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EVALUATION OF VEST RESTRAINT SYSTEM (VRS)

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INTERIM REPORT
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16. Abstract

An experimental vest-type restraint system has been evaluated in this basic research study for protection of drivers of heavy vehicles in mining operations (load hauling trucks, large loaders, scoopers and tractors). The objective of this unique restraint design is to provide the operator with a restraint system which can be issued as personal equipment and worn continuously in the work environment, thereby increasing usage and improving occupant protection and reducing the risk of injury in a collision or jolt type impact. In this first phase evaluation consisted of tasks including a literature review, analysis of accident data involving drivers of heavy equipment, human and physical factors review of the drivers' environment, and a subjective evaluation of the experimental restraint system. A dynamic test of a prototype restraint system was conducted. Objective evaluation and recommendations are outlined for a dynamic test protocol (Phase II) based upon the findings reported in this study.

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EVALUATION OF VEST RESTRAINT SYSTEM (VRS)

PHASE 1. INTERIM REPORT

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I. SUMMARY

Phase I of this basic innovative research study was intended to provide an objective basis for the conduct of dynamic testing in Phase II. The major conclusions are summarized as follows:

- A preliminary subjective analysis of the proposed restraint system indicates that the prototype vest can be comfortably and easily adjusted. An attractive feature is the concept that belts issued as personal equipment will be kept clean, in good condition, and will receive more use. Problems with fit and accommodation were found, with the shoulder webbing and vest too large for smaller individuals. The metal snaps of the prototype vest were difficult for a large person to close, and the subsequent use of velcro closure is an improvement. It was possible for a person to don the shoulder portion incorrectly. The attractiveness for females and smaller individuals where loose fit occurs may be a problem influencing acceptance. Factors not evaluated included use of the restraint system in hot environments, donning it over heavy clothes, or donning it in the cold with gloves.
- Nationwide accident data available to us (SDS data from workers compensation files) do not provide sufficient detail for meaningful analysis and use as a basis for identifying injury causations.
- Seat belts or vests may be expected to help prevent some injuries to heavy equipment operators under conditions of severe jolt, rollover, or impact, and to prevent ejection. The lap belt attachment alone would not be expected to reduce severity or incidence of head impact (indicated as injury site in six percent of accident cases reported) except in cases of vertical jolts, or result in significant influence or

prevention of chronic back problems (seldom reported to be a problem in these cases, and usually associated with ride quality of the seat).

- Review of accident reports available indicates that the most prevalent type of injury to heavy equipment operators occurs from vertical impacts of vehicles hitting holes in the road (18.6%), followed closely by vehicles striking solid objects such as rocks or other vehicles (17.4%). Other injuries were attributed in the accident reports to rough ground, running off a ledge or rock, hit by shovel bucket while loading, and the vehicle's being hit by a falling rock while loading. These impact factors accounted for 76.4 percent of the injuries reported. Only three percent involved rollovers.
- Vertical jolt is a significant cause of the injuries reported, followed by collision impact.
- Present use of seat belts appears to be very low. In only five percent of accident cases reported was use or non-use reported. In only two percent were seat belts reported to be worn, despite company policies that operators will wear belts.
- A new restraint system is warranted, based upon present usage and need for increased protection.
- Site accident data do not provide sufficient detail to determine specific injuries with confidence, or to conduct further analyses of injury causation.
- More than half (55.6%) of the reported injuries involved vertical loadings (+Gz) on the driver, resulting from bumps, jolts, and vertical impacts. Some 15.7% involved a frontal (-Gx) collision, and 13.5% were reported in lateral (±Gy) impact. These data indicate the most

prevalent directions of loading on the driver and suggest priority of test orientations.

- A preliminary dynamic frontal deceleration (30 g) at 20 mph velocity change of a 50th percentile dummy resulted in failure of the restraint at the stitching of the straps.
- Based upon the foregoing findings, a Phase-II dynamic test protocol is recommended as follows:

1. All tests will be conducted on the UMTRI Impact Sled with an instrumented 50th percentile male anthropomorphic dummy. No surrounding cab structure will be used.
2. Three frontal impact tests will be conducted with a velocity change of 20 mph and an average deceleration of 30 G.
   a. One test will be with a fixed vehicle seat and the proposed restraint system.
   b. One test will be with a fixed vehicle seat and a conventional lap belt.
   c. One test will be with a suspension-type vehicle seat and the proposed restraint system.
3. Two lateral impact tests will be conducted with a velocity change of 10 mph and an average deceleration of 20 G.
   a. One test will be with a fixed vehicle seat and the proposed restraint system.
   b. One test will be with a fixed vehicle seat and a conventional lap belt.
4. Four vertical jolt tests will be conducted with a 5-6 inch peak to peak sinusoidal displacement at 5 Hz.

a. Two tests will be with a fixed vehicle seat and the proposed restraint system.

b. One test will be with a fixed vehicle seat and a conventional lap belt.

c. One test will be with a fixed vehicle seat and no restraint system.

II. INTRODUCTION

The accident environment of the heavy equipment operator differs in several important respects from that of most other types of vehicles. Due to the extreme mass of the vehicle (ranging up to 180 tons or more) in relation to non-solid objects which may be struck, the impact generally results in low decelerations and the resultant motion (kinematics) of the driver may be minimal.

The limited accident data appear to indicate that the most frequent injury mechanism is a jolt caused by a vehicle hitting a hole in the road, or a solid object, or rough ground, by its running off a rock or ledge, being hit by a shovel bucket while loading, or by the vehicle's being hit by a falling rock while loading. These conditions account for three out of four driver accident injuries reported.

