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UNITED STATES ARMY

FRANKFORD ARSENAL

DEVELOPMENT OF ROCKET CATAPULT XM13

by

N. J. WAECKER

Project Orders: TRECOM 60-1
TRECOM 61-4

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ABSTRACT

XM9 Catapults were modified for use with the TRECOM LW-1 seat. These modifications consisted of:

(1) Change in nozzle angle from 52° to 36° 20'.

(2) Change in rocket grain length from 33.4 inches to 24.5 inches.

(3) Change in catapult charge to permit operation with lightweight seats.

The modified catapult was designated Catapult, Aircraft Personnel, XM13. A test program was conducted consisting of static, free-flight, and tower firings with human subjects. The XM13 catapults were considered acceptable for installation in hover craft, with recommendations that sled tests be conducted at forward velocity.

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INTRODUCTION

The purpose of this program was to provide a rocket catapult for use in personnel ejection from TRECOM test hover craft vehicles. These vehicles are fan driven, operating at low altitude.

The scope of the program follows:

(1) Design a rocket catapult for a specific lightweight seat, the LW-1.*

(2) Conduct tests to assure reliable operation within required limits of acceleration and rate of onset.

(3) Supply seven rocket catapults for installation in TRECOM test hover craft.

The XM13 Catapult was developed to meet the ejection needs of flight crewmen using LW-1 seats in experimental flying, platform-type, U. S. Army vehicles. This catapult is a modified M9 catapult, and fills the seat propulsion requirements for recovery at zero altitude and zero velocity.

Low cost was the dominant factor that influenced the design approach to the XM13 catapult. Components developed and qualified previously for Air Force catapults were used in its construction. The modifications were made to provide reduced thrust levels to both booster and sustainer phases, required because of the weight of the LW-1 seat compared to standard Air Force ejection seats.

This report presents a description of catapult operation, performance characteristics, and results of testing conducted on the XM13 catapult.

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*The LW-1 seat is explained in detail in "Ground Operational Recovery Tests of the LW-1 Ejection Seat," TCREC Technical Report 62-47, June 1962.

DEVELOPMENT

Theory

The rocket catapults used with Air Force supersonic aircraft were designed to propel seats weighing approximately 400 pounds and to maintain thrust levels not exceeding 15g. When fitted with a 36° nozzle and a 3.0 inch diameter launch tube, the standard M9 rocket catapult (which has a 52° nozzle and a 2.87 inch diameter launch tube) was acceptable for installation requirements. The M9 ballistic charge, however, was found (Firing Program No. 1, Appendix I) to exceed physiological limits when fired with a seat-man weight of 225 lb. The objective of the program was to modify the ballistic charge to meet the following requirements:

(1) Force onset not to exceed 200 g/sec at 70° F, with peak catapult force not to exceed 15 g.

(2) Force onset not to exceed 250 g/sec at 70° F, with peak catapult force not to exceed 12 g.

(3) Peak rocket force not to exceed 17 g at 70° F (measured through nozzle center line).

(4) Total ejected weight: 220 lb.

(5) Temperature range: -65° through +160° F.

It was anticipated that modification of the catapult (booster) charge and a reduction of rocket (sustainer) thrust would be required. The character of the booster charge did not lend itself to theoretical analysis; therefore, a firing program using a lighter ejected weight was selected as a practical approach to the problem. Data obtained from firings were interpreted and changes made to the booster charge throughout development.

The rocket charge was reduced in length to deliver a lower thrust. Reducing the length of the rocket grain does not adversely affect the burning characteristics, but only reduces the total impulse and thrust proportionately while the burning time remains constant.

Description

Design Data

The principal design characteristics of the XM13 catapult are listed in Table I. These characteristics reflect the design and ballistic requirements discussed previously.

TABLE I. Design Data

Stroke	36. in.
Weight (loaded)	23.5 lb
Piston area of motor tube	5.9 $in.^2$
Internal volume, booster tube	
Initial (loaded)	20 $in.^3$
At tube separation	230 $in.^3$
Bursting pressure	
Booster tube	2400 psi
Motor tube	8000 psi
Launch tube	1800 psi
Structural strength	
Compression	9000 lb
Tension	4000 lb
Nozzle angle relative to catapult center line	36° 20'
Rocket motor outside diameter	2.720 in.
Over-all length (center line mounting hole to base)	41.5 in.
Launch tube outside diameter	3.0 in.

Layout (Design Study)

At the outset, the XM9 catapult design was reviewed and the following changes were made:

(1) The rocket propellant grain was reduced in length from 33.4 to 24.5 inches.

(2) A metal sleeve, or filler, was designed to fill in the space created by shortening of the propellant grain.

(3) The launch tube diameter was redesigned from 2.87 to 3.0 inches.

(4) The nozzle angle was changed from 52° to 36° 20'.

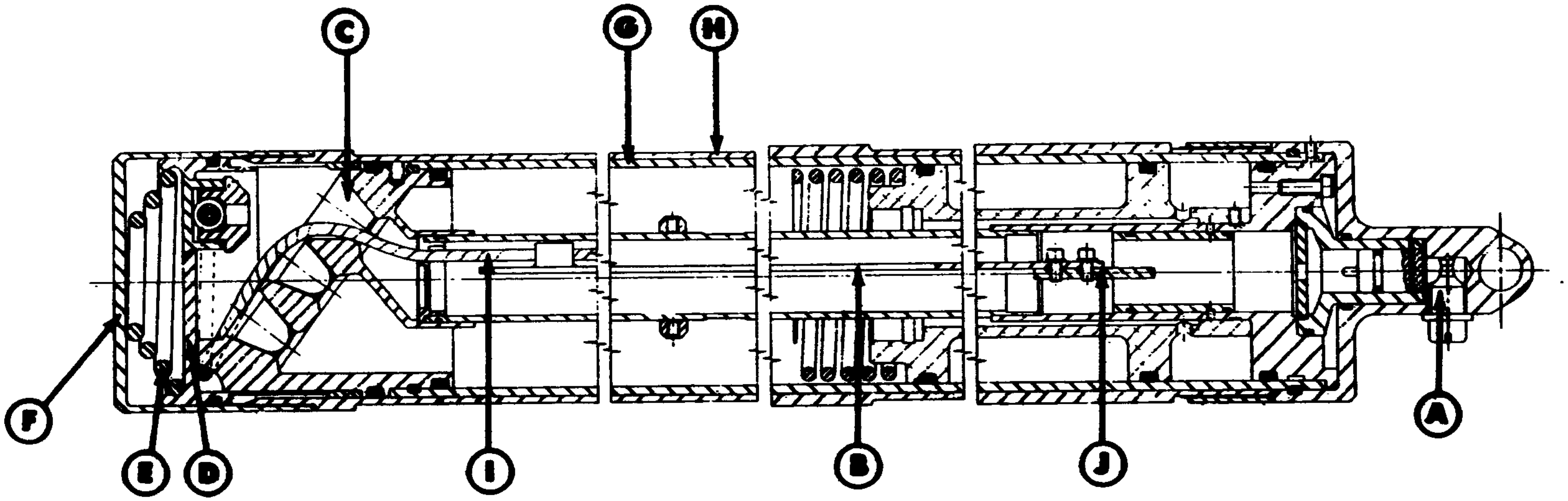
The calculations relating to the change in length of the rocket grain are presented in Appendix II. The resulting design for the XM13 catapult is shown in Figure A.

Method of Operation

Mechanical

The rocket-assisted catapult is actuated by the entrance of gas into the gas inlet (A)*. The gas pressure acts to shear the firing pin shear pin, and the firing pin is propelled forward into and initiates the catapult primer, which ignites the primary igniter. The igniter impinges on the booster propellant, which is bonded on the propellant strip assembly (B). The gas produced by the burning propellant flows through the booster tube and through the nozzle (C) connected to the booster tube. (There are seven nozzles, but only the booster tube nozzle is unplugged.) The propellent gas flows through this nozzle and through an orifice in the nozzle and acts against the can (D) to compress the spring (E) in the base cap (F). As the spring compresses, the can moves into the base cap, permitting the tangs to move inward. This frees the motor tube (G), allowing it to move out of the launching tube (H). As the motor tube telescopes out of the launching tube, the steel cable (I) connected to the can in the base cap extends. The cable becomes taunt shortly

*Letters in parenthesis refer to Figure 1.



A - Gas Inlet
B - Propellant Strip Assembly
C - Nozzle
D - Can
E - Spring
F - Base Cap
G - Motor Tube
H - Launching Tube
I - Steel Cable
J - Slide Valve

Figure A. XM13 Catapult

before tube separation, and when the cable no longer extends, the "T" bar to which it is connected pulls against the slide valve (J) and shears the four pins holding the slide valve in place. The slide valve is pulled down approximately one-half inch, and when it can no longer move and the cable can no longer extend, the cable snaps and the rocket motor tube separates from the launching tube.

Meanwhile, the movement of the slide valve has uncovered gas bypass ports, allowing the hot gases from the booster propellant to come into contact with and to fire the rocket igniter. The burning of the rocket propellant and the resultant propellent gas bursts and erodes the thinned wall areas of the booster tube and, also, ejects the plugs from the nozzles, allowing the rocket propellent gas to flow through all seven nozzles. The nozzles are canted so that the rocket thrust passes through the center of gravity of the seat and man combination. The rocket motor leaves the launching tube and the gas pressure propels the ejection seat and man into free flight. The resulting free flight motion is upward and forward.

Ballistic

Catapult (booster) Section. The booster section of the rocket catapult contains an igniter and primer in a cartridge and a booster strip (propellant strip) in place of a standard cartridge. This system was necessitated by the large expansion ratio (over 11:1) and the limit on the rate of rise of acceleration.

The booster strip is connected to a bar which is part of the slide valve. The propellant charge is bonded to a piece of cotton bunting and the cotton bunting is bonded to the booster strip.

The propellant charge on a typical booster strip (Figure 3) is divided into three sections. The first section to be ignited is composed of HEX-12 propellant, inhibited on each side by 0.005 inch thick ethyl cellulose tape. A series of 1/4 inch holes is punched in the strip of propellant, and the strip is then bonded to silicon tape which, in turn, is bonded to the booster strip. The second section of the booster strip is composed of uninhibited N-5 propellant, and the last section of the strip is composed of unperforated HEX-12 propellant, inhibited on both sides with ethyl cellulose tape.

When the catapult is fired, the igniter impinges on the first section of the booster strip. Since the holes were punched after the inhibitor tape was applied, the inner surfaces in the holes in the propellant start to burn. This progressive

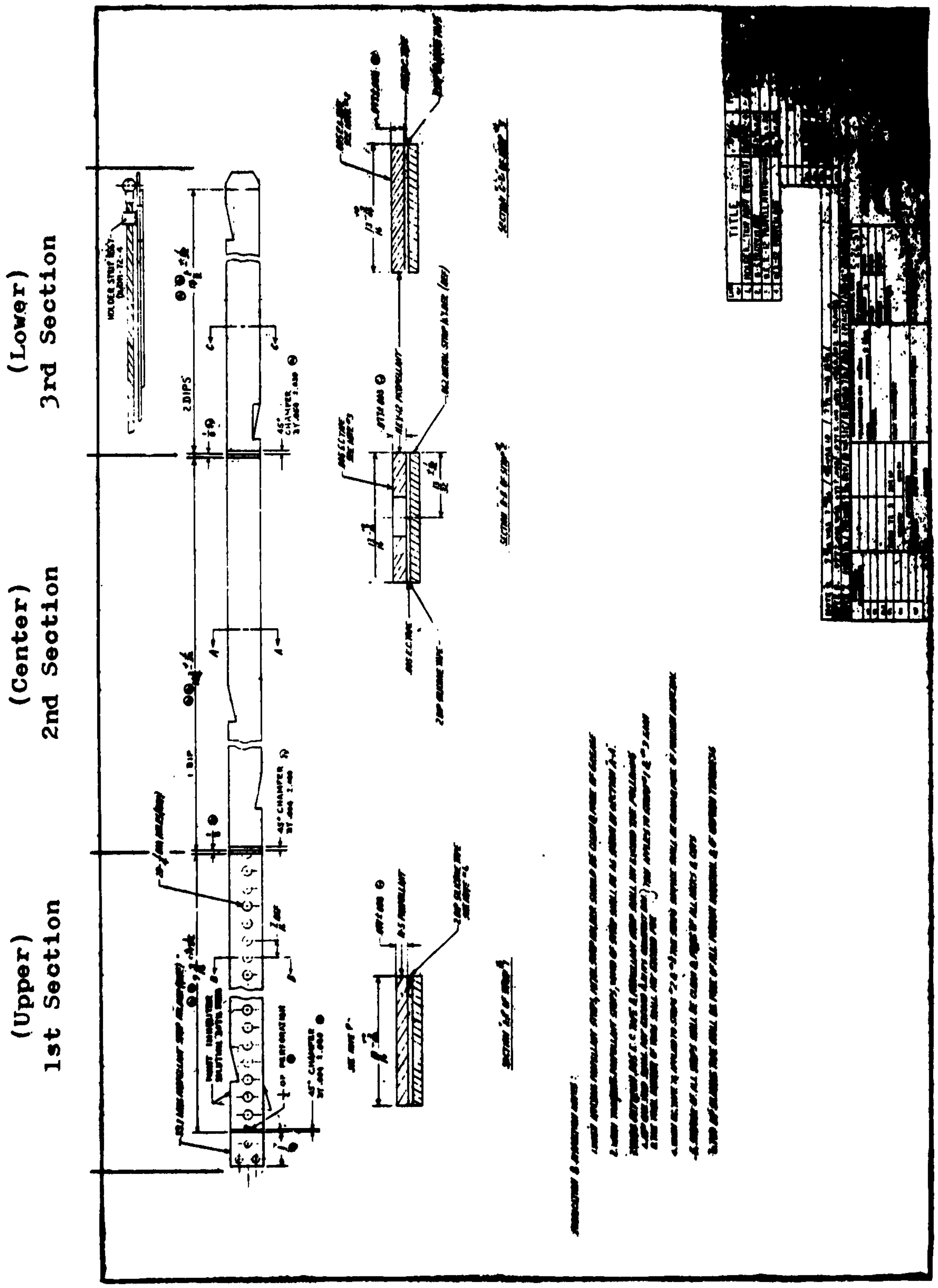


Figure B. Typical Loaded Propellant Strip for Rocket Catapult burning accounts for the rate of rise of the pressure-time curve (Figure C). As the volume of the catapult increases, the hot gases passing over the booster strip ignite the uninhibited N-5 propellant. This is a slower burning propellant than the HEX-12, and accounts for the central portion of the pressure-time curve (the slowly decreasing section of the curve). Gradually, the hot gases wipe the inhibitor off the third section of the booster strip and the neutral burning HEX-12 propellant is ignited. In this way, the ratio of exposed area of propellant to volume of the booster section is maintained. The mesa-type propellants used in the booster are each neutral burning, except for the perforated section; the overall system is progressive burning.

The grooves on the edges of the booster strip permit the gas to circulate around the strip in the booster tube. Figure D shows a partially burned booster strip, illustrating the progressive burning of the perforated section and the slower burning of the center N-5 type propellant (note the amount of burning on the edges of the first two sections). In this figure, the inhibitor is just beginning to wipe off the last section of the booster strip.

Rocket (Sustainer) Section. Reducing the length of the XM9 rocket grain does not adversely affect its burning characteristics; it only reduces its total impulse and thrust proportionately. The burning time remains constant since the grain burns radially and not lengthwise. The rocket grain, therefore, was reduced in length from 33.4 to 24.5 inches, to meet the lower thrust requirement.

The surface area-to-throat-area ratio (K_n) of the M9 sustainer was maintained in the XM13 catapult by reducing the throat area. This, in effect, lowered the J factor (ratio of the nozzle throat to port areas).

The grain used in the XM13 catapult is a cartridge-loaded grain, similar to that used in the M9 catapult. It uses HEX-12 propellant which is spiral wrapped with inhibitor on the outside diameter. Disk inhibitors are used on the ends, and the interior is partially inhibited with a dip inhibitor to give control of the ignition. All the grains used in the development tests of this catapult were manufactured in the Naval Propellant Plant.

