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DEVELOPMENT AND TESTING OF AN AUTOMATIC LAP BELT RETRACTION AND RELEASE SYSTEM

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The consequences of a poor or loosely adjusted restraint system have been well documented and have been shown to cause various crewmember injuries and also to degrade ejection seat performance. An automatic lap belt retraction and seat-man release system has been developed for use with the Navy's Maximum Performance Escape System ejection seat. The lap belt cinch-up device works simultaneously with the action of the

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inertia reel from independent gas generators, while the lap belt release device works simultaneously with the strap cutter from a common gas generator. In-house testing of improved cinch and release prototype devices is continuing.

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INTRODUCTION

An automatic lap belt retraction device has been developed to tighten the aircrewman's lap belt restraint prior to and during ejection. The development was undertaken to reduce the problems associated with ejecting while loosely restrained. It is known that aircrewmen often adjust their lap belts loosely in order to sit more comfortably during flight and to aid their maneuverability within the confines of the cockpit. Unfortunately, during an emergency situation which can lead to the decision to eject, it is unlikely that he will be able to properly adjust his lower restraint or would have the time or inclination to concern himself with the restraint while many other seemingly more important actions and decisions are occupying his time.

The consequences of a poor or loosely adjusted restraint during the ejection sequence have been well documented and have resulted in spinal and neck injuries during catapult thrust, submarining, impacting cockpit structure, and causing improper center of gravity (c.g.) alignment prior to and during rocket firing. The importance of a tight restraint is even more critical at higher air speeds where windblast forces add to the effect of shifting the crewmember in the seat and causing additional c.g. misalignment and hence, greater instability during ejection. This can also contribute to or help induce limb flail problems.

Powered inertia reels have been installed on operational ejection seats for a number of years to help position and restrain the crewman's upper torso prior to ejection. The development of an automatic lap belt retractor and tensioning device is a natural extension of the technology to further improve the effectiveness of the total seat restraint system.

D I S C U S S I O N

EARLY DEVELOPMENT WORK - PHASE 1

The initial effort to develop a lap belt cinching device into the ejection seat sequence was accomplished through the fabrication of a simple linear actuator which operated through pressure from a gas generator. Actuation of the generator produced gas pressure simultaneously into the inertia reel and the lap belt cinching mechanism. Prior to fabricating this "workhorse" model, preliminary data was obtained to determine belt loads, response times, and retraction distances that could be safely tolerated by human subjects.

Static Test Set-Up

To determine safe limits of retraction distance and belt forces, a static test seat set-up was used for this experiment. It consisted of an experimental crew seat modified with a manual lap belt tensioning device with a simple hand crank mechanism that could be used to ratchet back and tighten the lap belt on both sides. This seat (figure 1) was used in conjunction with volunteer personnel to develop the tolerable belt forces and appropriate retraction distances needed to properly tension the lap belt.

A strain gage load link was specially designed and installed in series with and between the lap belt and the crank mechanism to measure the applied belt forces. This crank mechanism positioned the lap belt at approximately 50 degrees with the seat pan surface, and this angle varied only slightly during application of the load. The handcrank ratcheting device was calibrated so that each notch took up a known amount of retraction of the lap belt.

Each subject that sat in the seat was instructed to initially adjust his lap belt to the degree that he felt was appropriate for flight. This was compared typically with adjusting the automotive lap belt in the recommended manner as a reference condition. The strain gage data was recorded on oscillograph paper, and this initial adjustment load was noted in each case. After the initial adjustment into the seat, each test subject pulled the handcrank belt tensioning device, which was conveniently located on the right side of the seat, and proceeded to tighten the device until he experienced noticeable but tolerable discomfort. In each case, the maximum belt loads and retraction distances were recorded. The instantaneous peak restraint forces during initial cinching averaged 179 pounds. The final belt loads recorded after final locking of the ratcheting device with the subject still sitting quietly in the seat averaged 97 pounds. The lap belt retraction distances varied between 4 to 5.8 inches. The initial adjustment tension averaged 12 pounds.

"Workhorse" Model Retraction System

Upon completion of the static evaluation, a ballistic "workhorse" model thruster device and gas generating system was developed in cooperation with the Frankford Arsenal for the purpose of gathering data sufficient to demonstrate the feasibility of the concept and to obtain information to be used for further design of a more practical system.

This system was configured and designed to be used in conjunction with a Martin-Baker inertia reel and with all associated hoses and connectors necessary for instrumentation pick-ups. A total of 12 lap belt retractor assemblies and 24 gas generators and associated plumbing were delivered. Complete system bench testing was conducted prior to delivery.

Test Plan and Set-Up

The test plan was designed to provide the following information:

1. To establish if a lap belt cinching system could be incorporated and function simultaneously with existing upper torso retractors (Ballistic inertia reels).

2. To establish if an inertia reel and lap belt cinch device could be accomplished with a single gas generating source and be able to maintain the Inertia Reel specification requirements regarding retraction rates and function time.

3. To determine what, if any, sequencing problems might be expected or required.

4. To obtain subjective response of volunteer subjects regarding all aspects of the retraction and cinching operation.

5. To determine what function time can be obtained.

6. To determine how long the residual loads can be tolerated.

A special test seat was fabricated for the human/dummy testing. The lap belt retractors were installed on the back of the test seat and connected to a crank mechanism which transferred the thruster force to the lap belt (figures 2 and 3). This link was designed so that upon actuation of the system, the belt would be retracted at least 2 inches along a line that would very closely approximate a straight line pull during the stroke, and that it would maintain a line of action of about 50 degrees with the seat pan surface (figure 4). The thrusters were placed parallel to the seat back because they were too long to be conveniently placed in-line with the action of the belt. Also, the crank mechanism configuration was being considered as a possible means for adapting this concept to some existing seat systems to try to demonstrate its applicability, and it would provide an opportunity to demonstrate its feasibility.

A total of 11 tests were conducted with the "workhorse" model as follows:

1. Four static dummy tests

2. Six static live subject tests

3. One dynamic dummy retraction test at 2 'G's.

Results of "Workhorse" Model Testing

Table 1 is a compilation of all 11 tests and identifies dummy size, test configuration and all instrumention data. It can be seen from table I that the lap belt loads that were generated were in very good agreement with the desired static load limits generated earlier. The four dummy tests verified the anticipated safe system performance. The retraction rates of the inertia reel in this configuration were within the required safe limits. The test subjects representing approximately the 5th and 95th percentiles were then each positioned for 3 test conditions; full back, one-half out, and full out as shown in table I, 6. The full out position is shown in figure 5.

In all the live subject tests, it was evident that the subject had a definite influence on the inertia reel retraction performance. The subject's normal reflex to oppose the force in anticipation of the retraction action of the reel caused a slow down of the speed with which he was retracted. The lap belt.retractors functioned adequately and the response measured did not appear to vary with that of the dummy tests. In all tests, the lap belt retraction was completed before the inertia reel. This was anticipated and appeared to be the proper sequencing action for best effectiveness. It was decided not to improve IR performance by increasing the generator pressure to overcome the inertia and muscle tension of the subject since this would, at the same time, increase the lap belt loads. It was determined that the retractors would always respond quicker than the IR since there was little inertia to overcome and they had a much shorter stroke distance. Sequencing, therefore, was not a problem and it did not matter whether or not the retractors operated from the same gas generator. The functioning time of the retractors was approximately 100 milliseconds.

The subjective response of the subjects was almost identical. They stated that the lap belt retractors provided an extremely tight belt, and they felt that they could tolerate that condition indefinitely with nothing more than some mild discomfort.

The results of this initial investigation were extremely successful and generated sufficient data to begin the development of a feasibility prototype which could be integrated into a seat and used for test and evaluation.

CURRENT DEVELOPMENT EFFORT - PHASE 2

The follow-up development work was conducted in conjunction with the development of the Navy's Maximum Performance Escape System (MPES). A set of requirements was developed based on the earlier work and was directed towards incorporation with the MPES seat. Although automatic lap belt retraction had been demonstrated in the initial tests, it now became necessary to develop a complete set of requirements to make the seat system restraint configuration fully operational. This required the addition of a lap belt release mechanism built into the retractor and development of an inertia reel strap cutter which is required to effect complete seat/man separation after ejection. The complete restraint system was designed and manufactured by the Pacific-Scientific Co. in accordance with the Navy's requirements. The seat mounted restraint hardware components consisted of:

1. One inertia reel

2. Two cinch and release assemblies figure 6

3. One strap cutter assembly figure 7

4. An initiator/gas generator assembly requiring three different and independent arrangements.

5. All necessary tubing, fittings, and manifolds

Figure 8 shows a breadboard layout of the lap belt cinch and release system.

Cinch and Release Assemblies

One complete set consists of two cinch and release assemblies which are the same except for left and right hand mounting provisions. Each assembly has a capability of 2 inches of strap take-up thereby reducing the loop length 4 inches. Each unit is designed for a nominal force of 50 pounds tension. They were designed with a positive locking action after cinching to preclude loosening. Also included in the latest model is an antire-engagement device to prevent inadvertant reattachment during the release phase.

The cinch-up function is accomplished by gas pressure from a single initiator assembly to both devices. The gas generator used is identical to the one used with the inertia reel. The device has been designed to allow for possible minor changes in the retraction force if higher loads are found to be desirable. The haul back or retraction load can also be adjusted by varying the internal volume of the manifold which connects the initiator assembly to both cinch and release devices.

Shoulder Harness Strap Cutter

The cutting of the straps is accomplished by a stainless steel knife blade which is driven against an anvil over which the inertia reel straps pass. The knife blade is driven by a piston that is held in place by a shear pin until the intitiator pressure exceeds the shear pin strength. This results in an extremely fast cutting action while the piston size provides sufficient force to produce a clean separation of the straps. The cutting device is powered by the same gas generator that releases the cinch and release assembly.

Two strap cutter configurations have been developed. One configuration was designed to only cut the inertia reel dual straps. The second strap cutter configuration cuts a tygon tube inflation inlet line feeding pressure to a head/neck support collar in addition to the dual straps. Either device is powered by the same gas generator. A standard PSCo generator and initiator are used for all three ballistic functions of the restraint system, and, although they are similar, they are used in different configurations requiring different mounting bracketry, manifolds, reducers and unions.

TESTING

Contractor Development Testing

Prior to delivery of the cinch and release systems to the NADC, contractor development testing was conducted. In addition to the functional operation a series of environmental tests was conducted which include: low temperature, high temperature, vibration, humidity, salt spray, and sand and dust (reference a). There were no malfunctions when both the components and complete system were fired following exposure to the above conditions. The component functional test data is shown in table II. The full system firing data is shown in table III.

In-House Verification Testing

The cinch and release system hardware was installed on the MPES seat, figure 9. A series of six dummy retraction and release firings was scheduled. Two tests were conducted with a 5th percentile dummy and four tests with a 95th percentile dummy. Tests 5 and 6 included a special hook-up to evaluate the feasibility and practicality of inflating a developmental neck support collar during the retraction phase by tapping off pressure from the left-hand retractor plumbing through a restrictor. The instrumentation for the test set-up consisted of pressure transducers to measure the pressure during cinch-up, release and cutter phase, and in the inertia reel. Two accelerometers were placed in the dummy chest and in the pelvic area to monitor the acceleration levels during retraction of the upper torso and lap belt. A schematic of the system ballistics, instrumentation location, and firing set-up is shown in figure 10.