Many injuries are occurring and could be prevented by operators' use of improved restraint systems. Before any system can be incorporated in a vehicle it is necessary to conduct tests to determine that the system functions as designed. Frequently dynamic tests will reveal unanticipated flaws that need to be corrected prior to installation.

In the case of operators of heavy equipment--loaders, tractors, and trucks--there are specific environmental problems which differ from that of other types of vehicles. The basic problem is that of providing the operator a simple, comfortable, effective restraint system. However, this is compounded by the problem of how to ensure that the system will actually be worn by the drivers. That this is a real and universal problem is indicated by numerous studies concluding that drivers do not appear to be using the belts presently supplied with vehicles. In heavy equipment most of the belts we have observed have been left unattached on the floor. They become very dirty and almost unusable.

The U.S. Bureau of Mines has devised a unique solution to this problem of non-use. The proposed vest restraint (VRS) system is intended to be issued to the drivers as personal equipment. Rather than being permanently installed in the vehicle, it could be worn to and from work by the driver, and simply "plugged in" to the vehicle being used. As personal equipment it would probably be kept clean, and the intent is to encourage greater driver usage. Various aspects of this solution are addressed in the following report.

The following interim report presents the results of the Phase I background evaluation of the U.S. Bureau of Mines VRS system, fabricated by Kaiser Manufacturing Company of Minneapolis for experimental use. The purpose of this preliminary review is to provide an objective basis to ensure that the test protocol to be conducted in Phase 2 will be most productive and that the dynamic tests will realistically address the collision environment to which drivers of heavy equipment are most commonly exposed.

To this end, the general objective of this basic research program has been to use a systems engineering approach to consider various aspects of the potential impact or vibration environment and effectiveness of the belt system proposed. In this regard, the restraint system has been evaluated from the disciplines of biomechanics, ergonomics, physical factors, and physical anthropology. Areas were examined from the broad point of view of experts within these areas.

Specific tasks accomplished during this phase include a limited literature review, an analysis of accidents involving drivers of heavy equipment, examination of the operator's environment from human and physical factors, ergonomics, and physical anthropology points of view, one dynamic test of a prototype system, and consideration of potential problems and effectiveness of the proposed belt system. These considerations have been kept in mind in formulating the dynamic test protocol, proposed to be conducted in Phase II.

III. LITERATURE SEARCH

A literature search was initiated at the onset of this program to try to identify studies in which the results would be particularly pertinent to this evaluation. The proposed U.S. Bureau of Mines vest restraint system features unique design considerations as well as aspects related to the human user's comfort, fit, acceptability, and protection. The features can be evaluated to some extent on a basis of prior experience and testing. In this regard no attempt was made to survey the entire field of restraint systems, since there are literally thousands of publications on restraint systems. Rather, the survey was aimed at selectively locating the few studies, patents, or publications where features were similar to those of the proposed system.

Initially, a Lockheed DIALOG computer search was conducted. The Dialog program is based upon three data bases, including all publications of the National Technical Information Service (NTIS), standards and specifications, and Engineering Index. However, this resulted in only 26 references. Of these, only four were considered to be at all applicable to the unique characteristics of the proposed system. As a result, this search was supplemented by review of UMTRI library files and personal files, containing over 6,000 publications on restraint systems.

As background, prior studies were reviewed which investigated the relationship between seat belts and injury reduction in heavy trucks. Although the highway environment differs in some respects from that of the open pit mine, heavy commercial trucks are the closest in size to the vehicles under study.

In the United States commercial motor carrier accident data are reported by the Bureau of Motor Carrier Safety (BMCS), and in selected cases by the National Transportation Safety Board (NTSB). An analysis and summary of 497 heavy truck accidents investigated between 1973 and 1976 was reviewed (Bureau of Motor Carrier Safety, 1977), as well as a more recent analysis of 346 heavy truck accidents during the 1977-1979 period (Bureau of Motor Carrier Safety, 1981). There were also 14 NTSB investigations during that period not included.

In the 843 heavy truck accidents investigated by BMCS between 1973 and 1979, 518 involved collisions. Of these, 141 accidents involved ejections of the non-restrained occupants, resulting in 147 fatalities and 53 injuries. During this period there were 137 head-on collisions, 226 rear-end collisions, 84 side impacts, and 17 other types of collisions. Single-vehicle accidents are separately categorized. Of 325 accidents involving only a single vehicle during this period, 211 trucks ran off the road and overturned, 24 overturned on the roadway, 38 hit a fixed object, 28 were loading/unloading accidents, and 24 were from other causes. No attempt in these statistical studies was made by BMCS to evaluate seat belt effectiveness, but it seems apparent that had these truck occupants been protected by seat belts, many less fatalities and less severe injuries would have occurred. The high fatality rate attributed to ejections, as well as roll-over and collision accidents where compartment space was not crushed in, might be areas where seat belts could have achieved injury reduction.

In Sweden heavy trucks are involved in 15 percent of the approximately 1,000 fatal accidents per year. A recent study of selected commercial truck accidents involving Volvos aimed to investigate injury location and causation as a basis for improving collision protection (Hogstrom and Svenson, 1980). Along with development of a safety steering wheel and reinforced cabs which are crash tested, it was found that the best injury reducing means was a three-point retractable safety belt. The authors of this Swedish study predicted that had this safety belt been used it could have minimized the injuries to the drivers in 74 percent of the truck accidents examined. Using the Abbreviated Injury Scale (AIS), compiled by the American Association for Automotive Medicine as a basis, they found that the six-point AIS rating in each case of injury could be reduced by at least one unit by use of the restraint system.