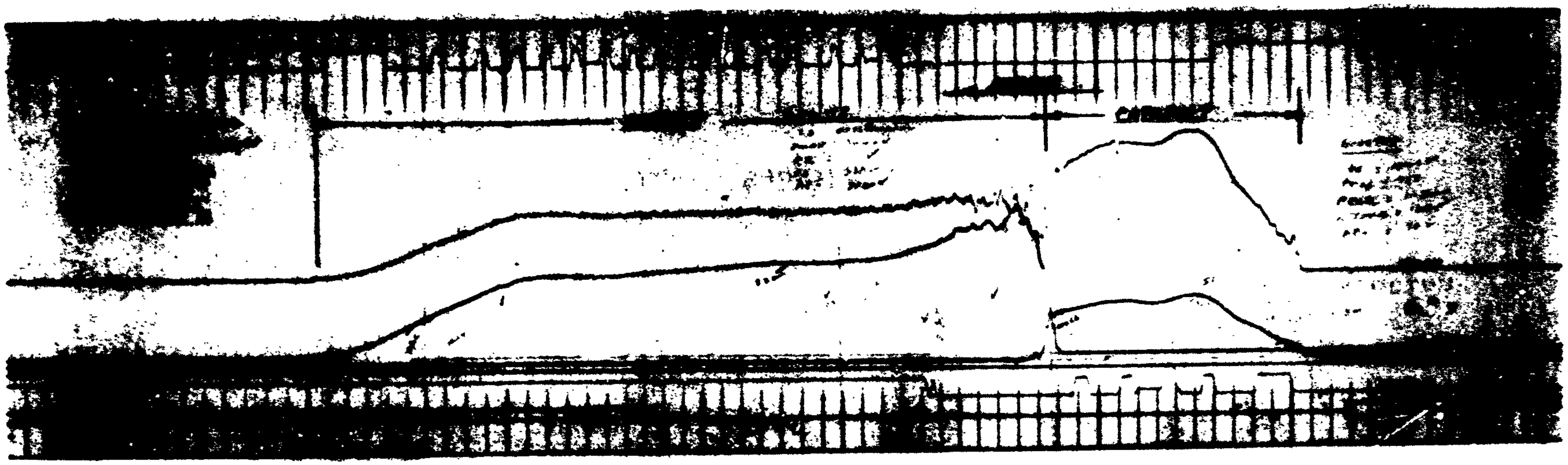


Figure C. Typical Performance Curve XM13 Catapult

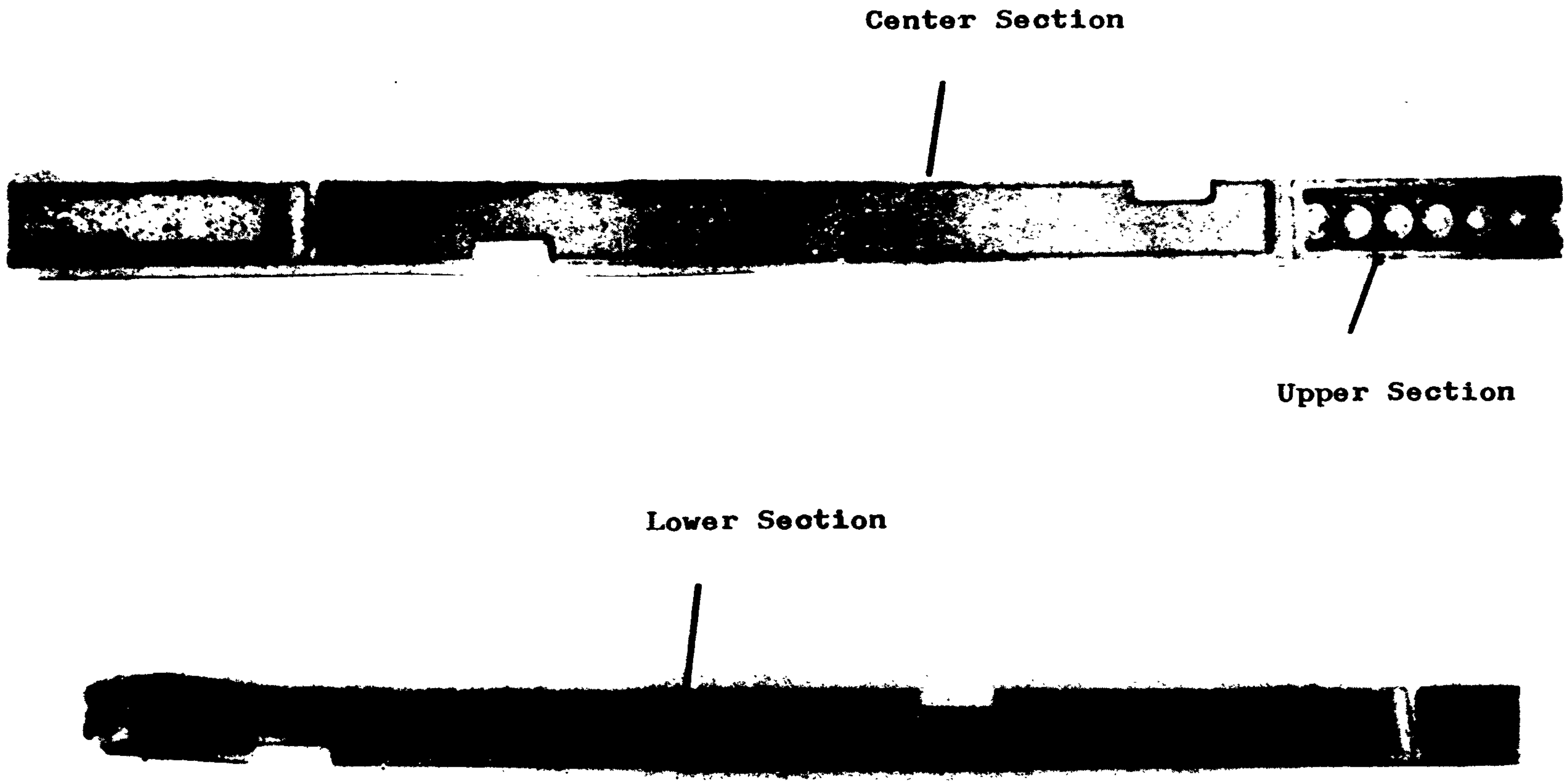


Figure D. Booster Strip Burning Pattern

Design Studies

Separate design studies were conducted on the sleeve and rocket igniter as test data were accumulated. These studies are discussed under development testing as they did not occur until considerable testing had been completed. Briefly, the sleeve was placed above the rocket grain to minimize erosion occurring at the nozzle, and it was found necessary to modify the rocket igniter to obtain reliable ignition at -65° F.

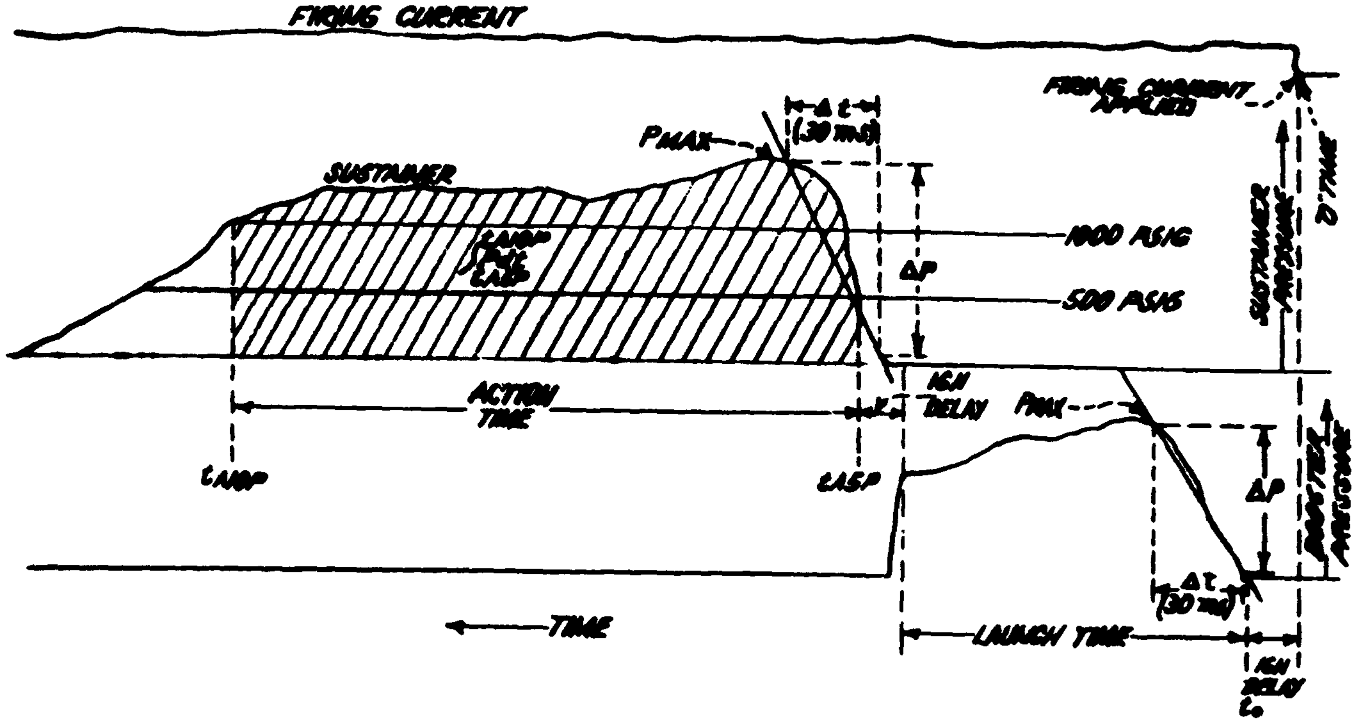
TESTING

Test Equipment and Instrumentation

The booster (catapult) section of the rocket catapult was tested on the vertical tower at Frankford Arsenal in catapults with the sustainer (rocket) section unloaded. After the booster charge was established, tests were made on the Frankford Arsenal horizontal test track at Fort Dix. These horizontal tests were accomplished by holding the sustainer section rigid and firing the booster section down the track into a sand brake. After separation, the sustainer burned in the static fixture on the horizontal track.

The data from the static test then were used to calculate the velocity which would have been obtained in a free-flight test. (A sample calculation is presented in Appendix II.) The data for these tests present the integral of the pressure-time curve with the action time as its limits, rather than the velocity at rocket burnout. This is discussed in Appendix II.

The instrumentation included pressure gages to measure the pressure in the launching tube and in the rocket motor. A thrust cell was used to provide thrust readings. The integral of the acceleration-time curve was used for determining the velocity. An accelerometer on the launching tube completed the instrumentation. Methods of measurement are detailed in Figure E.



NOTES ON METHOD OF MEASUREMENT:

Since the test fixture is additionally instrumented for recording both acceleration and thrust, the data measurements were made in the following manner:

1. Maximum catapult pressure - measured by a pressure gage.
2. Maximum catapult acceleration - measured by an accelerometer.
3. $\Delta G/\Delta T$ - average rate of rise of acceleration of catapult measured during steepest 0.030-second interval on acceleration-time curve.
4. Launch time - measured from zero pressure to catapult separation.
5. Maximum rocket pressure - measured by a pressure gage.
6. Rocket ignition delay - measured over interval from catapult separation to 500 psi on rocket pressure-time curve.
7. Rocket action time - measured over interval from 500 psi to 1000 psi on rocket pressure-time curve.
8. $\Delta G/\Delta T$ for rocket - derived from axial thrust-time curve.

Figure E. Methods of Measurement

The test program consisted of four distinct phases:

(1) Catapult charge tests;

(2) Complete item tests;

(3) Free-flight tests;

(4) Human subject tests.

Catapult charge tests were conducted on the tower at Frankford Arsenal. In these tests the catapult section only was fired, and measurements were taken of acceleration and velocity.

Complete item tests were conducted at Fort Dix, N. J., and at the Naval Propellant Plant, Indian Head, Md. In both cases a static test fixture was used. Measurements were taken of rocket as well as of catapult performance, and rocket ignition characteristics were determined from evaluation of data from these tests.

Free flight tests were conducted at North American Aviation, Inc. (NAA), Columbus Div., and Air Crew Equipment Laboratory (ACEL), Philadelphia, Pa. In all tests, LW-1 seats were used and the complete escape system, including chutes, was tested. In tests at ACEL, catapult rocket pressure data were obtained. In all tests, data were obtained on acceleration, velocity, and height of travel.

Human subject tests were conducted on the tower at ACEL, where human subjects were fired under the same accelerations previously measured in free flight tests. However, the subjects were confined to the tower track to prevent injury from possible failure of test equipment, such as chutes, etc.

Charge Development Tests

Firing Program No. 1. Six firings were conducted on the Frankford Arsenal tower to determine performance of the XM9 catapult charge with a 225-lb weight. The test results are summarized here, and round-by-round data are given in Appendix I.

Data Summary

	Peak Acceleration (g)	Rate of Acceleration (g/sec)
Maximum	16.6	510
Minimum	8.1	200

Because of the wide performance variation, it was concluded that the XM9 catapult charge required modification to function properly with 225-lb weight.

__Firing Program No. 2.__ Six firings were conducted with a charge modified to the following configuration:

HEX-12 propellant, 3-5/8 in. long, perforated, with sides inhibited and top end beveled 45°;

N-5 propellant, 15-1/2 in. long, 1 dip inhibitor;

HEX-12 propellant, 11-1/16 in. long, 2 dips inhibitor.

	Data Summary	
	Peak Acceleration (g)	Rate of Acceleration (g/sec)
Maximum	17.3	540
Minimum	13.4	390

Round-by-round data are listed in Appendix I.

The performance variation had been reduced, but the high acceleration and rate of acceleration made further work necessary to provide lower values.

__Firing Program No. 3.__ Six firings were conducted with the following charge:

HEX-12 propellant, 1.0 in. long, perforated, sides inhibited, and top end beveled 45°;

N-5 propellant, 15-1/2 in. long, 1 dip inhibitor;

HEX-12 propellant, 13-11/16 in. long, 2 dips inhibitor.

	Data Summary	
	Peak Acceleration (g)	Rate of Acceleration (g/sec)
Maximum	12.8	410
Minimum	11.6	360

Round-by-round data are listed in Appendix I.

Firing Program No. 4. Six firings were conducted with the following charge:

N-5 propellant, 15-1/2 in. long, 1 dip inhibitor, except for 1.0 inch at top; sides inhibited, top end beveled;

HEX-12 propellant, 14-11/16 in. long, 2 dips inhibitor.

Data Summary

	Peak Acceleration (g)	Rate of Acceleration (g/sec)
Maximum	14.2	420
Minimum	9.4	310

Round-by-round data are listed in Appendix I.

Firing Program No. 5. Six firings were conducted with the following charge:

HEX-12 propellant, 1.0 in. long, nonperforated, sides inhibited, beveled at top;

N-5 propellant, 15-1/2 in. long, 1 dip inhibitor;

HEX-12 propellant, 13-11/16 in. long, 2 dips inhibitor.

Data Summary

	Peak Acceleration (g)	Rate of Acceleration (g/sec)
Maximum	13.5	420
Minimum	8.9	300

Round-by-round data are listed in Appendix I.

Firing Program No. 6. Six firings were conducted with the following charge:

HEX-12 propellant, 1.0 in. long, nonperforated and completely inhibited. A small V-shaped notch was cut through the inhibitor at the top end;

N-5 propellant, 15-1/2 in. long, 1 dip inhibitor;

HEX-12 propellant, 13-11/16 in. long, 2 dips inhibitor.

	Data Summary	
	Peak Acceleration (g)	Rate of Acceleration (g/sec)
Maximum	14.2	440
Minimum	10.9	310

Round-by-round data are listed in Appendix I.

Firing Program No. 7. None of the programs had resulted in a reproducible charge, and a factorial program was conducted. The purpose of this program was to determine the effect of:

(1) Complete absence of HEX-12 propellant.

(2) Complete absence of N-5 propellant.

