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MAN'S CAPABILITY FOR SELF-LOCOMOTION ON THE MOON-PHASE II-BUNGEE SIMULATOR EVALUATION

by A. Camacho, W. Price, K. Walther, and W. Robertson

Prepared by
AiResearch Manufacturing Company
A Division of the GARRETT CORPORATION
Los Angeles, California

for Langley Research Center

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION WASHINGTON, D. C. MAY 1969

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ABSTRACT

A bungee-cord suspension system used for the simulation of lunar gravity was designed, fabricated and dynamically tested to provide data on the validity of the 1/6-g simulation. Two test subjects walked at 2 and 4 KPH, loped at 6 and 8 KPH and ran at 6 and 8 KPH on a hard surface at 1/6 g in the bungee-cord simulator. Metabolic costs were measured during a preexercise rest period, a 14-min exercise period, and a 6-min post exercise period. Dynamic testing of the simulator during jumping events with constant accelerative force input showed errors of 15.5 percent to 20.2 percent in total time aloft and -21.2 percent to -27.4 percent in maximum height achieved when compared to ideal time and height responses. Metabolic rates were similar to those reported in Phase I of this study. Differences between the bungee-cord simulator and the simulators used during Phase I could not be discriminated.

FOREWORD

This report was prepared by the Department of Life Sciences, AiResearch Manufacturing Company, a Division of The Garrett Corporation, Los Angeles, California. The technical assistance of E. C. Wortz, N. J. Belton, L. J. Miller and the outstanding effort and cooperation of the test subjects are gratefully acknowledged.

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SECTION I

INTRODUCTION

This report presents the results, methods, procedures and apparatus of a study to evaluate a bungee-cord lunar gravity simulator suspension system and to evaluate the metabolic cost of human locomotion at simulated 1/6 g with this simulator. The bungee-cord suspension system was developed and tested under Phase II of Contract NAS 1-7053 for NASA/Langley Research Center.

The objects of the study were to design, build and test a bungee-cord suspension system to simulate lunar gravity, to perform manned tests with this simulator, and to compare the results of these tests to results obtained from tests with other lunar gravity simulators.

The experimental conditions for the tests performed are shown in Table 3-2. The experimental program was designed to test the effects of the independent variables of velocity and gait with this type of simulator on such dependent variables as metabolic rate, total energy expenditure, and step rate.

SECTION 2

FACILITIES AND APPARATUS

GENERAL

The tests were conducted at the AiResearch/Garrett lunar simulation test facility. The treadmill system, suspension tower, physiological and metabolic apparatus, digital data system, environmental control system and computerized data reduction system are described in detail in AiResearch Report No. 68-3986, "Man's Capability for Self-Locomotion on the Moon, Volume I - Detailed Report," Contract NAS 1-7053, by E. C. Wortz, et al.

The bungee cord used for this suspension system was of sufficient length and force per unit deflection such that a deflection of one foot in the length of the cord during locomotion did not require a force exceeding 10 percent of the total lunar weight of the pressure suited subject, gimbal and backpack, i.e., 4 lb/ft for 40 lb lunar weight.

BUNGEE-CORD SUSPENSION SYSTEM

The bungee-cord suspension system is shown in Figures 2-1 and 2-2. A bungee cord was used to provide the constant vertical force. It was used in conjunction with a system already in existence at the Lunar Soil Simulation Facility. Figure 2-3 shows the previous turbine-operated suspension system modified into a bungee-cord suspension system. The basic system, consisting of a "C" brace gimbal, swivel, yoke with air pad bearing, cable and pulleys, a lightweight beam w/air pads, and the bungee-cord spring, provides the six degrees of freedom desired for reduced gravity simulation. The pulley arrangement allows the supported "C" frame to remain at a constant height during fore and aft movements of the yoke and air pad assembly. The sources of the degrees of freedom with reference to the subject's center of gravity are listed in Table 2-1.

TABLE 2-1

BUNGEE SIMULATOR DEGREES OF FREEDOM

Component	Degrees-of-Freedom
"C" Brace gimbal - pitch and roll	2
Swivel - yaw	1
Bungee cord take-up - vertical	1
Yoke (with air pads) - fore and aft	1
Beam (pivot and air pads) - lateral	1
Total degrees-of-freedom	6

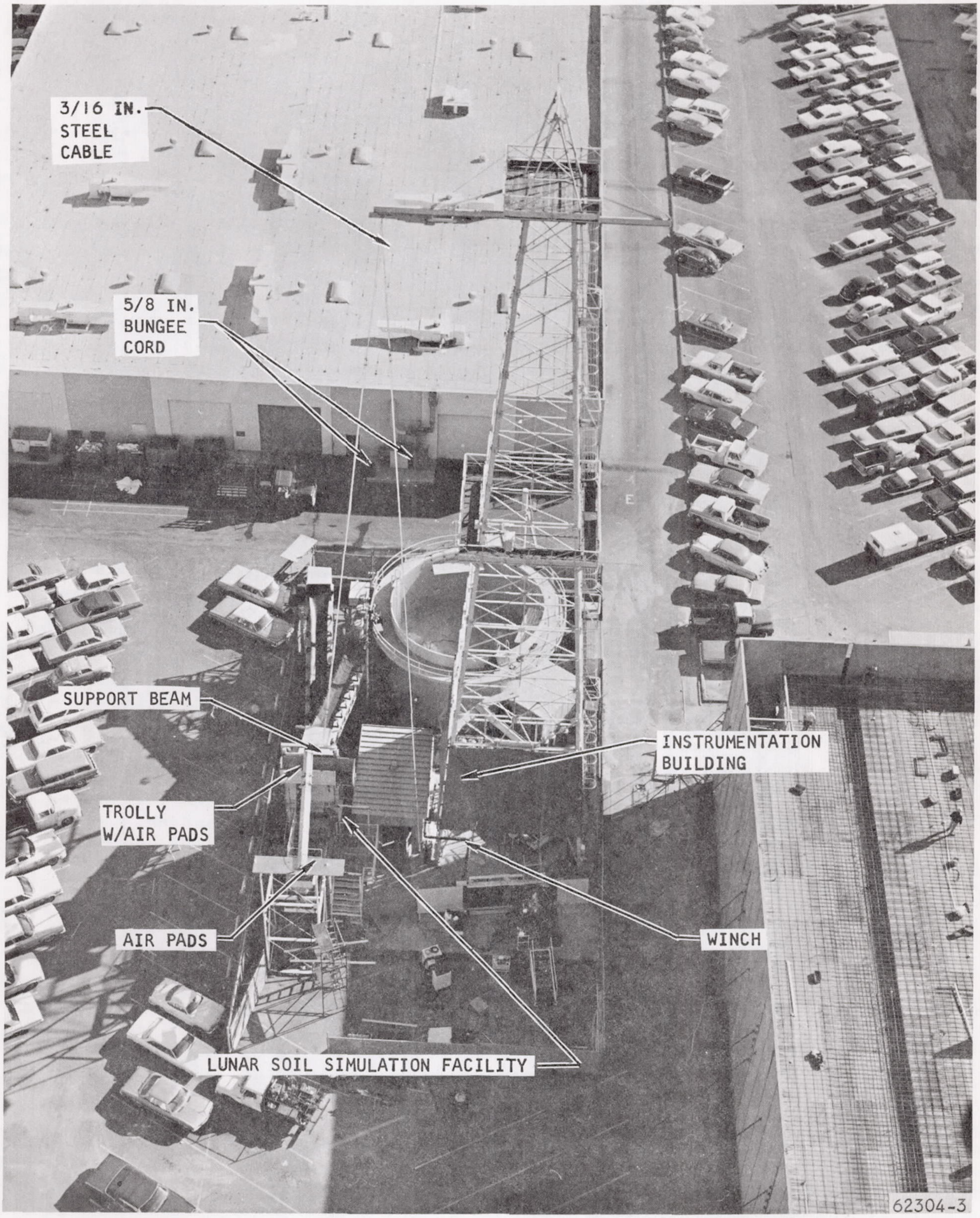

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Figure 2-1. Primary Test Area with Bungee-Cord Suspension System Installed

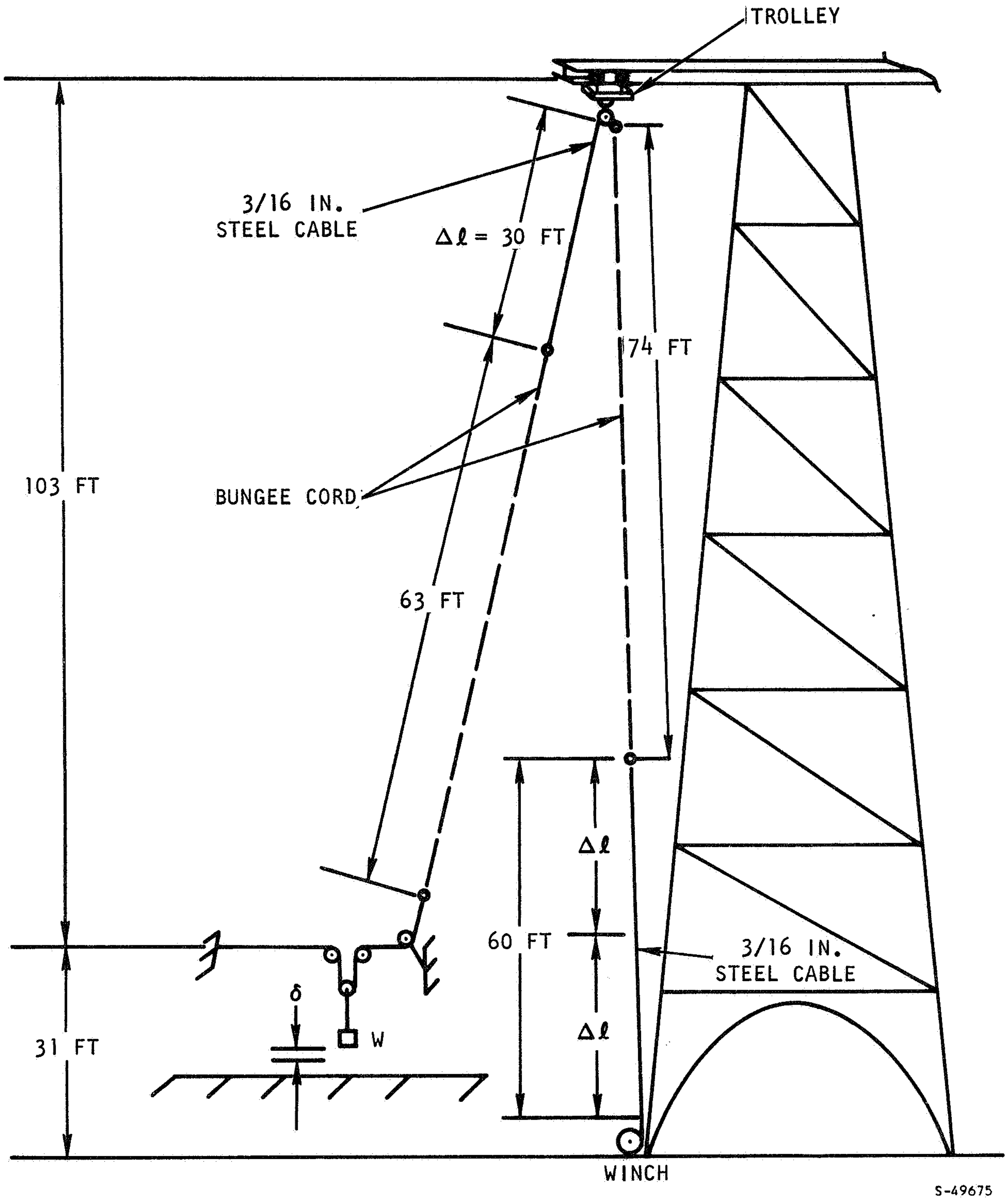

Figure 2-2. Layout of Bungee-Cord Suspension System

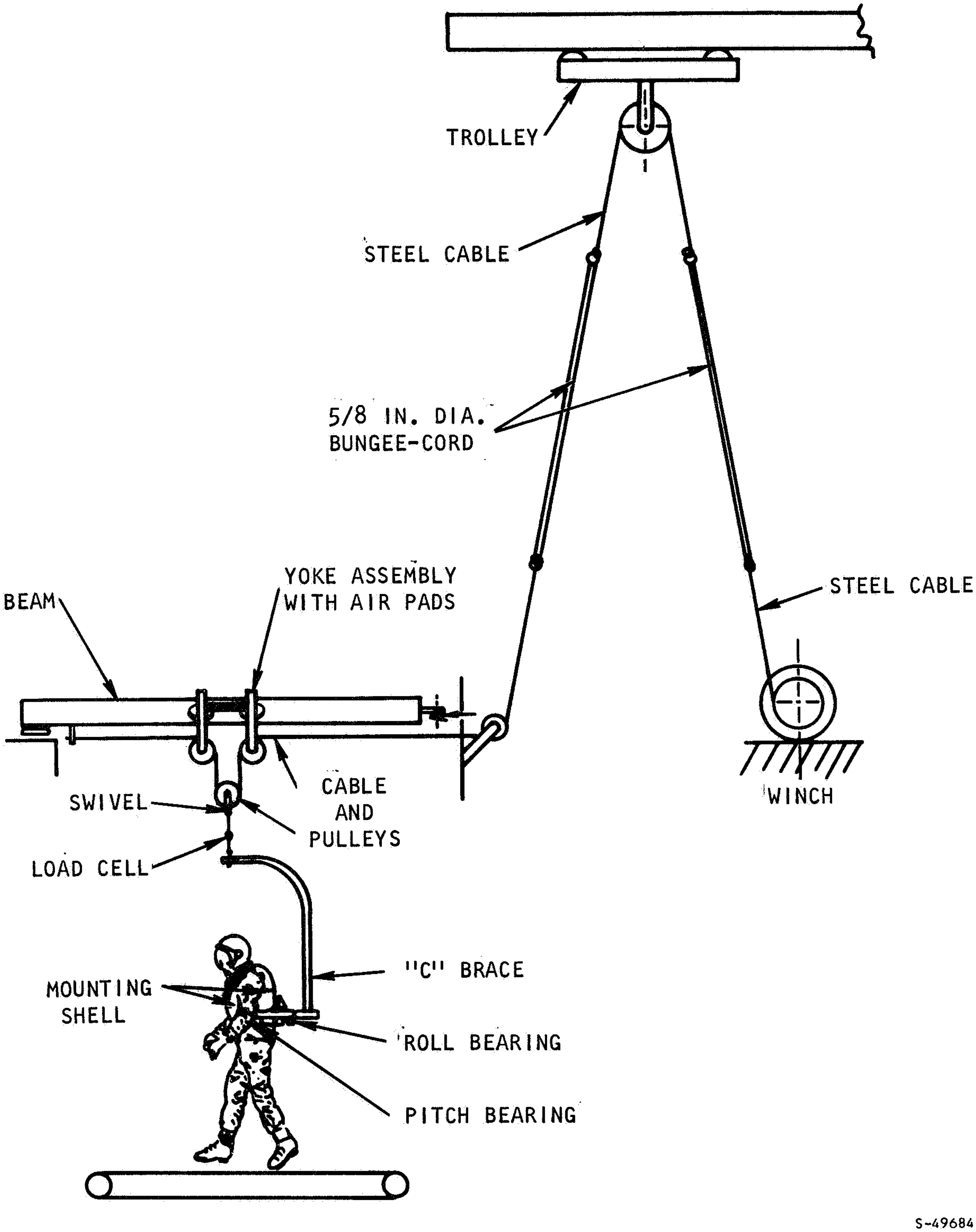

Figure 2-3. Schematic of Bungee-Cord Suspension System

BUNGEE CORD SELECTION TESTS

Due to the pulley arrangement shown in Figure 2-2, the bungee cord is loaded to a $\frac{W}{2}$ lb tension and deflects twice S, the movement of weight, W. The bungee-cord suspension system spring rate requirement of K = 4 lb/ft for a 40 lb lunar weight therefore limits the bungee cord used to a spring rate of K = 1 lb/ft. A design limit of a maximum jump of S = 2 ft was established; this requires a bungee cord deflection of 4 ft. A typical suited subject with a 75-lb backpack weighs approximately 240 to 270 lb. The bungee-cord load carrying design requirement would be approximately 100 to 113 lb. The physical test site dimensions limit each loaded bungee cord length to approximately 100 ft.

An off-the-shelf cord per MIL-C-56518 Type I was selected for preliminary feasibility tests. The cord consisted of strands of rubber encased in a woven cotton outer covering. Tests were conducted using 1/2- and 5/8-in. dia shock cords to determine which bungee-cord diameter would meet the required specifications.

A bungee cord of 74-ft length and 5/8-in. dia was then tested. It was found that 92 ft of loaded length was required to lift the 105 lb. Adding 2 lb to the suspended weight resulted in a deflection of 1.8 ft and a spring rate of K = 1.11 lb/ft. To increase the deflection to 4 ft the total loaded length of the bungee cord was doubled to approximately 150 ft. Repeating the spring rate test resulted in a spring rate of K = 1.0 lb/ft and a deflection of 4 ft.

As a result of the preliminary tests a 5/8-in. dia x 136-ft total length bungee cord divided into two sections of 63- and 73-ft lengths was selected to be used in the final test configuration (Figure 2-2). The bungee-cord suspension system's maximum lifting force was determined to be approximately 215 lb.

BUNGEE-CORD SUSPENSION TESTS

Effective Spring Rate Tests

The first test was performed to determine if the bungee cord selected for the final test configuration would meet the 10 percent of lunar weight requirement, i.e., 4 lb/ft for a 40-lb lunar weight. A mass of 212 lb was balanced about 3 ft above the treadmill surface. Results of adding or subtracting weights to the 212-lb mass are presented in Table 2-2. With 3.9 lb removed from the suspended mass, the weight bucket would not return to the neutral position. Removing 4.8 lb from the bucket allowed the bungee system to overcome the frictional hysteresis.