This finding is consistent with an earlier Department of Transport study of heavy truck accidents in England (Gratton & Hobbs, 1978). Utilizing the AIS criteria, it was reported that wearing of a seat belt would have reduced the mean overall level of injury in the accidents selected for study by one level. It was also concluded that seat belts would have reduced the severity of injury for about one-third to one-half of the fatalities.

Earlier this year a study of forklift truck overturns was completed at UMTRI which is also relevant to protection in heavy vehicles (Melvin, et al., 1982). In this study a number of rollover accidents were simulated using a variety of turning maneuvers and drop tests. The operator was simulated by restrained and unrestrained instrumented anthropomorphic dummies. A preceding study involving some 36 rollovers was conducted to simulate field accidents and evaluate the effects of restraint systems on the operator's motion during truck overturns (King, 1981).

Another area investigated in the literature included restraining devices similar to that proposed. The computer search resulted in no U.S.patents with some similarities. There may be others which were not accessed for some reason.

A prior literature and information search was conducted for the Bureau of Mines in regard to a study entitled, Development of Improved Seatbelt Systems for Surface Mining Equipment" (Carlson and Hoffman, 1981), although references were not provided in this report.

A review of previous vest-type restraint systems shows that few have been intended for ground vehicle operator use. One, however, is a form fitting garment, which was designed by J.W. Young at Ford Motor Company in 1968 (Snyder, 1970), and is shown in Figure 1.

Several early aircraft pilot restraints incorporated vest concepts. After analyzing the distribution of mass of the upper body, and finding that 90 percent of the upper body mass is above the fifth thoracic vertebra (level of armpits), Poppen (1958) designed the Douglas Model D prototype harness, illustrated in Fig. 2. This is one of the few harnesses designed by a physician on the basis of anatomical function and support required for upward ejection. While this was certainly not a pure vest system, the width and construction over the thoracic area, combined with a side form-fitting "girdle" belt, make it of peripheral interest (Snyder, 1970; p. 532).

Utilizing the principles of distributing impact force over a large area and to parts of the body best able to withstand high impact forces Bierman (1947) designed a vest harness of undrawn nylon (Fig. 3). Tests indicated this would protect humans from forces equivalent to 10,000