(3) Effect of the orifice plate, which had been used only on programs nos. 1, 2, and 4, and omitted on programs nos. 3, 5, and 6.

The round-by-round data are listed in Appendix I.

Results of tests indicated that an acceptable charge could not be made without using a combination of both propellants unless a considerably larger program was undertaken. Also, the orifice plate was of value.

The best results were obtained with a charge similar to that tested under Firing Program No. 5, with an orifice plate added.

Acceptance Tests

Firing Program No. 8. Eleven XM13 catapults were loaded, and a random sample of seven selected for test on the horizontal fixture. The remaining four were delivered to U. S. Army Transportation Research Command (TRECOM) after test completion.

All catapults were loaded so that the metal filler piece was adjacent to the nozzle. On rounds 1 and 2, severe nozzle erosion occurred, apparently due to the position of the filler piece. On round 2, the filler piece was perforated to induce turbulent flow and reduce erosion. The location was then changed and the propellant grain was placed adjacent to the nozzle. Erosion was not detected on any rounds with this arrangement.

Round-by-round data are listed in Appendix I.

The four catapults delivered to TRECOM were used in free flight tests. The test results are reported in TCREC Technical Report 62-47, June 1962, previously referenced.

Firing Program No. 9. Twenty-eight additional XM13 catapults were manufactured, to be used as follows:

6, at -65° F - Tests on horizontal fixture

6, at 70° F - Tests on horizontal fixture

6, at 160° F - Tests on horizontal fixture

3, at 70° F - Free flight tests

7, for delivery to TRECOM.

Round-by-round data for the horizontal fixture tests are listed in Appendix I.

The first round fired at -65° F resulted in misfire - failure to ignite the rocket motor at the end of the catapult stroke. To improve rocket ignition, the remaining catapults were modified as follows. One piece of HEX-12 propellant was placed in the space between the booster cylinder and the metal sleeve. This piece was 0.080 inch thick, 1 inch wide, and 7-1/2 inches long, with inhibitor on one side. The uninhibited surfaces were exposed to the catapult gases. Line of sight was maintained through holes in the booster tube and filler piece. In addition, several grains of boron pellets were pulverized and mixed with nitrocellulose lacquer. The resulting mixture was applied to the top several inches of rocket grain surface as a further aid to ignition.

Six additional firings were made at -65° F, with successful operation resulting. It was concluded that the igniter modification was a satisfactory solution to the misfire of round No. 1.

Catapults were fired with 315-lb weight, with successful operation. This weight represented the 95 percentile weight, i.e., weight including the heaviest man using the seat. This is considered the most severe structural test. The first three firings made at 70° F produced "hot spots" on the motor tube at the location of the metal sleeve. The sleeve material was changed from aluminum to steel, and this condition was corrected. The remaining firings at 70° F were made without incident.

At 160° F, one catapult malfunctioned as follows - the catapult extended approximately eight inches, at which point the rocket grain was ignited prematurely. Examination of metal parts showed a failure had occurred due to misalignment of the cable, causing pre-ignition. This defect was corrected and five successful firings were made at 160° F with corrected units.

As a result of the malfunctions and corrections, the final sample size consisted of the following:

6 ea catapults at -65° F

5 ea catapults at 70° F

5 ea catapults at 160° F

A typical performance record is shown in Figure C.

As a result of testing, it was concluded that the catapult performance met the specified limits of acceleration and rate of acceleration at 70° F, and performed reproducibly over the temperature range. Further testing of these catapults was performed at Air Crew Equipment Laboratory, (ACEL), Philadelphia, Pa., and data are reported in detail in Appendix III.

CONCLUSIONS

The MX13 Catapult demonstrated capability of operating with the lightweight seat, and providing adequate reproducible performance over the temperature range. Reliability of the unit was demonstrated by firings on static fixtures and in free-flight tests.

RECOMMENDATIONS

It is recommended that further tests with the LW-1 seats be conducted up to 300 knots, to establish confidence of operation over the range of velocity, zero to 300 knots.

APPENDIX I

FIRING PROGRAMS

Purpose:	Catapult charge development
Firing method:	Vertical tower
Propellant weight:	225 lb
Conditioned temperature:	+70° F
Direct measurements taken:	Acceleration and final velocity

Round No.	Maximum Acceleration (g)	Rate of Acceleration (g/sec)	Final Velocity (fps)
	Firing Program No. 1		
1	11.4	380	38.2
2	14.9	500	43.8
3	N.R.*	N.R.	33.0
4	14.7	490	42.7
5	16.6	510	44.8
6	8.1	200	30.3
	Firing Program No. 2		
1	15.5	470	N.R.
2	17.3	500	45.5
3	13.8	410	42.4
4	17.3	500	46.1
5	16.5	540	46.8
6	13.4	390	N.R.
	Firing Program No. 3		
1	N.R.	N.R.	40.4
2	11.9	400	39.7
3	11.9	360	38.3
4	11.6	390	39.4
5	12.1	390	40.2
6	12.8	410	41.2

*N.R. - No record.

Round No.	Maximum Acceleration (g)	Rate of Acceleration (g/sec)	Final Velocity (fps)
	Firing Program No. 4		
1	12.8	350	46.8
2	9.4	310	35.5
3	14.1	400	47.3
4	11.4	360	45.0
5	14.2	420	46.9
6	13.6	400	46.6
	Firing Program No. 5		
1	12.2	360	45.1
2	10.7	300	43.6
3	13.5	420	45.4
4	8.9	300	43.4
5	12.6	420	44.3
6	9.7	320	43.3
	Firing Program No. 6		
1	11.3	310	46.1
2	13.9	420	46.0
3	14.2	420	47.3
4	12.1	400	46.0
5	10.9	320	44.7
6	13.6	440	45.7

Firing Program No. 7

Round No.	Maximum Acceleration (g)	Rate of Acceleration (g/sec)	Final Velocity (fps)	Special Conditions*
1	4.6	150	15.2	A_1 B_1
2	15.4	400	47.1	A_1 B_2
3	8.4	270	31.5	A_1 B_3
4	5.0	170	N.R.	A_2 B_1
5	10.8	320	40.4	A_2 B_2
6	8.4	270	19.5	A_2 B_3

*Special Conditions:
- A_1 - 0.030 in. orifice
- A_2 - No orifice
- B_1 - No N-5 propellant
- B_2 - Similar to Firing Program No. 5 strip
- B_3 - No HEX-12 propellant

Firing Program No. 8

Purpose: Acceptance of four catapults for use in free-flight tests.

Firing method: Horizontal track

Propelled weight: 225 lb

Conditioned temperature: +70° F

Direct measurements taken

a. Catapult: Acceleration and final velocity

b. Rocket: Pressure

	Catapult			Rocket
Round No.	Maximum Acceleration (g)	Rate of Acceleration (g/sec)	Velocity (fps)	Maximum Pressure (psi)
1	12.2	280	42.8	2100
2	11.7	250	41.9	2500
3	10.7	230	41.8	1700
4	12.3	240	42.3	2200
5	11.7	260	41.8	2300
6	12.2	260	N.R.	N.R.
7	11.5	230	42.7	2000

Firing Program No. 9

Purpose: Acceptance of seven catapults for installation in test aircraft.

Firing method: Horizontal track

Propelled weight: 315 lb

Direct measurements taken

a. Catapult: Acceleration and final velocity

b. Rocket Thrust

		Catapult			Rocket		
Round No.	Temp (°F)	Max Accel (g)	Rate of Accel (g/sec)	Final Velocity (fps)	Max Thrust (lb)	Impulse (lb-sec)	Remarks*
1	-65	8.1	240	39	N.R.	N.R.	1
2		11.0	190	41	2910	526	
3		9.3	180	39	2310	569	
4		8.7	190	41	2680	586	
5		7.2	195	39	3360	543	
6		8.6	220	39	2300	518	
7		9.2	200	41	2940	588	

		Catapult			Rocket		
Round No.	Temp (°F)	Max Accel (g)	Rate of Accel (g/sec)	Final Velocity (fps)	Max Thrust (lb)	Impulse (lb-sec)	Remarks*
8	70	12.2	205	41	2030	668	
9		13.4	260	43	2500	N.R.	
10		10.6	250	43	2270	643	
11		14.6	220	43	2080	608	
12		12.0	225	44	2130	615	
13	160	17.4	350	N.R.	2510	N.R.	2
14		17.4	350	54	2290	618	
15		19.1	370	52	2290	632	
16		18.5	390	55	N.R.	N.R.	
17		18.3	390	53	2130	627	
18		19.2	350	53	2310	630	

*Remarks: 1 - Rocket failed to ignite.
2 - Rocket pre-ignition.

APPENDIX II

SAMPLE CALCULATIONS OF VELOCITY AND EJECTION HEIGHT

Velocity

Tests of the XM13 catapult were conducted in a static test fixture; however, by using the data obtained in the static test, the approximate velocity and ejection height which would have been obtained in a free flight test may be computed. The following formulas assume that the seat is balanced and that no aerodynamic forces exist.

$$V = \frac{I}{m}$$

where V = ejection velocity;

I = total impulse;

m = mass ejected.

Impulse

The total impulse is the sum of the impulses of the booster and the sustainer. The booster impulse (I_b) and the sustainer impulse (I_s) may be calculated as follows:

$$I_b = m\, V_b \cos \alpha$$

$$I_s = \int (C_f\, A_t \cos \alpha\, p dt - W dt)$$

where α = the rail angle (of the static fixture);

C_f = coefficient of thrust;

A_f = throat area of nozzle

p = instantaneous pressure

W = ejected weight (mg)

The sustainer impulse (I_s) could be calculated from the data measured in the static test ($\int pdt$), but since these equations are only approximationa, the sustainer impulse can conveniently be calculated from the equation:

$$I_s = 600 \cos (\beta - \alpha)$$

where β = the nozzle angle;

600 = the approximate impulse of the propellant grain in lb-sec.

Ejection Height

After the ejection velocity (V) is calculated, the equivalent ejection height (h) may be estimated as follows:

$$h = \frac{V^2}{2g}$$

Sample Calculations

The use of the preceeding equations may be demonstrated using the data obtained from round 10, Firing Program No. 9, Appendix I.

Velocity booster (V_b)	=	43 fps
Mass ejected (m)	=	225 lb/g slugs
Nozzle angle (β)	=	36°
Rail angle (α)	=	13°

$$V = \frac{I}{m} = \frac{I_b + I_s}{m}$$

But,

$$I_b = mV_b \cos \alpha$$

$$= 225/g \times 43 \times \cos 13°$$

$$= 290 \text{ lb-sec}$$

and

$$I_s = 643 \cos (36° - 13°)$$

$$= 580 \text{ lb-sec},$$

therefore

$$V = \frac{290 + 580}{225/g}$$

$$= 124 \text{ fps.}$$

Using this velocity, the ejection height is found to be

$$h = \frac{V^2}{2g} = \frac{124^2}{2g} = 240 \text{ ft.}$$

Calculations for Changing Length of Rocket Grain in the XM13 Catapult

The XM9 catapult (rocket) delivers 4400 lb of thrust, operating at 3000 psi.

$$F = P_c A_t C_f$$

where F = thrust, lb

P_c = chamber pressure, psi

$A_t = \frac{A_s}{Kn}$ = throat area, in.^{2}

A_s = propellant surface area, in.^{2}

Kn = ratio of propellant surface to nozzle throat area.

Holding all other factors constant and reducing the throat area will result in a reduction of thrust.

The XM13 catapult was programmed to deliver a thrust not exceeding 3200 lb, with an operating pressure of 3000 psi. This required a reduction in throat area of 26 percent and a corresponding reduction in A_s, propellant surface area. This was accomplished by a reduction in length from 33.4 to 24.5 inches. No other change was required since this is an outside and end-inhibited grain and the propellant surface area is a function of the internal geometry and the length.

APPENDIX III

U. S. NAVAL AIR ENGINEERING CENTER
Philadelphia, Pa. 19112

AEROSPACE CREW EQUIPMENT LABORATORY

MIPR No. FA-1242062 151

STATIC FREE FLIGHT PERFORMANCE AND HUMAN
EVALUATION OF U. S. ARMY XM-13 ROCKET CATAPULT
USING LW-1 ESCAPE SYSTEM

NAEC - ACEL-495 11 October 1963

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APPENDICES

A. Qualification firings of LW-1 ejection seat conducted on ACEL ejection tower - dummy and live

B. Results of LW-1 static ejections

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INTRODUCTION

MIPR No. FA-1242-62-151 was issued by the Frankford Arsenal on 11 January 1962 to the Air Crew Equipment Laboratory to obtain performance information with the XM-13 catapult (rocket assist) and the LW-1 ejection seat combination, and to investigate the physiological acceptance of the catapult/seat configuration.

SUMMARY OF RESULTS

Two free flight ejection tests were conducted at ground level and zero velocity to determine dynamic characteristics of catapult seat/man combination, using 5 and 95 percentile dummies.

Two ejection tower tests were conducted using human subjects to determine adequacy of the catapult/seat combination for use in operational aircraft (see Fig. Nos. 5 through 10).

The first free flight ejection test was conducted on 10 January 1962 employing a 5 percentile dummy and a total ejected weight of 241 lbs. for the complete system.

The second free flight ejection test was conducted on 20 January 1962 employing a 95 percentile dummy and a total ejected weight of 315 lbs. for the complete system.

The information obtained from instrumentation records indicates that the performance on each test was within safe physiological limits for human subjects.

A series of tower ejections was made using the modified NAMC steel catapult (vented), the LW-1 seat, and 5 and 95 percentile dummies to duplicate the parameters obtained from the two static firings (see Fig. Nos. 22 & 23). The required peak G and rate of onset were obtained experimentally by changing the internal volume of the NAMC catapult. A series of nine firings were conducted with a 5 percentile dummy at the approximate peak G and onset rate obtained from static firing no. 1 (see Appendix B).

A series of 14 firings was conducted with a 95 percentile dummy at the approximate peak G and onset rate obtained from static firing no. 2 (see Appendix B).

Evaluation of acceleration curves indicated that the acceleration forces were within physiological limits. Accordingly, tower firings were made with a 5 and 95 percentile human subject to complete the assigned test requirements (see Fig. Nos. 24, 25 & 26).

Static firing of the LW-1 seat and XM-13 rocket catapult imparted acceleration forces to anthropomorphic dummies which are considered within physiological limits (see Appendix B). On 10 January 1962 a 5 percentile dummy, LW-1 seat (see Fig. Nos. 2, 3 & 4), XM-13 catapult (rocket assist) were used to perform a free flight ejection at gound level zero velocity conditions. The first free flight test took place at Mustin Field, and was considered a successful ejection, although no motion picture coverage was obtained because of power failure of the photographic equipment.

Instrumentation acceleratior traces showed a peak G of 11 (see Fig. No. 1) and a rate of G onset of 335 G's per second. The rocket pressures developed are shown in Fig. No. 20. On 20 January 1962 a 95 percentile dummy, LW-1 seat, and XM-13 catapult (rocket assist) were used to perform a second free flight ejection test. This ejection, No. 2, was considered successful.

The trajectory peak was approximately 133 ft, with dummy vertical descent with opened parachute of 80 ft. and a sink rate of 28 ft. per second. Instrumentation acceleration traces showed a peak G of 9.5 and a rate of G onset of 180 G's per second. The rocket pressures developed are shown on Fig. No. 21. Simulating the peak G and G onset values obtained from the two static firings, tower ejections were made with human subjects in qualification tests of the LW-1 seat (see Fig. No. 18). To accomplish this, a modified NAMC steel catapult (40" stroke, vented) was used in conjunction with MK-3 MOD 0 cartridges. The internal volume of the catapult was modified to produce the required onset rate, simulating free flight ejection tests nos. 1 and 2, respectively.

Prior to firing human subjects, it was necessary to modify the shoulder strap fitting to prevent interference with subject's shoulder (see Fig. Nos. 15 & 16). It was also considered physiologically safer to provide head support during human subject tower ejections. This was accomplished by installation of a face curtain firing system (see Fig. No. 19).