Pulley Frictional Force Test

To determine the frictional force inherent in the pulleys, the bungee-cord was replaced with a counterweight as shown in Figure 2-4. A 200-lb weight was counterbalanced. A force of 6.3 lb,when added to either side of the system, would either lift or lower the weight from the maximum balanced height of the

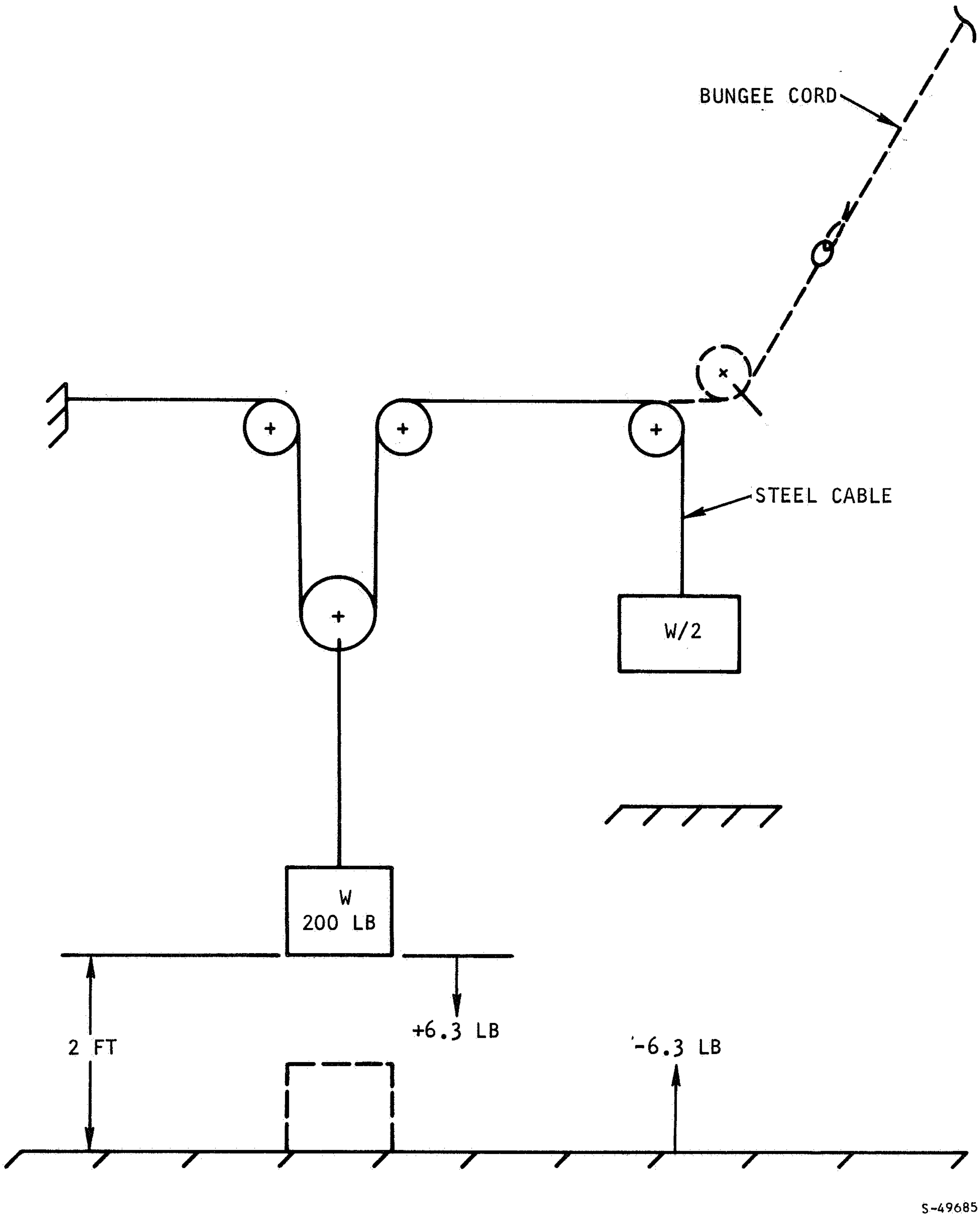

Figure 2-4. Test Setup for Determination of the Pulley Friction of the Bungee-Cord Suspension System

TABLE 2-2

RESULTS OF SPRING RATE TESTS

Δ Weight, lb	Deflection, in.	K, lb/ft
+3.9	10.5	4.46
+3.9	13.0	3.60
+3.9	11.5	4.06
-4.8	15.0	3.84
-4.8	17.0	3.39
-4.8	16.0	3.60

treadmill surface or vice versa. Thus, the total frictional force inherent in the pulleys is 6.3 lb.

Dynamic Tests

To evaluate the dynamic characteristics of the bungee-cord suspension system, a known vertical velocity was imparted to a suspended mass equivalent to a suited subject with 75-lb backpack at 1/6 g. The suspended mass was then allowed to free-fall in the vertical direction. The equations of motion for a free-falling object with an initial velocity V_0, and constant acceleration are:

$$\text{Max height} \qquad h_{max} = \frac{V_0^2}{2a} \tag{1}$$

$$\text{Total free-flight time } (T) = \frac{2V_0}{a} \tag{2}$$

The dynamic test setup is shown in Figure 2-5. A pneumatic piston provided the driving force. Varying the airflow rate through a manual shutoff valve changed the velocity to be imparted to the suspended weight. The velocity gradient during the startup was nonlinear but approached a constant velocity at the end of the 18-in. piston stroke. A pressure transducer measured air piston pressure. A reel-type position transducer mounted at the center of the overhead trolley measured the position of the weight. A weight-piston switch measured the fre-flight time. A load cell attached between the weight and load pickup cable measured the changes in pickup cable tension. The piston pressure, position transducer and contact switch signals were all recorded on an oscillograph recorder. The load cell signals were recorded on an Offner Dynagraph. The contact switch signals were also recorded on the Offner.

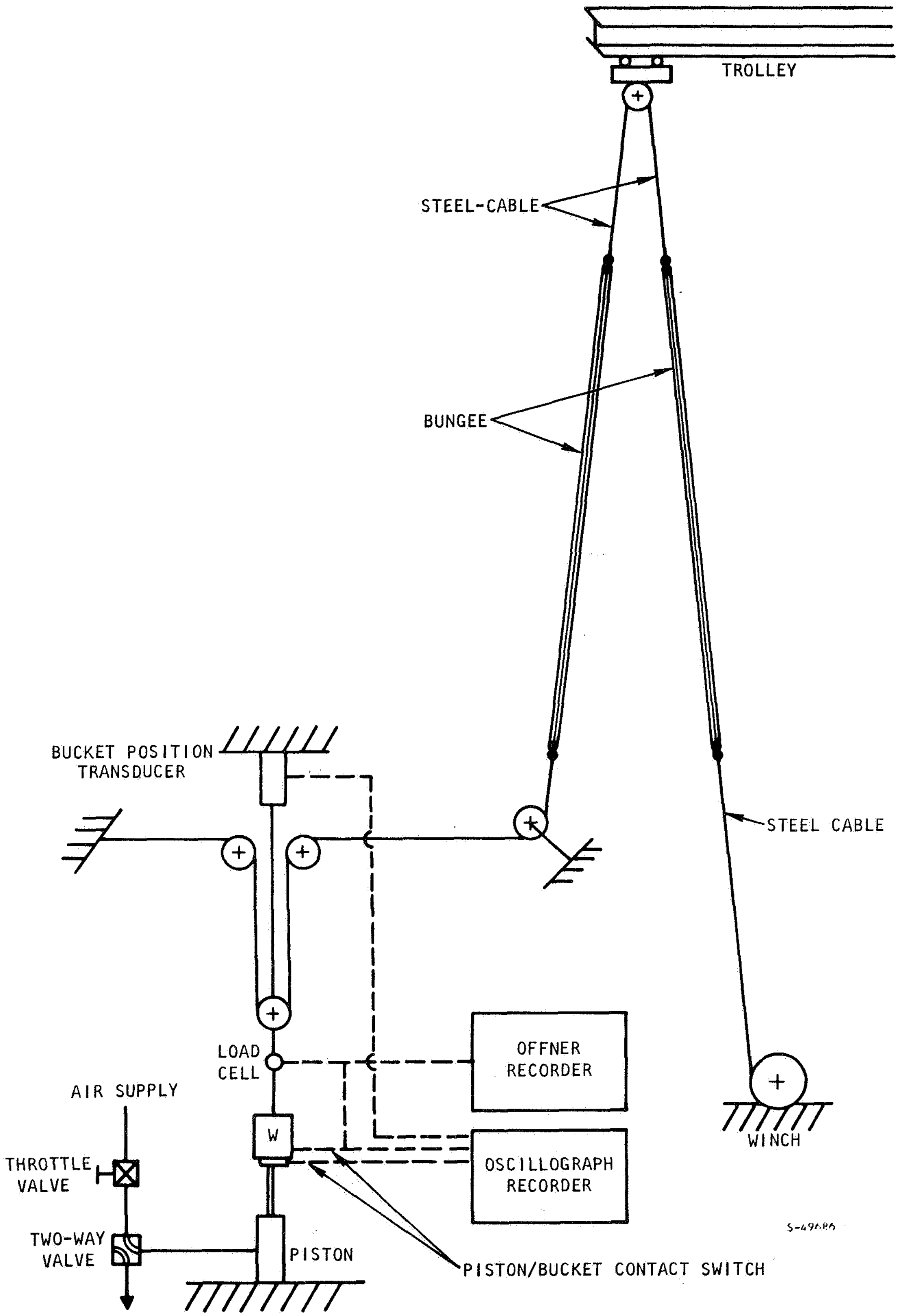

Figure 2-5. Dynamic Test Setup for the Bungee-Cord Suspension System.

A total of 23 separate tests were run at 9-, 15-, and 22-in. heights. Six repetitions at each height were recorded. Appendix A contains the data from three selected tests at each height.

Calculations were performed only for one selected test at each height. The initial and final velocities were graphically determined from the data. The maximum height was also measured from the data. Using the height versus time data and a curve fitting computer program the acceleration and velocity profiles were calculated. Table 2-3 compares the maximum height and total time between the ideal and bungee-cord suspension system. Figure 2-6 is a graphical comparison of curves for ideal and actual height versus ideal and actual time for a 15-in. maximum height jump.

To graphically determine the acceleration and velocity profile directly from the actual data would introduce a gross error, especially at the top of the curve where the slope is almost flat. A curve fitting computer program was used to transfer the actual data into a polynomial solution of at least a sixth-degree equation. Error was introduced when reading the height and time inputs of the recorded data. The velocity and acceleration data were obtained by taking the derivatives of computed equations. The acceleration and velocity profile results for tests 4, 10 and 19 are shown in Table 2-4.

Discussion of Test Results

The spring rate and deflection of the bungee-cord suspension system met the design requirements. Although temperature, humidity, age, and other variables all affect the physical properties of the bungee to some degree, no attempt was made to ascertain these relationships.

Results from the bungee-cord suspension system pulley frictional test indicate a high frictional load (6.3 lb) to move the balanced mass. A typical subject balanced at 1/6 g has approximately 40 lb of weight available to overcome the hysteresis in the system. Consequently, the hysteresis was not subjectively detectable.

The graphical comparison of the ideal and actual curves, shown in Figure 2-6, illustrates the error both in time and height. The percent difference from an ideal system ranges from +15.5 percent to +20.2 percent in total time. The percent difference from an ideal system for maximum height ranges between -21.1 percent and -27.4 percent. The data does not indicate that the bungee-cord suspension error increases with the increase in height. The results of Table 2-5 substantiate the hypothesis that simulation error is constant for increasing heights since the acceleration during ascent and descent is relatively constant.

The computed average acceleration data reasonably agree with the graphical average acceleration data (Table 2-6). A further manipulation of curve fitting to the actual data would bring the computed data in closer agreement to the graphical data.

TABLE 2-3

COMPARISON OF TOTAL FREE-FALL TIME AND MAXIMUM HEIGHT BETWEEN THE IDEAL STATE AND THE BUNGEE-CORD SUSPENSION SYSTEM

Test No.	V, in./sec	Ideal t, sec	Actual t, sec	Delta t, percent	Ideal h, in.	Actual h, in.	Delta h, percent
4	39	1.21	1.0	17.4	11.8	8.58	27.4
19	50	1.55	1.29	15.5	19.4	15.3	21.1
10	60.5	1.88	1.5	20.2	28.4	21.9	23.2

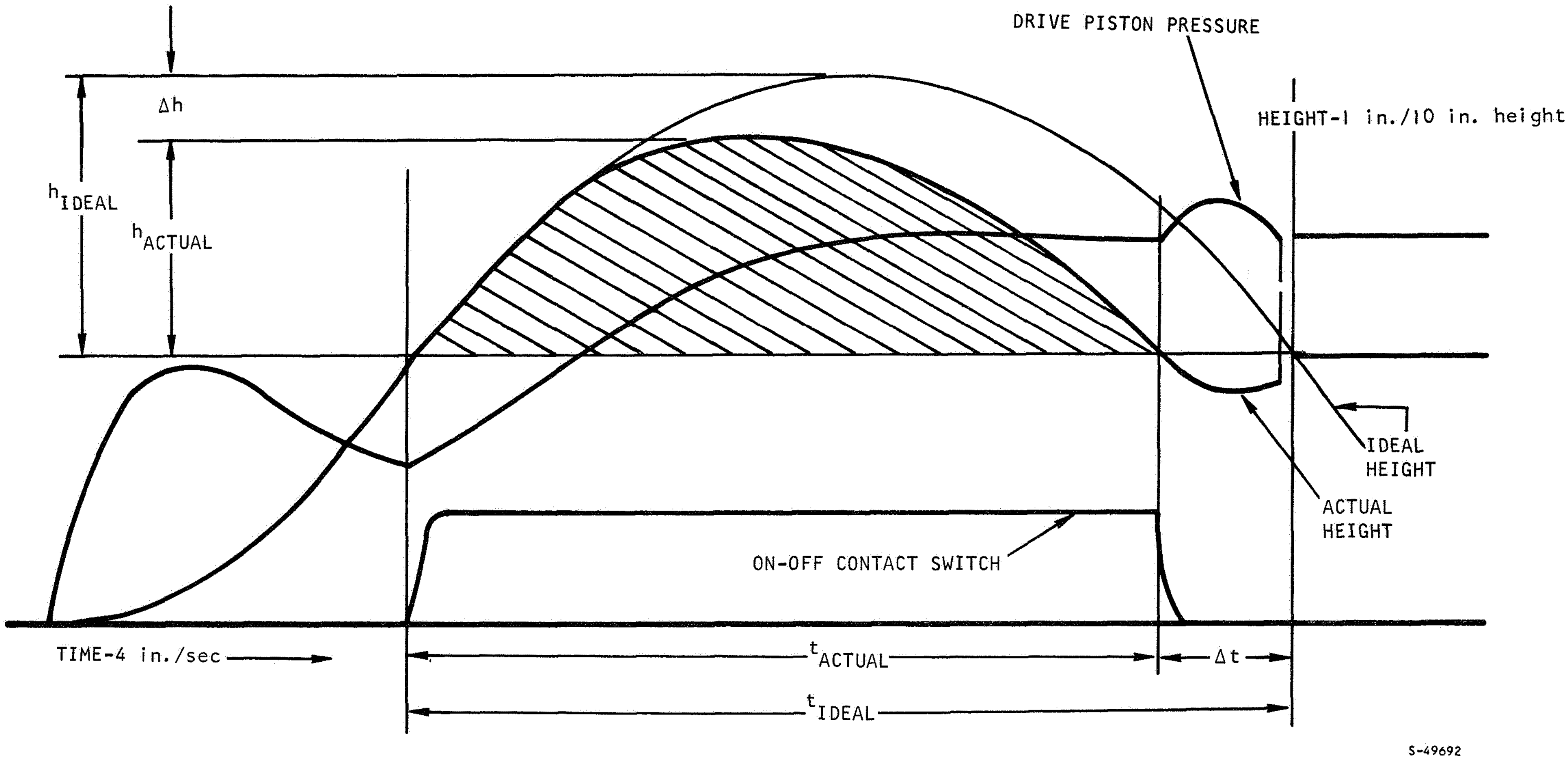

Figure 2-6. Dynamic Test Comparison of the Ideal and Actual Height versus Time for Dynamic Testing of the Bungee-Cord Suspension System.

TABLE 2-4

ACCELERATION AND VELOCITY PROFILE DATA

VELOCITY						ACCELERATION					
h_{max} = 9 in. Test No. 4		h_{max} = 15 in. Test No. 19		h_{max} = 22 in. Test No. 10		h_{max} = 9 in. Test No. 4		h_{max} = 15 in. Test No. 19		h_{max} = 22 in. Test No. 10	
Time, sec	**V, in./sec**	**Time, sec**	**V, in./sec**	**Time, sec**	**V, in./sec**	**Time, sec**	**a, in./sec^2**	**Time, sec**	**a, in./sec^2**	**Time, sec**	**a, in./sec^2**
0	+26.1	0	+54.7	0	+63.9	0	189.1	0	-80.1	0	-108
0.125	+29.6	0.1	+43.2	0.125	+51.2	0.125	-71.7	0.1	-77.4	0.125	-97.1
0.25	+17.6	0.2	+35.7	0.25	+39.4	0.25	-99.6	0.2	-95.7	0.25	-90.1
0.375	+6.9	0.3	+27.0	0.375	+28.4	0.375	-70.5	0.3	-103.4	0.375	-86.5
0.5	-0.8	0.4	+16.9	0.5	+17.8	0.5	-56.7	0.4	-91.9	0.5	-82.4
0.625	-8.2	0.5	+6.9	0.625	+7.8	0.625	-64	0.5	-68.6	0.625	-77.3
0.75	-16.8	0.6	-1.1	0.75	-1.5	0.75	-70.7	0.6	-48.3	0.75	-71
0.875	-25.2	0.7	-6.8	0.875	-9.9	0.875	-62.1	0.7	-45.5	0.875	-63.8
1.0	-32.9	0.8	-11.4	1.0	-17.4	1.0	-71.5	0.8	-65.9	1.0	-56.6
1.125	-48.5	0.9	-16.7	1.125	-24.1	1.125	-215.6	0.9	-98.7	1.125	-51.1
		1.0	-25	1.25	-30.4			1.0	-108.2	1.25	-49.7
		1.1	-35.7	1.375	-36.9			1.1	-25.7	1.375	-55.6
		1.2	-43.6	1.5	-44.7			1.2	-258.6	1.5	-77.3
		1.3	-42.2	1.625	-55.6			1.3	-903.6	1.625	-104.5
		1.4	-20.1					1.4			

TABLE 2-5

GRAPHICAL AVERAGE ACCELERATION
DURING ASCENT AND DESCENT

h_{max}, in.	Ascent Acceleration, in/sec^2	Descent Acceleration, in/sec^2	Nominal 1/6 g Acceleration, in/sec^2
9	83.4	51.6	
15	83.4	50.2	64.34
22	83.5	54.0	

TABLE 2-6

AVERAGE ACCELERATION DURING ASCENT AND DESCENT

Maximum Height, in.	Average Ascent Acceleration		Average Descent Acceleration	
	Computed, $in./sec^2$	Graphical, $in./sec^2$	Computed, $in./sec^2$	Graphical, $in./sec^2$
9	80.3	83.4	65.0	51.6
15	87.5	83.4	73.2	50.2
22	90.2	83.5	52.9	54

SECTION 3

PROCEDURES AND TEST DESIGN

SUBJECT SELECTION

Two subjects were used in this study. Both had previous pressure suit training and served as subjects throughout the Phase I study. They were selected because of the excellence of their attitude, health and physical capabilities. Because of their prior experience the subjects were familiar with the Gemini pressure suits, with locomotion on treadmills using various 1/6-g simulators and with the test procedure. Table 3-1 shows the anthropomorphic characteristics of these two test subjects.

