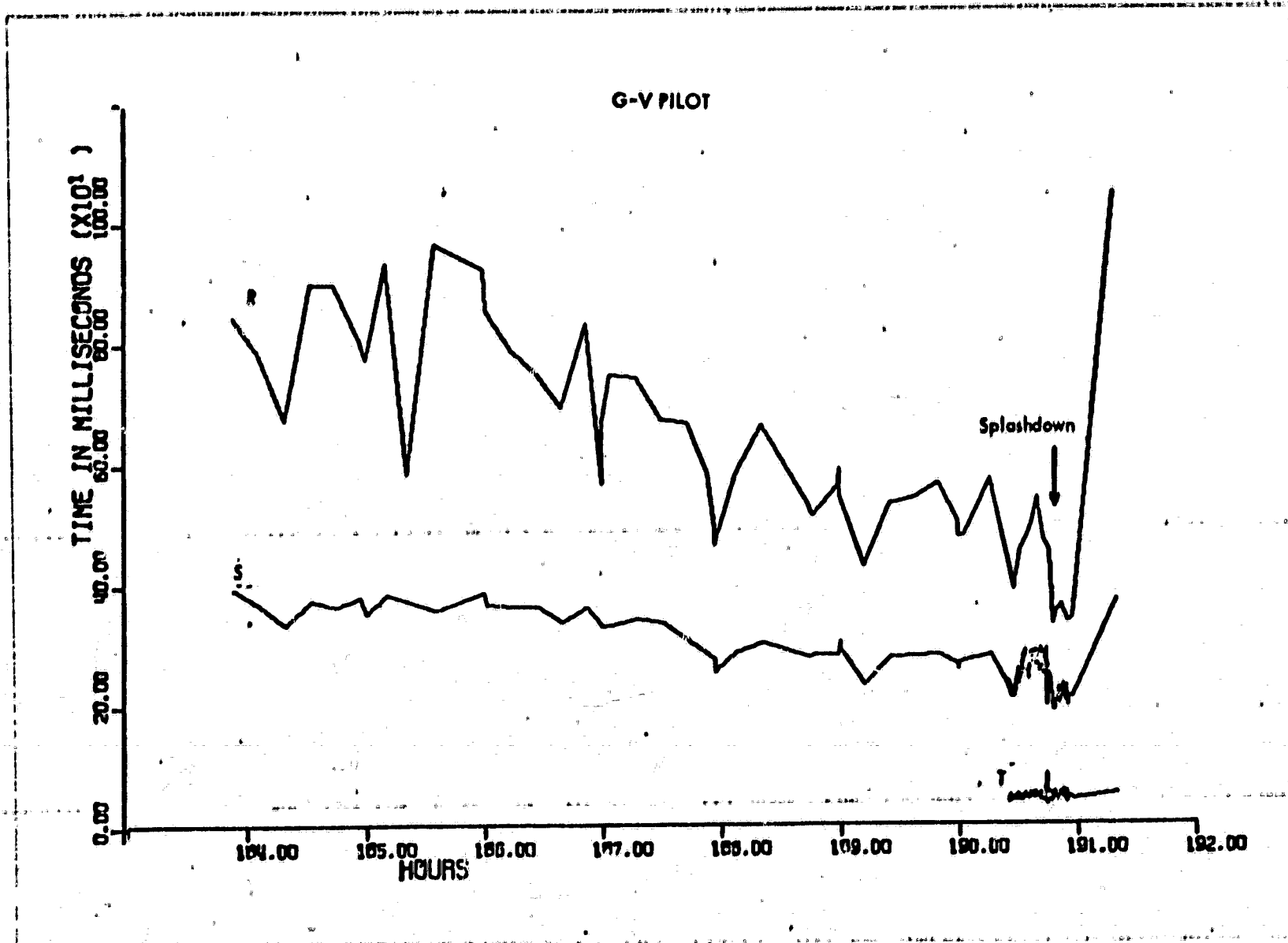


FIGURE 15

Effect of re-entry and the duration of the cardiac cycle and of its phases on the pilot of Gemini V. Coordinates are the same as in Figure 14. Splashdown occurred at 190 hours, 55 minutes and 14 seconds after lift-off.

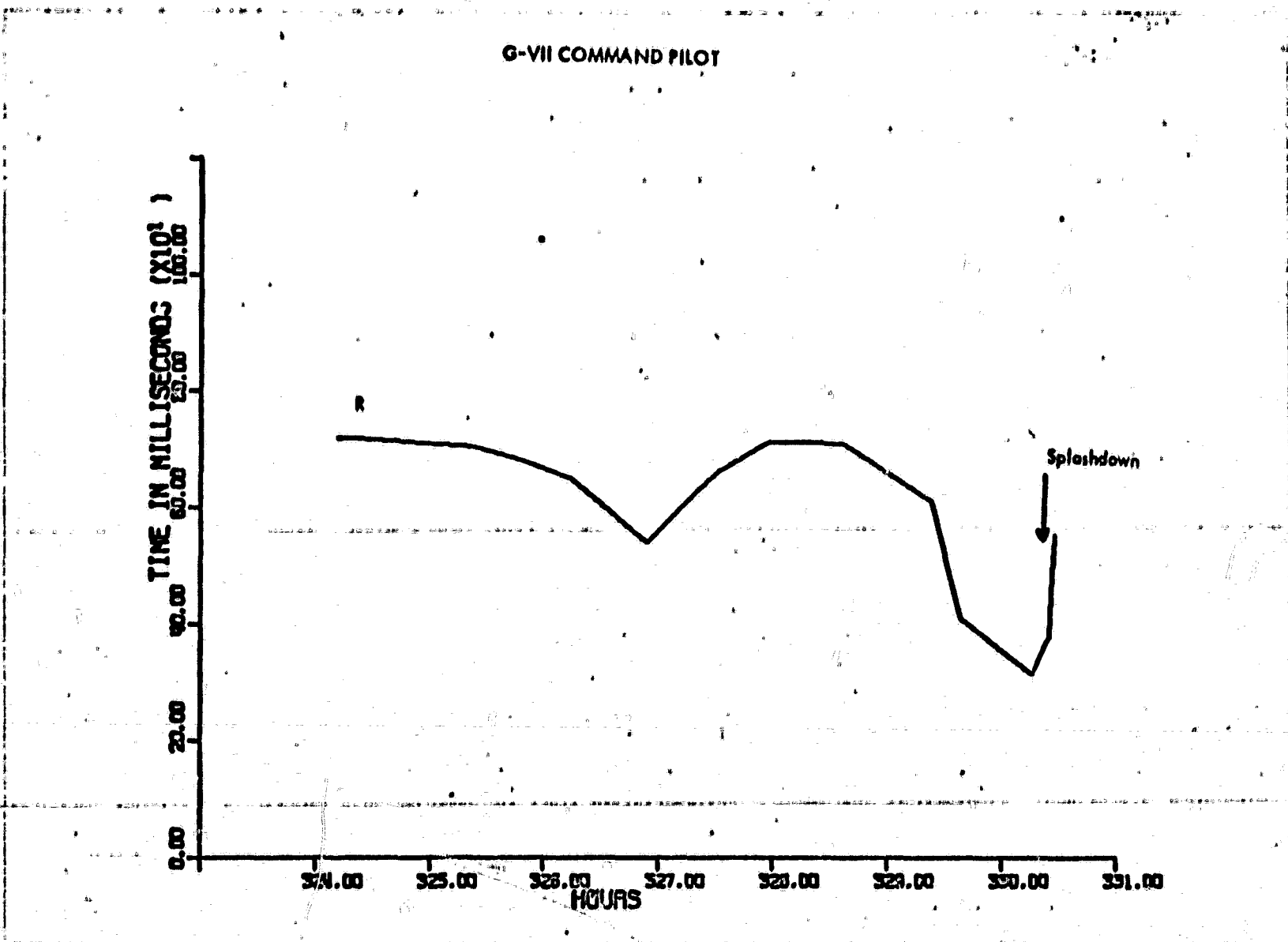


FIGURE 16

Effect of re-entry and the duration of the cardiac cycle of the command pilot of Gemini VII. The abscissa shows the hours into the mission. The ordinate is as in Figures 12 through 15. Surface contact (splashdown) occurred at 330 hours, 35 minutes, and 1 second after lift-off. The phonocardiogram was not recorded in the command pilot.

