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HELICOPTER TROOP/PASSENGER RESTRAINT SYSTEMS DESIGN CRITERIA EVALUATION

Richard W. Carr

Ultrasystems, Incorporated

Prepared for:

Army Air Mobility Research and Development Laboratory

June 1975

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HELICOPTER TROOP/PASSENGER RESTRAINT SYSTEMS DESIGN CRITERIA EVALUATION

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Fort Eustis, Va. 23604

EUSTIS DIRECTORATE POSITION STATEMENT

The objectives of the effort described herein were: (1) to design, fabricate, statically test, dynamically test, and evaluate a three-strap and a four-strap restraint system for helicopter troop seat occupants, and (2) to recommend modifications to the proposed Draft General Military Specification MIL-SXXXX(AV), "Restraint System, Aircraft Troop/Passenger", and USAAMRDL TR 71-22, "Crash Survival Design Guide". The contractor achieved these objectives.

The conclusions submitted by the contractor are considered to be valid. This directorate has revised the proposed Draft Gereral Military Specification to reflect the contractor's recommend changes, and the Draft Specification is being coordinated within the Army for eventual publication. Once published and applied, the improved aircraft troop/passenger restraint system Military Specification will ensure that passengers of future Army troop transport helicopters will be afforded a higher probability of survival during crash impact.

This report has been reviewed by this directorate and is considered to be technically sound. The technical monitor for this effort was Mr. George T. Singley III of the Structures Technical Area, Technology Applications Division.

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For many years the Army has been actively engaged in developing the technology and hardware to improve aircraft crashworthiness, with the emphasis placed on increasing occupant protection. As studies of injuries resulting from aircraft crashes increased the knowledge of injury causation, investigation focused attention on restraint systems and seats. Studies to develop techniques for improving seats and restraint systems revealed that while the

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seats remained essentially intact during a crash, the restraint systems did not possess sufficient strength to keep the occupant in the seat. In addition, the use of webbing materials having excessive elongation and restraint systems not configured to provide sufficient restraint in all directions were shown to have deleterious effects.

As investigations progressed, methods for improving the crashworthiness of both restraint systems and seats were developed and documented in the technical literature. In mid-1970, the Army initiated a development program to design, test, and optimize an aircrew restraint system and to prepare a military specification that would define the requirements for a new aircrew restraint system. During this program, previous and current technologies were reviewed to establish the state of the art in restraint system design and injury prediction techniques. An analytical investigation was performed to determine restraint system performance as a function of critical parameters, and a trade-off study of restraint system concepts was used to establish an optimum configuration. Desirable configurational aspects as well as material dimensions and properties were chosen, and the adequacy of the proposed system was demonstrated by static and dynamic testing of a prototype unit. Subsequently, the information from this program was also used to generate a draft specification for troop restraint systems.

The next step in the orderly development of advanced restraint systems that could be procured and used on new and current aircraft was to demonstrate that the requirements of the specifications were practical in terms of acceptable weight limits, within reasonable costs, and within existing production technology.

A systems analysis of the new restraint systems for both troop restraint systems was conducted. Hardware was designed and statically tested in accordance with the requirements of two proposed specifications. Design iterations were required on some hardware components, and three designs to be dynamically tested were developed. Dynamic testing of the restraint systems revealed additional weaknesses, design modifications were again incorporated, and testing was reconducted until satisfactory results were obtained. The proposed specifications were modified and refined in accordance with the test results, with the net effect that the two specifications as they now stand define advanced restraint systems providing optimum restraint for occupants of Army aircraft which can be built within existing state of the art, are low in weight, and have reasonable cost.

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CONTENTS

	Page
PREFACE	1
ILLUSTRATIONS	5
TABLES	12
INTRODUCTION	13
RESTRAINT SYSTEM ANALYSIS	15
PARAMETRIC STUDY	16
Input Velocity and Deceleration	17
Occupant Size	19
Restraint System Slack	20
Restraint Webbing Load Elongation	20
Restraint System Configuration	20
Seat Properties and Dimensions	22
Results and Conclusions	22
SPECIFICATION REVIEW	29
COMPONENT ANALYSIS	36
Adjuster	40
Buckle	43
Inertia Reel	48
Webbing	53
TRADE-OFF STUDY	59
RESTRAINT SYSTEM DESIGN	63
TYPE I - TROOP RESTRAINT SYSTEM	63
TYPE II - TROOP RESTRAINT SYSTEM	63
Webbing	63
Inertia Reel	65
Lift-Lever Buckle - Type I	66
Lift-Lever Buckle - Type II	66
Buckle Pad	67
Adjuster/Fitting	67
Lap Belt Assembly	67

Preceding page blank

CONTENTS (CONTD)

	Page
TEST FIXTURES	68
STATIC TEST FIXTURE	68
FUNCTIONAL TEST FIXTURE	70
BUCKLE RELEASE ACTUATOR	70
STATIC TESTS	73
WEBBING TESTS	73
HARDWARE COMPONENT TESTS	74
BUCKLE RELEASE TEST	77
BUCKLE FITTING EJECTION TEST	81
SHOULDER STRAP TEST	81
LAP BELT ASSEMBLY TEST	83
ADJUSTER TESTS	89
ACCELERATION RESISTANCE TEST	93
DYNAMIC TESTS	94
CONCLUSIONS AND RECOMMENDATIONS	108
APPENDIXES	
A. TEST FIXTURE DRAWING	109
B. ACCELERATION RESISTANCE ANALYSIS OF ADJUSTER	110
C. ACCELERATION AND FORCE/TIME HISTORIES	118

ILLUSTRATIONS

Figure		Page
1	Aircraft Troop/Passenger Restraint Systems. . .	16
2	Model of Passenger and Seat Used in SIMULA. . .	18
3	Input Crash Pulses - Longitudinal	19
4	Webbing Load-Elongation Baseline Properties . .	21
5	Ceiling-Mounted Troop Seat - Concept.	23
6	Head Severity Index Versus Occupant Size. . . .	26
7	Chest Severity Index Versus Occupant Size . . .	27
8	Shoulder Harness Load Versus Occupant Size. . .	28
9	Head and Chest Severity Index as a Function of Restraint System Stiffness	30
10	Belt Loads as a Function of Restraint System Stiffness.	31
11	Hip and Shoulder Displacement as a Function of Restraint System Stiffness.	32
12	Type I Troop Restraint System Mock-up	37
13	Prototype Lift-Lever Buckle	38
14	Proposed Restraint System	39
15	Typical Field Equipment - Arctic Ensemble . . .	41
16	Typical Field Equipment - Basic Ensemble. . . .	41
17	Shoulder Harness Placement - Type II Restraint System.	45
18	Webbing Stiffness Versus Belt Width	54
19	Average Belt Pressures as a Function of Webbing Width	56
20	Weight Increase as a Function of Webbing Width	57

ILLUSTRATIONS (CONTD)

Figure		Page
21	Load-Elongation Curves for Polyester Webbing. .	59
22	Two Troop Restraint System Designs.	64
23	Static Test Fixture	69
24	Functional Test Fixture	71
25	Buckle Release Test	72
26	Webbing Test Setup.	75
27	Webbing Load-Elongation Curves.	76
28	Type I Buckle Release Test Configuration. . . .	78
29	Type II Buckle Release Test Configuration . . .	78
30	Type I Buckle Release Posttest Configuration. .	79
31	Type II Buckle Release Posttest Configuration .	79
32	Shoulder Strap Test Configuration	82
33	Shoulder Strap Test Results	83
34	Type I Lap Belt Assembly - Pretest.	84
35	Type II Lap Belt Assembly - Pretest	84
36	Type I Lap Belt Assembly - Posttest	86
37	Type II Lap Belt Assembly - Posttest.	89
38	Adjuster Webbing Abrasion Test Configuration. .	90
39	Adjuster Webbing Abrasion Test Results.	91
40	Adjuster Adjustment Load Test	92
41	Adjuster Readjustment Load Test	92
42	Type I Restraint System - Drop Test	97
43	Type II Restraint System - Drop Test.	98

ILLUSTRATIONS (CONTD)

Figure		Page
44	Type II Restraint System - Sled Test No. 1	100
45	Type I Troop Restraint - Sled Test No. 1	102
46	Buckle Configuration - Type I Restraint System - Sled Test No. 1	103
47	Revised Type I Lap Belt	104
48	Type I Troop Restraint - Sled Test No. 2	105
49	Type I Troop Restraint - Sled Test No. 3	106
C-1	Drop Test Type I Restraint - Input Acceleration	118
C-2	Drop Test Type I Restraint - Head Acceleration - Longitudinal	118
C-3	Drop Test Type I Restraint - Head Acceleration - Lateral	119
C-4	Drop Test Type I Restraint - Head Acceleration - Vertical	119
C-5	Drop Test Type I Restraint - Chest Acceleration - Longitudinal	120
C-6	Drop Test Type I Restraint - Chest Acceleration - Lateral	120
C-7	Drop Test Type I Restraint - Chest Acceleration - Vertical	121
C-8	Drop Test Type I Restraint - Pelvis Acceleration - Longitudinal	121
C-9	Drop Test Type I Restraint - Pelvis Acceleration - Lateral	122
C-10	Drop Test Type I Restraint - Pelvis Acceleration - Vertical	122
C-11	Drop Test Type I Restraint - Seat Pan Acceleration - Longitudinal	123

ILLUSTRATIONS (CONTD)

Figure		Page
C-12	Drop Test Type I Restraint - Seat Pan Acceleration - Lateral	123
C-13	Drop Test Type I Restraint - Seat Pan Acceleration - Vertical	124
C-14	Drop Test Type I Restraint - Left Lap Belt Load	124
C-15	Drop Test Type I Restraint - Right Lap Belt Load	125
C-16	Drop Test Type I Restraint - Lower Shoulder Strap Load	125
C-17	Drop Test Type II Restraint - Input Acceleration	126
C-18	Drop Test Type II Restraint - Head Acceleration - Longitudinal	126
C-19	Drop Test Type II Restraint - Head Acceleration - Lateral	127
C-20	Drop Test Type II Restraint - Head Acceleration - Vertical	127
C-21	Drop Test Type II Restraint - Chest Acceleration - Longitudinal	128
C-22	Drop Test Type II Restraint - Chest Acceleration - Lateral	128
C-23	Drop Test Type II Restraint - Chest Acceleration - Vertical	129
C-24	Drop Test Type II Restraint - Pelvis Acceleration - Longitudinal	129
C-25	Drop Test Type II Restraint - Pelvis Acceleration - Lateral	130
C-26	Drop Test Type II Restraint - Pelvis Acceleration - Vertical	130
C-27	Drop Test Type II Restraint - Seat Pan Acceleration - Longitudinal	131

ILLUSTRATIONS (CONTD)

Figure		Page
C-28	Drop Test Type II Restraint - Seat Pan Acceleration - Lateral.	131
C-29	Drop Test Type II Restraint - Seat Pan Acceleration - Vertical	132
C-30	Drop Test Type II Restraint - Left Lap Belt Load	132
C-31	Drop Test Type II Restraint - Right Lap Belt Load	133
C-32	Drop Test Type II Restraint - Left Lower Shoulder Strap Load	133
C-33	Drop Test Type II Restraint - Left Upper Shoulder Strap Load	134
C-34	Drop Test Type II Restraint - Right Upper Shoulder Strap Load	134
C-35	Sled Test Type I Restraint - Input Acceleration.	135
C-36	Sled Test Type I Restraint - Head Acceleration - Longitudinal	135
C-37	Sled Test Type I Restraint - Head Acceleration - Lateral.	136
C-38	Sled Test Type I Restraint - Head Acceleration - Vertical	136
C-39	Sled Test Type I Restraint - Chest Acceleration - Lateral.	137
C-40	Sled Test Type I Restraint - Chest Acceleration - Vertical	137
C-41	Sled Test Type I Restraint - Pelvis Acceleration - Longitudinal	138
C-42	Sled Test Type I Restraint - Pelvis Acceleration - Lateral.	138
C-43	Sled Test Type I Restraint - Pelvis Acceleration - Vertical	139

ILLUSTRATIONS (CONTD)

Figure		Page
C-44	Sled Test Type I Restraint - Seat Pan Acceleration - Longitudinal	139
C-45	Sled Test Type I Restraint - Seat Pan Acceleration - Lateral.	140
C-46	Sled Test Type I Restraint - Seat Pan Acceleration - Vertical	140
C-47	Sled Test Type I Restraint - Left Lap Belt Load	141
C-48	Sled Test Type I Restraint - Right Lower Shoulder Strap Load	141
C-49	Sled Test Type I Restraint - Right Upper Shoulder Strap Load	142
C-50	Sled Test Type II Restraint - Input Acceleration.	142
C-51	Sled Test Type II Restraint - Head Acceleration - Longitudinal	143
C-52	Sled Test Type II Restraint - Head Acceleration - Lateral.	143
C-53	Sled Test Type II Restraint - Head Acceleration - Vertical	144
C-54	Sled Test Type II Restraint - Chest Acceleration - Longitudinal	144
C-55	Sled Test Type II Restraint - Chest Acceleration - Lateral	145
C-56	Sled Test Type II Restraint - Chest Acceleration - Vertical	145
C-57	Sled Test Type II Restraint - Pelvis Acceleration - Longitudinal	146
C-58	Sled Test Type II Restraint - Pelvis Acceleration - Lateral.	146

ILLUSTRATIONS (CONTD)

Figure		Page
C-59	Sled Test Type II Restraint - Pelvis Acceleration - Vertical	147
C-60	Sled Test Type II Restraint - Seat Pan Acceleration - Longitudinal	147
C-61	Sled Test Type II Restraint - Seat Pan Acceleration - Lateral	148
C-62	Sled Test Type II Restraint - Seat Pan Acceleration - Vertical	148
C-63	Sled Test Type II Restraint - Right Lap Belt Load	149
C-64	Sled Test Type II Restraint - Left Lower Shoulder Strap Load	149
C-65	Sled Test Type II Restraint - Left Upper Shoulder Strap Load	150
C-66	Sled Test Type II Restraint - Right Lower Shoulder Strap Load	150
C-67	Sled Test Type II Restraint - Right Upper Shoulder Strap Load	151

TABLES

Table		Page
1	Occupant Weight Distribution.	19
2	Restraint System Definitions.	22
3	Maximum Output Values for 95th Percentile Occupant.	24
4	Maximum Output Values for 95th Percentile Crash Pulse	25
5	Adjuster Location Trade-Off	42
6	Buckle Fitting Ejection Trade-Off	49
7	Effects of Webbing Width.	55
8	Restraint System Trade-Off.	60
9	Webbing Dimensions, Strength, and Elongation Requirements	65
10	Webbing Dimensions and Minimum Ultimate Strength.	74
11	Webbing Elongation Data	75
12	Hardware Test Results	76
13	Buckle Test Data.	80
14	Shoulder Strap Test Data.	82
15	Type I Lap Belt Assembly Test Data.	85
16	Type II Lap Belt Assembly Test Data	88
17	Adjuster Load Test Data	93
18	Dynamic Test Requirements	96
19	Summary of Drop Test Data	99
20	Summary of Sled Test Data	107

INTRODUCTION

The basic design of troop restraint systems presently used in Army aircraft has not been changed in many years, and consequently, the systems in use have not kept up with the state-of-the-art developments. Many include only a lap belt restraint, and all are made of high-elongation webbing which amplifies decelerative loading on the occupant. Hardware is inefficient, bulky, and does not provide many desired features. Furthermore, the systems provide inefficient restraint for lateral loading. Studies of rotary-wing accidents have shown that lateral loading prevails in more than 60 percent of the survivable accidents. Because of these shortcomings, a draft proposed military specification was written by the Eustis Directorate that defined two new troop restraint systems for use in Army aircraft. The design concepts, materials, and safety features previously found to be desirable for improving occupant protection were included in the specification.

Following the writing of this draft proposed specification, two programs were conducted under Contract DAAJ02-73-C-0077 and Contract DAAJ02-74-C-0034 to evaluate the design and test requirements of the proposed specification. The work completed on these two programs is documented in this report. All work was performed by Ultrasystems, Inc., the Dynamic Science Division, with Pacific Scientific Company (PSCo) as a subcontractor during the period of 1 June 1973 through 31 August 1974.

The objectives of the two programs were to analyze, design, fabricate, and test two types of troop restraint systems that met the requirements of the draft proposed military specification, MIL-R-XXXX(AV), entitled: "Restraint System, Aircraft Troop/Passenger." Since the restraint systems defined by this specification consisted of many complex components, which would be expensive to generate from scratch, the approach established for the programs was to maximize usage of existing hardware. The intent of the overall effort was to modify and refine the specification as necessary to define the requirements for improved troop restraint systems that could be produced by restraint system manufacturers using current production techniques and available materials.

The first phase entailed the analysis in detail of the restraint systems, as defined by the draft proposed specification, to ensure that the design requirements were adequate and not overly restrictive. The requirements for each individual component were carefully studied to ensure that correct and complete criteria had been specified, and the test methods were reviewed to make sure the important characteristics of the system would be tested. Special fixtures were designed to accomplish the static tests, and a test plan was prepared. Finally, a restraint system design complying with the specification was developed.

The proposed specification contains the requirements for two troop restraint systems: a single shoulder strap system and a double shoulder strap system. During Phase I, the designations for these restraint systems were changed from those originally defined in the draft proposed specification. The new definitions for the restraint systems are:

Type I - Lap Belt With Single Diagonal Shoulder Strap

Type II - Lap Belt With Two Independent Shoulder Straps

These are the definitions applied to the two restraint systems throughout this report.

Phase II was devoted to fabricating and testing the restraint systems that had been designed in Phase I. The restraint systems were assembled by PSCo while Dynamic Science fabricated the static test fixtures. Following the delivery of the restraint systems and checkout of the test fixtures, the restraints were subjected to static tests in accordance with the test plan prepared during the previous phase. After the tests were completed, results were used to establish and verify the performance requirements for the restraint system's components.

During the third and final phase of the program, two additional restraint systems of each type, reflecting the design changes that evolved from Phase II, were fabricated by PSCo and then dynamically tested by Dynamic Science. Two dynamic tests of the Type I and Type II restraint systems were conducted to verify that they could adequately restrain a 95th percentile trooper during two impact environments that are representative of a 95th percentile survivable aircraft crash.[1] One test was a vertical impact conducted on Dynamic Science's drop tower, and the other test was a horizontal impact conducted on Dynamic Science's horizontal test sled. The results of the tests demonstrated that troop restraint systems meeting the requirements of the draft proposed specification could be designed and fabricated within current restraint system technology. The tests also provided empirical data for the overall evaluation of the two types of troop restraint systems and the final revision of the draft proposed specification.

1. CRASH SURVIVAL DESIGN GUIDE, USAAMRDL TR 71-22, Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, October 1971, AD 733358.

RESTRAINT SYSTEM ANALYSIS

One of the initial tasks was to analyze the two types of troop restraint systems defined by MIL-R-XXXX(AV), Proposed Draft Military Specification: Restraint System, Aircraft Troop/Passenger. The purpose of this analysis was to identify necessary modifications to the draft proposed specification and to point out components of the restraint systems requiring design changes in order to adequately restrain occupants during a 95th percentile rotary-wing aircraft accident. Also, the practicality of using a single restraint system for all seat orientations was to be examined.

The restraint systems currently defined by the draft proposed military specification are shown in Figure 1. The Type II troop restraint system was designed to mount on a forward-facing or aft-facing troop seat and consists of a two-strap shoulder harness and a lap belt assembly. The two shoulder straps are attached to two single inertia reels. They extend forward and down over the occupant's upper torso, and are connected into the single-point release, lift-lever buckle. The lap belt sembly includes left- and right-hand belts, with adjuste that are connected together at the lap belt buckle. The I troop restraint system was designed to mount on a side-facing troop seat and is similar to the Type II restraint system, but it differs from the Type II restraint by having a single shoulder strap that passes diagonally across the occupant's upper torso. This difference implies that the inertia reel and single-point release buckle for the Type I system are different from the Type II system, but that the other components will be the same.

The two restraint system designs,

Type I (single shoulder strap) and

Type II (two shoulder straps),

were analyzed, and a weighted trade-off study was performed to determine the optimum restraint system features for both of these restraint systems. The hardware requirements of the proposed specification were examined, and for those requirements that were overly stringent or inadequate, changes were recommended. The test procedures established for demonstrating compliance of the restraint systems with the specification's requirements were also examined to be sure that sufficient and adequate tests were clearly defined. Finally, a comparative analysis of the two restraint system designs was performed which illustrated the trade-off between occupant protection and cost when either of the restraint systems was selected.

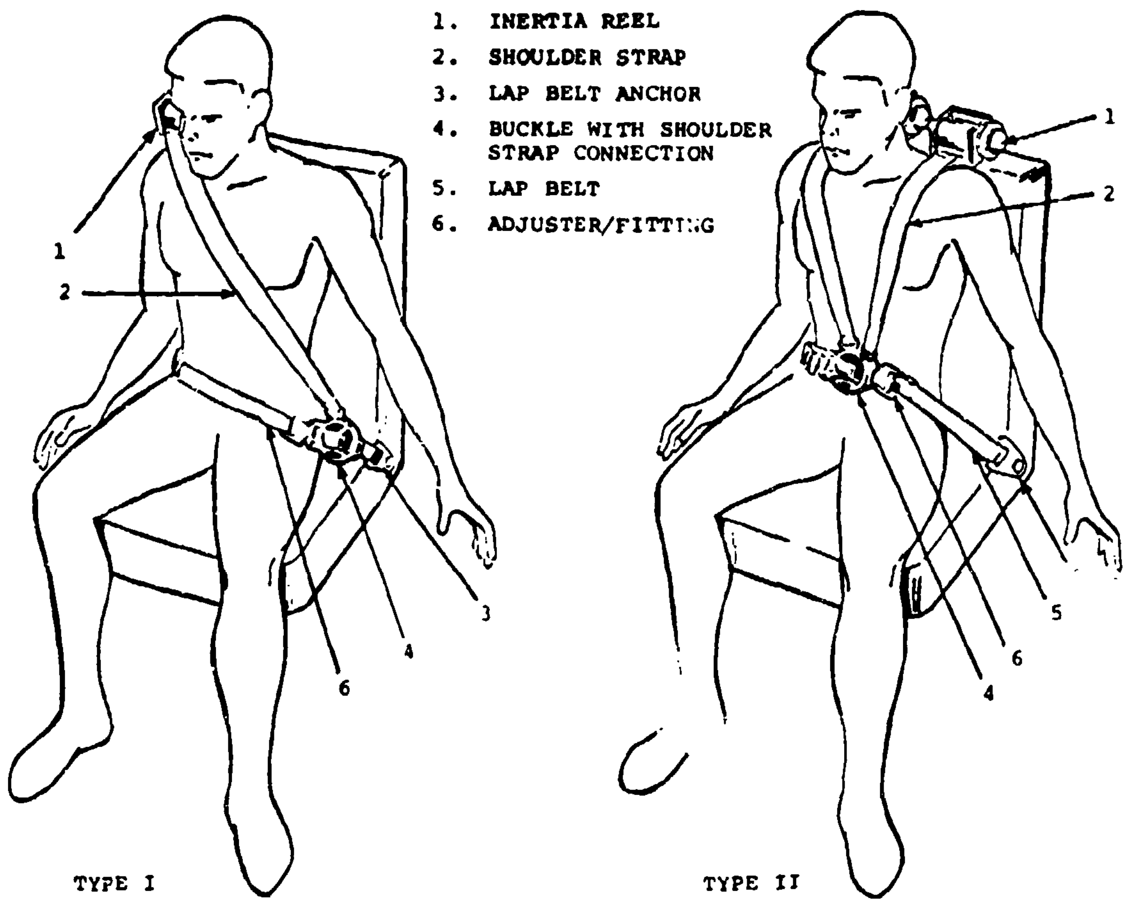


Figure 1. Aircraft Troop/Passenger Restraint Systems.

PARAMETRIC STUDY

A parametric study of restraint system variables was accomplished by using a two-dimensional occupant model. The system variables examined during this study were:

- Input Velocity and Deceleration
- Occupant Size
- Restraint System Slack
- Webbing Load Elongation
- Restraint System Configuration

Different values or characteristics were selected for each of these variables, and the model's dynamic response was computed by program SIMULA[2] for each specific set of parameter values. SIMULA computes the dynamic response of the two-dimensional model of a seated airplane passenger and seat that considers them to have a plane of symmetry with all the masses and forces located in this plane. Schematically, then, the system is as shown in Figure 2, where the passenger has been represented by eight concentrated masses at the most important joints of the body. The seat is considered to be a rigid body except for the legs and attachment fittings. The motions of the passenger and seat are given with respect to a non-Newtonian coordinate system fixed with respect to the cabin floor, with the x axis pointing forward along the floor and the y axis perpendicular to the floor in an upward direction. The seat belt is assumed to be attached at point A of the seat, which lies on the y axis when the seat is undeformed. The other end of the seat belt is assumed to be attached to the large mass at the pelvis so as to form a nonlinear spring between the two points. Similarly, the shoulder harness is assumed to act as a horizontal spring between the back of the seat and the mass at the neck and shoulders. The input to SIMULA is a negative acceleration applied at the base of the seat, and the response of the occupant is given relative to the noninertial reference frame.

Using SIMULA, the Gadd Severity Index for the head, chest, and pelvis, the restraint system loads and the displacement of the pelvis and shoulders were computed and then used to evaluate the effect of the different parametric values.

The parametric values selected for this study were based on the requirements of the proposed specification as described in the following paragraphs.

Input Velocity and Deceleration

The velocity change and deceleration of a survivable crash are not independent and were therefore considered as one variable, the input crash pulse. Three input pulses were originally considered: the 50th, 75th, and 95th percentile survivable crash pulses for the passenger compartment of rotary-wing aircraft as defined in USAAMRDL TR 71-22.[1] During the initial portion of this study, it became apparent that the 50th percentile pulse (G peak = 5.4 and ΔV = 28 fps) would not be severe enough for the cases being investigated to warrant its use. The model's response (accelerations, velocities, and displacements)

2. Collins, J. A., et al., CRASHWORTHINESS STUDY FOR PASSENGER SEAT DESIGN, Arizona State University, NASA Contract NSR 33-026-003, June 1962.

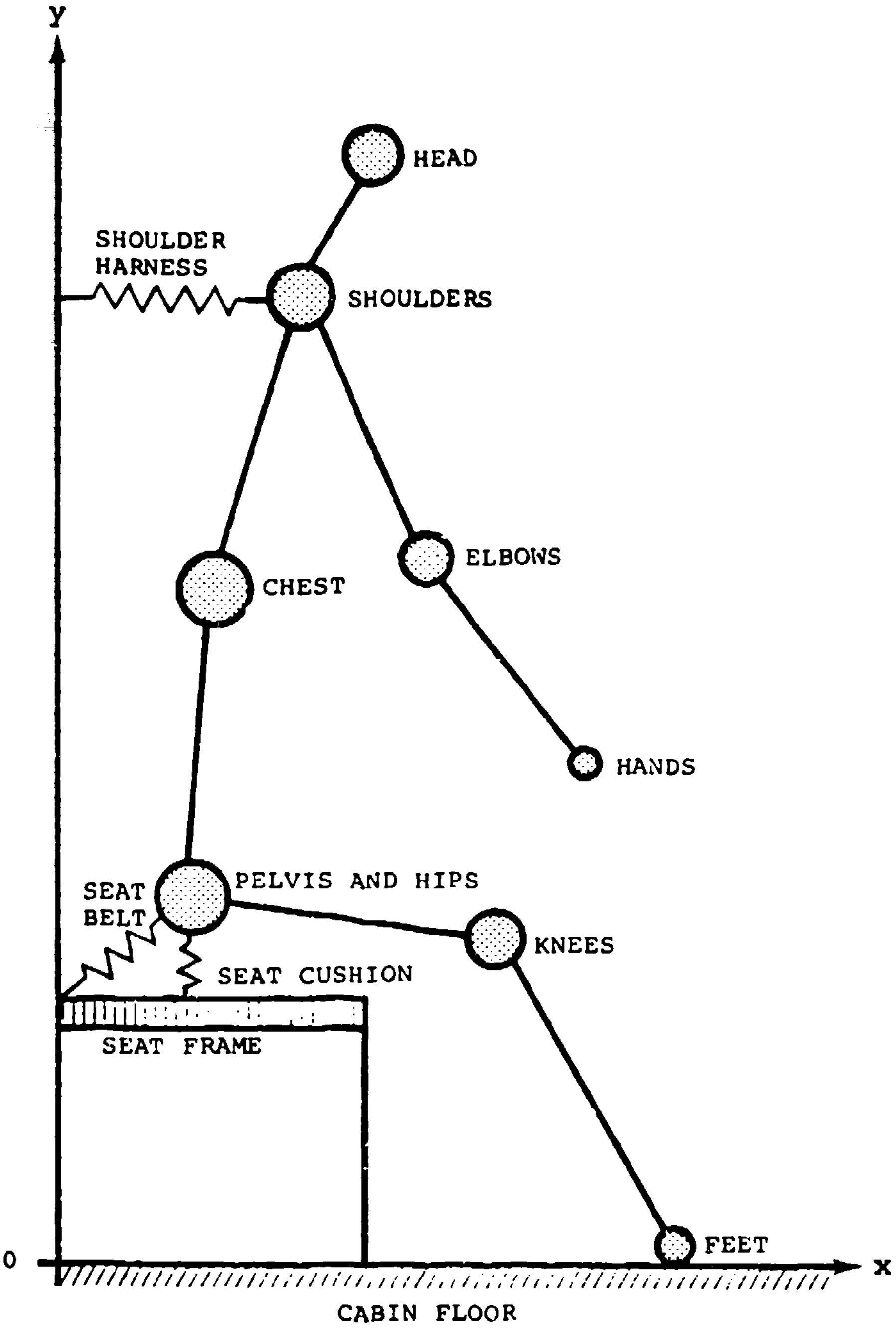


Figure 2. Model of Passenger and Seat Used in SIMULA.

for this pulse were significantly below any potentially dangerous level. Therefore, only the 75th and 95th percentile crash pulses shown in Figure 3 were used.

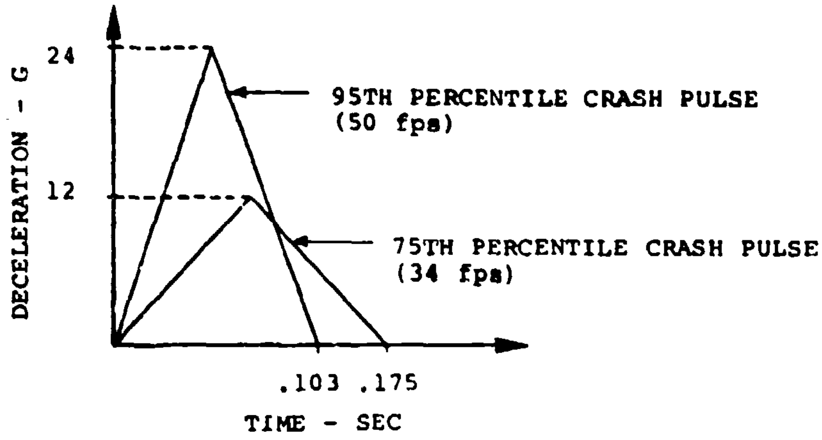


Figure 3. Input Crash Pulses - Longitudinal.

Occupant Size

Three occupant sizes, the 5th, 50th, and 95th percentile Army trooper, were selected. The body weights and equipment weights given in USANL TR 72-51-CE[3] and the proposed specification were used for each size. The distribution of the total weight for each size occupant is given in Table 1.

TABLE 1. OCCUPANT WEIGHT DISTRIBUTION

Component Weights (Lb)	Occupant Size		
	95th	50th	5th
Occupant - Nude	201.9	156.3	126.3
Clothing	7.0	7.0	7.0
Ammunition	6.5	6.5	6.5
Field Equipment	16.8	16.8	16.8
Other Equipment	10.0	10.0	10.0
Total Weight (Lb)	242.2	196.6	166.6

3. White, R. M., and Churchill, E., THE BODY SIZE OF SOLDIERS, U.S. ARMY ANTHROMETRY - 1966, USANL TR 72-51-CE, U.S. Army Natick Laboratories, Natick, Massachusetts, December 1971.

Restraint System Slack

The slack in the restraint system was selected to be 0 and 2.5 inches. These numbers were chosen respectively to be indicative of a tightly adjusted and loosely adjusted restraint harness.

Restraint Webbing Load Elongation

Three load-elongation curves for each webbing component were selected based on the webbing elongation requirements of the proposed specification and data from the newest low-elongation polyester webbing. Load-elongation data on new low-elongation polyester webbing (7 to 10 percent) from Murdock Webbing Company and Narricott Industries, Inc., indicated that the relationship between load and elongation for this type of webbing was essentially linear. Using this information, the webbing elongation and design load requirements given in the proposed specification were used to construct a linear load-elongation relationship for each type of webbing. To obtain the other variations in webbing properties, the slopes of these initial linear relationships for baseline properties were simply halved and doubled. This resulted in webbing properties for each webbing which were softer than, equal to, or stiffer than the requirements given in the proposed specification. Since numerous data indicate that the unloading slope for webbing is generally higher than the loading slope, a factor of three, based on previous belt elongation tests,[4] was used to calculate the unloading slopes. The baseline webbing properties (i.e., those required by the proposed specification) used for each type of webbing are shown in Figure 4.

Restraint System Configuration

The two restraint system configurations, Type I and Type II (Figure 1), defined by the proposed specification were used for this study. Since the basic difference between the two restraint systems is the type of shoulder harness (double strap or single strap), the webbing properties for the shoulder harness were used to differentiate restraint systems in the occupant model. The effective stiffness used for the Type II system was twice the stiffness of the Type I shoulder harness webbing, and the stiffness used for a Type I system was the same as the Type I shoulder harness webbing. There were two shoulder

4. McHenry, R. R., and Naab, K. N., COMPUTER SIMULATION OF THE AUTOMOBILE CRASH VICTIM IN A FRONTAL COLLISION - A VALIDATION STUDY, CAL Report No. YB-2126-V-1R, Cornell Aeronautical Laboratory, Buffalo, N. Y., July 1966.

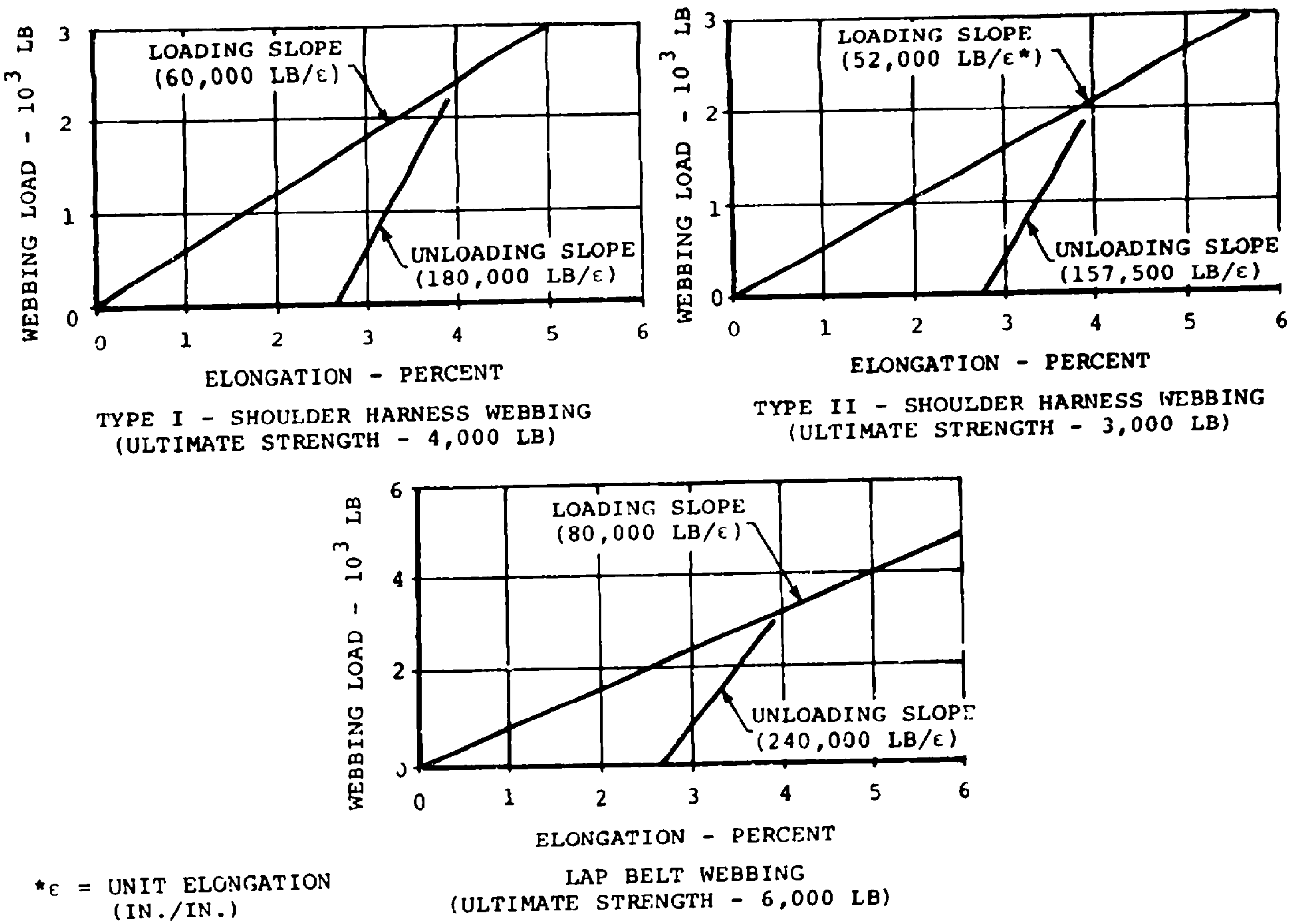


Figure 4. Webbing Load-Elongation Baseline Properties.

harness configurations (i.e., webbing properties) for each lap belt webbing used for this study, making a total of six restraint systems. The identification number and the webbing properties for these six restraint systems are given in Table 2.

TABLE 2. RESTRAINT SYSTEM DEFINITIONS

Restraint System ID	Lap Belt Webbing	Shoulder Harness Webbing	Restraint System Type
1	B.L.*/2	B.L./2	II
2	B.L./2	B.L./2	I
3	B.L.	B.L.	II
4	B.L.	B.L.	I
5	2 B.L.	2 B.L.	II
6	2 B.L.	2 B.L.	I

*B.L. - Baseline Webbing Properties

Seat Properties and Dimensions

The seat configuration used to determine seat properties, restraint attachment locations, and belt lengths was obtained from a recent effort by Boeing-Vertol Company[5] to develop crashworthy troop seats for U.S. Army helicopters. The conceptual design, shown in Figure 5, illustrates the envelope dimensions typical for the next-generation troop seat; it was used along with the seat weight to determine the dimensional and inertial inputs for the computer program. The weight used for the seat was 8.3 pounds, which is the estimated weight of troop seats for the UTTAS helicopter.

Results and Conclusions

The occupant response generated by the computer program is measured in terms of severity indices, accelerations, belt loads, and displacements which are defined as output variables. The

5. Reilly, M. J., HELICOPTER TROOP SEAT INVESTIGATION - INTERIM TECHNICAL REPORT (PHASE II) D210-10592-1, Boeing Vertol Company, Philadelphia, Pa., February 1973.

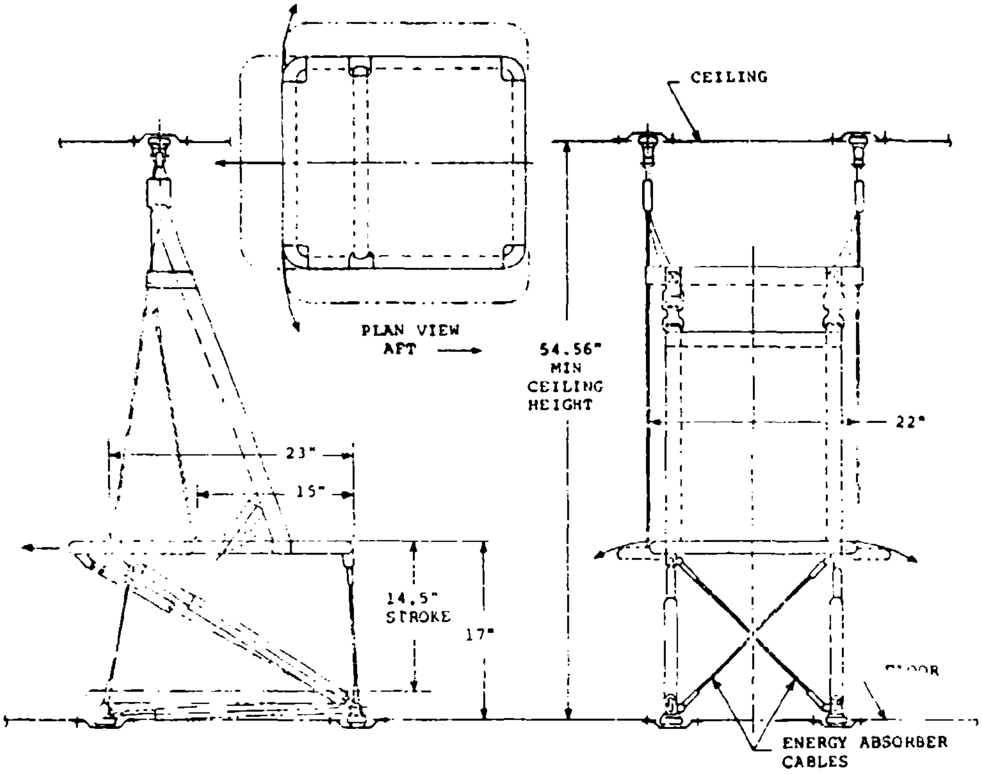


Figure 5. Ceiling-Mounted Troop Seat - Concept.

severity indices are calculated values that provide a relative measure for the severity of body segment acceleration time histories. Other accelerations, belt loads, and displacements are functions of time whose peak value and time duration must be determined for comparison.

The Gadd Severity Index was used in order to evaluate the relative severity of the various impacts and is defined by the equation

$$SI = \int_{t_o}^{t_s} a^n \, dt$$

where SI = Severity Index

a = acceleration as a function of time (G)

n = weighting factor greater than 1

t = time (sec)

Published data indicate that a weighting factor should place relatively greater weight upon the acceleration than upon the duration. This is particularly true for impacts against hard, flat surfaces of skeletal components, such as the head, which are less viscoelastic than soft tissue. The exponent n has a value of 2.5 for frontal impacts of th head and face and a lower value for viscoelastic materials such as soft tissue. In those cases where impact does not occur, the correlation between the severity index and injury has not been established; however, the severity index is still a useful tool for comparing different acceleration responses for relative severity. Research is continuing to expand the application of the severity index; however, existing data are insufficient for predicting chest and pelvic injuries with confidence. Severity indices were calculated for these body portions using the 2.5 exponent (same as for the head) because it is still a good indicator for comparing the relative severity of complex acceleration pulses. The other output variables were evaluated by comparing their peak values and time durations.

The magnitude of the occupant's response in terms of severity indices, belt loads, and body displacements was found to vary directly with the magnitude of the input pulse. The 95th percentile crash pulse caused significantly higher values for these output variables than did the 75th percentile crash pulse. A comparison of the responses generated by these two crash pulses for a 95th percentile occupant using a Type I and Type II restraint with baseline webbing properties (Restraint Systems 3 and 4) is shown in Table 3.

TABLE 3. MAXIMUM OUTPUT VALUES FOR 95TH PERCENTILE OCCUPANT

Restraint System	Pulse %	Severity Index			Restraint Loads/Displacements			
		Head	Chest	Pelvis	Lap (Lb)	Shoulders (Lb)	Hips (In.)	Shoulders (In.)
3	95th	889	22.0	29.9	3611	3039	2.71	2.80
(Type II)	75th	123	3.2	5.1	2341	1249	1.82	1.34
4	95th	1006	28.9	35.9	3623	3139	2.71	3.55
(Type I)	75th	138	4.3	5.9	2346	1331	1.83	1.71

The effect of increasing occupant size was generally found to be an increase in the magnitude of the response. An exception to this trend was the severity index for the chest and pelvis, which was less for the 50th percentile occupant than for the other two occupant sizes. Time precluded an investigation as to precisely why this phenomenon occurs, but apparently the redistribution of the occupant's weight in conjunction with the webbing stiffness caused the acceleration levels of the chest and pelvis to be lower for the 50th percentile occupant. The maximum response to a 95th percentile crash pulse for the three occupant sizes using the Type I and Type II restraint systems with three variations in webbing properties are presented in Table 4. Selected data from this table have been plotted in Figures 6, 7, and 8 to illustrate the effect of occupant size on the severity index for the head and chest and on shoulder harness loads. From these data it can be seen that the difference in response between the two types of restraint systems for each occupant size becomes smaller as the webbing becomes stiffer. It should also be noted that the peak responses of Restraint System 2 are noticeably greater than the response of the other restraint systems, indicating that a high-elongation (soft) webbing should not be used for a single-shoulder-strap restraint system.