EXPERIMENTAL DESIGN

The experimental program was designed to test the effects of the independent variables of velocity and gait on such dependent variables as metabolic rate and step rate for subjects using the bungee-cord suspension system at simulated lunar gravity. The test conditions are presented in Table 3-2.

TEST PROCEDURE

Subject Preparation

The subjects arrived at the dressing room of the test facility in a post-absorptive state. They first stripped to the nude, weighed, and donned the lower under garments worn with the pressure suit. The bioinstrumentation was then put in place and the subjects resumed the donning of the pressure suit. Before walking to the simulator facility the subject again weighed himself, this time dressed in the pressure suit.

Bungee-Cord Suspension Procedure

Prior to subject arrival at the test site the air pads were activated and checked for proper operation. The bungee-cord tension was pre-loaded to approximately 150 lb. Ropes were used to hold the "C" frame in position. When the test subject arrived at the test site the subject's bioinstrumentation was checked by connecting the bioinstrumentation connector plug to the mating suit plug and physiologic signals recorded.

The test subject was then attached to the gimbaled "C" frame using a molded fiber-glass shell. The ventilating gas hoses and instrumentation plugs were connected and suit vent flow established. The subject's nose clip was fitted into place and taped. The helmet was donned and locked down. The subject's communication was checked out. The bifurcated mouthpiece and respirometer connections were made and checked. The suit was then pressurized to 3.5 psig. A leak test of the bifurcated mouthpiece and hoses was then made. Another check was made on all suit connections and closures and the suit was again checked for leaks.

TABLE 3-1

ANTHROPOMORPHIC CHARACTERISTICS OF TEST SUBJECTS

Subject	Age, yrs	Height		Weight		Body Surface Area, M^2	Lean Body Mass, Kg
		Inches	CM	Lb	Kg		
D.B	25	68	172.7	152.2	69.18	181	56.5
M.G.	26	68-3/4	174.6	151.0	68.64	182	52.01

TABLE 3-2

TEST CONDITIONS

Simulator and Suit Mode	Slope, deg	Surface Conditions	Back Pack	Gait	Velocity, km/hr	Number Of Subjects	Total Tests
Bungee-Cord (6-degree of freedom) Pressurized Suit (3.5 psi differential)	0^0	Smooth-hard	75 lb	Walk	2 4	2 2	12
				Lope	6 8	2 2	
				Run	6 8	2 2	

The "C" frame tie down ropes were released and the bungee-cord tension increased until the subject was in a 1/6 g condition. The bungee-cord suspension system's maximum lifting force is approximately 215 lb. Therefore, the subject was manually lifted off the treadmill surface by the back of the "C" frame. Lead weights were added as necessary to trim the subject's pitch and roll axes. The subject was then required to jump to evaluate his balance and to walk back and forth to determine if the air pads were functioning properly.

Leakage checks were performed at all hose connections to the bifurcated mouthpiece and respirometer. Instrumentation signals were observed prior to starting and at the completion of each test. After each test the subject was asked if he had any problems or comments. Upon completion of the test modes, the "C" frame was tied down and the subject removed from the simulator assembly. After the subject removed his suit and bioinstrumentation sensors, he was asked to comment on the tests with respect to task difficulty, comfort, and other factors that may have affected his performance.

Test Sequence

After the subject was suspended and pressurized to 3.5 psig above atmospheric pressure he was instructed to begin breathing through the bifurcated mouthpiece and his physiological state was continuously monitored until the end of the test. When it was determined that he was in a steady state of rest the test was begun with a countdown to "start test." A 2 min resting period, during which the resting metabolic rate was measured, was followed by a countdown to "start treadmill." The subject walked, ran or loped, according to previous instructions, at one of the various pre-selected velocities for a 14-min period. Data samples were taken every minute. At the sixteenth minute (2-min rest and 14-min exercise periods) the treadmill was stopped and 6 min of post-exercise recovery data was taken while the subject remained standing still on the treadmill. Before the next test could be started the subject was asked about his general well-being, and his heart rate had to be within 10 percent of the initial resting value. Each subject walked at 2 and 4 KPH, loped at 6 and 8 KPH and ran at 6 and 8 KPH on a horizontal treadmill with a smooth but hard surface. Each carried a 75-lb back pack containing various metabolic sampling equipment.

Data Collection

All instrumentation and data collection procedures are described in detail in the final report for Phase I of this contract. The load cell traces for the six test modes of each subject are presented in Appendix B.

SECTION 4

RESULTS AND DISCUSSION

RESULTS

The principal physiological dependent variable measured during these tests was metabolic rate. Metabolic rate was measured by indirect calorimetry using the techniques described in the final report for Phase I.

It is generally accepted that when the body is exercised the aerobic metabolic requirements should change as a step-function. However, the body reacts as a resistor-capacitor linked input so that the aerobic metabolic rate actually rises as an exponential to a steady-state level which is maintained until exercise is stopped (that is, a steady-state level is maintained unless there are additional inputs to the system). When the exercise is stopped there is an exponential decay to the pre-exercise resting value. The difference between the initial logarithmic rise and the assumed step function requirement is the so-called "oxygen deficit," while the area under the curve during the period of logarithmic decay is called "oxygen debt." The oxygen debt is equal to the oxygen deficit. Figure 4-1 is a curve of metabolic rate as a function of time and demonstrates these concepts.

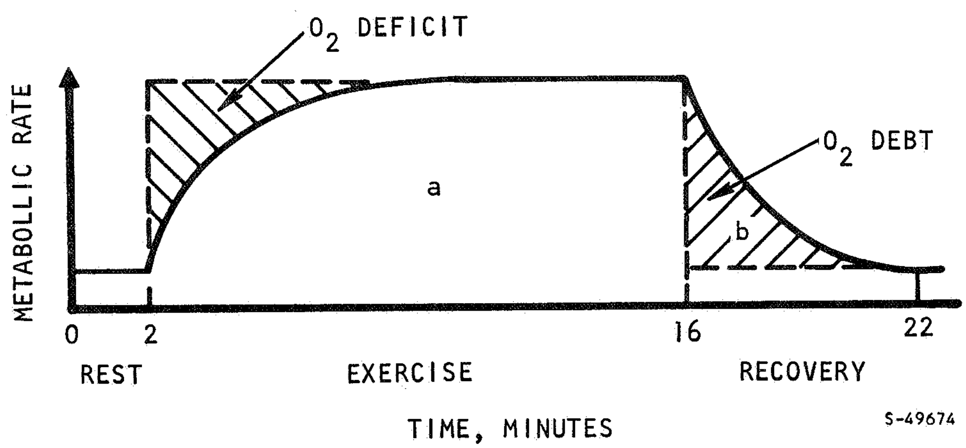

Figure 4-1. Metabolic Rate as a Function of Time

The results presented in Figures 4-2 through 4-7 are the individual data for the two subjects studied. The curves for changes in metabolic rate with time have been faired to conform to the theories of physiology and are representative of the data. When several of the manually faired curves were checked against a computer-fitted curve, there were no appreciable differences; the manually faired curves were determined acceptable for graphing purposes.

The energy values in Table 4-1 represent average values for the two subjects of areas under various portions of the curve of metabolic rate vs time. Areas were determined using Simpson's rule of integration which states

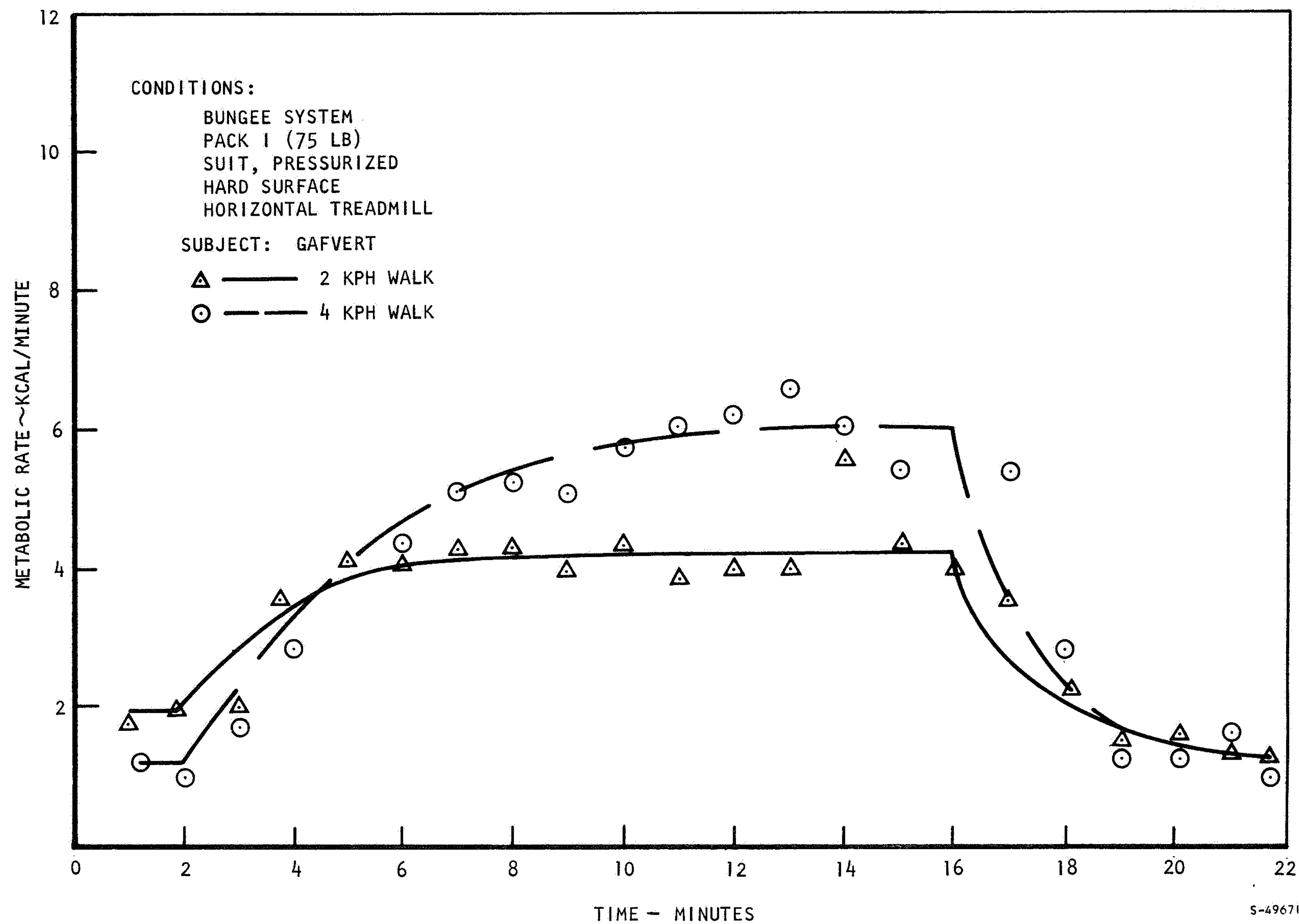

Figure 4-2. Time Course Changes in Metabolic Rates for Walking at Simulated 1/6 G Using the Bungee-Cord Suspension System (Gafvert).

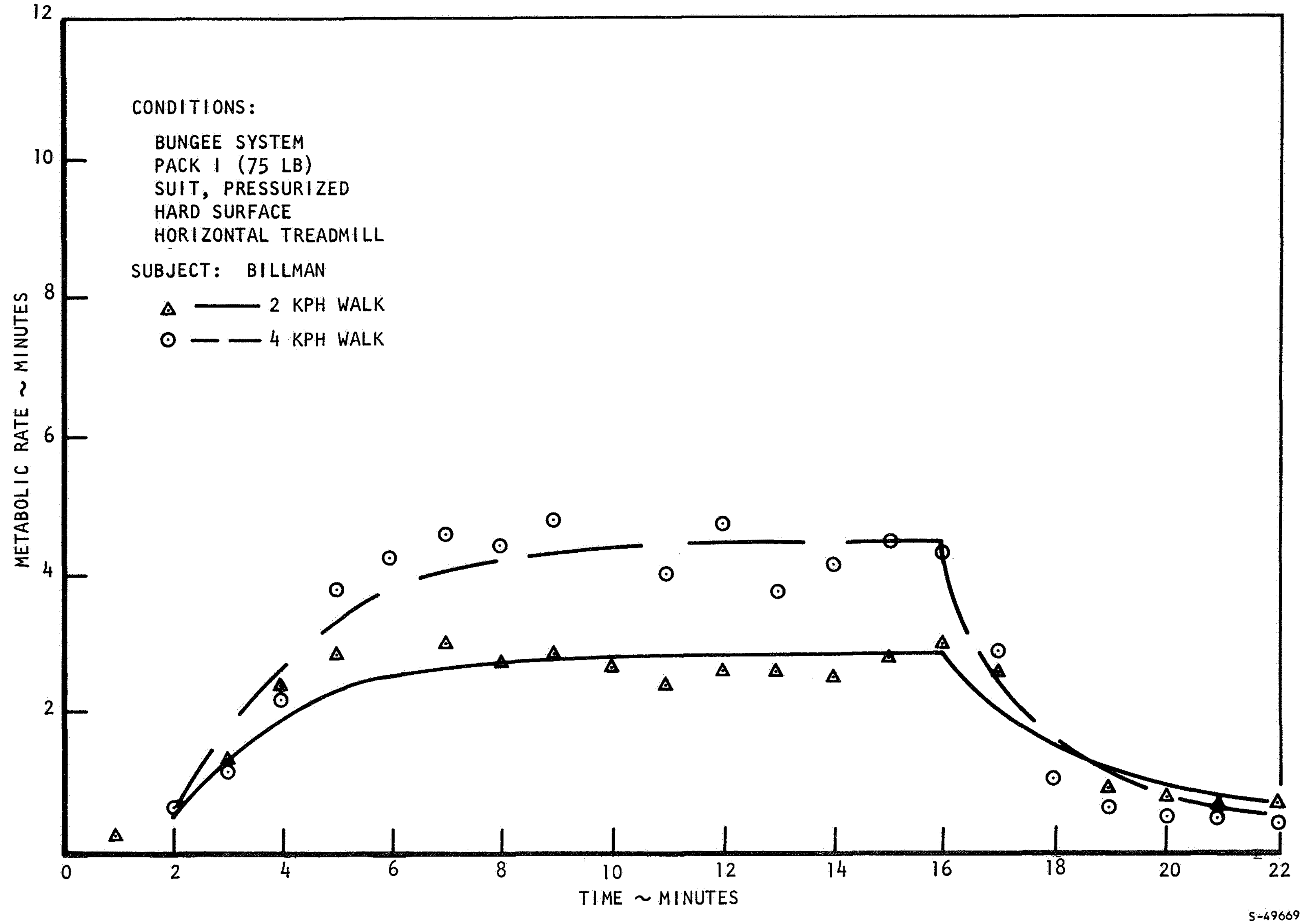

Figure 4-3. Time Course Changes in Metabolic Rates for Walking at Simulated 1/6 G Using the Bungee-Cord Suspension System (Billman).

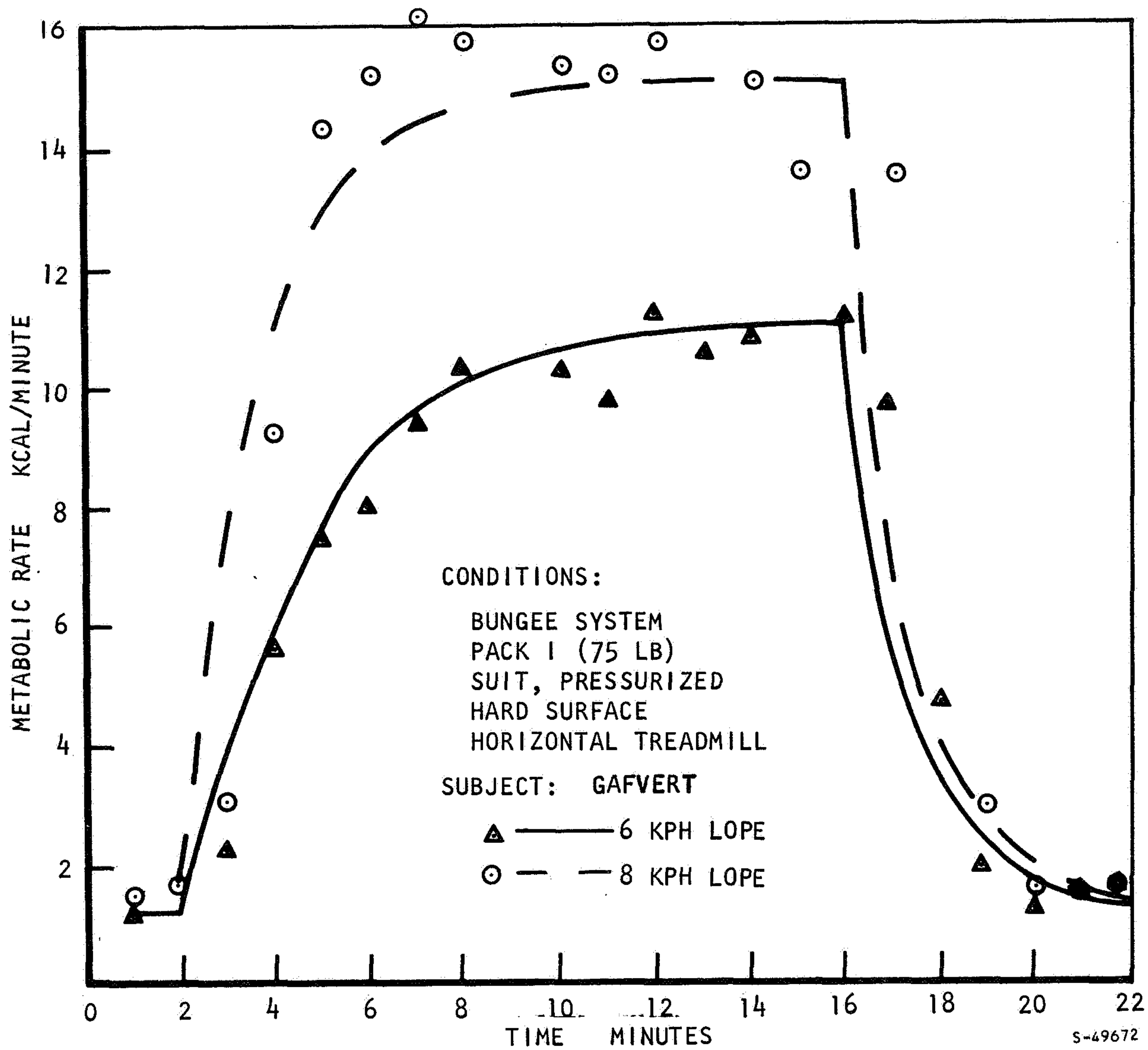

Figure 4-4. Time Course Changes in Metabolic Rates for Loping at Simulated 1/6 G Using the Bungee-Cord Suspension System (Gafvert).