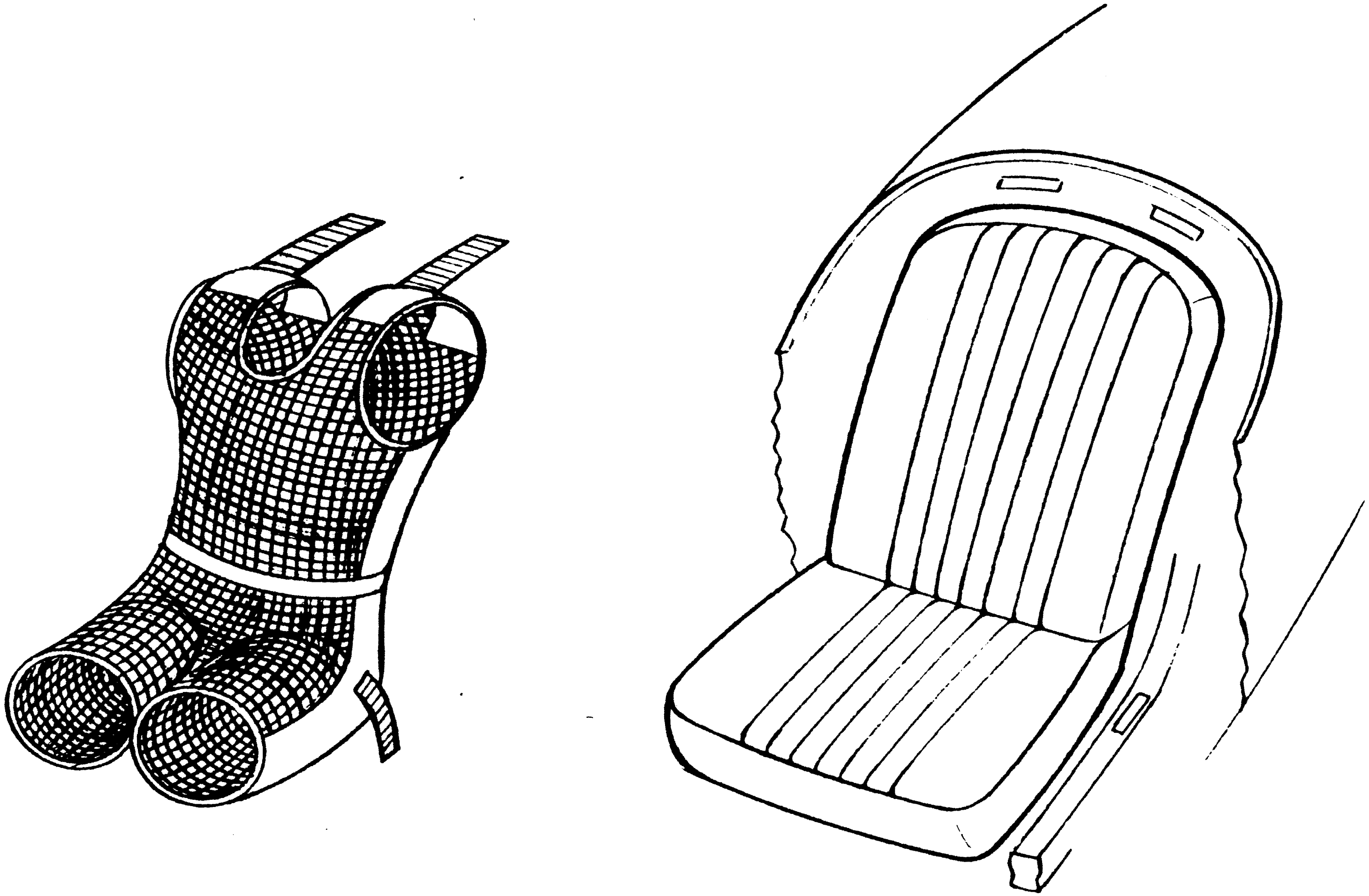

Fig. 1. Experimental full-body vest-type restraint system concept designed for race drivers, after Young (Snyder, 1970).

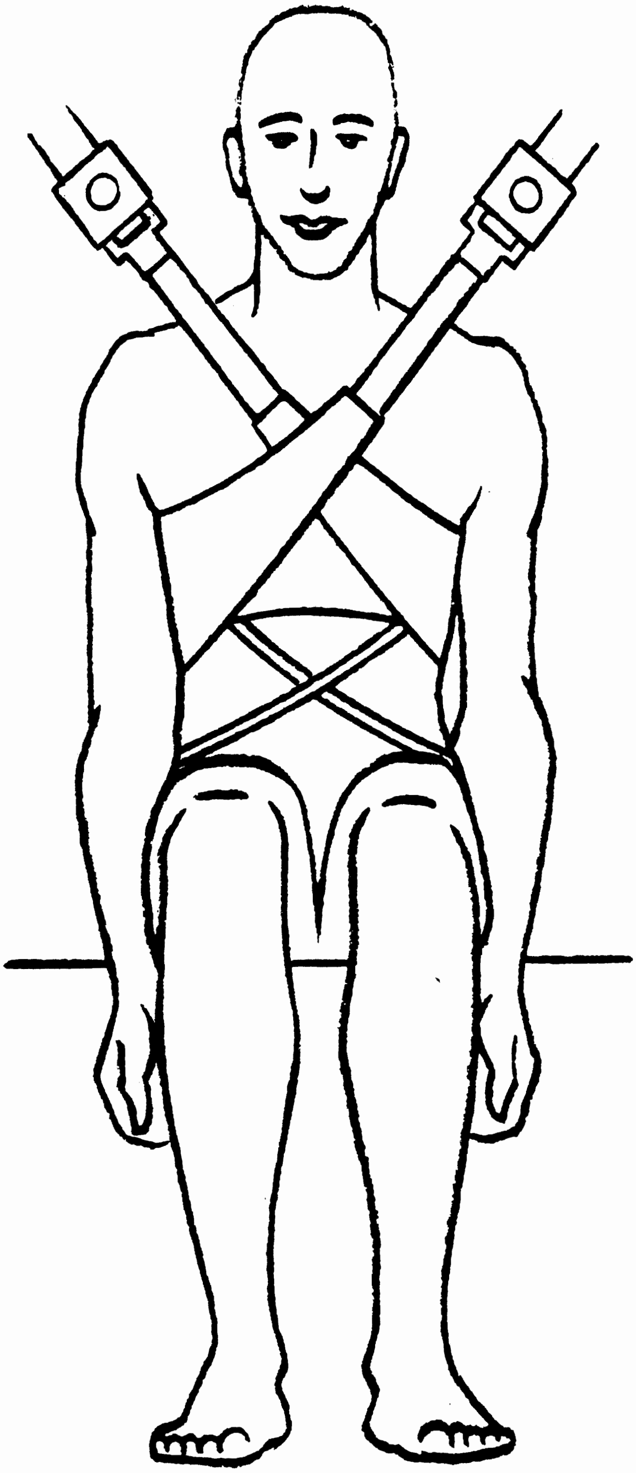

Fig. 2. Experimental Douglas Model D aircraft restraint harness designed by Poppen (1958) to offer the pilot maximum protection in upward ejection.

lbs. on a dummy. With this system human volunteers exposed to 15 foot free falls were decelerated in less than 0.2 seconds at only 6 g.

The application of a vest-type restraint was proposed about 1947 for airline pilots and passengers, by Flight Safety, Inc., a company in Philadelphia, based upon Dr. Bierman's designs.

This vest was constructed of nylon duck with a strength of 14,000 lbs. (400 lbs. per linear inch). It was chosen also because of being sufficiently elastic to provide the form-fitting characteristics necessary for maximum distribution of an impact load over the thorax area contacted by the vest. Design strength was 4,800 lbs. at each waist attachment and 2,400 lbs. at each shoulder strap. The vest provided an area of 156 square inches protection, in contrast to about 40 square inches of usable area in the standard lap belt. UNOLYN (trade name) straps were designed to protect against 100 g peak impacts. A unique feature (1947) was the use of inertia locks.

This vest design is illustrated in Fig. 4 for the airline pilot, and in Fig. 5 for the passenger configuration. Of primary importance was the restraint to the upper body to prevent head and upper torso contact with injurious structures during a crash impact.