TABLE 4. MAXIMUM OUTPUT VALUES FOR 95TH PERCENTILE CRASH PULSE

Restraint System	Occupant Size (%)	Severity Index			Restraint Loads		Displacements	
		Head	Chest	Pelvis	Lap (Lb)	Shoulders (Lb)	Hips (In.)	Shoulders (In.)
1 (Type II)	95th	982	31.6	43.8	3834	3366	4.00	4.00
	50th	837	26.2	38.6	3129	2516	3.65	2.77
	5th	534	28.7	42.4	2407	1566	2.87	1.90
2 (Type I)	95th	1090	46.3	55.4	3868	3456	4.12	5.55
	50th	1102	39.1	50.2	3127	2758	3.68	4.17
	5th	786	39.9	53.8	2834	2021	3.29	3.34
3 (Type II)	95th	889	22.0	29.9	3611	3039	2.71	2.80
	50th	690	17.4	27.0	3139	2353	2.33	1.90
	5th	559	23.5	34.0	2869	1990	1.72	2.14
4 (Type I)	95th	1006	28.9	35.9	3623	3139	2.71	3.55
	50th	814	21.6	31.3	3154	2413	2.35	2.50
	5th	637	27.1	40.4	2905	1877	2.09	2.17
5 (Type II)	95th	761	15.7	22.2	3670	3267	1.92	2.26
	50th	669	14.8	19.7	3242	2485	1.69	1.52
	5th	564	23.4	29.7	3028	2089	1.43	1.56
6 (Type I)	95th	790	16.7	26.8	3725	2917	1.94	2.54
	50th	680	13.4	23.1	3301	2334	1.71	1.76
	5th	560	19.7	32.4	3063	1996	1.61	1.58

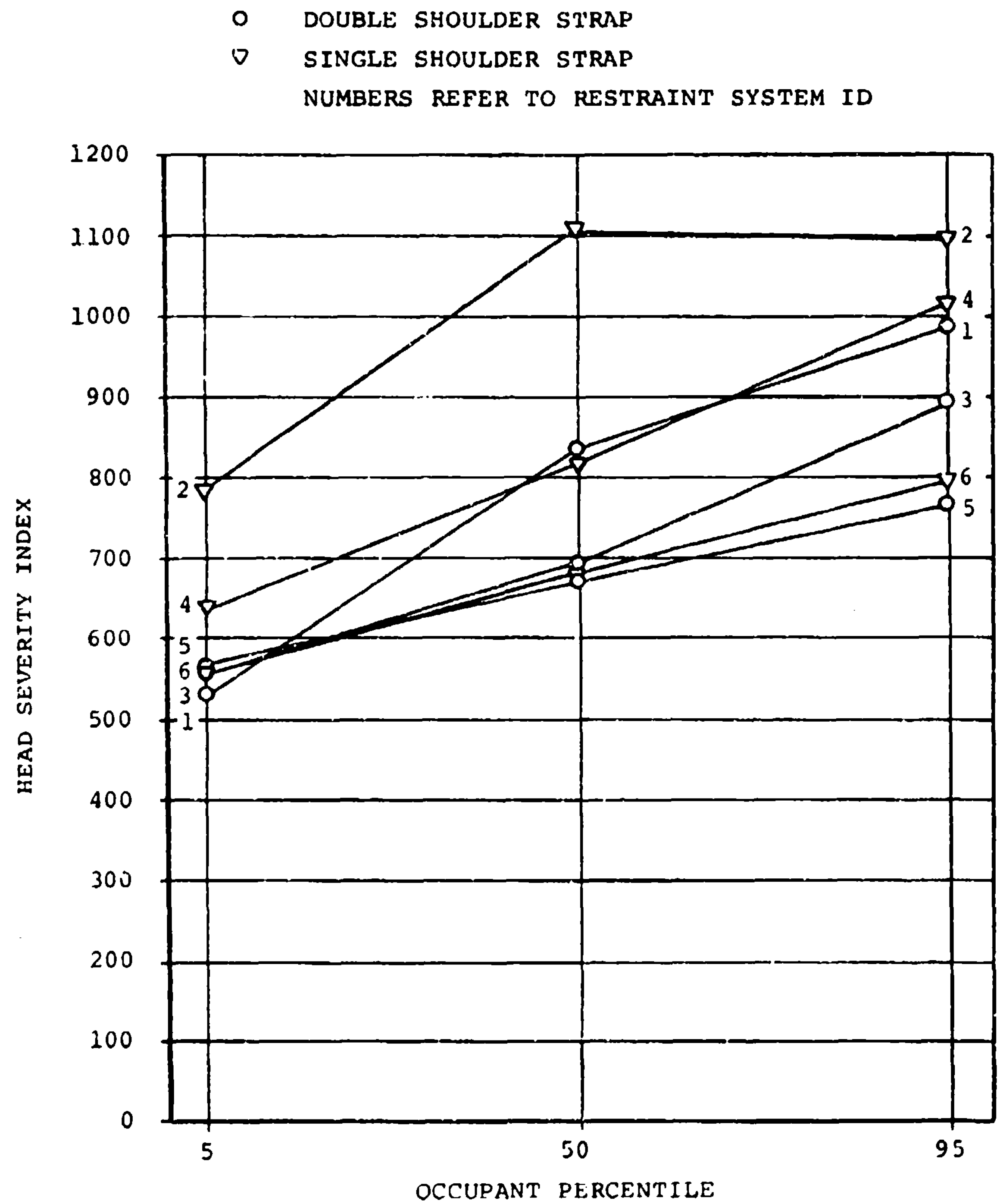


Figure 6. Head Severity Index Versus Occupant Size.

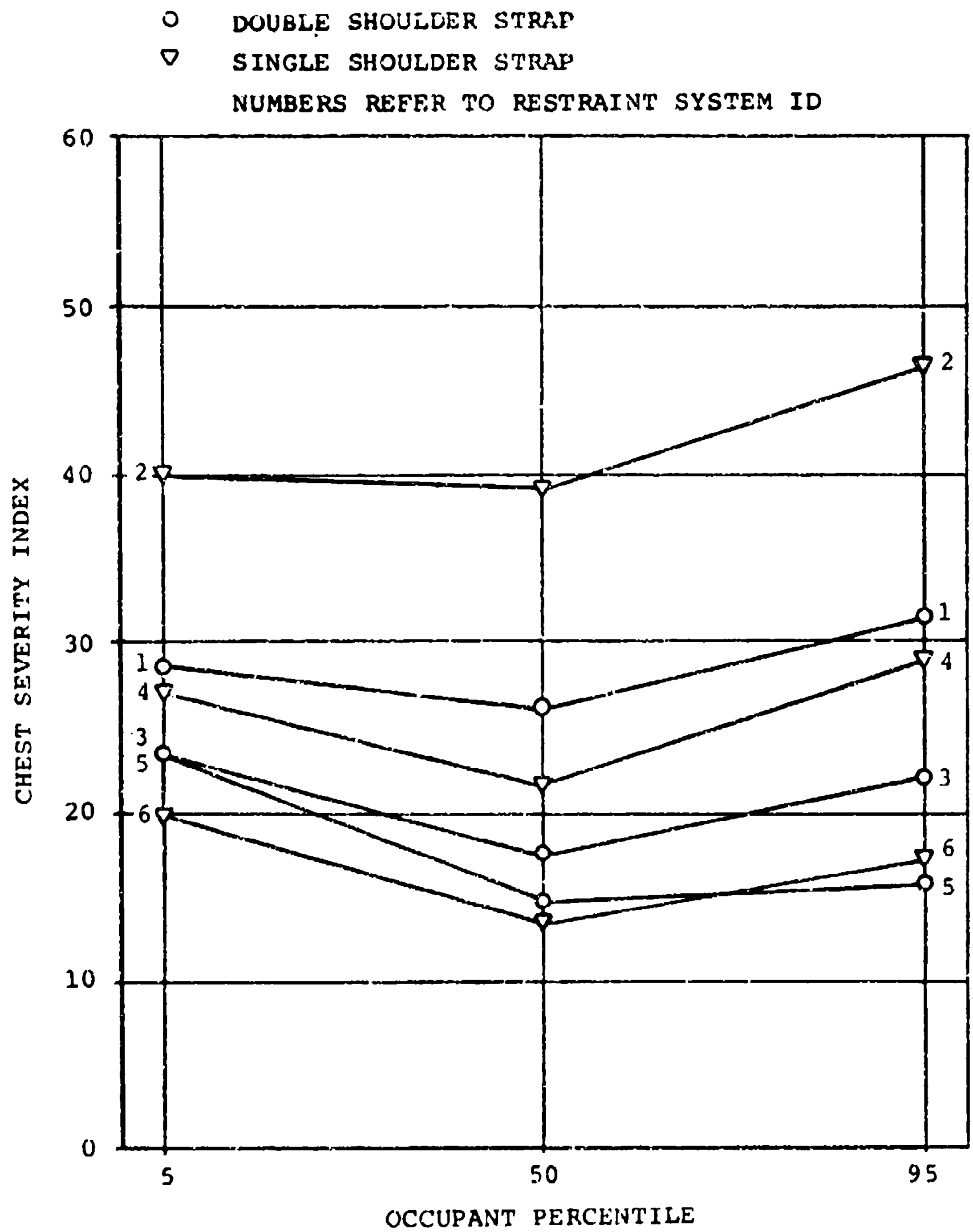


Figure 7. Chest Severity Index Versus Occupant Size.

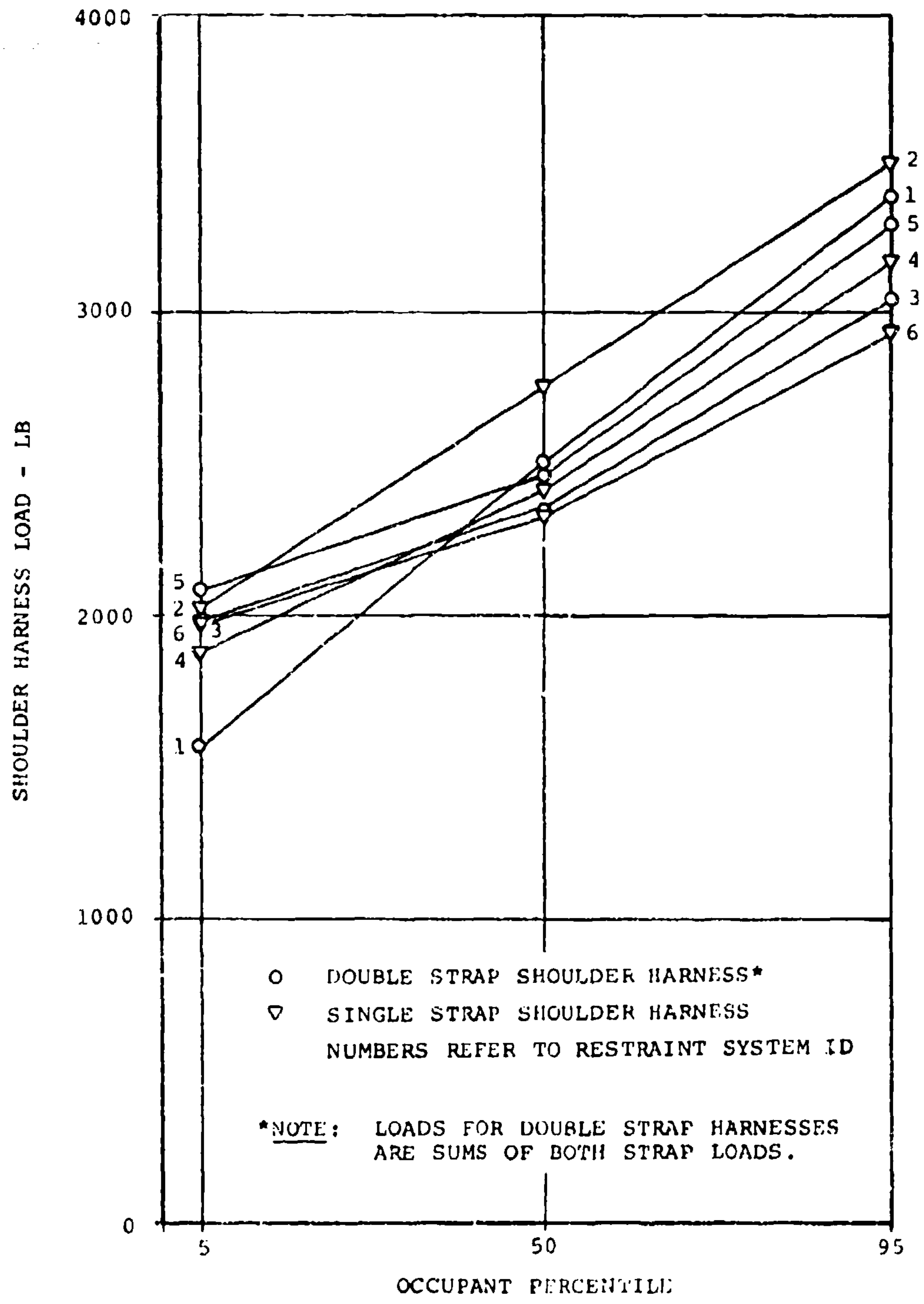


Figure 8. Shoulder Harness Load Versus Occupant Size.

The effect of slack in the restraint harness in each case investigated was to increase the severity indices and restraint harness loads with the increase becoming much more pronounced as the webbing stiffness was increased. This result agrees with a previous study[6] and indicates that the slack in the restraint system should be kept to a minimum.

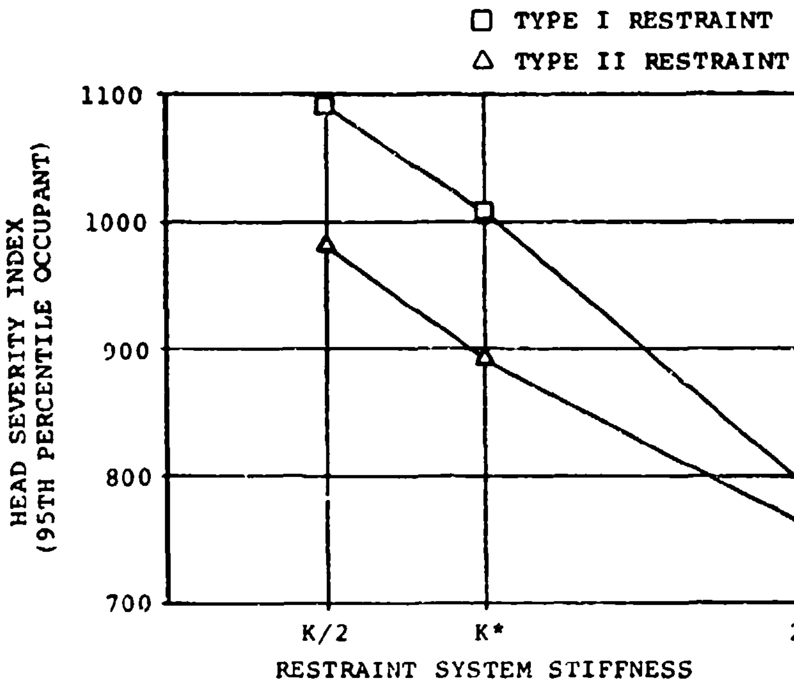
The influence that webbing load-elongation characteristics (webbing stiffness) have on the output variables is illustrated in Figures 9, 10, and 11. The general trend evident from these graphs is that the magnitude of the output variables is reduced as the webbing stiffness is increased, with a greater reduction occurring as the webbing stiffness increases from K/2 to K than occurs when the stiffness increases from K to 2K. The exceptions to this trend are the shoulder harness load for the Type II restraint systems. Lack of time again prevented detailed analysis of this occurrence; however, a cursory examination indicated that it was caused by the difference in shoulder harness and lap belt stiffness, which becomes more pronounced as the restraint system stiffness increases.

The differences in the output variables caused by each restraint configuration (Type I and Type II) are presented in Table 4 and also illustrated in Figures 9, 10, and 11. In general, the Type II restraint (two shoulder straps) results in lower severity indices, belt loads, and body displacements than does the Type I restraint (single shoulder strap), but the difference in restraint system performance becomes appreciably smaller as the stiffness of the webbing increases.

SPECIFICATION REVIEW

A specification review meeting was held for the purpose of reviewing the proposed specification along with the results of the restraint system analysis and preliminary design. The personnel attending this meeting were the two consultants for the program and representatives from USAAMRDL, USAARL, Dynamic Science, and Pacific Scientific Company. The results of the computer analysis and trade-off study were presented and discussed along with some preliminary hardware designs. This was followed by a review of the principal sections of the proposed specification. Throughout the meeting, various aspects of the restraint system design, application, and requirements were examined.

6. Kourouklis, G., et al., THE DESIGN, DEVELOPMENT, AND TESTING OF AN AIRCREW RESTRAINT SYSTEM FOR ARMY AIRCRAFT, USAAMRDL TR 72-26, Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, June 1972, AD 746631.



*K - BASELINE WEBBING PROPERTIES

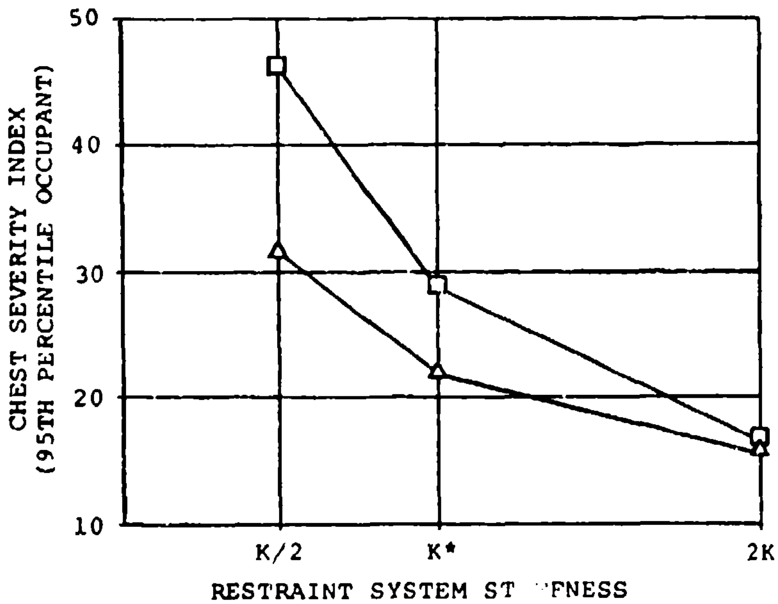
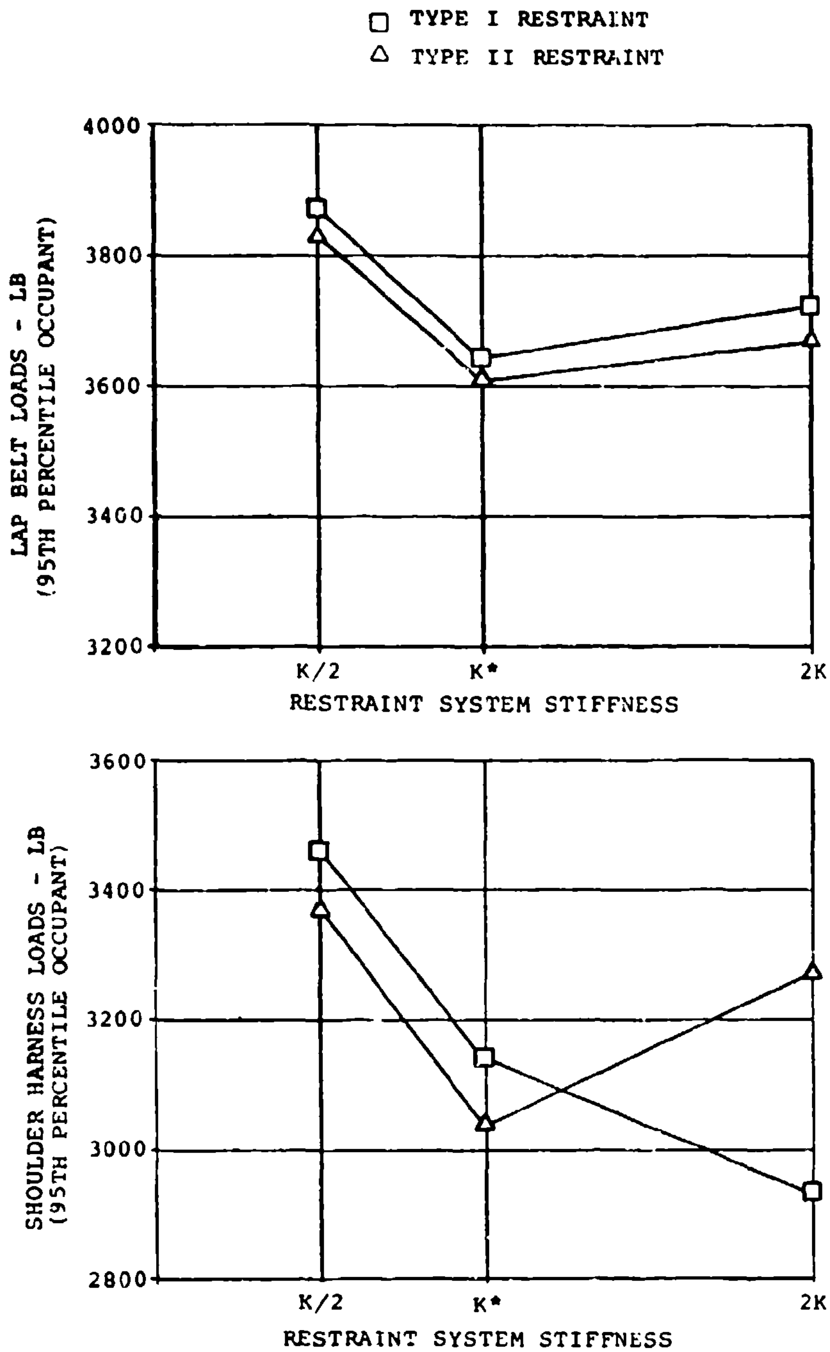


Figure 9. Head and Chest Severity Index as a Function of Restraint System Stiffness.



*K - BASELINE WEBBING PROPERTIES

Figure 10. Belt Loads as a Function of Restraint System Stiffness.

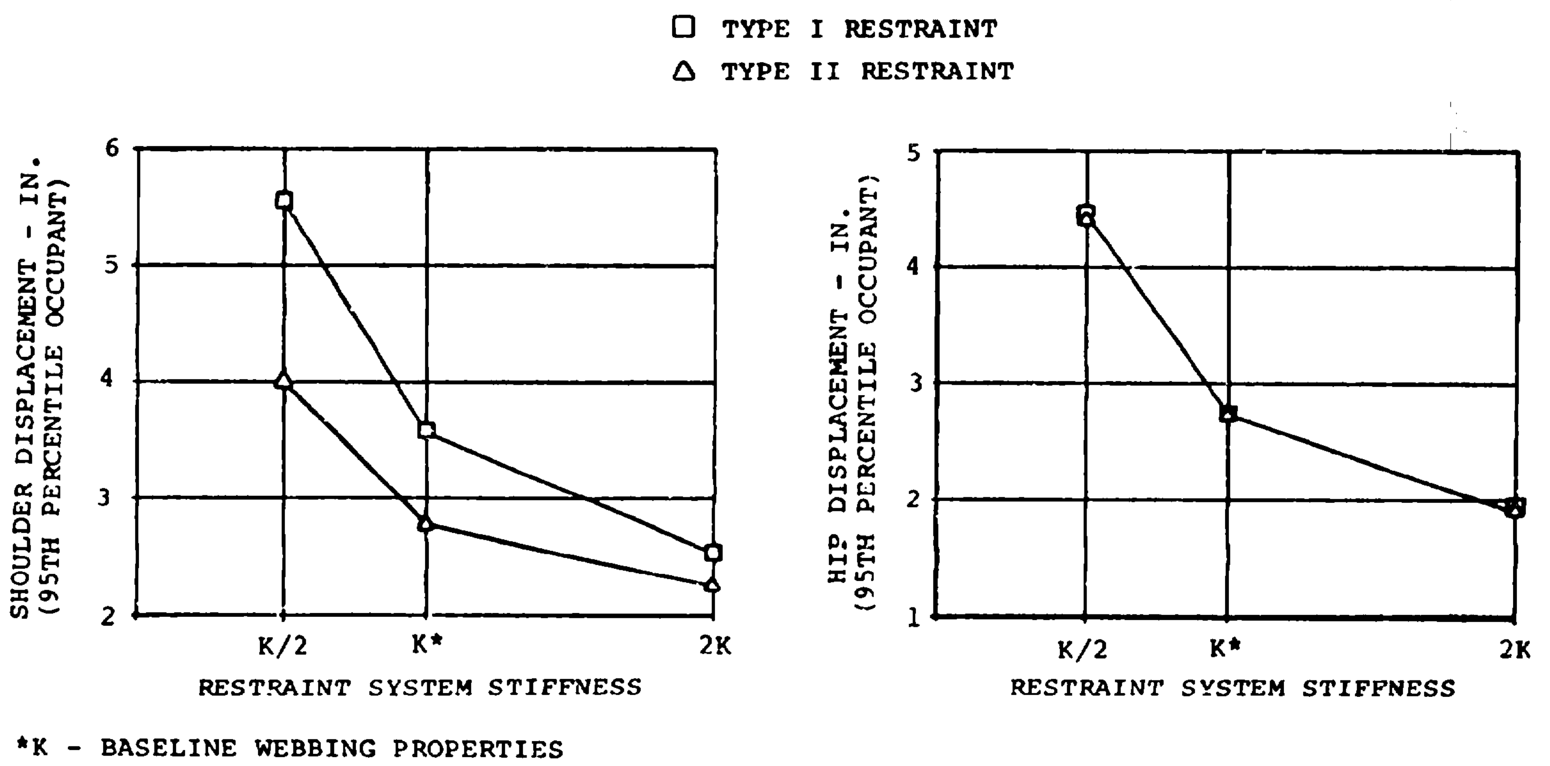


Figure 11. Hip and Shoulder Displacement as a Function of Restraint System Stiffness.

The possibility of having a completely adequate troop restraint system used on future troop transport helicopters was discussed. The evaluation factors for a troop restraint system and order of priority were thought to be: (1) ease of ingress/egress, (2) cost, (3) weight, and (4) protection.

The necessity for low-elongation webbing was extensively reviewed. It was decided that, if a webbing with 5-percent elongation at the specified design loads could be obtained, it would be significantly better than existing webbings with 9- to 10-percent elongation and should be used. However, it was the consensus that if only a 2- or 3-percent elongation improvement over existing webbing could be achieved, then the added complication of incorporating a newly developed webbing into the restraint systems would not be warranted.

During the meeting, it was noted that the elongation at design load of the new 1-3/4-inch-wide polyester webbing, developed for Contract DAAJ02-73-C-0050 and intended for use as a shoulder harness strap, might not be any lower than the elongation of standard military polyester webbing (MIL-W-25361, Type III). If this proved to be correct, there would be no justification in using the webbing since it would increase cost (moderately) and create possible hardware problems because of its low thickness. The advantage of the low-elongation webbing is to reduce the dynamic overshoot of the occupant and limit his forward movement during high longitudinal crash loads. Minimizing the occupant's motion decreases the probability of head impact with other obstacles in the crew station or troop compartment. It was decided that if additional effort to significantly reduce the elongation of the new polyester webbing was not successful, standard military webbing (MIL-W-25631) or automotive webbing should be used for the shoulder harness straps.

The webbing width for the shoulder harness straps was also discussed. The question was raised about why the 1-3/4-inch-wide webbing had been selected, since the pressure distribution would have been better if the 2-1/4-inch-wide webbing had been used. One reason for not using the 2-1/4-inch-wide webbing was that its use would necessitate redesign of the inertia reel. It was pointed out that Pacific Scientific has an existing inertia reel with a 2-inch-wide spool, and that there is a low-elongation polyester webbing 2 inches wide currently being used in automotive restraint systems. Since accident studies[7]

7. McElhaney, J. H., et al., BIOMECHANICS OF SEAT BELT DESIGN, 16th Stapp Car Crash Conference, pp. 321-344, Society of Automotive Engineers, Inc., New York, N. Y., November, 1972.

have indicated that these automotive restraints perform well and significantly reduce serious injuries, it was agreed that the use of a 2-inch-wide shoulder harness should be considered for use in the troop restraint systems.

The thickness of the new low-elongation webbing (0.045 inch) caused some concern and was discussed. It was thought that the thinner webbing might tend to stiffen up under load and provide a sharp edge which could lacerate the neck of a decelerating occupant. Various means of evaluating the relative cutting ability of loaded webbings of various thicknesses were discussed; however, it was decided that the dynamic loading conditions could not be duplicated to the extent necessary for the conclusive results in a static type test. Simulation of this situation would require dynamic testing which was outside the scope of this program. It was also stated that no injuries of this type are mentioned in the present literature, and further discussion resulted in the conclusion that concern over possible neck injuries due to shoulder strap webbing was unwarranted. This decision was based on the experience of the automotive community, particularly in Australia where shoulder strap usage is mandatory, which indicates that the type of low-elongation webbing being considered for this program does not contribute to neck injuries.

The vertical location of the inertia reel was discussed, with some consideration given to placing it 29 inches above the seat reference point. This location would permit the occupant to easily grasp the loose end of the shoulder straps and not require him to reach down behind his back to pick up the buckle fitting. However, this would result in an extremely high shoulder strap attachment point with a 5th percentile occupant, and could be potentially dangerous in a lateral loading situation by allowing the straps to contact the occupant's neck or lower cheek. It was suggested that perhaps the same ease of usage could be obtained by locating the inertia reel at approximately 27-1/2 inches above the seat reference point and designing the strap ends to extend out, roughly perpendicular to the seat back, instead of hanging down. This could be accomplished by impregnating the ends of the straps with a plastic or some other material to make them stiff enough to support their own weight without bending, and designing the inertia reel and guide to engage a small portion of the stiff straps and thus support them. It was decided that the vertical location of the inertia reel and the storage position of the shoulder straps should be investigated using the mock-up restraint system.

It was agreed that the inertia reel should be capable of holding 45 inches of webbing, measured from the front face of the inertia reel to the center of the lock slot in the buckle fitting. It was later decided that this webbing length should be measured from the front face of the inertia reel to the webbing fold at the fitting, thus providing a more exact definition of the webbing length.

During the meeting it was indicated that a desirable feature of the buckle would be to have the lift release always rotate toward the fixed fitting. This would permit the buckle release and belt separation to be accomplished with one motion of the hand. To provide this feature for the single-shoulder-strap restraint system, the buckle would require a fitting slot on both the top and the bottom so that it could be used on either side of the aircraft. This would mean a different buckle for the Type I and Type II restraint systems. After some discussion it was concluded that commonality of the buckles would take precedence over this feature.

Later, it was suggested that for a single-shoulder-strap restraint system, two lap belt straps of equal length and each containing an adjuster be considered. Application of this configuration to either side of the aircraft would simply require that the lap belt length be adjusted through the adjusters so that the buckle is located on the inside hip as desired. This would produce a completely common buckle for both the single and double shoulder strap systems, however, at the expense of an additional adjuster for the Type I system and excessive length of lap belt webbing. It was decided to evaluate this configuration using the mock-up restraint system.

The use of the combination adjuster/fitting at the buckle increased the length of the rigid hardware in the lap belt. With the buckle located on the hip, the combined rigid length was such that the hip bone created a fulcrum about which the buckle could rotate. This appears to be an undesirable configuration, and it was decided that the option of placing the adjuster in the webbing away from the buckle fitting should be evaluated with the restraint system mock-up. It was also decided that a pad behind the lap belt buckle should be adopted and the possibility of using a pad behind the adjusters in the lap belt should be investigated.

Following the specification review meeting, a mock-up of the proposed restraint system was assembled by Pacific Scientific and then used by Dynamic Science to investigate hardware location. The mock-up restraint was a Type I system made to approximate the specification's drawings using existing components. It consisted of the following items:

- One PSCo Mark I Inertia Reel with Southern Weaving T1200 (2.0-inch-wide, 0.045-inch-thick) polyester webbing used as the shoulder strap.

- The prototype lift-lever buckle.

- Two lap belts (RH and LH) with Southern Weaving T1200 webbing, standard anchors, and standard plug-in adjusters. The 2-inch-wide T1200 webbing was used in place of the specified 2-1/4-inch-wide Murdock webbing because the only adjusters available at this time were made for 2-inch widths.

The restraint system was mounted on a general-purpose seat in accordance with the seat mounting provisions of the proposed specification as shown in Figure 12. The prototype lift-lever buckle with the lap belts and shoulder harness attached is shown in Figure 13. The operation of the restraint and hardware locations under various restraint conditions for different occupant sizes was examined, and this resulted in recommended changes to the proposed restraint system design.

COMPONENT ANALYSIS

A study of the proposed restraint system was made to establish that the requirements were not overly restrictive or costly and that the configurations were satisfactory. The restraint system initially proposed by Pacific Scientific Company, shown in Figure 14, was a Type II restraint consisting of two inertia reels, two shoulder straps, a single-point release buckle, and two lap belt straps with anchors and plug-in adjusters. A Type I system was obtained by simply removing one inertia reel and shoulder strap from this system. The components of the proposed restraint system were individually examined, and the results were used to establish the final design and to determine quantitative values for the trade-off study.

A weighted trade-off study was used to select the optimum restraint system features for the Type I and Type II restraint systems. For this study, numerical weighting values, whose summation was unity, were established for several factors pertaining to the utility of a restraint system. These factors and their weighting values were:

- Occupant Protection 0.25

- Ease of Usage 0.19

- Comfort 0.15

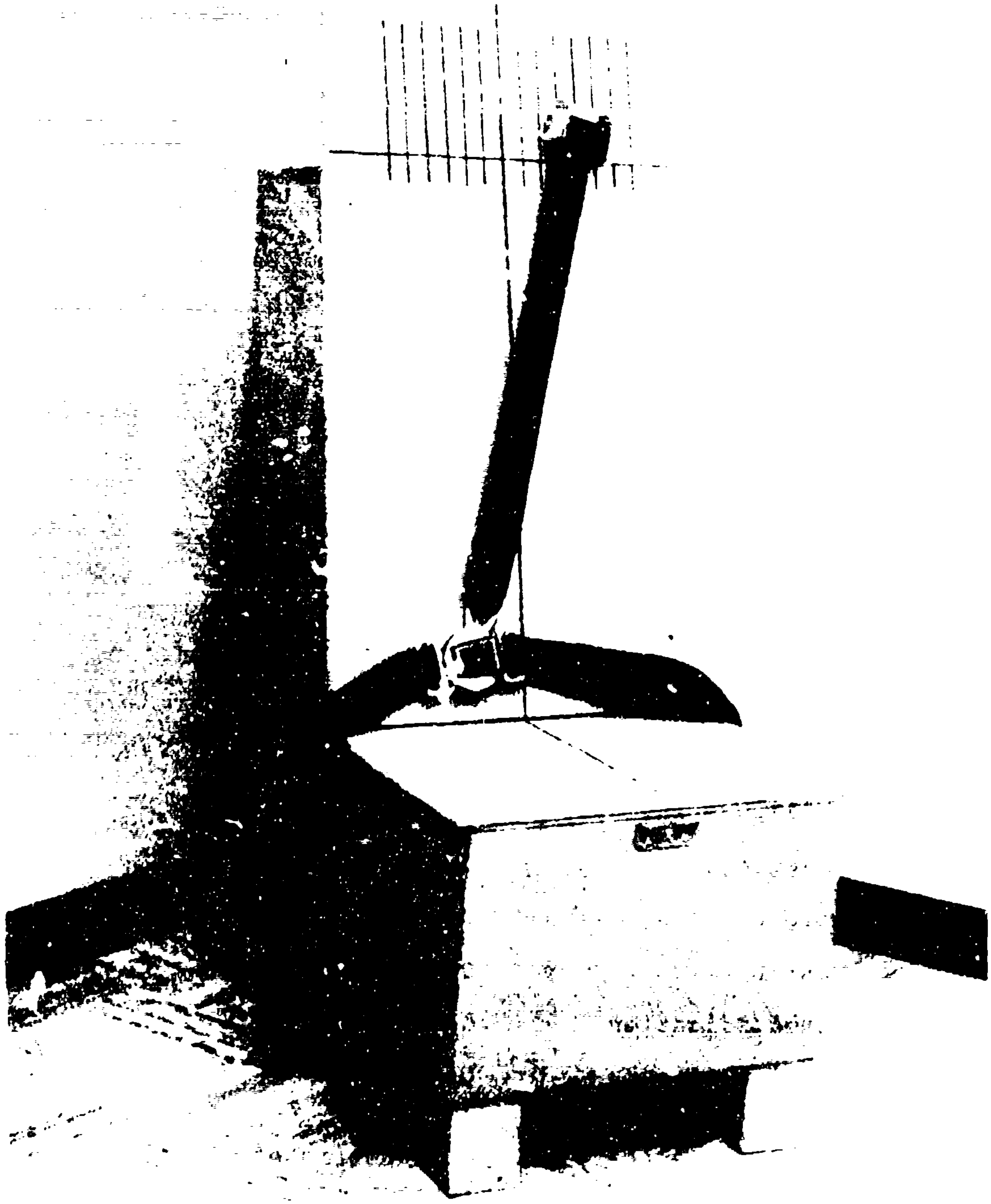


Figure 12. Type I Troop Restraint System Mock-up.

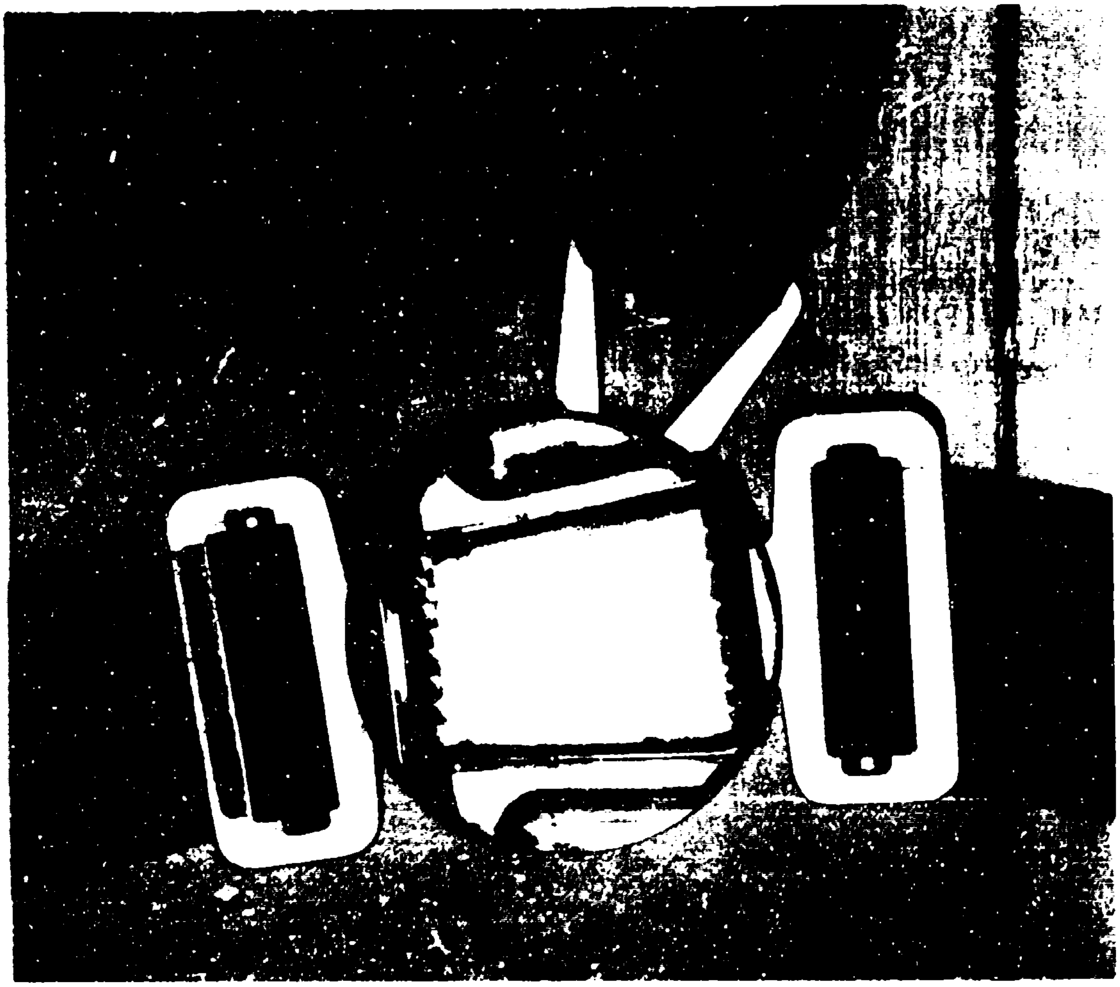


Figure 13. Prototype Lift-Lever Buckle.

- Snagging 0.14
- Weight 0.10
- Cost 0.06
- Standardization 0.05
- Service Life 0.06

The first factor, occupant protection, was given the highest value because it is the principal function of the restraint system. If there was not a need for providing any protection for the occupant, then there would be no requirement for the restraint system.

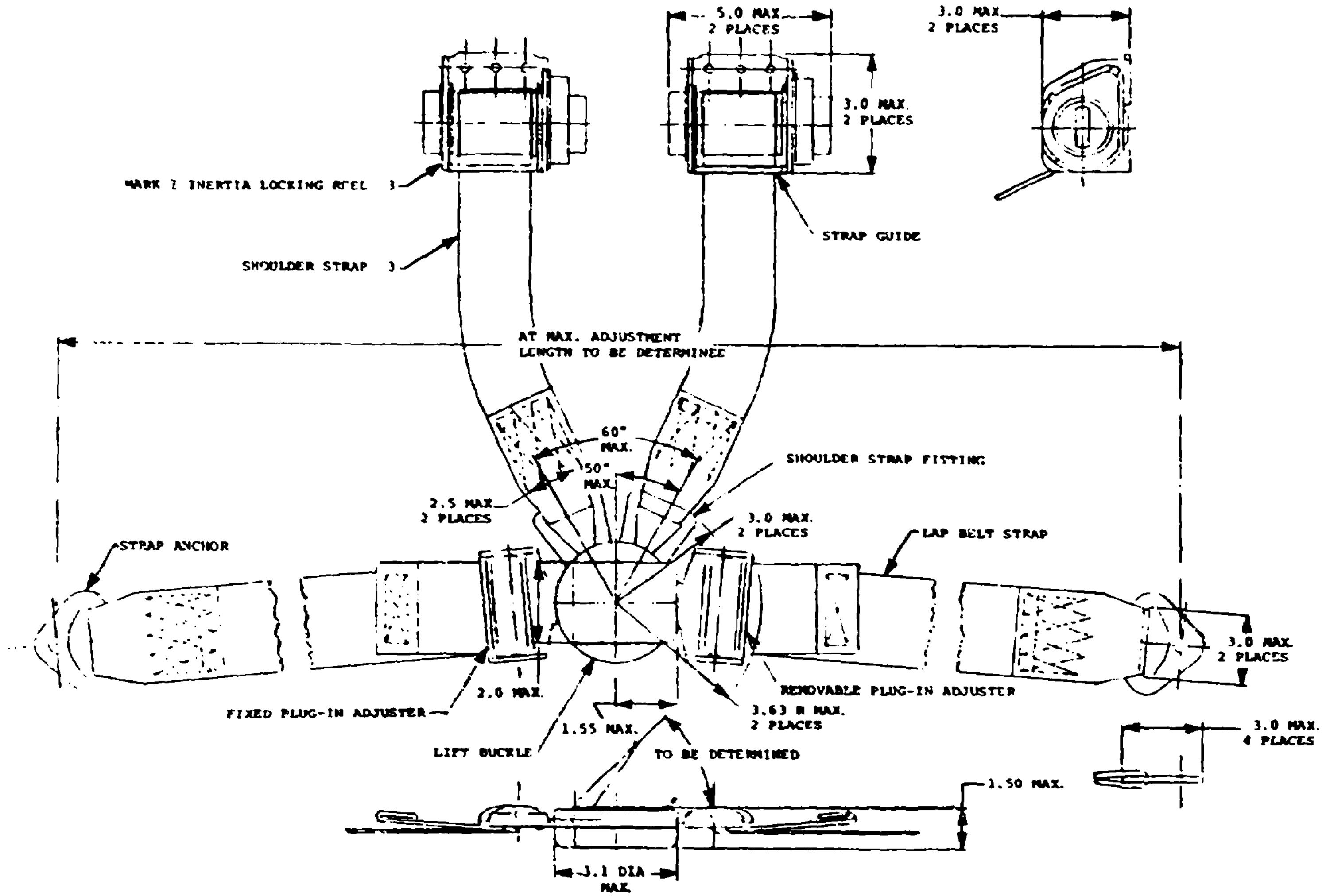


Figure 14. Proposed Restraint System.

The next three factors, ease of usage, comfort, and snagging potential, were also judged to be important from the occupant protection standpoint since they directly affect the usage of a particular restraint system and were therefore given relatively high numerical values. A restraint system with a poor rating for any of these factors will probably not be used by an Army trooper, which results in his having no restraint at all and increasing the probability of injury. The values for the remaining factors, weight, cost, standardization, and service life, were given lower relative ratings because they are essentially factors that affect the cost of the restraint system rather than its restraint or protection potential.

Adjuster

The study of the adjuster was directed toward its placement in the lap belt assembly. Originally, the proposed specification called for the adjuster to be combined with the anchor, which would be located at the attachment of the lap belt to the seat frame. It later became apparent that difficulty might be encountered by troops attempting to operate an adjuster at this location. An Army trooper is likely to have field equipment, such as a pistol belt with canteen, first aid kit, and ammunition pouch, strapped around his waist. Some typical field ensembles are shown in Figures 15 and 16. Some of this equipment would be placed at or above the adjuster/anchor when the trooper is sitting in the seat, making adjustment of the lap belt cumbersome and difficult. Therefore, two alternative locations for the adjuster were examined. One was somewhere in the webbing between the anchor and buckle fitting, and the other was to combine the adjuster with the plug-in buckle fitting. The first approach would most probably result in the adjuster being placed over the iliac crests of the pelvis, which is not a recommended location.[1] Locating the adjuster in the webbing would also mean that an additional separate component (the adjuster) would be added to the restraint system. This would preclude any weight and/or cost savings that might have been obtained by combining the adjuster with either the buckle fitting or the anchor, and it would add another item to the Army's restraint system inventory. Combining the adjuster with the buckle fitting would place the adjuster close to the buckle in an easy-to-reach location and away from the hard points of an occupant's skeletal structure. Placement of the adjusters at the buckle fitting should also result in a weight and cost savings by combining two functions (adjustment and latching) into one component. Each of these possible locations for the adjuster was evaluated against the factors of the trade-off study as shown in Table 5. These results indicate that the optimum location for the adjusters is at the buckle. Subsequently, this configuration was examined using the mock-up

Figure 15. Typical Field Equipment - Arctic Ensemble.

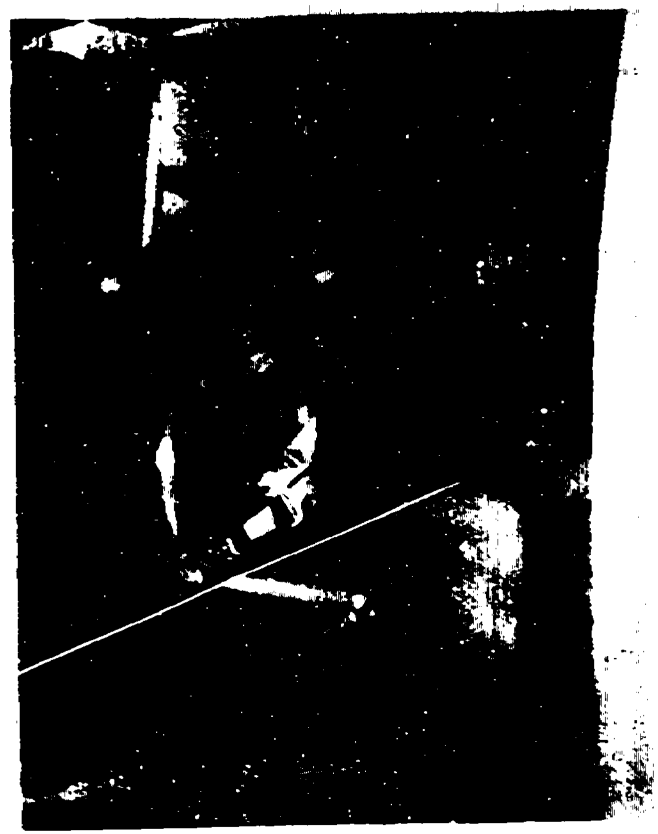


Figure 16. Typical Field Equipment - Basic Ensemble.