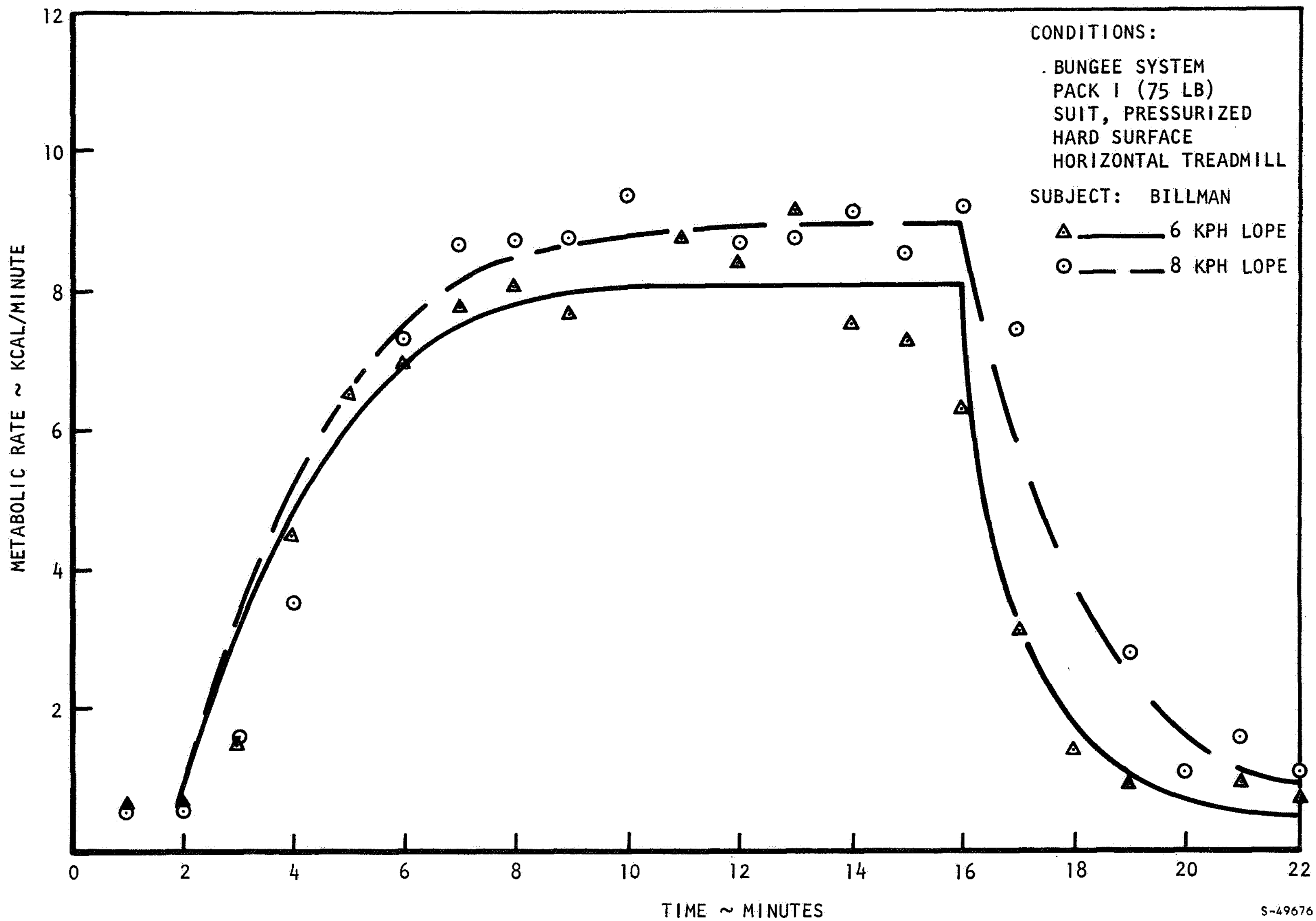

Figure 4-5. Time Course Changes in Metabolic Rates for Loping at Simulated 1/6 G Using the Bungee-Cord Suspension System (Billman).

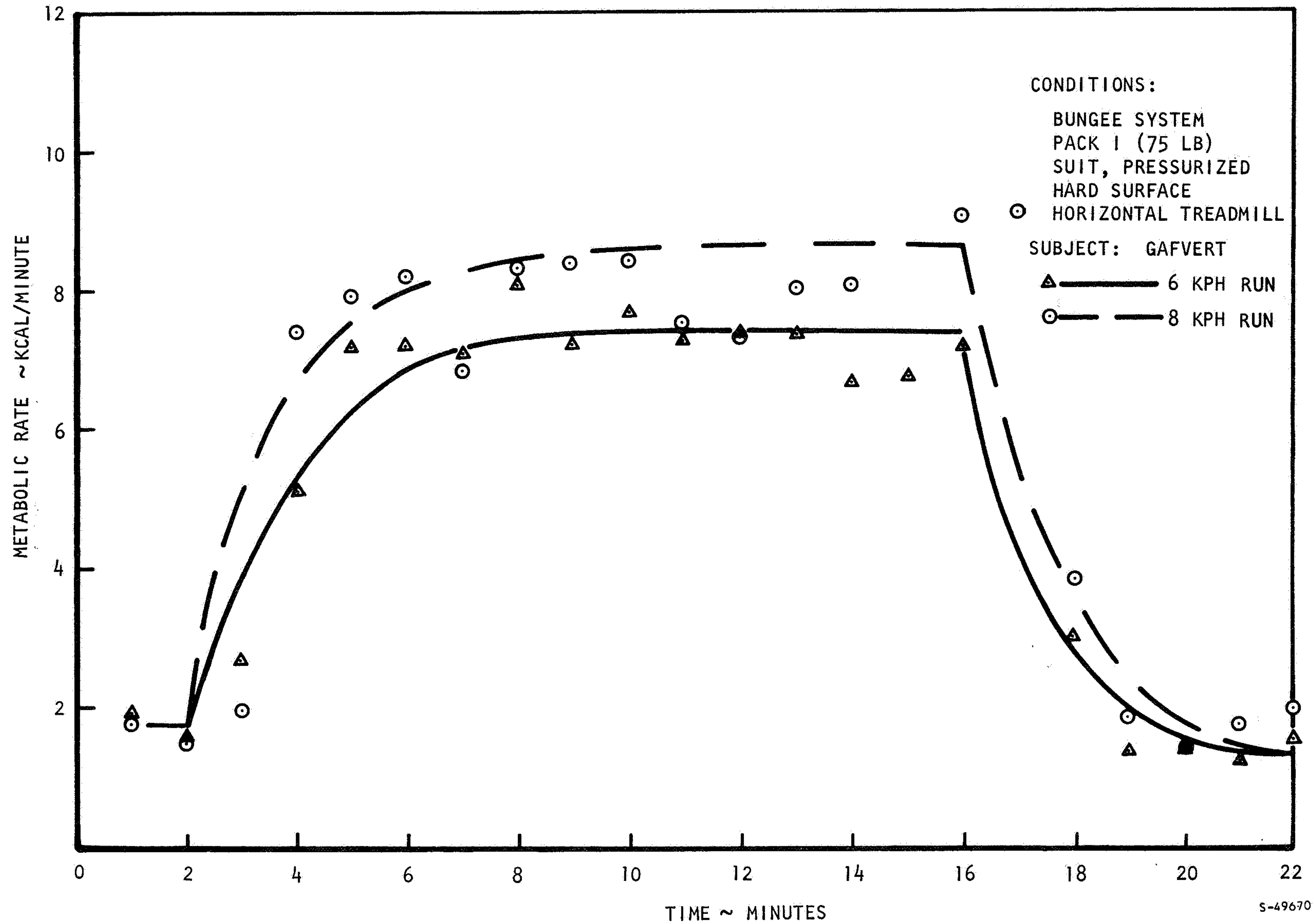

Figure 4-6. Time Course Changes in Metabolic Rates for Running at Simulated 1/6 G Using the Bungee-Cord Suspension System (Gafvert).

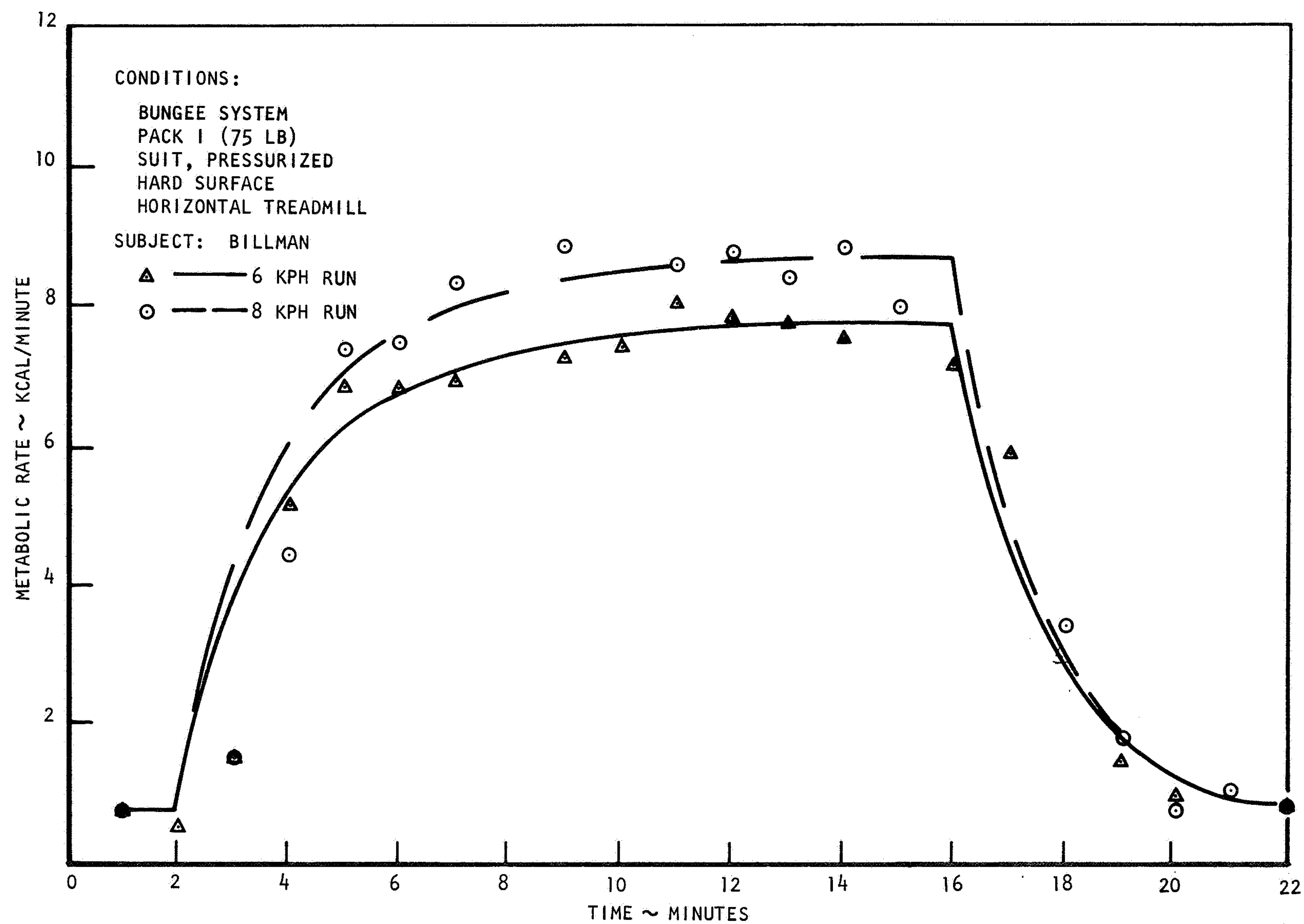

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Figure 4-7. Time Course Changes in Metabolic Rates for Running at 1/6 G Using the Bungee-Cord Suspension System (Billman).

TABLE 4-1

TOTAL ENERGY AND PROPORTIONAL ENERGY REQUIREMENTS FOR LOCOMOTION ON HORIZONTAL, BUNGEE-CORD SIMULATOR WITH 75-LB PACK AND PRESSURIZED SUIT

Gait	Velocity, km/hr	Average Total Energy, kcal (Col. I)	Average Energy During Work, kcal (Col. II)	Average Energy Post-Work, kcal (Col. III)	Ratio of Col. III/ Col. I (Col. IV)	Total Energy Cost of Work Done, kcal (Col. V)	Average Energy Cost, kcal/min (Col. VI)	Steady-State Energy Cost, kcal/min (Col. VII)
Walk	2	56.77	45.09	11.68	0.205	50.33	3.60	3.57
	4	74.78	61.07	13.71	0.183	70.33	5.02	4.90
Lope	6	130.85	109.82	21.02	0.160	124.25	8.88	9.44
	8	167.20	145.70	21.49	0.128	159.92	11.42	11.75
Run	6	109.09	92.71	16.38	0.150	102.67	7.33	7.25
	8	121.52	101.23	20.29	0.166	114.92	8.21	8.36

that the area under a curve can be estimated by adding up the area of polygons fitted under that curve. The average total energy, shown in Column I of Table 4-1, represents the total area under the curve from the start of exercise to the end of the test and is an average for the two subjects. For example, the total energy for the typical curve of Figure 4-1 would be the area under the curve during the period of exercise (2 min to 16 min) plus that of the recovery period (16 min to 22 min). Column II gives the average energy used by the subjects during the work period (area "a" under curve from 2 min to 16 min). Column III shows the average of the total energy during the recovery period following exercise, the cross-hatched area under the curve plus the resting level energy from 16 min to 22 min. Area "b," the cross-hatched area during recovery, is the so called oxygen debt and represents the energy required to repay the oxygen deficit acquired during the work phase. Column IV gives the ratio of post-exercise metabolism to the total energy requirement (Column II/Column I). Column V shows the average total energy cost of the work performed (Column VI x 14 min). Column VI gives the average energy cost per minute for the exercise task (area "a" plus "b") divided by 14 min. Finally, Column VII shows the actual average steady state metabolic rate measured during the last portion of the exercise period.

Table 4-2 presents the steady state metabolic data from these tests. Included are the individual steady state metabolic rates, the mean metabolic rate of the two subjects, and the mean metabolic rate and standard deviation from data collected at the same velocities during the first MOM testing phase using the TOSS simulator. It can be seen from this table that the mean values for the current tests fit within one standard deviation of previous data. Those individual values which do not lie within one standard deviation are within the range of values noted during earlier testing.

Figure 4-8 shows in graphic form the metabolic rates for these subjects. The lines shown connect the mean values. The individual metabolic rates are also plotted for comparison. As with previous tests the walk data tends to blend directly into the run data on a continuous curve. The mean lope data is considerably higher than for running at the same velocities.

Table 4-3 shows the data for step rates. Included are the individual step rates, the step rate mean values, and the mean value and standard deviation from earlier MOM tests. The mean values of the current tests fit within one standard deviation of the previous tests and the individual values fall within the range of values for previous MOM tests.

DISCUSSION

Statistical analyses are relatively meaningless with only 2 subjects and therefore, only apparent differences can be described. However, since the mean values for each locomotive gait/velocity lie within one standard deviation of the TOSS data from Phase I of this program, the same statistical implications can be used on these data.