DISCUSSION

The Air Crew Equipment Laboratory conducted a series of tests on the LW-1 escape system. Two of the tests were free flight tests at zero-zero conditions made at Mustin Field; the remaining tests were controlled ejections on the ejection seat tower at Bldg. #79. The free flight or static tests no. 1 and 2 were made with a 5 and 95 percentile dummy, respectively. The first test was made without photographic coverage. The Hulcher camera seized from cold weather and the power supply failed for the Fairchild camera. Instrumentation was obtained through a telemetering package installed in the dummy's chest cavity. Since all other facilities required for the test had been readied, it was decided to go without camera coverage. Oscillograph records of test no. 1 (see Fig. No. 20) indicate the following forces were obtained:

a. 647 psi booster phase developed over .16 seconds of effective stroke, with a 335 G per second onset rate.

b. Peak vertical acceleration of seat was 11.0 G.

c. Peak vertical acceleration of dummy, measured at dummy hip was 12.5 G.

Fig. No. 12 shows the ground plot pattern from ejection to touchdown. The forces obtained from test no. 1 were later simulated on the ejection tower.

Test no. 2 was made 20 January 1962 and was complete with film coverage. Agair, instrumentation was obtained through a telemetering package installed in the dummy's chest cavity. Oscillograph record (see Fig. No. 21) of test no. 2 indicate the following forces were obtained.

a. 678 psi booster phase developed over .18 seconds of effective stroke with a 176 G per second onset rate.

b. Peak vertical acceleration of seat was 9.4 G.

c. Peak vertical acceleration of dummy measured at dummy hip was 9.5 G. Fig. No. 13 & 14 show the ground plot and trajectory plot, respectively, pattern from ejection to touch down. The forces obtained from Test No. 2 were later simulated on the ejection tower.

It should be noted that during the free flight Test no. 1, the parachute passed through the rocket exhaust flame and was extensively burned (see Fig. No. 11). Had the flame burned through the tape at the outer circumference of the parachute, failure would have been certain.

It is the opinion of this activity following careful examination of the burned and structurally damaged parachute, that the present LW-1 seat is not fully acceptable for service use. This opinion was expressed in Commanding Officer, Naval Air Material Center letter XG-5:CTK:eeh13100 (3806) of 11 April 1962.

The program was continued on the ACEL ejection tower. A MK-3 MOD 0 cartridge was selected as the source of power. The catapult used was the NAMC type steel barrelled, and was vented to control decay of the internal pressure, with a 40" stroke. The internal volume was controlled by inserting plugs in the bore of the catapult.

A series of nine tower ejections was conducted using a 5 percentile dummy and the LW-1 seat to simulate the results of free flight Test No. 1.

A series of 14 tower ejections was then conducted using a 95 percentile dummy and the LW-1 seat, to simulate the results of free flight test No. 2.

A new LW-1 seat was installed on the tower, and was modified by installing a face screen firing system to provide for proper head positioning during human subject firings, and for subject's actuations of the firing. The propellant in MK-3 MOD 0 cartridges was reduced to provide low G level firings for indoctrination of subjects prior to the actual qualification tests. Test of the retention system for the human subjects revealed that the shoulder strap attachment fitting would dig into the subject's shoulder during ejection (see Fig. No. 15). The shoulder harness and attachment fitting were modified to eliminate this interference before human subject firing (see Fig. Nos. 16 & 17). Qualification tests were then made on the LW-1 seat, using 5 and 95 percentile subjects. A comparison of oscillograph tracings of free flight vs. tower tests shows the close simulation of G and onset from tower tests with the G and onset previously recorded from free flight tests (see Fig. Nos. 27 & 28). The pressure curves for the tower firings differ in shape from the free flight tests because of the difference in total ejected weight. The tower ejections required an additional 150 lbs. for the cradle and adapter.

CONCLUSIONS

The test results obtained from two static firings and ejection tower evaluation firings indicate that the XM-13, LW-1 seat/man combination produce peak G and G onset values which are physiologically endurable. In addition, the peak trajectory heights obtained during static firings were such that both 5 and 95 percentile subjects were able to descend vertically with the sink rate at 30 ft. per second (see Fig. No. 14).

RECOMMENDATIONS

1. Accept system with following modifications:

a. Incorporate parachute deployment delays to avoid rocket exhaust and thus prevent burning of the parachute.

b. Modify shoulder strap fitting.

c. Install face curtain firing system for head support.

QUALIFICATION FIRINGS OF LW-1 EJECTION SEAT CONDUCTED ON ACEL EJECTION TOWER - DUMMY AND LIVE

TOWER FIRING NO.	DATE OF TEST	MAIN CHARGE (GRAMS)	TOTAL EJECTED WEIGHT (LBS.)	DUMMY WEIGHT (LBS.)	TOWER HEIGHT OBTAINED (FT.)	PEAK G SEAT FRAME	PEAK CATAPULT PRESSURE (PSI)	RATE OF ONSET G/SEC.	NAME OF SUBJECT
4410	2/2/62	MK-3 MOD 0	367.5	134	30.0	12.2	1160	245	
4411	2/2/62	"	367.5	134	26.5	10.2	970	196	
4412	2/3/62	"	367.5	134	29.0	12.0	1240	326	
4413	2/3/62	"	367.5	134	30.5	12.9	1330	343	
4414	2/7/62	"	367.5	134	28.0	12.0	1200	335	
4415	2/7/62	"	367.5	134	29.5	13.0	1325	318	
4416	2/7/62	"	367.5	134	32.5	13.6	1370	361	
4417	2/7/62	"	367.5	134	30.0	12.7	1255	340	
4418	2/8/62	"	419.5	200	27.0	11.9	1420	300	
4419	2/8/62	"	419.5	200	24.0	10.6	1150	230	
4420	2/10/62	"	419.5	200	31.5	11.1	1110	182	
4421	2/10/62	"	419.5	200	30.5	10.4	1020	173	
4422	7/10/62	"	434.5	215	29.5	10.7	1120	166	
4423	2/10/62	"	419.5	200	26.0	9.4	1060	165	
4424	2/10/62	"	419.5	200	26.0	10.0	1080	175	
4425	2/10/62	"	419.5	200	27.5	9.9	1124	175	
4426	2/10/62	"	419.5	200	26.5	9.5	1068	166	
4427	2/14/62	"	367.5	134	29.5	12.5	1300	326	
4428	2/14/62	"	419.5	200	24.5	10.0	1070	178	
4429	2/14/62	"	419.5	200	26.0	10.1	1095	190	
4430	2/14/62	"	419.5	200	24.5	9.1	995	170	
4431	2/14/62	"	419.5	200	26.5	10.0	1100	228	
4432	3/17/62	"	437.0	204	24.0	9.1	1047	170	
END OF DUMMY TESTS									
4433	3/20/62	37.06	381.0	158	12.0	- -	- -	- -	LT B. LOWI
4434	3/22/62	36.20	319.0	156	9.5	- -	- -	- -	F. H. Lee
4435	3/26/62	MK-3 MOD 0	430.0	207	24.0	8.4	1018	175	K. Roach
4436	3/23/62	MK-3 MOD 0	378.5	155	31.0	- -	- -	- -	F. H. Lee
4437	3/23/62	MK-3 MOD 0	207.0	430	25.0	- -	- -	- -	K. Roach

APPENDIX A

RESULTS OF LW-1 STATIC GROUND LEVEL FREE FLIGHT TESTS

TEST NO.	DATE	DUMMY SIZE (PERCENTILE)	TOTAL EJECTED WEIGHT (LBS.)	EJECTION ANGLE (DEGREES)	PEAK TRAJECTORY (FT.)	VERTICAL DESCENT (FT.) FULLY OPEN PARACHUTE	PEAK CATAPULT FORCE G's	MAXIMUM RATE OF ACCEL. ONSET G/SEC.	PEAK CATAPULT PRESSURE PSI	PEAK ROCKET FORCE G's	PEAK ROCKET PRESSURE PSI
1	1/10/62	5	241	13	Not Obtained	Not Obtained	11.0	335	651	7.4	3150
2	1/20/62	95	315	13	133	80	9.5	180	690	4.5	3540

APPENDIX B

ACCELEROMETERS MOUNTED ON LW 1 SEAT

PHOTO NO: CAN-341719(L)-1-62 Figure No. 1

5 PERCENTILE DUMMY AND SEAT CONFIGURATION FOR STATIC EJECTION WITH ARMS REMOVED TO COMPENSATE FOR WEIGHT OF TELEMETERING PACKAGE

PHOTO NO: CAN-341720(L)-1-62 Figure No. 2

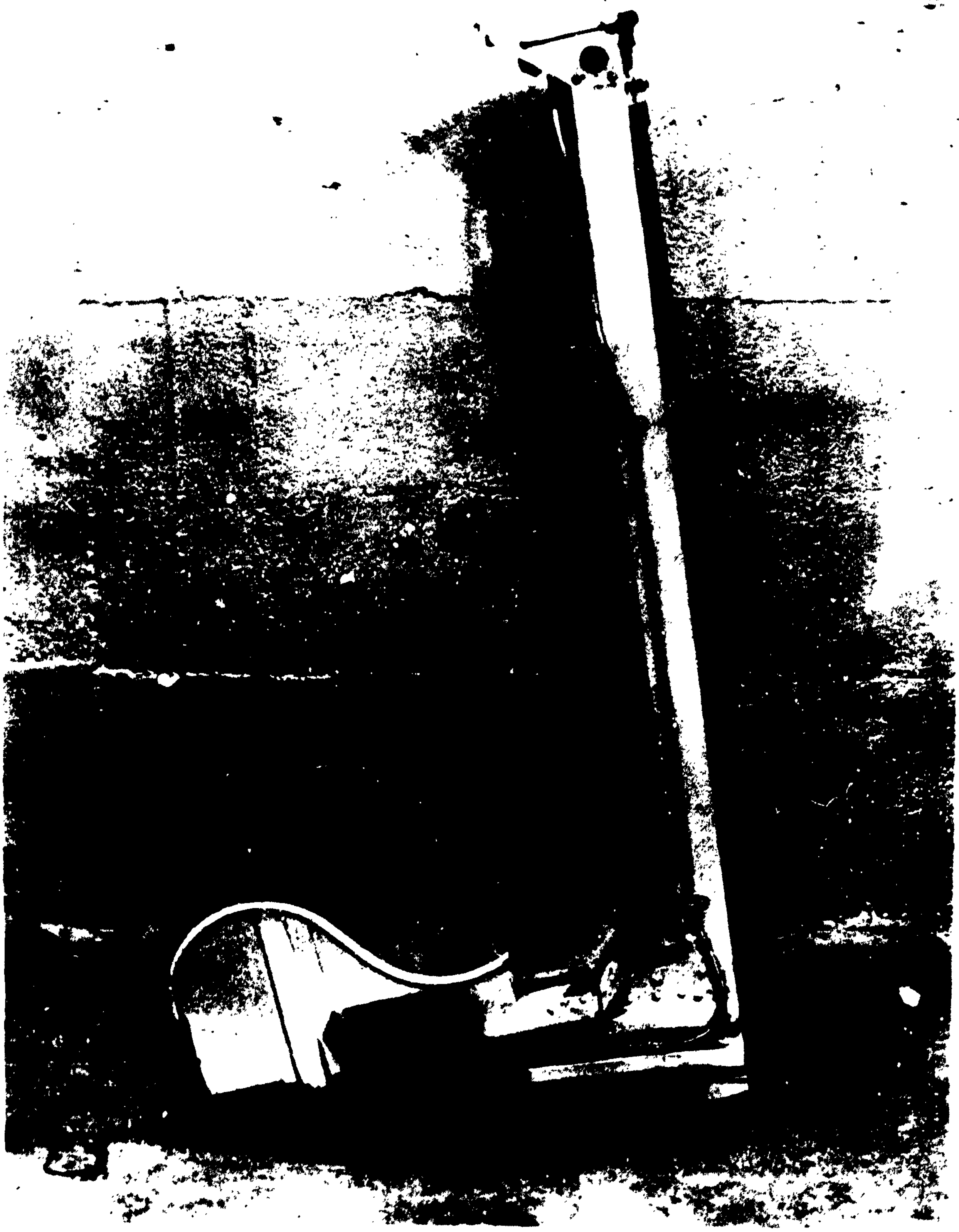
5 PERCENTILE DUMMY AND SEAT CONFIGURATION FOR STATIC EJECTION

PHOTO NO: CAN-341721(L)-1-62

Figure No. 3

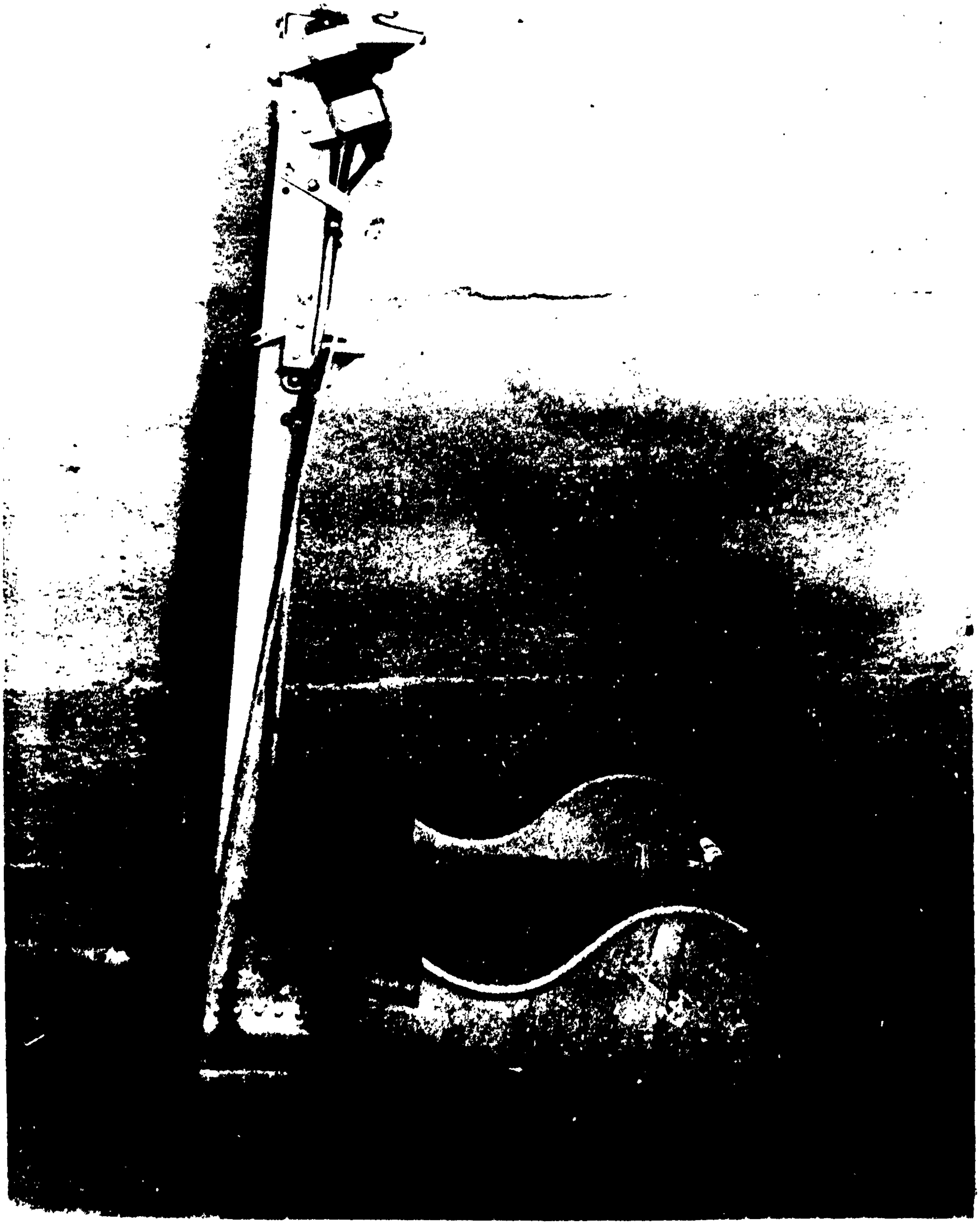
THREE-QUARTER VIEW OF 5 PERCENTILE DUMMY AND SEAT CONFIGURATION FOR STATIC EJECTION