TABLE 5. ADJUSTER LOCATION TRADE-OFF

Restraint System Features	Accident Protection	Ease of Usage	Comfort	Snag Resistance	Weight	Cost	Standard-ization	Service Life	Total	Ranking
	Wt = .25	Wt = .19	Wt = .15	Wt = .14	Wt = .10	Wt = .06	Wt = .05	Wt = .06		
Buckle	90 / 22.5	95 / 18.0	80 / 12.0	90 / 11.2	88 / 8.8	88 / 5.3	90 / 4.5	80 / 4.8	87.1	1
Webbing	80 / 20.0	90 / 17.1	70 / 10.5	70 / 9.8	80 / 8.0	80 / 4.8	80 / 4.0	85 / 5.1	79.3	3
Anchor	95 / 23.5	48 / 9.1	95 / 14.3	90 / 12.6	90 / 9.0	90 / 5.4	90 / 4.5	90 / 5.4	83.8	2

restraint system, and it was apparent that this was the natural location for the adjusters. It was therefore decided that the lap belt adjusters should be located at, and be integral with, the buckle fittings.

Buckle

The proposed specification calls for a single-point lift-lever release buckle with a metal-to-metal cam that is permanently attached to the right-hand lap belt. Release of the fitting is accomplished by lifting the buckle faceplate away from the plane of the buckle. The buckle must be capable of accepting three releasable fittings plus one fixed fitting for the two-shoulder-strap system (Type II) and two releasable fittings plus a fixed fitting for the single-shoulder-strap system (Type I).

Examination of this requirement for the single-shoulder-strap restraint system revealed that two buckles might be needed so that the Type I system could be used on either side of the aircraft. A study of the placement of the buckle for the Type I restraint system indicated it should be located on the inboard side of the occupant, which implies that there should be a left- and right-hand configuration for this restraint system. If the fixed fitting location on the buckle is kept the same for both left- and right-handed configurations, then there will be a 180-degree difference in the buckle orientation between the two configurations. This could require two different buckles or a buckle with a shoulder strap attachment on both the top and bottom sides of the buckle. Only one of these attachments would be used for a given restraint configuration.

The possibility of using two lap belt straps of equal length and each containing an adjuster was also considered. Application of this configuration to seats on either side of the aircraft would simply require that the lap belt length be adjusted, through the adjusters, so that the buckle was located on the inside hip as desired. This would produce a completely common buckle for both the single and double shoulder strap systems, however, at the expense of an additional adjuster for the Type I system and an excessive length of lap belt webbing.

An examination of this concept using the mock-up restraint revealed that for seats on one side of the aircraft the buckle would be attached to a long length of webbing. This was thought to be an unacceptable condition since the range of motion for the buckle would increase its chance of being damaged and possibly cause injury to an occupant adjacent to an empty seat in the event of a crash. Therefore, it was decided to design the buckle for right- and left-hand use by having a shoulder harness attachment on the upper and lower half of the buckle. The buckle could then be rotated 180 degrees for the opposite-hand single-shoulder-strap configuration. This would allow the short fixed strap to be consistently located on the inboard side of an aircraft.

Another aspect of the buckle design examined was the location of the fixed fitting with respect to the lift-lever hinge. It was determined that the fixed fitting should be on the same side of the buckle as the lift-lever hinge. This places the lever hinge and fixed fitting on the inboard side of the restraint system, and is the configuration currently required by the proposed specification. Based upon trials with the mock-up restraint, it was determined that this configuration was easy to operate; and, more importantly, the chance of inadvertent operation of the lift lever by the occupant's hand or arm passing over the buckle was greatly reduced.

It appeared that the buckle location for the single-shoulder-strap restraint system should not be located in the center of the lap belt, but toward the opposite hip, away from the side the shoulder strap comes over. This would position the shoulder strap so that the center of pressure is linearly coincident with the center of gravity of the occupant and thus produce a stable loading to the upper torso. If the center of pressure is located to one side, such as would appear to result from having the single shoulder strap come into a centrally located buckle, then a moment is developed which would cause the body to rotate about the strap. To examine this problem, various inertia reel, shoulder strap, and buckle locations were compared with the centers of gravity of the head and torso of a 5th percentile and a 95th percentile U.S. Army trooper. Twelve shoulder strap positions were evaluated. Four inertia reel locations starting at 3 inches off the centerline of the occupant and moving outboard at 1-inch increments were examined together with three buckle locations: the lap belt seat attachment, the occupant's hip, and the center of the lap belt. Each inertia reel and lap belt position was evaluated by constructing a line connecting the two end points and comparing this with the occupant's center of gravity. The results are illustrated in Figure 17, with the solid line showing the selected configuration. The location of the buckle at the occupant's hip was selected because it provided the best path for the shoulder strap for the range of occupant sizes considered, and it was an accessible location. Placement of the buckle at the lap belt attachment appears to be somewhat better from the standpoint of placing the shoulder strap above the occupant's center of gravity. However, for troops equipped with combat gear, this location would be cumbersome and inaccessible and might result in the restraint system's not being used

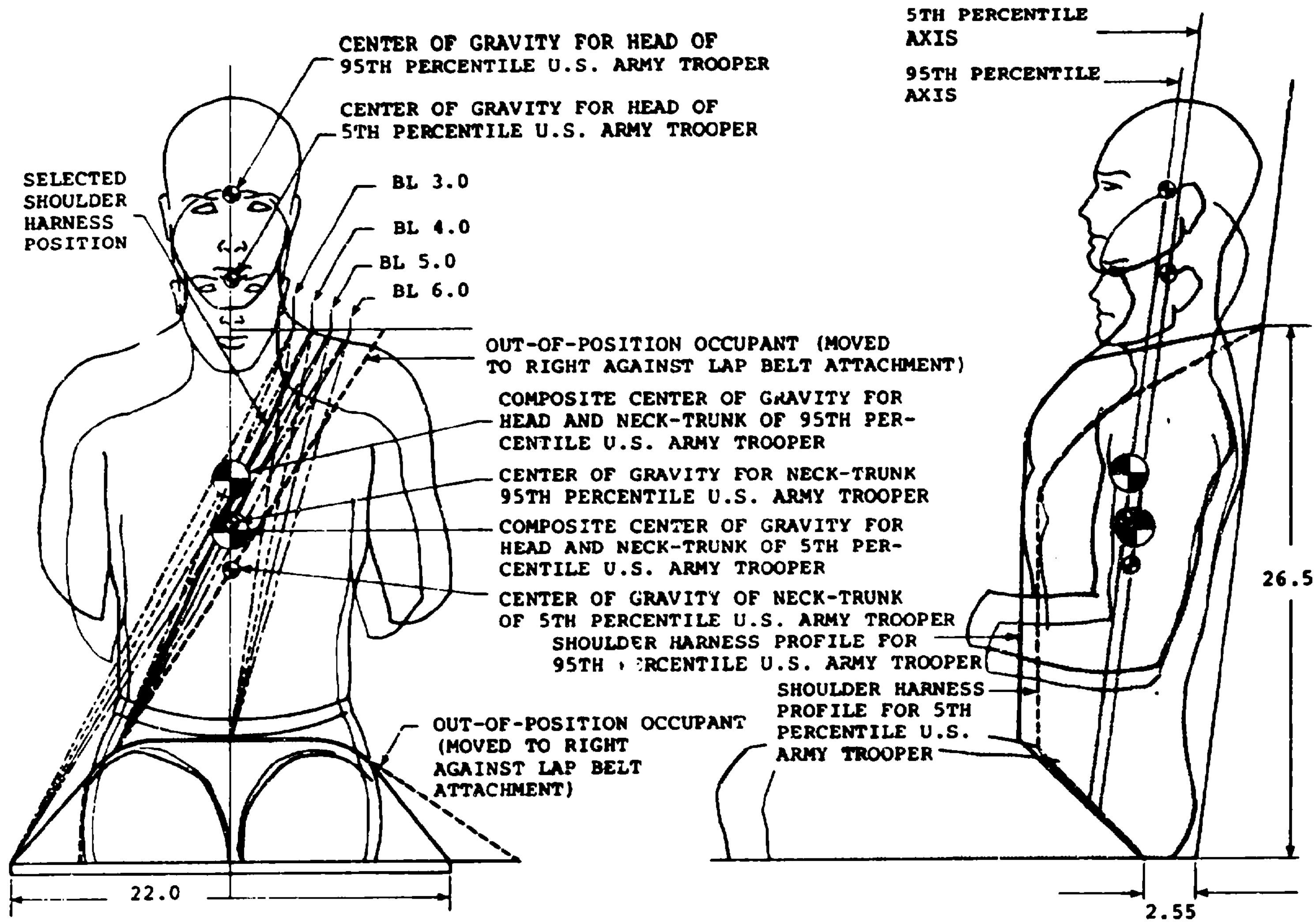


Figure 17. Shoulder Harness Placement - Type II Restraint System.

at all. The heavy dotted line shown in the frontal view of Figure 17 indicates a potential problem of an out-of-position occupant. With a 22-inch-wide seat, the occupant can slide to one side, which would permit his center of gravity to rise above the shoulder strap.

The proposed restraint system (Figure 14) has an included angle of 60 degrees between the shoulder harness fitting centerlines. This angle is greater than the 35-degree maximum allowed angle between buckle fittings for a Type II restraint required by the proposed specification; however, it is less than the 45-degree angle, measured from the vertical centerline, required for a Type I restraint. For the Type II buckle, the purpose for the maximum angle requirement is to keep the shoulder harness fittings positioned as close as possible to each other at the top of the buckle. However, there is a minimum angle that will permit sufficient extension of the fittings into the buckle with enough metal around the latching dog to enable transfer of the load from the fittings to the buckle. This situation was examined for the configuration shown, and it was felt that the 35-degree included angle requirement would not necessarily preclude a proper transfer of the load from the fittings to the buckle. Therefore, it was decided that the 35-degree maximum angle should be retained, but that the centerlines of the fittings would not necessarily have to intersect at the geometrical center of the buckle. They could intersect below the buckle's horizontal centerline.

The entry angle for the single-shoulder-strap buckle was examined utilizing the mock-up restraint system, and it was determined that a nominal entry angle for the shoulder harness fitting with the buckle located at the occupant's hip was approximately 35 degrees. This examination also revealed that there should be a minimum angle specified also. Therefore, it was decided that the angle requirement for the shoulder strap entry angle of the Type I restraint system should be between 30 and 40 degrees. This angle should be defined as the angle between the centerline of the shoulder strap fitting and the vertical centerline of the buckle.

The two shoulder strap entry angles recommended for the Type I and Type II buckles are those that would be desired if the buckle were going to be used as either a Type I or a Type II buckle. However, in the proposed restraint system (Figure 14) the buckle was intended to be used as both a Type I and Type II restraint system buckle. For this situation it was felt that the 60-degree angle between shoulder strap fittings would be an acceptable compromise. It is recommend that these angle requirements (60 degrees between fittings or 30 degrees between fitting and vertical centerline of the buckle) be used for buckles that might possibly be employed in a Type I or Type II restraint system.

Another aspect of the single-point release buckle which was examined was the fitting rotation angle requirement. The shoulder harness fittings are required to rotate through a 15-degree minimum angle, and lap belt fittings are required to be rotatable through a 30-degree minimum angle. The intent of this requirement is to permit alignment of the fitting strap and buckle with the load path, thus minimizing moments imposed on the assembly. It is apparent, however, that this requirement could be relaxed so that buckles which efficiently incorporate rigidly restrained fittings that would withstand the moments imposed can be used. To be compatible with this alignment requirement, an ideal fitting attachment at the buckle would be one that allowed the fitting to rotate within the plane of the buckle. A fixed fitting attachment, such as Pacific Scientific's, which could not rotate and thereby align itself with the loads, was felt to be satisfactory provided it could withstand the nonaligned loads. It was subsequently decided that an optimum fitting should rotate in the plane of the buckle, but a fixed fitting would be acceptable provided it could withstand the loads imposed during a dynamic test. The buckles to be supplied by Pacific Scientific for this program had fixed fitting attachments.

The simultaneous release of all buckle fittings was another requirement examined during the analysis. The requirement for all fittings to release within a particular angular rotation envelope of the lift-lever is intended to assure that all members of the restraint system are released. It would be extremely undesirable to have less than all intended releases accomplished in the case where an occupant is being restrained in an inverted aircraft. Release of only a few of the fittings might result in an orientation of the occupant which severely reduces his chances of escape; because of this consideration, a severe tolerance limit for the release angle was imposed by the proposed specification. However, there was some evidence that indicated this requirement is too strict in terms of the cost involved in machining the buckle parts to the low tolerances that would be necessary for all fittings to be released simultaneously. To determine what a more reasonable angle for a fitting release might be, a Pacific Scientific rotary buckle was tested.

The test consisted of turning the buckle by hand with a 150-pound tensile load in the lap belt and observing the release of the fittings. The result of this test was that it would be physically impossible to release less than all the fittings when they are under a load. With the buckle fitting loaded, a release force must be applied through the handle that overcomes the frictional force between the fitting and the latch dog. The instant this frictional force is overcome, the handle will rotate to the stops and release all of the fittings because the release force being applied to the handle cannot be removed quickly enough to prevent the handle from being fully rotated. Therefore, it is not necessary for all fittings to release within 15 minutes of each other, and normal tolerances can be used in machining the fittings and buckle components. Although these tests were conducted with a rotary buckle, the results are applicable to a lift-lever buckle, and it was recommended that the requirement for all fittings to release be within 2 degrees of handle rotation.

The positive ejection of buckle fittings was examined, and it was determined that this feature should be added to the single-point release buckle. With most existing systems, actuation of the release mechanism does not positively eject fittings. This usually does not cause a problem since some load is present in all of the straps that release and this load retracts the fitting. If, however, slack exists in one of the restraint members, the fitting will not be removed from the locked position in the buckle, and return of the release handle to its original position relocks the fitting. This results in partial restraint and requires another release operation by the occupant which can cause a problem in a combat situation, such as troop deployment or after a crash when egress speed is highly desirable. The positive ejection feature was evaluated in the trade-off study, and the results shown in Table 6 indicate that it is a desirable feature. Therefore, it was recommended that the single-point release buckle for the troop restraint system incorporate a positive-ejection mechanism for the fittings. This mechanism need not totally eject the fitting from the buckle; it needs only to move the fitting a sufficient distance to eliminate the possibility of relocking upon release of the actuation handle.

<u>Inertia Reel</u>

The inertia reel originally specified in the proposed specification for a Type II restraint system was a dual-spool reel with a single inertia locking mechanism. The primary reason for this choice was to assure simultaneous locking of both shoulder straps, thereby eliminating the possibility of upper torso restraint by a single shoulder strap. This would prevent any violent or potentially injurious rotation of the upper torso that might result from different locking times of two separate inertia reels.

TABLE 6. BUCKLE FITTING EJECTION TRADE-OFF

Restraint System Features	Accident Protection	Ease of Usage	Comfort	Snag Resistance	Weight	Cost	Standard-ization	Service Life	Total	Ranking
	Wt = .25	Wt = .19	Wt = .15	Wt = .14	Wt = .10	Wt = .06	Wt = .05	Wt = .06		
Ejecting	NA	90 / 17.1	89 / 13.3	90 / 12.6	85 / 8.5	85 / 5.1	NA	85 / 5.1	61.7	1
Nonejecting	NA	75 / 14.3	90 / 13.5	65 / 9.1	90 / 9.0	90 / 5.4	NA	90 / 5.4	56.7	2

The principal disadvantage of a single dual-spool inertia reel stems from the requirements for occupant rotation and lateral movement in the performance of flight operations. This type of movement demands different lengths of webbing to be withdrawn from the individual spools and produces a necessity for independent spools. If the spools are not independent, then a rotation or a lateral movement of the occupant can cause a backlash in the reel. For example, consider the occupant rotating to his right, thus requiring a much longer extension of the left shoulder harness than the right. Because both straps must unwrap equal amounts, excess webbing will be deployed from the right spool. This excess will accumulate and eventually backlash the reel.

One possible solution to this problem is to use a differential mechanism between the two spools, such as the one used in the F111 inertia reel. The differential permits the desired amount of webbing to be withdrawn from each individual spool, thus eliminating the backlash problem; however, its use imposes heavy weight and cost penalties on the system.

Another system that might be considered is two separate spools which are simultaneously locked by a single locking mechanism. This will assure that if either spool locked, both would be locked. However, examination of this configuration revealed that it may actually decrease reliability of the system as compared to a two-reel system.

It was determined that the upper torso restraint of a single shoulder harness is probably better than no shoulder harness restraint at all (previously it had been thought that the locking of one shoulder harness would probably be less desirable than if neither locked). If it can be presumed that the locking of one shoulder harness is superior to locking of neither, then the reliability of the two-reel system is greater. This is because the probability of two reels not locking is significantly less than the probability of one reel not locking. Another consideration was that tests conducted by Pacific Scientific using two inertia reels have not presented a problem; rather, locking of two reels has occurred simultaneously in all cases and provided the desired crash protection while having much more acceptable normal operational characteristics. An additional argument in favor of dual reels was that they have been used for years in jet airliners with no reported evidence of improper operation or failure of one reel to lock simultaneously with the other. Therefore, it was recommended that two independent reels be used for the Type II restraint system.

Two additional requirements for the inertia reel were also examined. One was the webbing capacity of the reel and the other was the inertia reel control. In the requirements section of the proposed specification, total retraction of the shoulder harness webbing was specified. However, the specification's drawing of the inertia reel indicated that the capacity of the reel should only be 12 inches. With a reel capacity of 12 inches, the shoulder harness length required to initially put on the restraint system would be outside the reel when the system is in the stored position. Examination of these two configurations indicated it would be best for the reel to fully retract the webbing.

Originally the inertia reel drawing specified a manual lock control. This requirement was studied and subsequently deleted, since it added unessential complexity to the system.

The webbing pulloff point for the inertia reel was also examined. The vertical distance above the seat reference point specified in the proposed specification was 25.5 to 26.5 inches. This dimension is specified to insure that the shoulder strap attachment is above the mid-shoulder height of the occupant, preventing compression loading of the spine. However, the latest anthropometric data[3] show the mid-shoulder height of an erect Army 95th percentile trooper to be 26.6 inches, which indicates that the vertical dimension of the webbing pulloff point should be changed. Since this value (26.6 inches) does not take into account the normal "slouch" of an occupant, it was recommended that the vertical distance above the seat reference point for the webbing pulloff point be 26 to 27 inches.

For the horizontal location, each restraint system was analyzed separately. Since the Type II restraint has two shoulder straps connected at a centrally located buckle, the horizontal separation of the inertia reels should be small so that the shoulder straps can provide some lateral support. Using the mock-up restraint, the acceptable range of horizontal separation was determined to be between 4 and 8 inches. This distance was measured between the centerlines of the inertia reels and was symmetrical about the vertical centerline of the seat. The 4-inch dimension was the closest that two inertia reels could be placed, and 8 inches was the maximum distance that the reels could be separated and still provide good lateral support.

The horizontal location for the Type I inertia reel was determined by locating the reel at butt lines placed at 1-inch increments from the centerline and evaluating the restraint provided by that particular configuration. The evaluations for each butt line were:

- <u>One-Inch Butt Line</u>

  The shoulder harness strap rides principally on the neck, and the lower strap has a tendency to work up the torso on the buckle side. Also, the reel can be struck by the head with normal movement of the occupant. However, the occupant's center of gravity is below the diagonal strap.

- <u>Two-Inch Butt Line</u>

  The webbing tends to fold between the collarbone and neck, causing the shoulder strap to bear uncomfortably on the neck. Also, the reel can be easily struck by the head. The occupant's center of gravity is below the diagonal strap.

- <u>Three-Inch Butt Line</u>

  The webbing bears less on the neck as it crosses the collarbone. The diagonal strap is more comfortable than the 2.0-inch butt line location, but the reel can be struck by the head when leaning to the side. The occupant's center of gravity is below the shoulder strap.

- <u>Four-Inch Butt Line</u>

  The webbing crosses the collarbone, with a small portion touching the neck, and the diagonal strap feels comfortable. The occupant's center of gravity is below the diagonal strap.

- <u>Five-Inch Butt Line</u>

  The strap just touches the neck as it crosses the collarbone. The center of gravity is close to being above the diagonal strap.

- <u>Six-Inch Butt Line</u>

  The strap is off the neck and lower on the torso. The strap slides below the collarbone with the reel locked, and there is a tendency for the upper torso to rotate over the shoulder strap.

- <u>Seven-Inch Butt Line</u>

  The shoulder strap is off the neck and stays on the low side of the collarbone. The shoulder strap is below the occupant's center of gravity, with a strong tendency for the upper torso to rotate about the strap.

Based on this study, a horizontal location for the Type I inertia reel of 4.0 ±0.5 inches was selected.

Webbing

The analysis of the webbing was directed toward the effects of belt width and the elongation of new polyester webbings.

Existing data on the elongation characteristics of new polyester webbing indicated that the elongation varies linearly with the applied load and that the webbing stiffness (lb/elongation) is a function of belt width. Using the elongation data supplied by Murdock Webbing Company and Pacific Scientific Company on new low-elongation webbing, a linear relationship between belt width and webbing stiffness, shown in Figure 18, was established. With this function between belt width and stiffness, the shoulder harness and lap belt loads corresponding to different webbing widths were determined from the results of the parameter study. These loads are presented in Table 7 along with the contact areas for each belt width that were used to determine belt pressures. These values are also shown in Table 7 and are plotted as a function of belt width in Figure 19. These curves indicate that the average belt pressure decreases as the webbing width increases, and the lap belt widths of 2.25 inches and greater have pressures that are below the severe pain level.[8]

One obvious result of increasing the webbing width is to add additional weight to the restraint system. This weight increase is caused by the additional weight of both the webbing and its associated components, such as adjusters and fittings. The percentage of restraint system weight increase for the shoulder strap and lap belt of the Type I and Type II system is shown in Figure 20. The base weights of 3.2 pounds for the Type I system and 4.2 pounds for the Type II system are the estimated weights for each of these restraints. The increase in restraint system weight due to wider webbing alone was used to establish the lower boundary for weight increase. Since there will be additional weight over and above the increase in webbing because of the additional weight of the material required to widen the components associated with the webbing, an upper boundary on weight increase was also established. The upper boundary was determined by calculating an increase in component weight in the same proportion as the webbing's weight increase. This weight increase was chosen as an upper boundary

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8. Lewis, S. T., and Stapp, J. P., HUMAN TOLERANCE TO AIRCRAFT SEAT BELT RESTRAINT, Aerospace Medicine, Vol. 29, 1956.

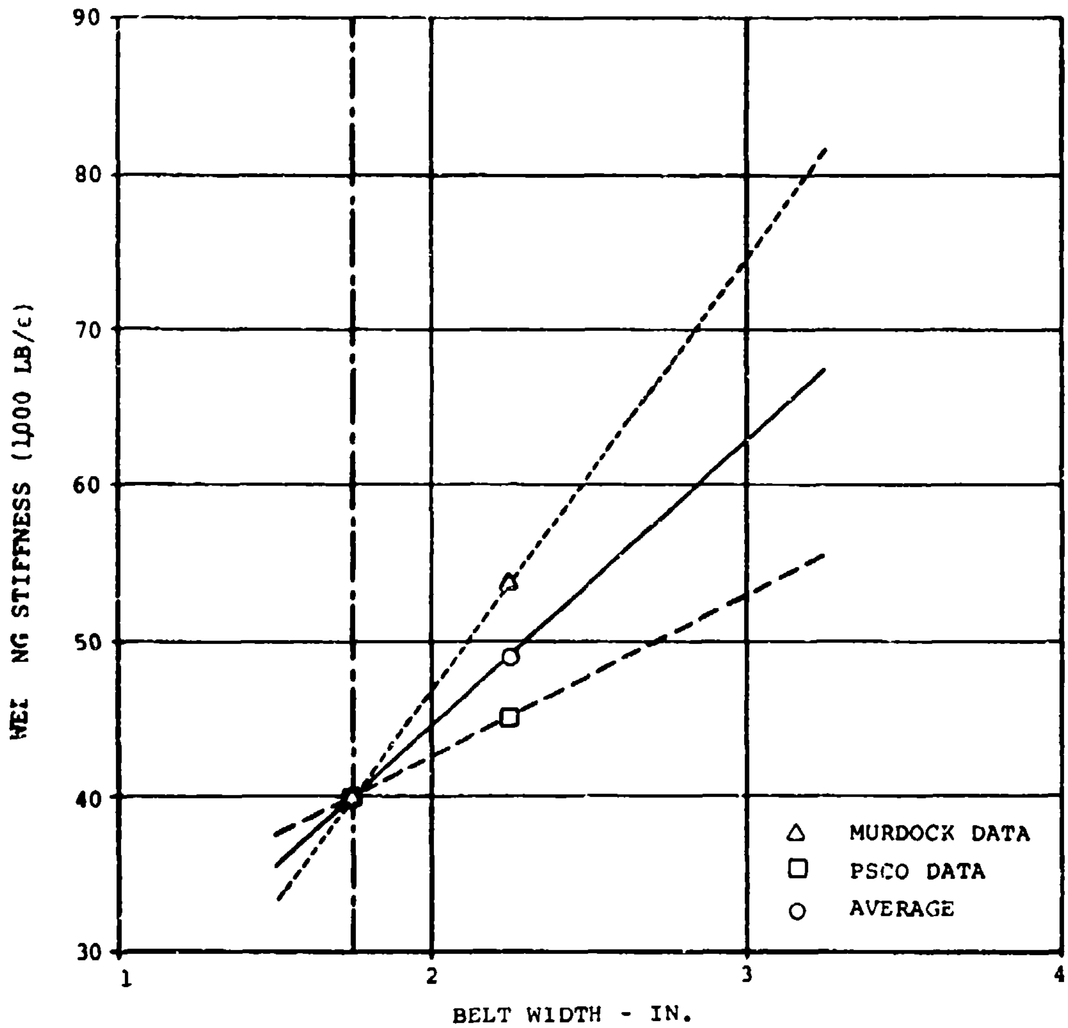


Figure 18. Webbing Stiffness Versus Belt Width.

since it might be expected that an increase in the width of the component would not necessarily increase its weight in the same proportion as the webbing's.

A study of the elongation characteristics of several webbings resulted in the selection of a new webbing for the shoulder strap. It was Southern Weaving T1200 webbing, which is 2 inches wide and 0.045 inch thick and has a breaking strength of 6,000 pounds. This change in shoulder harness webbing from the proposed 1-3/4-inch webbing resulted from the fact that at the Specification Review Meeting it was noted that the 1-3/4-inch-wide

TABLE 7. EFFECTS OF WEBBING WIDTH								
Restraint System	Restraint Member	Occupant Size (%)	Webbing Widths (In.)					
			1.75	2.00	2.25	2.50	2.75	3.00
			Belt Contact Areas (Sq. In.)					
TYPE II	Shoulder Harness	95th	80.5	92.0	103.5			
		5th	73.5	84.0	93.5			
	Lap Belt	95th		41.0	46.0	51.3	56.3	61.5
		5th		32.0	36.0	40.0	44.0	48.0
TYPE I	Shoulder Harness	95th	45.5	52.0	57.5			
		5th	41.2	47.0	53.0			
	Lap Belt	95th		41.0	46.0	51.3	56.3	61.5
		5th		32.0	36.0	40.0	44.0	48.0
			Belt Load (Lb)					
TYPE II	Shoulder Harness	95th	3250	3175	3100			
		5th	1700	1775	1850			
	Lap Belt	95th		3180	3785	3760	3735	3710
		5th		2450	2500	2550	2600	2650
TYPE I	Shoulder Harness	95th	3350	3300	3250			
		5th	1950	1925	1900			
	Lap Belt	95th		3850	3822	3795	3767	3740
		5th		3790	2798	2805	2812	2820
			Belt Pressures (PSI)					
TYPE II	Shoulder Harness	95th	40.4	33.5	29.9			
		5th	23.1	21.1	19.8			
	Lap Belt	95th		92.9	82.0	73.3	66.4	60.4
		5th		76.6	69.4	63.8	59.1	55.2
TYPE I	Shoulder Harness	95th	73.6	63.5	56.5			
		5th	47.4	41.0	35.8			
	Lap Belt	95th		93.9	83.0	74.0	67.0	60.8
		5th		87.3	77.8	70.0	63.9	58.8

webbing obtained from Murdock Webbing Company and originally intended for use as the shoulder strap webbing might not be the best webbing available. To investigate this possibility, Pacific Scientific compared the elongation properties of the following webbings:

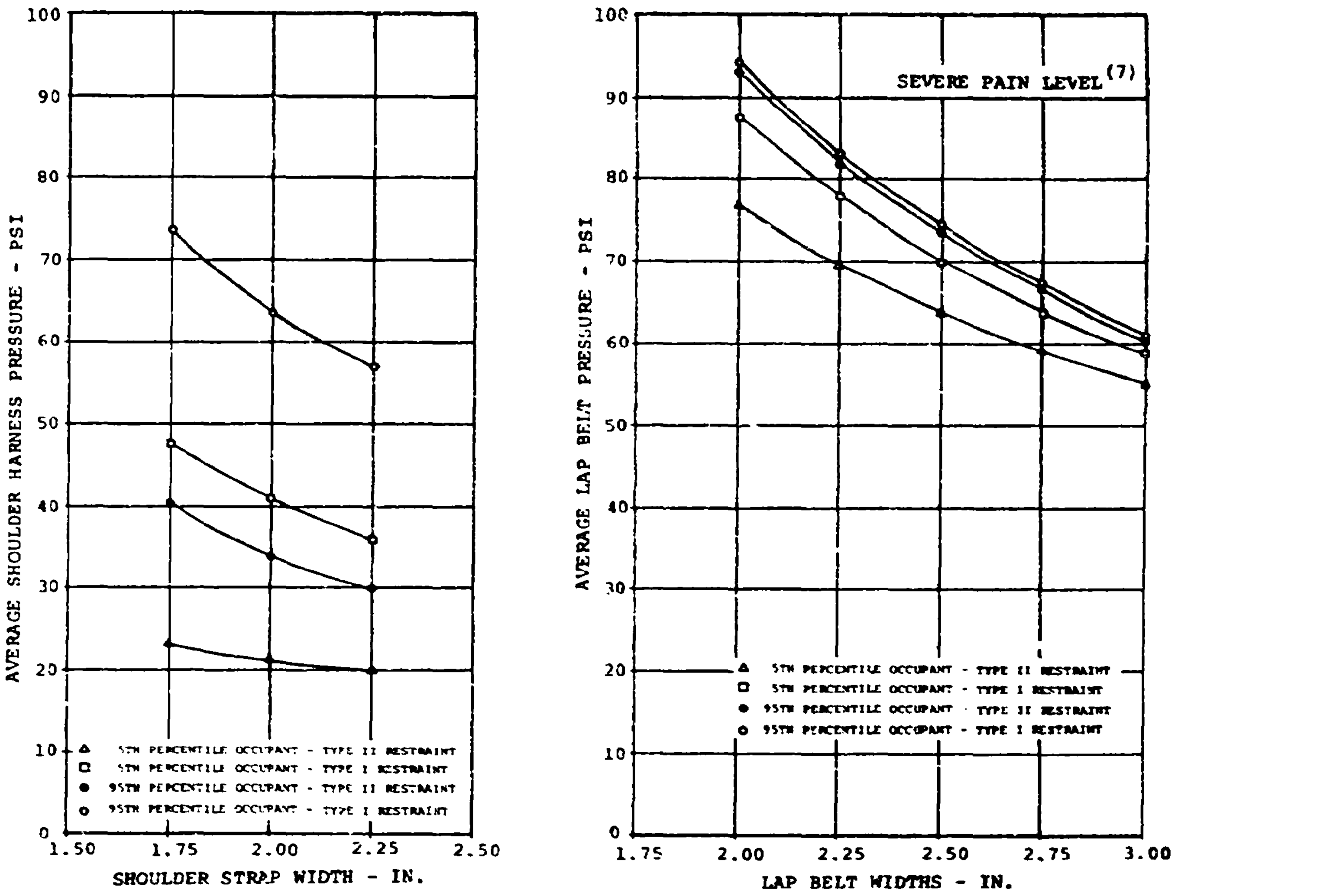


Figure 19. Average Belt Pressures as a Function of Webbing Width.

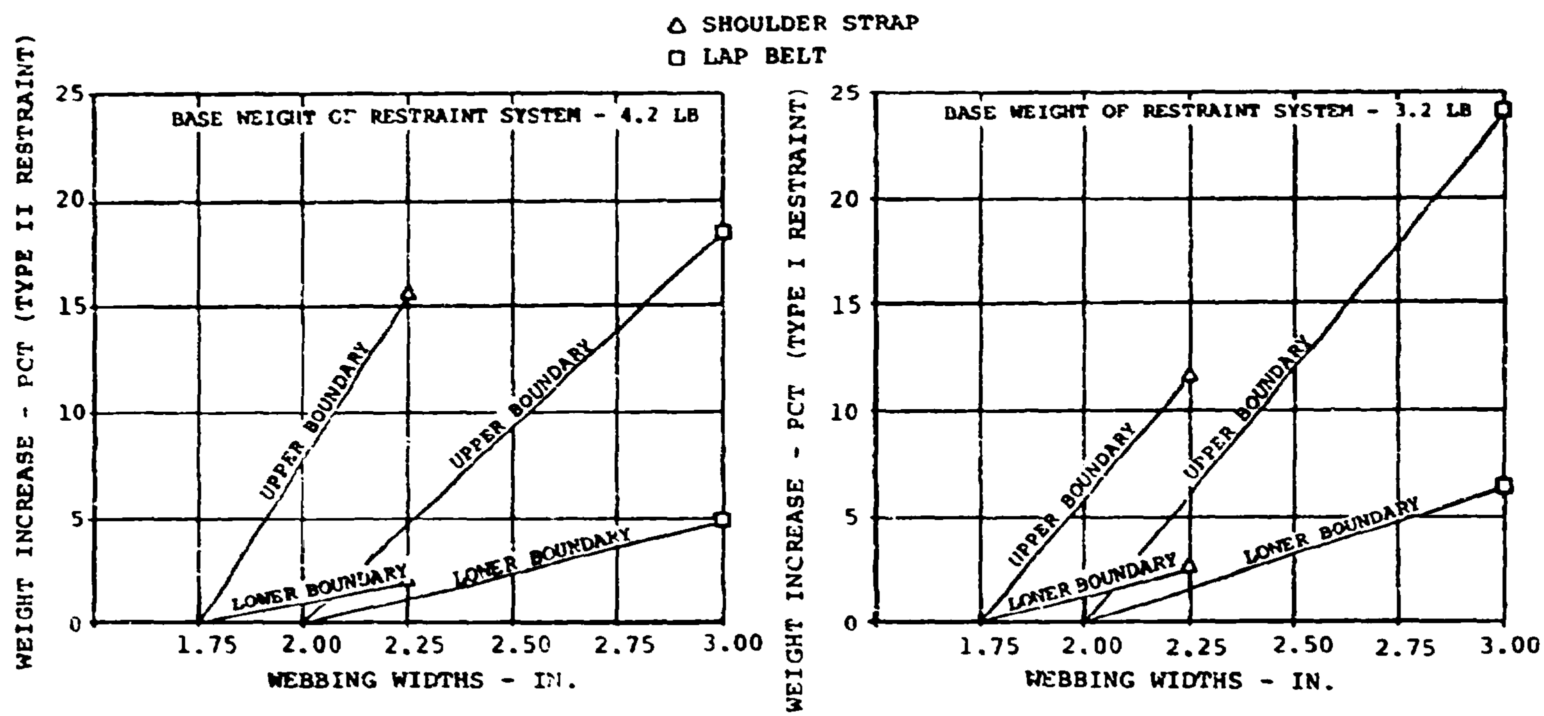


Figure 20. Weight Increase as a Function of Webbing Width.

- Southern Weaving T1200

  (0.045 in. x 2.0 in., breaking strength - 6,000 lb)

- Narricot 72-349

  (0.045 in. x 1.938 in., breaking strength - 6,000 lb)

- Murdock (experimental webbing)

  (0.043 in. x 1.75 in., breaking strength - 6,000 lb)

- MIL-W-25361 Type II

  (0.070 in. x 1.75 in., breaking strength - 6,000 lb)

- MIL-W-25361 Type III

  (0.080 in. x 1.75 in., breaking strength - 7,000 lb)

The load-elongation curves for these webbings are shown in Figure 21 and indicate that the elongations at the design load of the shoulder strap webbing (4,000 pounds) are:

- Southern Weaving T1200 - 8.9 percent
- Narricot 72-349 - 10.7 percent
- Murdock - 10.3 percent
- MIL-W-25361 Type II - 9.3 percent
- MIL-W-25361 Type III - 8.7 percent

From the standpoint of elongation at design loads, it appears that the best webbing is MIL-W-25361 Type III; however, the elongations of the MIL-W-25361 webbings may be uncharacteristically low. The maximum elongations allowed by the specification for an applied load of 3,000 pounds are 13 percent for Type II and 12 percent for Type III. Also, for the range of loads to which a restraint harness would most likely be exposed (1,000 to 4,000 pounds), the Southern Weaving T1200 has the lowest elongation for a particular load. Since this webbing is 2 inches wide, it would provide better distribution of the shoulder harness loads than the 1-3/4-inch-wide webbing, and it would not cause any hardware problems with the inertia reel because the proposed reel was originally designed for 2-inch webbing. This webbing is also readily available since it is currently being manufactured for automotive use. Therefore, it was decided that the Southern Weaving T1200 webbing should be used

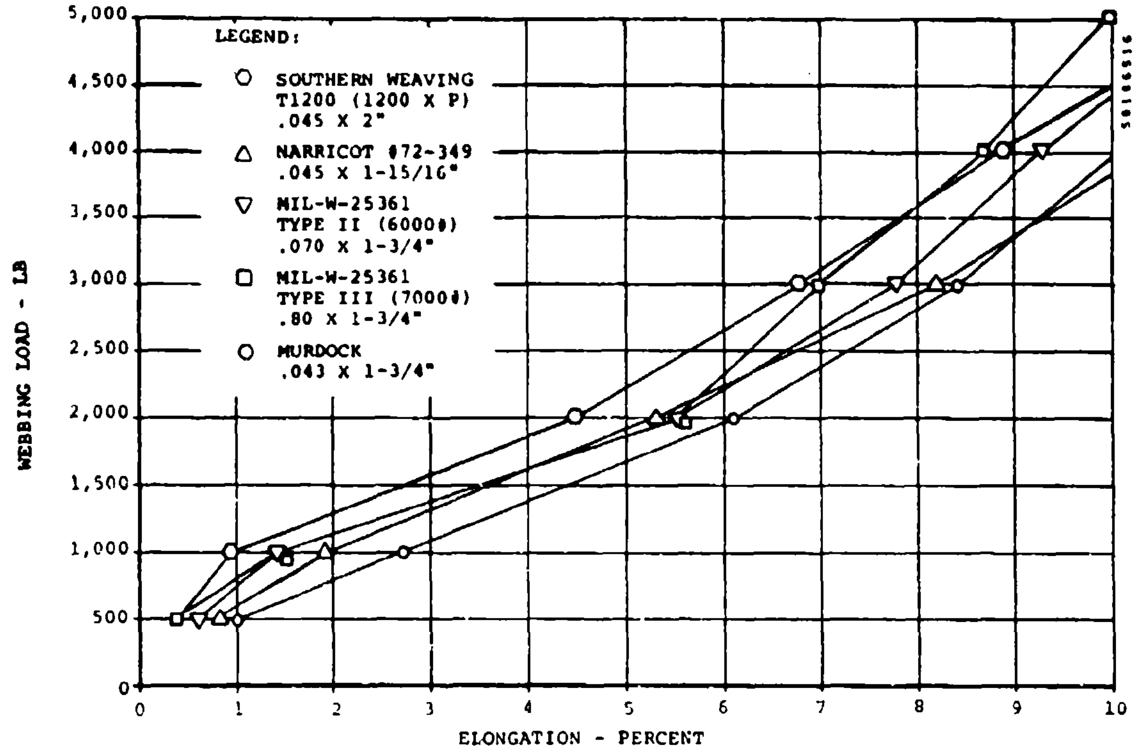


Figure 21. Load-Elongation Curves for Polyester Webbing.

for the shoulder harness and the proposed specification should be changed to reflect this increase in shoulder harness webbing width. The only color for T1200 webbing available at this time is black, but for future procurements the webbing could be dyed the desired olive drab color.

TRADE-OFF STUDY

A weighted trade-off study of the two restraint systems was performed, and the results are presented in Table 8. Ratings for each evaluation factor in the trade-off study were determined for each restraint system. These values in turn were used to calculate a total weighted rating for each restraint system and establish the relative ranking for the Type I and Type II restraint systems. The results of the trade-off study indicated that the Type II restraint is the best troop restraint system.

The accident protection ratings were established by comparing the potential for injury of the two restraint systems. A relative value of 85 was determined for the Type II system

TABLE 8. RESTRAINT SYSTEM TRADE-OFF

Restraint System Features	Accident Protection	Ease of Usage	Comfort	Snag Resistance	Weight	Cost	Standard-ization	Service Life	Total	Ranking
	Wt = .25	Wt = .19	Wt = .15	Wt = .14	Wt = .10	Wt = .06	Wt = .05	Wt = .06		
Restraint System										
Type II	85 / 21.3	25 / 4.8	25 / 3.8	25 / 3.5	89 / 8.9	74 / 4.4	90 / 4.5	85 / 4.1	56.3	1
Type	10.3	33 / 6.3	33 / 5.0	33 / 4.6	90 / 9.0	75 / 4.5	45 / 2.3	90 / 5.4	47.4	2

based on its ability to provide adequate restraint during a crash situation. By comparing the head severity index and shoulder harness pressure of each restraint system along with the restraint provided against directional crash pulses, it was found that the Type I system had a 52-percent increase in injury potential. This value was then used to calculate an accident protection rating of 41 for a Type I system.

The relative ratings for ease of usage, comfort, and snag resistance were determined by examining the number of straps and fittings in each restraint system. There are three straps in a Type I restraint and four straps in a Type II restraint. Since the rating for each of these evaluation factors should be inversely proportional to the number of straps, the reciprocal of the number of straps was used to calculate an ease of usage, comfort, and snag resistance rating of 25 for a Type I system and 33 for a Type II system.

The anticipated weights of the Type I and the Type II troop restraint systems are 3.25 pounds and 4.25 pounds, respectively. The difference, of course, is because of the absence of one inertia reel and shoulder strap, which will weigh 1 pound, in the Type I restraint. This difference of 1 pound can appear to be a substantial increase in weight when compared with just the weight of the restraint system, i.e., there is approximately a 33-percent increase in restraint system weight in going from a Type I to a Type II restraint. However, when compared with the total weight of the number of troops in a particular aircraft, its significance diminishes. For instance, the number of troops UTTAS can carry is 12, and if the weight of a 50th percentile, fully outfitted trooper (197 pounds) is used for each occupant, the total weight of a full complement of troops is 2,364 pounds. The 12 pounds difference in total restraint system weight (1 pound per restraint system) is such a small fraction of the total occupant weight (0.51 percent) that it must be judged relatively insignificant when evaluating the two restraint systems. In view of this and because it was felt these weights could not be significantly reduced, ratings of 89 and 90 were respectively assigned to Type I and Type II restraint systems.

The same approach was used to establish the rating values for cost. The estimated difference in price of $25.00 between a Type I and a Type II system was considered to be insignificant when compared to the estimated cost of $15,000 for training an Army trooper. Since the estimated cost for the restraint systems can probably be reduced, lower ratings were used. The rating values determined for the Type I and Type II restraint systems were 75 and 74, respectively.

The rating values for standardization were based on the fact that there was only one configuration for a Type II restraint while there were two configurations (right-hand and left-hand) for the Type I restraint. This implies that from the standpoint the Type I restraint. This implies that from the standpoint of standardization, the Type II restraint should be twice as good as a Type I. The service life ratings were determined from the number of components in the restraint system. Since the Type II restraint has more components than the Type I, it was rated slightly lower on service life.

RESTRAINT SYSTEM DESIGN

The detailed design of the Type I and Type II Troop Restraint Systems was accomplished by Pacific Scientific Company after requirements had been exactly defined. Concurrent with the design and testing efforts, changes were made to the hardware as new interpretations were made of the specification or additional information on the requirements was obtained. The final configuration of each type of restraint system is illustrated in Figure 22, and a description of each troop restraint system and its components is given in the following paragraphs. The numbers in parentheses refer to PSCo drawings, which are on file at the Eustis Directorate.

TYPE I - TROOP RESTRAINT SYSTEM

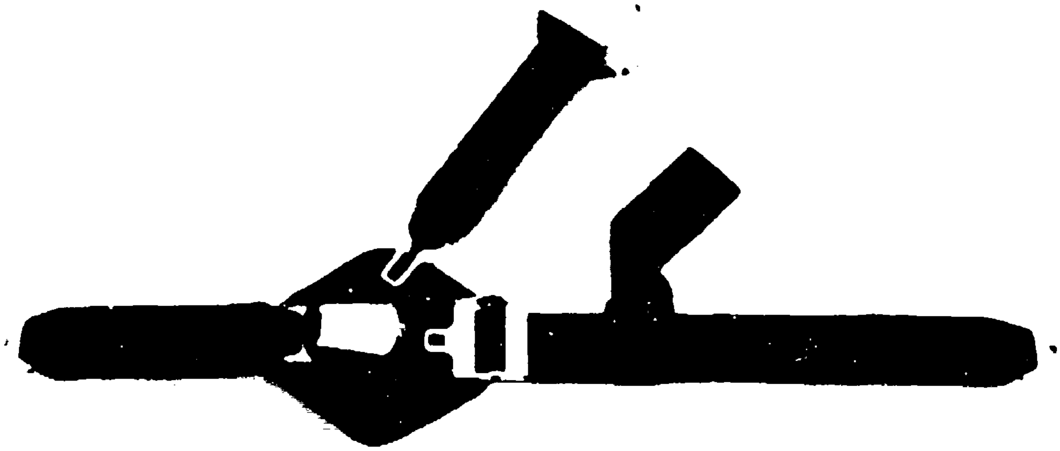
A Type I restraint system (1107058) consists of a lap belt and single shoulder strap that may be either a right- or a left-hand system, depending on where it would be installed in the aircraft. The right-hand system has the buckle on the right side and a strap over the left side. The buckle is fixed to the right-hand lap belt. The left-hand system has a buckle on the left side and the strap over the right shoulder. The buckle is fixed to the left-hand lap belt. The change from a right- to a left-hand system is accomplished by rotating the buckle 180 degrees, since there is an extra shoulder strap fitting socket on the bottom side of the buckle when it is in the right-hand position.