TABLE 4-2

STEADY-STATE METABOLIC RATES

Gait	Velocity, kph	Simulator	Metabolic Rate ~ kcal/min			
			Billman	Gafvert	Mean ($\overline{X}$) MOM II (2 Subjects)	MEAN ±1 S.D. MOM I (6 Subjects)
Walk	2	MOM II (Bungee)	2.65	4.49	3.57	-----------
		MOM I (TOSS)	3.91	4.78	----	4.12 ±1.25
	4	MOM II (Bungee)	4.30	5.51	4.90	-----------
		MOM I (TOSS)	5.28	7.07	----	5.99 ±1.08
Run	6	MOM II (Bungee)	7.43	7.06	7.25	-----------
		MOM I (TOSS)	4.93*	7.70*	----	7.29 ±2.19*
	8	MOM II (Bungee)	8.64	8.08	8.36	-----------
		MOM I (TOSS)	8.50	6.22	----	8.42 ±0.83
Lope	6	MOM II (Bungee)	7.00	11.88	9.44	-----------
		MOM I (TOSS)	8.53	9.74	----	10.44 ±2.28
	8	MOM II (Bungee)	8.78	14.72	11.75	-----------
		MOM I (TOSS)	10.04	11.70	----	10.94 ±2.28

* Data for 6 KPH walk from MOM I (No data for 6 KPH run)

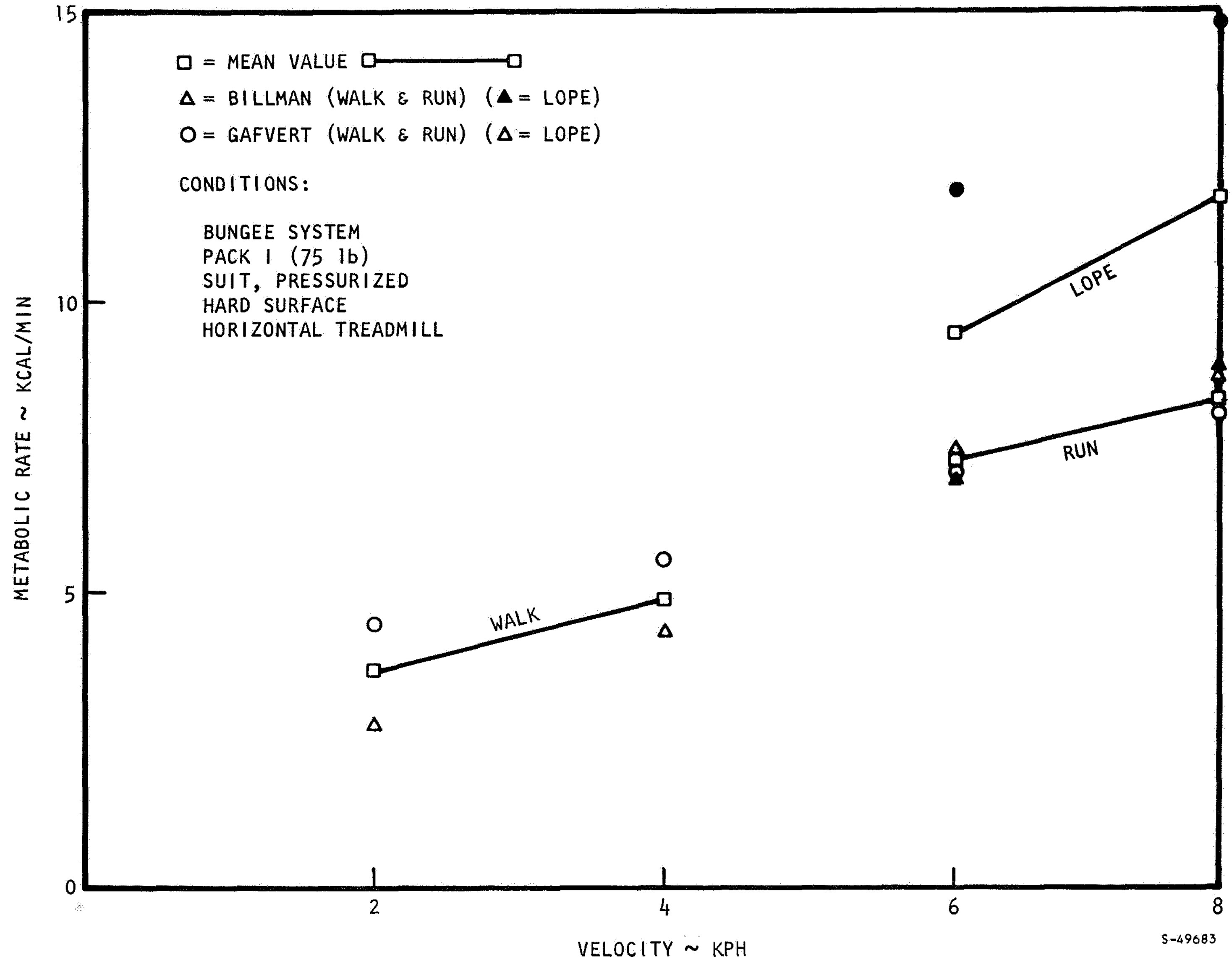

Figure 4-8. Steady-State Metabolic Rate for Locomotion at Simulated 1/6 G Using the Bungee-Cord Suspension System.

TABLE 4-3

STEADY-STATE STEP RATE

Gait	Velocity, kph	Step Rate, steps/min			
		Billman	Gafvert	Mean ($\overline{X}$)	MOM I
Walk	2	94	74	84	80.17 ±8.03
	4	112	100	106	113.33 ±13.91
Run	6	120	142	131	137.17 ±13.23*
	8	148	146	147	136.67 ±16.08
Lope	6	60	52	56	49.67 ±9.91
	8	64	50	57	61.33 ±10.20

*Data for 6 kph walk from MOM I.

Since these data do not appear different from previous testing, there appears to be no difference between the TOSS and Bungee simulators when the metabolic cost of performing locomotion at 1/6 g in the Gemini suit is used as a criterion. The effect of the suit on the cost of locomotion within the two simulators cannot be determined from these data. This leads to the following possible explanation:

(1) There is no difference between the cost of locomotion between the two types of simulation.

(2) The variance in metabolic data between subjects can obscure subtle differences between simulators, and the use of only two subjects does not permit objective statistical comparisons of the simulators.

(3) The use of the relatively rigid Gemini pressure suit masks potential differences between the two simulators as evaluated by the metabolic cost of locomotion.

CONCLUSIONS

On the basis of the observations and tests to evaluate the bungee-cord suspension system for use in 1/6-g simulations, it was noted that:

(1) A graphic analysis of the dynamic response of the bungee-cord simulator as compared to the desired ideal response showed a +15.5 percent to +20.2 percent difference in total time and -21.1 percent to -27.4 percent difference in maximum height for jumping events.

(2) There were no discernible differences between the metabolic rate data for the Phase I study using the TOSS and inclined-plane simulators and those reported for this study.

(3) There were no apparent differences between the simulator of this study and the Phase I study based on metabolic rate. The reason for the lack of difference, if in fact there are real differences, is not understood. However, the use of only two subjects eliminates the potential of any objective measure based on statistical techniques.

APPENDIX A

DYNAMIC TEST DATA FOR THE BUNGEE-CORD LUNAR GRAVITY SUSPENSION SYSTEM

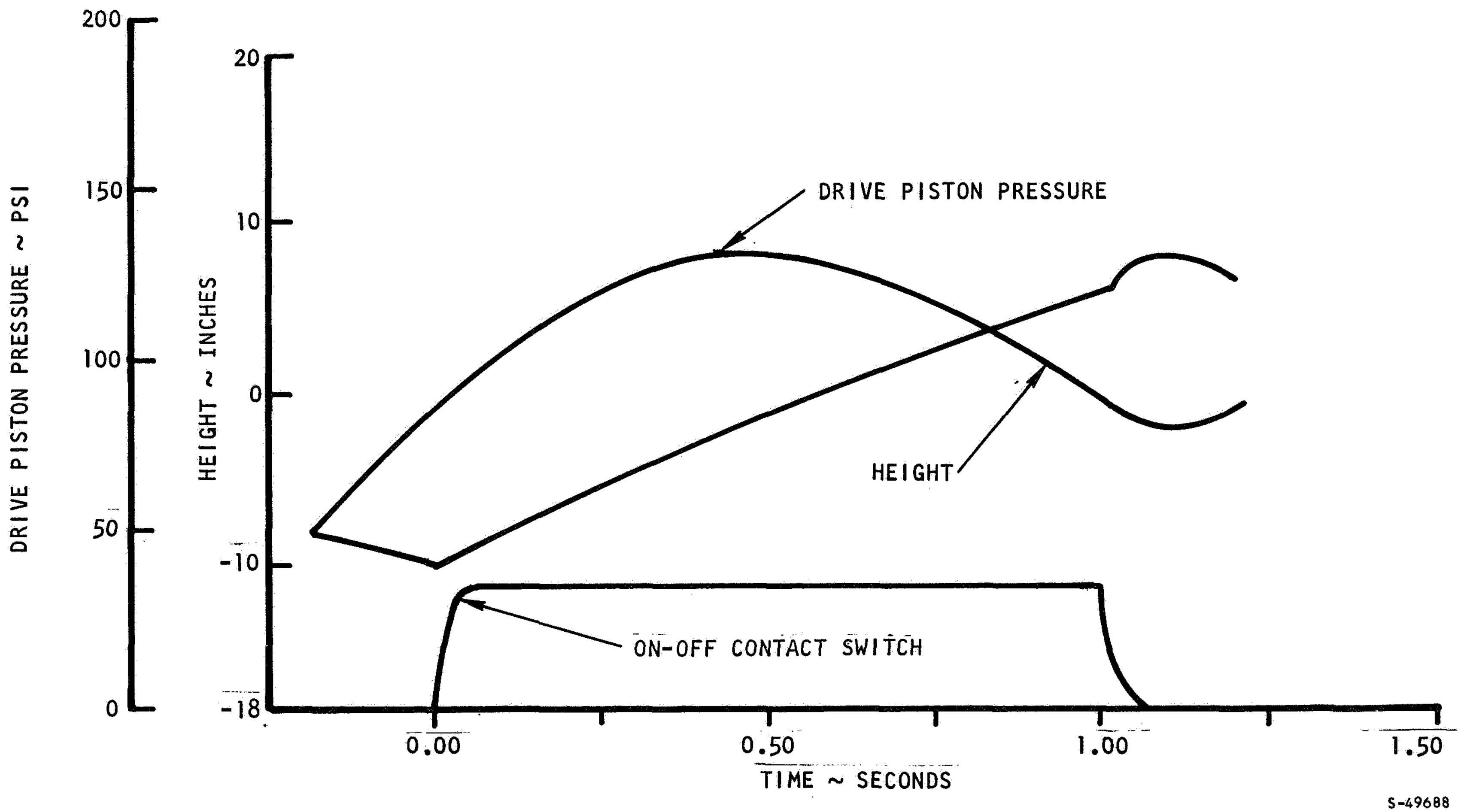

Figure A-1. Dynamic Test No. 3, Maximum Height = 9 in.

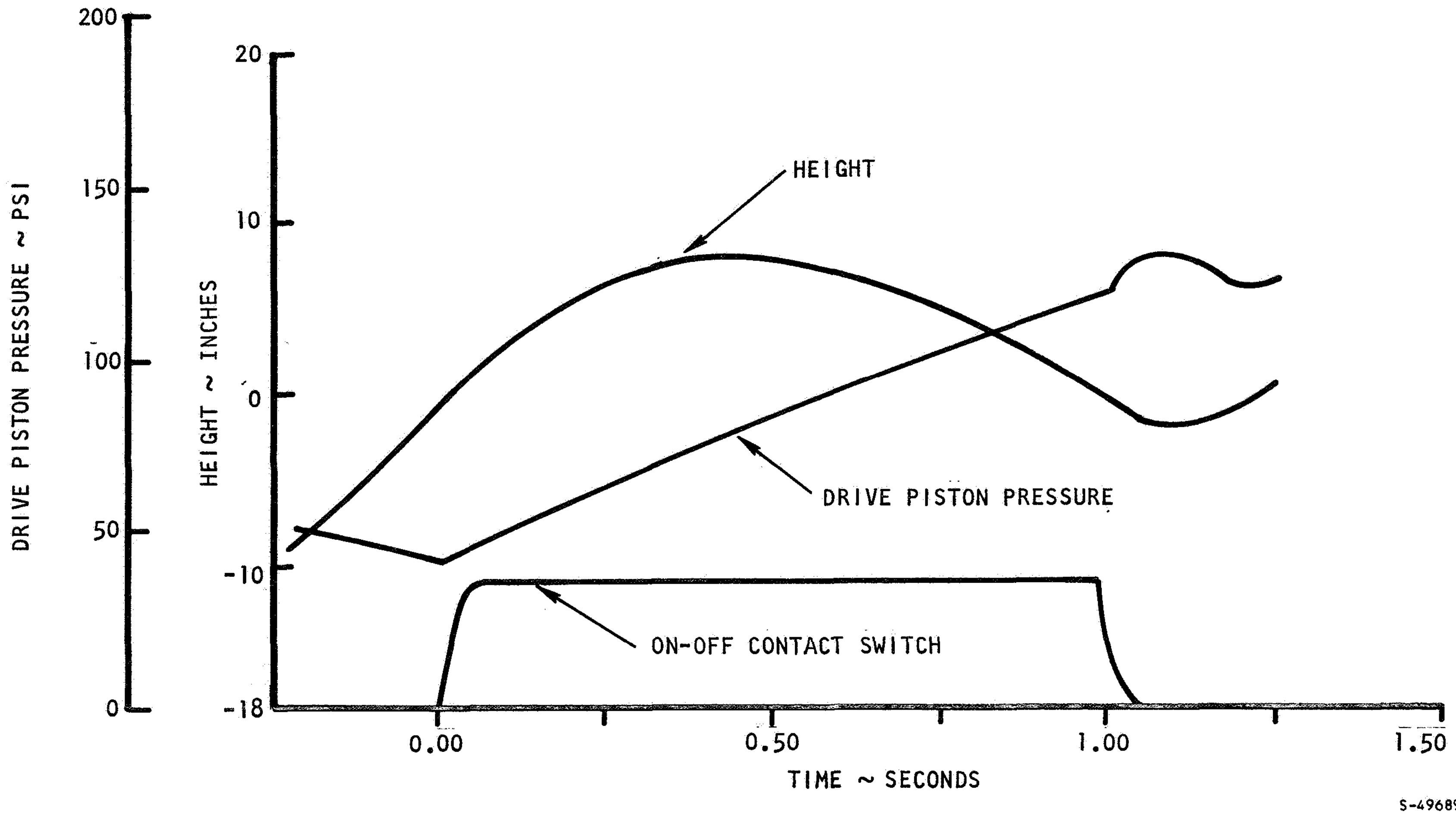

Figure A-2. Dynamic Test No. 4, Maximum Height = 9 in.

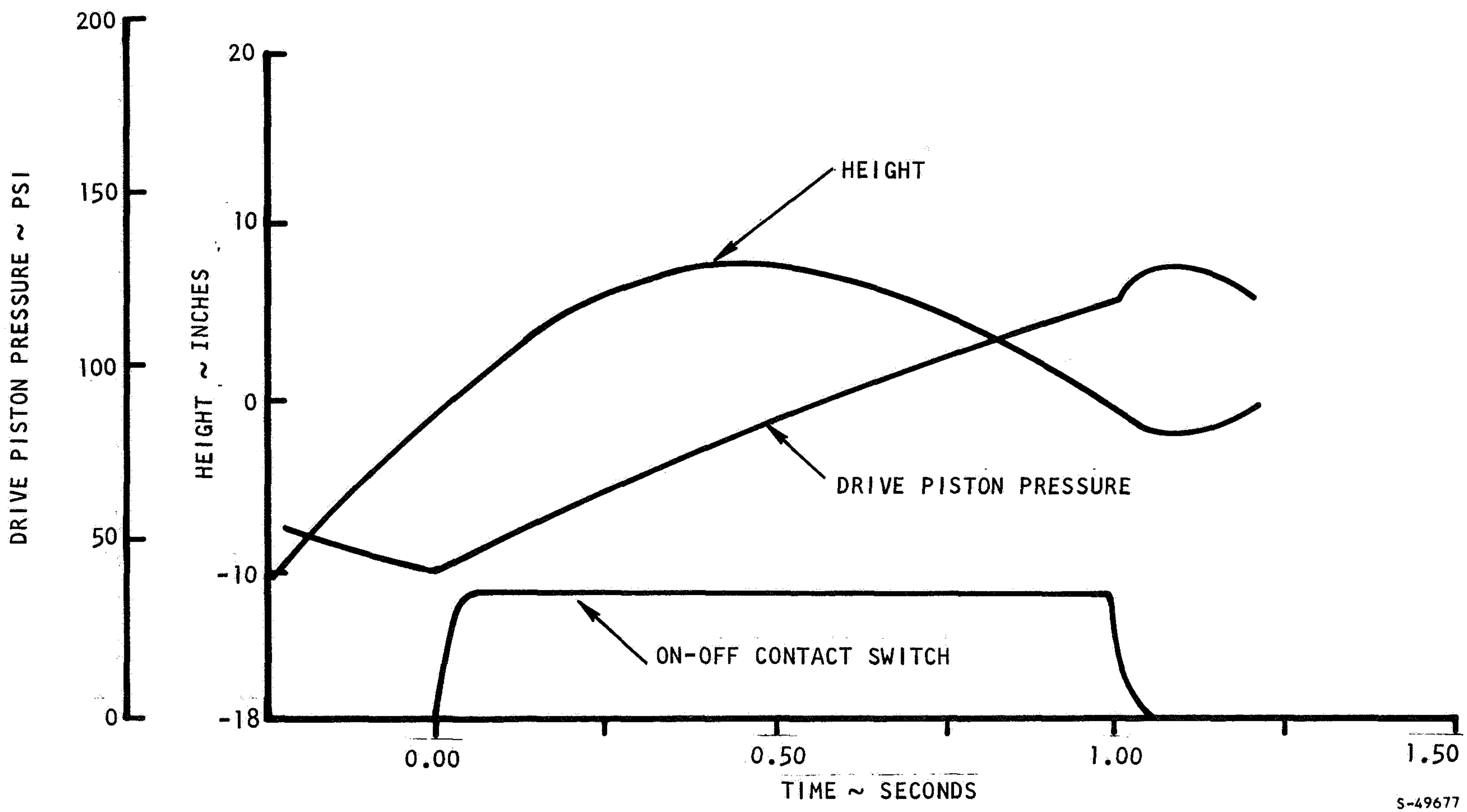

Figure A-3. Dynamic Test No. 5, Maximum Height = 9 in.

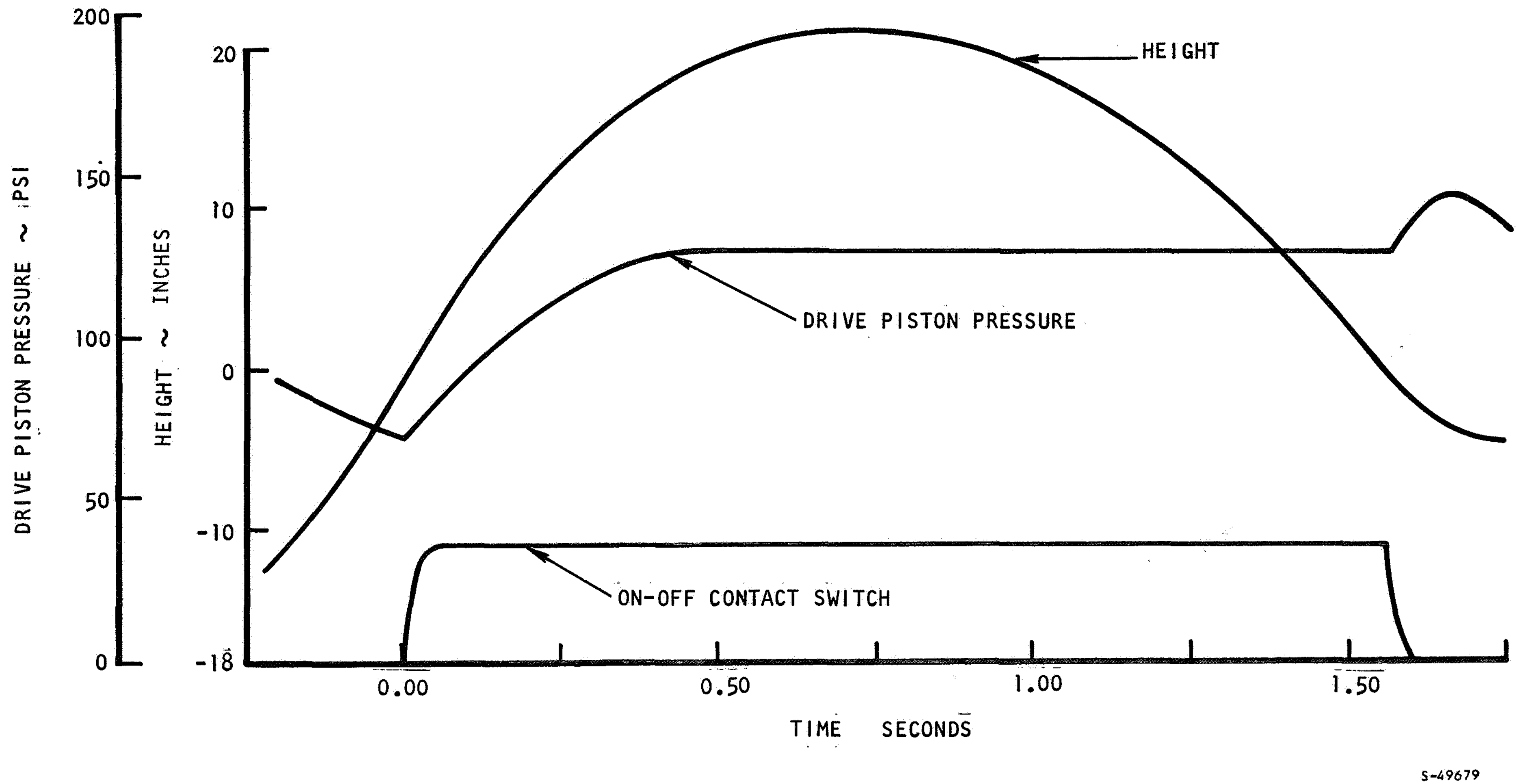

Figure A-4. Dynamic Test No. 9, Maximum Height = 22 in.