A recent application of the vest-restraint concept has been designed for mobile crew members of aircraft in the RAF. Still in the design state, the proposed safety harness consists of a series of straps sewn onto a standard life preserver. The objective of this design is primarily to prevent aircrew working near open doors from falling out of the aircraft. Drop tests with anthropomorphic dummies up to 9.7 G resulted in no damage to the straps of the safety harness and its stitching (Reader, 1980).

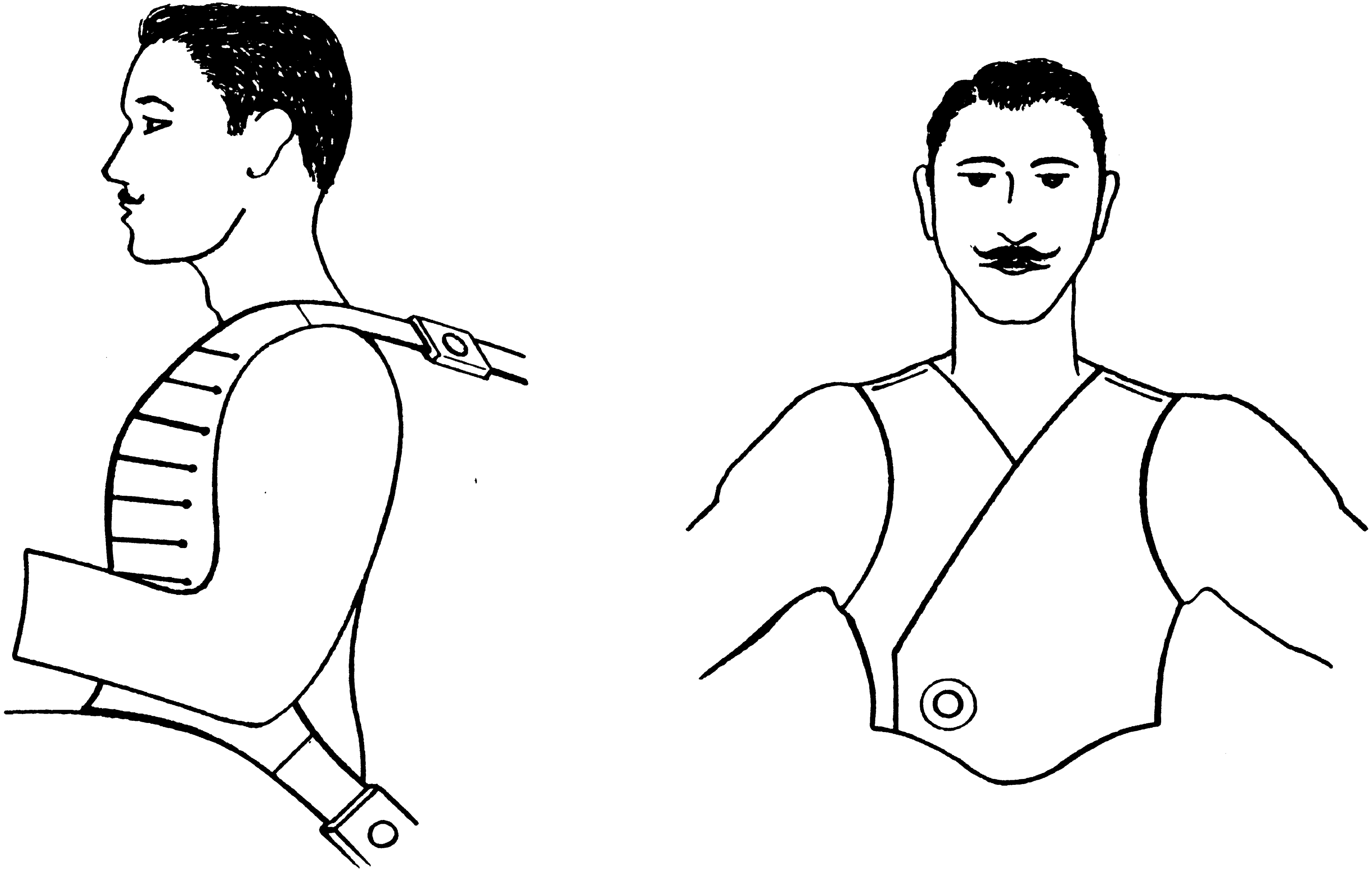

Fig. 3. U.S. Navy experimental Model C vest restraint (Bierman, 1947).