Test Results

Table IV is a compilation of the six tests listing dummy size, dummy position, and peak levels of instrumentation data. Figures 11 & 12 show the typical dummy set-up for the one-half out and full out positions.

In general, the test data verified that the development goals were attained for the MPES seat configuration restraint system. The lap belt functioning time never exceeded 40 milliseconds to peak value which reaffirmed that lap belt cinch up would occur before the retraction action of the inertia reel. With this system, as configured for the MPES application, the lap belt retractors and the inertia reel fire simultaneously but operate from independent gas generators, as described previously.

Test No. 1 was conducted with the lap belt moderately slack, and the inertia reel straps pulled out approximately 9 inches. Upon actuation, the lap belt retracted 1¼ inches on each side. The release phase resulted in a momentary hang-up on the right-hand thruster. It was determined that this was not due to any mechanical malfunction, but to frictional resistance caused by the pull angle the lap belt takes from its installation position with the thruster. This would not necessarily be a problem, since during in-flight seat/man separation sequence that seat would have aerodynamic forces acting on it which would aid to rapidly disengage it from the strap. However, it is possible that the release mechanism could relock itself as a result of a sudden pressure loss either through leakage or rapid cooling of the gasses. This possibility will be eliminated in a more advanced design. Figure 13 shows the lap belt in the released position.

Test No. 2 was conducted with the 5th percentile dummy 18 inches out from the seat back and the lap belt adjusted loosely. Upon actuation, the lap belt retractors moved 1.9 inches on each side. The time to reach peak value loads on this inertia reel increased because of the increased travel distance for the dummy. However, the peak response time for the retractors did not change from the previous test because there is little change in its retraction distance. Most of the variation in response time can be attributed to the normal variance in the ballistics train.

Test No. 3 was conducted with the 95th percentile dummy positioned away from the seat back approximately 9 inches. For this test, the lap belt was adjusted snugged up fairly tight. In this case the cinchers only retracted 3/16 inches on one side and 9/16 inches on the other side. The lap belt loads peaked at approximately 100 pounds force which was considered the desired limit for this condition. All system functions such as the release and strap cutter operation performed satisfactorily.

Test No. 4 was again conducted with a 95th percentile dummy and positioned full out from the seat back, approximately 18 inches. The cincher retraction data was not obtained from direct measurement, due to instrumentation problems, but the film analysis indicated almost full retraction on both sides. The lap belt loads were predictably lower for this test condition, but still maintained an acceptable minimum load as required.

All four tests successfully verified the performance requirements of the system design. Figures 14, 15, 16 & 17 show the instrumentation traces for these tests. The belt load traces in test 2 show an immediate loss of load following actuation of the system. This performance was purposely programmed to happen since the lock rings were previously removed from the cinchers. This was done to prevent the possible scoring of the units cylinder wall permitting refurbishing of the units so more than one firing could be obtained with each retractor.

Test No. 5 - Upon successful performance of the previous four tests, it was decided to investigate the feasibility of employing an inflatable neck support collar in conjunction with the cinch-up cycle by tapping off pressure from one of the cinchers and plumbing it through a restrictor line to the neck bag. Figures 18 & 19 show the set-up. A 95th percentile dummy was used for this test and was positioned full out, approximately 18 inches. Upon actuation of the generator, the lap belt retractors were able to exert 44 and 49 pounds force on the belt and retracted 1.25 and 1.9 inches, respectively. The inflatable neck collar experienced a momentary peak pressure of 8.4 PSI which was far lower than anticipated. Upon routine cleaning of the plumbing after the test, the restrictor line was found to be clogged with a piece of "O" ring material that got into the system. Additionally, rapid deflation of the collar resulted from a loose hose clamp. This caused a sharp pressure drop in the lap belt cinch device, but it still managed to provide a sufficient retraction force.

Test No. 6 was a repeat of test 5. In this instance, the cinch pressure was identical to the previous test and exerted 60 pounds force on the right-hand side and 51 pounds force on the left side, which resulted in a belt retraction of 1.75 inches on both sides. The neck support collar (figures 20 and 21) was inflated to a peak pressure of 31.5 PSI, but rapidly deflated due to the expected leakage in the bladder seams. From a review of the test film, it was apparent that the neck collar was fully inflated before the upper torso reached the back of the seat. The test also indicated that it is feasible for cinch-up and neck collar inflation to be accomplished from a single gas generating source. However, to assure optimum performance, the gas generator would have to be modified. An important factor that must be considered during advanced development is that existing gas generators produce toxic gas which may present a hazzard to the crew members at some time during the escape sequence. This is especially true for the inflatable but porous neck support collar which releases the gas in the vicinity of the crewman's head.

CONCLUSIONS

In all the six tests conducted, the pyrotechnics gave fairly consistent performance. The retraction device functioned in every test. The lap belt loads varied from as low as 51 to 104 pounds depending on whether a neck collar was in or out of the system. The major variation in load is a function of the amount of pretest lap belt tensioning. However, the generated loads were well within tolerable comfort levels at the high end and sufficient for effective tightening at the low end in accordance with previously established performance levels. The strap cutter functioned perfectly in all tests.

The only potential problem area was the "hang-up" of the release socket in the cylinder due to the angle that the cable makes with the axis of the cylinder. There is a potential hazzard that the locking balls would re-engage the ball release plunger before it separated. Subsequent to these tests, a redesign of this release mechanism was completed. It incorporated an antire-engagement feature consisting of a release spring which prevents inadvertent relocking. Recent firings of the release function have shown the antire-engagement feature to be effective and reliable. In addition, a redesign of the strap cutter has been completed which allows simultaneous cutting of the inertia reel straps and 1/2 inch O.D. tygon tubing, and neck collar inflation line. Recent testing of this cutter configuration has also shown it to be effective. Although use of the inflatable neck support collar with the MPES seat restraint system has not yet been established as a definite requirement, the technology area has been established and has shown that it can be incorporated in the future. Inhouse testing of the improved cinch and release prototype model is continuing and efforts are underway to initiate full scale development.