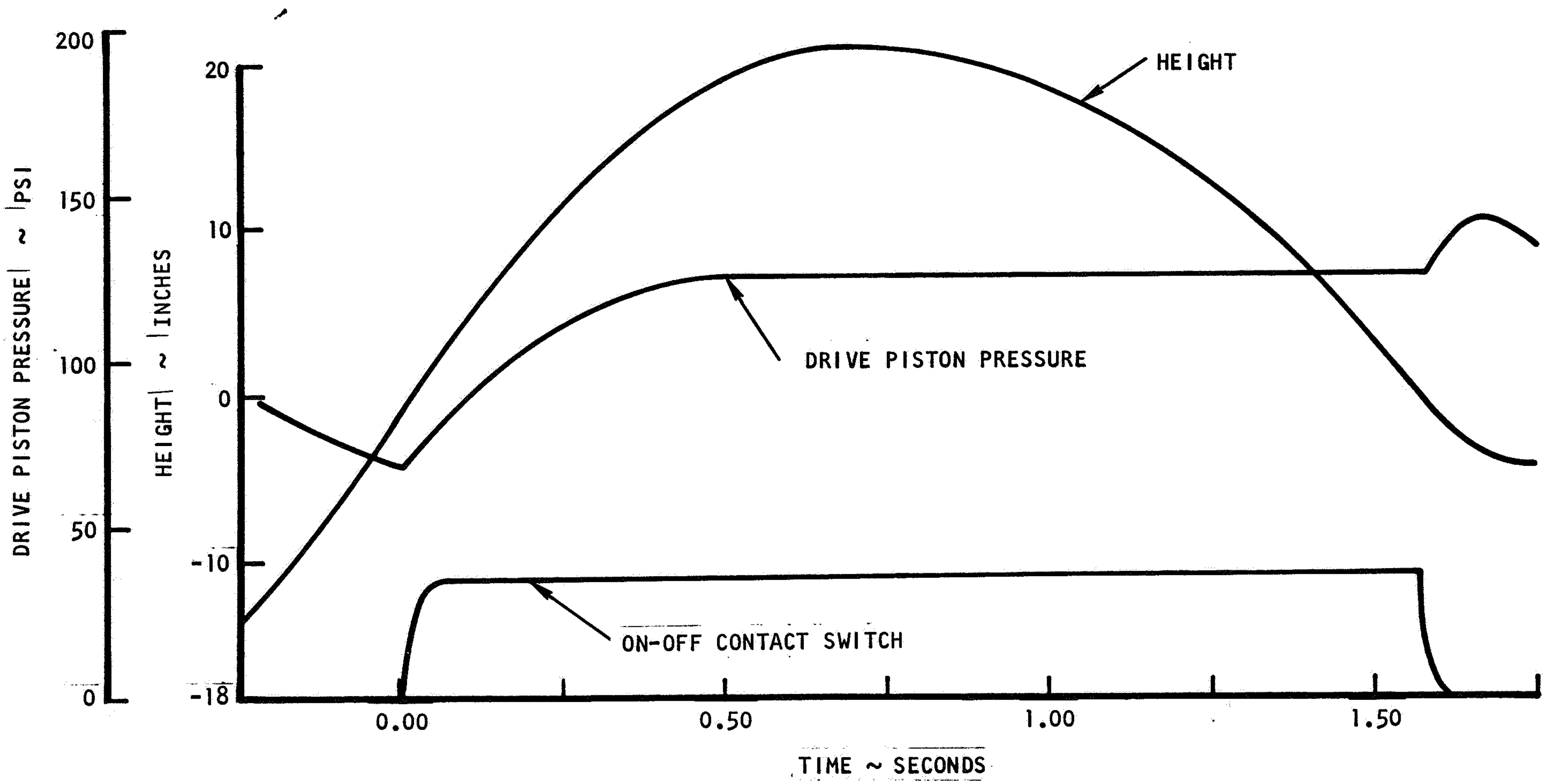

Figure A-5. Dynamic Test No. 10, Maximum Height = 22 in.

S-49678

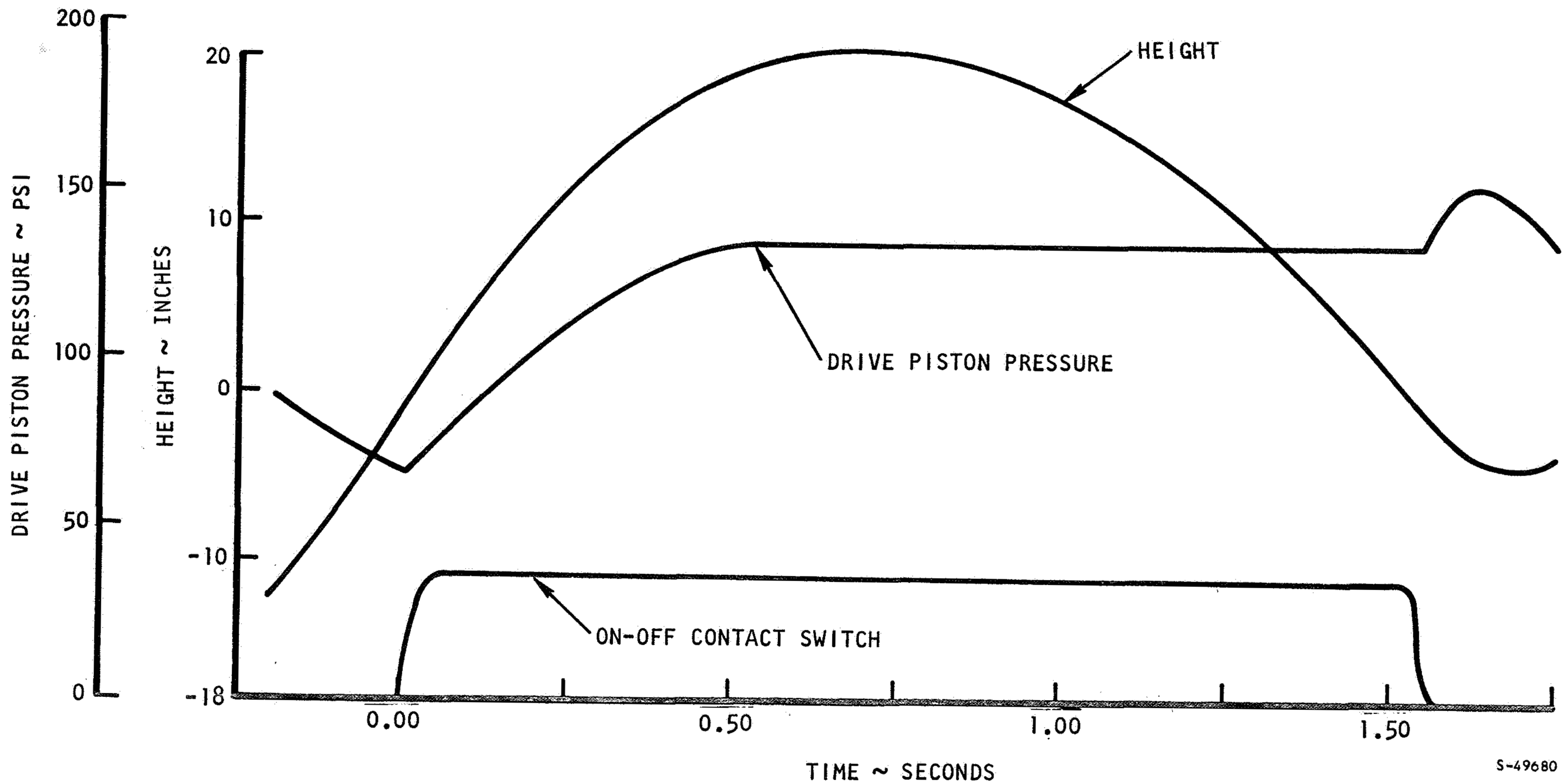

Figure A-6. Dynamic Test No. 11, Maximum Height = 22 in.

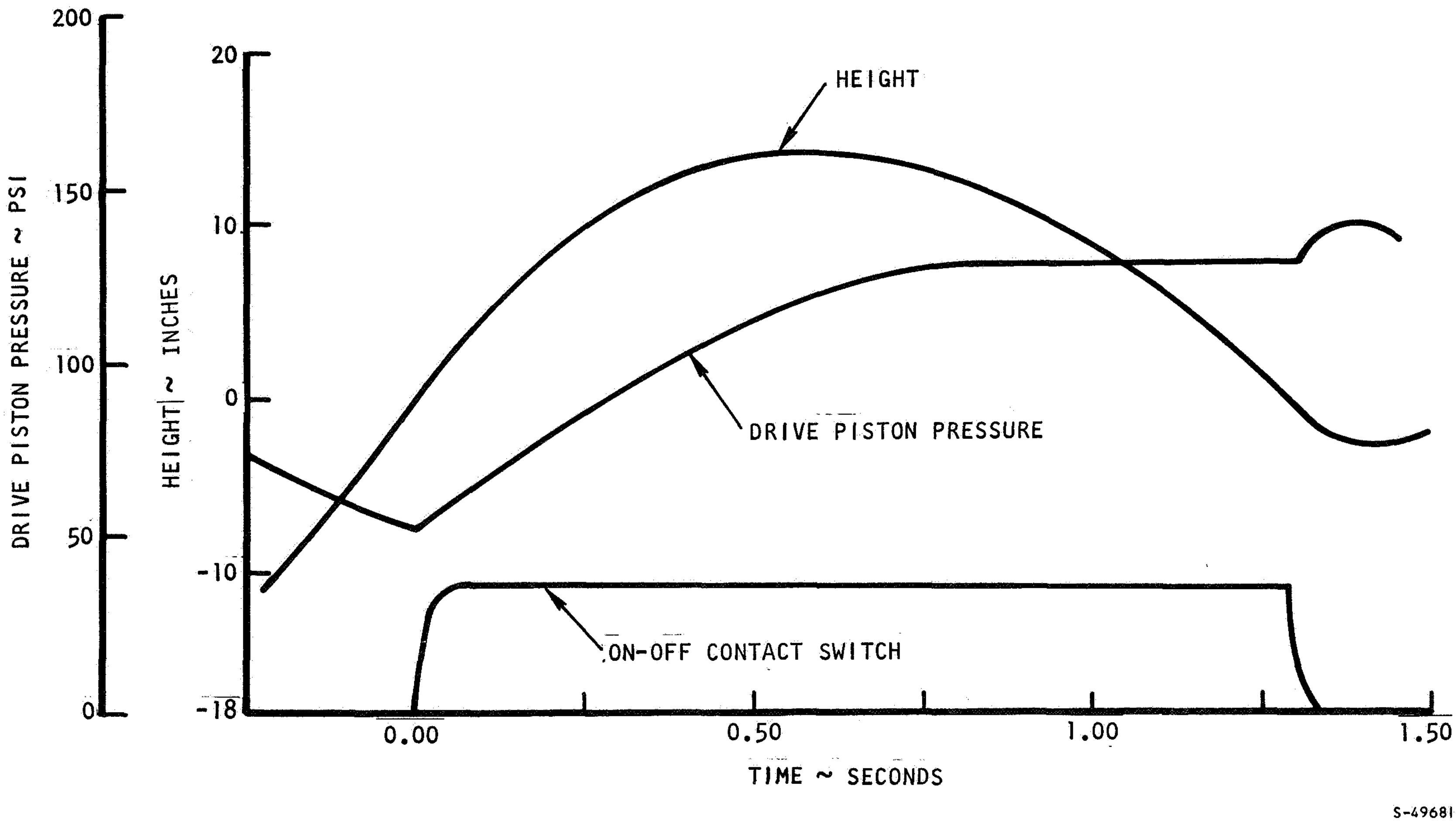

Figure A-7. Dynamic Test No. 18, Maximum Height = 15 in.

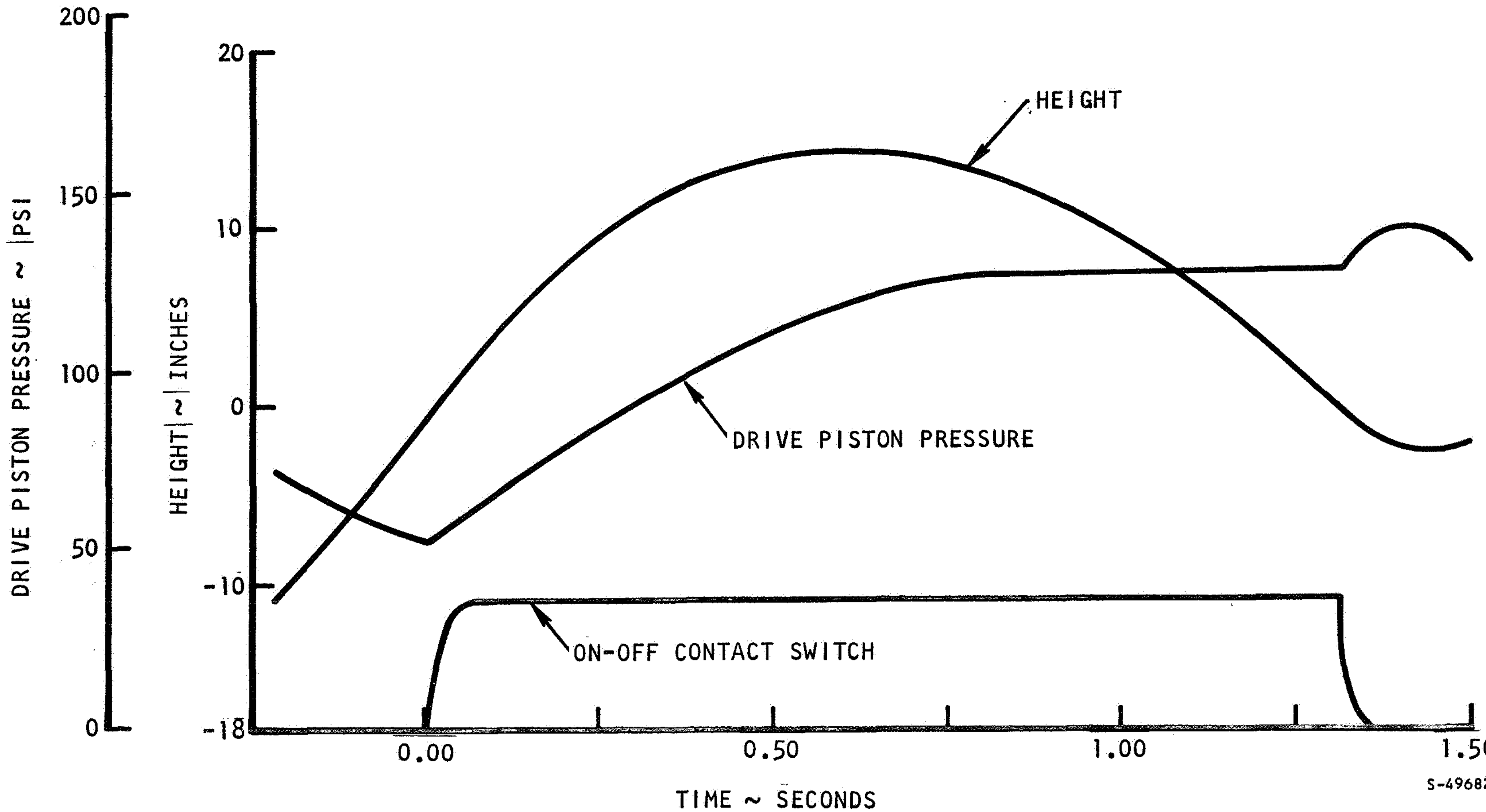

Figure A-8. Dynamic Test No. 19, Maximum Height = 15 in.