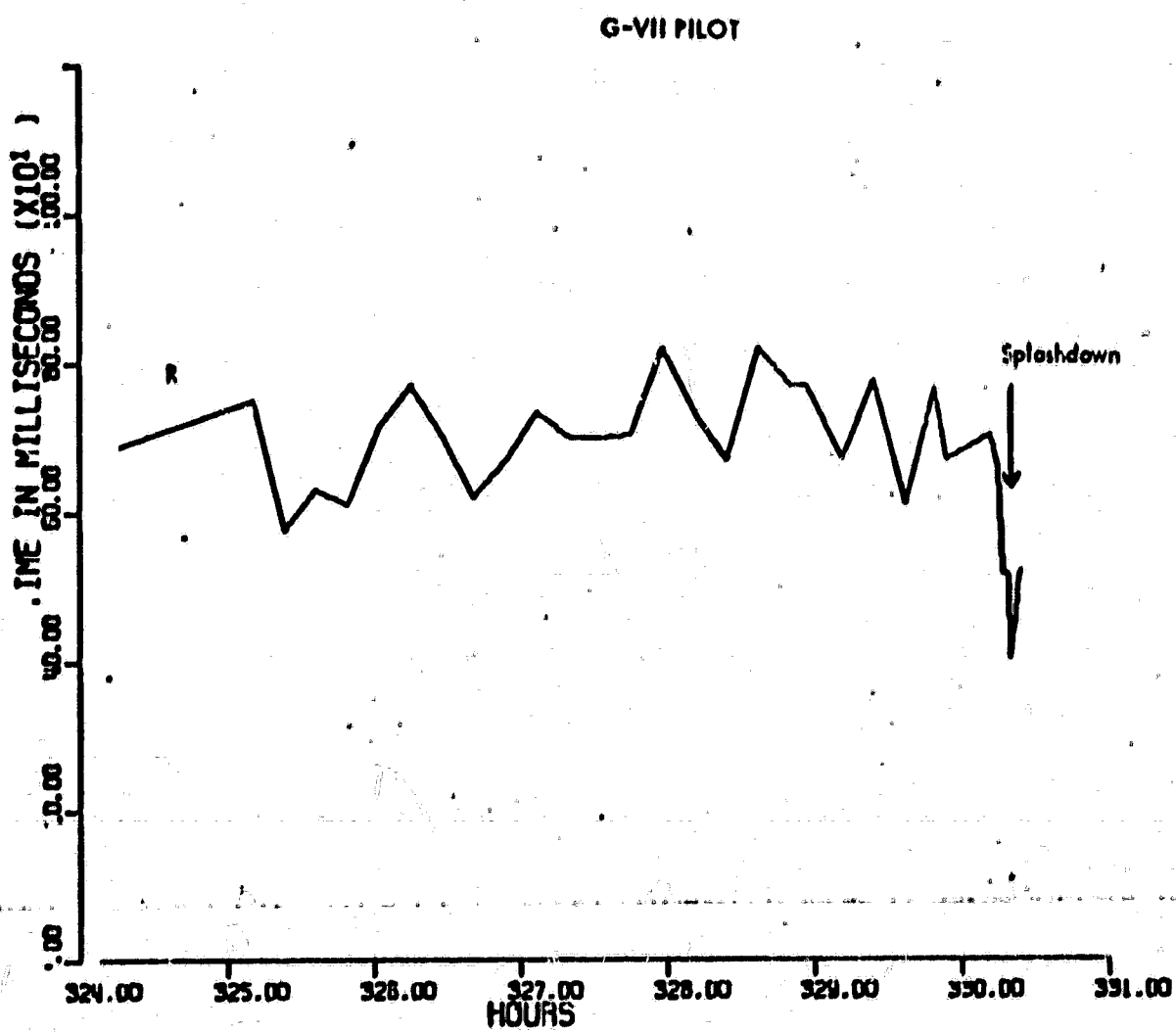


FIGURE 17

Effect of re-entry and the duration of the cardiac cycle of the pilot of Gemini VII. The abscissa shows the hours into the mission. The ordinate is as in Figures 12 through 16. Surface contact (splashdown) occurred at 330 hours, 35 minutes and 1 second from lift-off. The phonocardiogram was not recorded at this time.

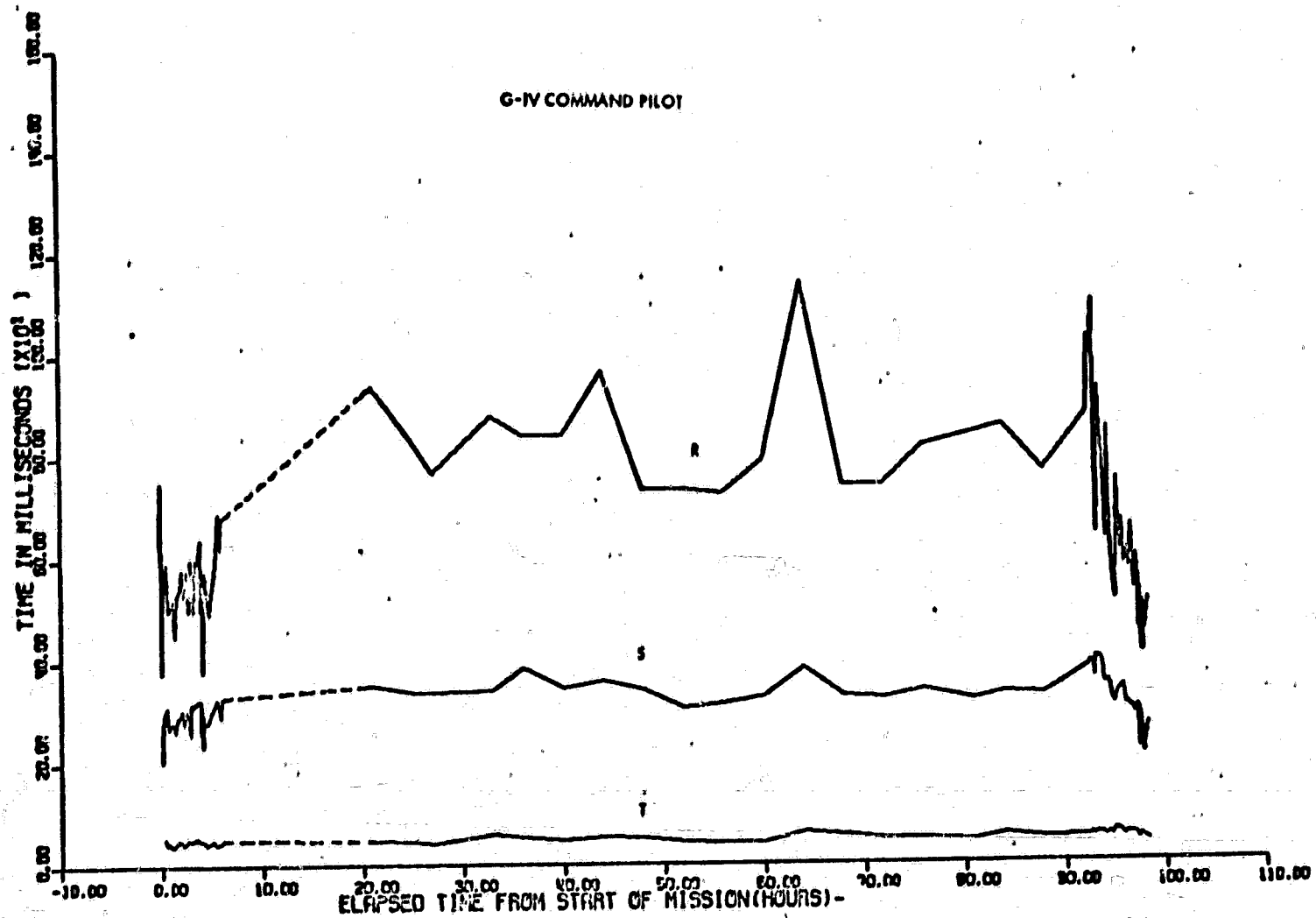


FIGURE 18

Serial changes of the duration of the cardiac cycle and of its phases throughout the mission of the command pilot of Gemini IV. The abscissa shows the elapsed time from the start of the mission in hours. Values pre-lift-off are shown preceding 0 time. The ordinate indicates time in milliseconds for easy reference of the duration of the cardiac cycle (R) of the electromechanical systole (S) and of the electromechanical delay (T).