TYPE II - TROOP RESTRAINT SYSTEM

The Type II restraint system (1107048) is a lap belt and dual shoulder strap system located symmetrically about the torso. Each shoulder has an individual strap and inertia reel, and the shoulder straps attach to the buckle which is located at the center of the lap belt. The buckle is in the same orientation as the Type I right-hand system with the fixed lap belt on the right-hand side. The Type II system has the same components as the Type I system with the addition of one inertia reel with shoulder strap.

Webbing

The webbing used for the troop restraint systems is a low-elongation polyester webbing. Two webbing sizes are used; the physical properties for each of these are described in Table 9. The lap belt webbing is a special low-elongation polyester webbing developed by Murdock for use in an aircrew restraint



Type I Restraint System

Type II Restraint System

Figure 22. Two Troop Restraint System Designs.

TABLE 9. WEBBING DIMENSIONS, STRENGTH, AND ELONGATION REQUIREMENTS					
Component	Thickness (in. ±0.010)	Width (in. ±1/16)	Maximum Elongation at Design Load (%)	Minimum Breaking Strength (lb)	Design Load (lb)
Lap Belt	0.055	2-1/4	8.5	6,000	4,000
Shoulder Straps Type I and Type II	0.055	2	9	6,000	4,000
Note: All loads are applied in straight tension.					

system,[9] while the shoulder strap webbing is T1200 webbing manufactured by Southern Weaving Company and commonly used in automotive restraint systems.

Analysis of weathering data for the polyester ' ers indicated that a polyester webbing, such as that used in the troop restraint systems, would retain 71 percent of its strength after being in service for 5 years. This analysis was based on the assumption that during the service life of 5 years, the webbing would be exposed to continuous direct sunlight 20 percent of the time. Relating this to the webbing being used for the troop restraint system, a webbing that is required to have an ultimate strength of 4,000 pounds at the end of 5 years, needs to have an initial strength of 5,634 pounds, which is 6 percent less than the ultimate strength requirements for the troop restraint system webbing. The webbing for the troop restraint systems is required to have an initial ultimate strength of at least 6,000 pounds and, after being in service for 5 years, should still be capable of sustaining a 4,320-pound load, which is adequate for occupant protection.

Inertia Reel

The inertia reel assembly (1107368-01) is a modification of Pacific Scientific Company's Mark I Reel that uses steel components (4130) to meet the 4,000-pound design load requirement. The inertial reel meets the locking and tension load requirements of MIL-R-8236 but it does not have the cover or manual control that is required by MIL-R-8236.

9. Carr, R. W., and Desjardins, S. P., AIRCREW RESTRAINT SYSTEM DESIGN CRITERIA EVALUATION, USAAMRDL TR 7[illegible], Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, February 1975.

The inertia reel will retract and store 40 inches of 0.045-inch-thick webbing, but because this amount tends to interfere with the locking bar, the length of webbing on the spool that will inertia lock is limited to 32 inches. This does not affect the performance of the inertia reel because when the shoulder strap is in use and plugged into the buckle, more than 12 inches have been unreeled, leaving less than 32 inches on the spool, all of which will inertia lock.

The shoulder strap consists of a buckle fitting (1107370-01) and 2-inch-wide T1200 polyester webbing. One end of the shoulder strap is attached to the inertia reel by a stitched loop. The other end of the webbing is folded and looped through the fitting and stitched with number 3 nylon thread per Federal Specification V-T-295A. The complete stitch pattern used was two 4-point "W-W" patterns facing each other to minimize overlap and staggered to spread over the width of the webbing; the total length of the stitch pattern is 2.13 inches. The fitting end of the shoulder strap is impregnated lightly with a resin material for approximately 5.5 inches. This stiffens the end so that the shoulder strap can be placed in an easily accessible location by a positioner supplied by the seat manufacturer when the inertia reel is installed.

Lift-Lever Buckle - Type I

The Type I lift-lever buckle (1101628-01) is a modified version of Pacific Scientific Company's high-strength rotary buckle that has been redesigned for lift-lever operation. The buckle has one socket for the lap belt adjuster/fitting and two sockets for the shoulder strap fittings, which are located 35 degrees from the vertical centerline in the upper and lower left-hand quadrants to permit the use of the buckle with either a right- or a left-handed system. The lift lever pivots from the right-hand side, and all three sockets have ejector springs that prevent the fittings from reengaging once the lift lever is actuated. Right-hand usage of the lift-lever buckle is with the fixed lap belt fitting on the right side and the shoulder strap inserted into the socket in the upper left-hand quadrant. Left-hand usage is obtained by simply rotating the buckle 180 degrees and inserting a shoulder strap fitting into the socket, which is now located in the upper right-hand quadrant. The fixed lap belt fitting is now on the left-hand side of the buckle.

Lift-Lever Buckle - Type II

The Type II lift-lever buckle (1101614-01) is also a modification of Pacific Scientific Company's high-strength rotary buckle that was redesigned for lift-lever operation. The buckle has two sockets for shoulder strap fittings that are 35 degrees apart and located symmetrically with respect to the vertical centerline of the buckle. In addition, the buckle has one socket for a releasable lap belt adjuster/fitting that is coincidental with the horizontal centerline. The lift lever hinges from the right-hand side, and the three sockets controlled by the lift lever have ejector springs to prevent the fittings from being reengaged once the lift lever is actuated.

Buckle Pad

The buckle pad (1107367) is common to both types of restraint systems and is therefore large enough to pad the buckle fittings for all possible configurations. The pad is a slightly rounded and flattened octagonal shape that is semipermanently attached to the buckle by means of a thin, lightweight backing plate and four screws. The cover is a textured vinyl plastic, and the padding is a PVC and nitrile rubber blended foam pad.

Adjuster/Fitting

The adjuster/fitting (1101626-01) is a plug-in type adjuster that is used on both Type I and Type II restraint systems. The adjuster was designed for the 2.25-inch-wide by 0.055-inch-thick low-elongation polyester webbing and plugs directly into the buckle fitting socket. The lap belt is adjusted (i.e., tightened) by pulling on the loosened end of the lap belt that has been threaded through the adjuster. This can be done with the adjuster connected to the buckle. The lap belt is readjusted or loosened by disconnecting the adjuster/fitting from the buckle and rotating the adjuster fitting frame so that the locking cam releases the webbing.

Lap Belt Assembly

The lap belt assembly (1107372) is a length of 2.25-inch-wide by 0.055-inch-thick low-elongation polyester webbing that is free on one end and stitched to an anchor (1107369-01) on the other end. The webbing is looped through the slot on the anchor, folded twice, and stitched with number 3 nylon thread per Federal Specification V-T-295A. The complete stitch pattern consists of four 4-point "W-W" patterns facing each other in pairs and distributed over the width of the webbing with a single box pattern at the extreme ends. The total length of the stitch pattern is 3.25 inches.

TEST FIXTURES

Special fixtures were designed or modified to perform the operational and strength evaluations of the troop restraint systems. These fixtures were used to test restraint system components in accordance with the proposed specification and were designed for two separate functions (strength tests and operational tests). In general, the static test fixture (DSL602) was used to perform the strength tests on the restraint system, and the functional test fixture (DSL603) was used for the tests that evaluated the operational characteristics of the restraint system. The numbers in parentheses are Dynamic Science drawing numbers. The relationship between the tests and fixtures was as shown below.

The tests performed on the functional test fixture were:

- Adjuster load test
- Adjuster webbing abrasion test

The static test fixture was used for:

- Lap belt assembly test
- Shoulder harness test
- Buckle release test

The buckle release test required the buckle release actuator (DSL606) to operate in conjunction with the static test fixture. Both the static test fixture and the functional test fixture were developed for a related program.[9] The assembly drawing for the buckle release actuator is presented in Appendix A.

STATIC TEST FIXTURE

The static test fixture (DSL602) was designed to apply tension loads of varying magnitude to the various restraint system components. The loads were applied by hydraulic cylinders attached to the fixture frame, and load cells were placed between the hydraulic cylinder and the test article to measure the loads that were applied.

The basic structure of the static test fixture consists of a combination of "I" beams that form the lateral and longitudinal load-carrying members. The beams also provide the mounting points for the lap belt on one axis and the shoulder harness on the other axis. As shown in Figure 23, hydraulic

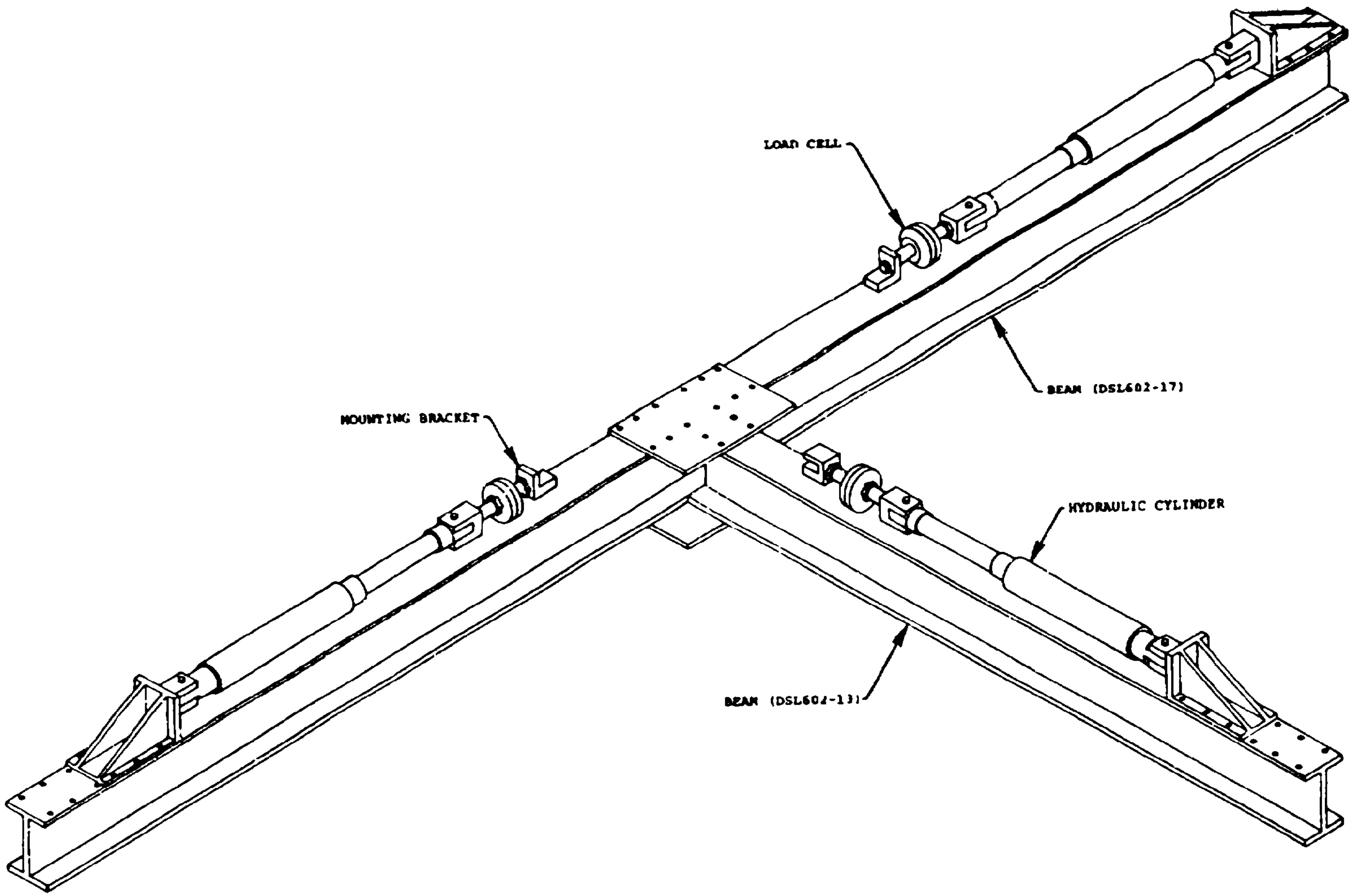


Figure 23. Static Test Fixture.

cylinders are positioned at both ends of the beam (DSL602-17) for the purpose of keeping the buckle positioned on the centerline of the fixture. Another hydraulic cylinder is located on the beam (DSL602-13) for application of shoulder harness loads. Provisions such as mounting holes and adapters are provided for all of the required test setups, and the fixture has been designed so that it can be easily disassembled.

FUNCTIONAL TEST FIXTURE

The functional test fixture (DSL603) is a slider crank mechanism. The power drive system consists of a 1/2-horsepower DC motor that drives a 30:1 worm gear speed reducer. The reducer output shaft is connected to an electric clutch-brake, and the output of the clutch-brake is connected by a shaft to the crank (DSL603-21). The connecting rod (DSL603-19 or DSL602-37) connects the crank to the traveler base (DSL603-17). This mechanism is shown in schematic form in Figure 24. The motor's rpm is governed by a variable transformer-type speed control, making it possible to continuously adjust the motor's speed as well as reverse its direction. Timing signals for activating the clutch-brake were supplied by a limit switch activated by the timing cam (DSL603-27) attached to the gear reducer's output shaft.

BUCKLE RELEASE ACTUATOR

The buckle release actuator fixture (DSL606), as shown in Figure 25, is used as an adapter to the static test fixture (DSL602) to actuate the buckle and provide the required release data. The fixture is positioned on the static test fixture after the buckle location has been determined. The actuator fixture provides the force required to release the lift-lever buckle while the restraint system is under a simulated 1G load, which is applied by the test fixture. The other functions of the actuator fixture are to measure the load at which the buckle releases and at what angle the release occurred. These data are taken by using a 0-to-1000 inch-ounce torque cell and a precision potentiometer. The potentiometer is chain driven from a sprocket that is attached to the torque cell. The sprocket ratio from the torque cell to the potentiometer is 8:1, which makes it possible to increase the number of turns on the potentiometer during the buckle release sequence and therefore increase the resolution of the rotation angle data. The force is generated by using the same DC motor, speed reducer, and brake-clutch that is used on the functional test fixture (DSL603). The required output rpm from the speed reducer is 3.3 rpm.

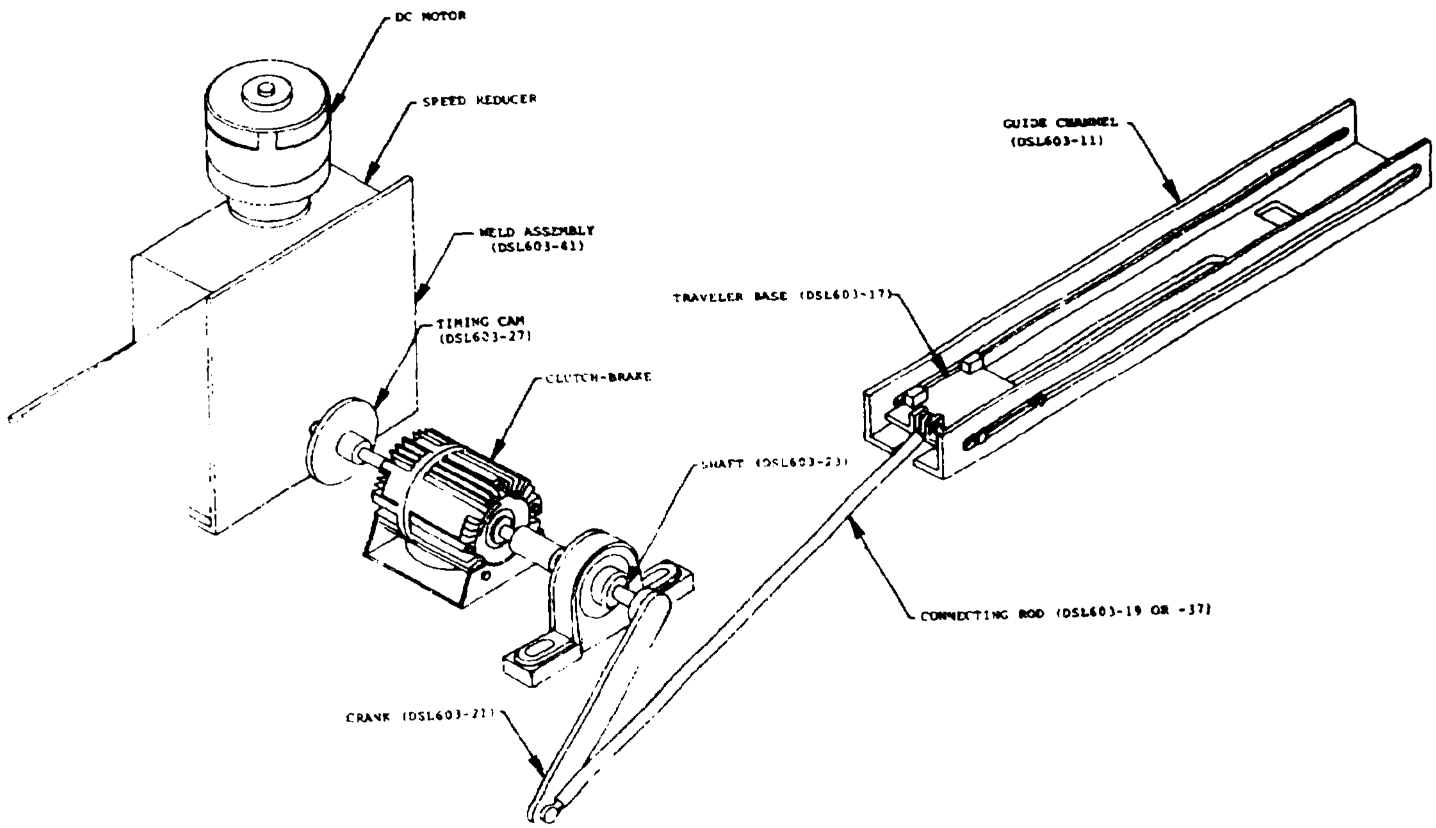


Figure 24. Functional Test Fixture.

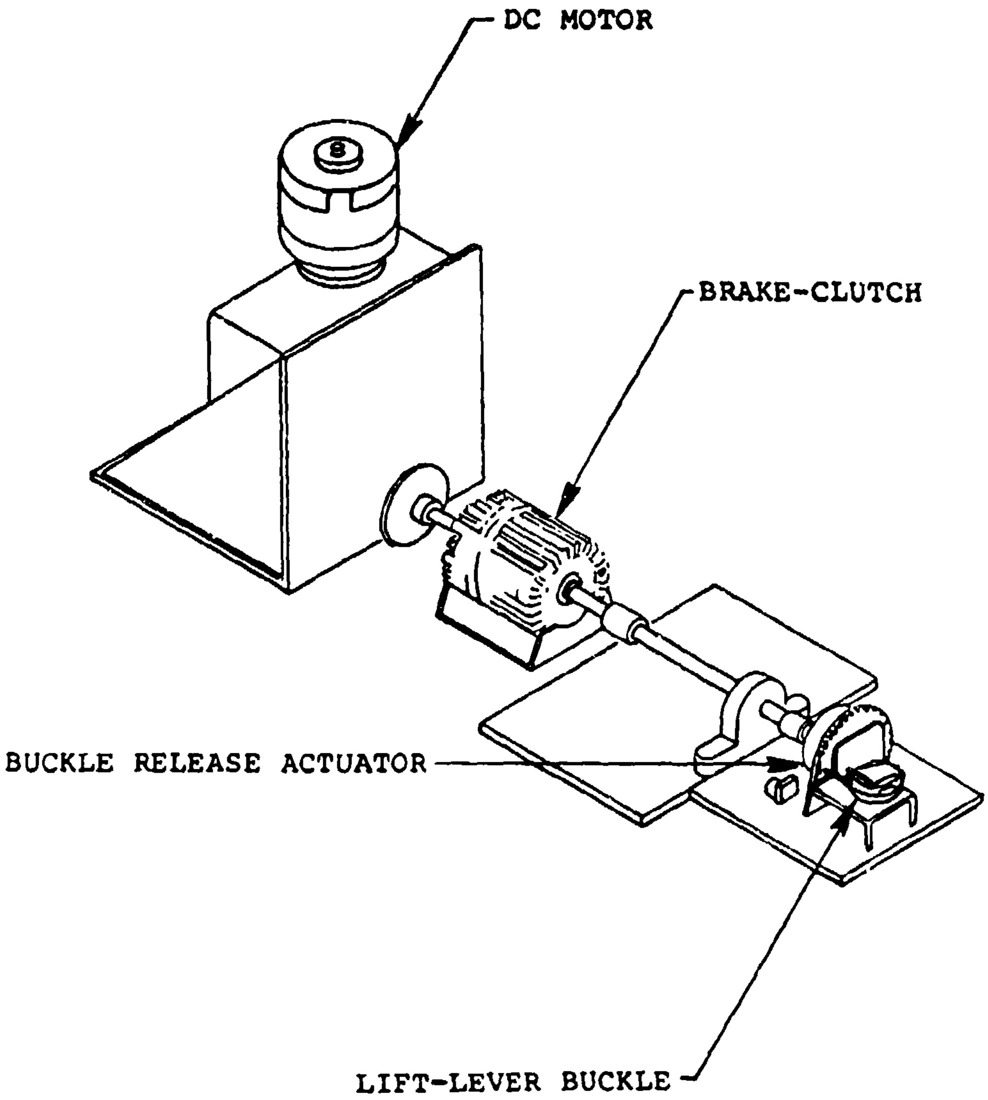


Figure 25. Buckle Release Test.

STATIC TESTS

Troop restraint systems manufactured by Pacific Scientific Company were statically tested to verify their capability of meeting the static test part of the quality assurance provisions of the proposed specification. The tests were conducted on components and subassemblies of the restraint system to ensure that efficient restraint can be provided during a 95th percentile light or rotary-wing aircraft accident, as defined in USAAMRDL TR 71-22,[1] and that normal operating characteristics of the restraint system meet or surpass the specification's requirements.

The static tests were set up to be conducted on the components and subassemblies of a delivered restraint system using a tensile test machine and the special test fixtures previously discussed. With the exception of the webbing tests, no special pieces of restraint system hardware were required for any of the tests. A series of six static tests was conducted on components and subassemblies of the troop restraint systems that could generally be described as either strength tests or operational tests. The strength tests were conducted on

- Webbing
- Lap Belt Assembly
- Shoulder Strap Assembly
- Hardware Components

to ensure that the strength and elongation requirements of the specification were satisfied and to determine the failure load and failure mode of each of these components.

The operational tests were conducted on

- Adjuster
- Buckle

to ensure that each of these components would operate properly over the expected life of the restraint system and, in the case of the buckle, after being subjected to simulated crash loads.

WEBBING TESTS

The purpose of the webbing tests was to verify that the elongation of the three webbings used in the restraint system were equal to or less than that specified by the webbing supplier, and that the ultimate strengths of the webbings were greater than or equal to the minimum ultimate strengths shown in Table 10.

TABLE 10. WEBBING DIMENSIONS AND MINIMUM ULTIMATE STRENGTH

Component	Width (in. ±1/16)	Thickness (in. ±.010)	Minimum Ultimate Strength (lb)
Lap Belt	2-1/4	0.046	6,000
Shoulder Straps Type I and Type II	2	0.045	6,000

Two webbing tests were conducted, one for each webbing size; however, only the 2-inch-wide webbing was tested on this program. The 2-1/4-inch-wide webbing was tested on a related program.[9] The test specimen in each of these tests was a single 54-inch length of webbing. The webbing length was gripped with webbing test jaws complying with Method 4108.1 of Federal Test Method Standard 191. The jaws were placed in a universal testing machine as shown in Figure 26. The gauge length of webbing over which the elongation was measured was 5 inches, marked on the webbing so that with the webbing specimen mounted in the test jaws, neither mark was closer than 1-1/2 inches to the clamps. The test jaws were then separated at a rate of 0.75 inch per minute, and the elongation of the webbing gauge length, as a function of applied load, was incrementally recorded at 500-pound intervals. The test jaws were momentarily stopped for each elongation measurement, which consisted of a visual reading of the gauge length from a handheld scale. These readings were recorded simultaneously with the force readings visually taken from an SR4 strain indicator. The elongation was specifically measured at the design load of the webbing. Testing continued until failure of the webbing occurred. The load-versus-elongation data are shown in Table 11 and Figure 27.

HARDWARE COMPONENT TESTS

The hardware component tests were conducted to determine the ultimate load and failure mechanism of each piece of metallic hardware in the restraint system. These tests were conducted by Pacific Scientific Company. Each type of hardware component of the two troop restraint systems was mounted in PSCo's tensile testing machine and loaded to failure. The results of these tests are summarized in Table 12.

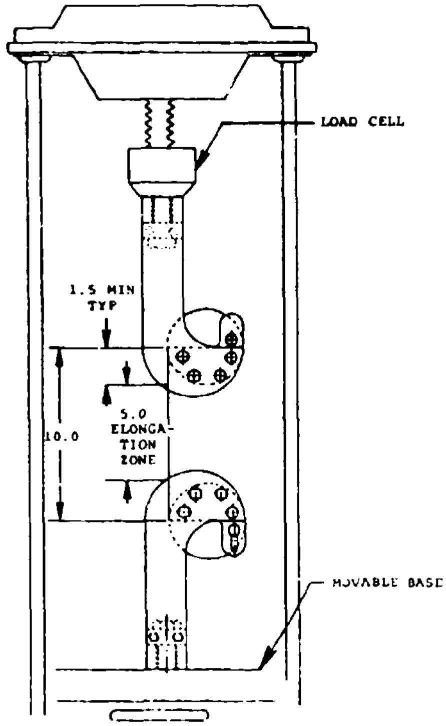


Figure 26. Webbing Test Setup.

TABLE 11. WEBBING ELONGATION DATA

Load (lb)	Elongation of 2.00-in. Wide Webbing		Elongation of 2.25-in. Wide Webbing*	
	Inch	Percent	Inch	Percent
100 Preload	5.00	0.0	5.00	0.0
500 Preload	5.08	1.6	5.03	0.6
1,000 Preload	5.15	3.0	5.08	1.6
1,500 Preload	5.25	5.0	5.19	3.8
2,000 Preload	5.35	7.0	5.28	5.6
2,500 Preload	5.45	9.0	5.32	6.4
3,000 Preload	5.50	10.0	5.37	7.4
3,500 Preload	5.55	11.0	5.42	8.4
4,000 Preload	5.60	12.0**	5.47	9.4**
4,500 Preload	5.65	13.0	5.51	10.2
5,000 Preload	5.70	14.0	5.56	11.2
5,500 Preload	5.75	15.0	5.60	12.0
6,000 Preload	5.85	17.0	5.66	13.2
6,500 Preload	5.95	19.0	5.71	14.2
7,000 Preload	Failure @ 6,664 lb		5.76	15.2
			Failure @ 7,250 lb	

*Data taken from Reference 9.
**Design Load Elongation.

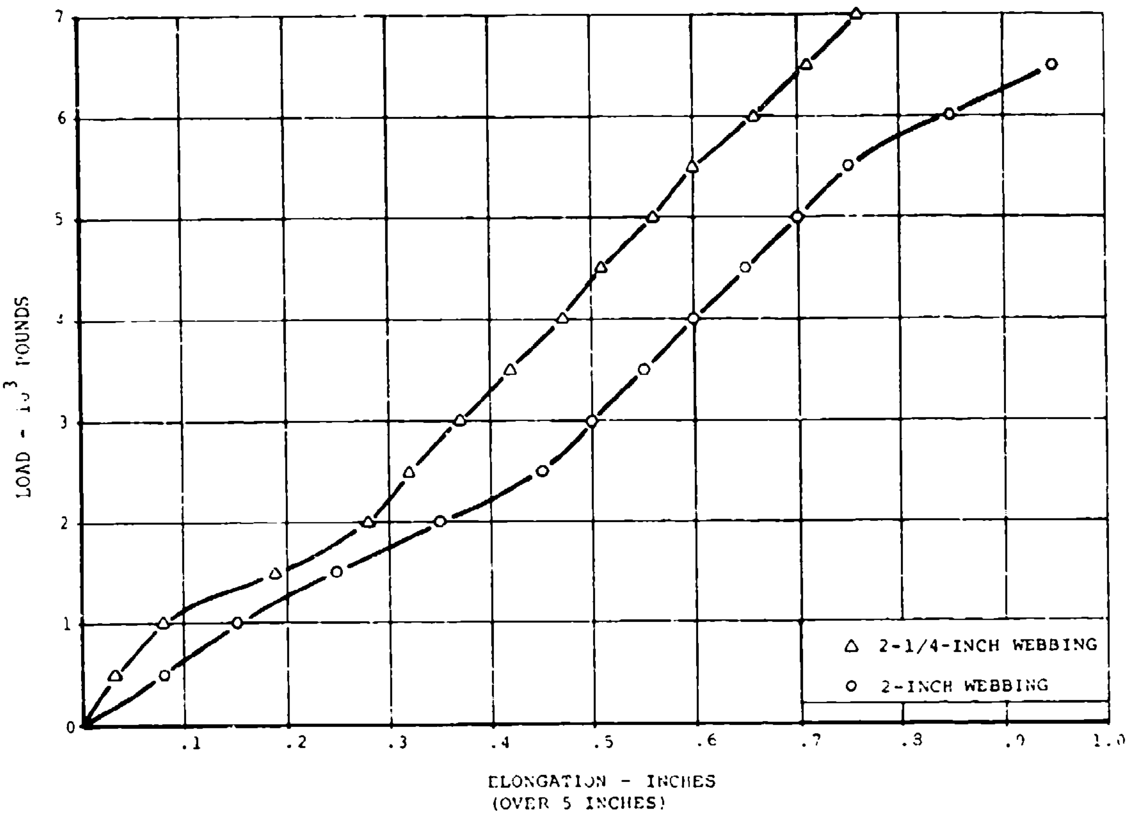


Figure 27. Webbing Load-Elongation Curves.

TABLE 12. HARDWARE TEST RESULTS

Hardware Component	Failure Load (lb)	Failure Mechanism
Inertia Reel	4300	Lacking Bar Failure
Shoulder Strap Fitting	4250	Webbing Failure
Lift-Lever Buckle (Lap Belt Attachment)	4750	Fitting Failure
Shoulder Strap Attachment	4750	Fitting Failure
Adjuster/Fitting	4300*	Webbing Failure
Lap Belt Anchor	5280	Webbing Failure

*This unit is in development stage and failure load may not be representative of a production unit.

BUCKLE RELEASE TEST

The buckle release test was performed on a Type I and Type II lift-lever buckle. The buckle and the buckle release actuator (DSL606) were mounted on the static test fixture (DSL602). The test configurations are as shown in Figures 28 and 29. The purpose of this test was to demonstrate the performance and repeatability of the buckle's quick-release mechanism. The test requirements were also established to demonstrate the fitting release performance of the buckle with residual loads in the webbing members roughly typical of those which might exist in an overturned aircraft, and the weight of the occupant would be supported entirely by the restraint system. The static test fixture was used to apply the following simulated residual loads to each of the buckle fittings, while the buckle release actuator provided the means for rotating the buckle handle, as well as measuring the torque applied to the handle and its angular rotation.

Component	Load
Lap Belt Strap	100 ±10 lb
Shoulder Harness Strap	
Type I	200 ±10 lb
Type II (Each Strap)	100 ±10 lb

To begin the test the restraint system was adjusted into place using the hydraulic cylinders, and the strap loads were then applied uniformly until the preload values were reached. The buckle release actuator was positioned to lift the buckle lever, the instrumentation was energized, and the DC motor was started. When the motor speed had stabilized at 100 rpm, the brake was released and the clutch engaged. This activated the release mechanism which lifted the buckle handle and released the fittings. After the buckle had released all the fittings, the clutch was disengaged and the brake was set. The positions of the two buckles and fittings after the test are shown in Figures 30 and 31. This procedure was repeated five times for each of the two types of restraint systems with the data recorded in Table 13. The results of the tests were used to establish the rotation angle required to release all the straps from a starting position and to determine the release angle or angles for each buckle fitting.

During each rotation of the buckle handle, a similar sequential release pattern for the fittings was observed. The shoulder strap fittings were the first to be released, and the separation

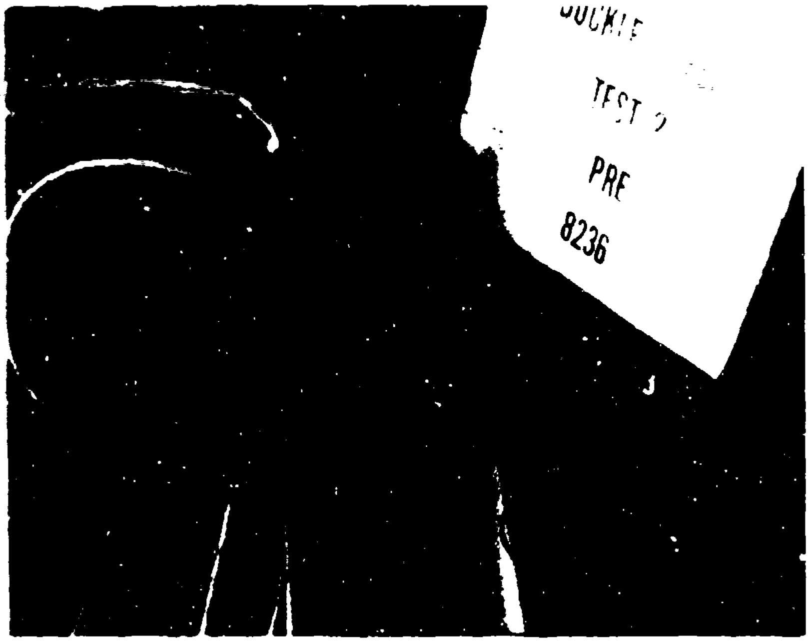


Figure 28. Type I Buckle Release Test Configuration.

Figure 29. Type II Buckle Release Test Configuration.

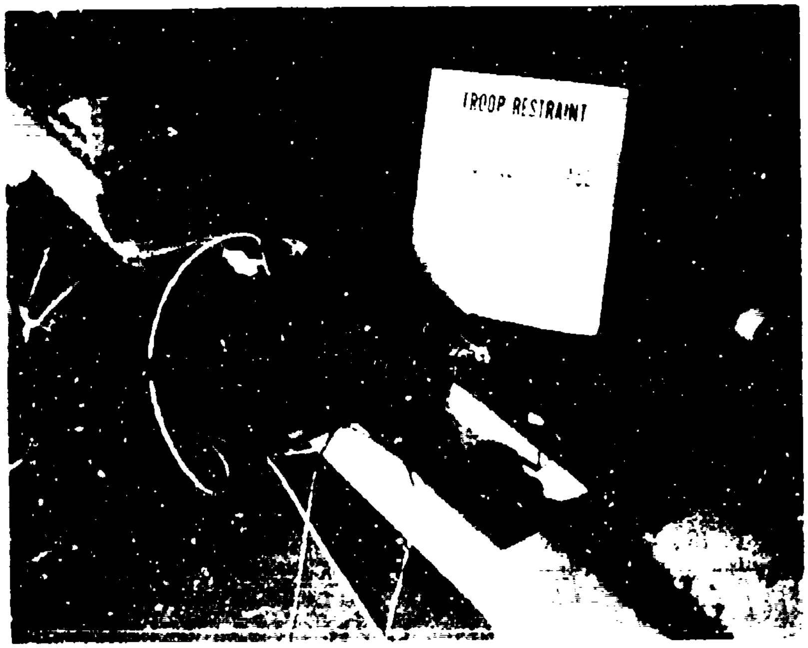


Figure 30. Type I Buckle Release Posttest Configuration.

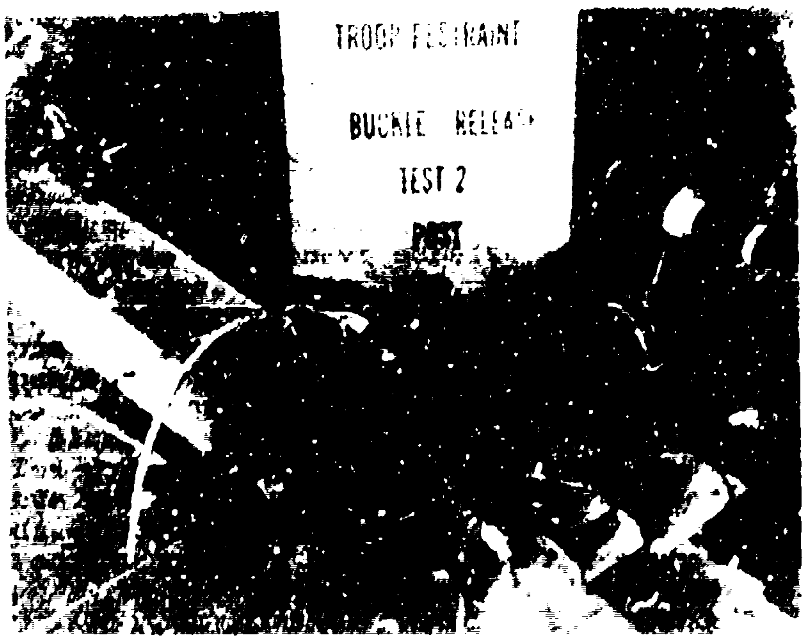


Figure 31. Type II Buckle Release Posttest Configuration.

TABLE 13. BUCKLE TEST DATA						
Type IA Shoulder Harness System						
Test No.	Release Angle (deg)		Lift-Lever Release Torque		Ejection of Fittings	Simultaneous Release
	(SH)	(Lap)	In.-oz	In.-lb	(Yes or No)	(Yes or No)
1	34.7	48.6	328.0	20.5	Yes	No
2	37.0	51.9	243.0	15.2	Yes	No
3	34.7	50.9	243.0	15.2	Yes	No
4	34.7	50.9	250.0	15.6	Yes	No
5	34.7	50.0	275.0	17.2	Yes	No
Type IIA Shoulder Harness System						
1	37.0	49.6	400.0	25.0	Yes	No
2	37.0	49.0	343.7	21.5	Yes	No
3	37.0	50.0	393.8	24.6	Yes	No
4	37.0	50.0	350.0	21.9	Yes	No
5	39.3	50.0	393.8	24.6	Yes	No

from the buckle of both fittings in the Type II system was essentially simultaneous. Next, after additional handle rotation, the lap belt fitting was released from the buckle. This resulted in two distinct release events for each actuation of the buckle: one for the shoulder strap fitting or fittings, and one for the lap belt fitting. However, this was not considered to be detrimental to the operation of the buckle since tests of a similar type buckle[9] revealed that the sequential release was primarily caused by the technique used to test the buckle. If the buckle was free to move as it would during actual usage, it was physically impossible not to release all fittings simultaneously. Therefore, based on the average difference between the release events from all tests, the maximum difference in handle rotation between release of the first and last fitting was set at 15 degrees.

BUCKLE FITTING EJECTION TEST

Each buckle (Type I and Type II) was mounted on the static test fixture (DSL602) with all fittings fully engaged and no load (including that which might be applied by the weight of the webbing) applied to them.

The buckle handle was then manually lifted. After each actuation of the buckle's handle, the fittings were visually inspected, and in both cases all the buckle fittings were released from the latch dog.

SHOULDER STRAP TEST

The purpose of the shoulder strap test was to demonstrate the integrity of the inertia reel, measure its failure load, and determine the elongation of the assembly at the design load.

This test was conducted on the static test fixture (DSL602) as shown in Figure 32. The inertia reel was mounted to the angle (DSL602-11) with the shoulder strap adjusted to an initial length of 31.0 inches, and the fitting was attached to the angle (DSL602-11) across the fixture. The inertia reel was then manually locked by depressing the lock bar. Next, an initial preload of 100 pounds was applied to the assembly by the hydraulic cylinder, and elongation indicators were attached next to the buckle fitting and the inertia reel. The actual elongation of the shoulder strap assembly was determined by subtracting the length pulled off the inertia reel from the total elongation measured.

During the first test the inertia reel failed at a load of 3,419 pounds when the retaining tabs that attached the outside axle of the spool to the ratchet wheels sheared off. This was a test failure for the inertia reel, which was supposed to have an ultimate strength of 4,000 pounds. After examining the broken hardware it was decided to use 4130 steel instead of mild steel for the spool's outside axle and to try improving the "staking" of the axles' tabs to the ratchet wheels.

This design change was incorporated, and a second shoulder strap test was conducted with the reworked inertia reel. This time the inertia reel failed at 3,500 pounds when the lock bar tabs were sheared off by the ratchet wheels on the spool of the inertia reel. The probable cause of this failure was thought to be the yield strength of the material being out of specification. Therefore, the inertia reel was rebuilt with a new lock bar made from a different lot of material. This unit was then successfully tested, and the data from this test are presented in Table 14. The inertia reel failed at 4,100

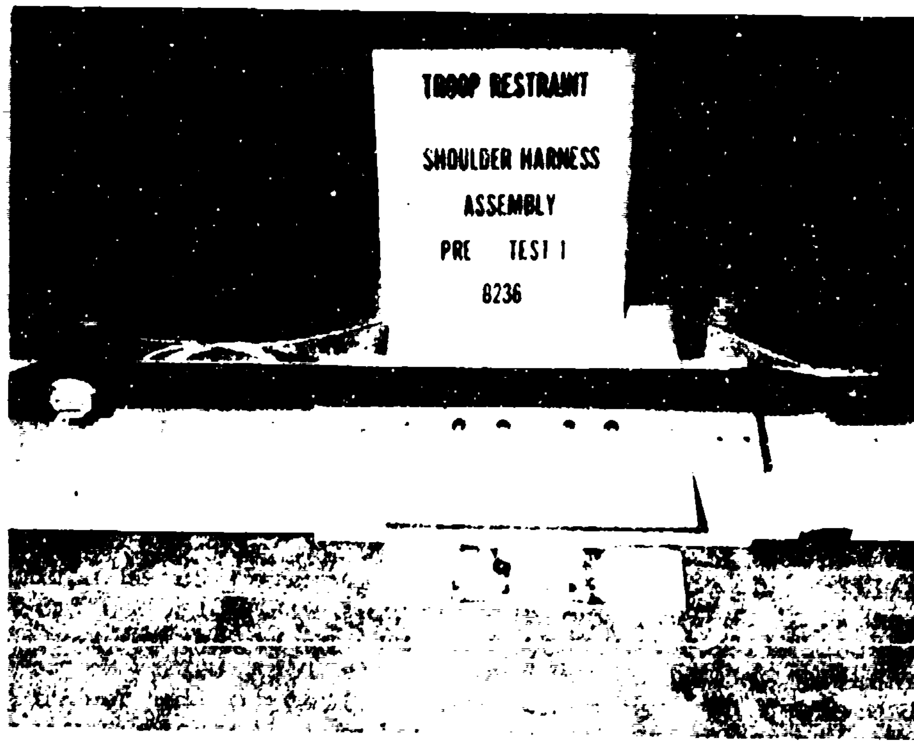


Figure 32. Shoulder Strap Test Configuration.

TABLE 14. SHOULDER STRAP TEST DATA

Shoulder Harness Load (lb)	Total Elongation (in.)	Inertia Reel Slippage (in.)	Actual Elongation (in.)
100 Preload	0.	0.	0.
500 Preload	0.55	0.35	0.20
1,000 Preload	1.17	0.70	0.47
1,500 Preload	1.99	0.95	1.04
2,000 Preload	2.74	1.33	1.41
2,500 Preload	3.45	1.53	1.92
3,000 Preload	4.34	1.95	2.39
3,500 Preload	5.15	2.40	2.75
4,000 Preload	5.75	2.82	2.93
Failure @ 4,100 pounds			

pounds by shearing a tooth off of the lock bar, and the elongation of the assembly at 4,000 pounds was 2.93 inches. The final results of the shoulder strap test, illustrating the failures that occurred, are shown in Figure 33.

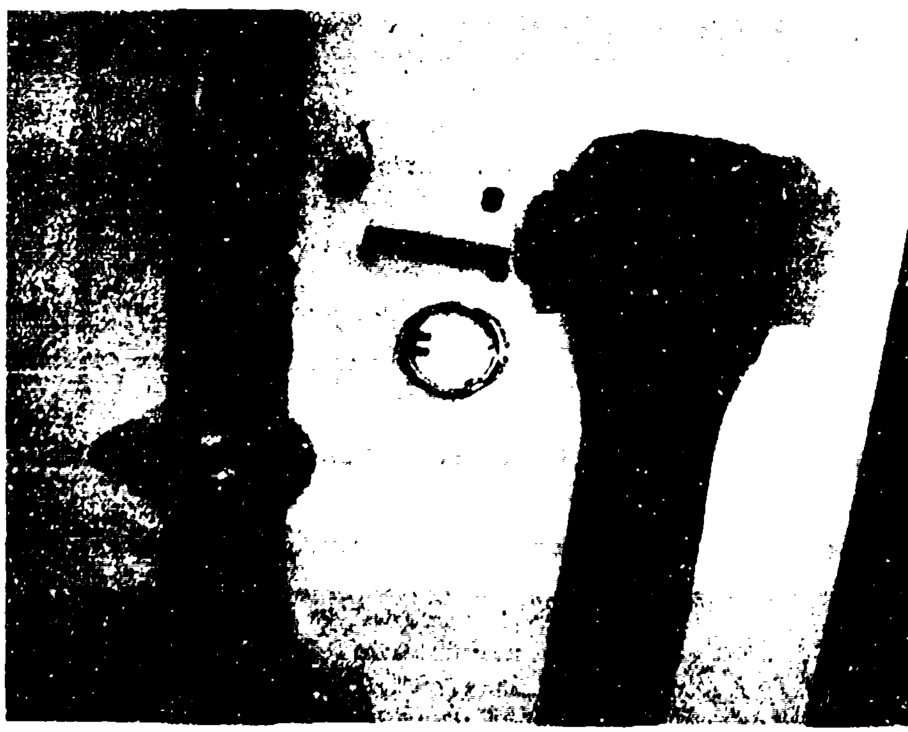


Figure 33. Shoulder Strap Test Results.

LAP BELT ASSEMBLY TEST

The purpose of the lap belt assembly test was to demonstrate the ability of the lap belt webbing, adjusters, end fittings, and buckle to withstand, as an assembly, the design load of 4,000 pounds. The webbing's elongation and adjuster slippage were also measured as part of this test.