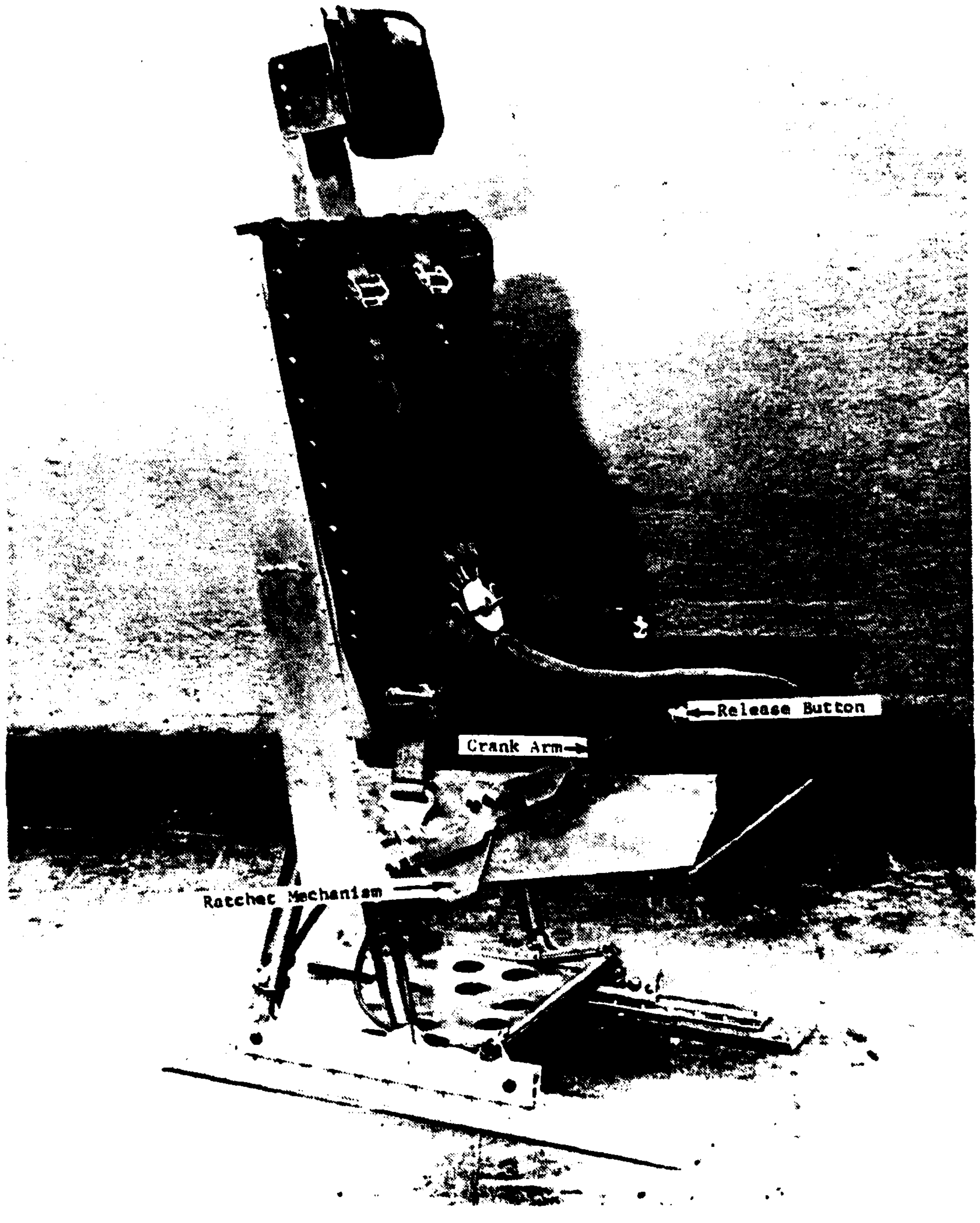


Figure 1 - Fixed Seat with Manual Cinch-up Mechanism

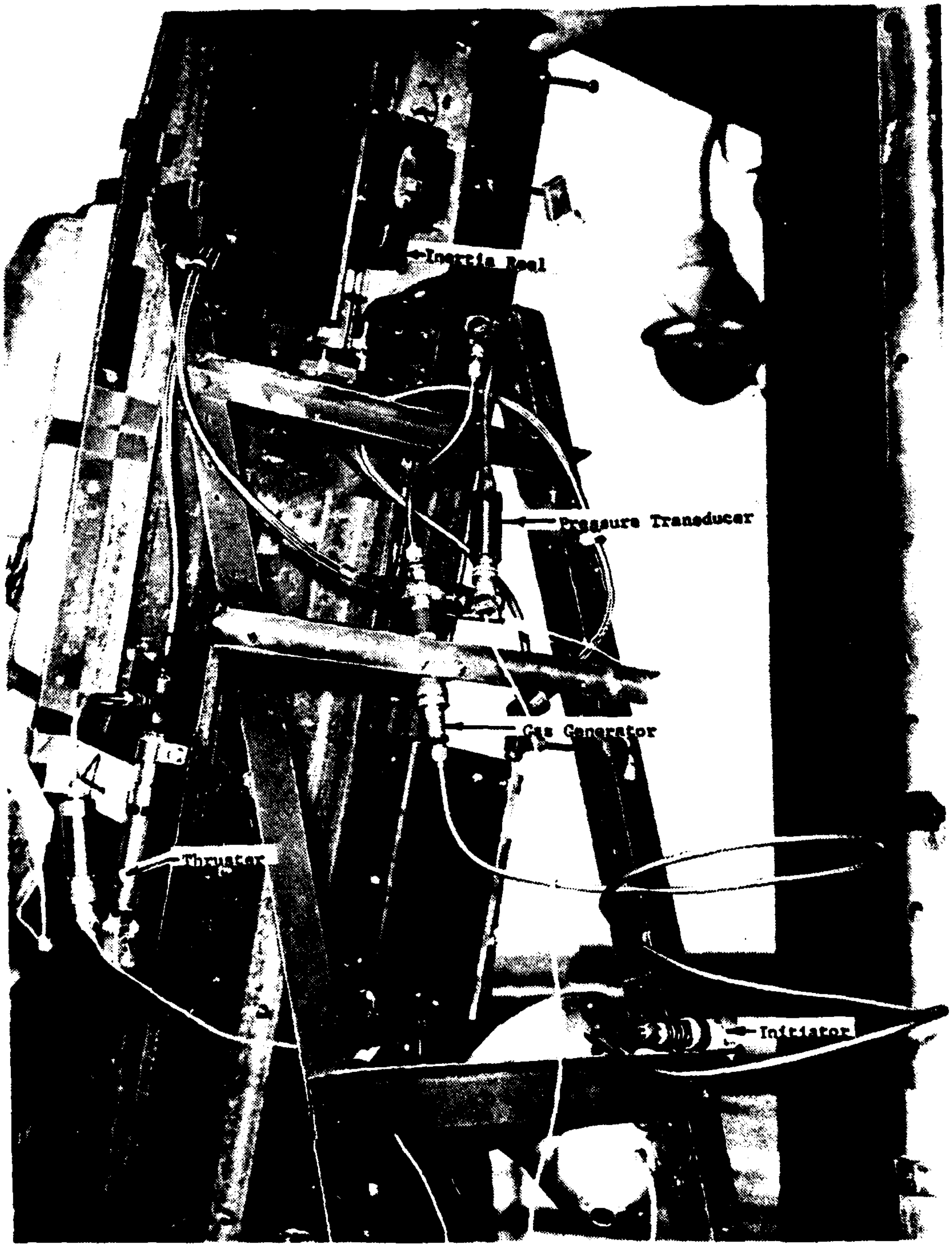


FIGURE 2 - Test Seat With Crank Mechanism, Thruster And Gas Generator - Rear View

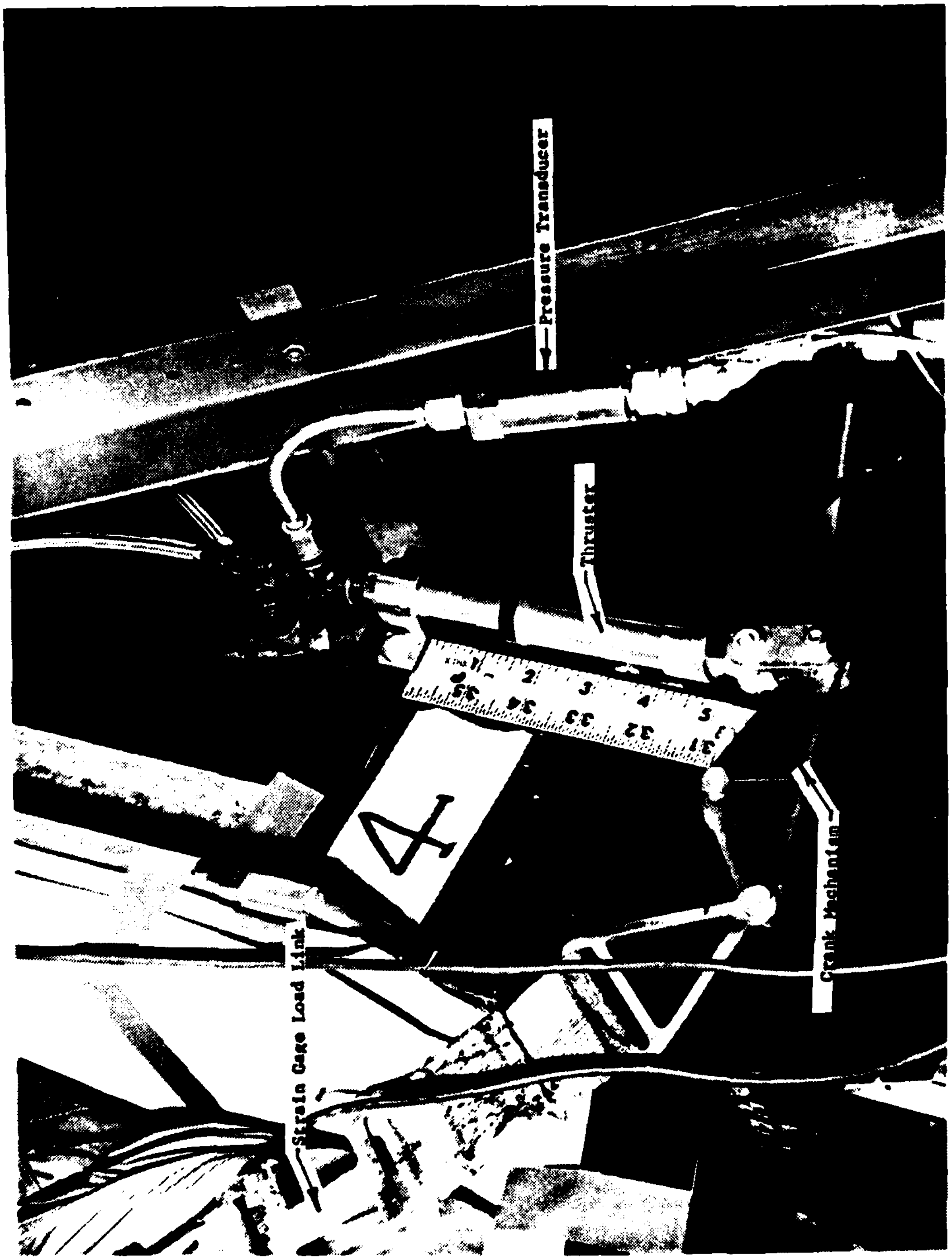
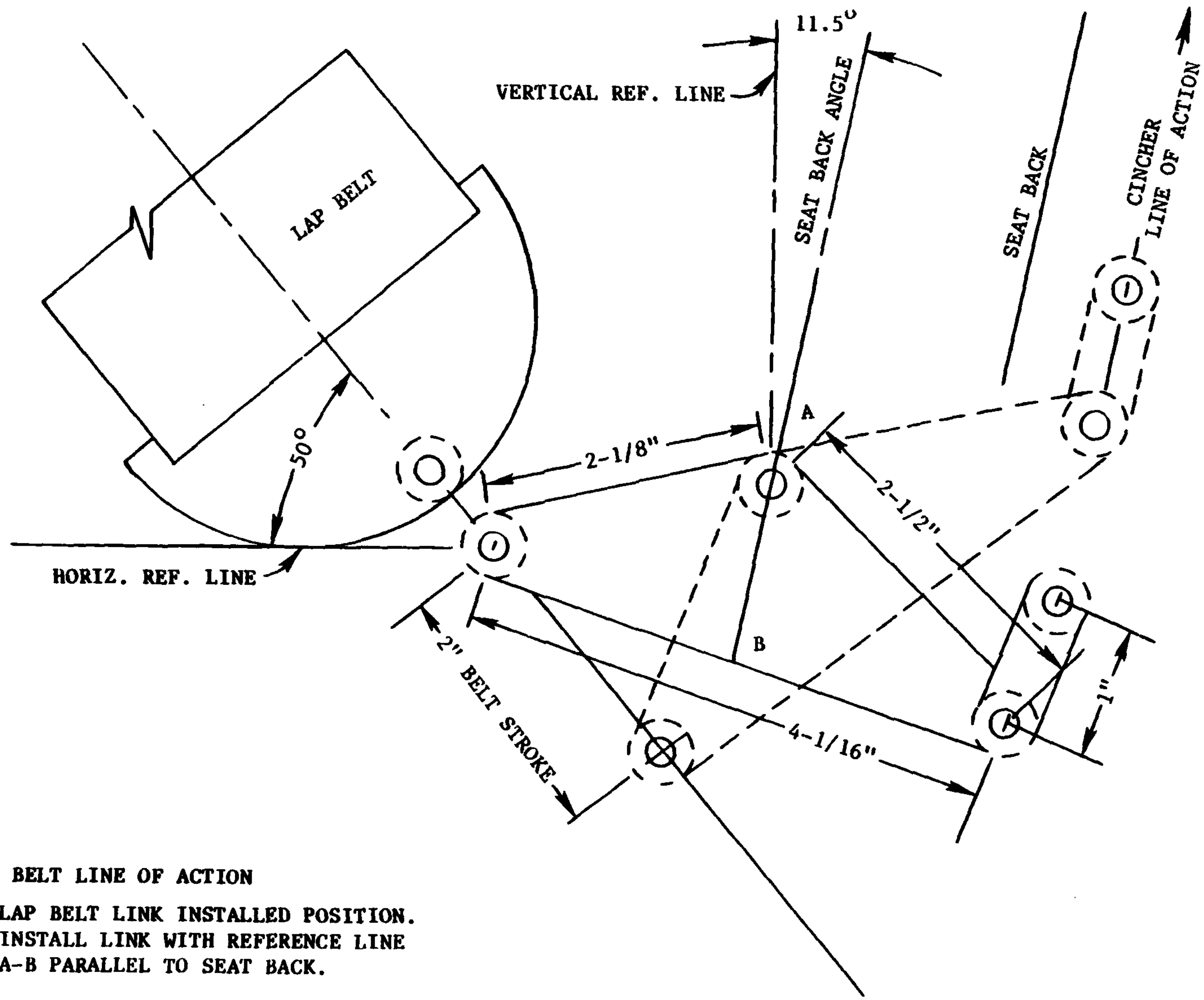