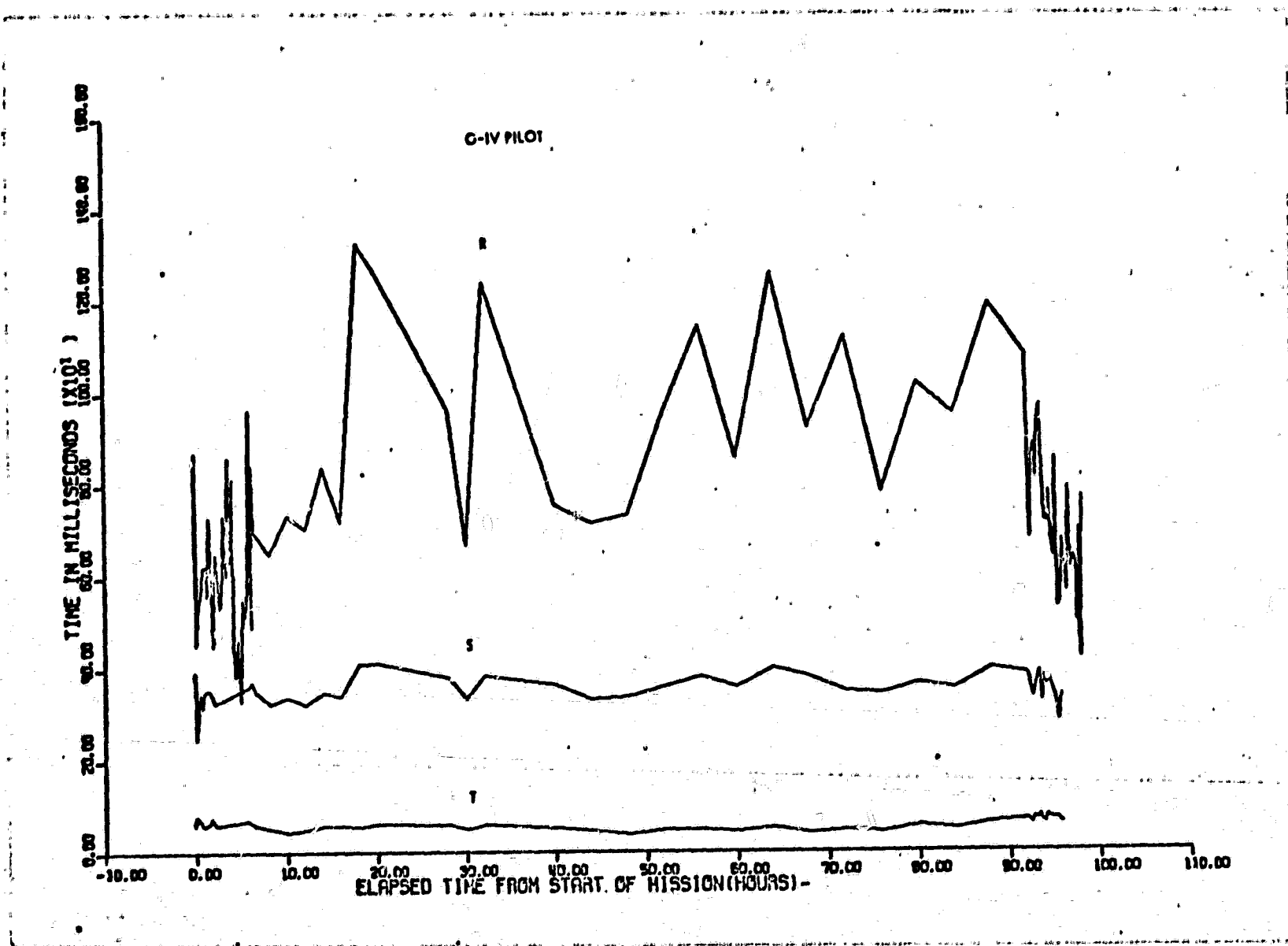


FIGURE 19

Serial changes of the duration of the cardiac cycle and of its phases throughout the mission of the pilot of Gemini IV. Coordinates are the same as in Figure 18.

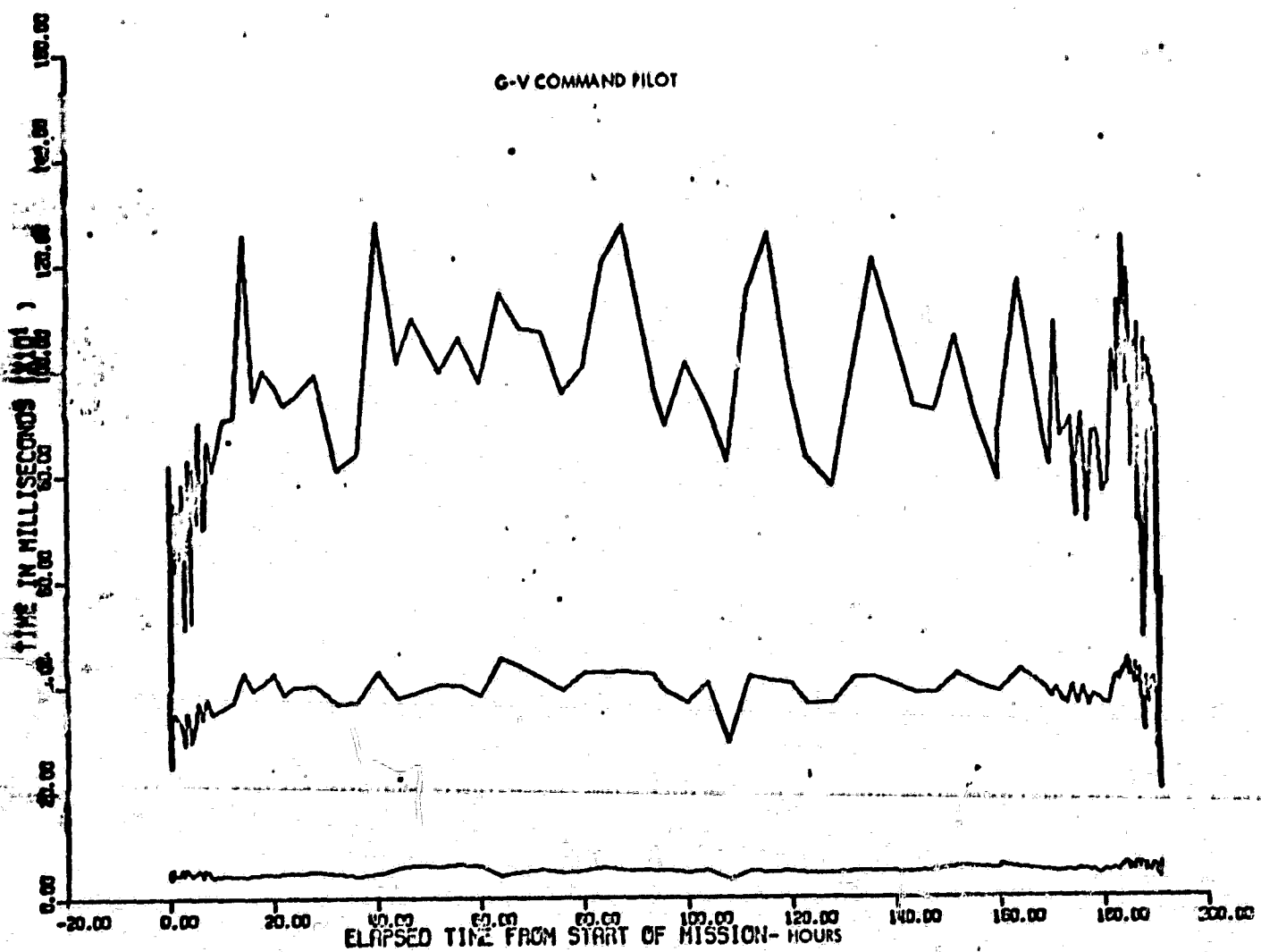


FIGURE 20

Serial changes of the duration of the cardiac cycle and of its phases throughout the mission of the command pilot of Gemini V. Coordinates are the same as in Figures 18 and 19, but notice the different scale of the abscissa.