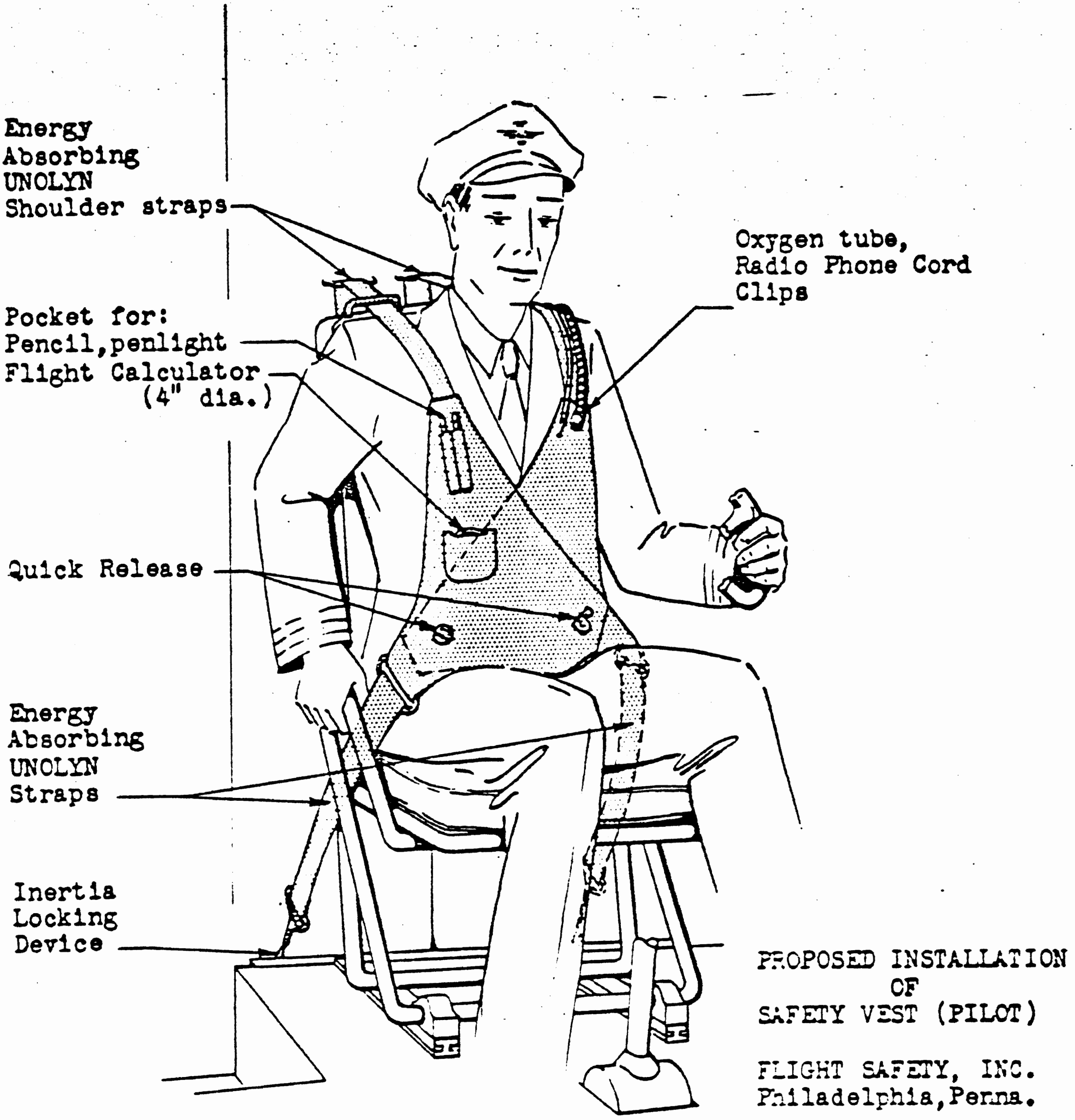

Fig. 4. Illustration of proposed vest-type restraint system for airline pilot by Flight Safety, Inc. in 1947, based upon U.S. Navy research of Bierman.