PHOTO NO: CAN-341722(L)-1-62 Figure No. 4



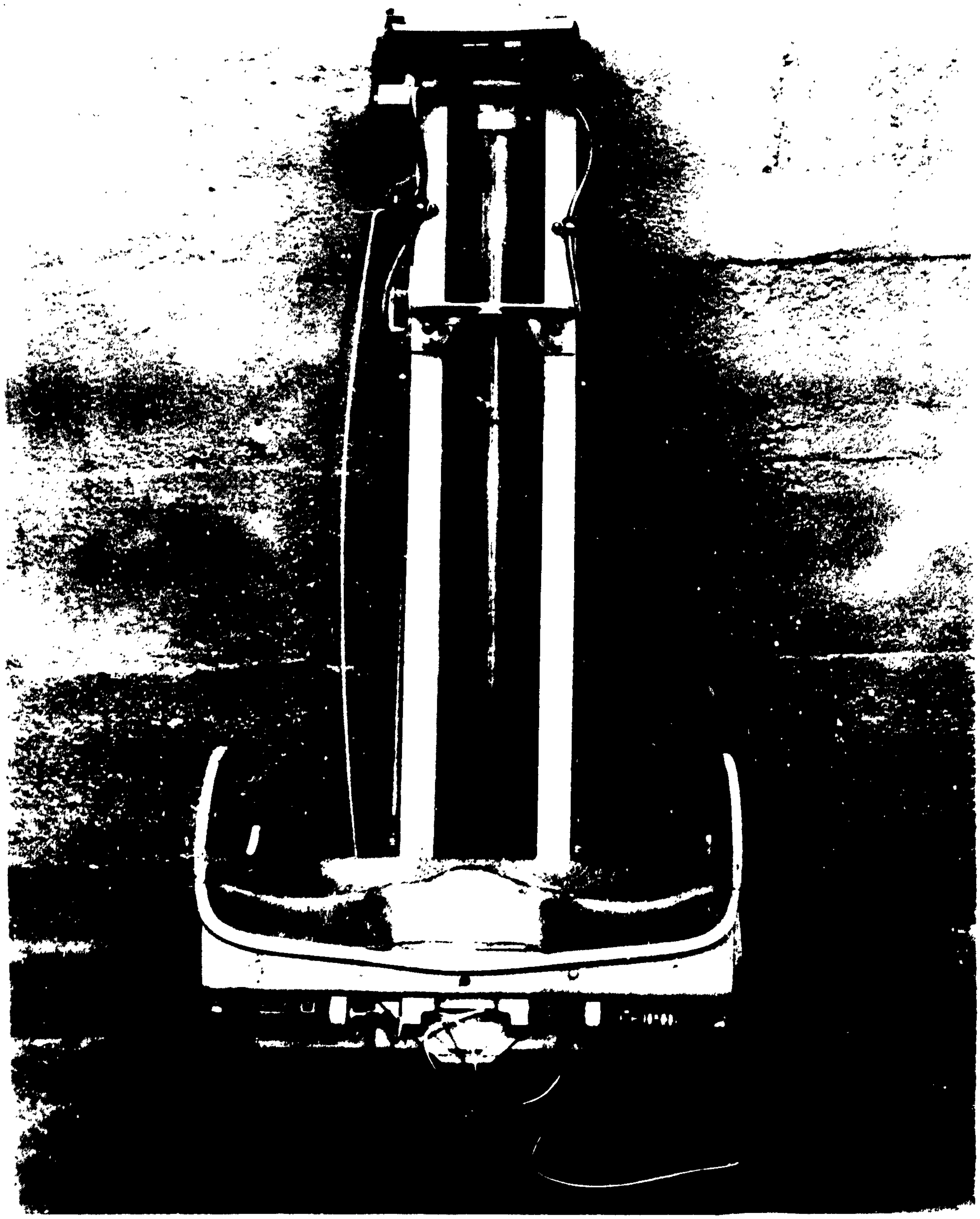
LEFT SIDE VIEW OF LW-1 SEAT AND XM-13 CATAPULT (ROCKET ASSIST)

PHOTO NO: CAN-341723(L)-1-62 Figure No. 5



RIGHT SIDE VIEW OF LW-1 SEAT AND XM-13 CATAPULT (ROCKET ASSIST)

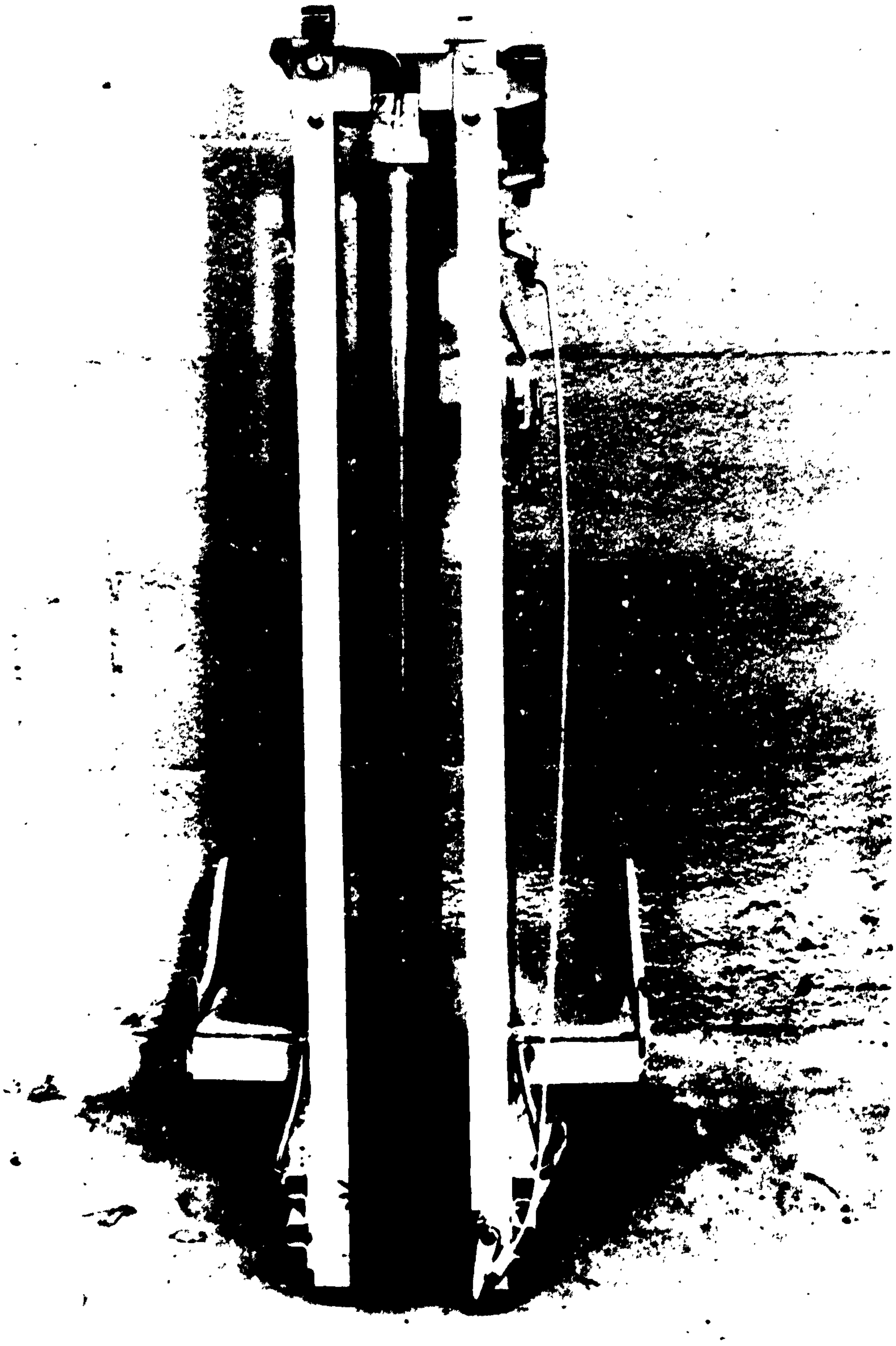
PHOTO NO: CAN-341730(L)-1-62 Figure No. 6



LW-1 SEAT AND XM-13 CATAPULT (ROCKET ASSIST)

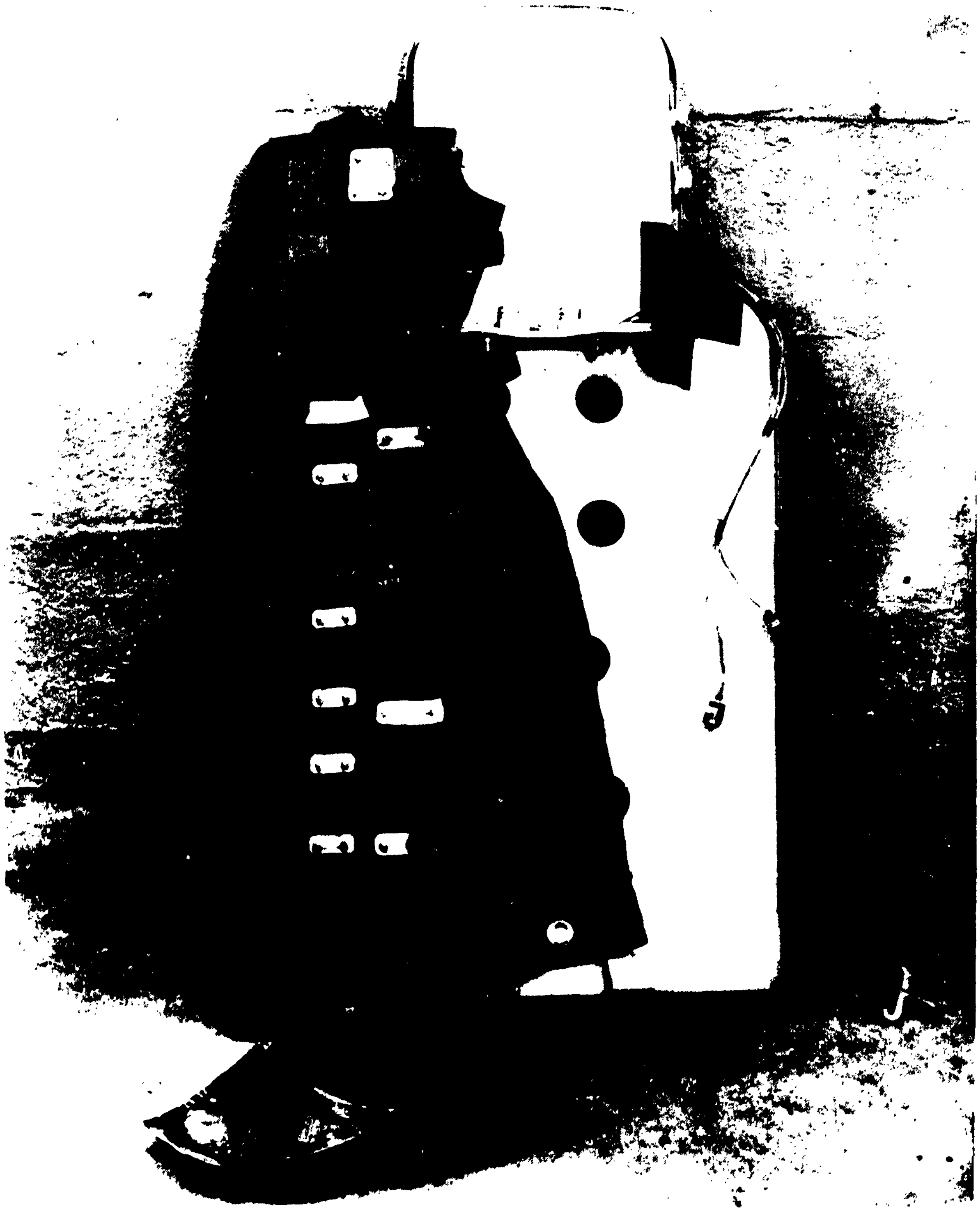
PHOTO NO: CAN-341724(L)-1-62

Figure No. 7



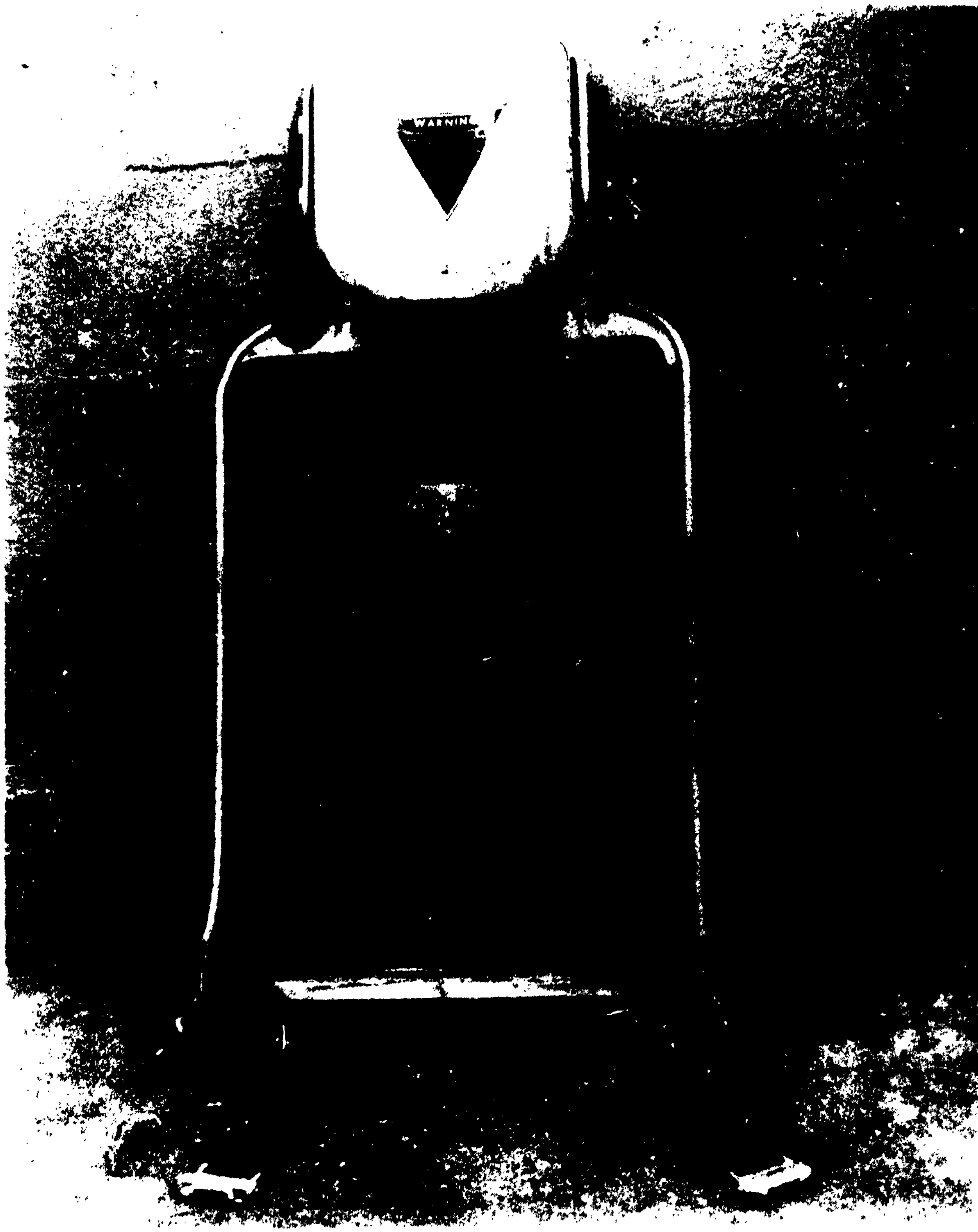
BACK VIEW OF LW-1 SEAT AND XM-13 CATAPULT (ROCKET ASSIST)