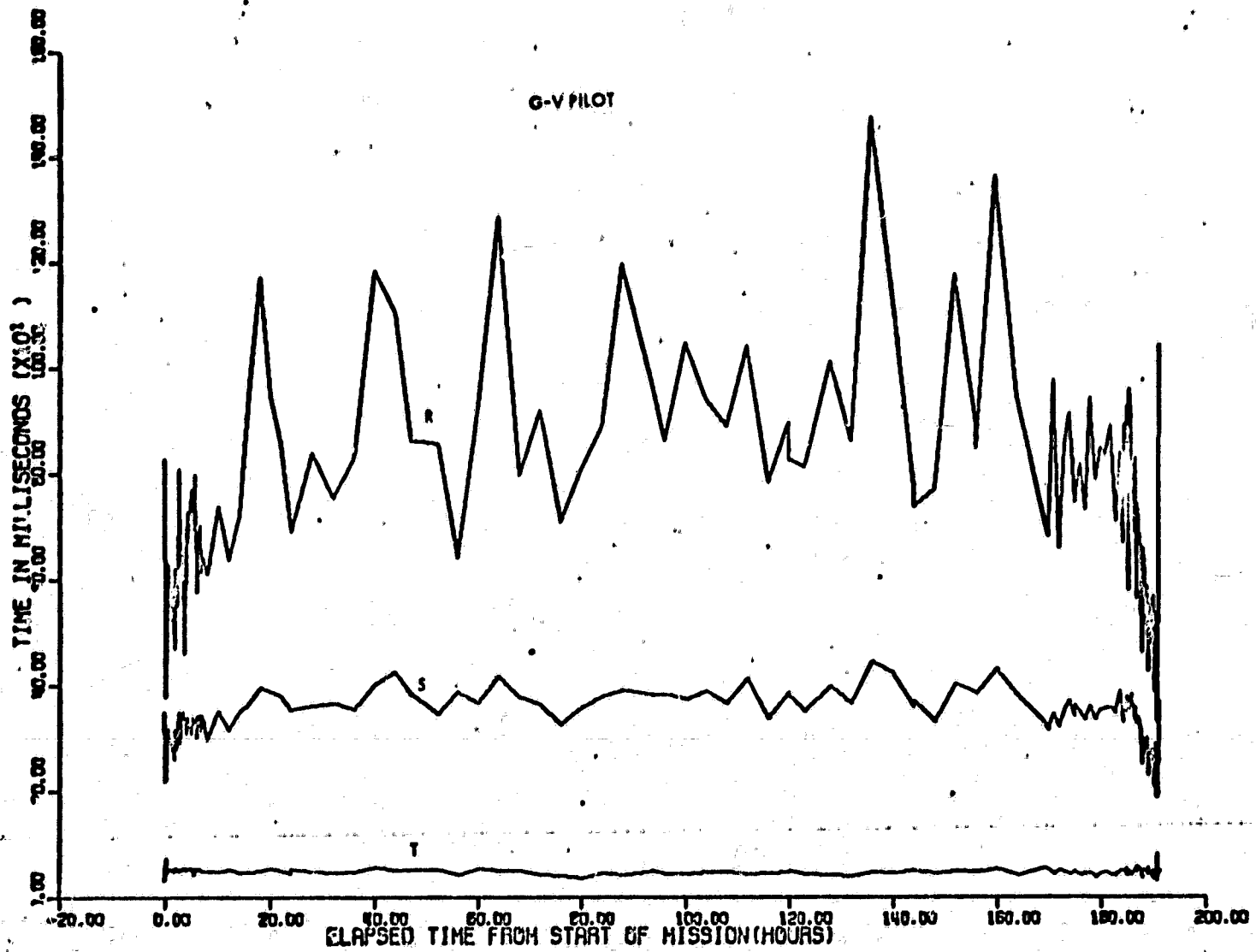


FIGURE 21

Serial changes of the duration of the cardiac cycle and of its phases throughout the mission of the pilot of Gemini V. Coordinates are the same as in Figure 18 through 20, but notice the different scale of the abscissa.

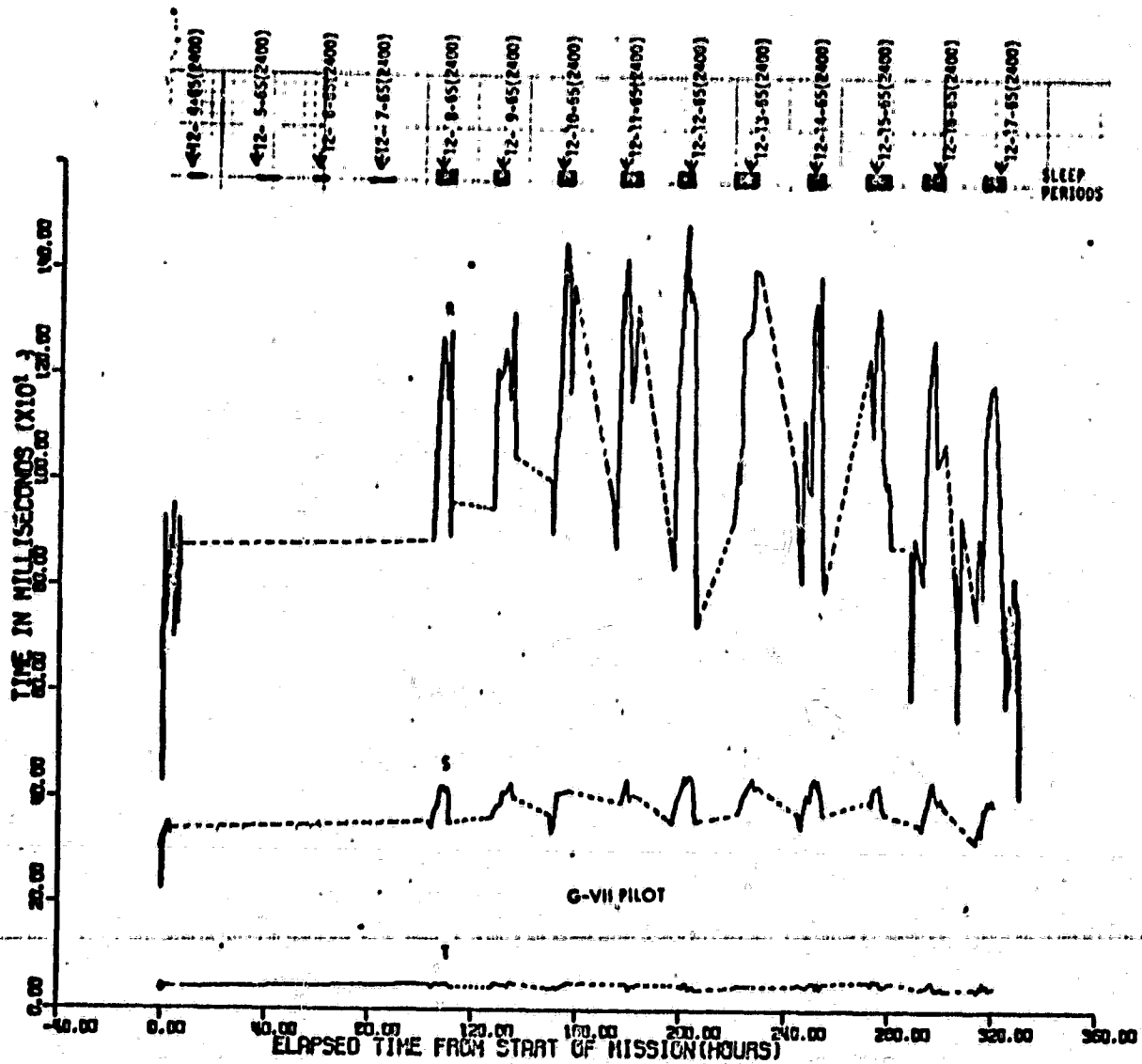


FIGURE 22

Serial changes of the duration of the cardiac cycle and of its phases throughout the mission of the pilot of Gemini VII. Coordinates are the same as in Figures 18 through 21, but notice the different scale of the abscissa. The biomedical recorder was discontinued from four hours of the mission until the 5th day. The broken lines show the intervals where no measurements were made. Sleep periods are indicated on top of the graph.

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FOR A BETTER COPY CONTACT DOCUMENT ORIGINATOR.