The tests used the static test fixture (DSL602) with the Type I and Type II lap belt assemblies mounted and adjusted as shown in Figures 34 and 35. A preload of 100 pounds was then applied, and elongation reference points were marked on the webbing so that they could be compared to the scales located on the test fixture. Reference points were also fixed to the adjuster frames to indicate adjuster slippage. The actual

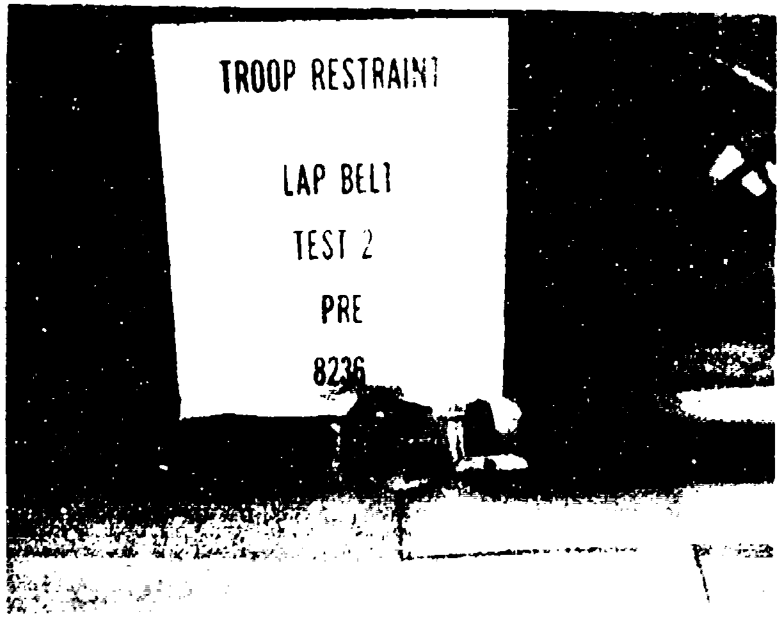


Figure 34. Type I Lap Belt Assembly - Pretest.

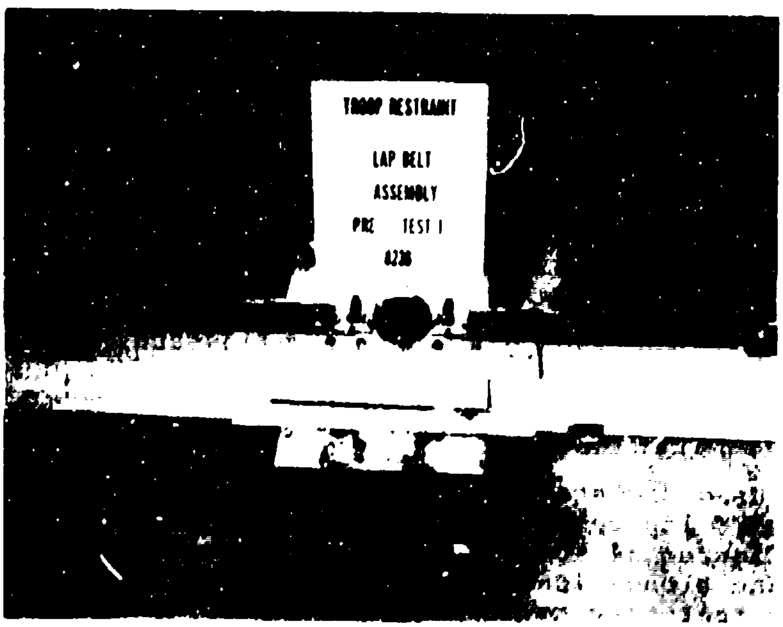


Figure 35. Type II Lap Belt Assembly - Pretest.

elongation of the lap belt assembly was equal to the total elongation minus the adjuster slippage. The loading was continued by pulling with the hydraulic cylinders at an average rate of 2 inches per minute, and as the belt assembly was loaded, the total elongation and adjuster slippage were measured until failure occurred. The elongation and adjuster slippage were measured and recorded at 500-pound intervals.

The lap belt assembly from a Type II restraint system was the first to be subjected to the lap belt assembly test. When the lap belt load reached 2,500 pounds, there was excessive webbing slippage (approximately 2 inches) through the releasable adjuster/fitting. This constituted a test failure of the adjuster, which was designed to carry 4,000 pounds. The cause of the adjuster slippage was thought to be too smooth a surface on the locking bar due to the protective plating, and it was decided to increase the roughness of the locking bar's surface by sandblasting it.

This modification was made, and the Type I lap belt assembly test was successfully completed. The load-elongation data from this test are presented in Table 15. The assembly held the design load of 4,000 pounds, but failed at 4,300 pounds when the releasable fitting fractured and permitted the lap belt to separate from the buckle. The results of this test are shown in Figure 36.

TABLE 15. TYPE I LAP BELT ASSEMBLY TEST DATA

Lap Belt Load (lb)	Total Elongation (in.)	Adjuster Slippage (in.)	Actual Elongation (in.)
100 Preload	0.	0.	0.
500 Preload	0.36	0.05	0.31
1,000 Preload	0.73	0.10	0.63
1,500 Preload	1.30	0.17	1.13
2,000 Preload	1.92	0.23	1.69
2,500 Preload	2.31	0.26	2.05
3,000 Preload	2.80	0.35	2.45
3,500 Preload	3.29	0.43	2.86
4,000 Preload	3.78	0.52	3.23
Failure @ 4,300 pounds			

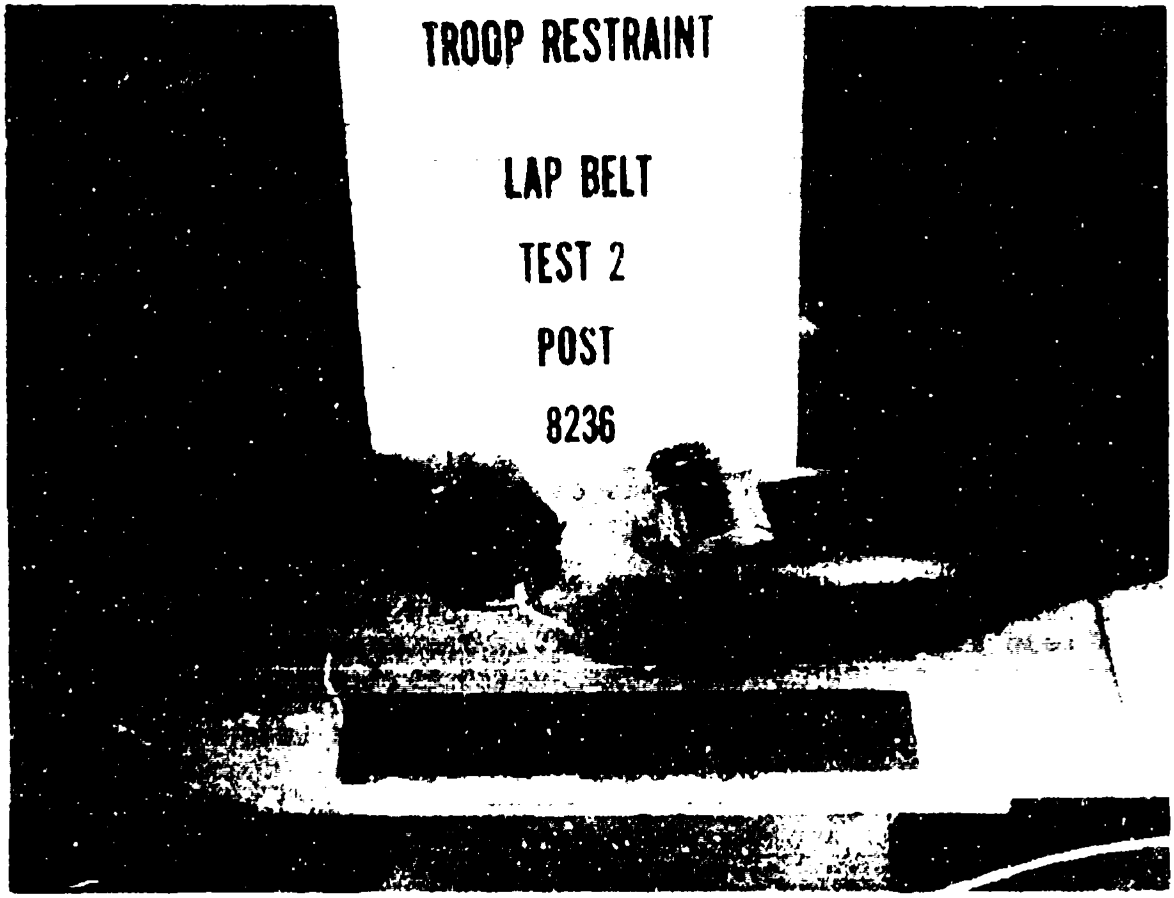


Figure 36. Type I Lap Belt Assembly - Posttest.

Next the Type II lap belt assembly test was conducted, but a premature failure occurred at 3,900 pounds when the retaining tabs on the fitting dog sheared off and the lap belt was released from the buckle. This lap belt assembly was then returned to Pacific Scientific Company for repair.

The reworked units were subsequently tested, and a premature failure occurred at 3,750 pounds when excessive slippage occurred in the adjuster. The adjuster's design was the same as that used for the Type I lap belt that successfully passed the lap belt assembly test, which indicates that the adjuster design was somewhat marginal. In addition to failure of the lap belt strength test, the adjustability of the adjuster was unacceptable. The lap belt could only be lengthened or shortened with great difficulty, and it was evident that the adjuster would not pass the adjuster load test. These two problems with the adjuster, load-carrying capability and adjustability, were discussed with Pacific Scientific Company. It was decided that PSCo would rework the adjuster again in an attempt to make it comply with the specification, and a Type II buckle with the adjusters was returned to them for design modifications.

The adjusters and buckle were reworked and tested by PSCo and returned to Dynamic Science. In the tests conducted by PSCo the adjusters held a 4,100-pound load. However, to enable the adjuster to hold this high load without slipping, the surfaces which come in contact with the webbing (loading clip and cam) were sandblasted to increase roughness and thus holding capability. While this process enhanced the holding capability of the adjuster, it degraded the adjustability characteristic and made it extremely difficult either to adjust or to readjust the adjuster.

Since the nonadjustability of the adjuster was a serious problem, Dynamic Science reinvestigated the adjuster's design in an effort to determine how to improve ease of adjustment; some modifications were developed. These initial changes consisted of moving the loading clip back 0.050 inch and putting a flat on the back side of the cam. The modifications resulted in a better reaving arrangement for the webbing and an improvement in the adjustability of the adjuster.

The modified adjuster was tested for holding strength, with disappointing results. The adjuster failed at 3,900 pounds (design load - 4,000 pounds) by tearing the webbing approximately 5/8 inch at the locking cam. Since this was only a small webbing failure, a new section of webbing was installed in the adjuster and it was tested again. This time the webbing failed at the locking cam at a load of 3,600 pounds. The webbing was torn across its width 2-1/8 inches (the webbing width is 2-1/4 inches) and the adjuster frame was bent out of plane from the applied load.

This modification and test was the final iteration of hardware rework and retest for the initial adjuster design in an attempt to develop an adjuster that met the requirements of the specification. However, Pacific Scientific Company continued on their own to develop a satisfactory adjuster and met with some success in their attempts. By changing the cross-sectional profile of the locking cam and its pivot point, PSCo was able to improve the adjustability while keeping the load-carrying capacity in excess of 4,000 pounds. New adjusters were fabricated and delivered to Dynamic Science.

Subsequently the new adjusters were tested as part of a Type II lap belt assembly, and a failure occurred at 2,700 pounds when there was excessive webbing slippage through one adjuster.

The adjuster was taken to PSCo and examined to determine the cause of the failure. Comparison of the failed adjuster with a prototype adjuster that consistently held in excess of 4,000 pounds revealed a slight variation in construction. The prototype adjuster had square corners on the opening in the frame and a knurled lateral ridge along the top of the cam's gripping surface. These features were added to the adjuster that had failed. It was retested and held 4,000 pounds. It appeared that the knurl across the gripping surface had greater effect on the load capacity of the adjuster than the squaring of the corners in the frame opening. The other adjuster in a Type II lap belt assembly was then likewise changed, and the assembly was tested to determine its load-elongation properties. These data are shown in Table 16. The assembly held 4,000 pounds for approximately 1 minute and then failed at the adjuster, as shown in Figure 37, when the webbing tore.

TABLE 16. TYPE II LAP BELT ASSEMBLY TEST DATA

Lap Belt Load (lb)	Total Elongation (in.)	Total Adjuster Slippage (in.)			Actual Elongation (in.)
		L	R	T	
100 Preload	0	0	0	0	0
500	0.43	0.08	0.07	0.15	0.28
1,000	1.02	0.15	0.10	0.25	0.77
1,500	1.68	0.18	0.17	0.35	1.33
2,000	2.15	0.24	0.24	0.48	1.67
2,500	2.59	0.27	0.29	0.56	2.03
3,000	2.93	0.32	0.33	0.65	2.28
3,500	3.30	0.38	0.37	0.75	2.55
4,000	3.53	0.47	0.47	0.94	2.59
4,500	Failure @ 4010#				
5,000					
5,500					
6,000					

Figure 37. Type II Lap Belt Assembly - Posttest.

ADJUSTER TESTS

After being tested as part of the lap belt assembly, the adjuster was also subjected to a webbing abrasion test and an adjustment load test. The purpose of the webbing abrasion test was to demonstrate that the adjuster would allow the webbing to be drawn through it, without undue wear or damage to the webbing or the adjuster. The adjuster load test was conducted to demonstrate that the force required to make a webbing adjustment did not exceed 15 pounds.

The webbing abrasion test was conducted by mounting the adjuster to a special plate installed on the functional test fixture (DSL603-55). With the adjuster attached and bolted in place on the guide channel (DSL603-11), the adjuster was positioned in the release mode. Next, the free end of the webbing was threaded through the adjuster and attached to the traveler base (DSL603-17). The webbing was than pulled down through the clearance slot in the guide channel. With the webbing's free end placed 4 inches away from the adjuster, a 2-pound weight was attached. This was the minimum weight which would pull the webbing back through the adjuster at a rate that eliminated backlash. The configuration for the webbing abrasion test is illustrated in Figure 38.

Figure 38. Adjuster Webbing Abrasion Test Configuration.

To conduct the test, the motor was energized, and after operating speed had been reached, the clutch was engaged. This caused the webbing to be pulled back and forth through the adjuster at an average rate of 20 ±2 inches per second. This operation was repeated 1,000 times in 10-cycle increments to avoid excessive heating of the webbing due to friction. A small temperature increase was noticeable after the webbing had been cycled through the adjuster ten times. To prevent this effect from influencing the test results, the adjuster and webbing were permitted to reach room temperature before the next series of ten tests was made.

No fraying of the webbing or concentrated areas of wear were observed in the webbing. However, during the return stroke of the adjustment cycle, the webbing favored one side of the adjuster, and the radius of the knurled bar caused a small deformation of the webbing that produced a noticeable curl in the webbing when it was removed from the adjuster. For comparison purposes, the test sample is shown in Figure 39 next to an untested sample. After the abrasion test was completed, the webbing strap was subjected to a 4,000-pound load. This indicated that the deterioration of the webbing due to abrasion was not sufficient to decrease its load below the design load of the lap belt.

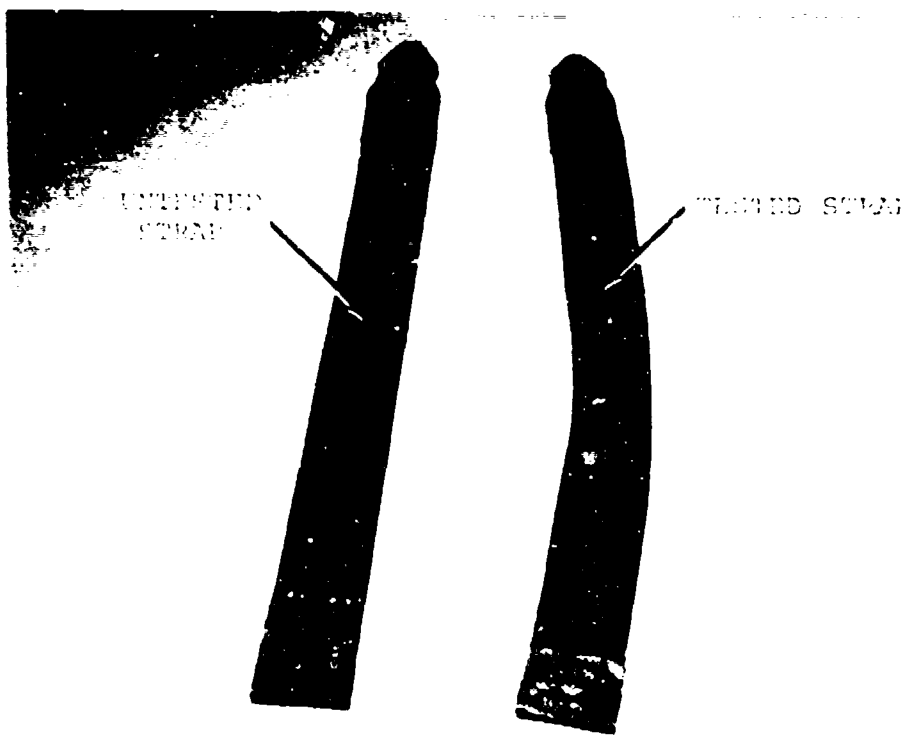


Figure 39. Adjuster Webbing Abrasion Test Results.

The adjuster load test was performed by attaching the webbing to a spring scale and measuring the adjustment and readjustment load as the adjuster was pulled away from the scale. The test configurations for both of these measurements are shown in Figures 40 and 41. This sequence was repeated five times for each loading made, and the data from this test, presented in Table 17, indicated that both the adjust and readjust loads were well below the 15-pound maximum limit. In addition, neither the adjuster nor the webbing showed any wear or damage as a result of these tests. As a result of these tests and because of the relative difficulty of readjusting the adjuster, it was recommended that the maximum adjust/readjust load be changed to 7.5 pounds in the specification.

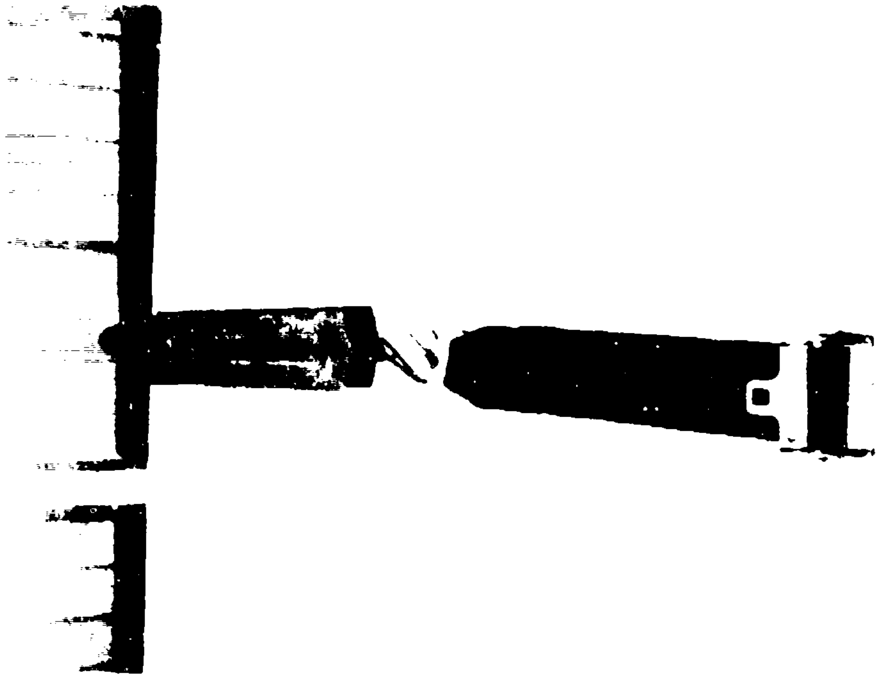


Figure 40. Adjuster Adjustment Load Test.

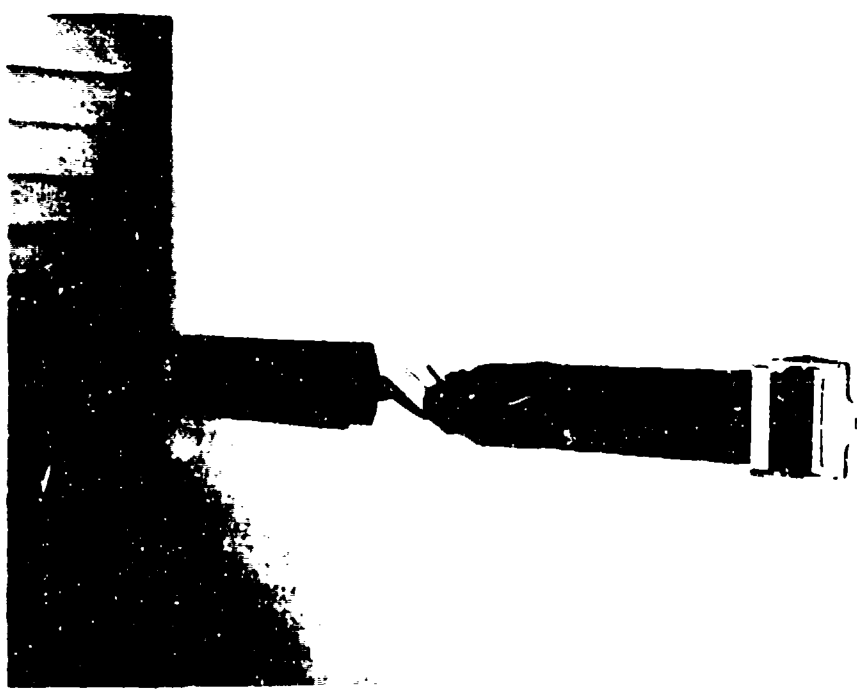


Figure 41. Adjuster Readjustment Load Test.

TABLE 17. ADJUSTER LOAD TEST DATA		
	Adjuster Resistance Load (lb)	
Test Number	Adjust	Readjust
1	1.3	6.5
2	1.0	5.5
3	1.0	5.0
4	1.0	4.0
5	1.3	4.5

ACCELERATION RESISTANCE TEST

The adjuster's locking mechanism was to have been subjected to a triangular acceleration pulse with a 45G peak and a time duration of 100 msec in the critical direction with no preload on the webbing and with no unlocking motion of the mechanism occurring during the test. However, this test could be waived if an analysis was performed showing that no unlocking could be caused by the test load. For this program, an analysis was performed, and the results, demonstrating that the adjuster will not unlock, are presented in Appendix B. The adjuster design used for this analysis was changed slightly after the analysis was completed. However, an examination of the new design indicated tnat the results of the analysis would not be affected.

DYNAMIC TESTS

Each type of troop restraint system (Type I and Type II) was subjected to the two dynamic tests required by the proposed specification in order to verify that it could adequately restrain a 95th percentile occupant during two impact environments that are representative of a 95th percentile survivable aircraft crash. One test was a vertical impact conducted on Dynamic Science's drop tower, and the other test was a horizontal impact conducted on Dynamic Science's horizontal test sled. The occupant used for these tests was a 95th percentile anthropomorphic dummy (Sierra Model 292-895) clothed with thermal underwear and equipped with a helmet, armored vest, and vest type survival kit. The armored vest was positioned on the dummy's back to simulate the equipment an Army trooper carries on his back (i.e., rucksack or field pack). The weights for the dummy and its associated equipment are given below:

Item	Weight (lb)
Anthropomorphic Dummy (95th Percentile)	202.0
Clothing (Total)	7.0
Boots	4.0
Socks	0.2
Thermal Underwear	2.8
Equipment (Total)	33.0
Helmet	3.3
Body Armor (Ballasted to simulate troop equipment)	27.7
Survival Vest	2.0
Total Occupant Weight	242.0

The dummy was restrained in a fixture type seat (rigid) with the test restraint system. Accelerometers and webbing load cells were used to measure restraint system loads and the acceleration response of various dummy segments, seat, and test input.

Before either test was started, the dummy was inspected to be sure it was in good operating condition, and its joints were adjusted to provide a 1G resistance to the movement of various limbs. Triaxial accelerometer mounts were placed in the head, chest, and pelvic area of the dummy and also on the seat pan and seat base to measure the accelerations in three orthogonal directions. The weight of the dummy was then adjusted to 202 pounds to represent a 95th percentile Army trooper.[3] A single accelerometer was mounted in the drop cage and/or sled to measure the input pulse. Webbing load cells were placed on each of the restraint system members close to their anchor points to measure the load/time history imposed on each element of the restraint system. The restraint system to be tested was mounted on the rigid test seat and connected with the dummy in the seat. All slack was then adjusted out of the restraint system.

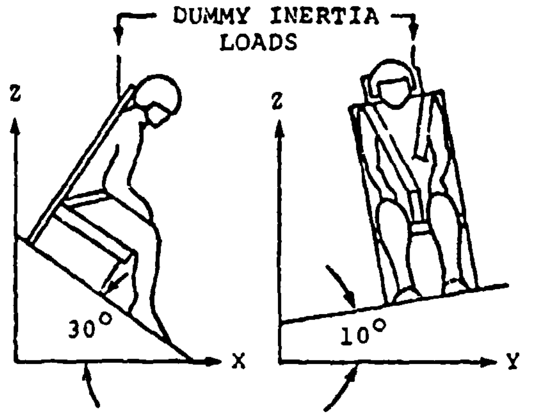
The initial conditions and input pulse specified for the two dynamic tests are shown in Table 18. For the vertical impact test, the seat containing the restrained dummy was mounted on a base that simulated the seat being positioned at a 30-degree forward pitch and a 10-degree roll relative to the input deceleration vector. The velocity change required for this test was 50 feet per second over a time duration of 0.065 second with a peak deceleration of 48G. For the horizontal impact tests, the seat containing the restrained dummy was mounted on a horizontal test sled at 0 degrees pitch and roll and a 30-degree yaw attitude relative to the input deceleration vector. The specified change in velocity for this test was 50 feet per second over a time duration of 0.103 second with a peak deceleration of 30G. The deceleration waveforms required for both tests were triangular.

The configurations of the dummy and restraint system both before and after the vertical impact of the Type I restraint system are shown in Figure 42, while before and after photos of the vertical impact of the Type II restraint system are shown in Figure 43. During each of the dynamic tests, the restraint system performed quite satisfactorily. There were no component failures; and from the final position of the dummy, it was apparent that the restraint system performed its primary function of keeping the occupant in the seat, although there was a small amount of "submarining" of the dummy under the lap belt noticed during each test. Acceleration and load data measured during the two vertical impacts are summarized in Table 19. Time response plots of the data summarized in this table are presented in Appendix C. The data presented were filtered at 250 Hz in analog form and digitally filtered at 100 Hz.

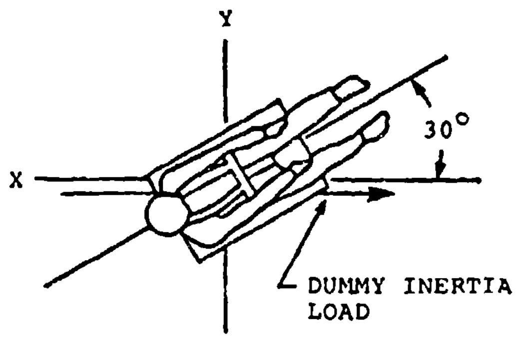
TABLE 18. DYNAMIC TEST REQUIREMENTS

TEST CONDITIONS AND SEAT ORIENTATION

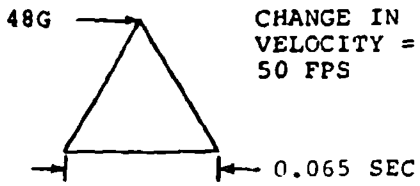
TEST 1: DOWNWARD, FORWARD, AND LATERAL LOADS



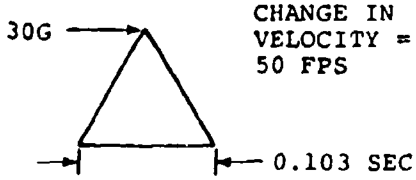
TEST 2: FORWARD AND LATERAL LOADS



TEST PULSE REQUIRED*

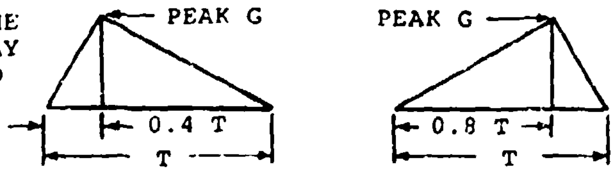


CHANGE IN VELOCITY = 50 FPS



CHANGE IN VELOCITY = 50 FPS

*THE RISE TIME FOR THE TRIANGULAR PULSES MAY VARY BETWEEN THE TWO VALUES ILLUSTRATED (T - TIME):

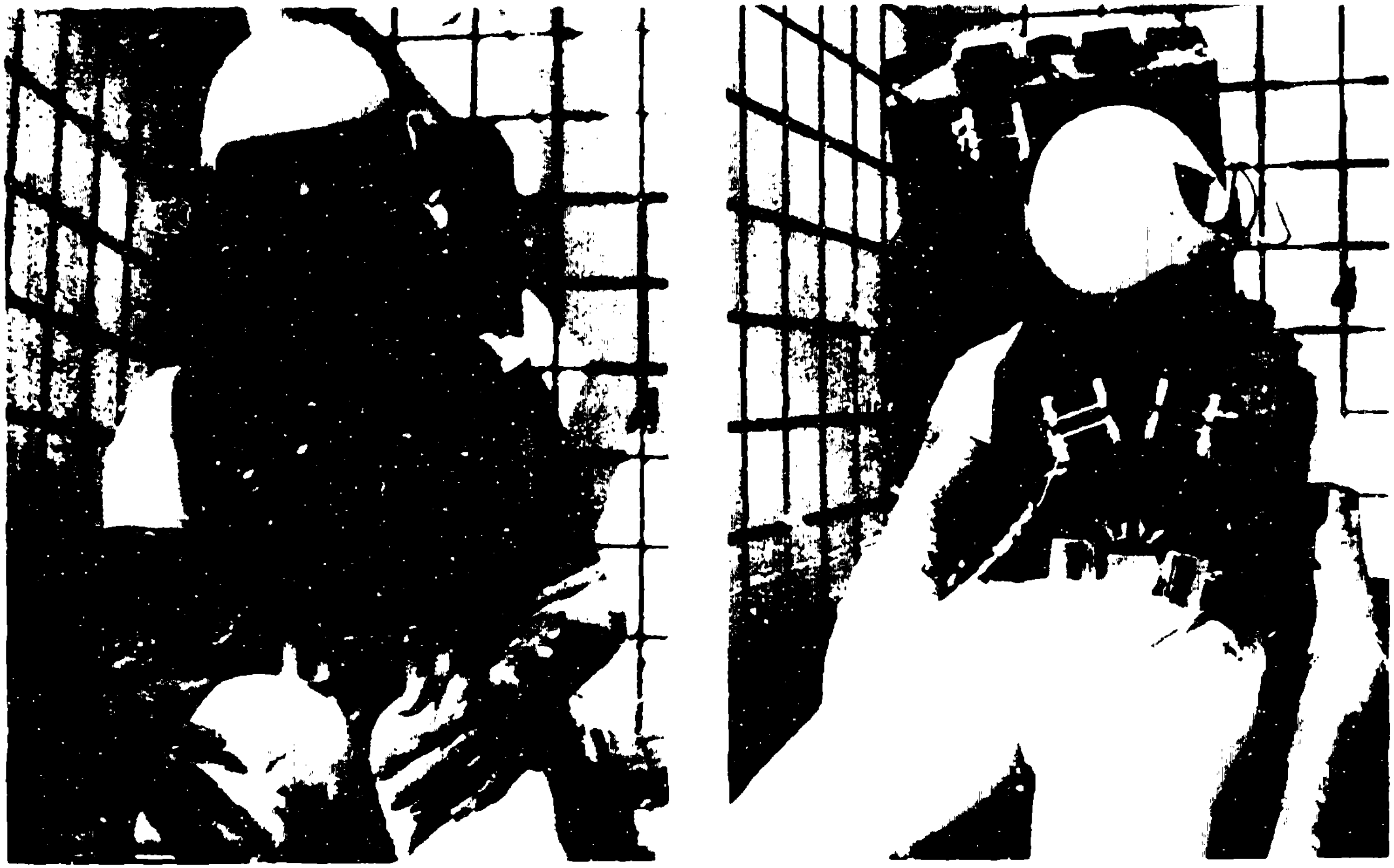


The horizontal impact tests (Test 2 of Table 8), of both types of troop restraint systems, were completed following the vertical impacts. The sled test of the Type II restraint system was conducted first; the initial and final positions of the dummy and restraint system are shown in Figure ^1. The restraint system survived the dynamic loading; however, there was noticeable "submarining" of the dummy, and his final position was partially off the rigid test seat.

Pretest Configuration

Posttest Configuration

Figure 42. Type I Restraint System - Drop Test.



Pretest Configuration　　　　Posttest Configuration

Figure 43. Type II Restraint System - Drop Test.

TABLE 19. SUMMARY OF DROP TEST DATA				
	Type I Restraint		Type II Restraint	
Transducer Location and Axis	Peak Load (G or lb)	Time (msec)	Peak Load (G or lb)	Time (msec)
Accelerometers				
Drop Cage	53.8	50	47	49
Dummy Head (X)	70.[illegible]	81	43.8	110
Dummy Head (Y)	40.2	86	23.1	112
Dummy Head (Z)	88.1	53	97.5	62
Dummy Head - Resultant	88.6	53	99.3	62
Dummy Chest (X)	37.8	50	43.5	55
Dummy Chest (Y)	30.5	56	18.9	65
Dummy Chest (Z)	142.5	53	89.4	93
Dummy Chest - Resultant	145.4	53	93.2	62
Dummy Pelvis (X)	84.5	123	59.3	108
Dummy Pelvis (Y)	23.6	74	23.8	58
Dummy Pelvis (Z)	37.7	81	49.6	25
Dummy Pelvis - Resultant	84.5	123	61.5	59
Seat Pan (X)	32.9	51	26.6	48
Seat Pan (Y)	8.5	51	13.4	32
Seat Pan (Z)	85.6	55	43.3	51
Seat Pan - Resultant	89.0	55	50.4	51
Load Cells				
Lap Belt - Left	1942	100	2607	90
Lap Belt - Right	2024	82	1297	90
Lower Shoulder Strap - Left	-	-	961	89
Upper Shoulder Strap - Left	-	-	390	83
Lower Shoulder Strap - Right	2719	71	*	-
Upper Shoulder Strap - Right	*	-	906	66
Injury Criteria				
Head Severity Index	1192	-	1092	-
Chest Severity Index	1324	-	708	-
Pelvis Severity Index	856	-	668	-

*Faulty Data Channel.

Pretest Configuration

Posttest Configuration

Figure 44. Type II Restraint System - Sled Test No. 1.

The Type I restraint system was tested immediately after the Type II system and produced a failure of the lap belt assembly which allowed the dummy to come off the seat and end up on the sled platform next to the seat. The initial and final configurations for this test are shown in Figure 45. Examination of the restraint system after the tests revealed that the short section of the lap belt webbing, permanently connecting the buckle to the anchor fitting, had failed where the webbing was attached to the buckle. The initial position of the buckle and the webbing failure are shown in Figure 46. A preliminary failure analysis indicated that the cause was either bad webbing or excessive dynamic loads. Since the webbing had a stiffened support cover made from a shrinkable tubing, a strong possibility existed that the webbing was weakened by the high temperatures needed to shrink the sleeving around the buckle load plate. There was a considerable reduction in tubing size needed for this configuration which may have required excessive heating to make a tight fit.

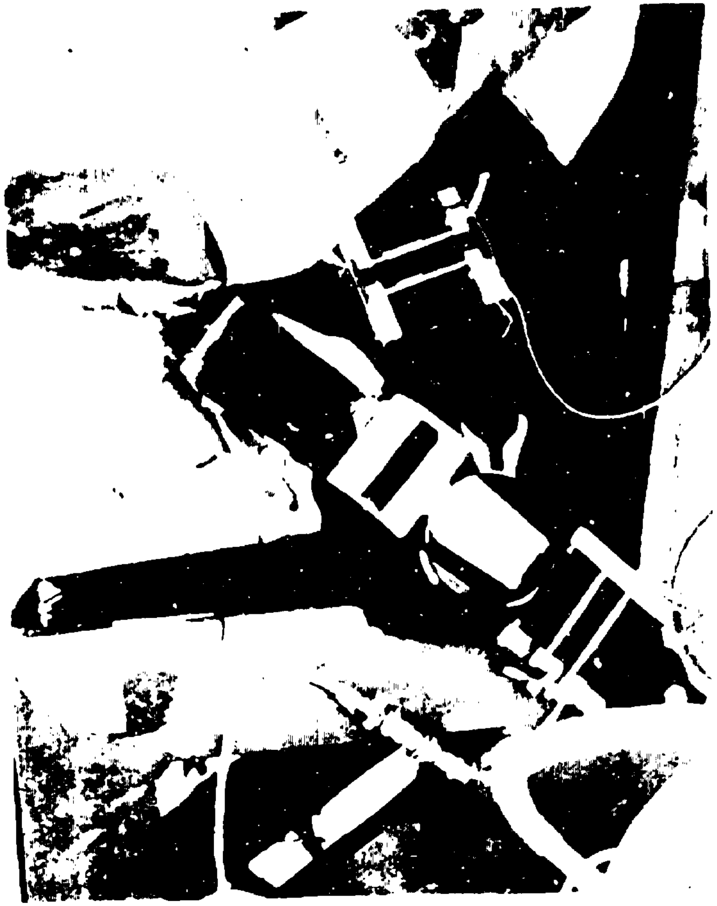
Another difficulty noticed with the Type I lap belt, once it was installed, was the position of the buckle. The extremely short section of the lap belt produced an undesirable entry angle at the buckle for the shoulder strap fitting which may have caused the short lap belt section to see an excessively high dynamic load.

Based on these observations, it was decided to modify the Type I lap belt design, eliminating the shrinkable sleeving and increasing the length of the short lap belt an additional 4 inches. This new configuration is shown in Figure 47. These design changes were incorporated, and the horizontal impact test of the Type I restraint system was again conducted. The results of the test initially appeared quite satisfactory in that no hardware failure occurred and the final position of the dummy was not objectionable. Figure 48 illustrates the configuration of the dummy and restraint system before and after this test. Unfortunately, when the acceleration data were examined, it was discovered that the input pulse reached a peak of only 23G instead of 30G. This was too low a value to consider the test a success, and the restraint system was tested again the following day. For this test the input velocity was increased slightly and the peak deceleration reached 30G. The restraint system survived this test; and although the dislocation of the dummy was severe, and included extreme "submarining," his final position was still on the seat. The positions of the restraint system and dummy before and after this final test of the Type I restraint system are shown in Figure 49.

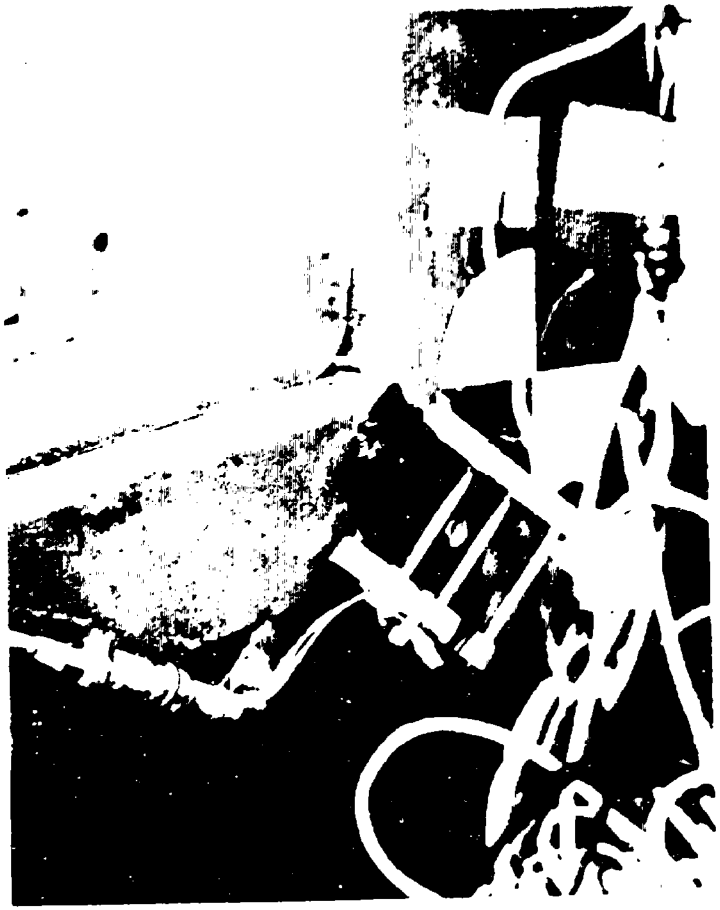
Pretest Configuration

Posttest Configuration

Figure 45. Type I Troop Restraint - Sled Test No. 1.



Pretest Configuration



Posttest Configuration

Figure 46. Buckle Configuration - Type I Restraint System - Sled Test No. 1.

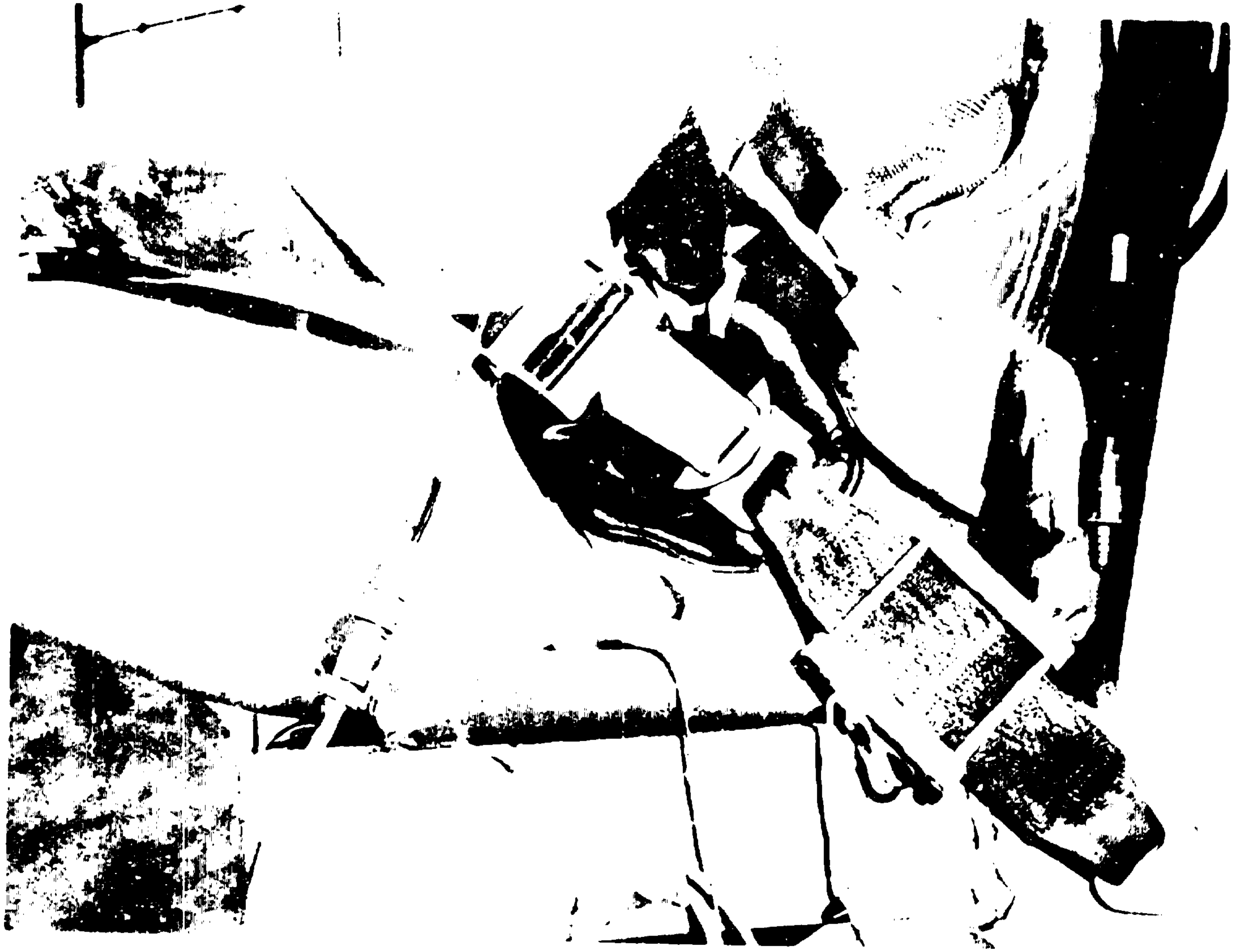


Figure 47. Revised Type I Lap Belt.

Pretest Configuration

Posttest Configuration

Figure 48. Type I Troop Restraint - Sled Test No. 2.

Pretest Configuration

Posttest Configuration

Figure 49. Type I Troop Restraint - Sled Test No. 3.

A summary of the decelerations and restraint system loads measured during the successful horizontal impacts of the Type I and Type II troop restraint systems is presented in Table 20. The peak loads and decelerations and the time after impact that each occurred are presented. Time response plots of the data summarized in this table are shown in Appendix C. The data shown were filtered at 250 Hz in analog form and digitally filtered at 100 Hz.

TABLE 20. SUMMARY OF SLED TEST DATA

Transducer Location and Axis	Type I Restraint		Type II Restraint	
	Peak Load (G or lb)	Time (msec)	Peak Load (G or lb)	Time (msec)
Accelerometers				
Sled	33.7	84	30.0	86
Dummy Head (X)	116.0	183	98.4	120
Dummy Head (Y)	60.0	182	60.3	116
Dummy Head (Z)	87.6	92	82.1	105
Dummy Head - Resultant	130.0	183	110.1	119
Dummy Chest (X)	*	-	36.3	86
Dummy Chest (Y)	35.5	109	32.2	120
Dummy Chest (Z)	45.3	74	43.3	185
Dummy Chest - Resultant	*	-	51.6	185
Dummy Pelvis (X)	26.4	106	28.5	122
Dummy Pelvis (Y)	23.5	69	31.0	109
Dummy Pelvis (Z)	25.1	123	24.6	99
Dummy Pelvis - Resultant	37.2	117	37.7	109
Seat Pan (X)	29.2	83	28.6	83
Seat Pan (Y)	18.4	9[illegible]	17.7	82
Seat Pan (Z)	1**	-	1**	-
Seat Pan - Resultant	34.6	81	33.6	83
Load Cells				
Lap Belt - Left	3152	108	*	-
Lap Belt - Right	*	-	1626	94
Lower Shoulder Strap - Left	-	-	504	97
Upper Shoulder Strap - Left	-	-	1092	99
Lower Shoulder Strap - Right	2561	103	1257	101
Lower Shoulder Strap - Right	2718	103	2819	103
Injury Criteria				
Head Severity Index	3870	-	2794	-
Chest Severity Index	*	-	406	-
Pelvis Severity Index	273	-	257	-

*Faulty Data Channel
**Average Deceleration

CONCLUSIONS AND RECOMMENDATIONS

One of the conclusions that evolved from this program is that injuries and fatalities can be reduced in potentially survivable accidents involving future Army aircraft if such aircraft are equipped with restraint systems meeting the requirements of the draft proposed specification. In addition, the lower loads measured on the Type II restraint system during the dynamic tests indicate that the Type II system should be safer than the Type I system; therefore, it is recommended that the restraint system to be used if at all possible.