FIGURE 3 - Test Seat With Crank Mechanism And Thruster - Side View



LAP BELT LINE OF ACTION

1 LAP BELT LINK INSTALLED POSITION.
2 INSTALL LINK WITH REFERENCE LINE A-B PARALLEL TO SEAT BACK.

FIGURE 4 _ Lap Belt Link Installation Layout

TABLE I

LAP BELT/LOAD LINK RETRACTOR THRUSTER TEST PROGRAM DATA

TEST NO.	SUBJECT	RISER RIGHT	LOADS LEFT	LAP BELT CONFIG.	UPPER TORSO CONFIG.	LEFT LAP BELT LOAD	RIGHT LAP BELT LOAD	HORIZ. ACCEL. DUMMY	ACTUAT. TIME	MAX REEL PRESS	MAX. THRUSTER PRESS. LS/RS
1	5% DUMMY	85	88	LOOSE	10 IN. OUT	124	120	1.89	0.168	1685	1809/1795
2	95% DUMMY	00	00	SNUG	FULL BACK	86	90	0.0		1151	1235/1176
3	50% DUMMY	102	77	LOOSE	14 IN. OUT	106	75.9	1.88	0.218	1238	1242/1242
4	50% DUMMY	84	68	TIGHT	12 IN. OUT	86.4	81.5	1.52	0.173	1192	1242/1242
5	SAUERS 206 LBS	0	0	SNUG	BACK	65	40	LIVE	0.240	1299	1307/1307
6	SAUERS 206 LBS	70	53	SNUG	8 IN. OUT	56.7	47	LIVE		1021	1059/1036
7	SAUERS	100	95	SNUG	FULL OUT	71.8	54.7	LIVE	0.243	1429	1490/1490
8	GRIFF	-	-	SNUG	BACK	51	48.6	LIVE		1064.9	1098/1105
9	GRIFF	46	54	SNUG	9 IN. OUT	95	103	LIVE		1056	1116/1111
10	GRIFF	100	67	SNUG	FULL OUT	119.6	122.8	LIVE		1323	1424/1352
11	50% DUMMY	66	77	SNUG	16 IN. OUT	110	95	2.4 g			

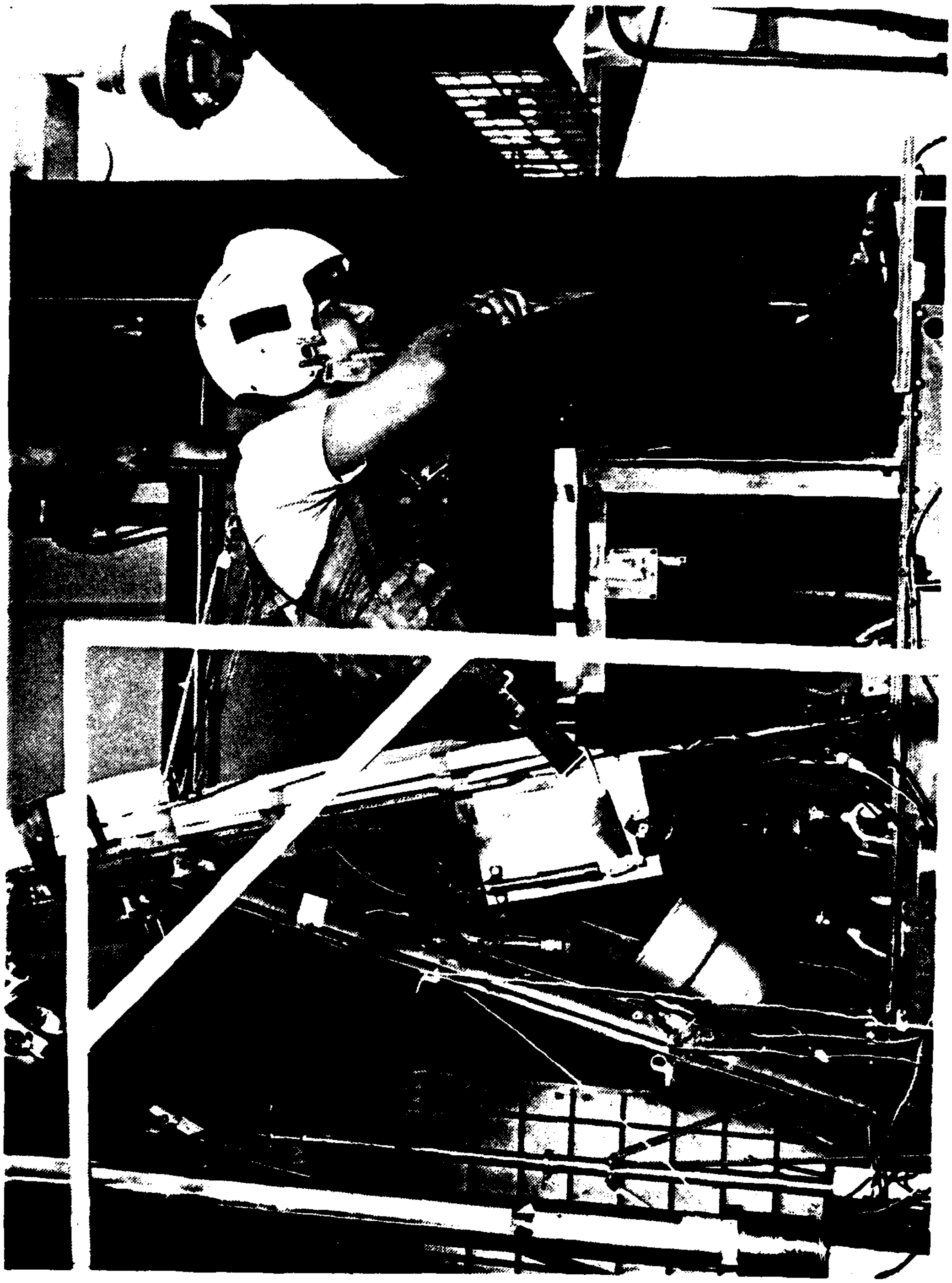


FIGURE 5 - Subject In Full Out Position

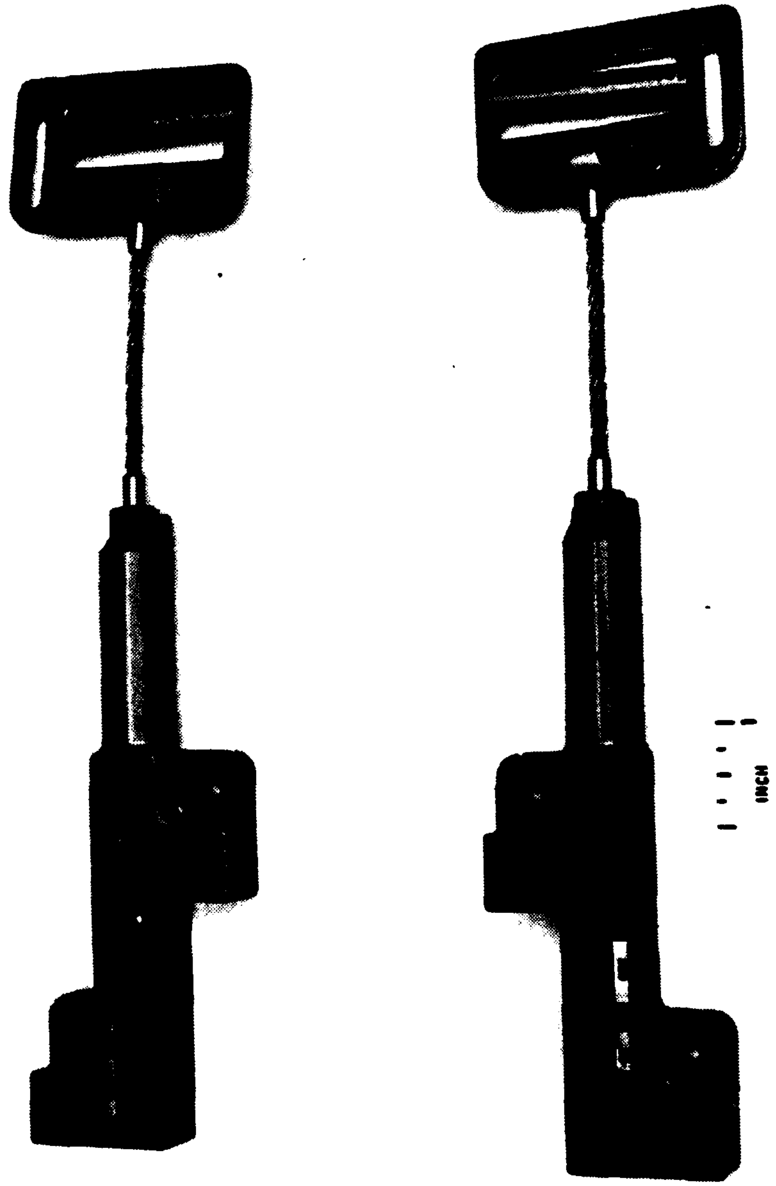


FIGURE 6 - Cinch And Release Assembly

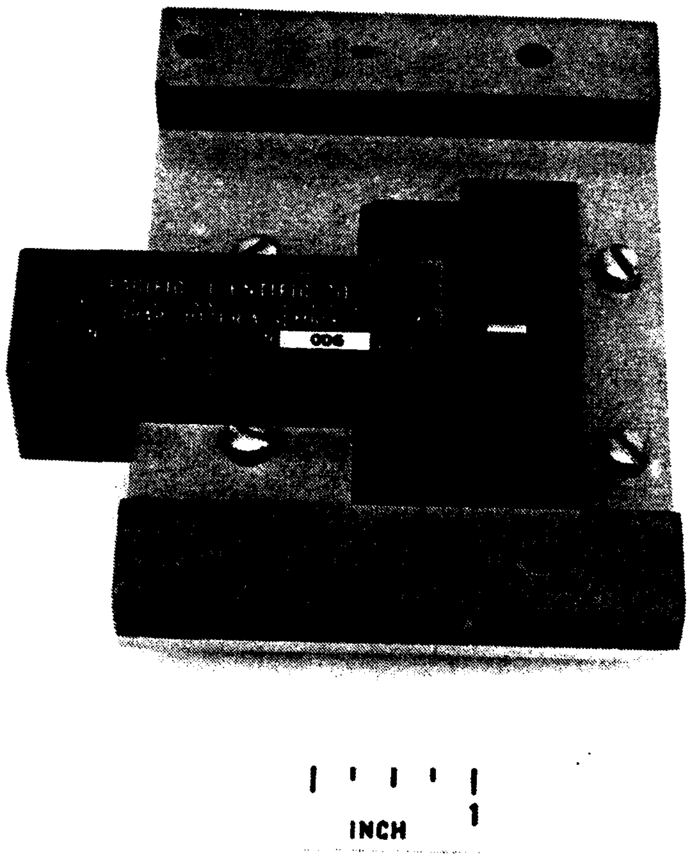


FIGURE 7 - Strap Cutter Assembly

FIGURE 8 - Bread Board Layout Of Cinch And Release System

TABLE II

CINCH AND RELEASE AND STRAP CUTTER COMPONENT FUNCTIONAL DATA

(Nitrogen Operation)

Par.	Test	12 lb. wt. - psi		Cutter - psi	
		Lift	Release	Retaining Pin	Cut Strap
2.	Initial Functional	265	56	168	325
3.	Low Temperature	360	138	192	396
5.	High Temperature	265	47	150	238
6.	Vibration	330	50	170	360
7.	Shock	330	52	168	324
8.	Humidity	475	110	158	335
9.	Salt Spray	310	57	168	522 (400) ⚠1
10.	Sand and Dust	320	68	168	510 (400)

⚠1 Second operation with solenoid used to introduce the gas.