PHOTO NO: CAN-341726(L)-1-62 Figure No. 8



BACK VIEW OF LW-1 SEAT AND PARACHUTE CONTAINER

PHOTO NO: CAN-341725(L)-1-62 **Figure No. 9**

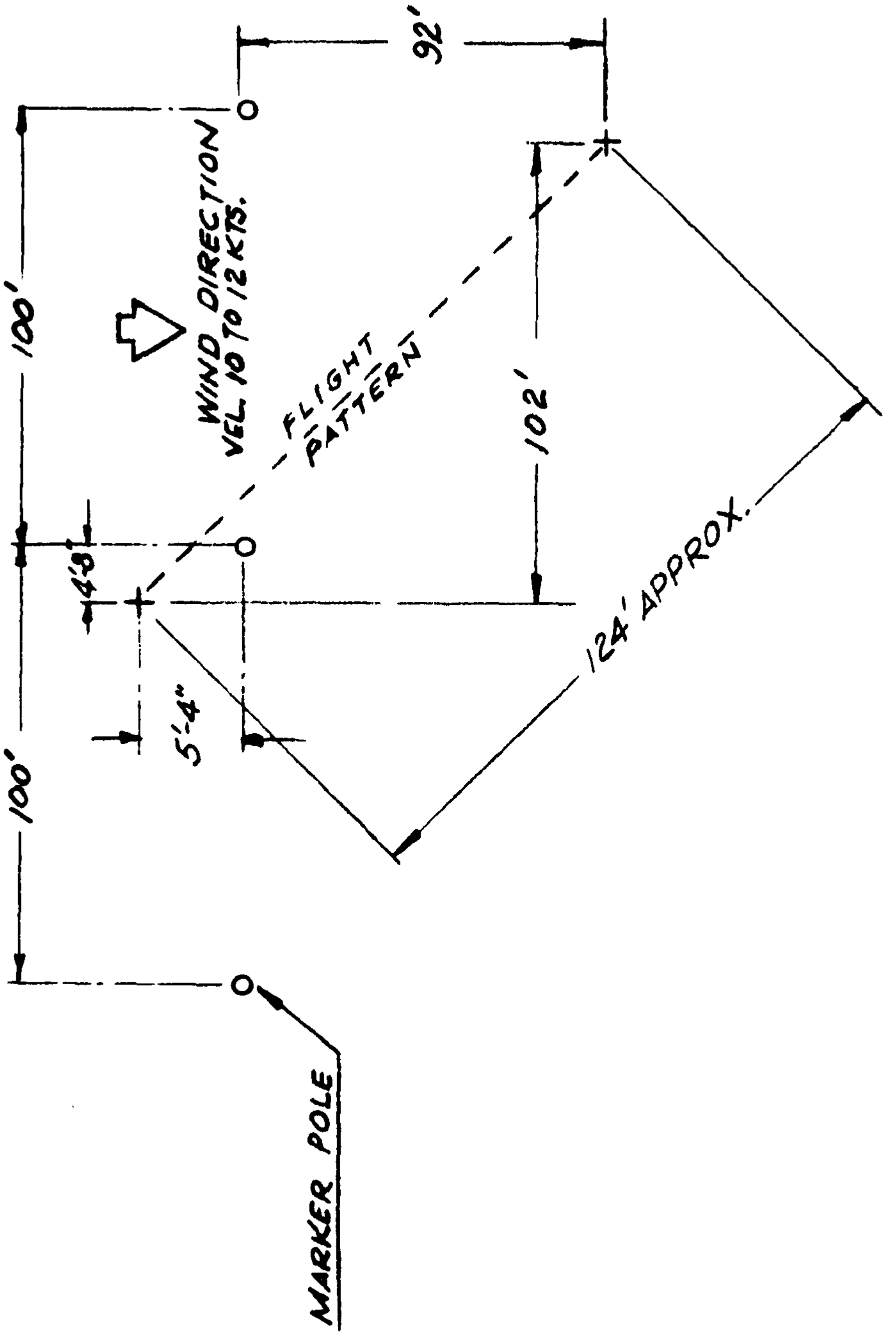


FRONT VIEW OF LW-1 SEAT BACK, BACK PAD AND PARACHUTE

PHOTO NO: CAN-341729(L)-1-62 Figure No. 10

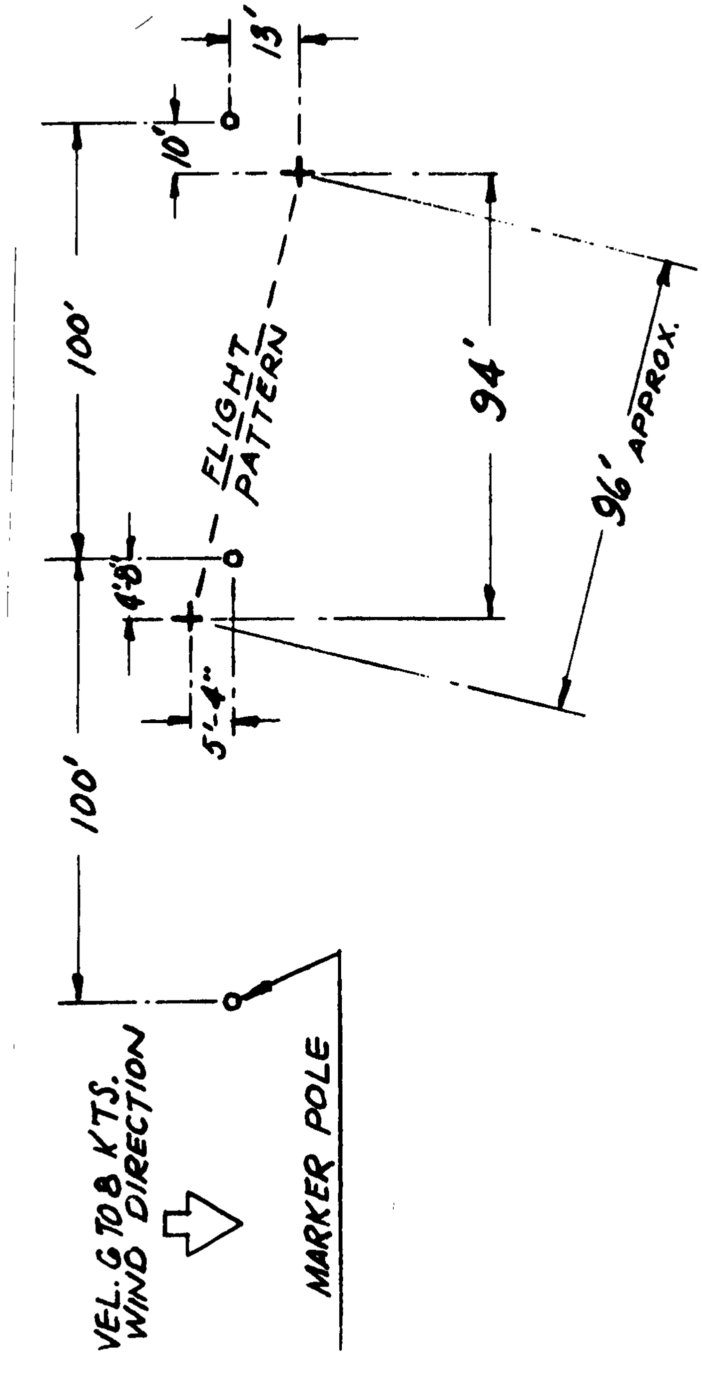
DAMAGE TO PARACHUTE CANOPY FROM ROCKET EXHAUST FLAME (TEST NO. 1)

PHOTO NO: CAN-341728(L)-1-62 Figure No. 11



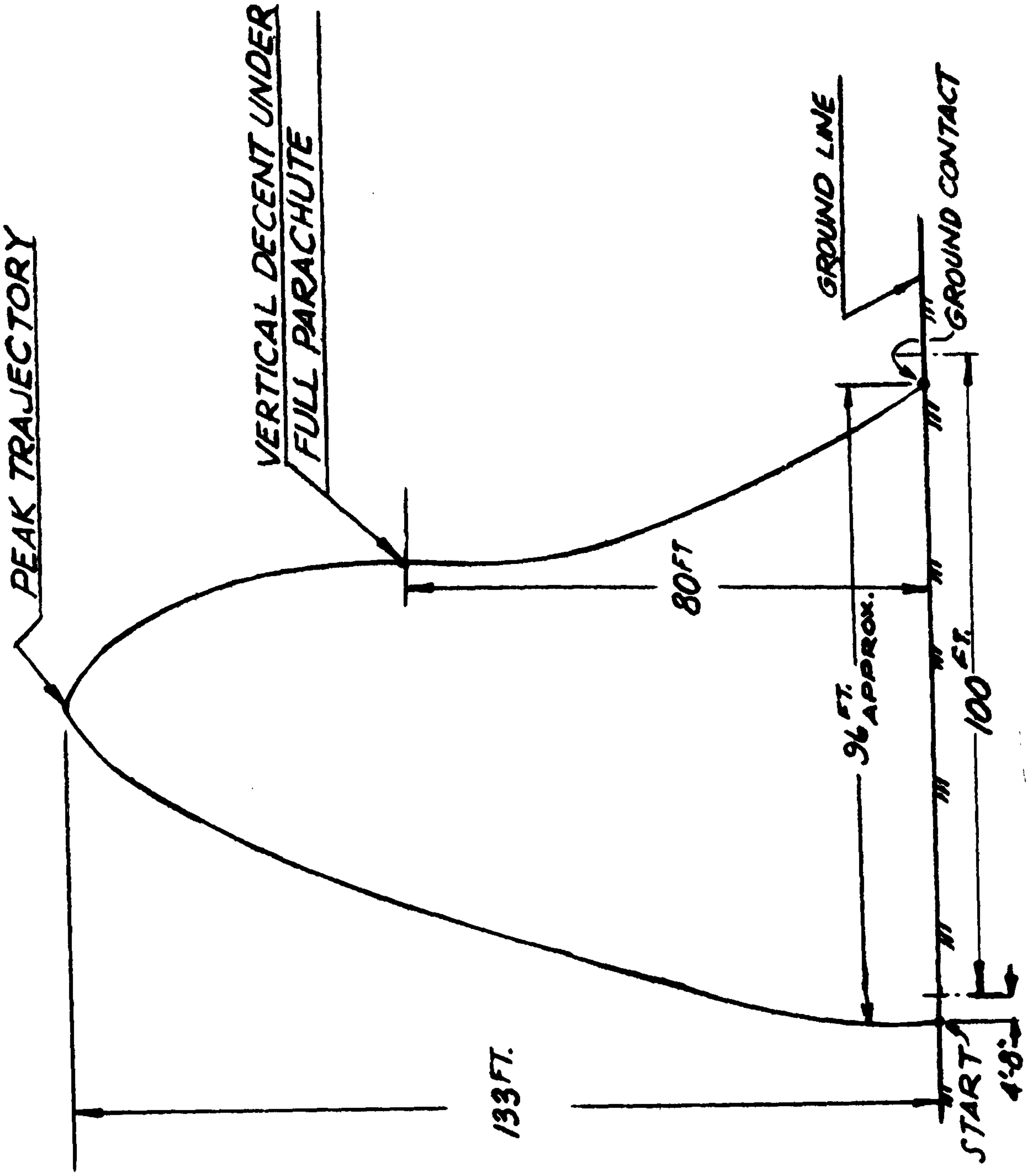
LW-1 SEAT GROUND PLOT PATTERN (TEST NO. 1)

PHOTO NO: CAN-352747(L)-6-63 Figure No. 12



LW-1 SEAT GROUND PLOT PATTERN (TEST NO. 2)

PHOTO NO: CAN-352748(L)-6-63 Figure No. 13



TRAJECTORY PLOT FOR STATIC TEST NO. 2

Figure No. 14

PHOTO NO: CAN-352749(L)-6-63

INTERFERENCE OF SHOULDER STRAP FITTING WITH SUBJECT'S SHOULDER

PHOTO NO: CAN-343292(L)-3-62 Figure No. 15

SHOULDER STRAP FITTING MODIFIED BY ACEL TO ELIMINATE CONTACT WITH SHOULDER

PHOTO NO: CAN-343290(L)-3-62 Figure No. 16

ROCKET-JET RELEASE FITTING MODIFIED TO PROVIDE ADJUSTMENT

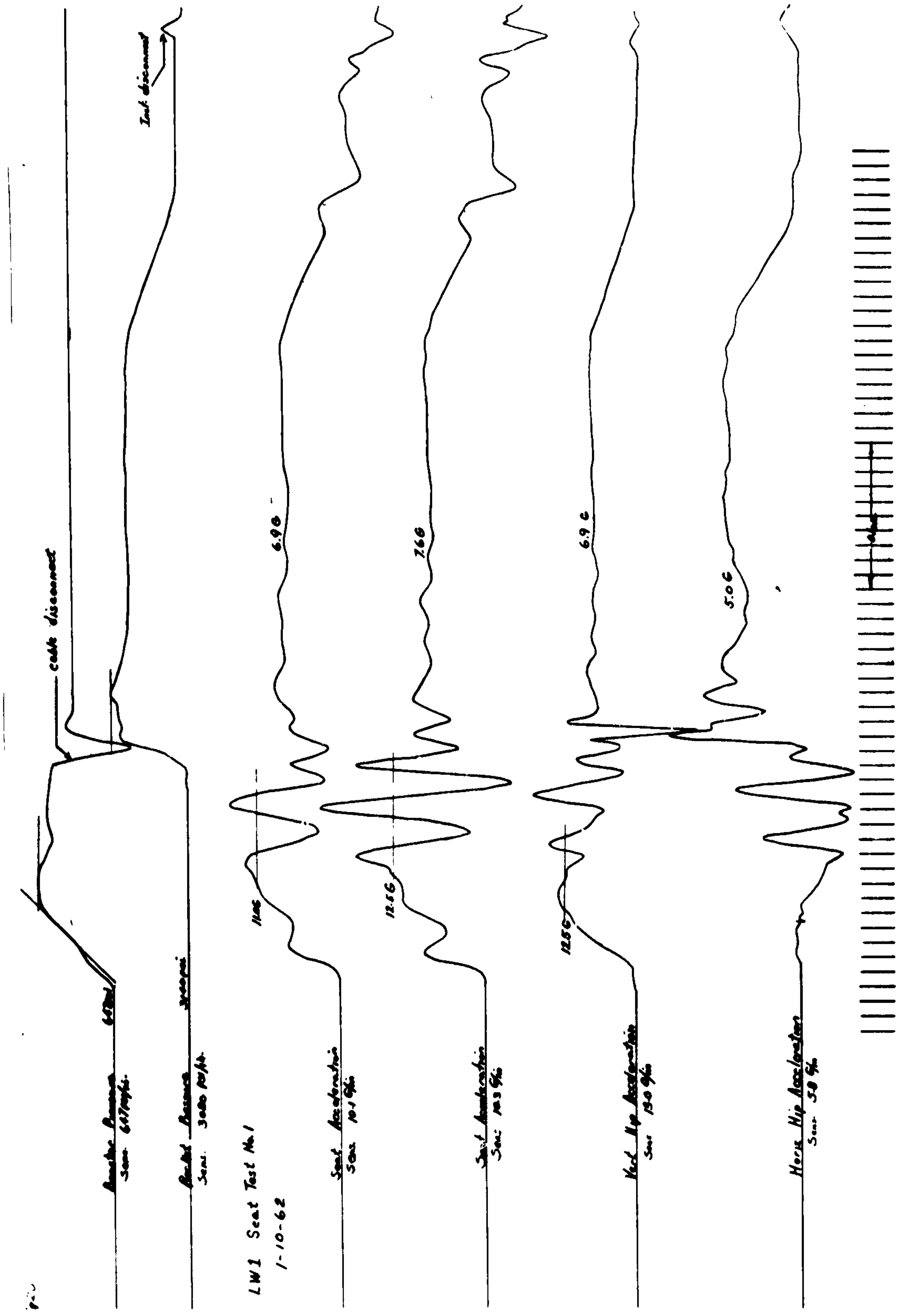
PHOTO NO: CAN-343289(L)-3-62 Figure No. 17