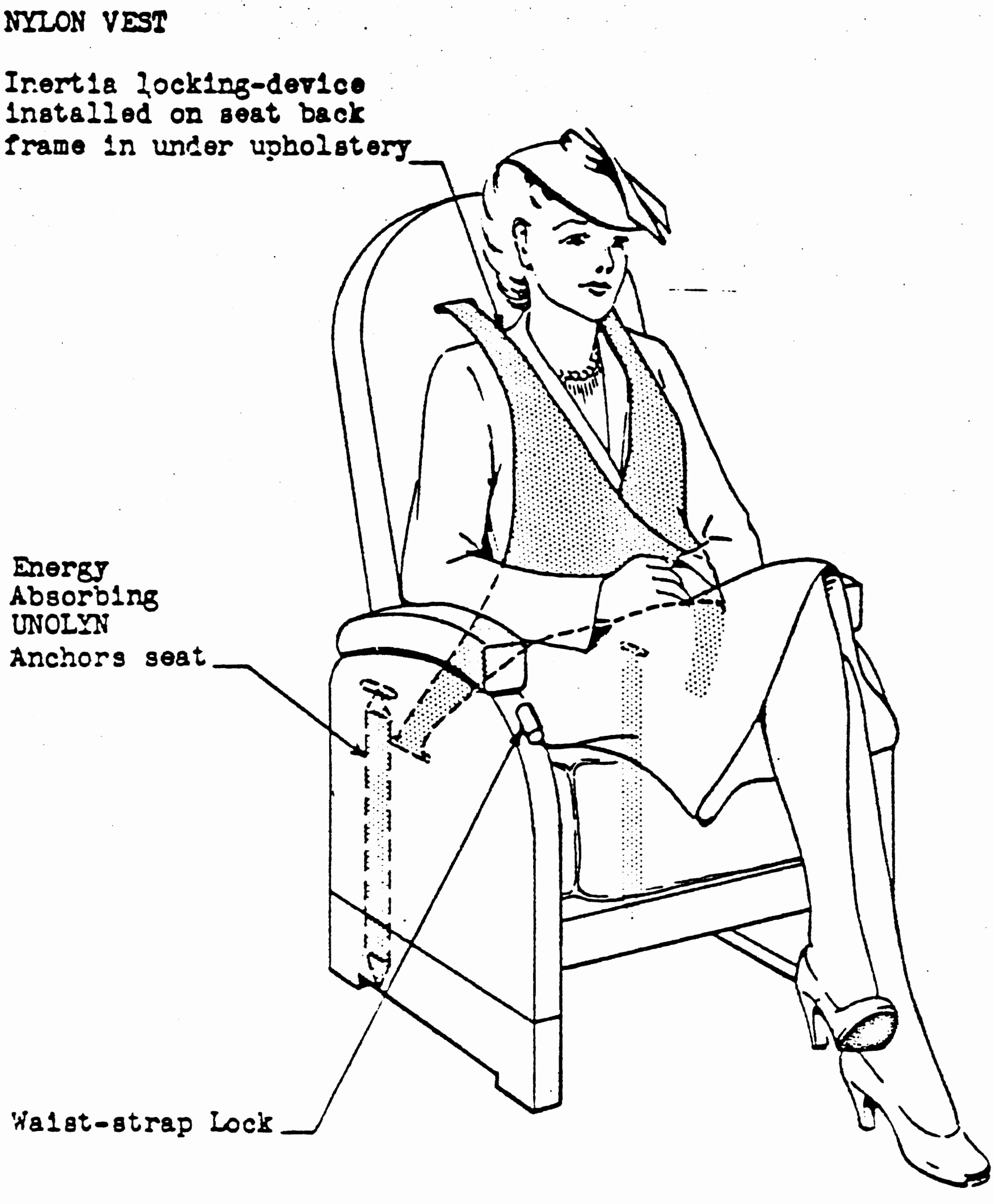

Fig. 5. Restraint concept for "Safety Vest" for airline passengers, proposed in 1947.

Vest-type restraint systems have been previously used or evaluated primarily with regard to aviation or aerospace environments. Probably the largest collection of vest restraint designs can be found in a study conducted at Northrop Corporation by Ripley (1966). A number of advanced techniques evaluated for space flight and vest systems were among those offering the greatest potential protection to the operators, and are illustrated in Figs. 6-23, following.

Two torso "vest" type restraint systems were fabricated, one of dacron webbing, and the other of dacron webbing and dacron fabric, were also tested by Northrup in 1966. Each vest consisted of a form fitting front and eight straps to the seat. The dacron webbing vest was tested to 25,000 lbs. prior to stitching failure of the upper right strap. The dacron fabric vest was tested to 19,040 lbs., when first stitching failure occurred (Ripley, 1966). Fig. 20 illustrates such a system.

A full-body restraint is shown in Fig. 21, and Fig. 22 shows, a concept for early space crewman designed by Snyder at the Applied Research Laboratory of the University of Arizona College of Engineering in 1959-1960, employing extremity retraction and a protective vest.

The space crew restraint system used in APOLLO missions is illustrated in Fig. 23. Note that it represents a much simpler system than the foregoing hard-shell concepts. While no "vest" per se was worn, note the arrangement of upper torso restraint straps and undergarment.

This literature survey indicates that vest-type restraint systems have been associated with designs and concepts offering optimum protection to the occupant. Such designs have primarily been related to