A comparison of the weights of the two troop restraint systems with a standard military restraint system now in use is shown in the following table, which demonstrates that either the Type I or the Type II troop restraint system would be an improvement over the standard double-shoulder-strap military system.

SYSTEM WEIGHT COMPARISON
(POUNDS)

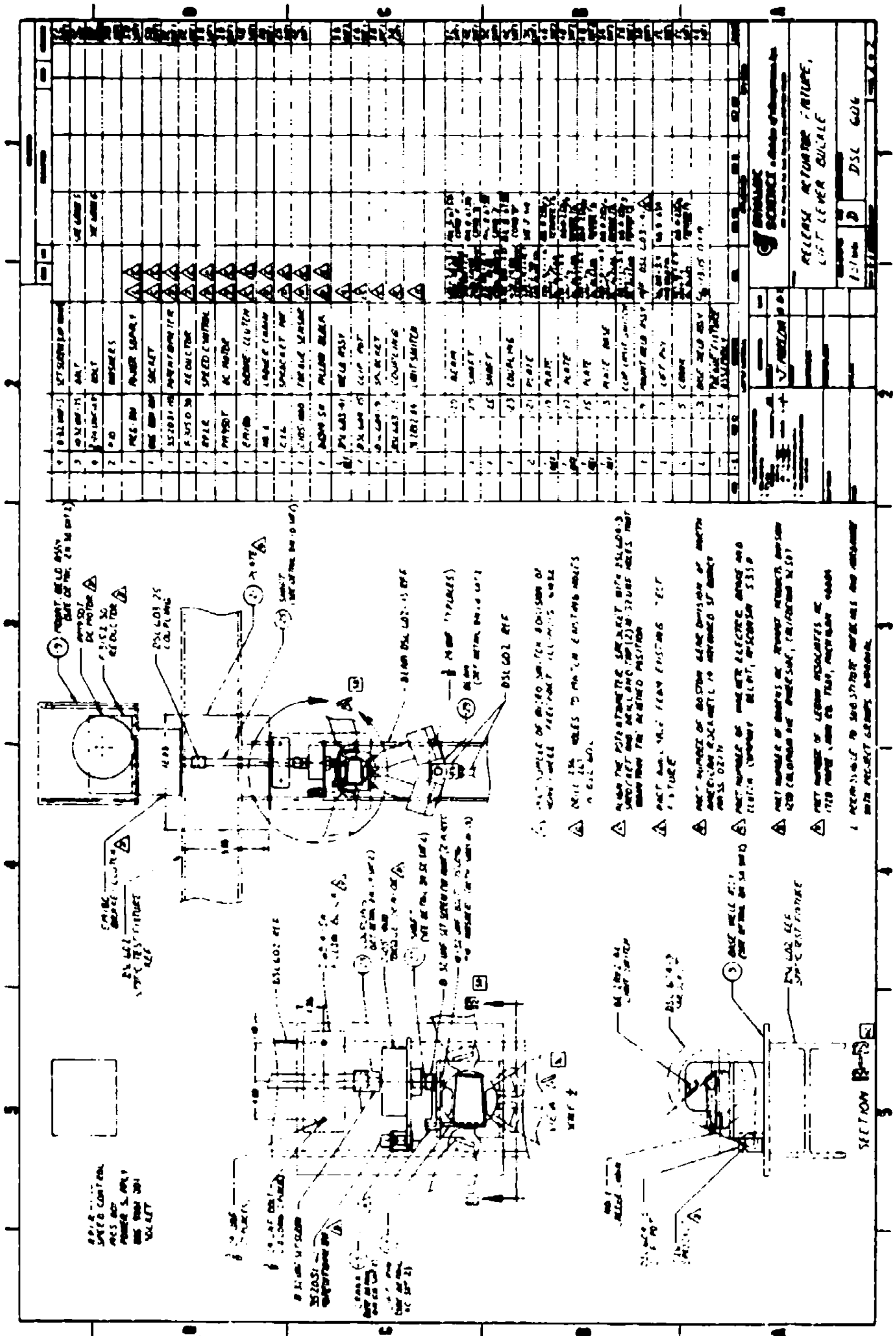
Component	New Type I System	New Type II System	Standard System (2 Shoulder Straps)
Lap Belt Assembly (includes buckle)	1.53	1.81	2.06*
Shoulder Strap Assembly (includes inertia reel)	1.08	2.16	2.16
Total System Weight	2.61	3.97	4.22

*MS22033

The revised draft specification and the final restraint system designs were demonstrated to be practical since the restraint systems were fabricated within the current manufacturing state of the art. The newer advanced troop restraint systems show a favorable decrease of weight over comparable existing systems and can increase the capability to provide adequate protection to Army aircraft passengers. The new inventory of Army aircraft including the Utility Tactical Transport Aircraft System (UTTAS) is currently being procured. It is recommended that the new troop restraint systems developed under this program be incorporated into the UTTAS at the production stage and into all existing aircraft as soon as economics permit.

APPENDIX A

TEST FIXTURE DRAWING

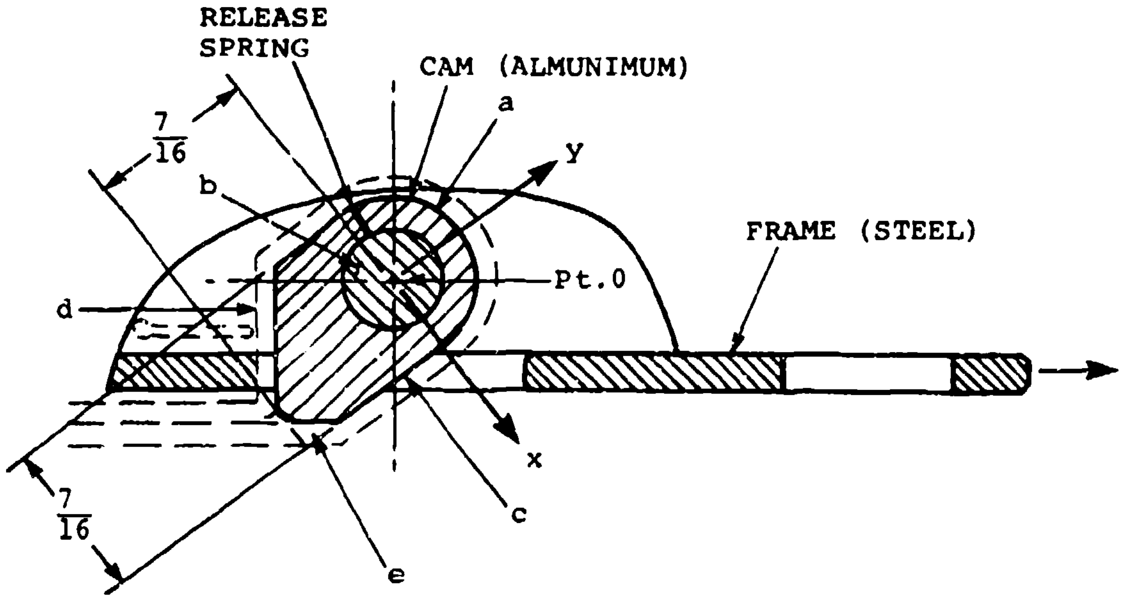


APPENDIX B

ACCELERATION RESISTANCE ANALYSIS OF ADJUSTER

The objective of this analysis is to show that the adjuster's cam will not release when the adjuster is subjected to an acceleration of 45G. For this analysis it is assumed that there is no tension load in the webbing. (This is a conservative assumption.)

The geometry of the adjuster is shown below.

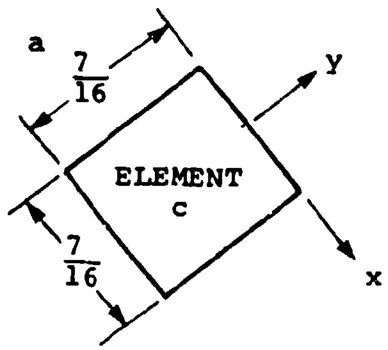


The analysis will illustrate that an acceleration of 45G applied in the x direction will not cause the cam to rotate against the minimum restraining torque of the release spring, which has been measured at 0.781 in.-lb.

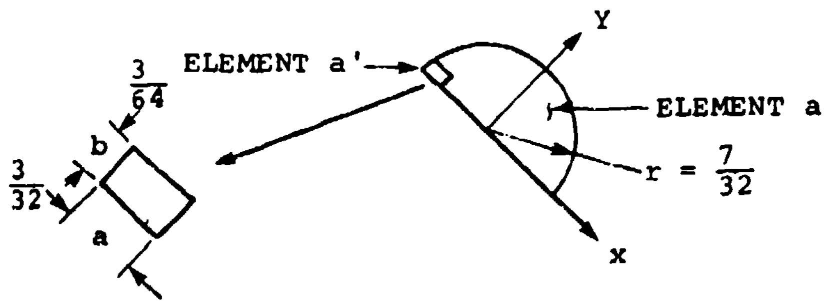
The mass moment of inertia of the cam is

$$I_{cam} = I_a + I_c - I_b - I_d - I_e$$

where I_c is the mass moment of element c



and I_a is the mass moment of element a.



Calculate I_a:

$$I_a + I_{a'} = \frac{1}{2}\,Ma\;r^2$$

where $\quad M_a = \pi\,\frac{r^2}{2}\,\ell \times \rho$

$\ell = 2.25$ in.

$\rho = 0.0031$ slug/cu in.

$$\therefore\quad M_a = \frac{(3.14)(0.219)^2}{2} \times 2.25 \times 0.0031$$

$$M_a = 0.525 \times 10^{-3}\ \text{slugs}$$

now $$I_{a'} = \frac{1}{12} M_{a'} \ (a^2 + b^2) + M_{a'} d^2$$

where $$d = 7/32 - 3/64 = 11/64 = 0.172 \text{ in.}$$

and $$M_{a'} = (0.047) \times (0.094) \times 2.25 \times (0.0031)$$

$$M_{a'} = 0.308 \times 10^{-4} \text{ slugs}$$

$$I_{a'} = \frac{0.308 \times 10^{-4}}{12} [(0.047)^2 + (0.094)^2] + 0.308 \times 10^{-4} \times (0.172)^2$$

$$I_{a'} = 0.283 \times 10^{-7} + 0.911 \times 10^{-6}$$

$$I_{a'} = 0.939 \times 10^{-6}$$

now $$I_a = \frac{1}{2} M_a r^2 - I_{a'}$$

$$= \frac{0.525}{2} \times 10^{-3} \times (0.219)^2 - 0.939 \times 10^{-6}$$

$$= 0.126 \times 10^{-4} - 0.939 \times 10^{-6}$$

and $$I_a = \underline{\underline{0.117 \times 10^{-4}}} \text{ slugs - in.}^2$$

Calculate I_c:

$$I_c = \frac{M_c a^2}{6} + \frac{M_c a^2}{4}$$

where $$a = 0.438$$

$$M_c = a^2 \times \ell \times \rho$$

$$M_c = (0.438)^2 \times 2.25 \times (0.0031)$$

$$M_c = 0.134 \times 10^{-2} \text{ slugs}$$

now $I_c = \frac{(0.134 \times 10^{-2})(4.38)^2}{6} + \frac{(0.134 \times 10^{-2})(0.438)^2}{4}$

$I_c = 0.428 \times 10^{-4} + 0.643 \times 10^{-4}$

$I_c = \underline{\underline{1.071 \times 10^{-4}}}$ slugs - in.^{2}

Calculate I_b:

$I_b = \frac{1}{2} M_b r^2$

where $r = 0.125$

$M_b = \pi r^2 \times \ell \times \rho$

$M_b = (3.14) \times (0.125)^2 \times 2.25 \times (0.0031)$

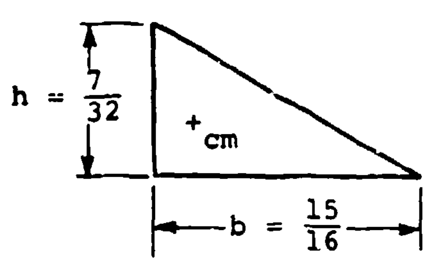
$M_b = 0.342 \times 10^{-3}$ slugs

now $I_b = \frac{(0.342 \times 10^{-3})}{2} (0.125)^2$

$I_b = \underline{\underline{0.267 \times 10^{-5}}}$ slugs - in.^{2}

Calculate I_d:

Cross-sectional Area for Element d



$$I_d = I_{dcm} + I_{dtr}$$

$$I_{dcm} = \frac{M_d}{18}(h^2 + b^2)$$

$$M_d = \frac{1}{2}\, hb \times \rho$$

$$= \frac{(0.219)(0.313)(0.0031)}{2}$$

$$M_d = 0.106 \times 10^{-3} \text{ slugs}$$

$$I_{dcm} = \frac{(0.106 \times 10^{-3})}{18}[(0.219)^2 + (0.313)^2]$$

$$I_{dcm} = 0.859 \times 10^{-6}$$

$$I_{dtr} = Mr^2$$

where $$r^2 = (0.438 - \frac{0.219}{3})^2 + \frac{(0.313)}{3}^2$$

$$r^2 = 0.144$$

$$I_{dtr} = (0.106 \times 10^{-3})(0.144)$$

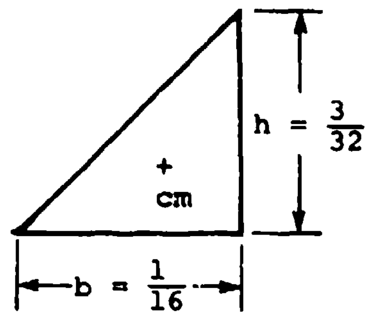
$$I_{dtr} = 0.153 \times 10^{-4}$$

$$I_d = 0.859 \times 10^{-6} + 0.153 \times 10^{-4}$$

$$I_d = \underline{\underline{0.162 \times 10^{-4}}} \text{ slugs - in.}^2$$

Calculate I_e:

Cross-sectional Area for Element e



$$I_e = I_{ecm} + I_{etr}$$

$$I_{ecm} = \frac{Me}{18}(h^2 + b^2)$$

$$M_e = \frac{1}{2} hb \times \rho$$

$$M_e = \frac{(0.094)(0.063)}{2} \times (0.0031)$$

$$M_e = 0.918 \times 10^{-5} \text{ slugs}$$

$$I_{ecm} = \frac{(0.918 \times 10^{-5})}{18} [(0.094)^2 + (0.063)^2]$$

$$I_{ecm} = 0.653 \times 10^{-8}$$

$$I_{etr} = M_e r^2$$

where $$r^2 = (0.438 - \frac{0.094)}{3}^2 + (0.218 - \frac{0.063)}{3}^2$$

$$r^2 = 0.204$$

$$I_{etr} = (0.918 \times 10^{-5})(0.204)$$

$$I_{etr} = 0.187 \times 10^{-5}$$

$$I_e = 0.653 \times 10^{-8} + 0.187 \times 10^{-5}$$

$$I_e = \underline{\underline{0.188 \times 10^{-5}}} \text{ slugs - in.}^2$$

Now $$I_{cam} = I_a + I_c - (I_b + I_d + I_e)$$

$$I_{cam} = (0.117 + 1.071) \times 10^{-4} - (0.267 + 1.62 + 0.188) \times 10^{-5}$$

$$I_{cam} = 1.188 \times 10^{-4} - 0.2075 \times 10^{-4}$$

$$I_{cam} = 0.9805 \times 10^{-4} \text{ slugs - in.}^2$$

$$M_{cam} = M_a + M_c - (M_a + M_b + M_d + M_c)$$

$$= (0.525 + 1.34) \times 10^{-3} - (0.308 + 3.42 + 1.06 + 0.0918) \times 10^{-4}$$

$$= 1.865 \times 10^{-3} - 0.488 \times 10^{-3}$$

$$M_{cam} = 1.377 \times 10^{-3} \text{ slugs}$$

Determine radius of gyration - r

$$I_{cam} = M_{cam} r^2$$

$$r^2 = I_{cam}/M_{cam}$$

$$= \frac{0.9805 \times 10^{-4}}{1.377 \times 10^{-3}}$$

$$r^2 = 0.712\ 10^{-1} = 0.0712$$

$$r = 0.267 \text{ in.}$$

The torque (T) resulting from an applied acceleration of 45G is

$$T = M_{cam} r \times 45\ (32.2)$$

$$T = 1.377 \times 10^{-3} \times (0.267) \times (1.45 \times 10^{3})$$

$$T = 0.533 \text{ in.-lb}$$

The minimum restraining torque maasured for the release spring is 0.781 in.-lb, which is greater than the cam torque of 0.533 in.-lb. Therefore, the adjuster will not release the webbing when subjected to an acceleration of 45G.

$$\text{Safety Margin} = \frac{0.781}{0.533} = 1.47$$

APPENDIX C

ACCELERATION AND FORCE/TIME HISTORIES
(Filters: 250 Hz Analog; 100 Hz Digit .1)

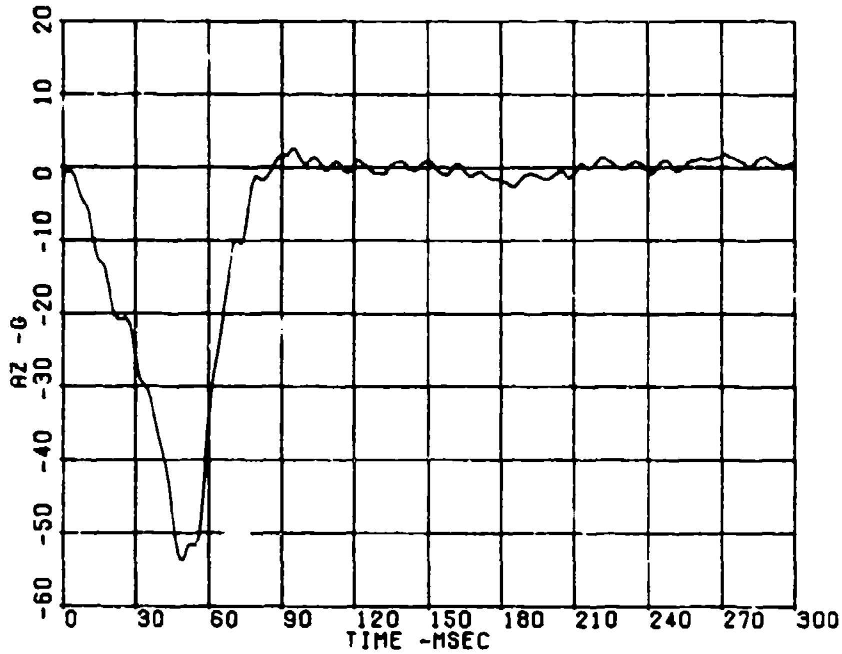


Figure C-1. Drop Test Type I Restraint - Input Acceleration.

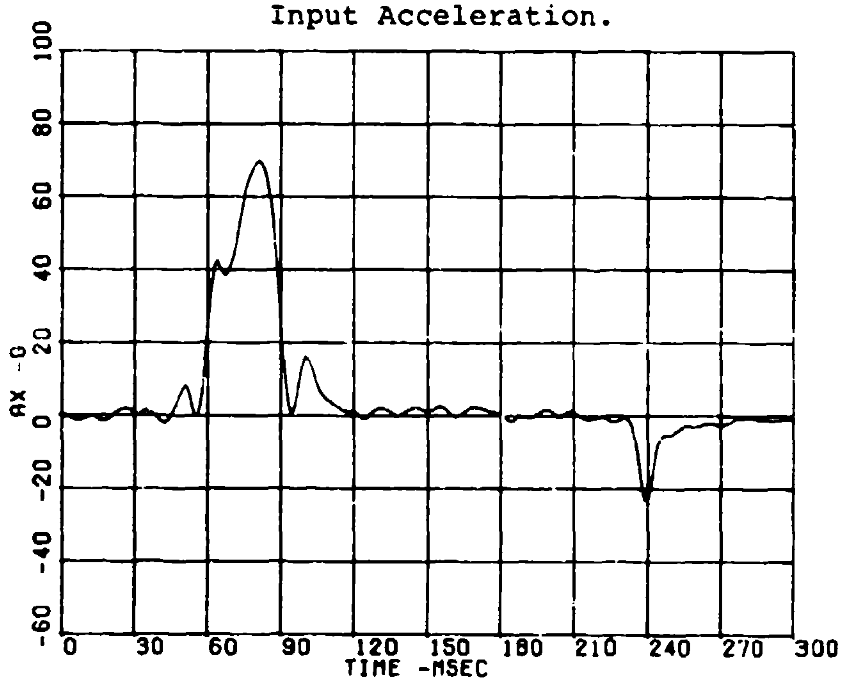


Figure C-2. Drop Test Type I Restraint - Head Acceleration - Longitudinal.

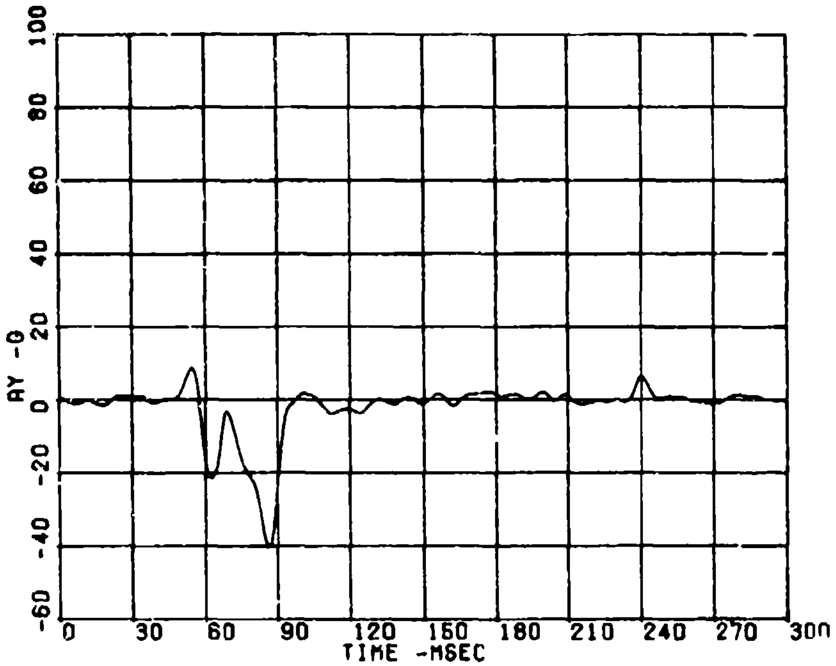


Figure C-3. Drop Test Type I Restraint - Head Acceleration - Lateral.

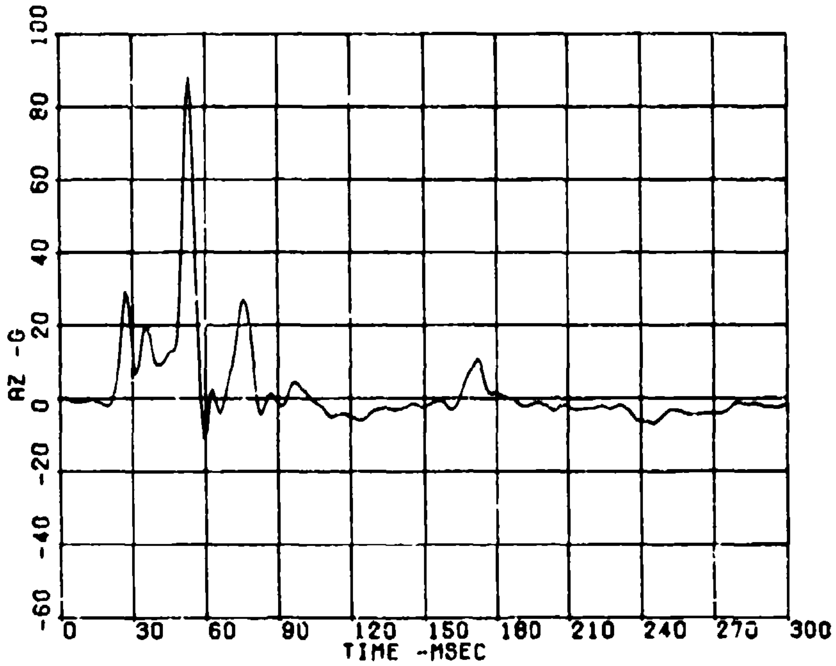


Figure C-4. Drop Test Type I Restraint -- Head Acceleration - Vertical.

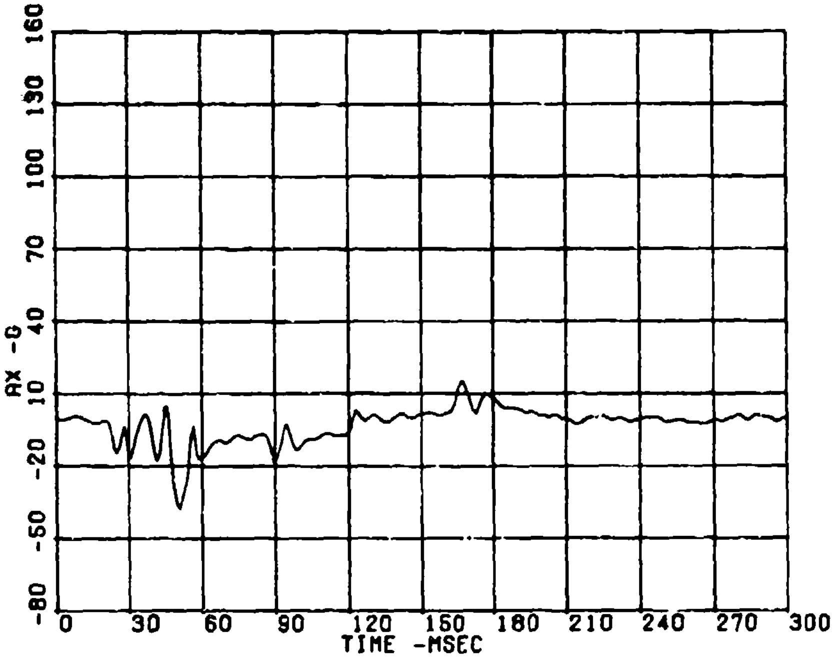


Figure C-5. Drop Test Type I Restraint - Chest Acceleration - Longitudinal.

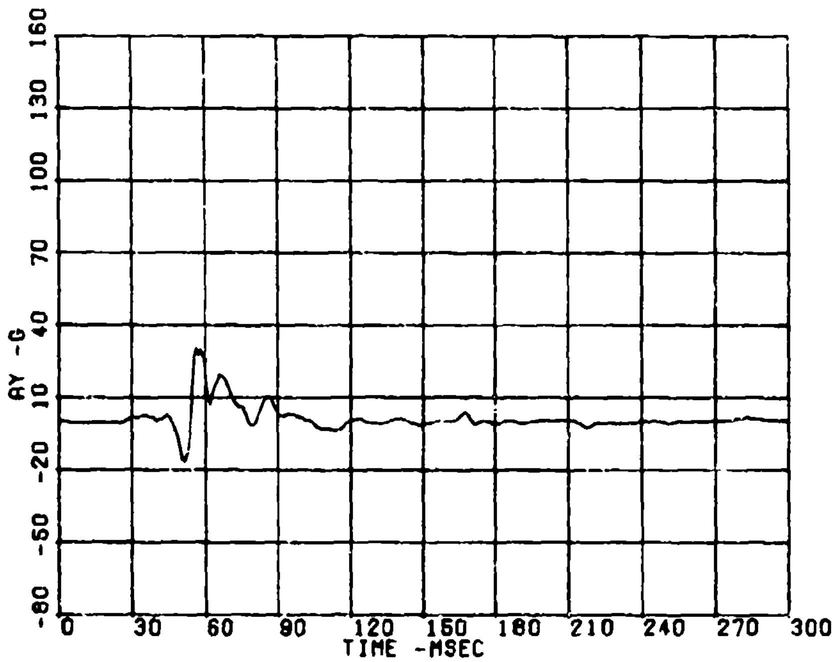


Figure C-6. Drop Test Type I Restraint - Chest Acceleration - Lateral.

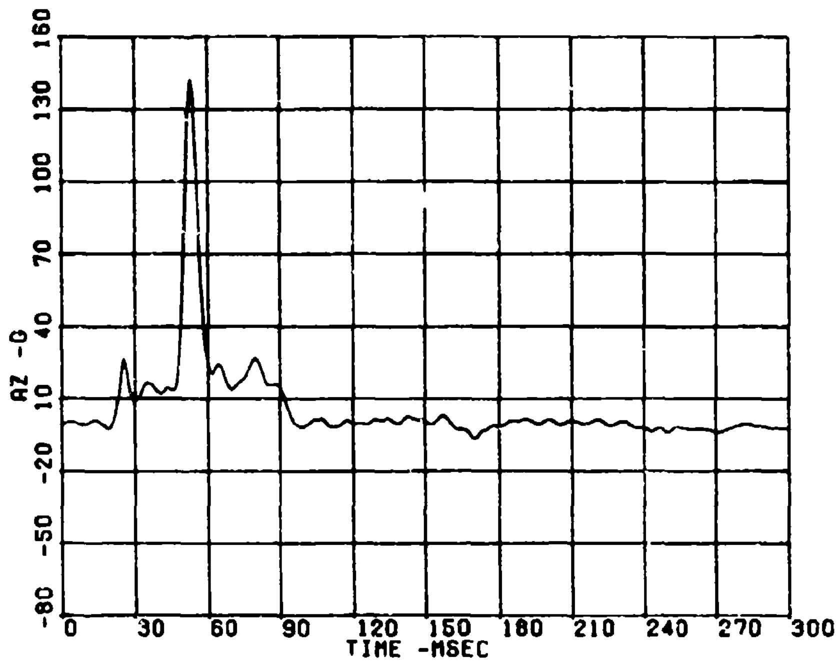


Figure C-7. Drop Test Type I Restraint -
Chest Acceleration - Vertical.

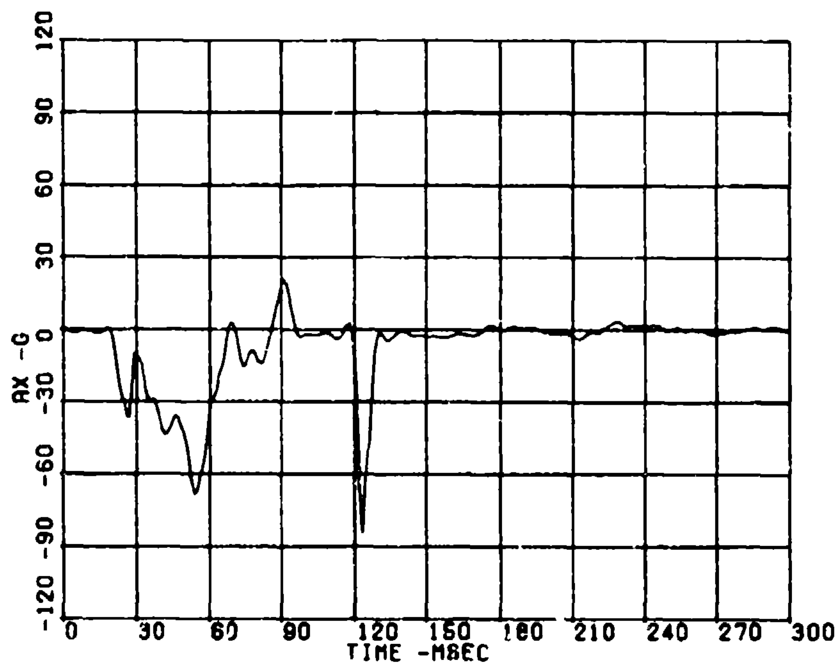


Figure C-8. Drop Test Type I Restraint -
Pelvis Acceleration - Longitudinal.

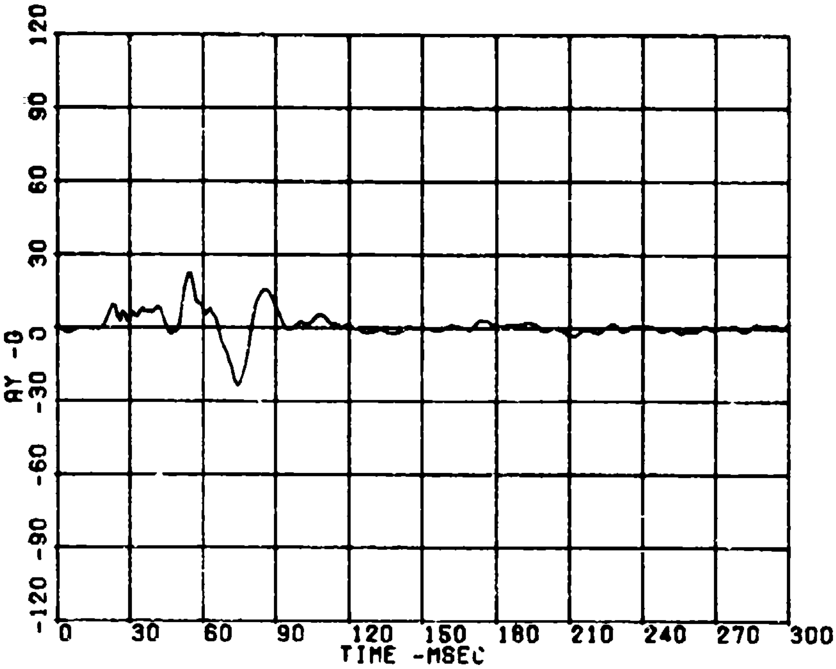


Figure C-9. Drop Test Type I Restraint - Pelvis Acceleration - Lateral.

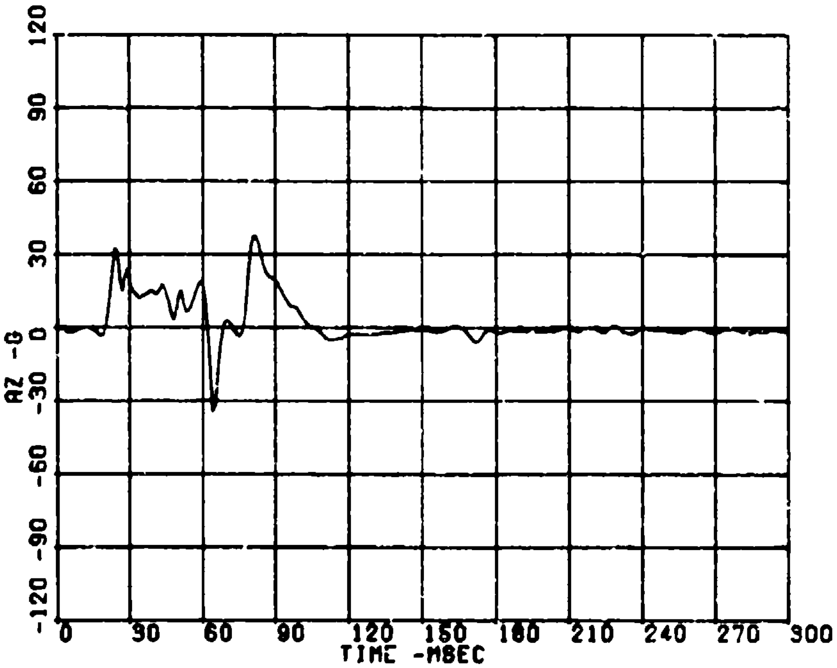


Figure C-10. Drop Test Type I Restraint - Pelvis Acceleration - Vertical.

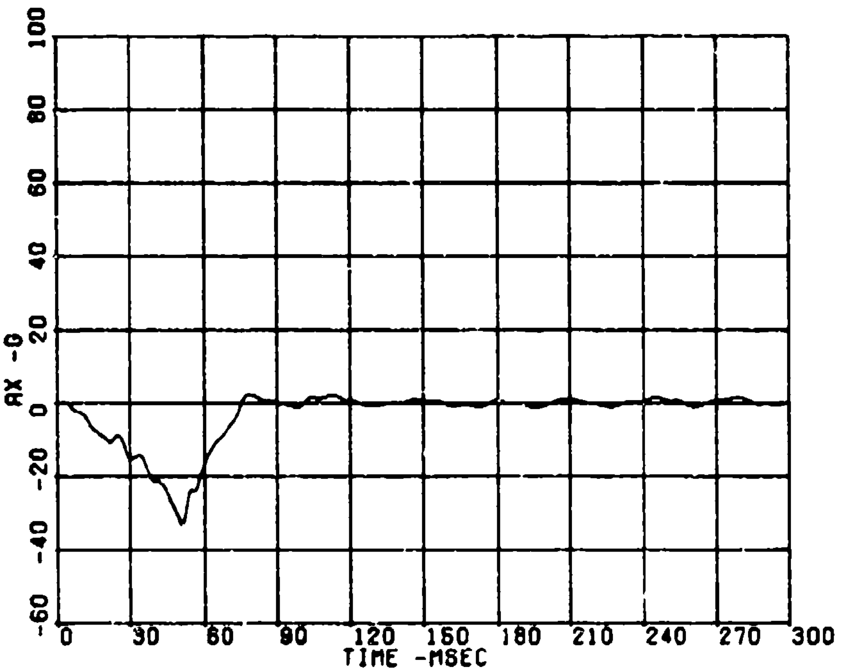


Figure C-11. Drop Test Type I Restraint -
Seat Pan Acceleration - Longitudinal.

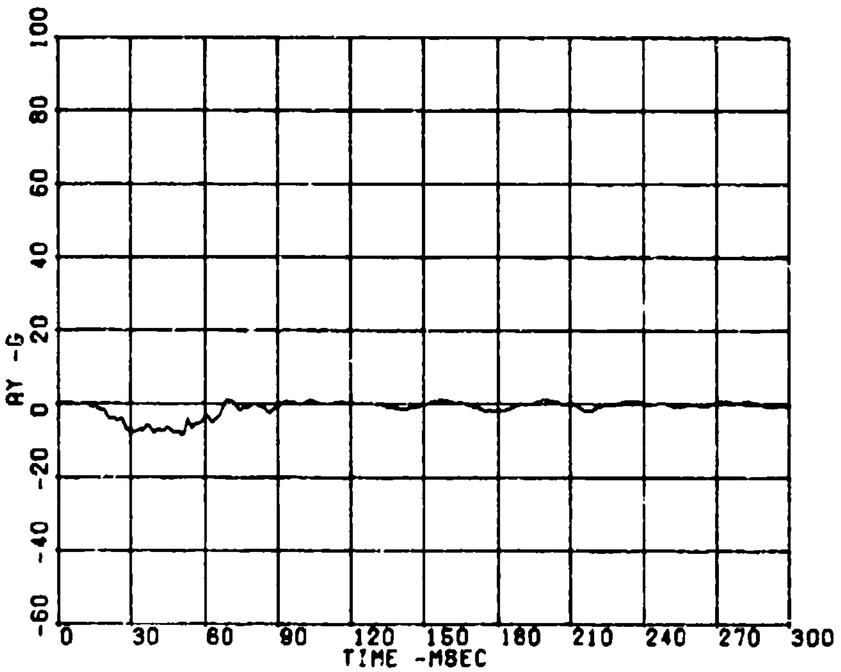


Figure C-12. Drop Test Type I Restraint -
Seat Pan Acceleration - Lateral.

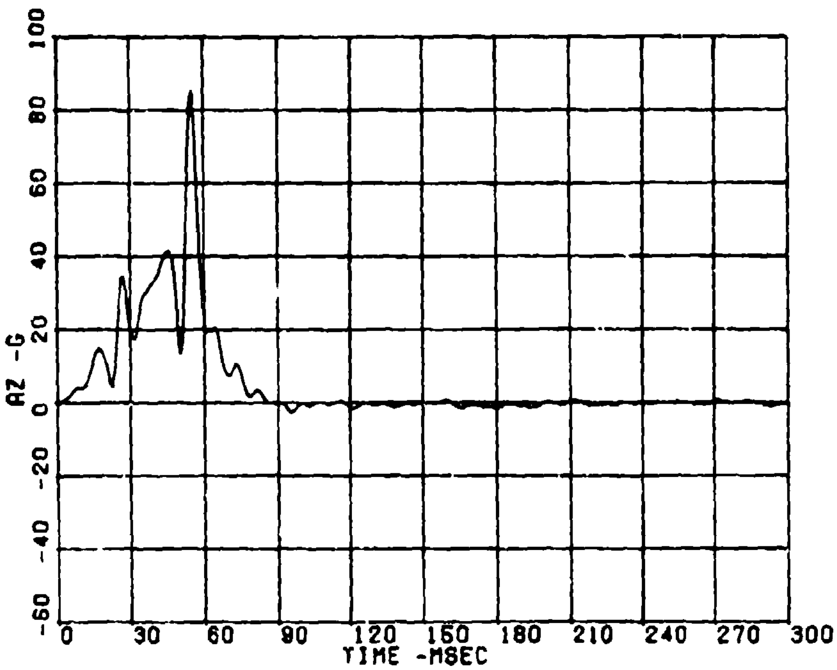


Figure C-13. Drop Test Type I Restraint - Seat Pan Acceleration - Vertical.

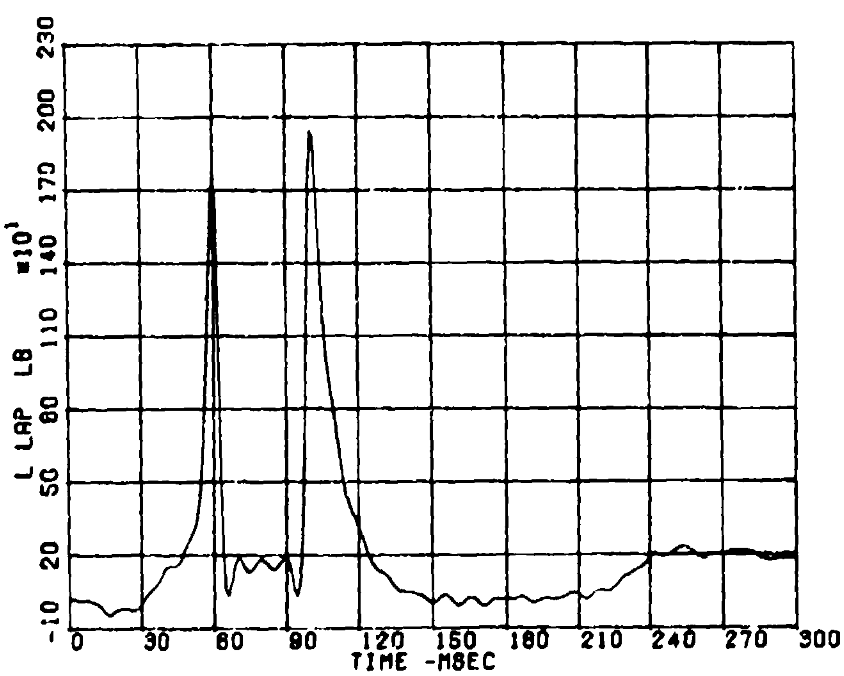


Figure C-14. Drop Test Type I Restraint - Left Lap Belt Load.

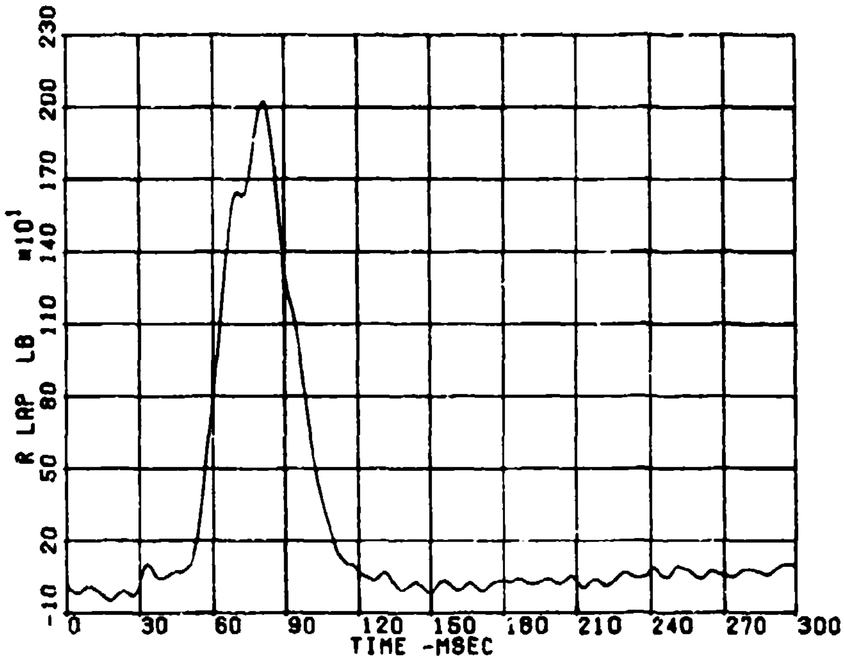


Figure C-15. Drop Test Type I Restraint - Right Lap Belt Load.

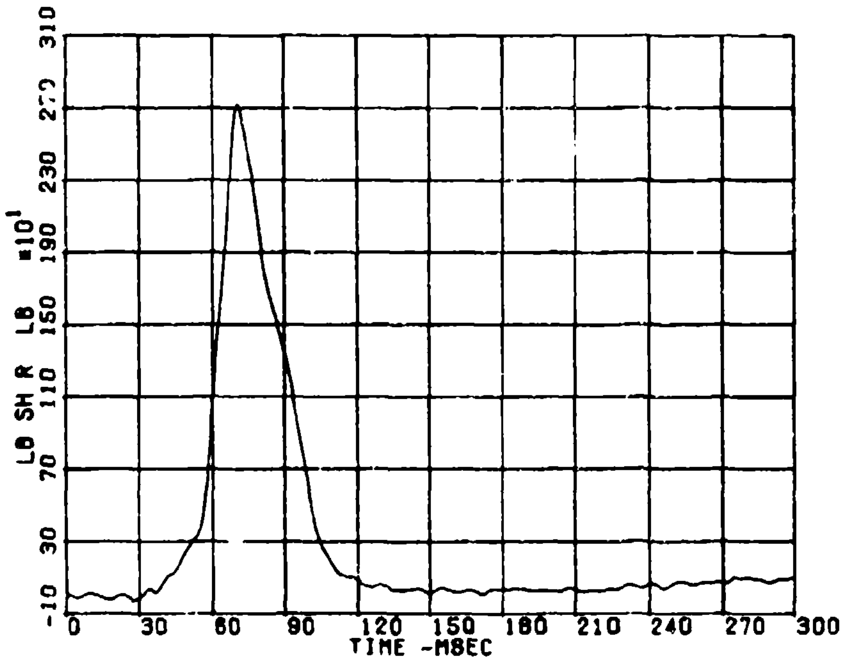


Figure C-16. Drop Test Type I Restraint - Lower Shoulder Strap Load.