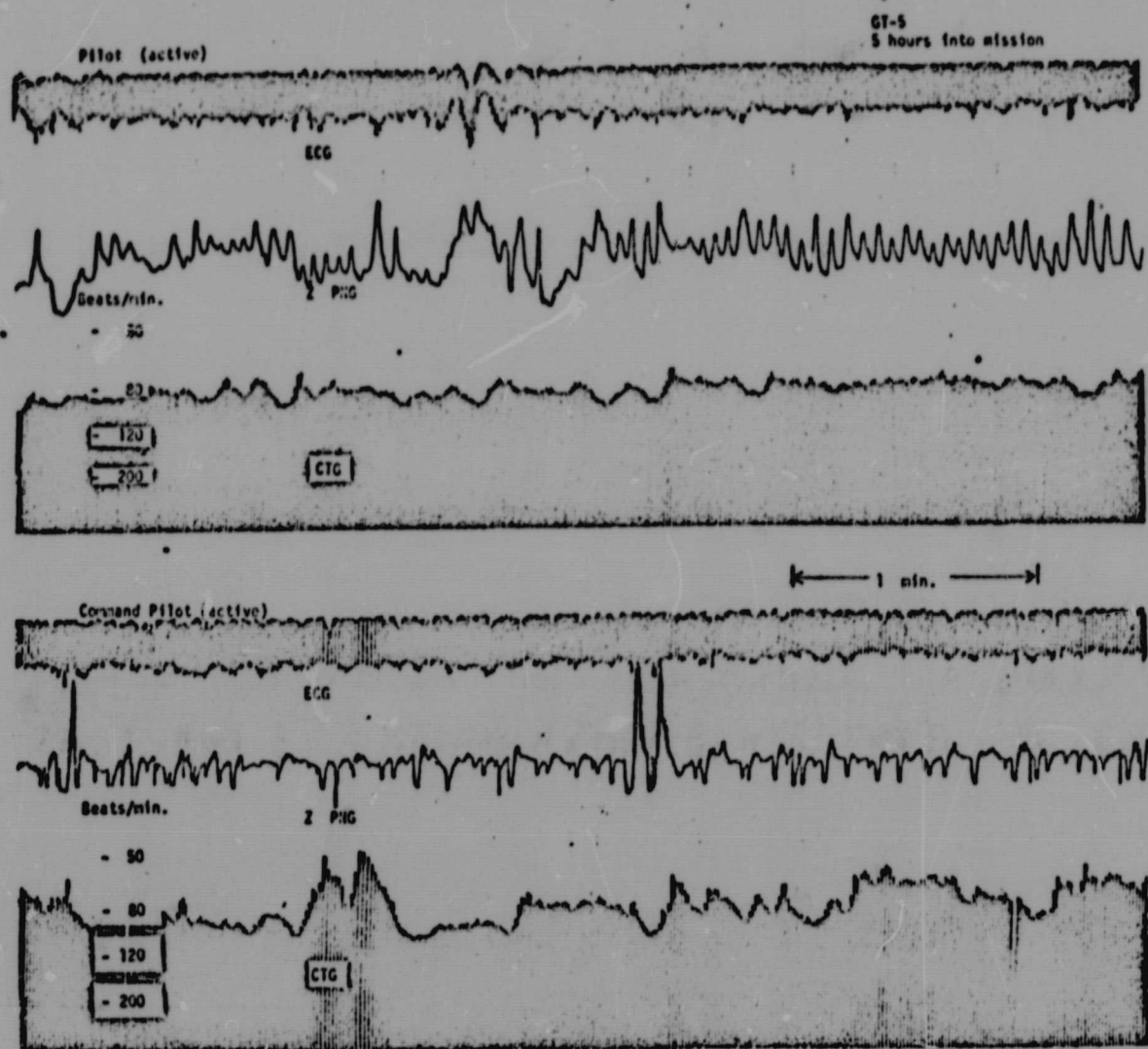


FIGURE 23

Fluctuations in instantaneous heart rate during a period of activity of the astronauts of Gemini V. This record was obtained playing back the biomedical tape recording on a six-channel direct writing instrument (Physiograph-six*). All channels are identified. The impedance pneumogram of the pilot records inspiration as an upward deflection while that of the command pilot shows inspiration downward. Notice that the instantaneous heart rate of both astronauts fluctuated considerably at this time into the mission. An acceleration of the heart rate is reflected in a downward displacement of the cardiogram while a deceleration is shown by an upward displacement of the graph.

* E & M Instruments, Houston, Texas

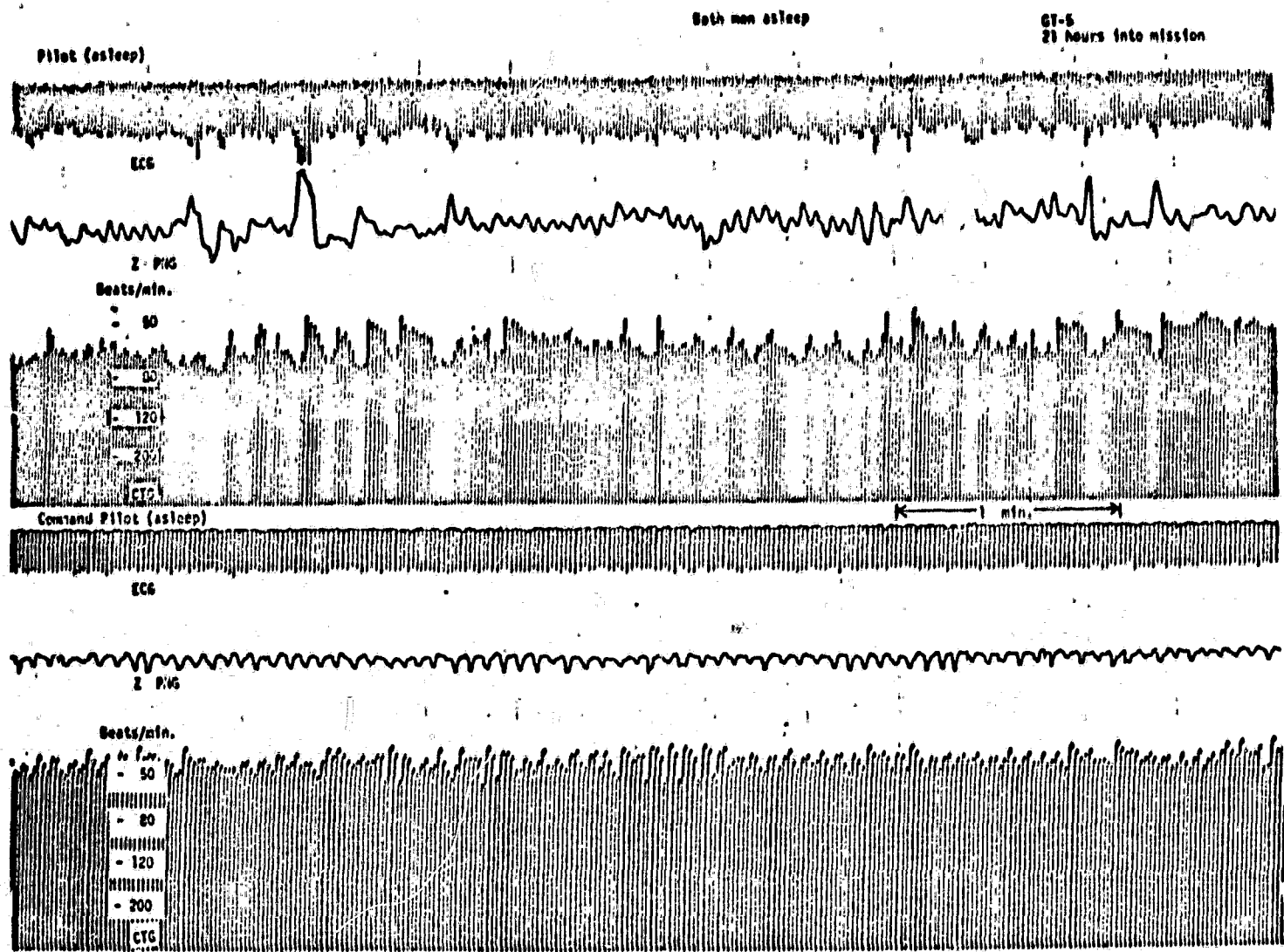


FIGURE 24

Fluctuations of the instantaneous heart rate during the periods of sleep of the astronauts of Gemini V. This graph was obtained similarly to that of Figure 23, and it is identically related. Notice the correlation between the respirations and the fluctuations of the instantaneous heart rate in both astronauts. The pattern of breathing is more regular on the command pilot than on the pilot. The heart rate of the command pilot is considerably lower (below 50/minute on the average).

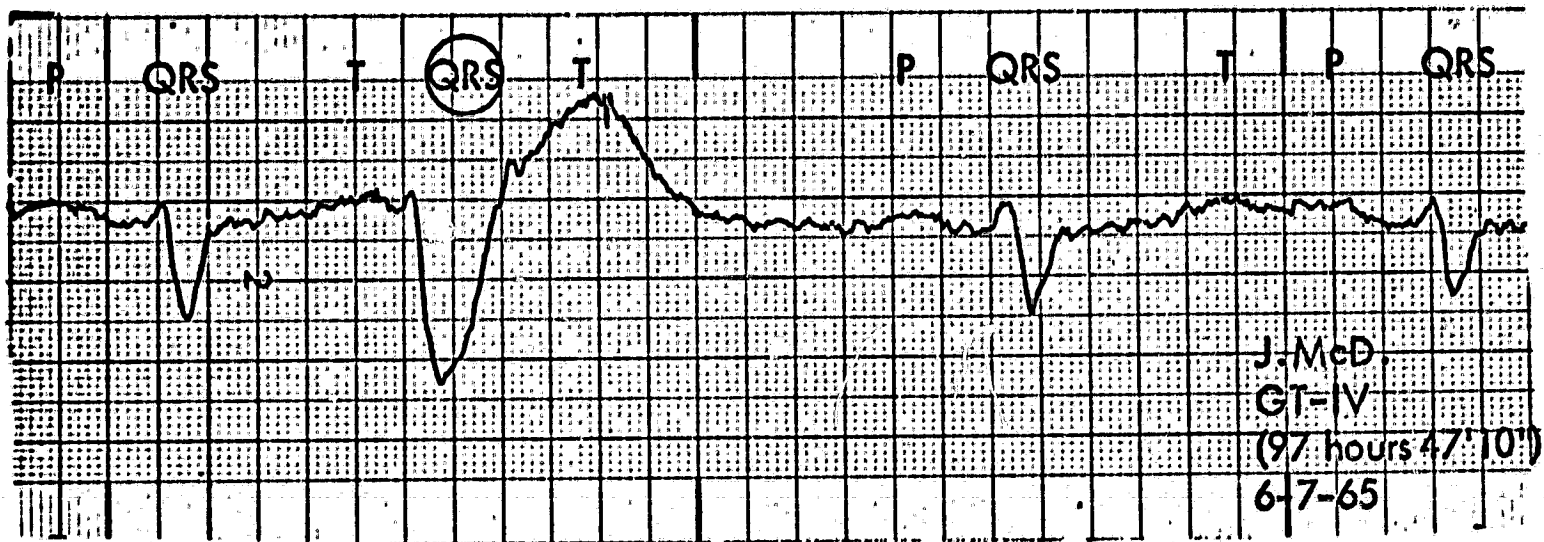


FIGURE 25

Extrasystole detected at re-entry of command pilot of Gemini IV. The premature ventricular contraction is clearly identified in the tracing and it is followed by a typical compensatory pause.