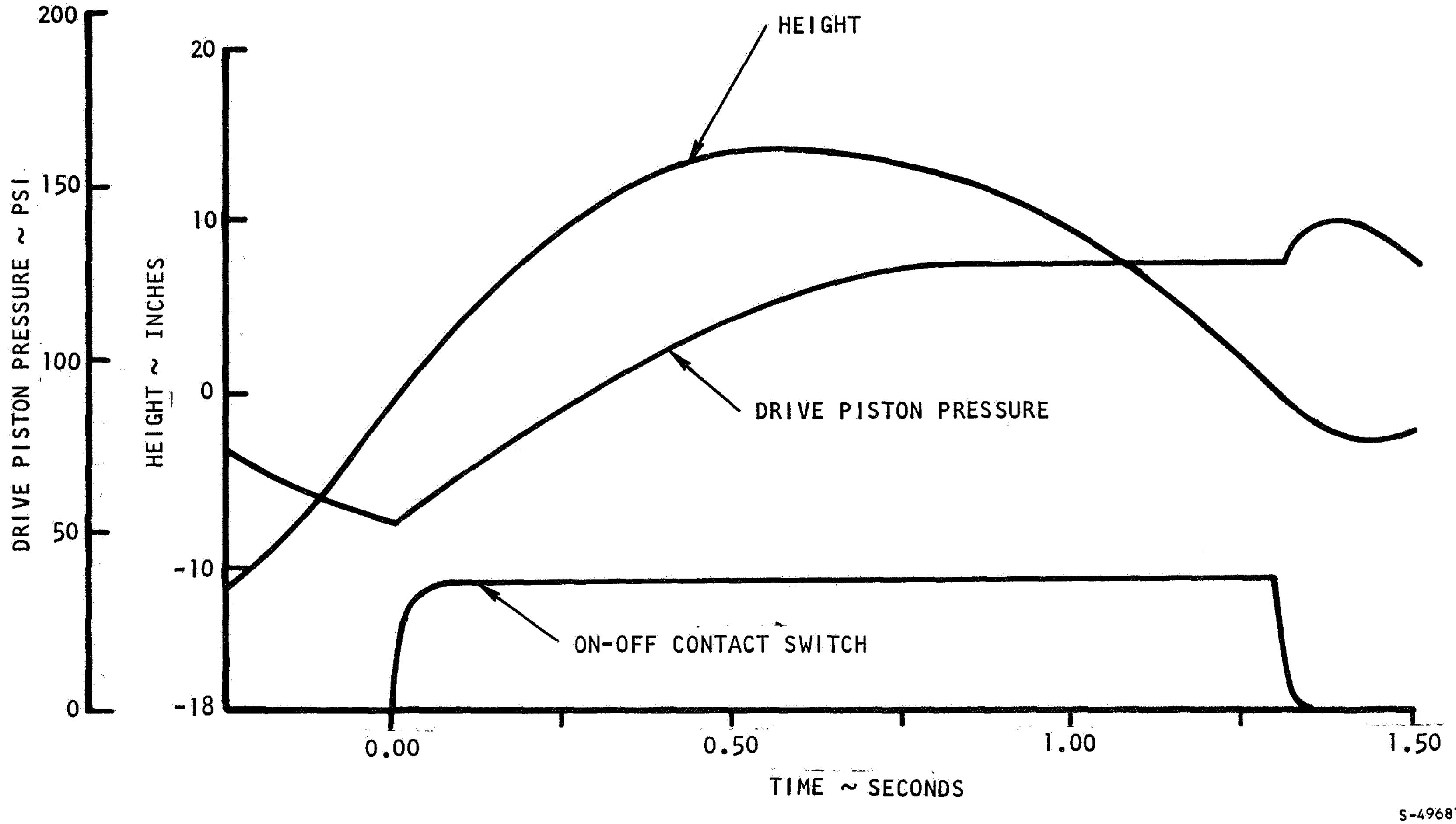

Figure A-9. Dynamic Test No. 20, Maximum Height = 15 in.

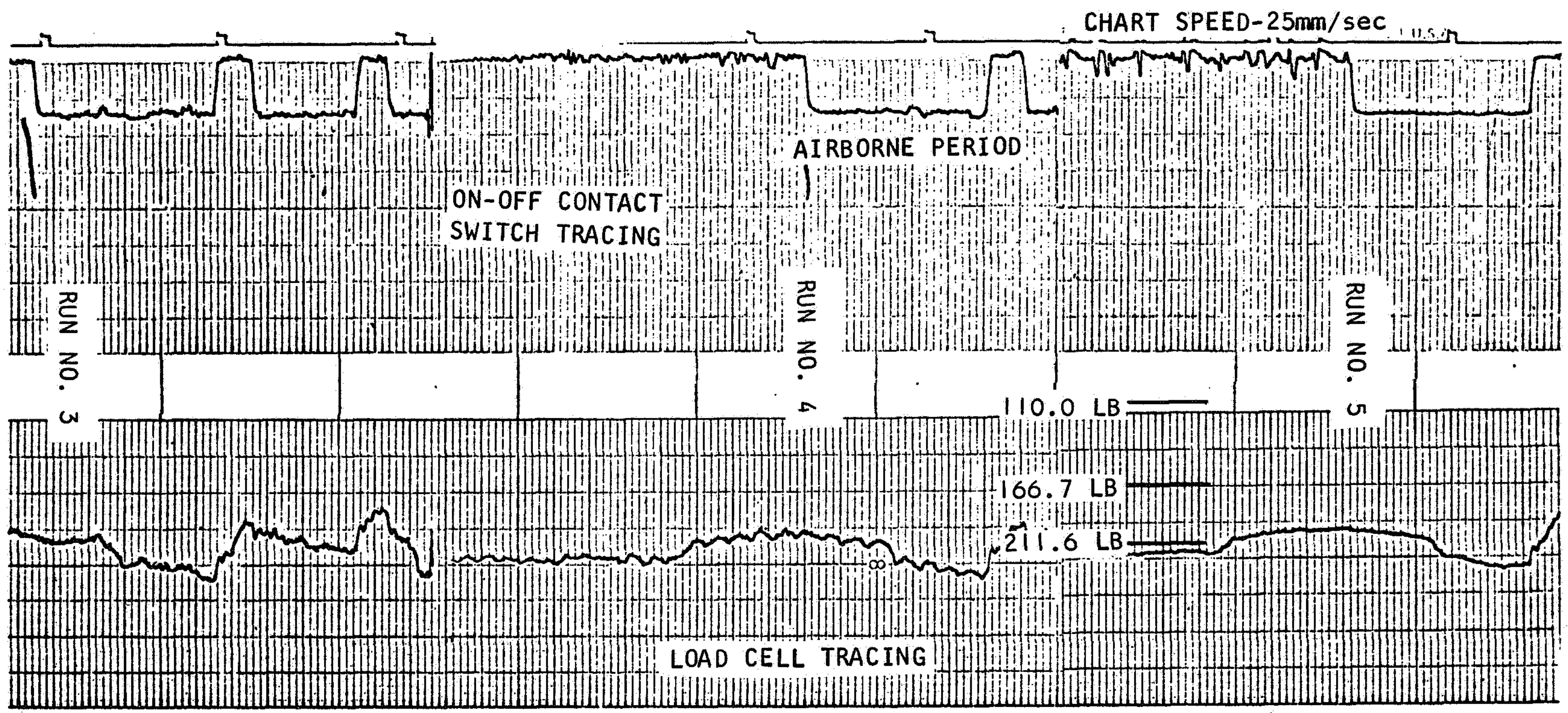

Figure A-10. Load Cell Data for Dynamic Tests 3 through 5

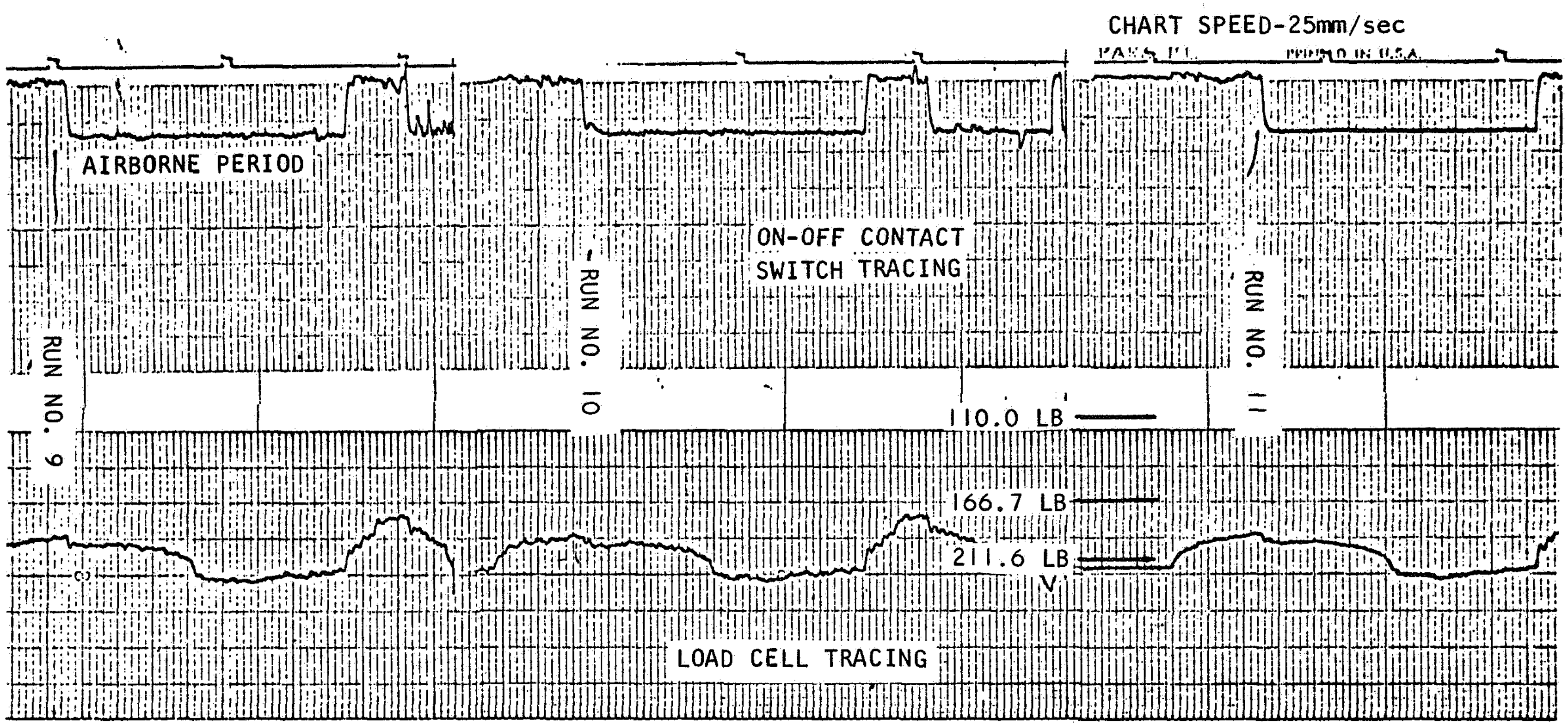

Figure A-11. Load Cell Data for Dynamic Tests 9 through 11

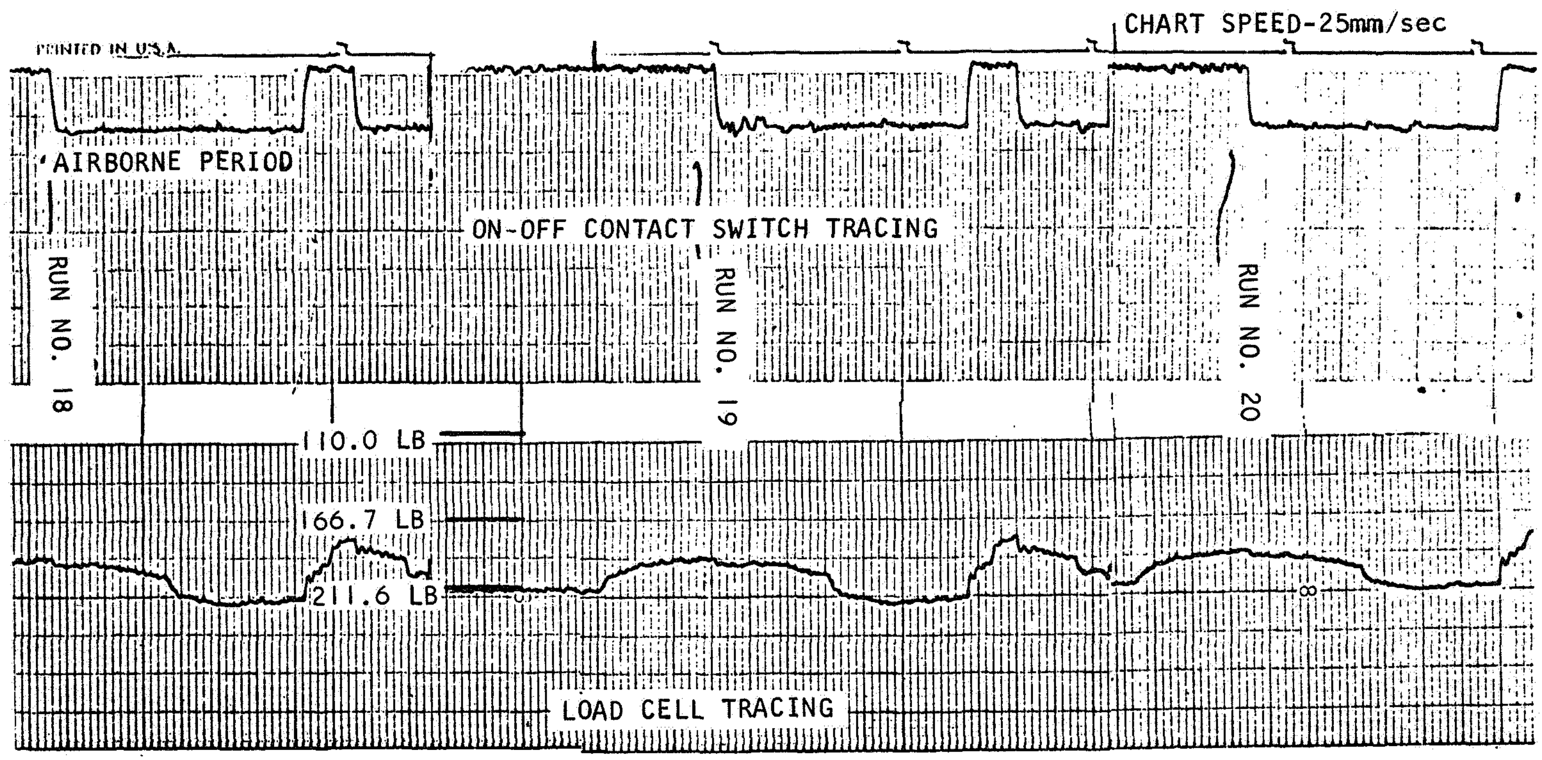

Figure A-12. Load Cell Data for Dynamic Tests 18 through 20

APPENDIX B

LOAD CELL DATA FOR SUBJECTS USING THE BUNGEE-CORD SUSPENSION SYSTEM

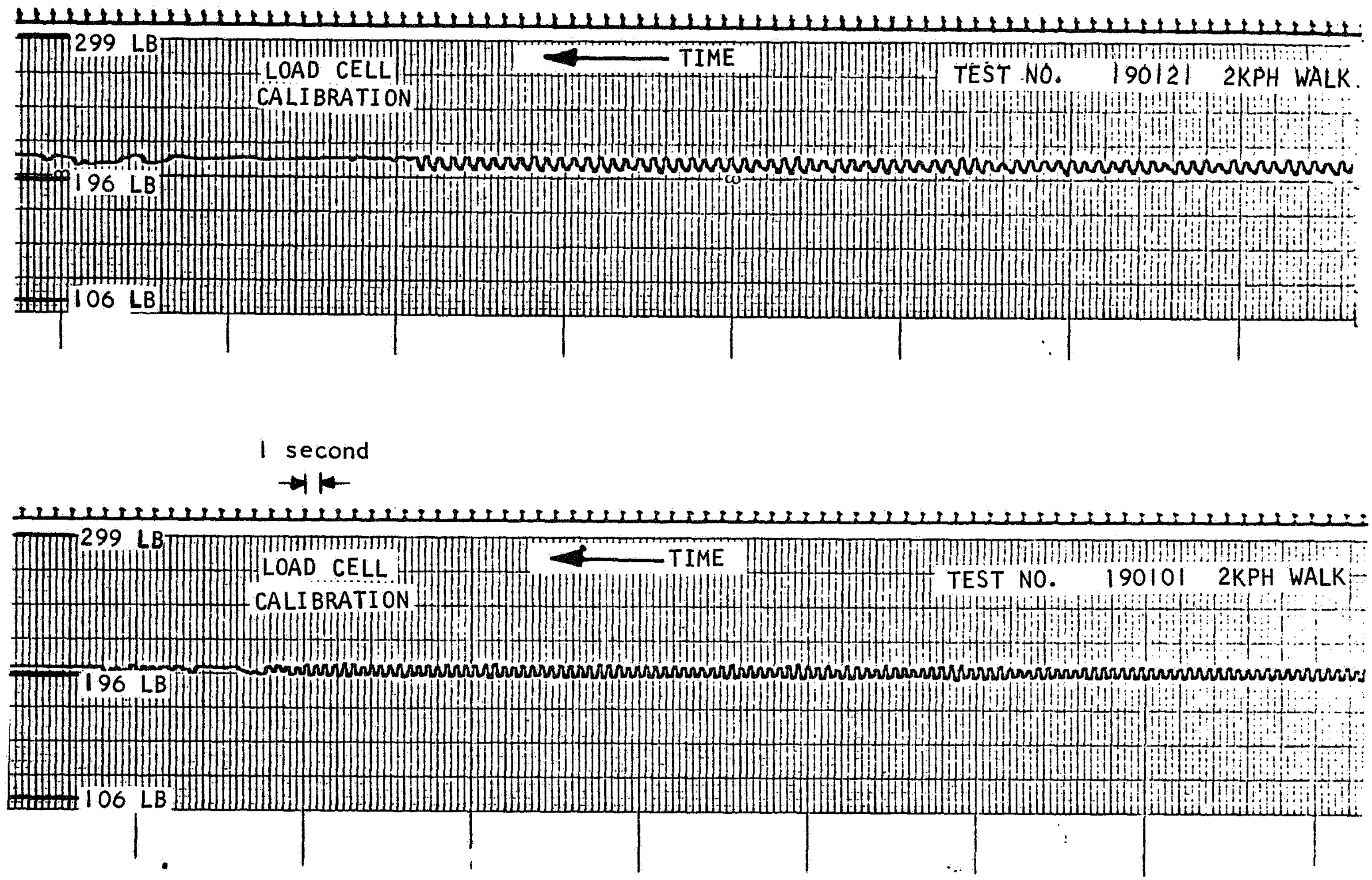

Figure B-1. Load Cell Data for Subjects Walking at 2 KPH at 1/6 G Using the Bungee-Cord Suspension System.