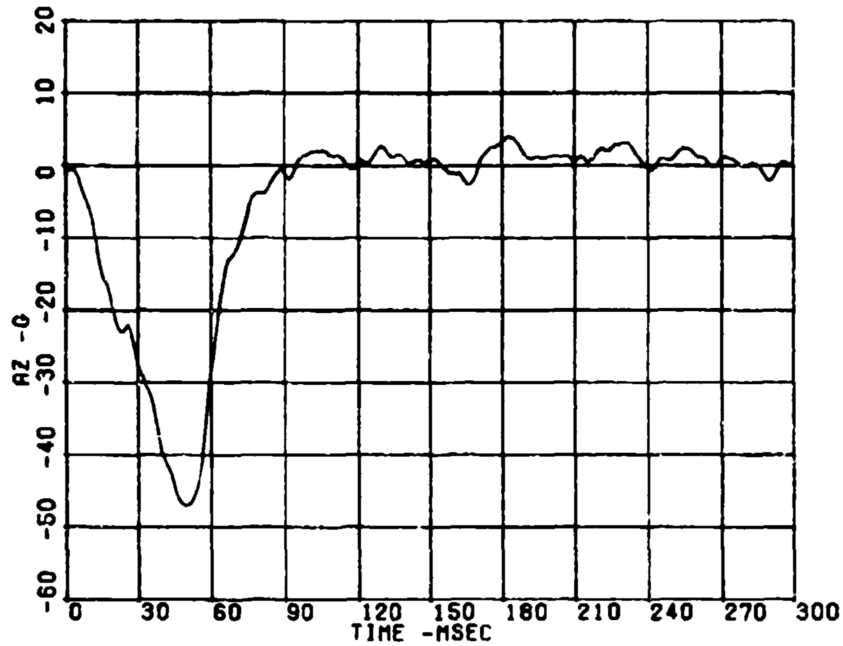


Figure C-17. Drop Test Type II Restraint - Input Acceleration.

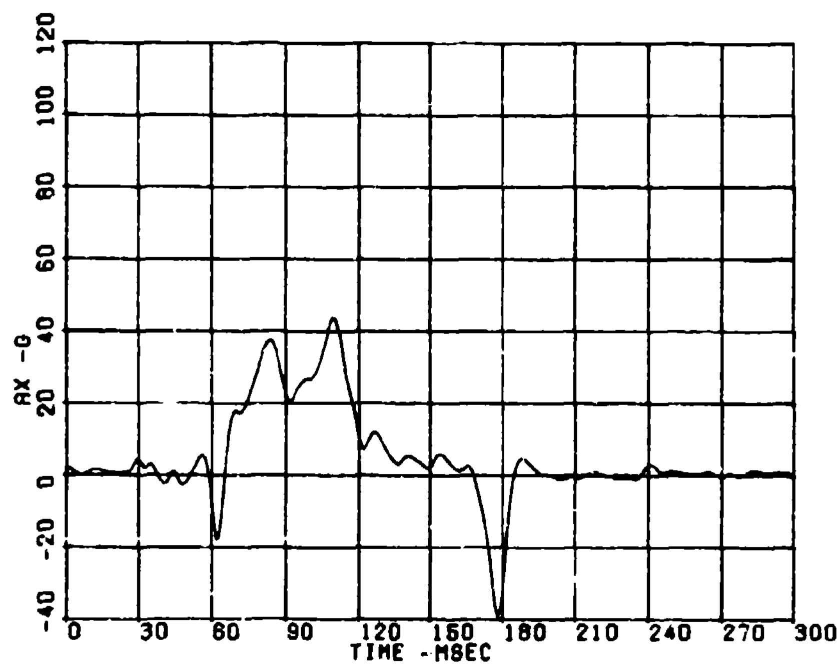


Figure C-18. Drop Test Type II Restraint - Head Acceleration - Longitudinal.

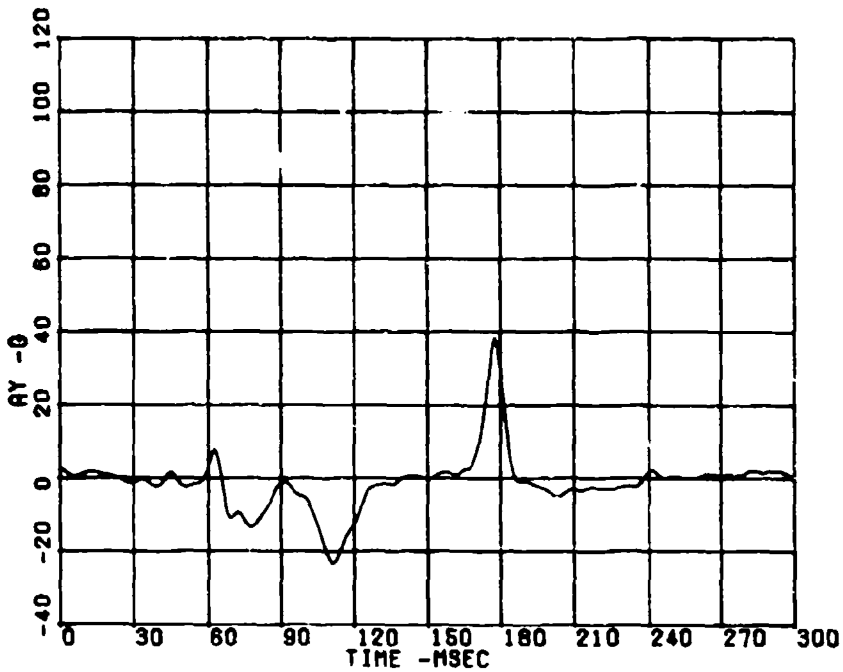


Figure C-19. Drop Test Type II Restraint - Head Acceleration - Lateral.

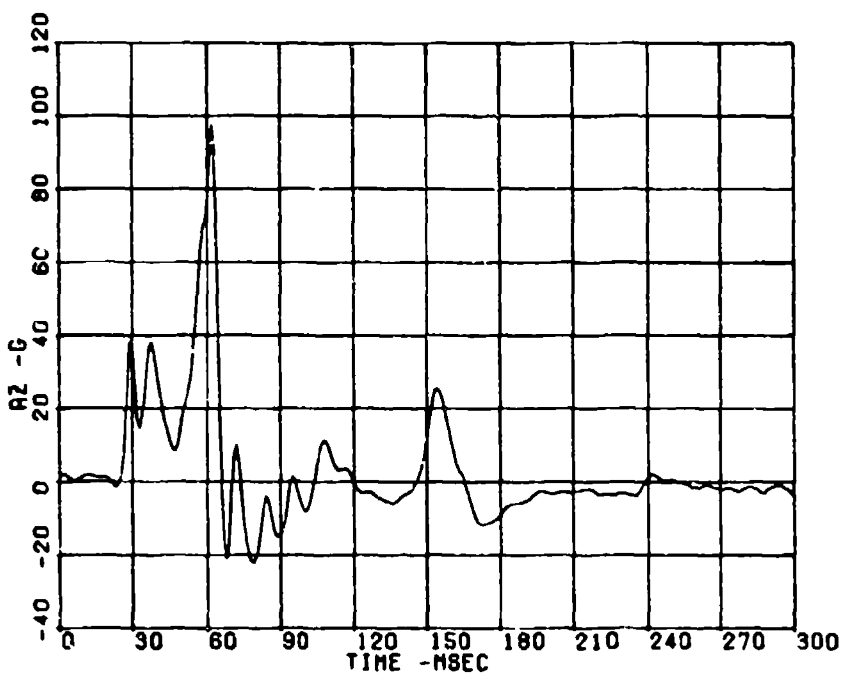


Figure C-20. Drop Test Type II Restraint - Head Acceleration - Vertical.

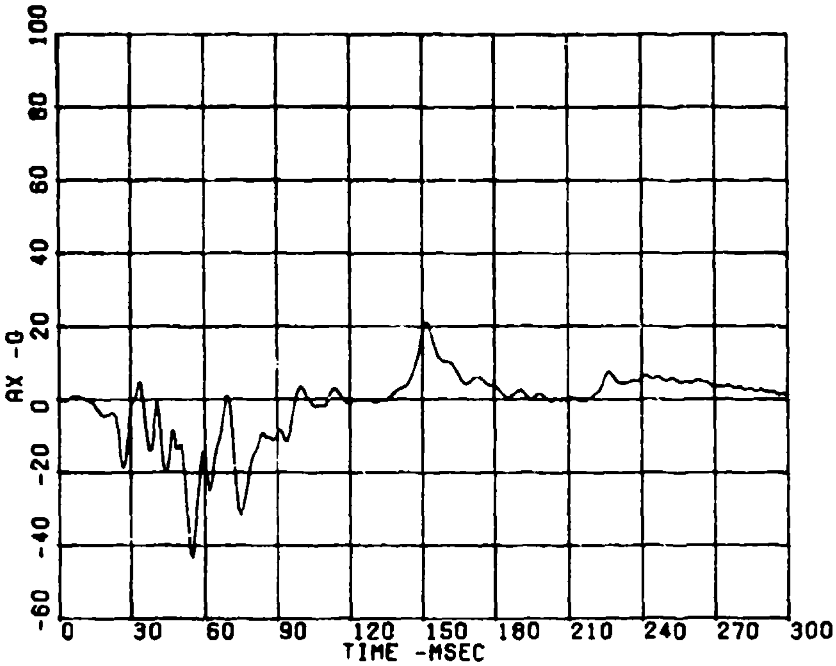


Figure C-21. Drop Test Type II Restraint - Chest Acceleration - Longitudinal.

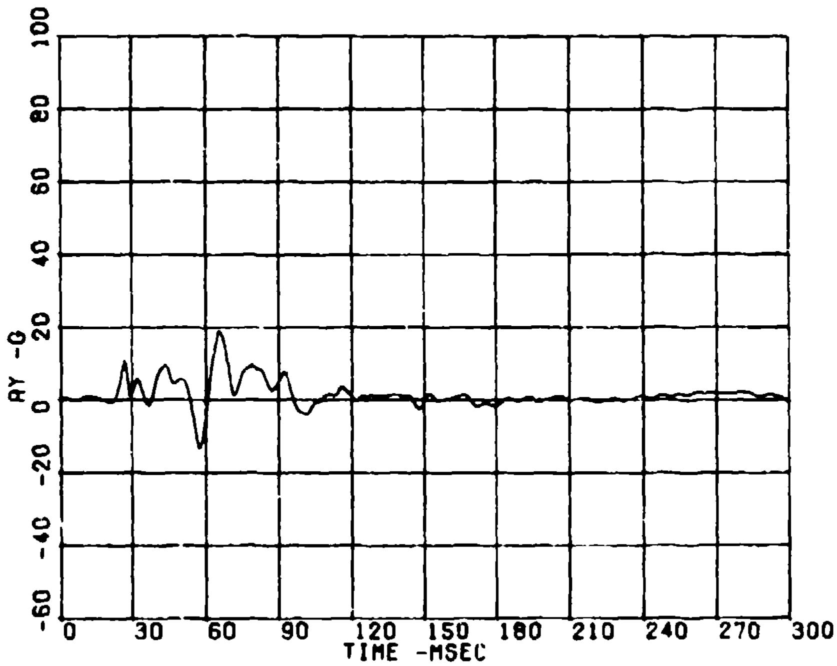


Figure C-22. Drop Test Type II Restraint - Chest Acceleration - Lateral.

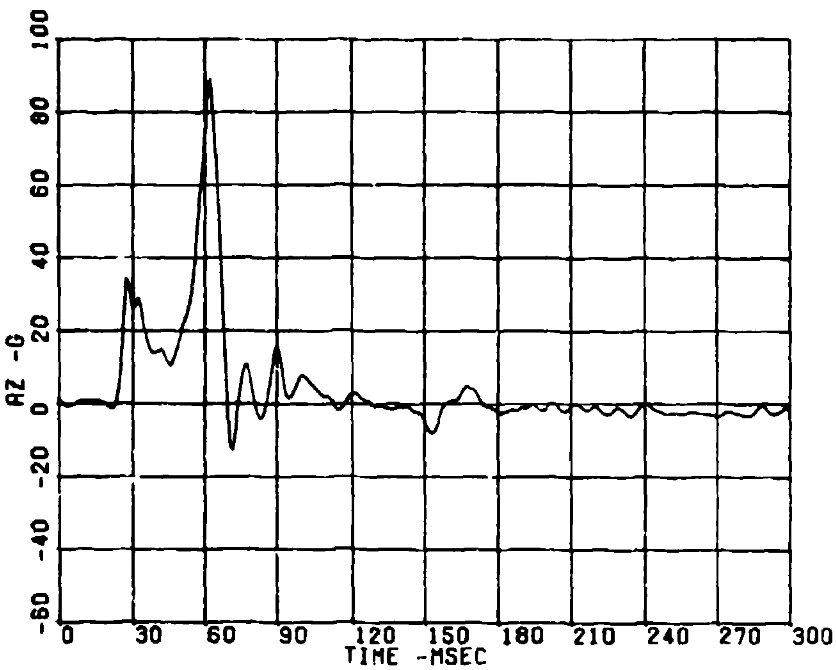


Figure C-23. Drop Test Type II Restraint - Chest Acceleration - Vertical.

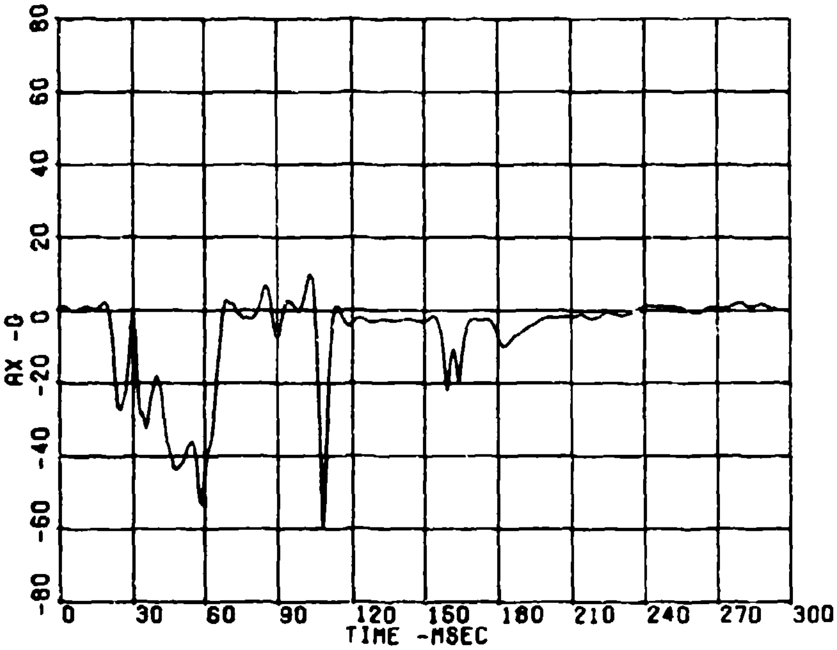


Figure C-24. Drop Test Type II Restraint - Pelvis Acceleration - Longitudinal.

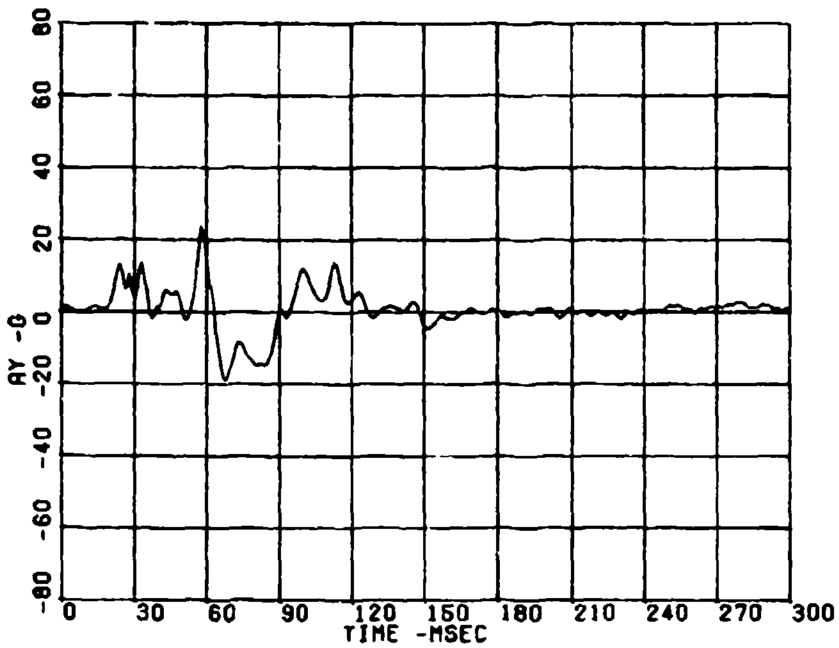


Figure C-25. Drop Test Type II Restraint - Pelvis Acceleration - Lateral.

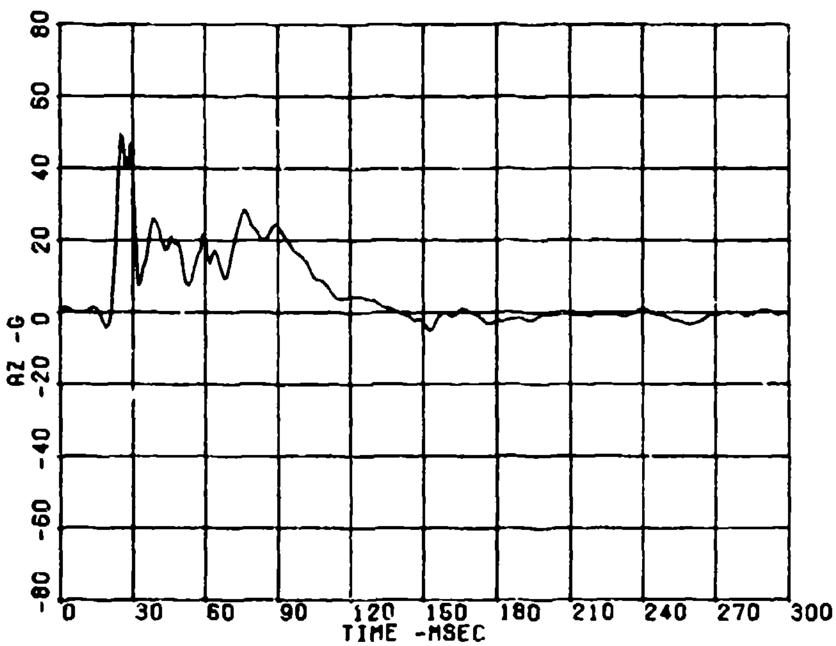


Figure C-26. Drop Test Type II Restraint - Pelvis Acceleration - Vertical.

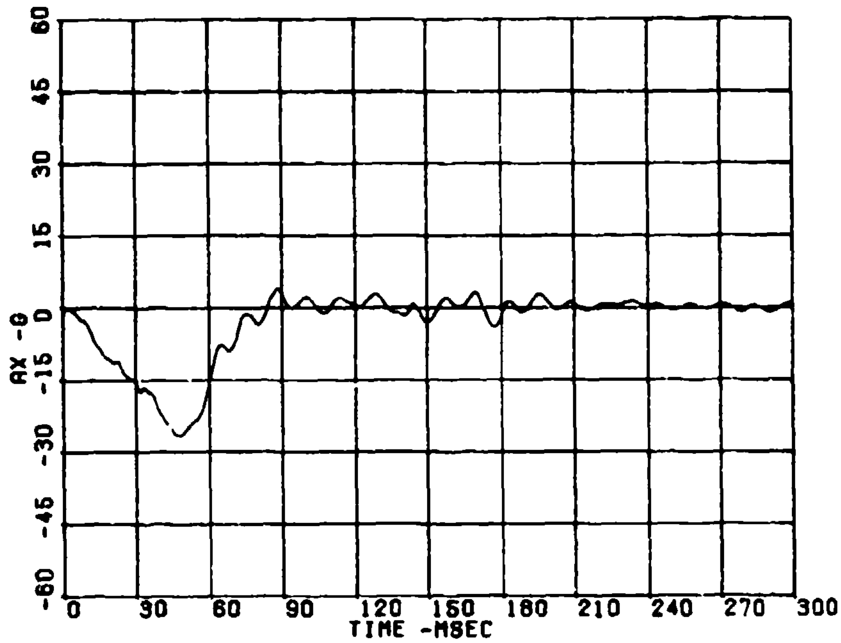


Figure C-27. Drop Test Type II Restraint - Seat Pan Acceleration - Longitudinal.

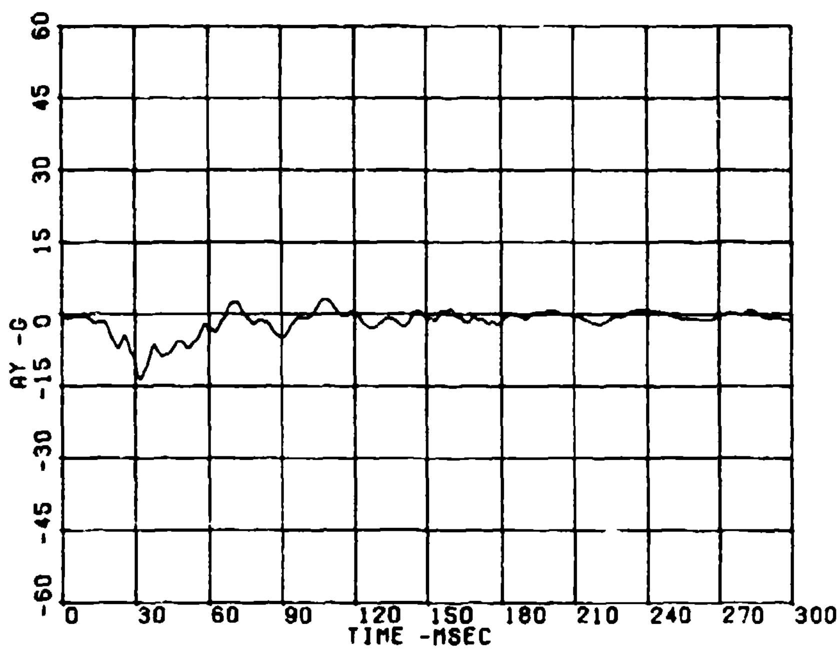


Figure C-28. Drop Test Type II Restraint - Seat Pan Acceleration - Lateral.

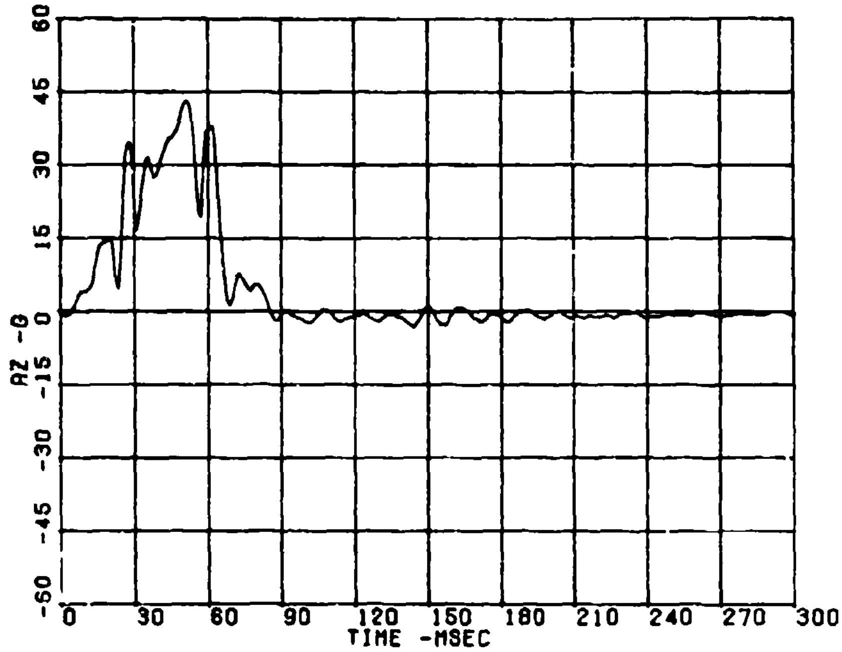


Figure C-29. Drop Test Type II Restraint - Seat Pan Acceleration - Vertical.

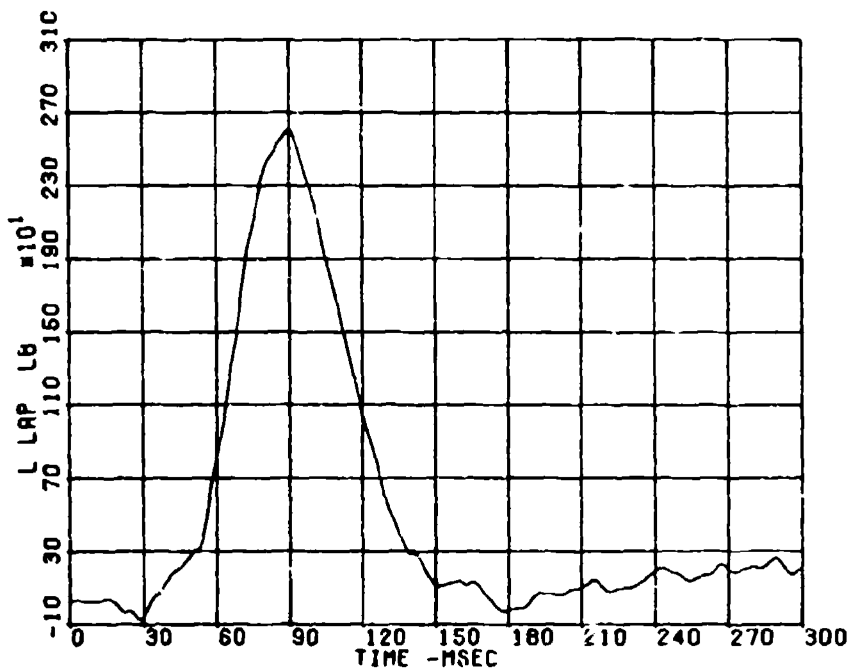


Figure C-30. Drop Test Type II Restraint - Left Lap Belt Load.

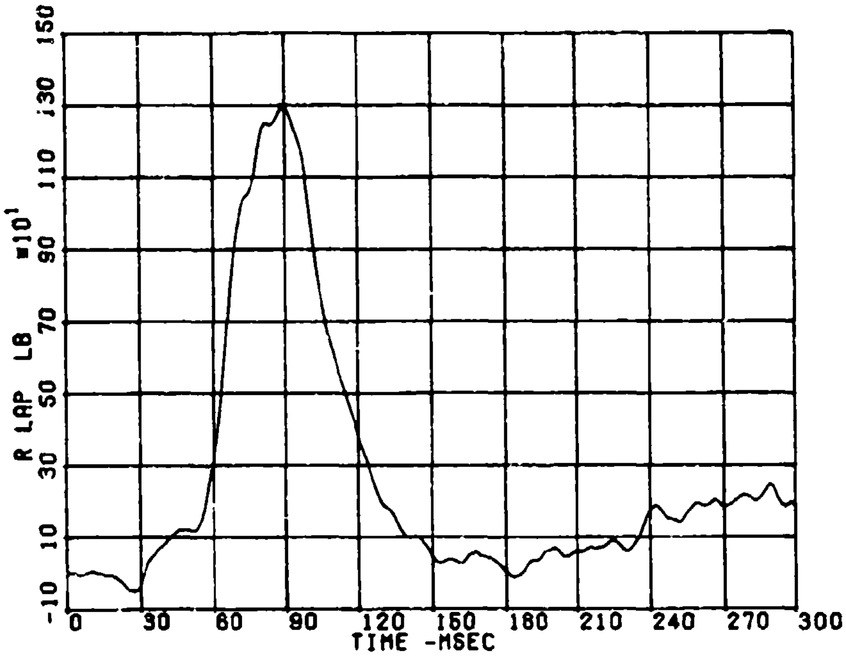


Figure C-31. Drop Test Type II Restraint - Right Lap Belt Load.

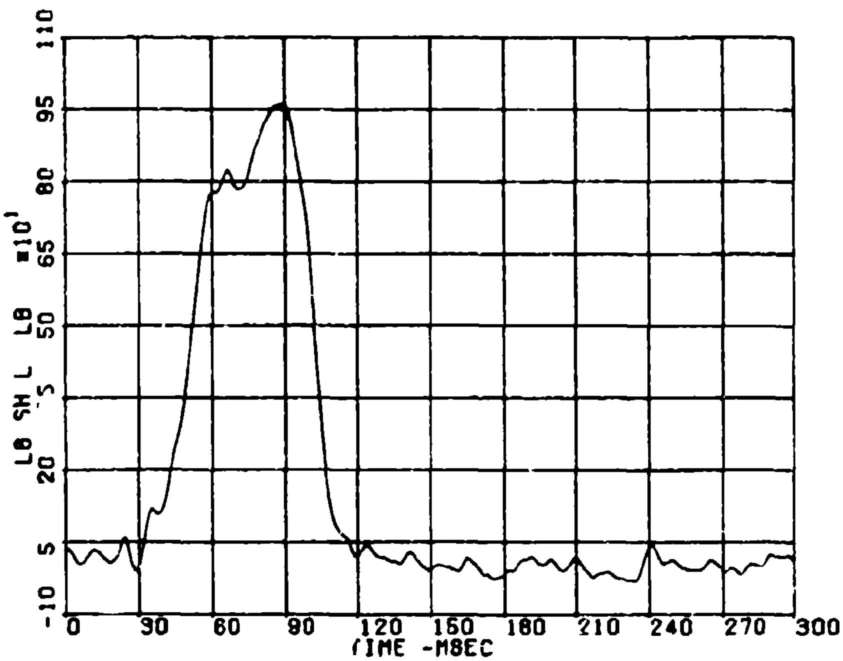


Figure C-32. Drop Test Type II Restraint - Left Lower Shoulder Strap Load.

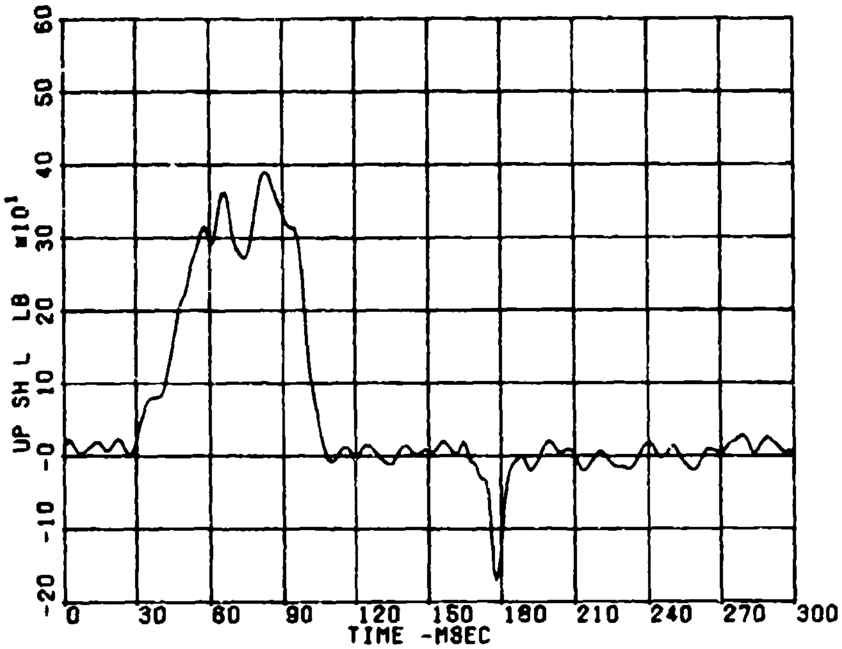


Figure C-33. Drop Test Type II Restraint -
Left Upper Shoulder Strap Load.

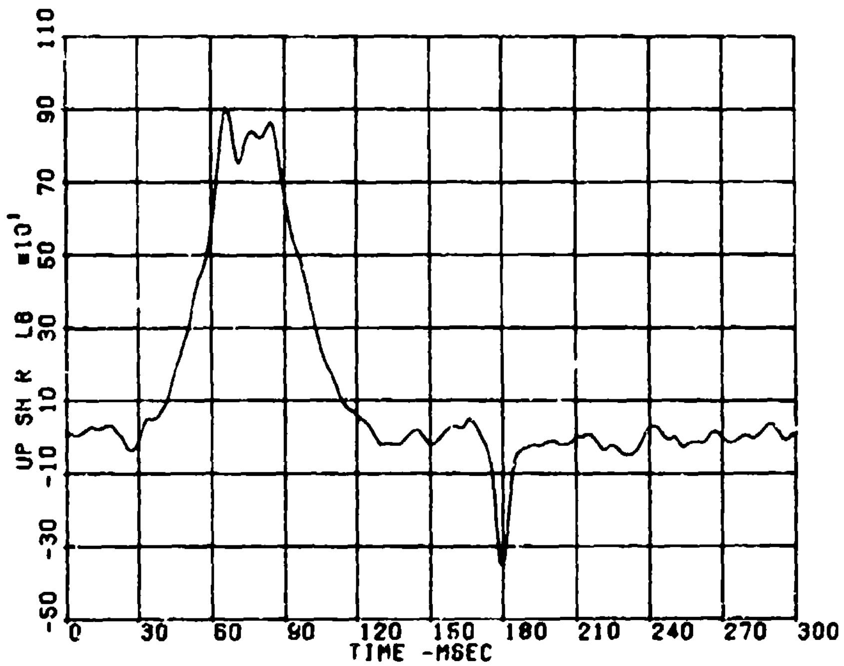


Figure C-34. Drop Test Type II Restraint -
Right Upper Shoulder Strap Load.

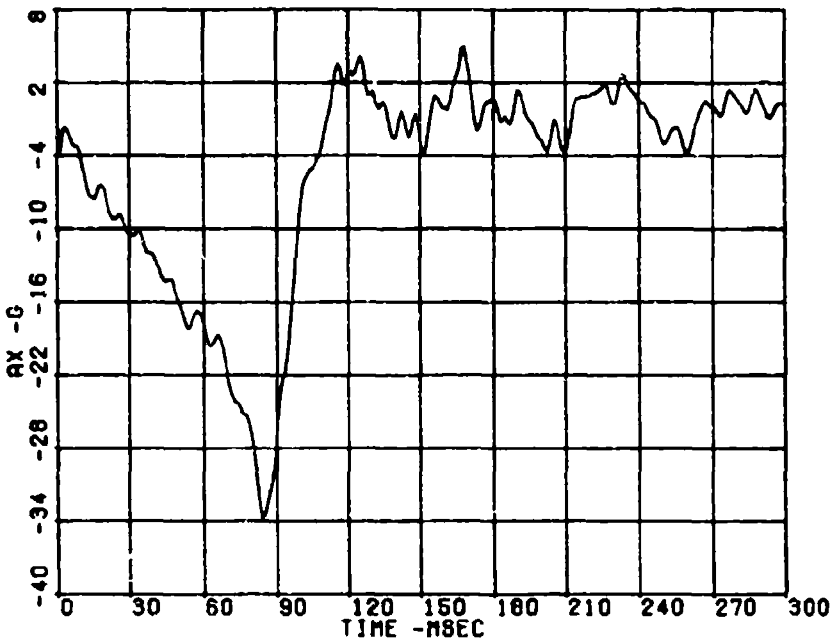


Figure C-35. Sled Test Type I Restraint - Input Acceleration.

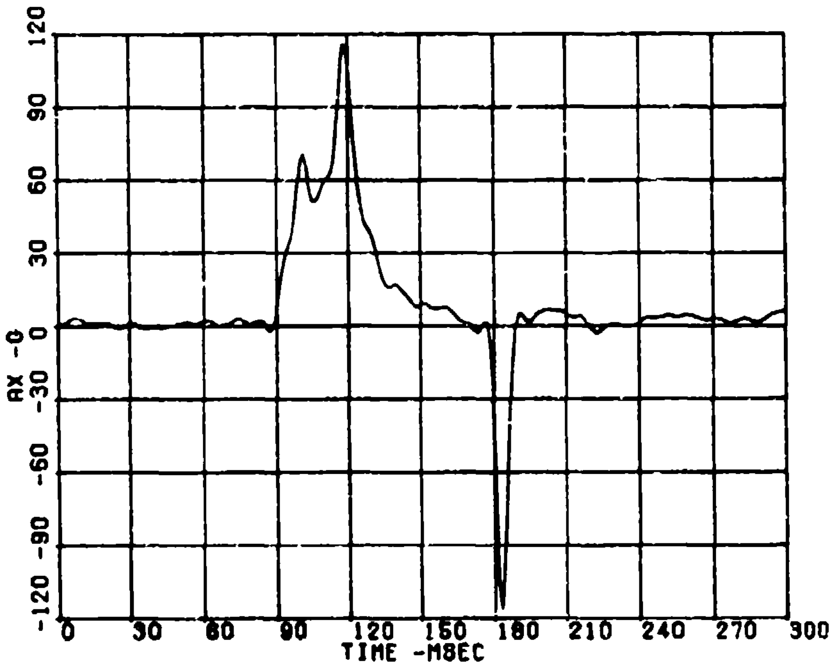


Figure C-36. Sled Test Type I Restraint - Head Acceleration - Longitudinal.

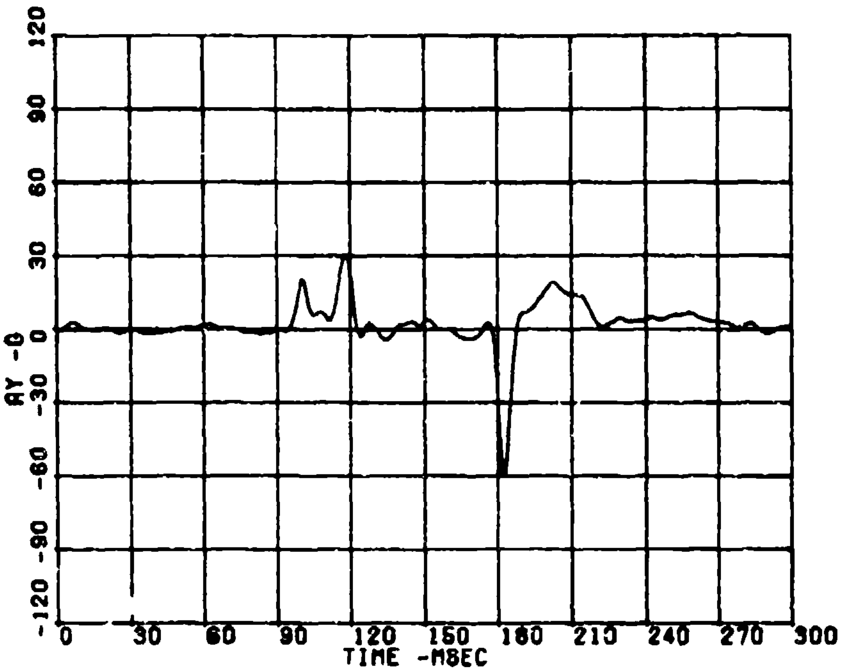


Figure C-37. Sled Test Type I Restraint - Head Acceleration - Lateral.

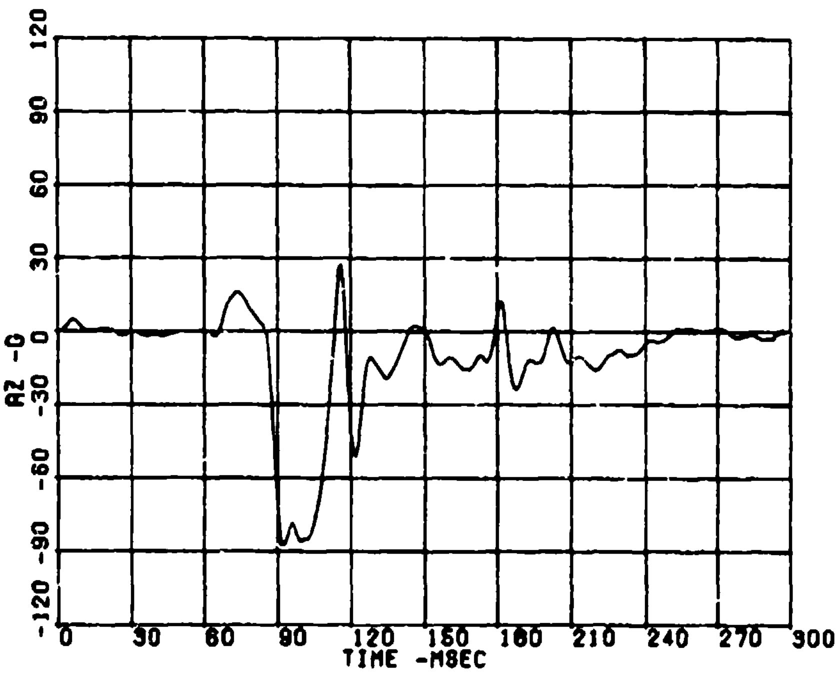


Figure C-38. Sled Test Type I Restraint - Head Acceleration - Vertical.

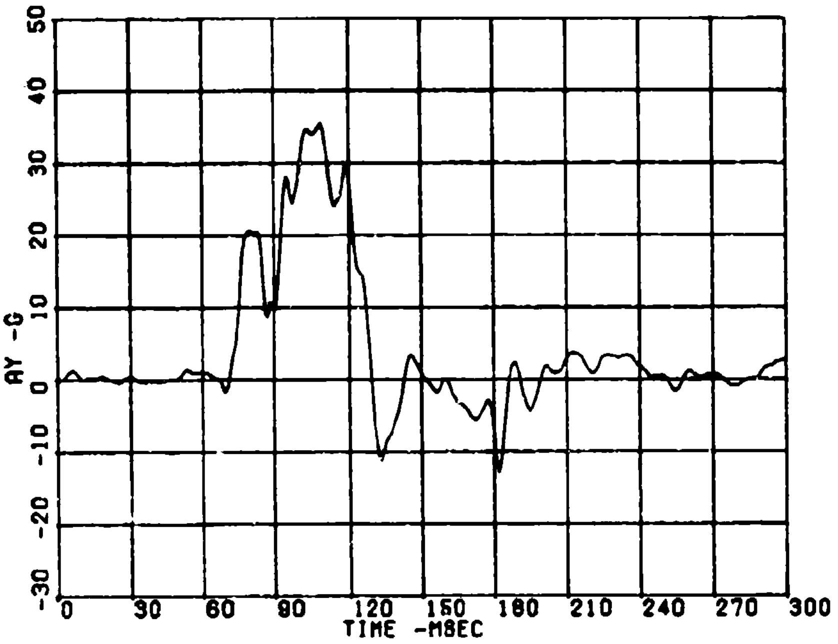


Figure C-39. Sled Test Type I Restraint - Chest Acceleration - Lateral.

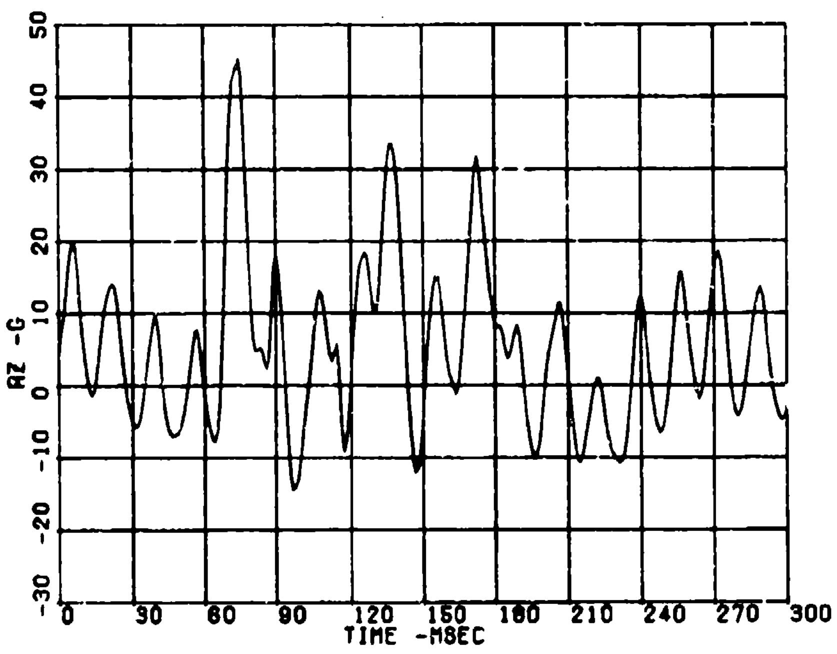


Figure C-40. Sled Test Type I Restraint - Chest Acceleration - Vertical.

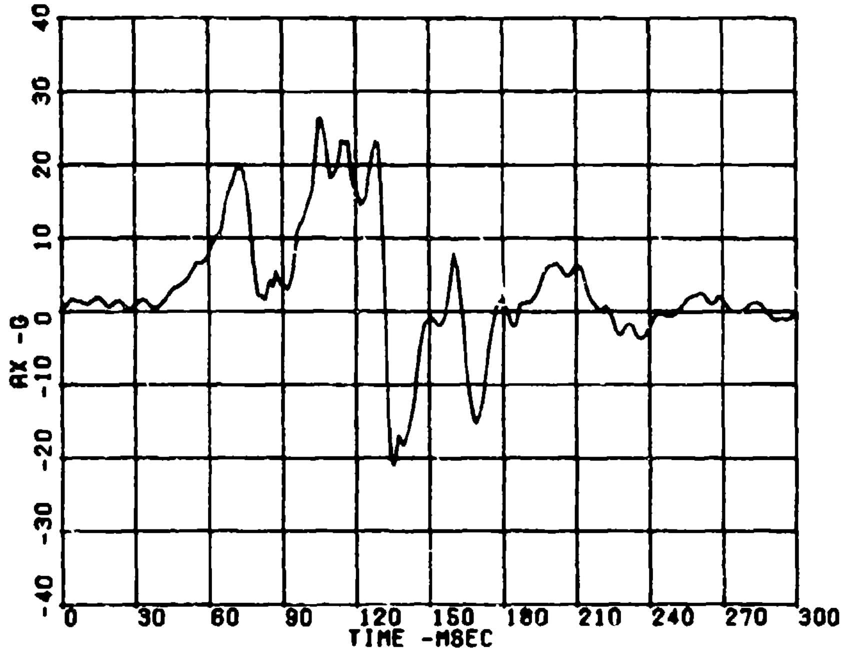


Figure C-41. Sled Test Type I Restraint - Pelvis Acceleration - Longitudinal.