SUBJECT IN POSITION TO ACTUATE LW-1 SEAT ON EJECTION TOWER

PHOTO NO: CAN-343291(L)-3-62 Figure No. 18

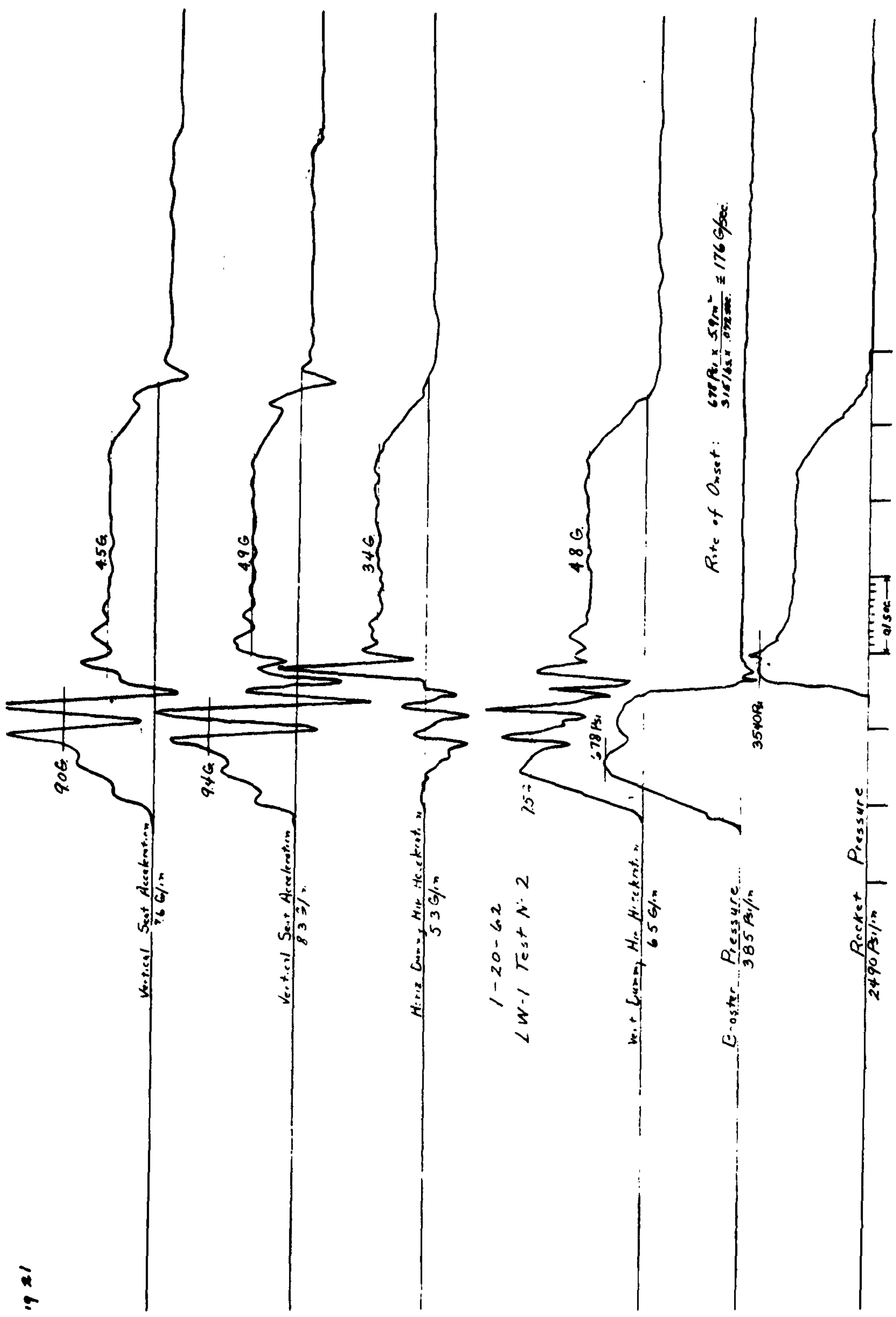
MODIFICATION FOR FACE CURTAIN INSTALLATION

PHOTO NO: CAN-343288(L)-3-62 Figure No. 19



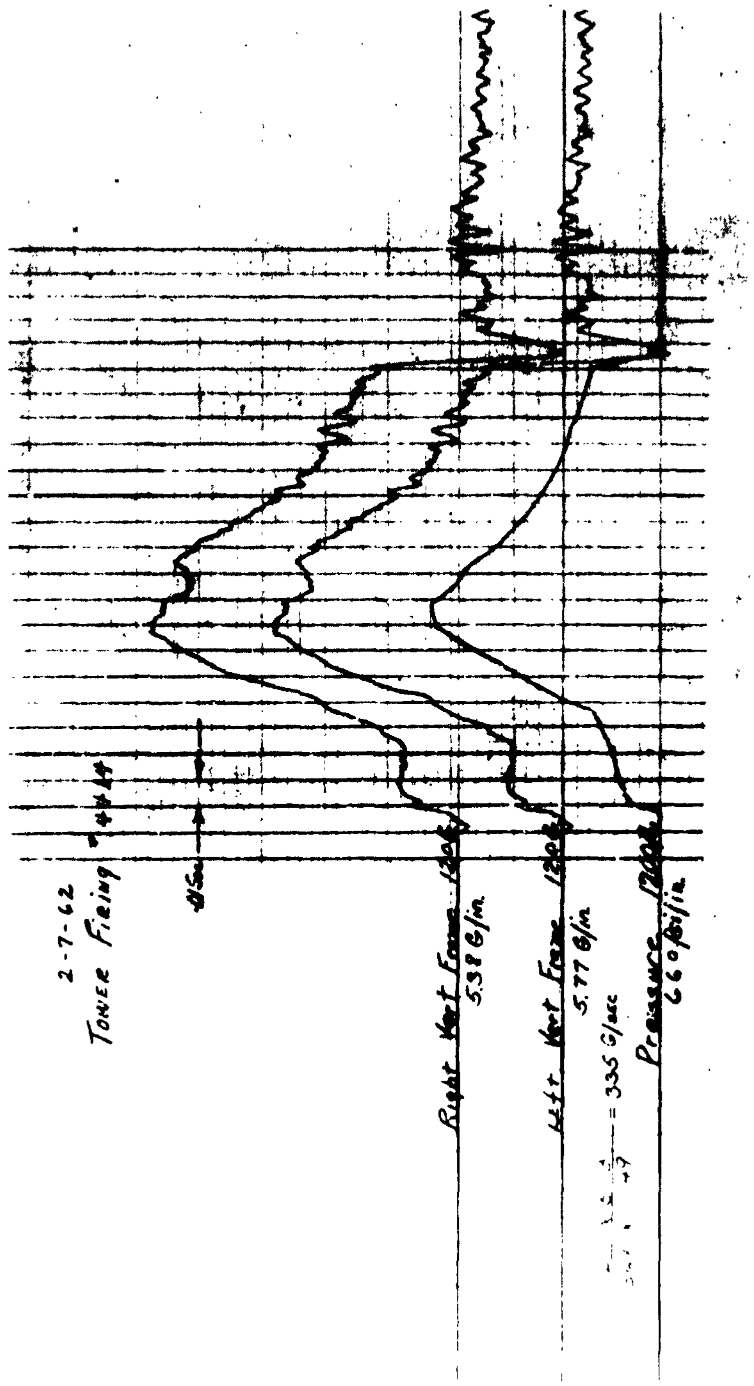
OSCILLOGRAPH RECORD OF STATIC FIRING NO. 1 WITH 5 PERCENTILE DUMMY ON LW-1 SEAT

PHOTO NO: CAN-352750(L)-6-63 **Figure No. 20**



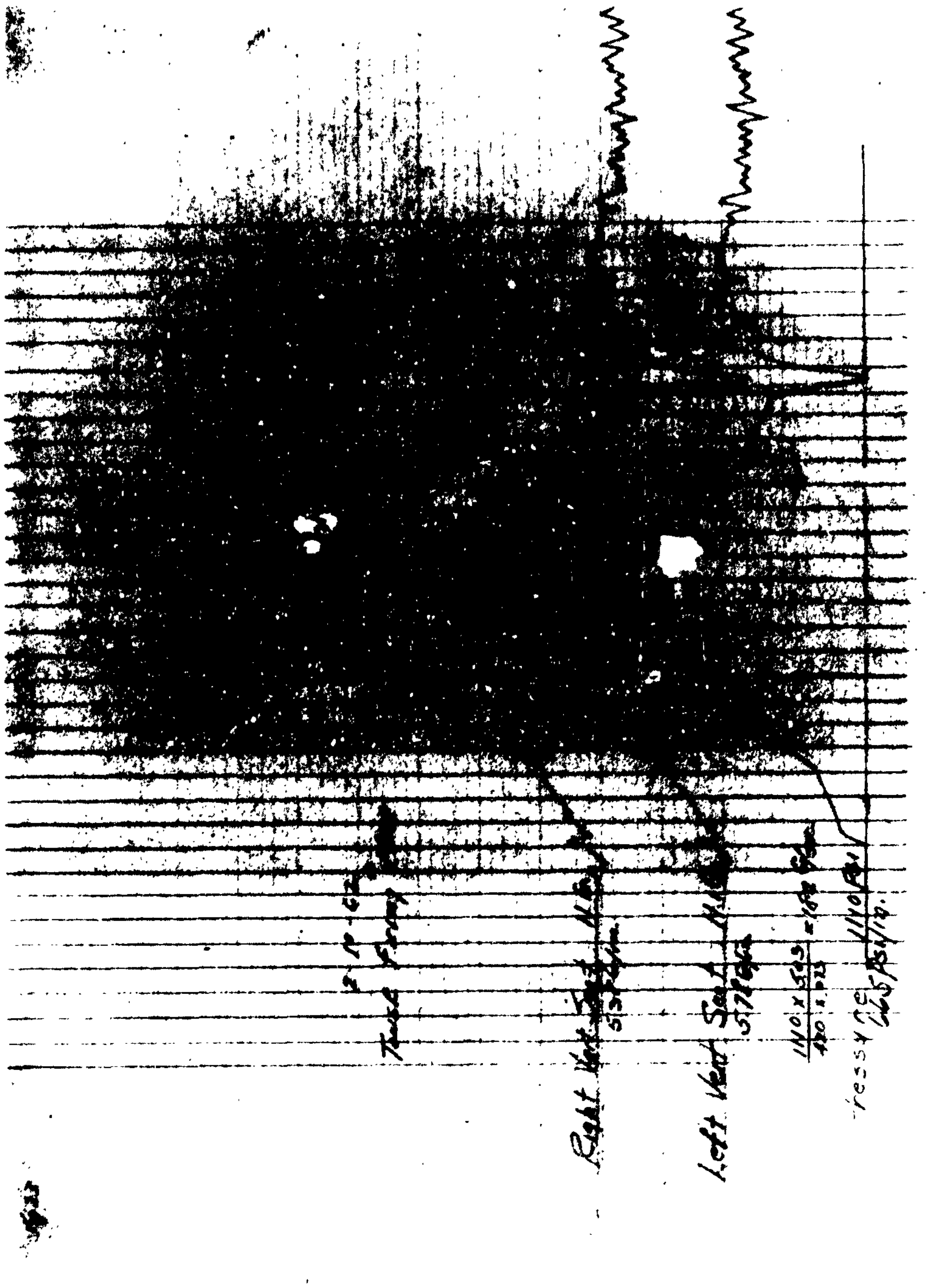
OSCILLOGRAPH RECORD OF STATIC FIRING NO. 2 WITH 95 PERCENTILE DUMMY ON LW-1 SEAT