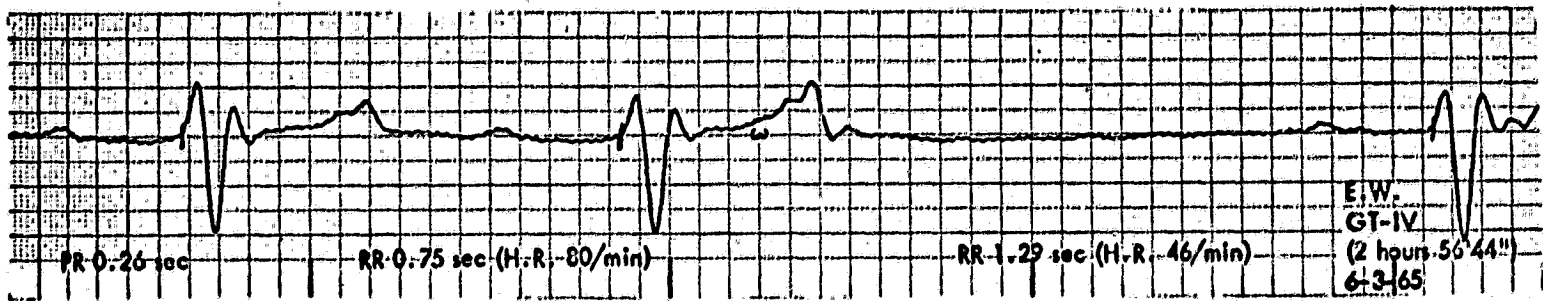


FIGURE 26

First degree AV block recorded on the pilot of Gemini IV. The PR interval is measured at 260 milliseconds regardless of the duration of the cardiac cycle as clearly seen in this tracing.

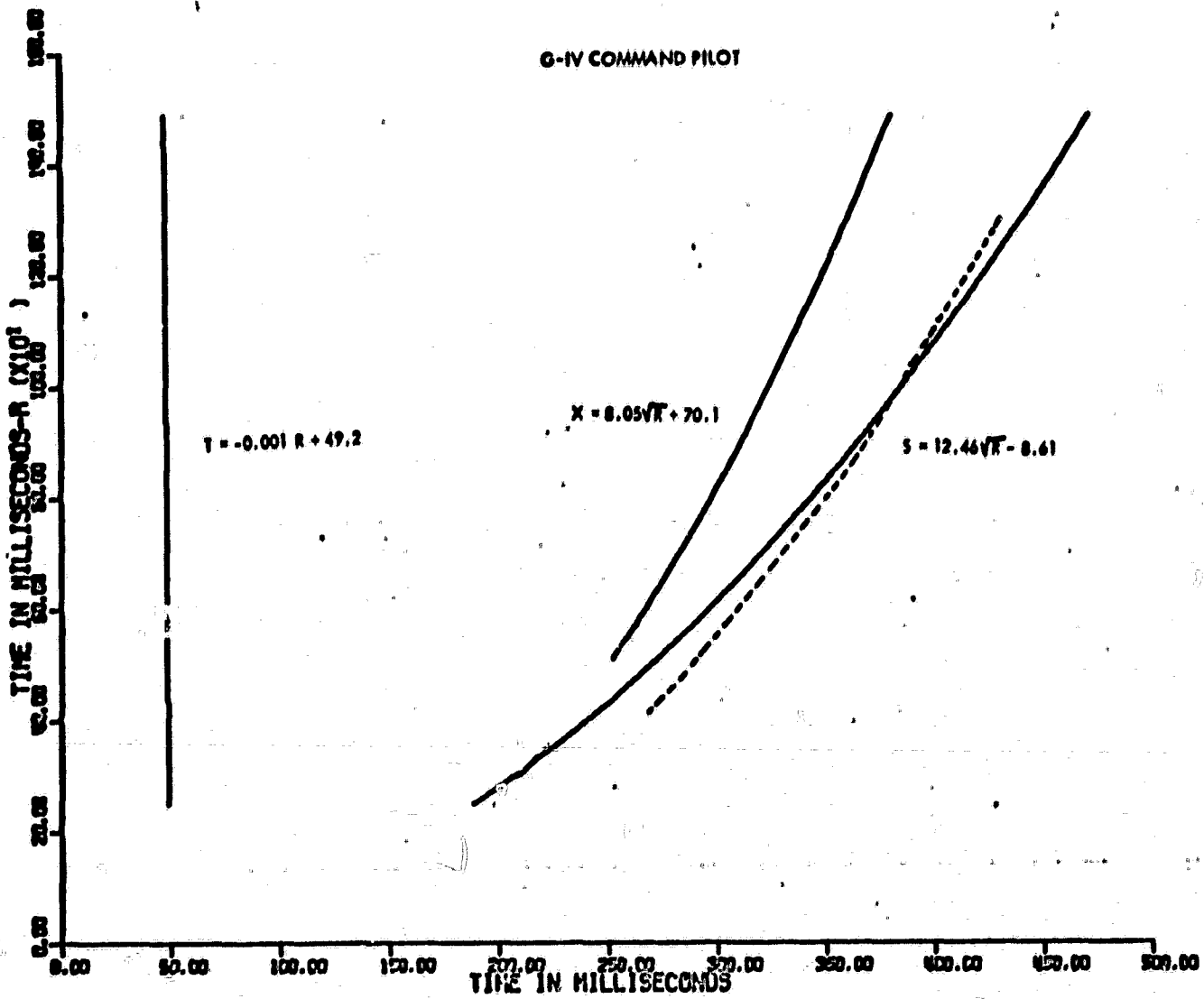


FIGURE 28

Relationship between the duration of the cardiac cycle and that of its phases on the command pilot of Gemini IV. The abscissa shows time in milliseconds and can be used for reference of the duration of the electromechanical delay (T), of the electromechanical systole (S), and of the time interval between the first and second heart sounds (X). The ordinate indicates the duration of the cardiac cycle (R) in milliseconds. The equations that describe the regression lines are shown in the figure. The dotted line is the regression line of S as a function of R in healthy subjects according to Shah and Slodki.