TAPLE III

CINCH AND RELEASE AND STRAP CUTTER SYSTEM FIRING DATA

Tape No	Temp. °F	CINCH △1		RELEASE △2		CUTTER △2	
		Pressure psi	Force lbs	Pressure psi	Time sec.	Pressure psi 2	Time sec.
1	70°F	1300	70				
2	70°F			800	0.012	800	0.010
3	70°F	1350	70				
4	70°F			780	0.010	800	0.010
5	-65°F	750	26				
6	-65°F			510	0.012	620	0.041
7	-65°F	400	20				
8	-65°F			500	0.025	560	0.094
9	200°F	820	40				
10	200°F			580	0.016	580	0.040
11	200°F	800	40				
12	200°F			600	0.015	600	0.040

△1 Data taken at .185 sec. after initiation of cinch system.
△2 Data taken at .050 sec. after initiation of release system.

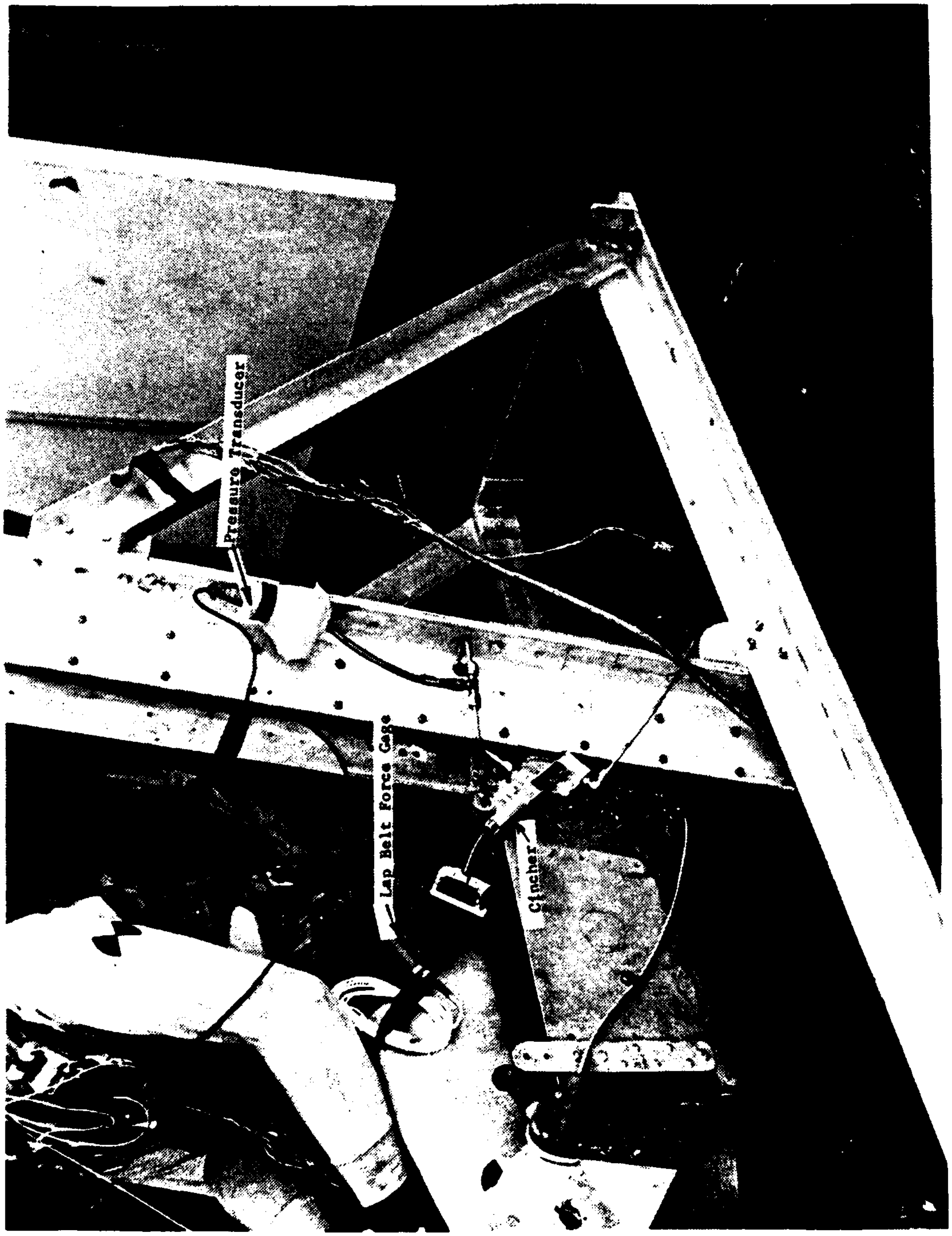


FIGURE 9 - Cinch And Release System Installed on MPES Seat

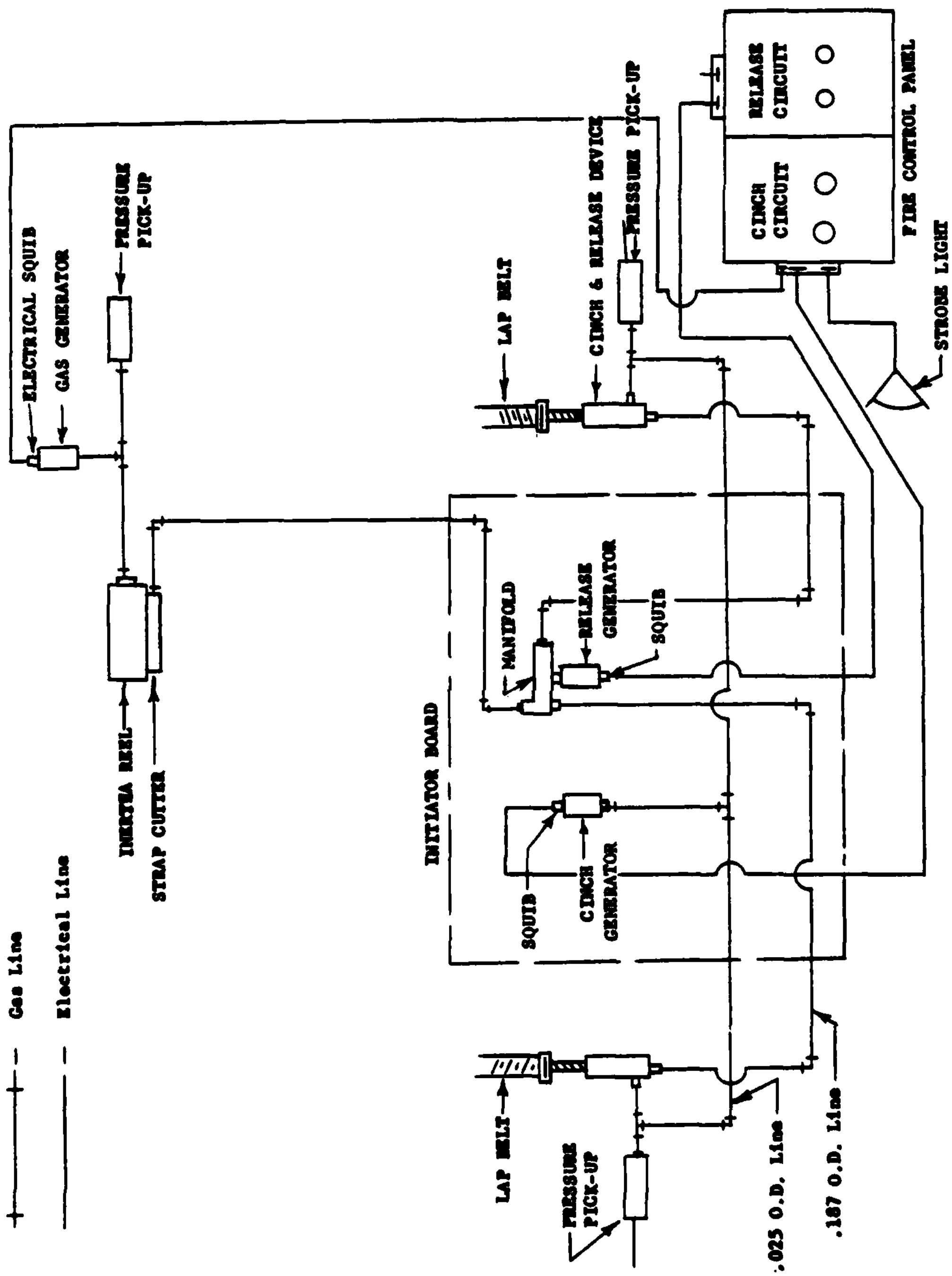


FIGURE 10 - Schematic Of System Ballistics, Instrumentation And Firing Set-Up

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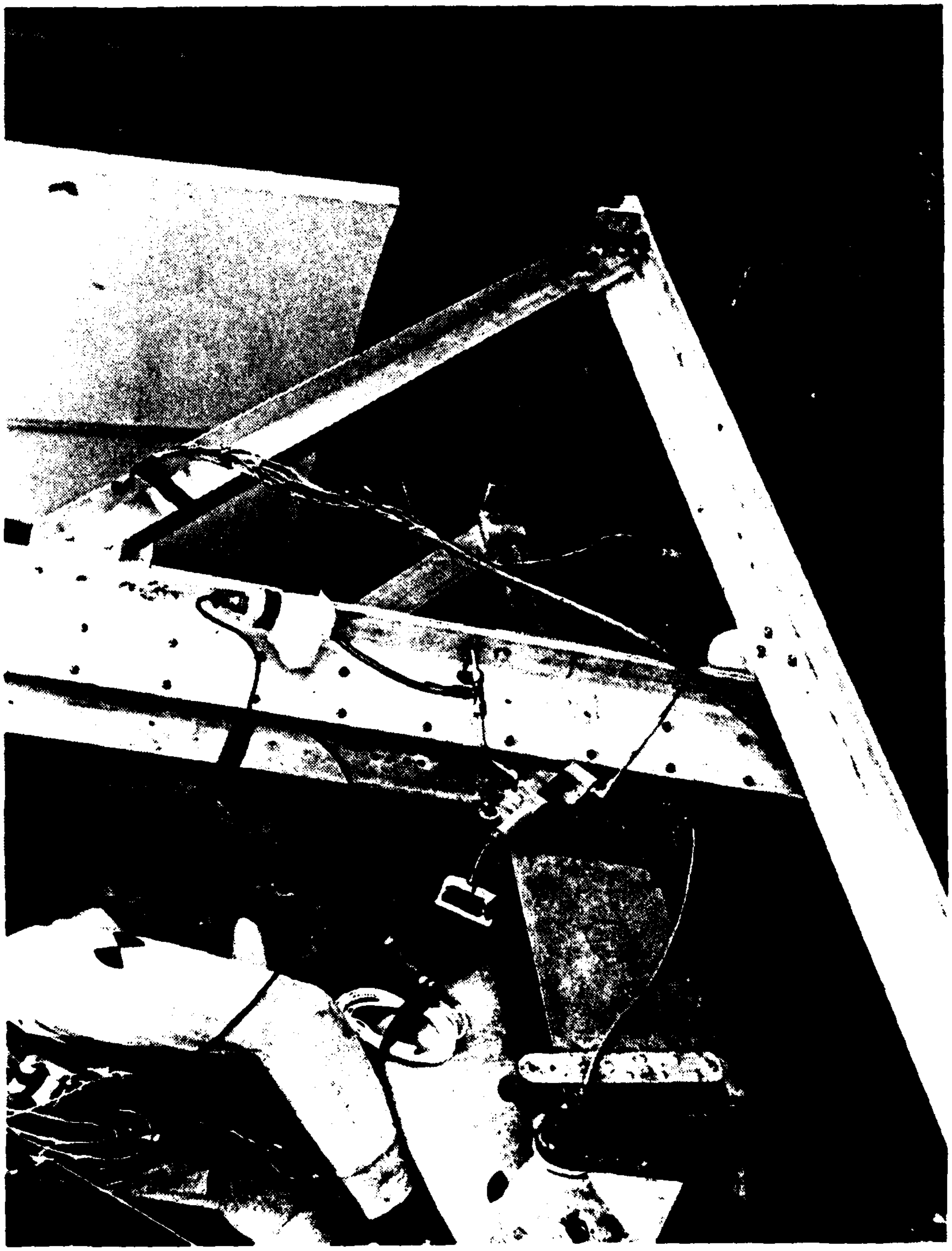