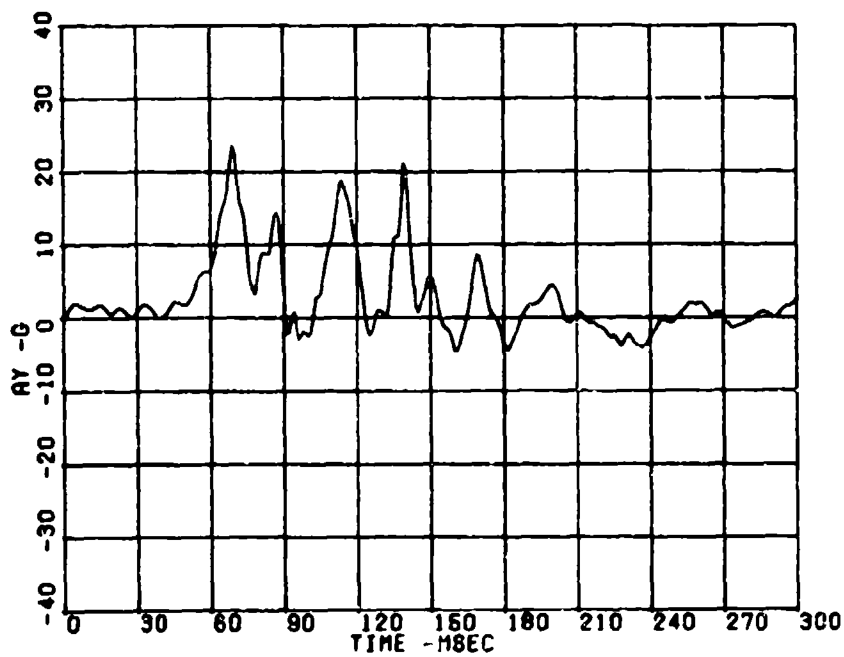


Figure C-42. Sled Test Type I Restraint - Pelvis Acceleration - Lateral.

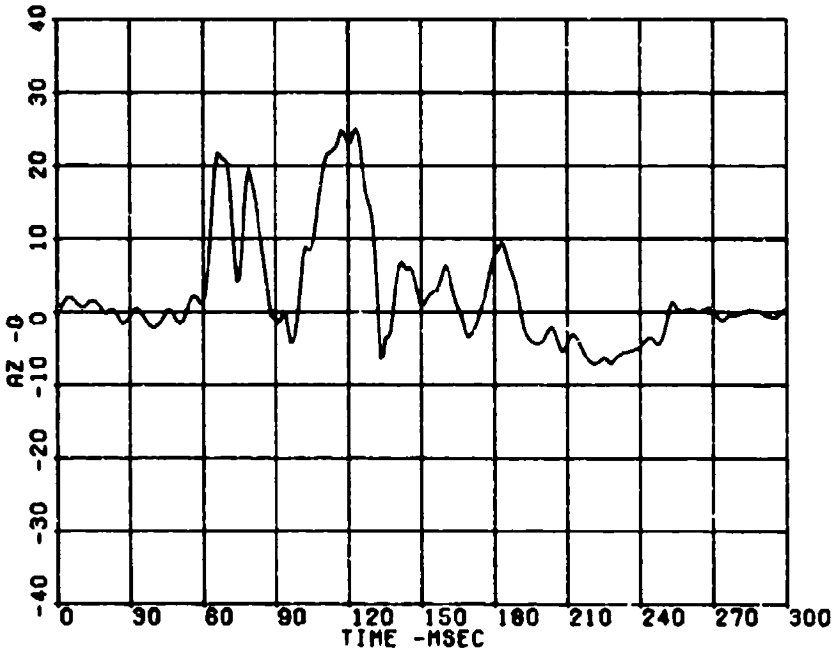


Figure C-43. Sled Test Type I Restraint - Pelvis Acceleration - Vertical.

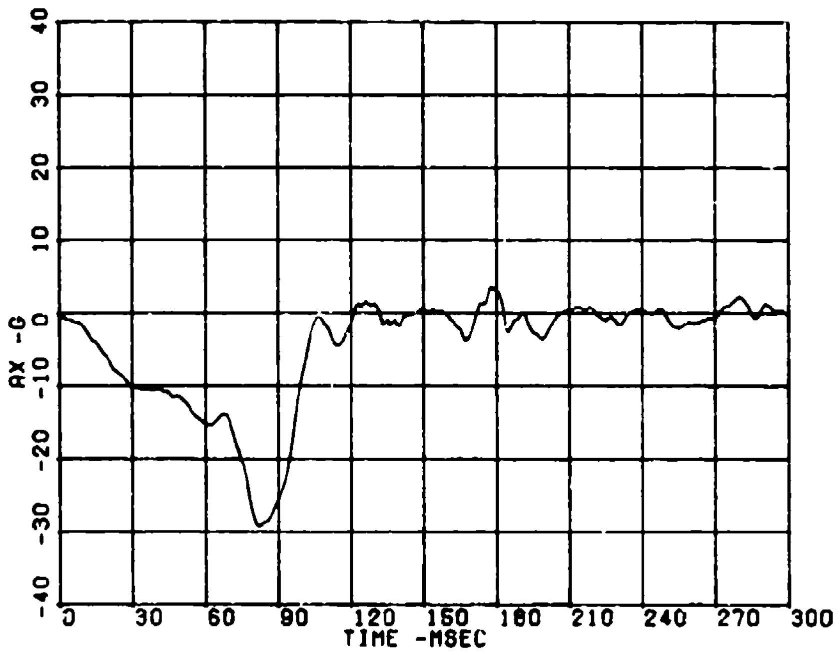


Figure C-44. Sled Test Type I Restraint - Seat Pan Acceleration - Longitudinal.

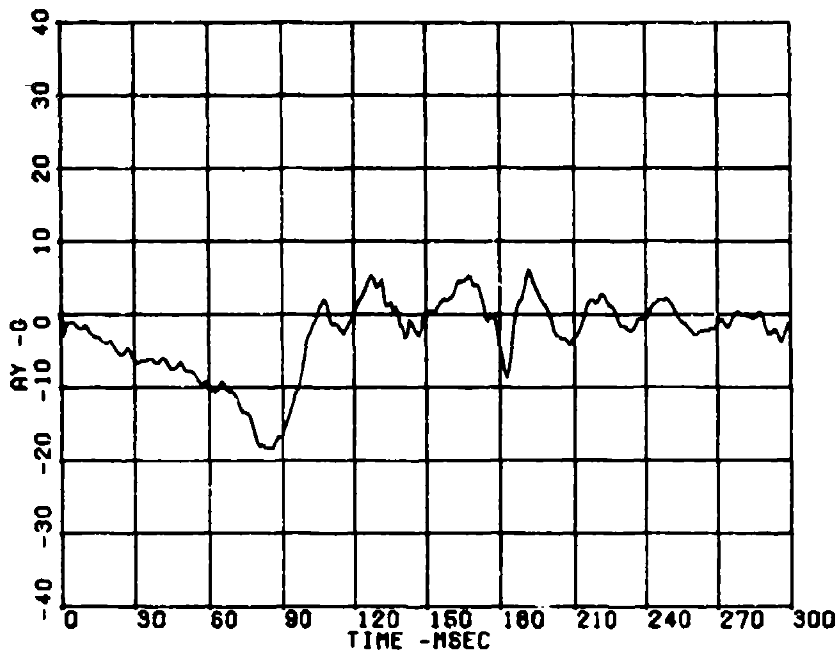


Figure C-45. Sled Test Type I Restraint - Seat Pan Acceleration - Lateral.

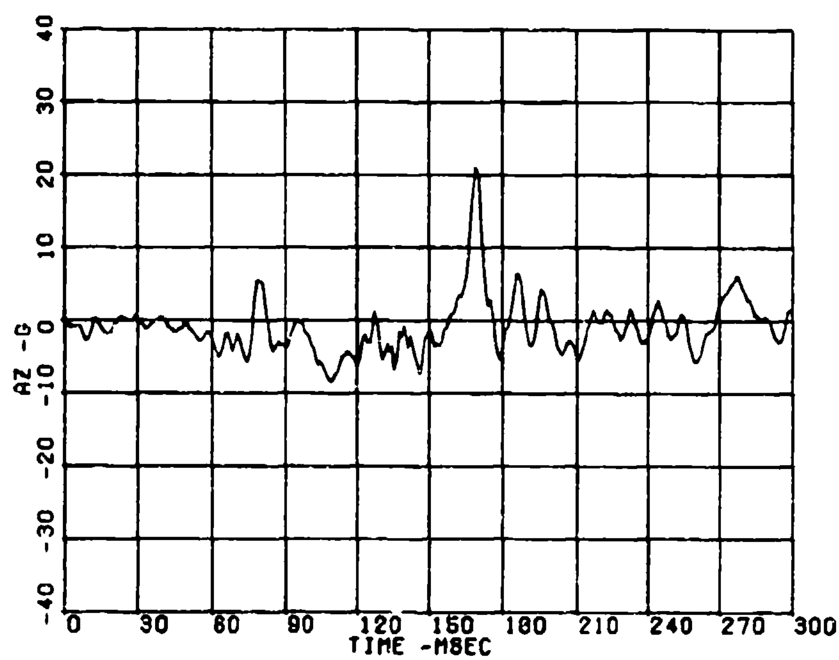


Figure C-46. Sled Test Type I Restraint - Seat Pan Acceleration - Vertical.

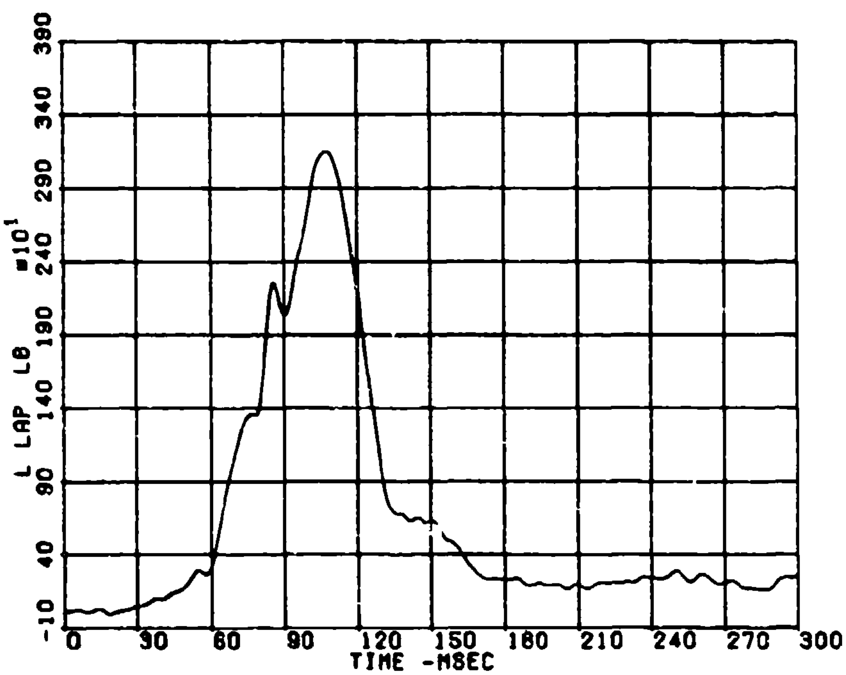


Figure C-47. Sled Test Type I Restraint - Left Lap Belt Load.

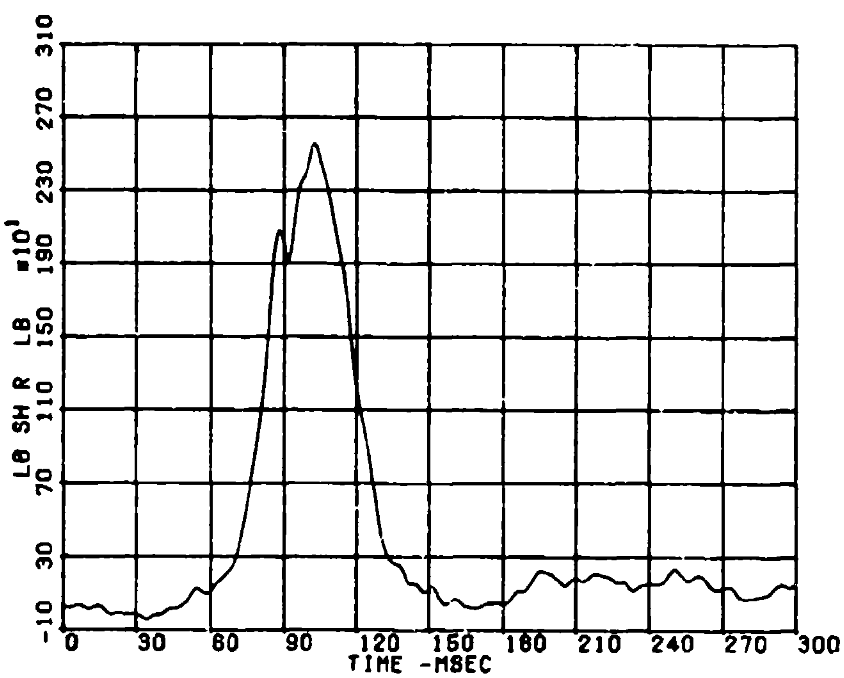


Figure C-48. Sled Test Type I Restraint - Right Lower Shoulder Strap Load.

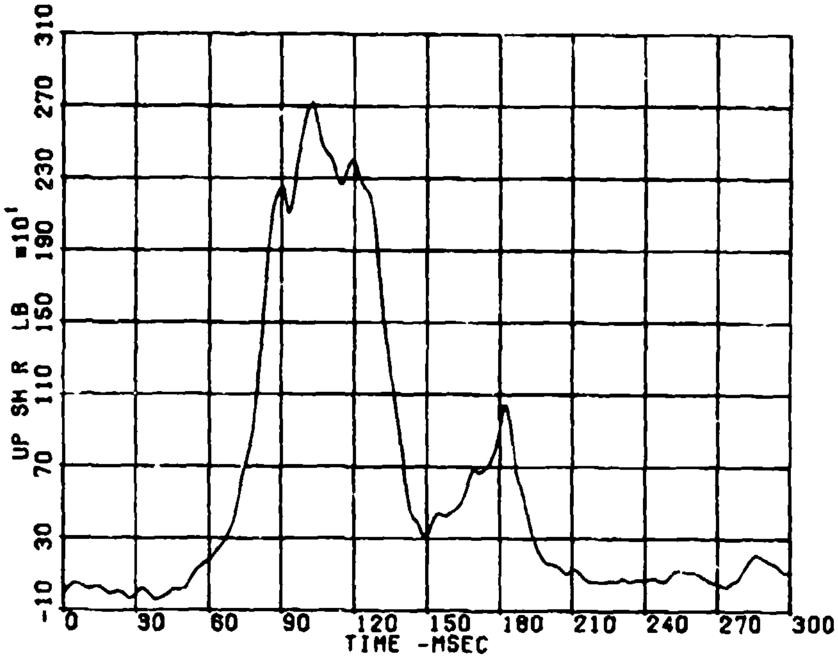


Figure C-49. Sled Test Type I Restraint - Right Upper Shoulder Strap Load.

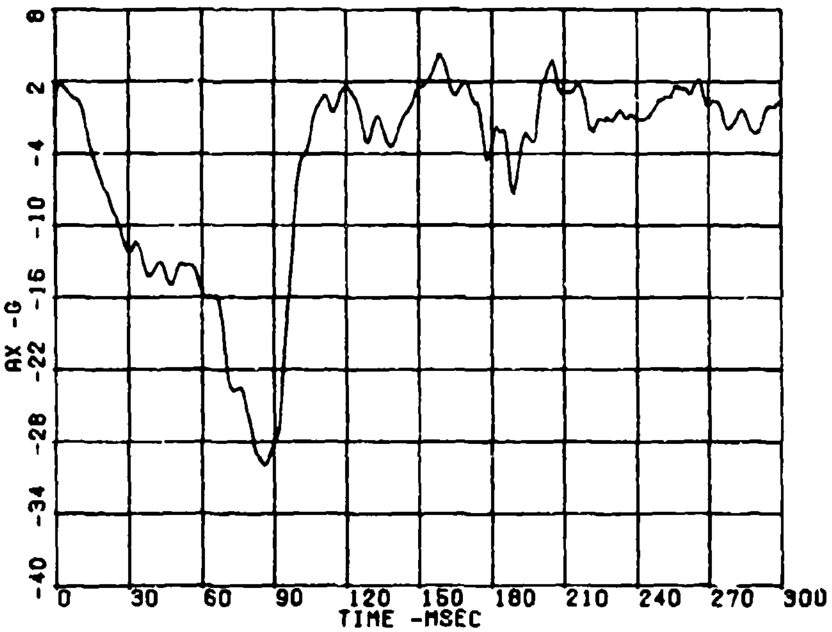


Figure C-50. Sled Test Type II Restraint - Input Acceleration.

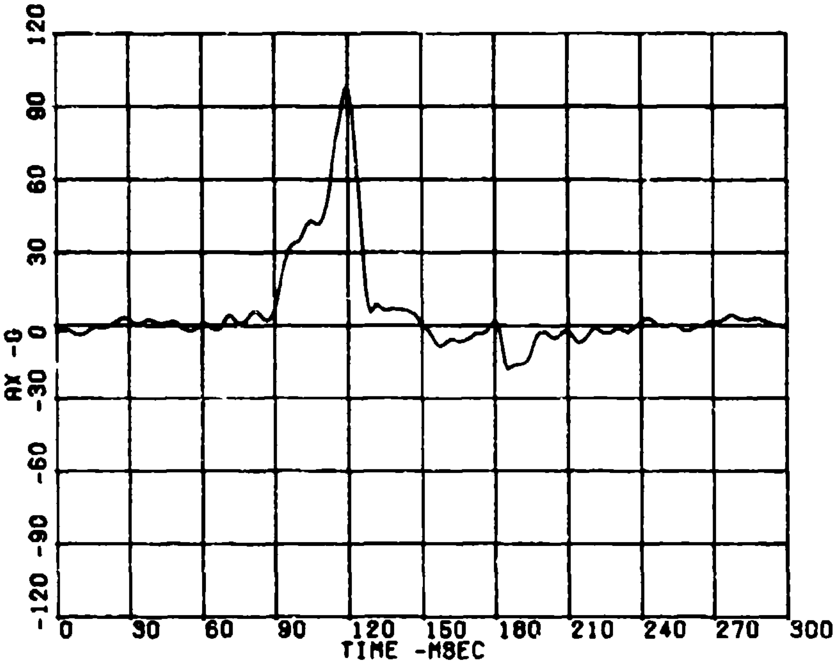


Figure C-51. Sled Test Type II Restraint - Head Acceleration - Longitudinal.

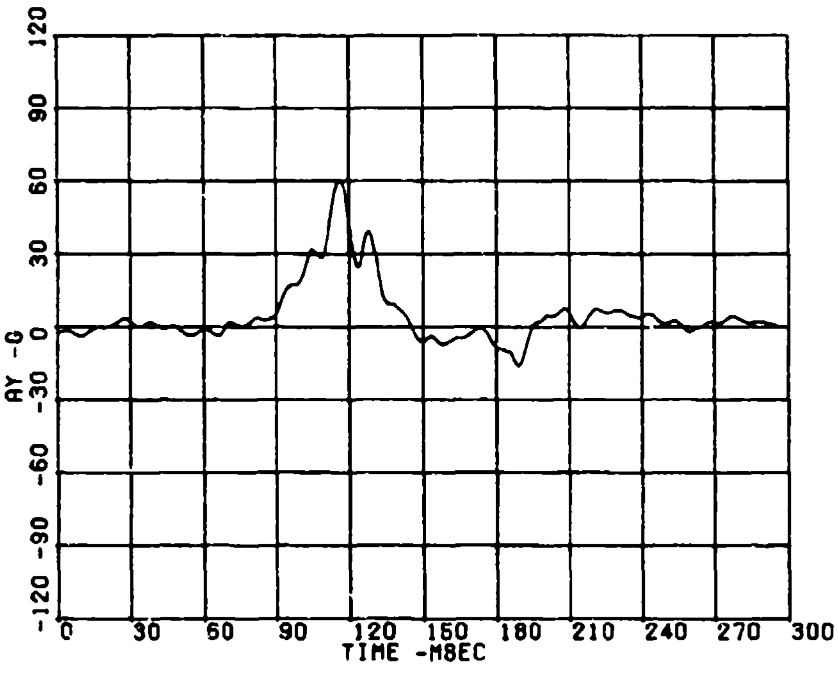


Figure C-52. Sled Test Type II Restraint - Head Acceleration - Lateral.

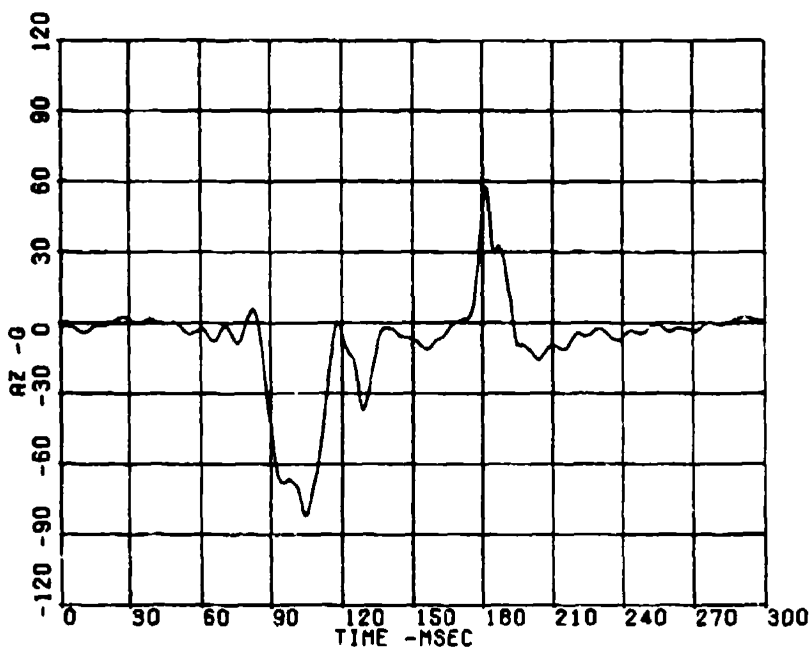


Figure C-53. Sled Test Type II Restraint - Head Acceleration - Vertical.

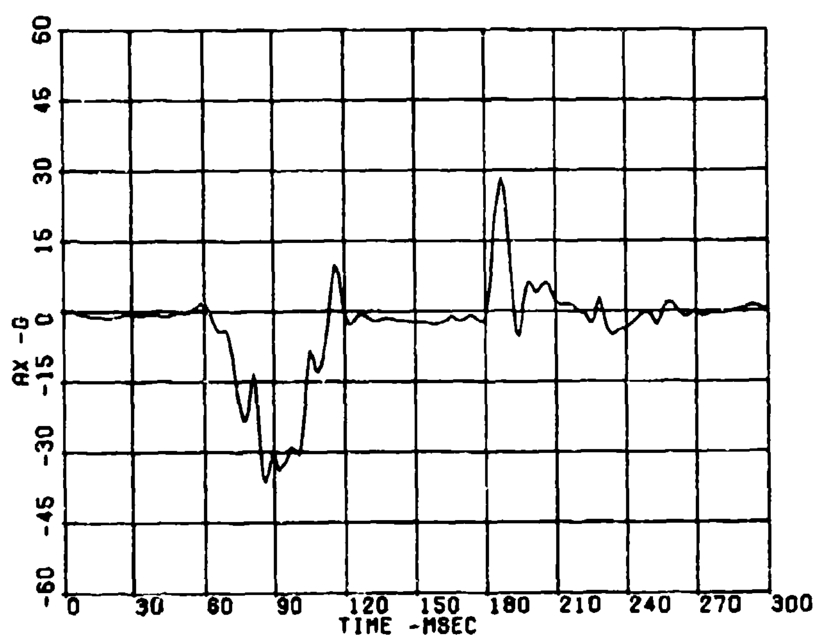


Figure C-54. Sled Test Type II Restraint - Chest Acceleration - Longitudinal.

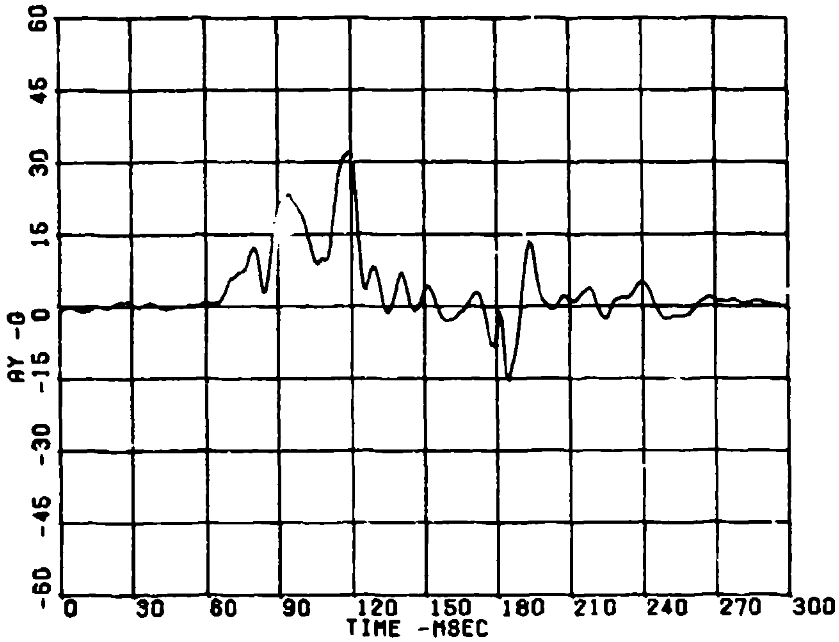


Figure C-55. Sled Test Type II Restraint - Chest Acceleration - Lateral.

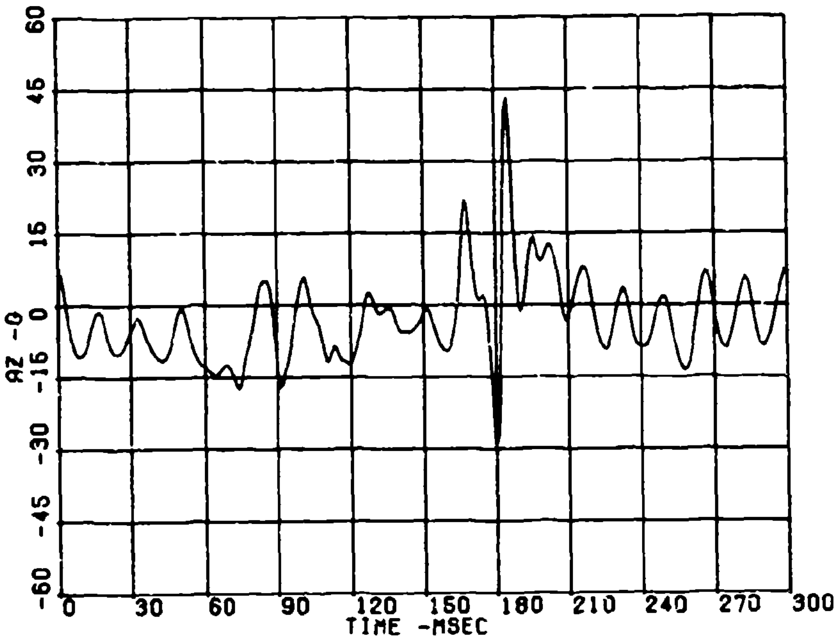


Figure C-56. Sled Test Type II Restraint - Chest Acceleration - Vertical.

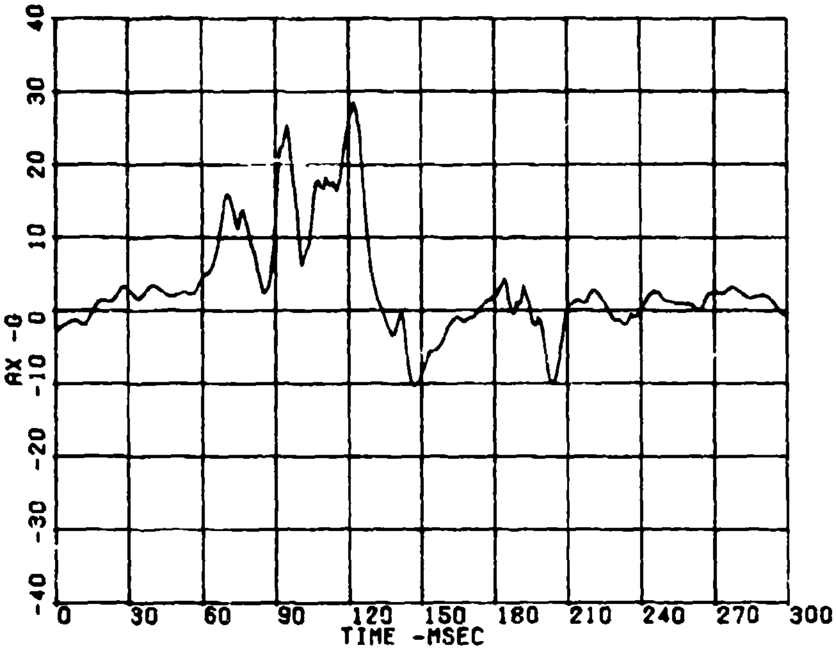


Figure C-57. Sled Test Type II Restraint - Pelvis Acceleration - Longitudinal.

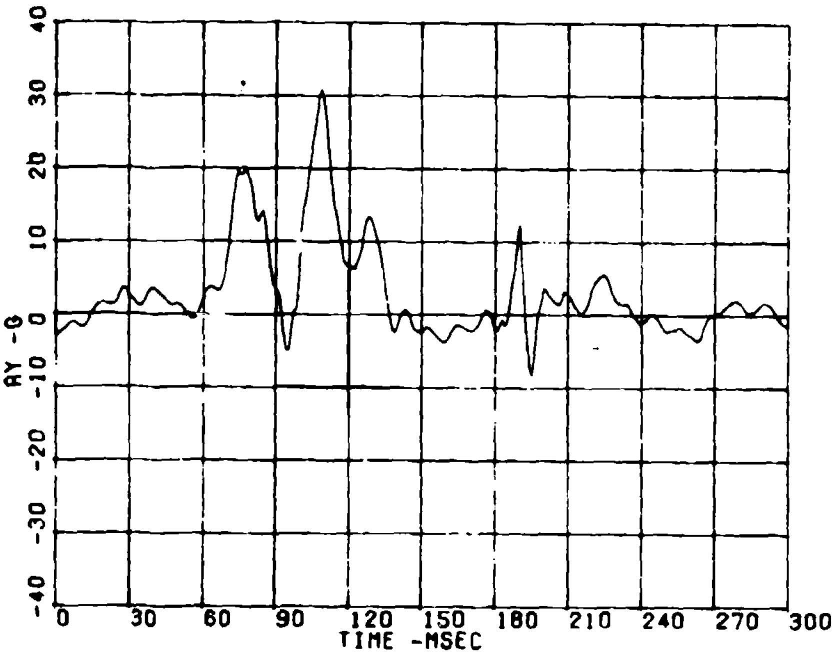


Figure C-58. Sled Test Type II Restraint - Pelvis Acceleration - Lateral

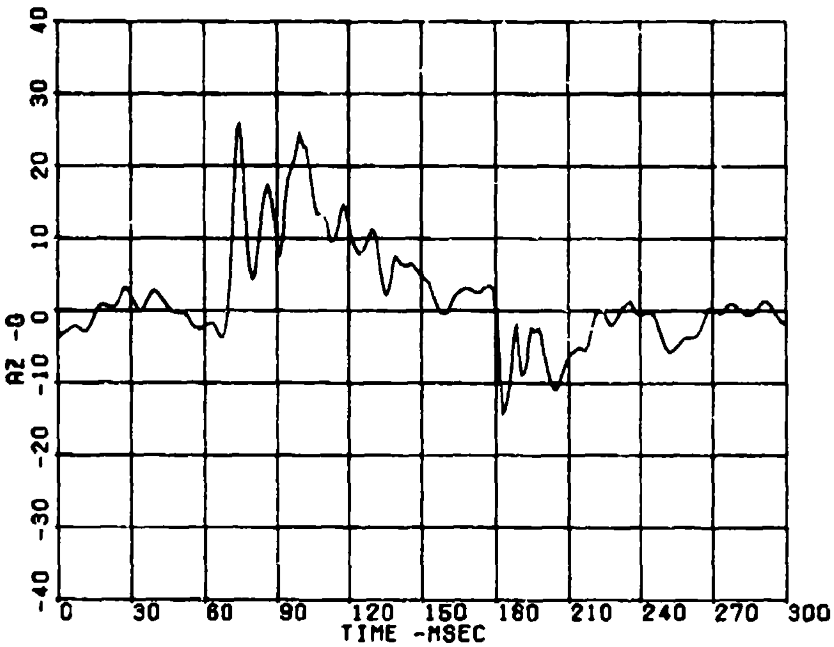


Figure C-59. Sled Test Type II Restraint - Pelvis Acceleration - Vertical.

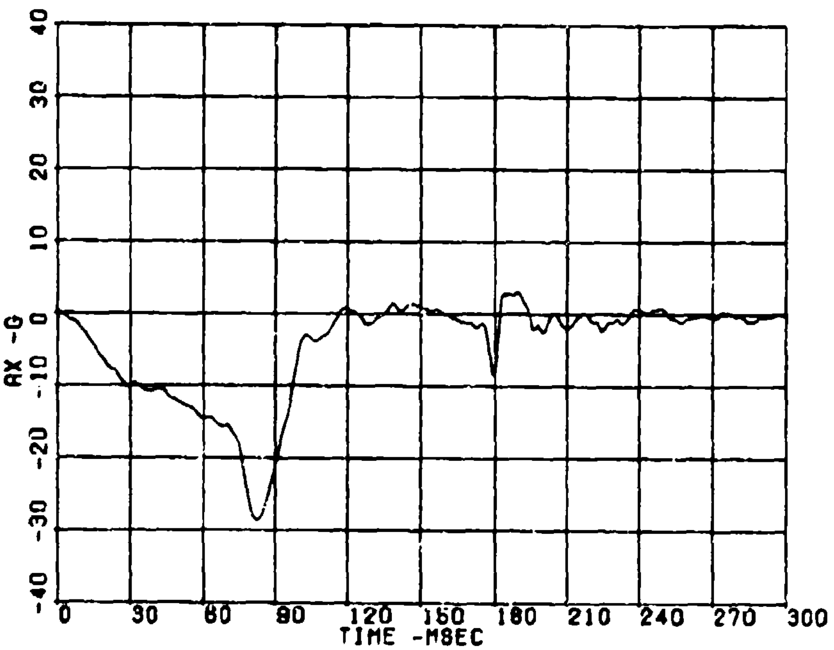


Figure C-60. Sled Test Type II Restraint - Seat Pan Acceleration - Longitudinal.

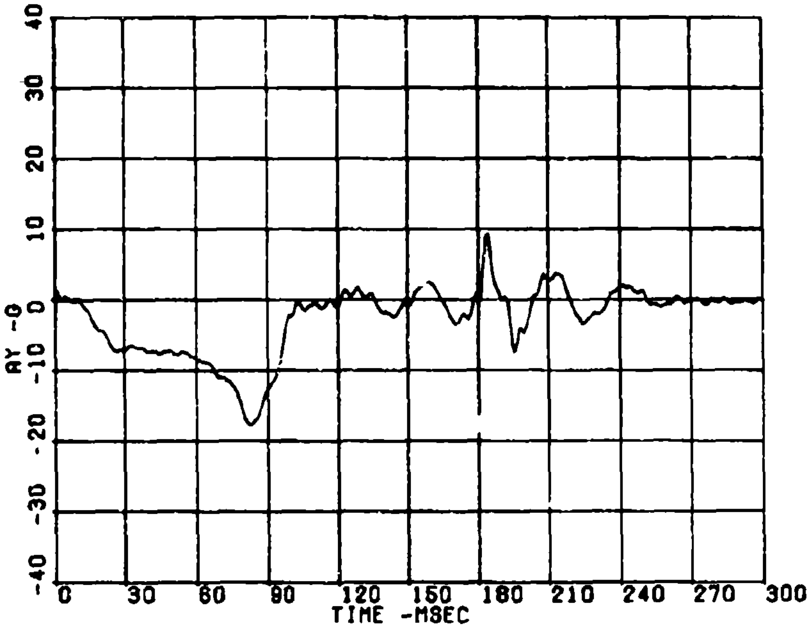


Figure C-61. Sled Test Type II Restraint - Seat Pan Acceleration - Lateral.

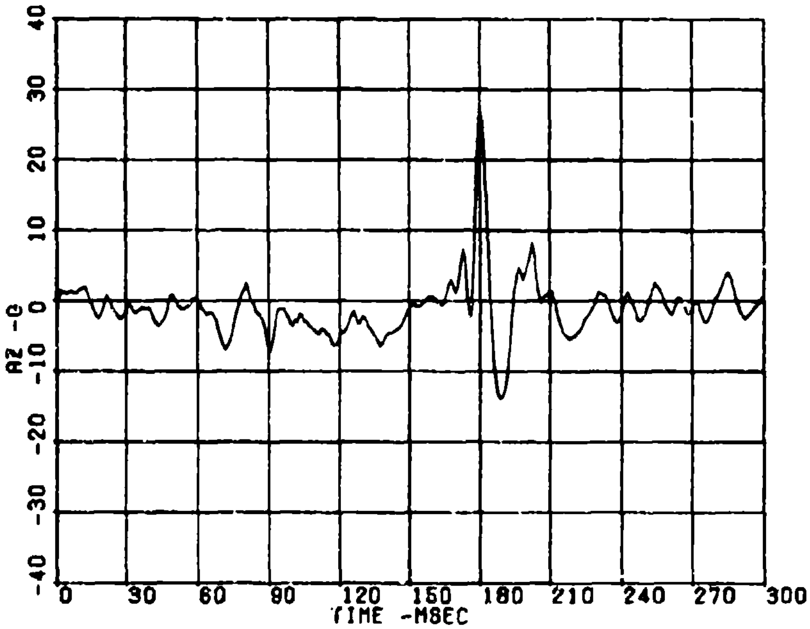


Figure C-62. Sled Test Type II Restraint - Seat Pan Acceleration - Vertical.

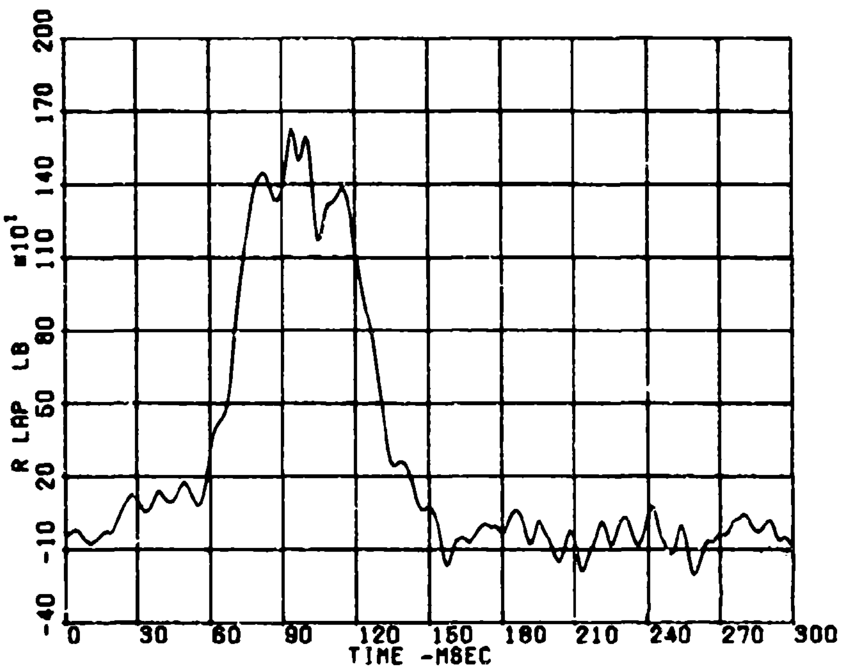


Figure C-63. Sled Test Type II Restraint - Right Lap Belt Load.

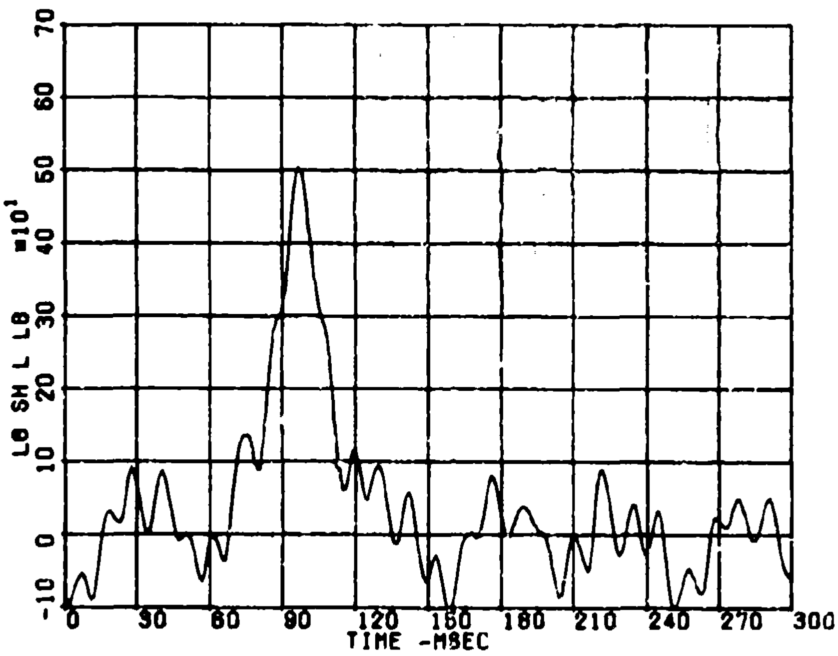


Figure C-64. Sled Test Type II Restraint - Left Lower Shoulder Strap Load.

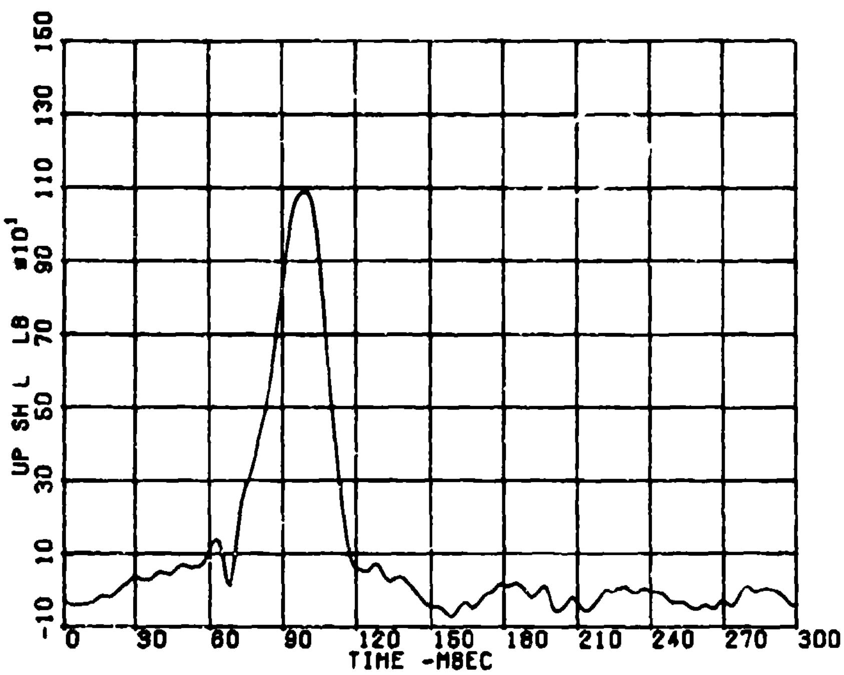


Figure C-65. Sled Test Type II Restraint - Left Upper Shoulder Strap Load.

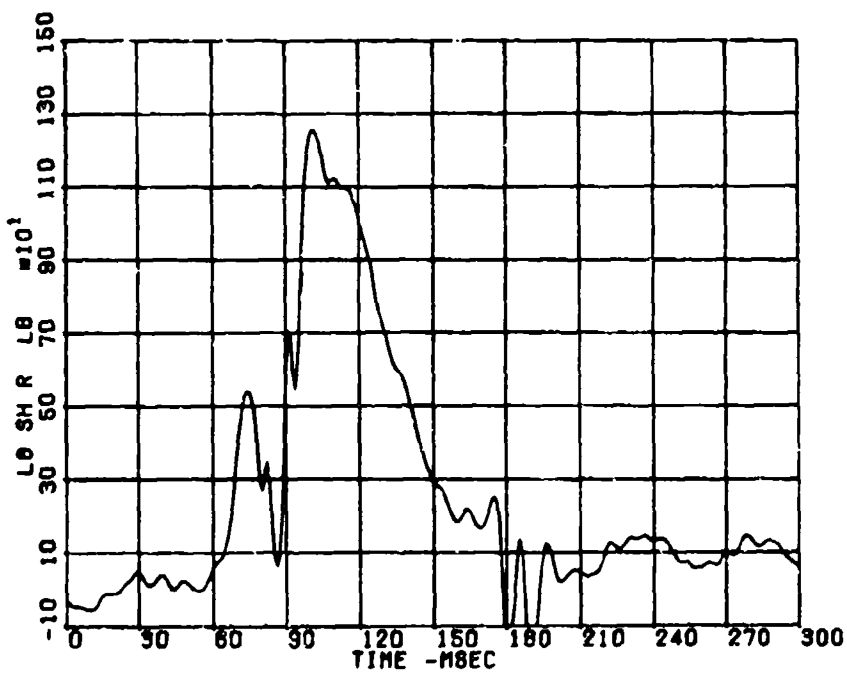


Figure C-66. Sled Test Type II Restraint - Right Lower Shoulder Strap Load.

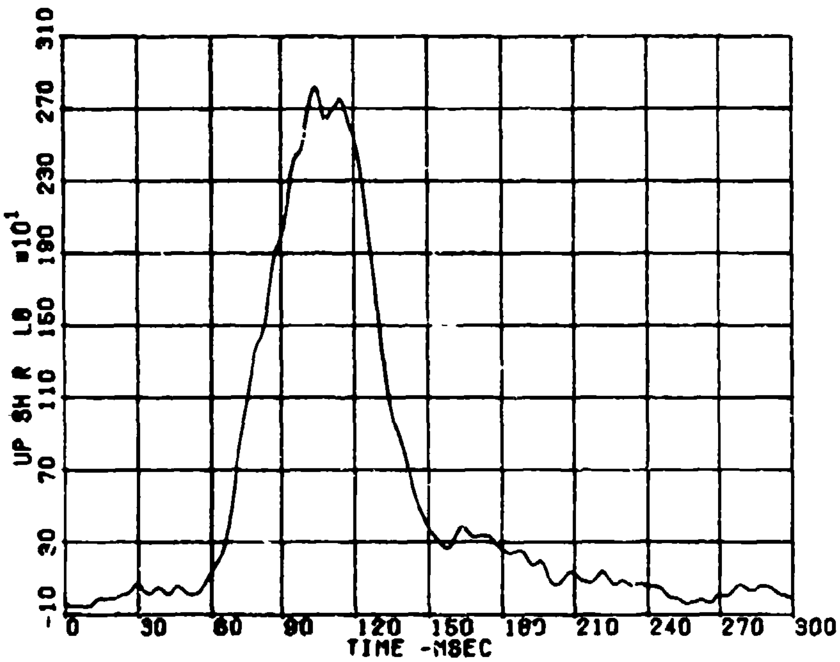


Figure C-67. Sled Test Type II Restraint - Right Upper Shoulder Strap Load.

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