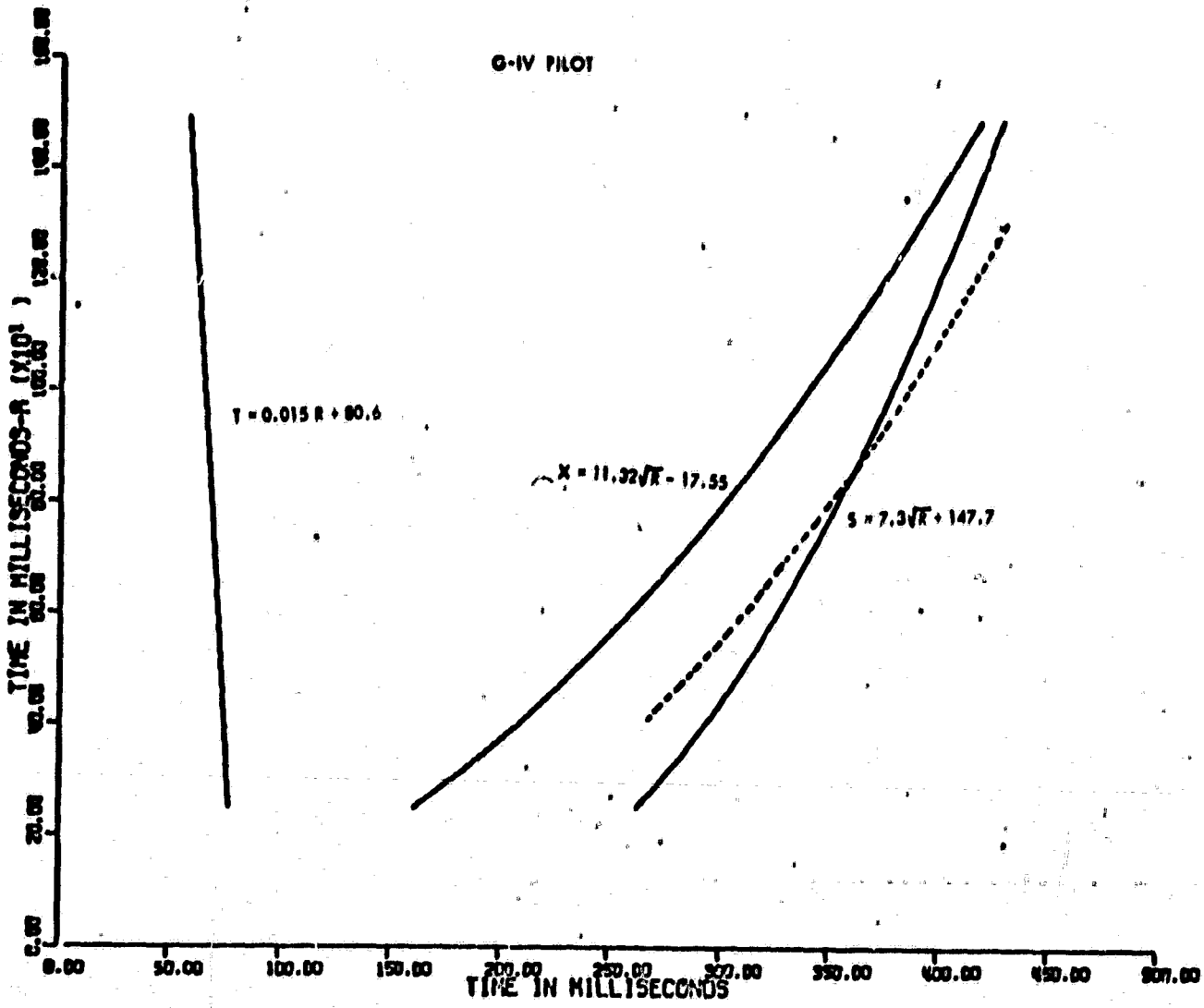


FIGURE 29

Relationship between the duration of the cardiac cycle and that of its phases on the pilot of Gemini IV. Coordinates and regression lines are as in Figure 28.

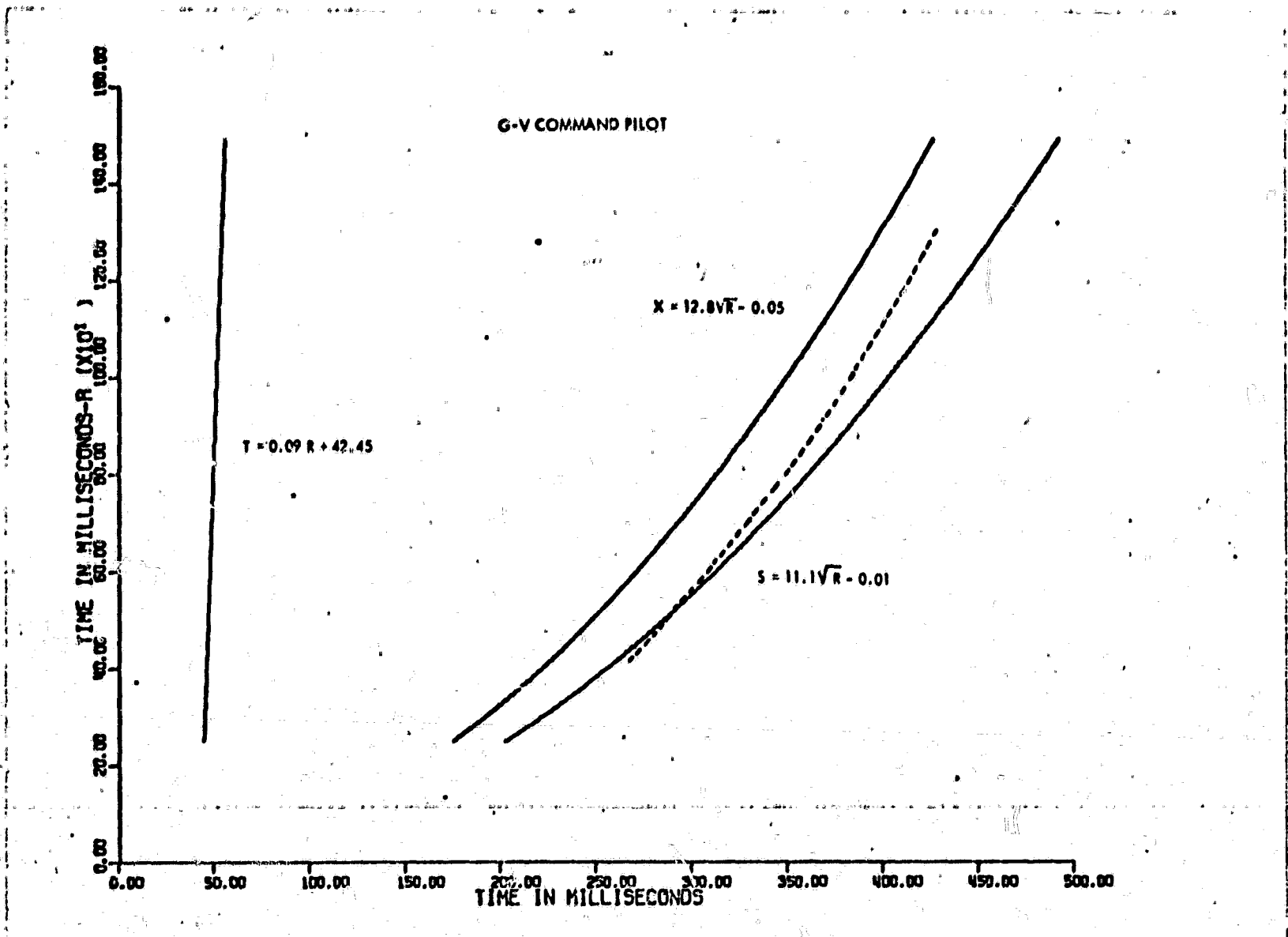


FIGURE 30

Relationship between the duration of the cardiac cycle and that of its phases on the command pilot of Gemini V. Coordinates are as in Figures 28 and 29.

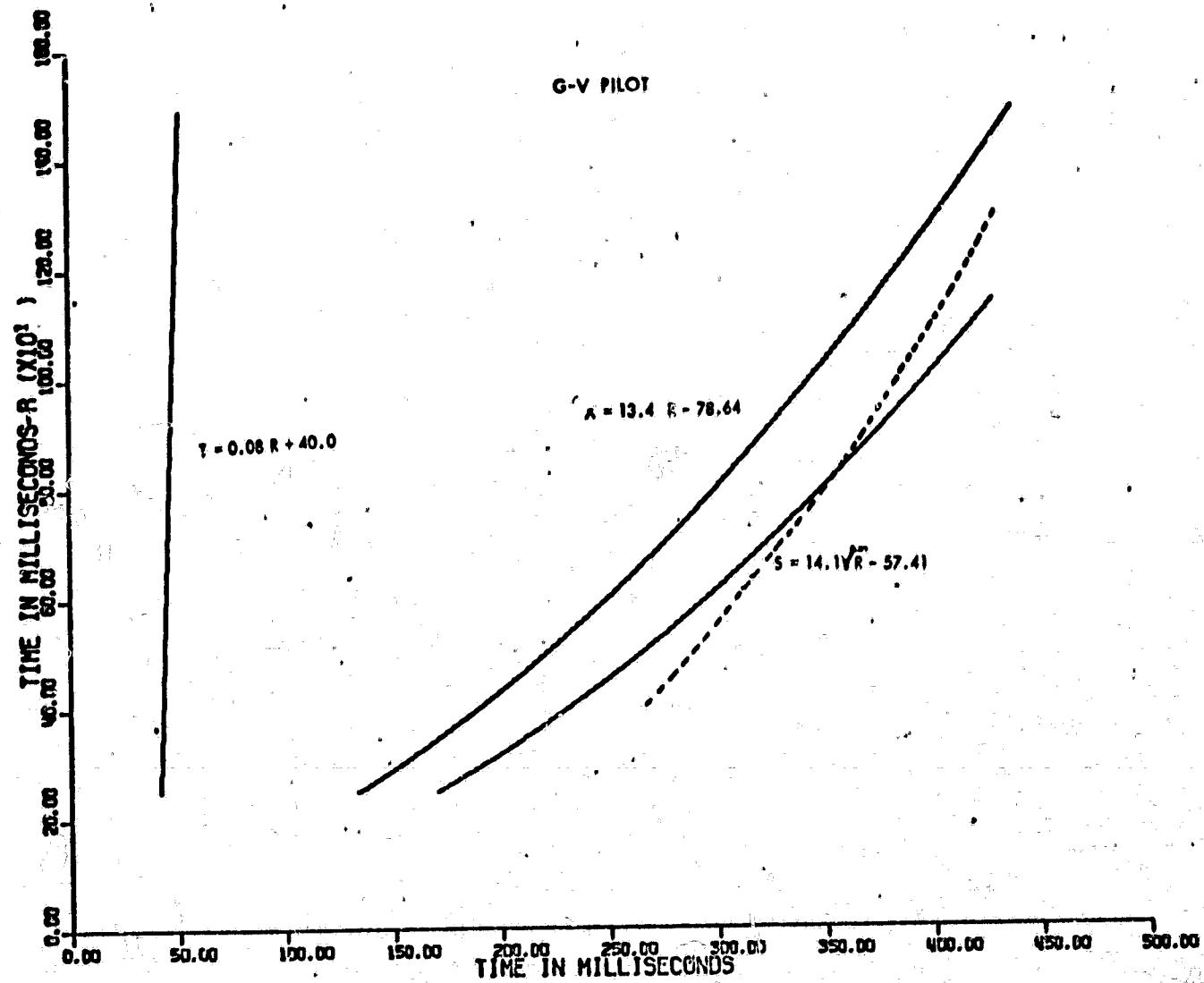


FIGURE 31

Relationship between the duration of the cardiac cycle and that of its phases on the pilot of Gemini V. Coordinates are as in Figures 28 through 30.