FIGURE 11 - Half Out Pre-Test Condition

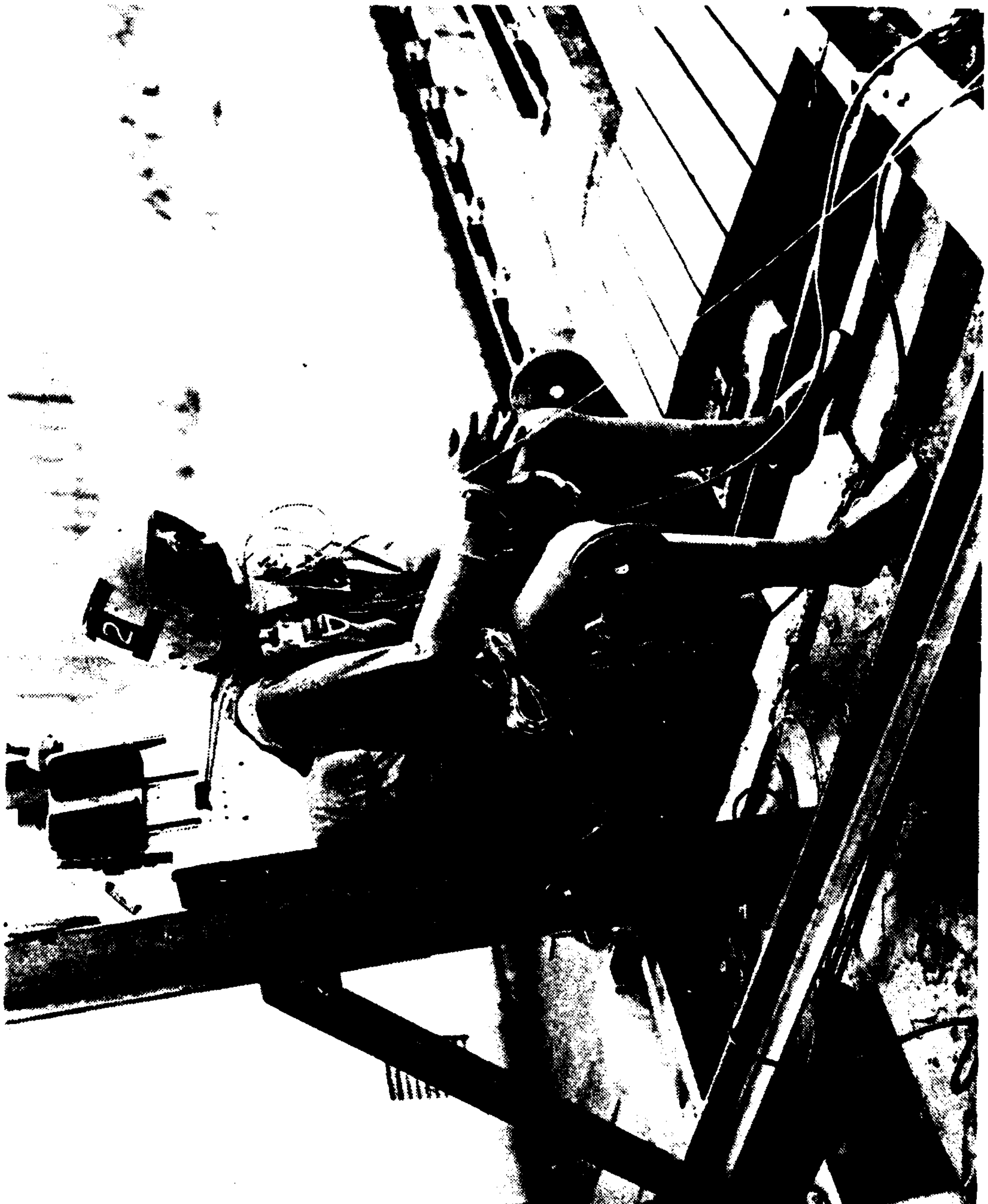

FIGURE 12 - Full Out Pre-Test Position

FIGURE 13 - Release Condition

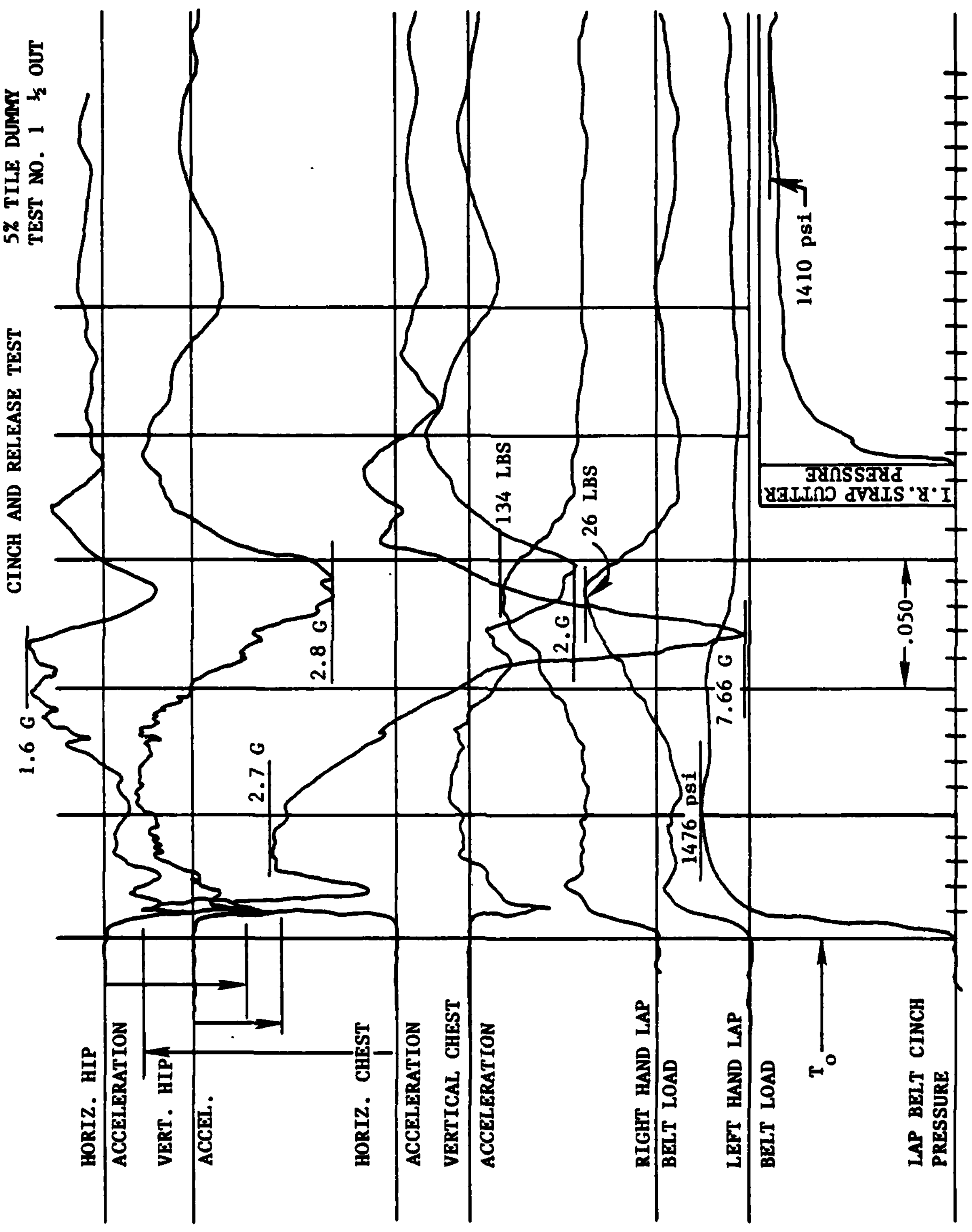

FIGURE 14 - Oscillograph Record Of Test No. 1

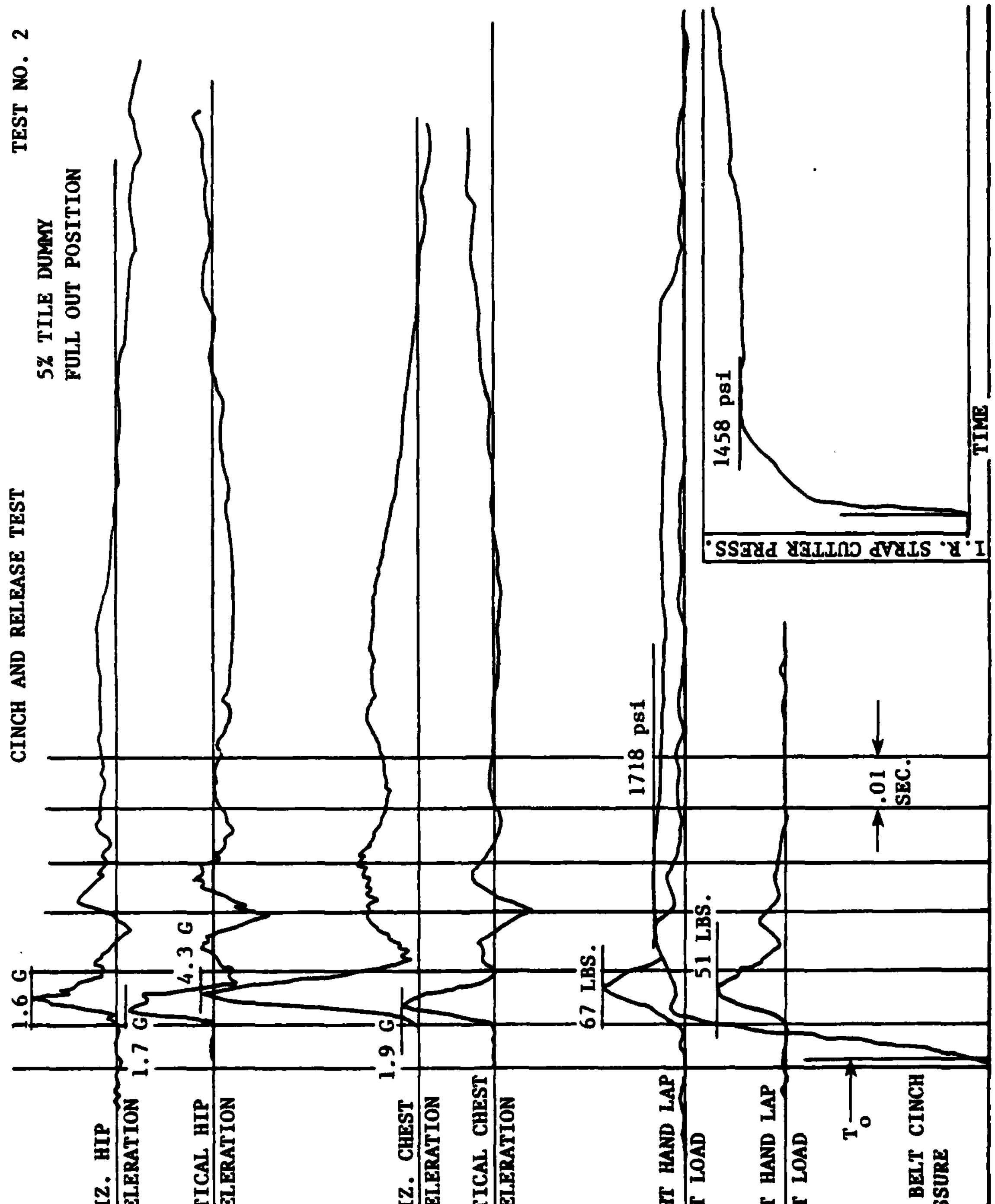

FIGURE 15 - Oscillograph Record Of Test No. 2

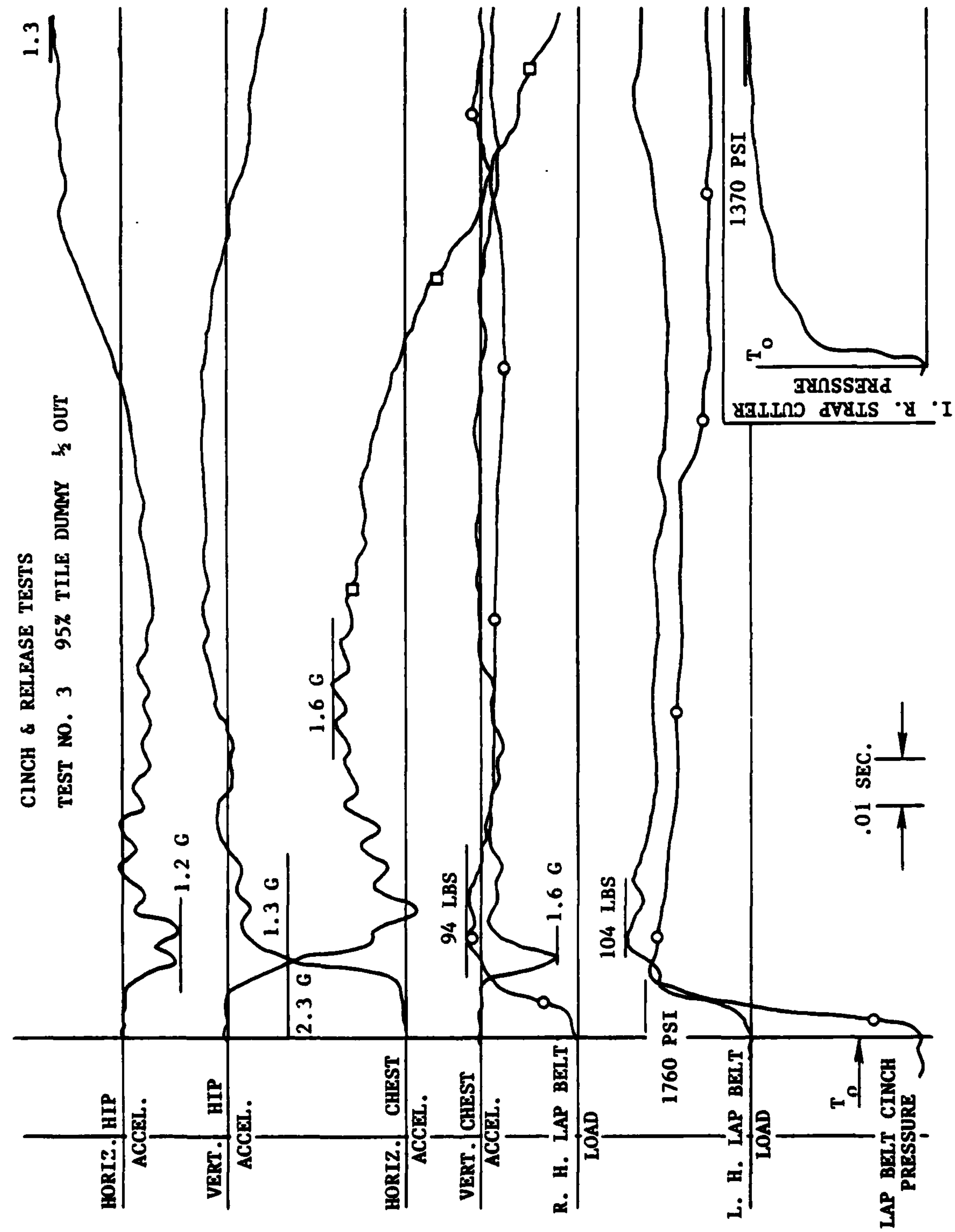

FIGURE 16 - Oscillograph Record Of Test No. 3