PHOTO NO: CAN-352751(L)-6-63 **Figure No. 21**



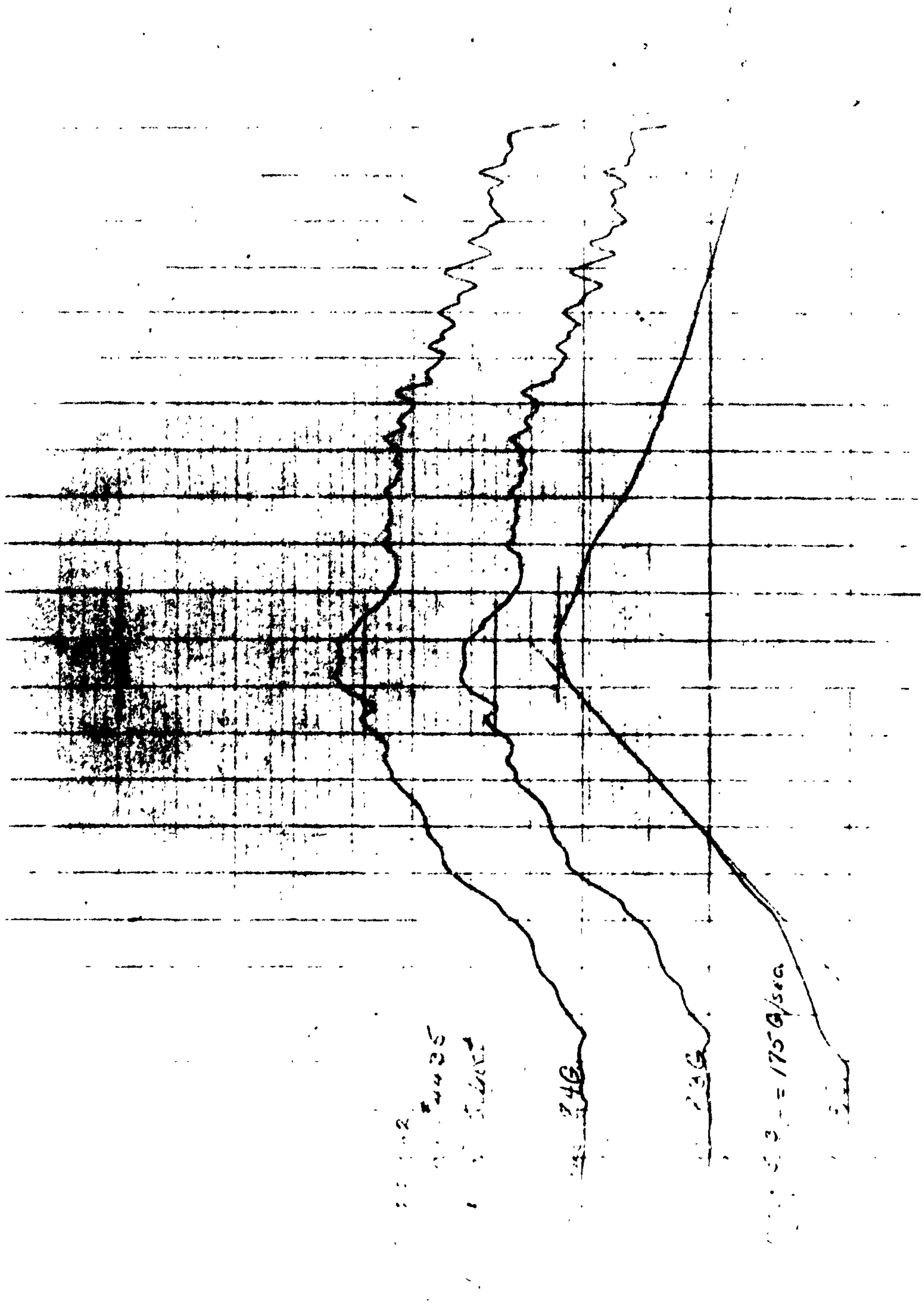
OSCILLOGRAPH RECORD OF TOWER EJECTION NO. 4414 WITH 5 PERCENTILE DUMMY

PHOTO NO: CAN-352752(L)-6-63 Figure No. 22



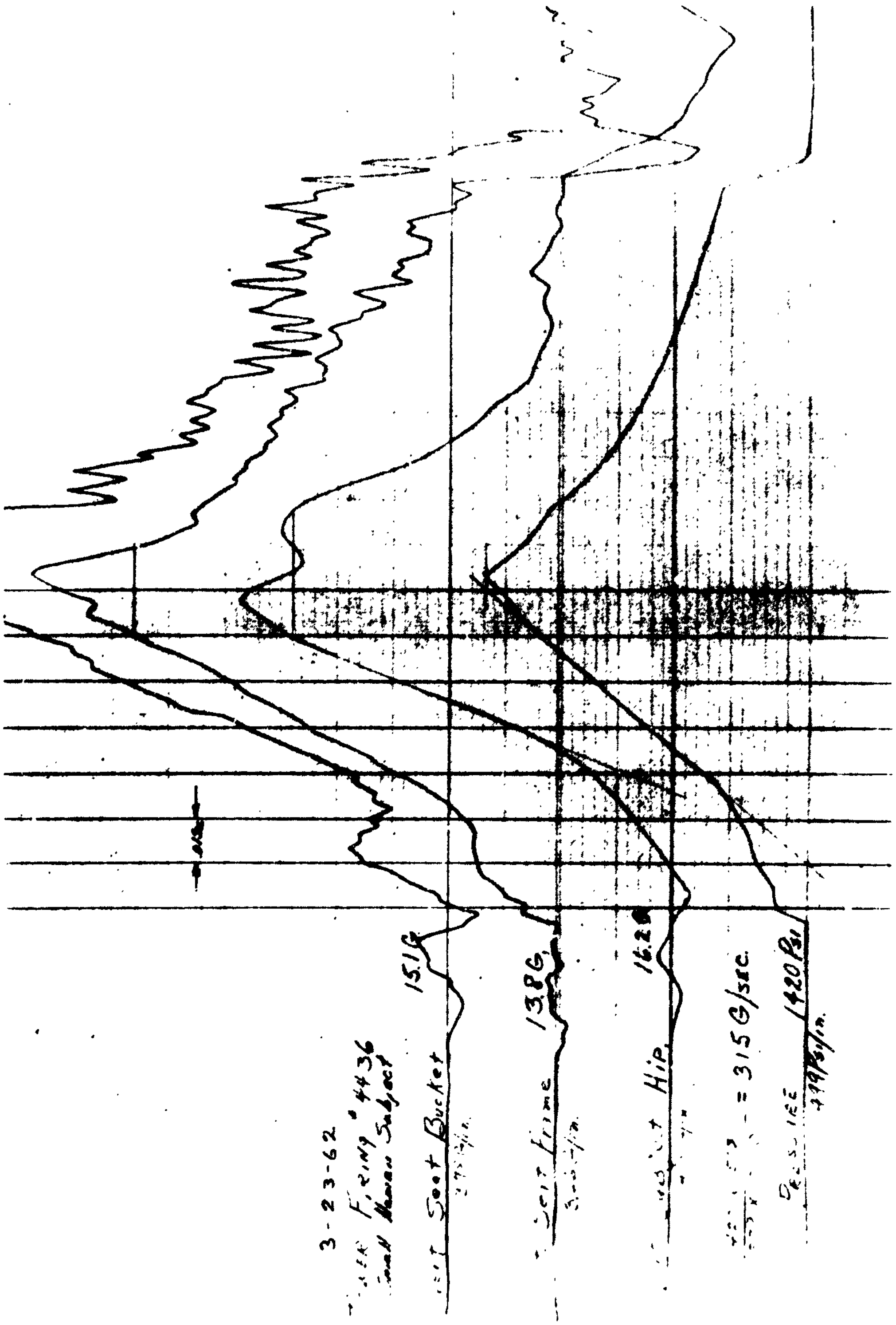
OSCILLOGRAPH RECORD OF TOWER EJECTION NO. 4420 WITH 95 PERCENTILE DUMMY

PHOTO NO: CAN-352753(L)-6-63 Figure No. 23



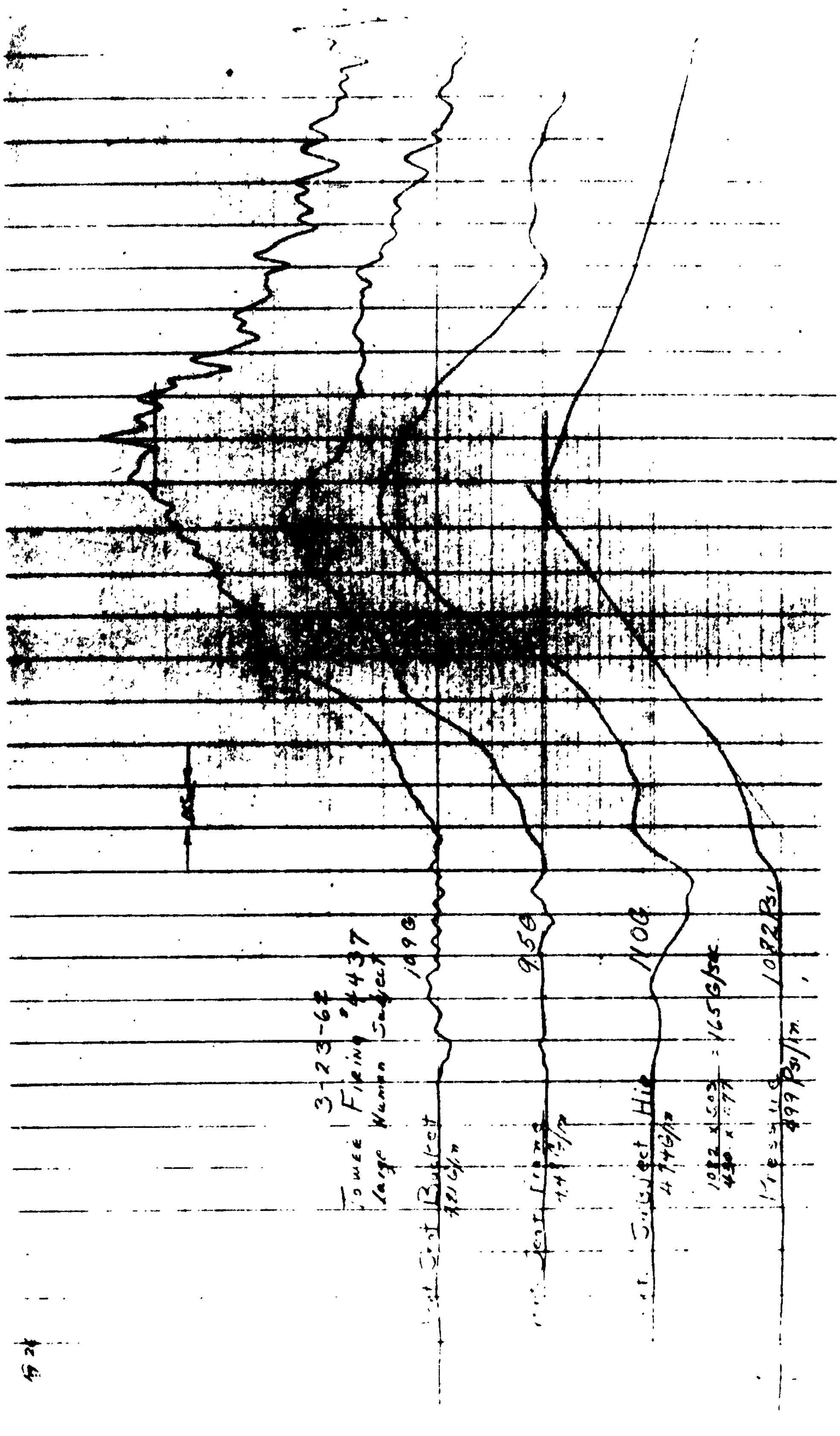
OSCILLOGRAPH RECORD OF TOWER EJECTION NO. 4435 USING LARGE HUMAN SUBJECT

PHOTO NO: CAN-352754(L)-6-63 Figure No. 24



OSCILLOGRAPH RECORD OF TOWER EJECTION NO. 4436 USING SMALL HUMAN SUBJECT

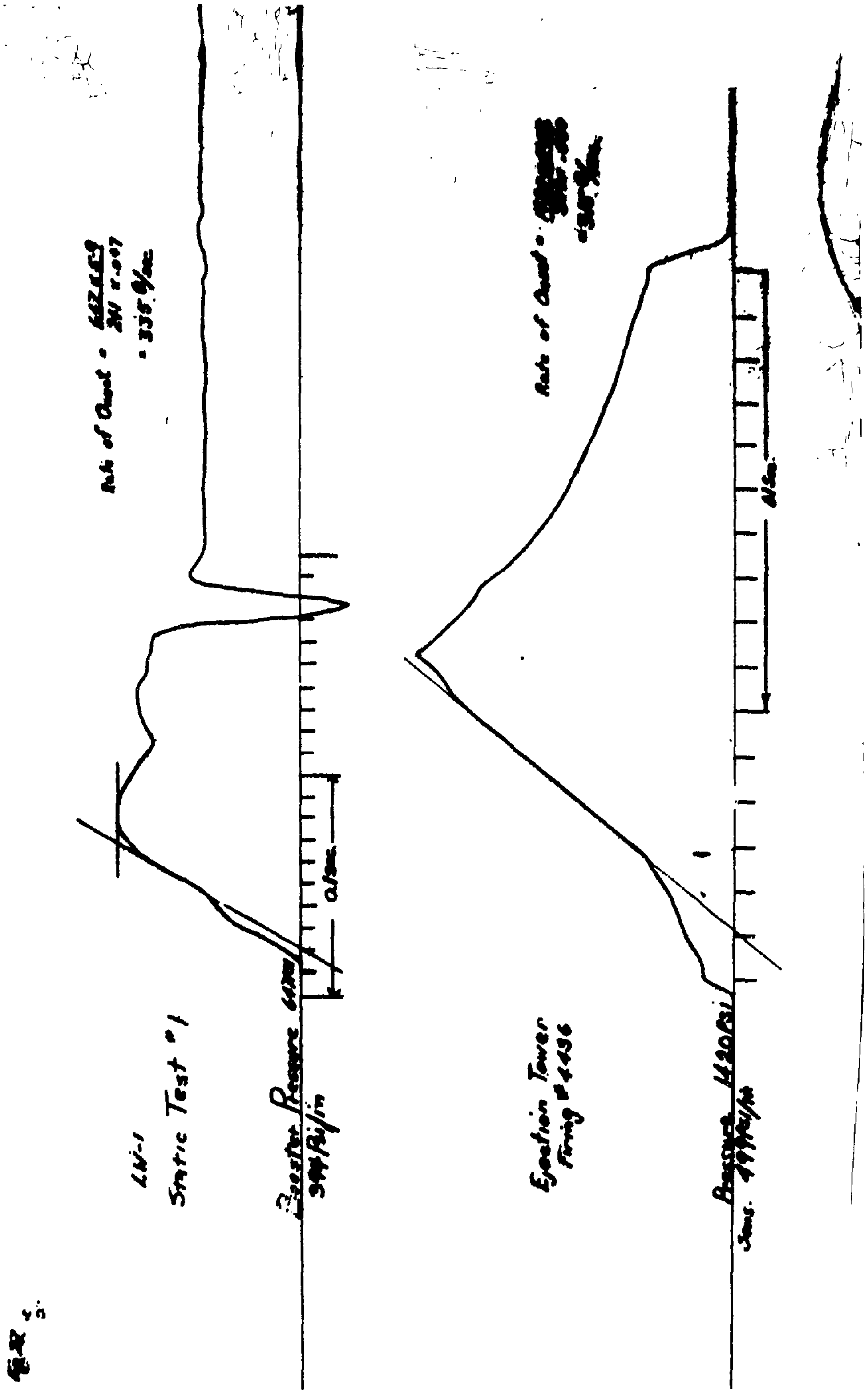
PHOTO NO: CAN-352755(L)-6-63 Figure No. 25



OSCILLOGRAPH RECORD OF TOWER EJECTION NO. 4437 USING LARGE HUMAN SUBJECT

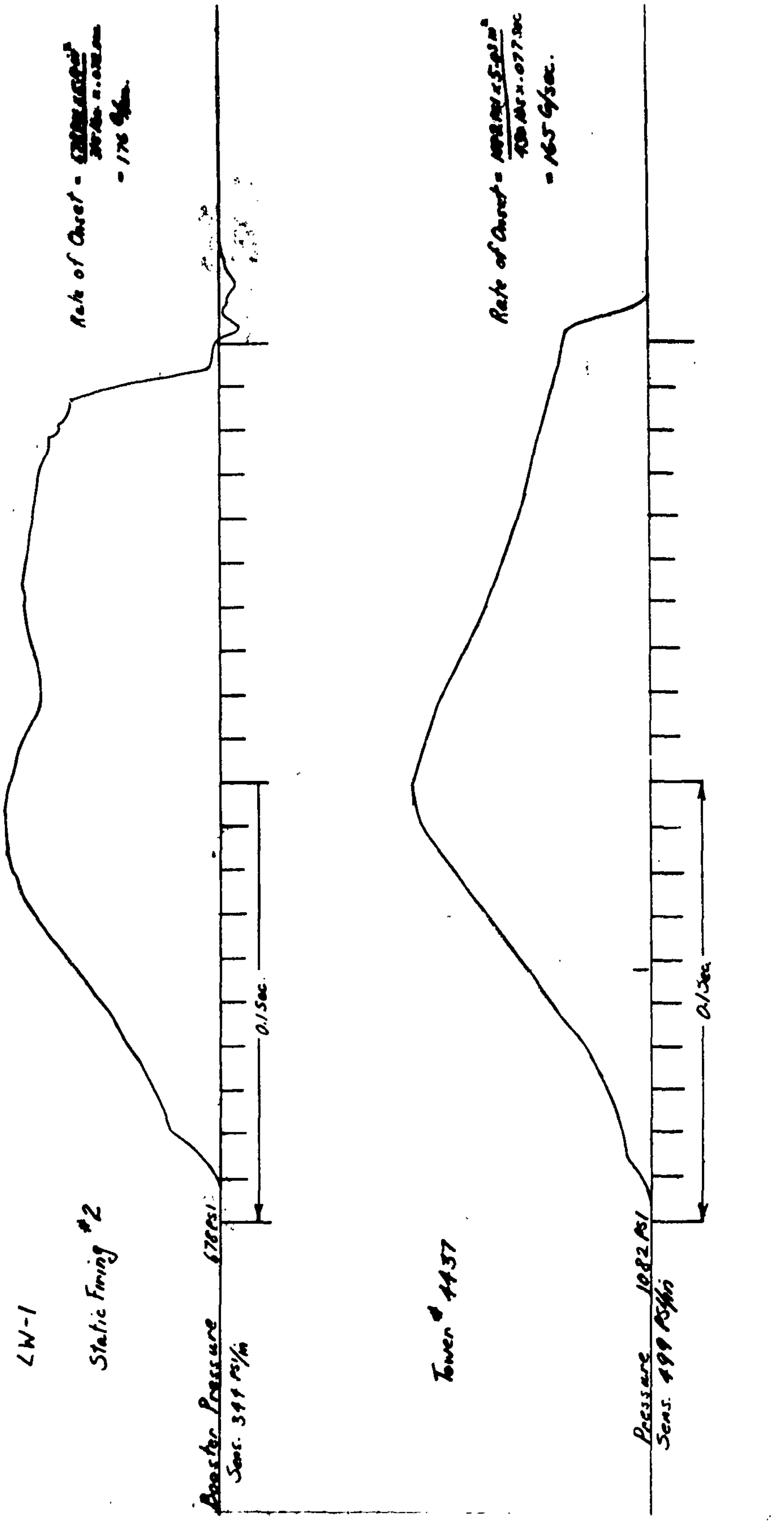
PHOTO NO: CAN-352756(L)-6-63

Figure No. 26



COMPARISON OF STATIC TEST NO. 1 AND TOWER EJECTION NO. 4436

PHOTO NO: CAN-352757(L)-6-63 Figure No. 27



COMPARISON OF STATIC TEST NO. 2 AND TOWER FIRING NO. 4437

PHOTO NO: CAN-352758(L)-6-63 Figure No. 28

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(1) Change in nozzle angle from 52° to 36°20'.
(2) Change in rocket grain length from 33.4 inches to 24.5 inches.
(3) Change in catapult charge to permit operation with lightweight seats.

The modified catapult was designated Catapult, Aircraft Personnel, XM13. A test program was conducted consisting of static, free-flight, and tower firings with human subjects. The XM13 catapults were considered acceptable for installation in hover craft, with recommendations that sled tests be conducted at forward velocity.

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