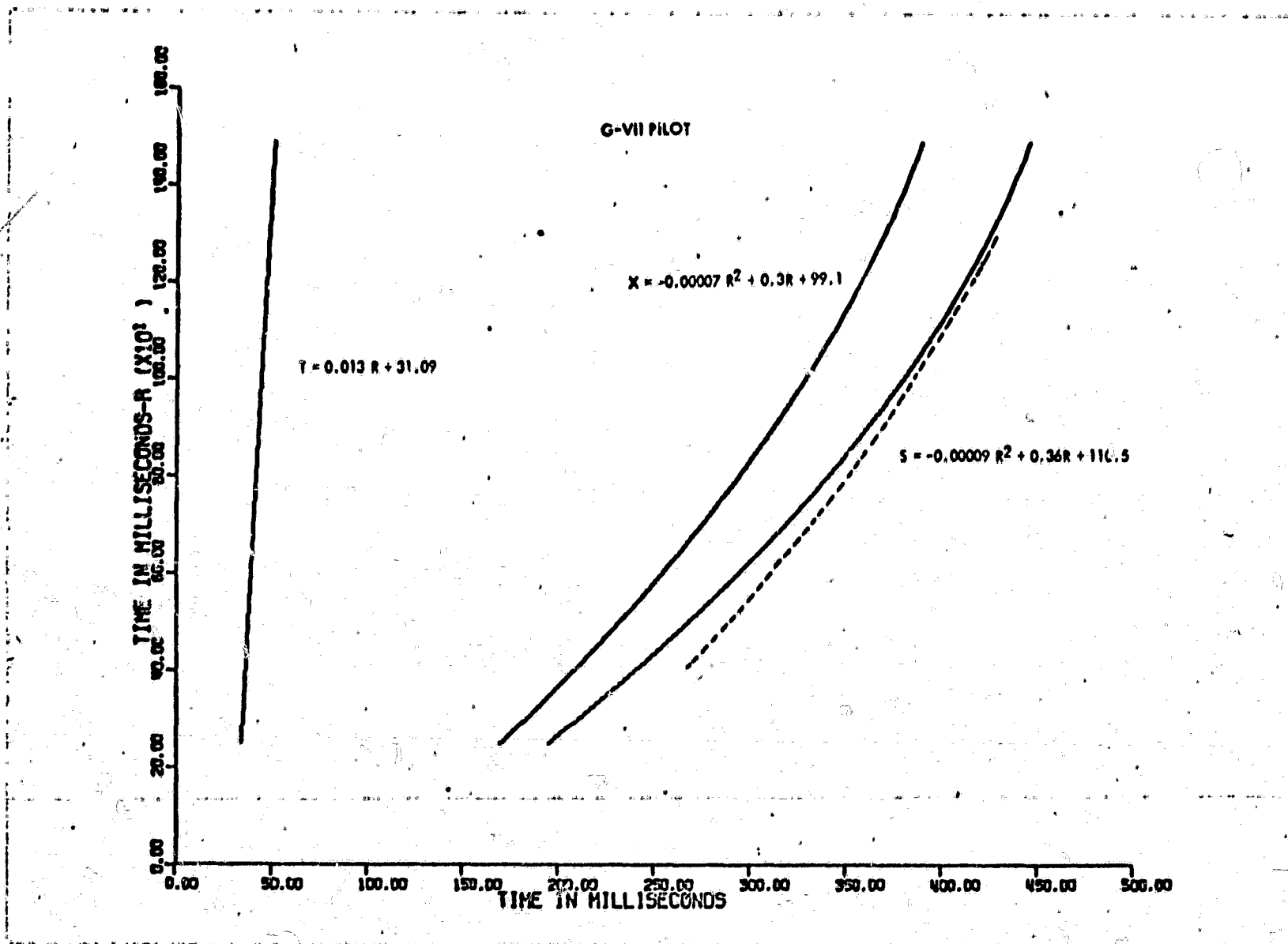


FIGURE 32

Relationship between the duration of the cardiac cycle and that of its phases on the pilot of Gemini VII. Coordinates are as in Figures 28 through 31.

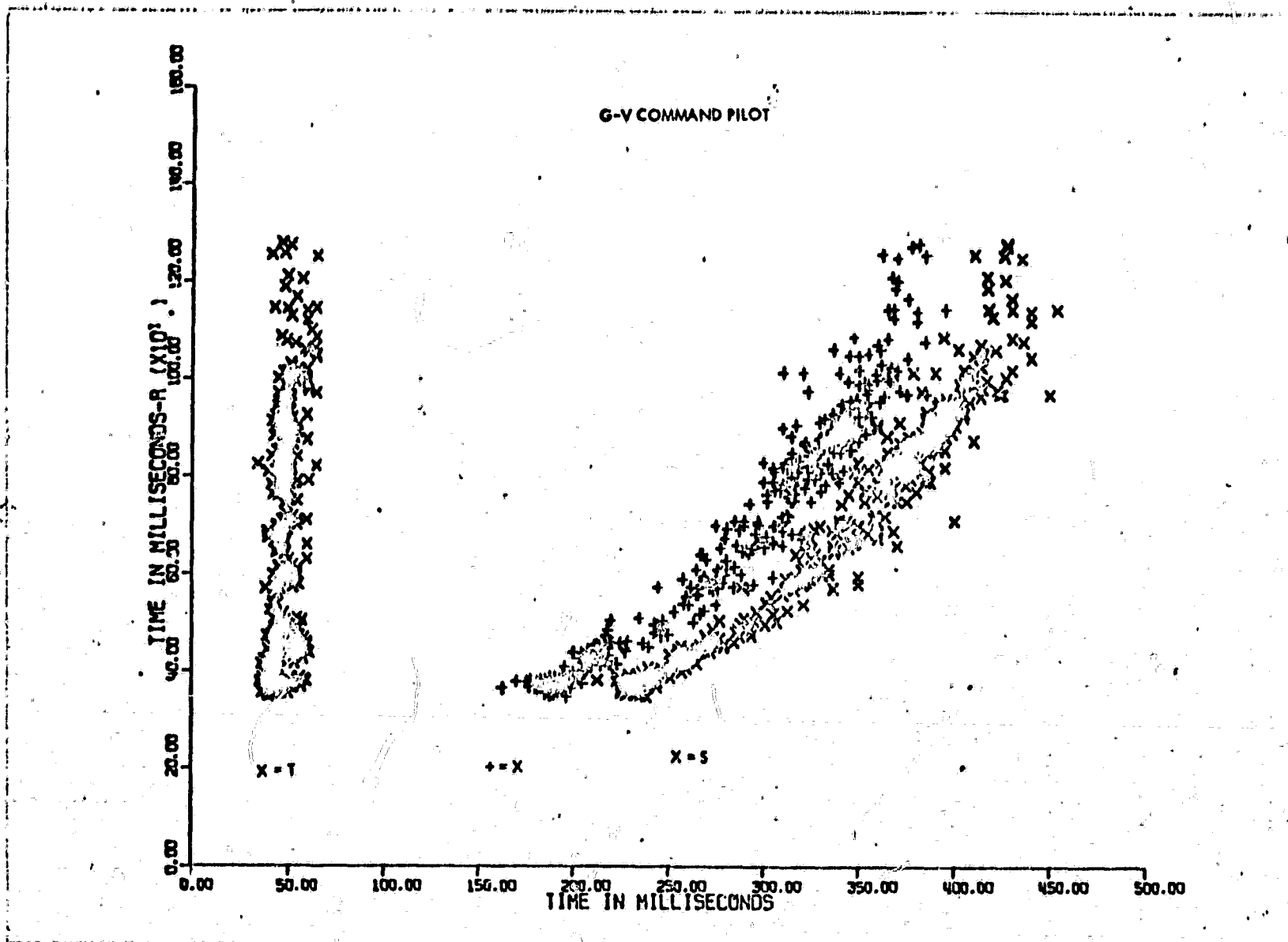


FIGURE 33

Scattergram of the average values of the phases of the cardiac cycle in relation to its duration in the command pilot of Gemini V. Coordinates are the same as in Figures 28 through 32. The regression lines of Figure 30 are the best curve fits for the values shown in this scattergram.