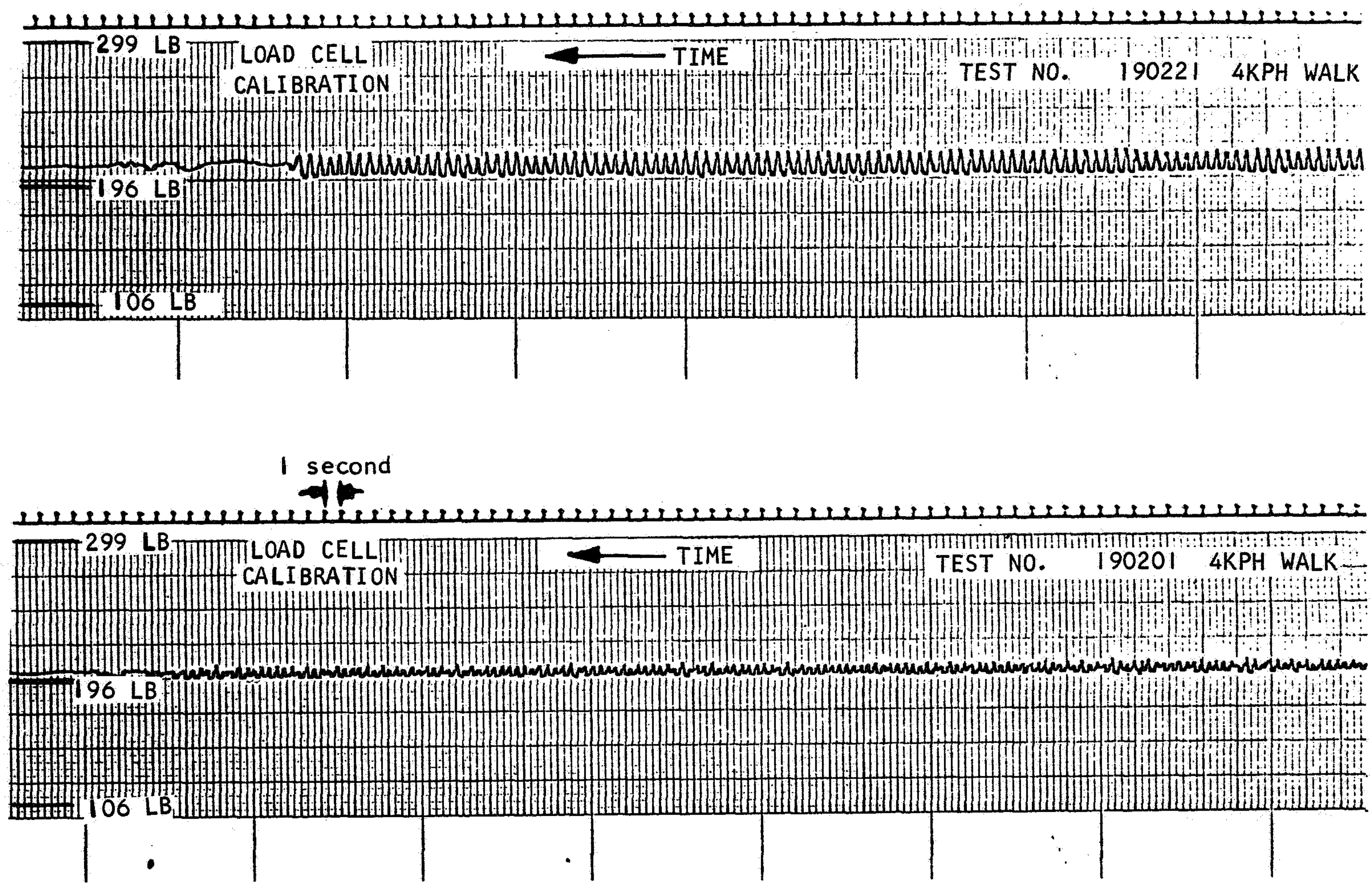

Figure B-2. Load Cell Data for Subjects Walking at 4 KPH at 1/6 G Using the Bungee-Cord Suspension System

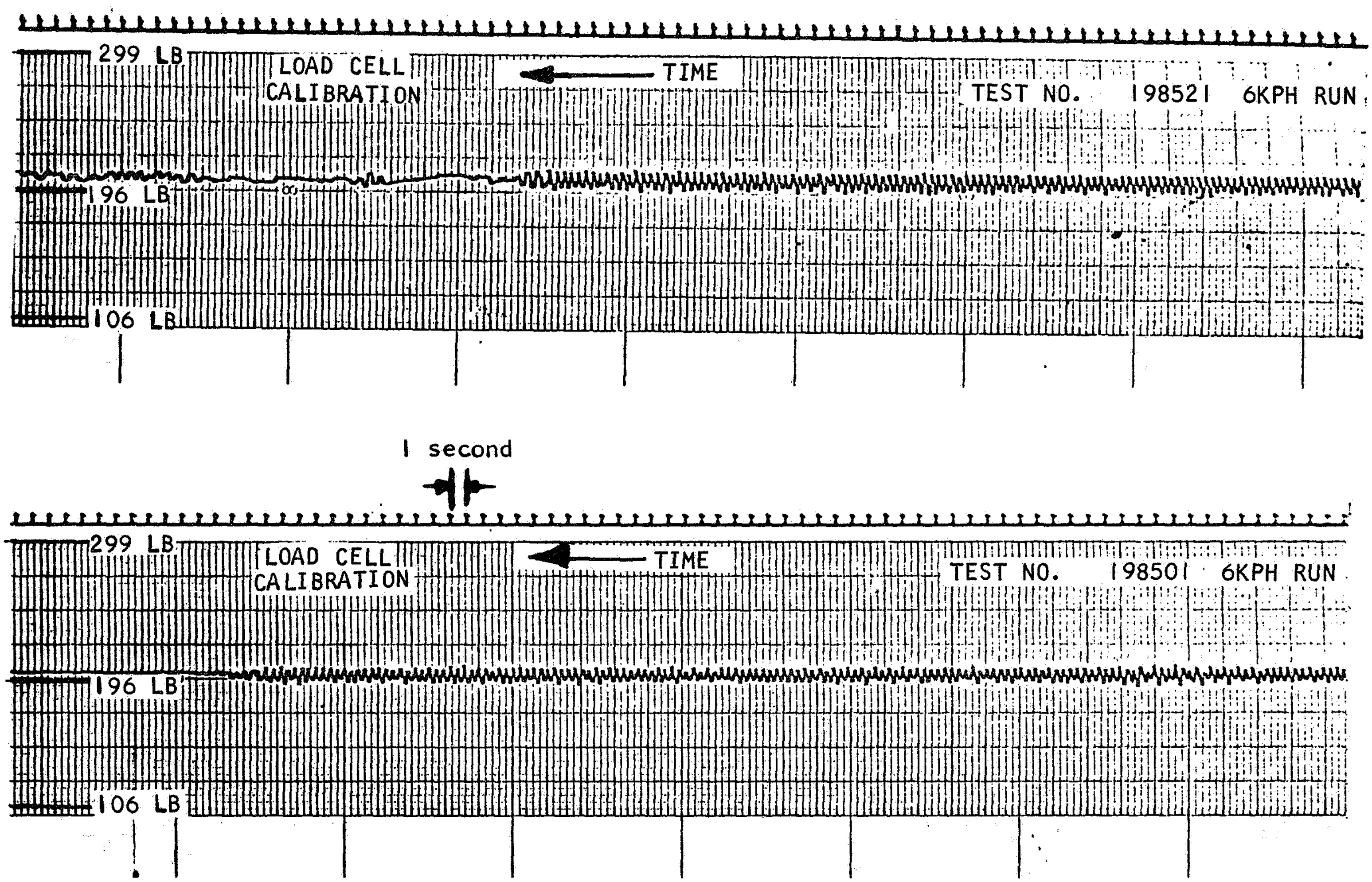

Figure B-3. Load Cell Data for Subjects Running at 6KPH at 1/6 G Using the Bungee-Cord Suspension System

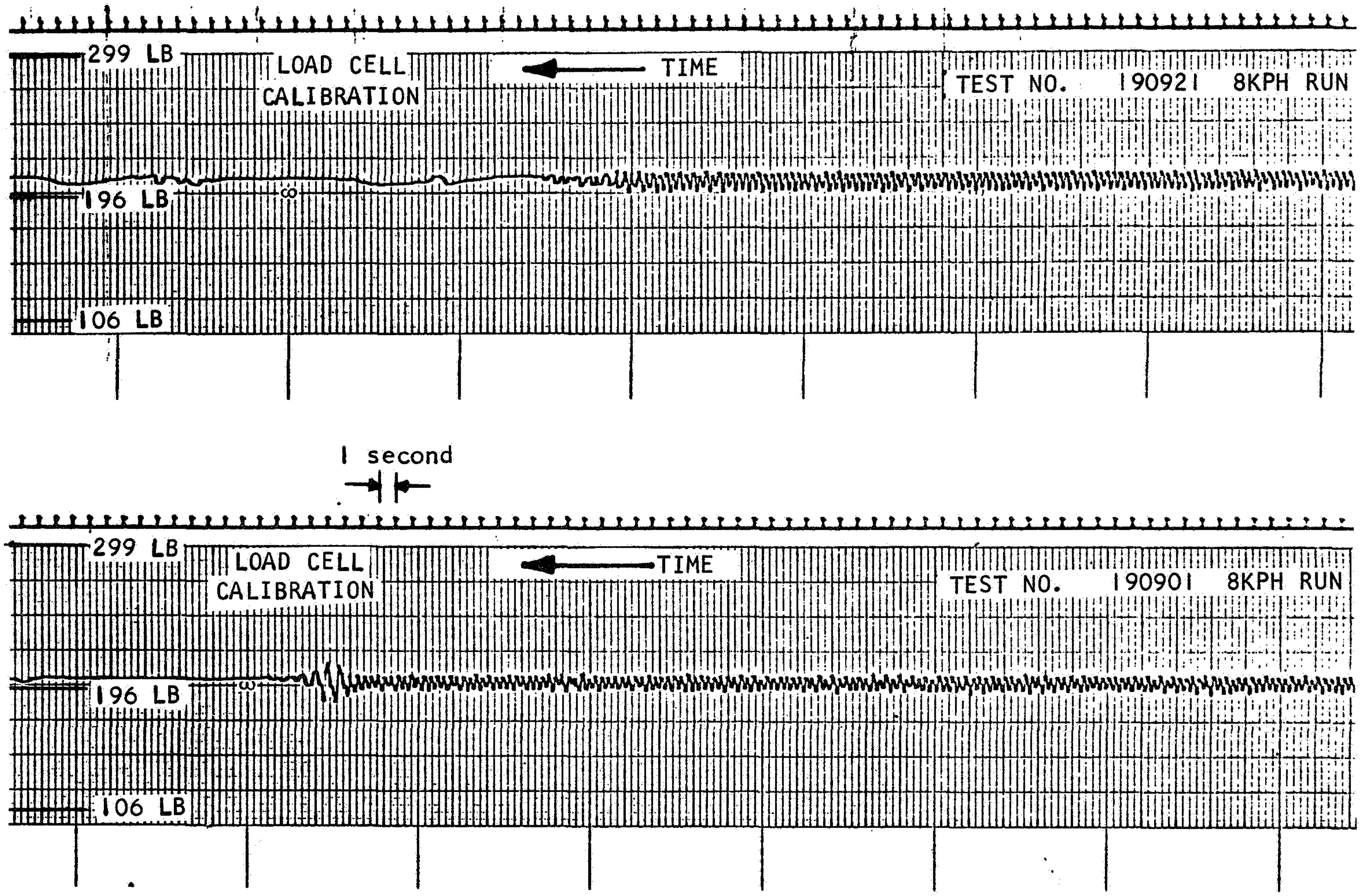

Figure B-4. Load Cell Data for Subjects Running at 8 KPH at 1/6 G Using the Bungee-Cord Suspension System

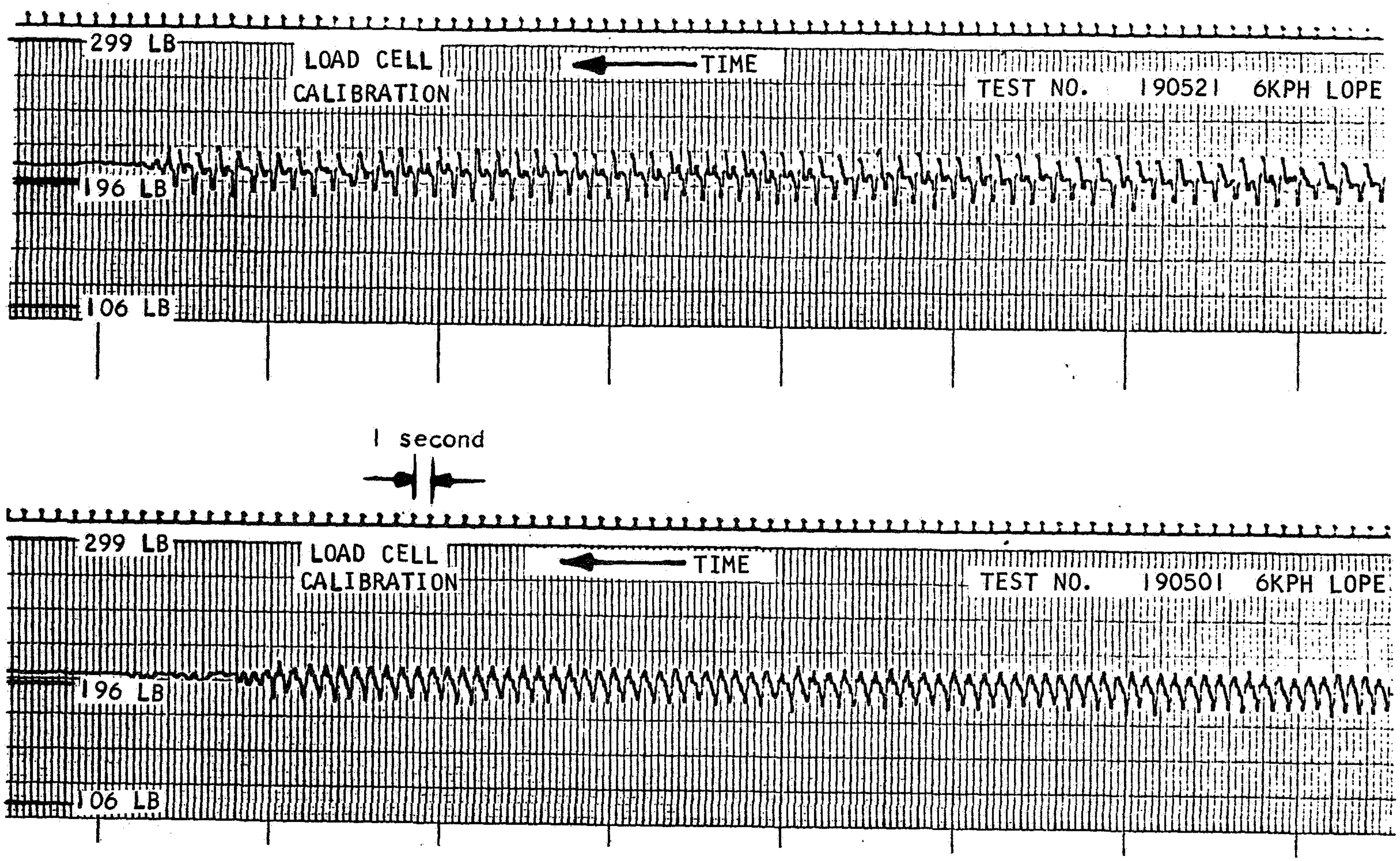

Figure B-5. Load Cell Data for Subjects Loping at 6 KPH at 1/6 G Using the Bungee-Cord Suspension System.

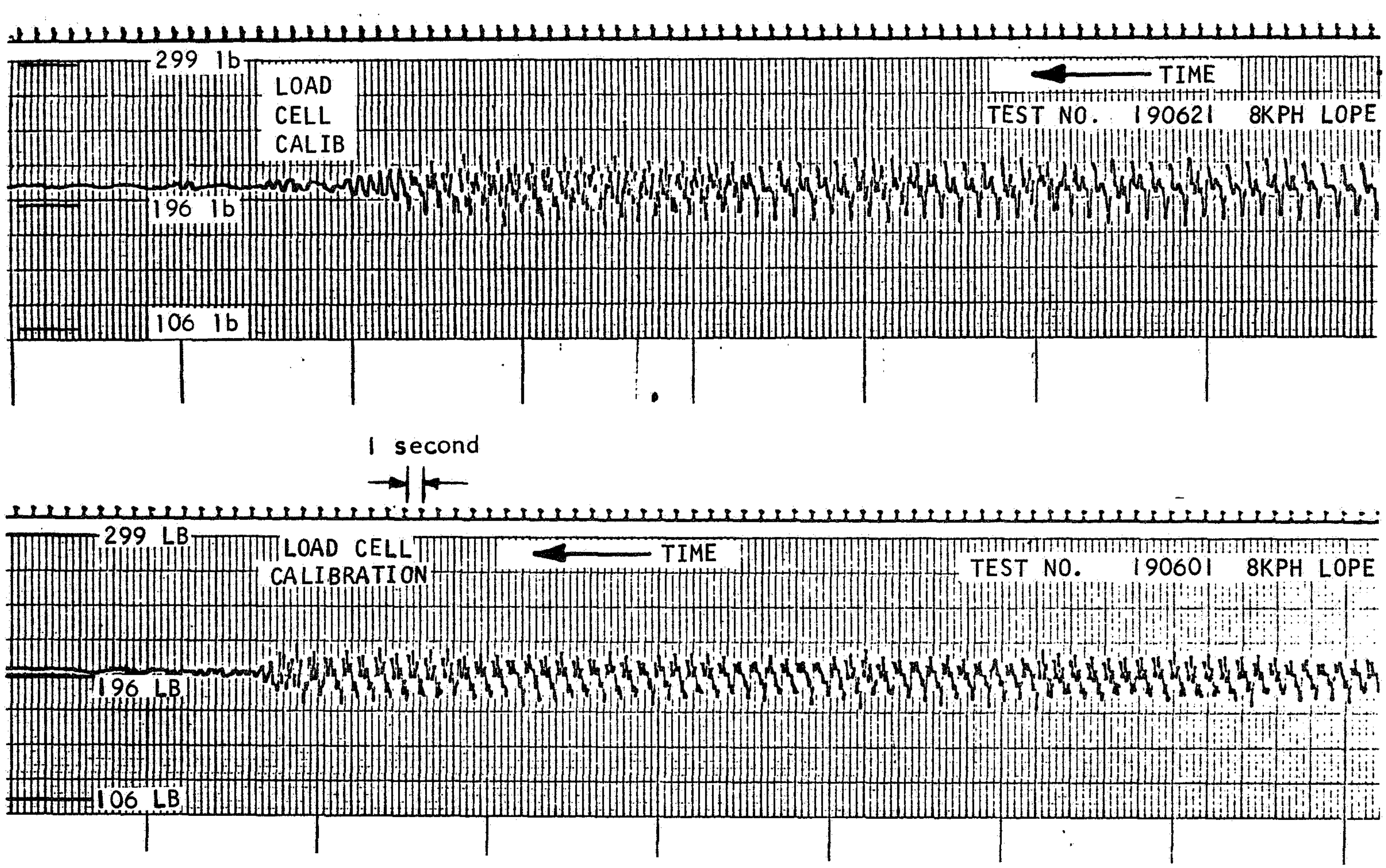

Figure B-6. Load Cell Data for Subjects Loping at 8 KPH at 1/6 G Using the Bungee-Cord Suspension System.