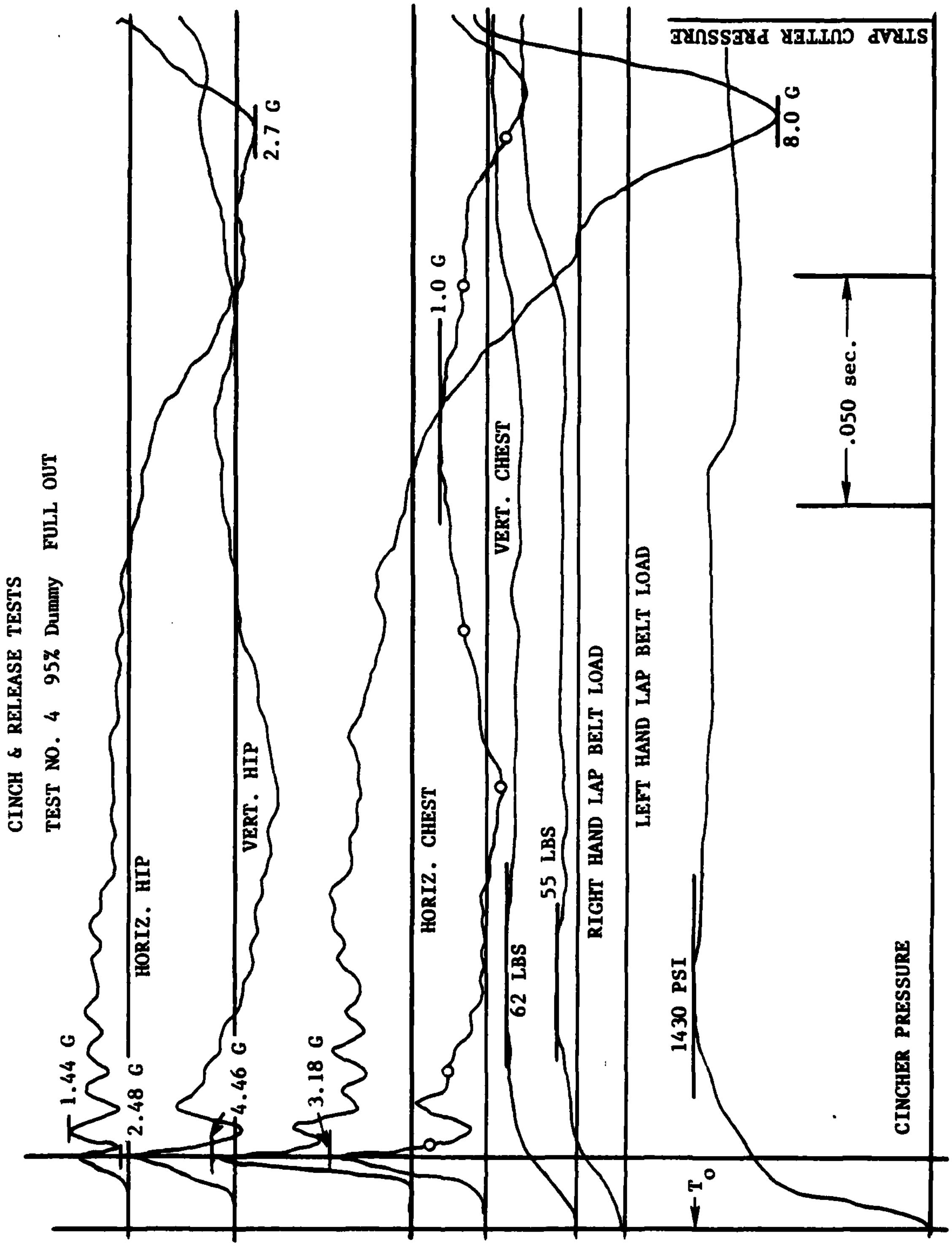

FIGURE 17 - Oscillograph Record Of Test No. 4

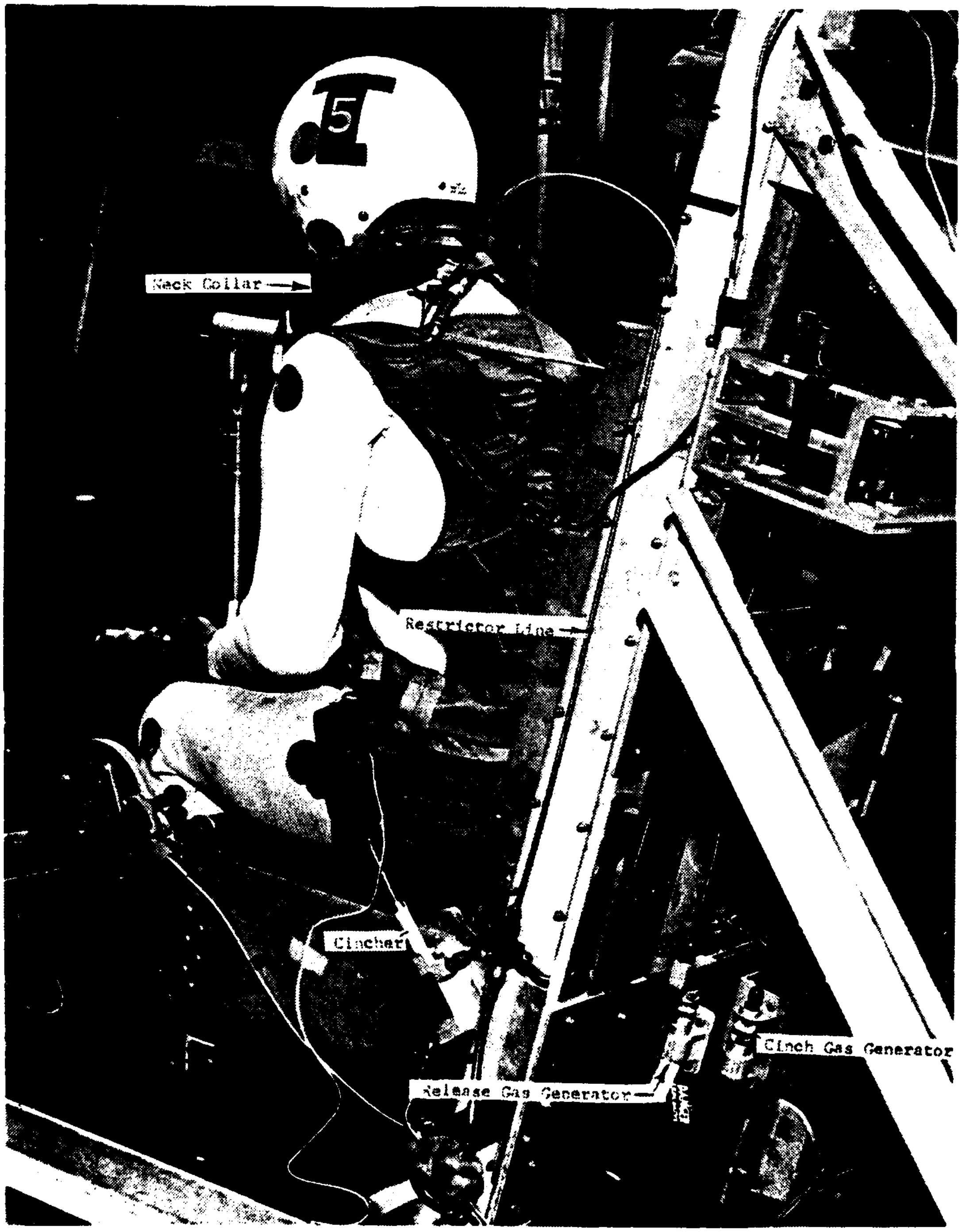

FIGURE 18 - Head-Neck Support Collar Test Set-Up - Rear View

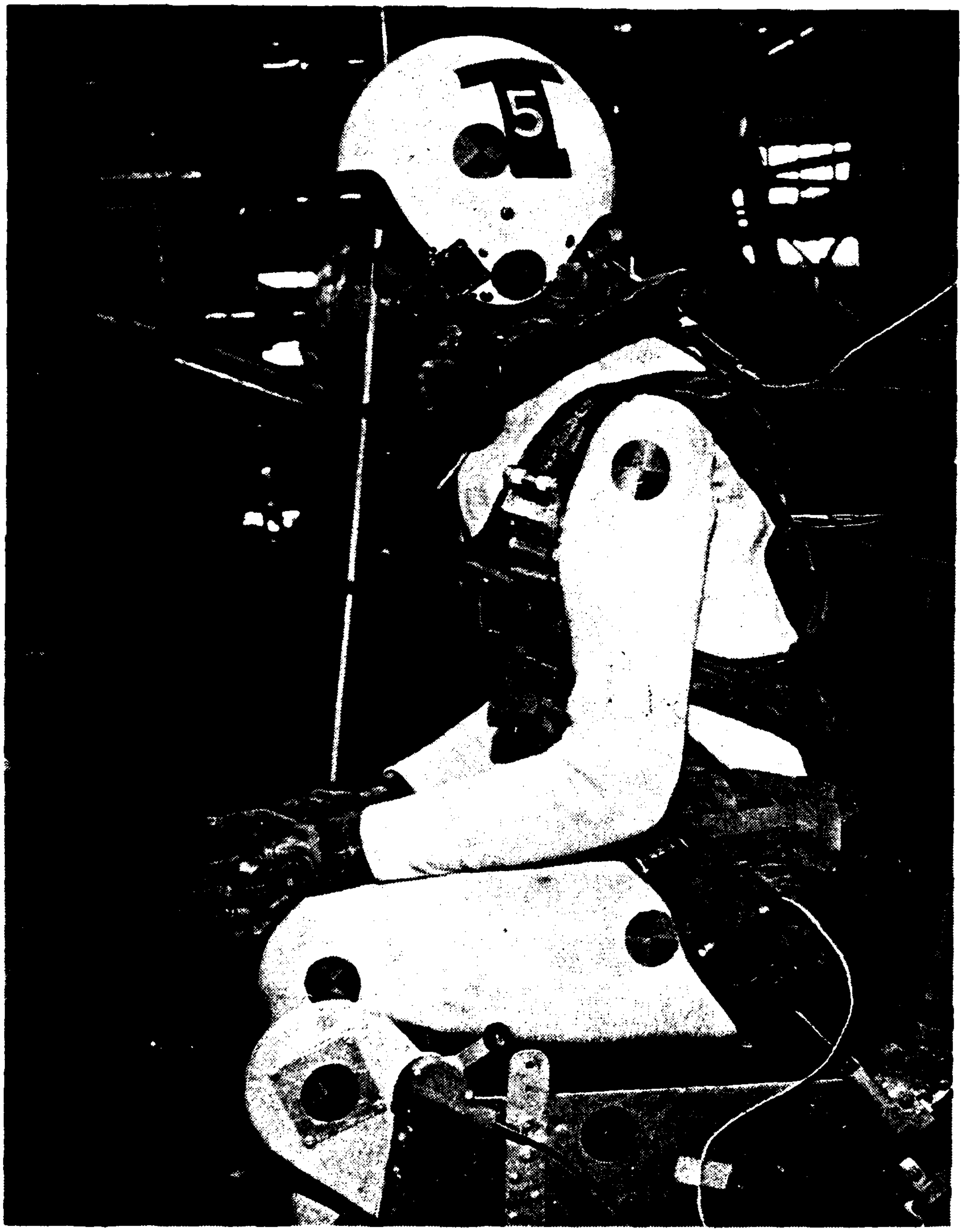

FIGURE 19 - Head-Neck Support Collar Test Set-Up - Side View

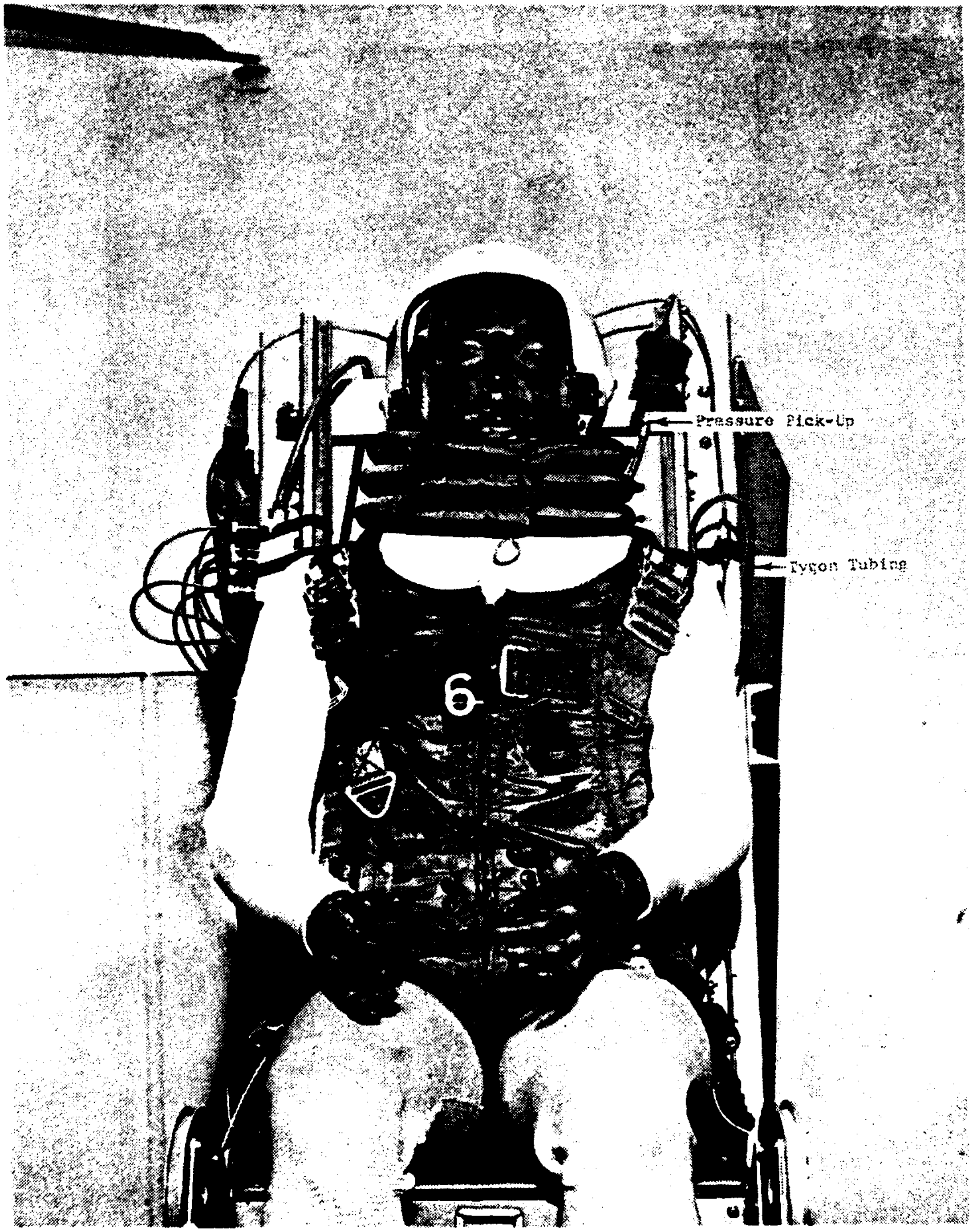

FIGURE 20 - Head-Neck Support Collar - Inflated Condition - Front View

FIGURE 21 - Head-Neck Support Collar - Inflated Condition - Rear View

REFERENCES

a. Summary of the Design, Development, and Testing of a Retraction and Restraint System for the MPES Seat, Data Report 1254, Pacific Scientific Co.

b. Development Testing, Test Report No. 762, Pacific Scientific Co.

c. Summary of the Redesign, Development, and Testing of the Retraction and Restraint Components for the MPES Seat, Data Report 1484, Pacific Scientific Co.