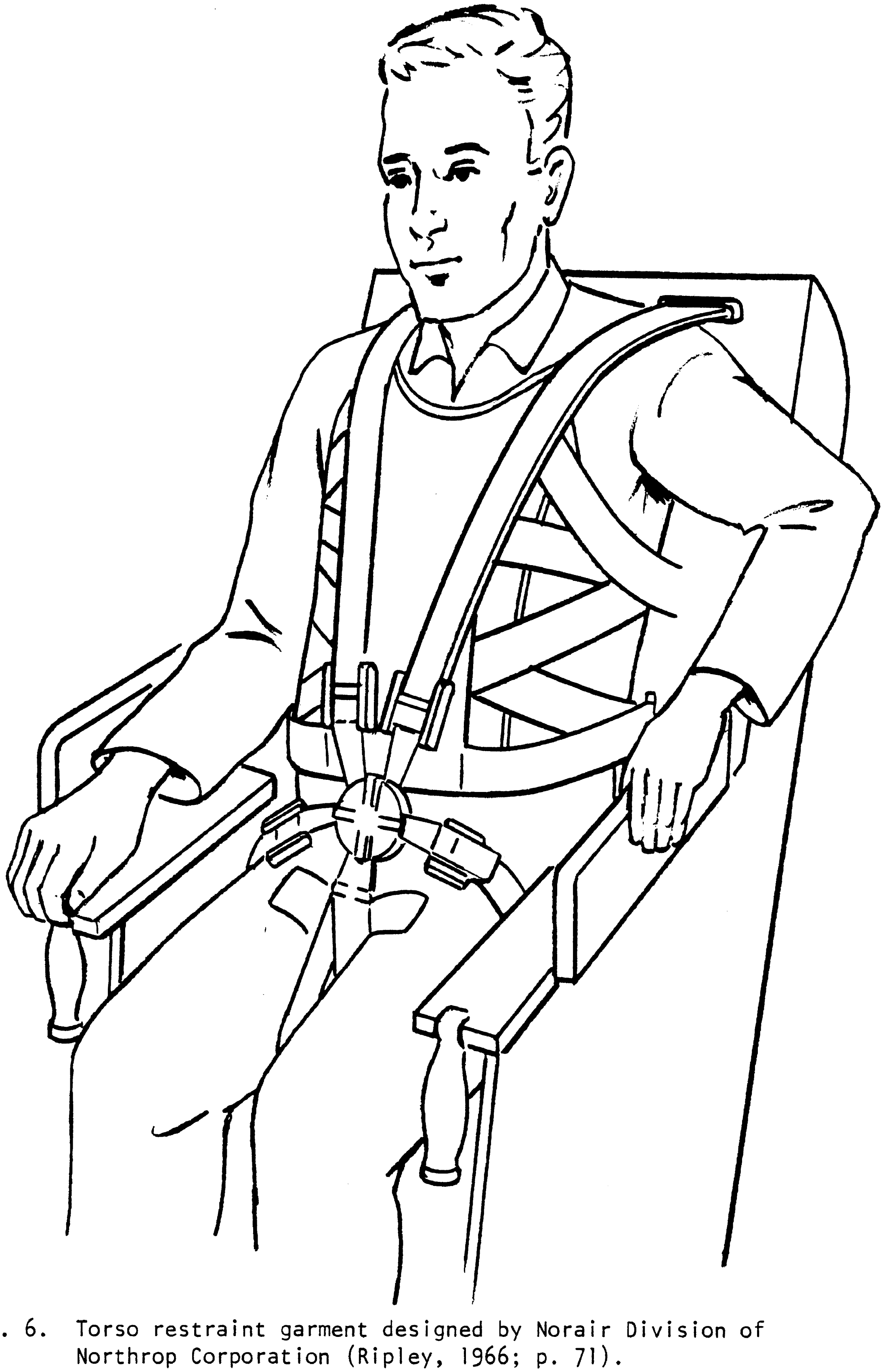

Fig. 6. Torso restraint garment designed by Norair Division of Northrop Corporation (Ripley, 1966; p. 71).

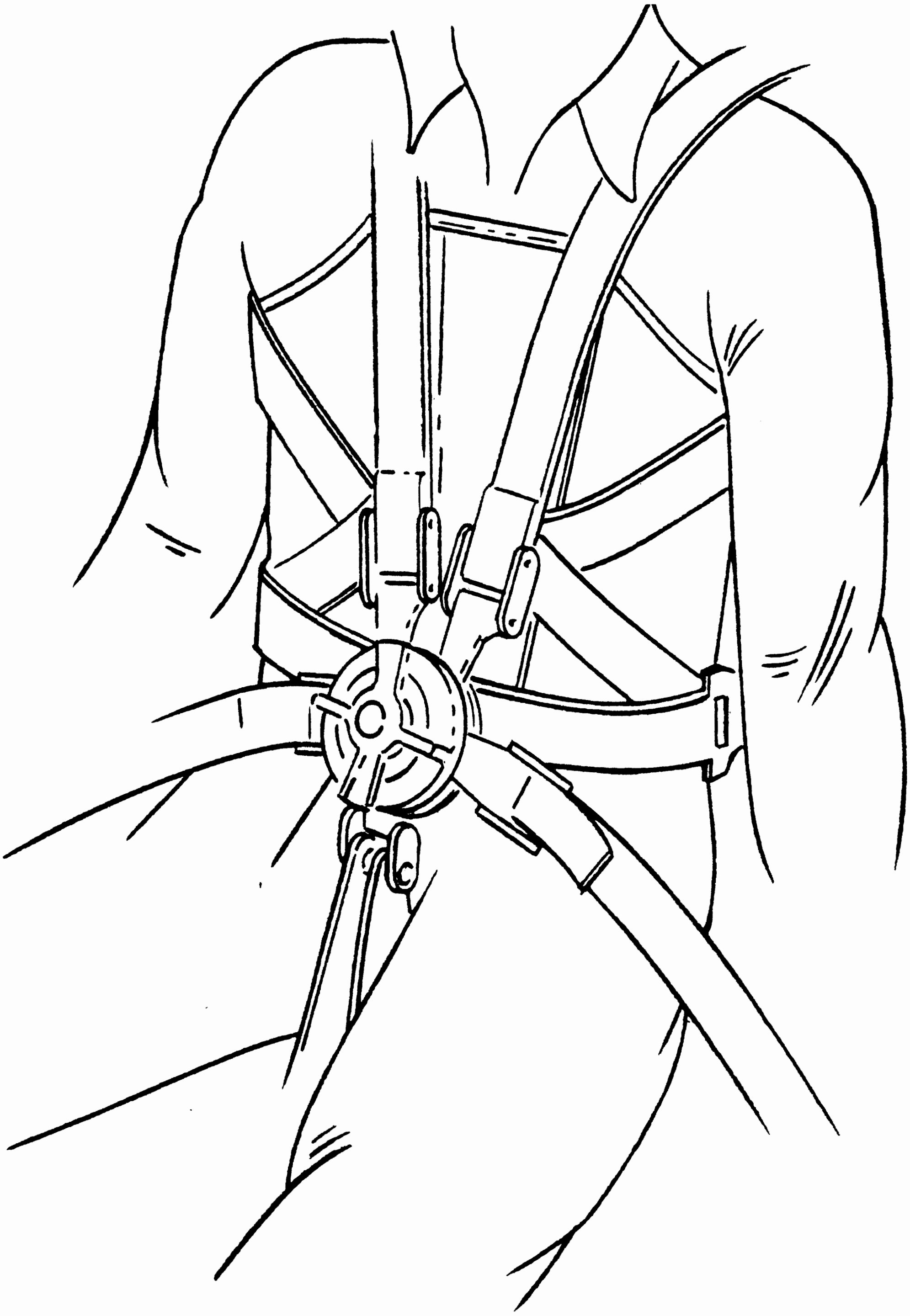

Fig. 7. Full body restraint system incorporating webbed "vest" upper torso protection (Ripley, 1966).

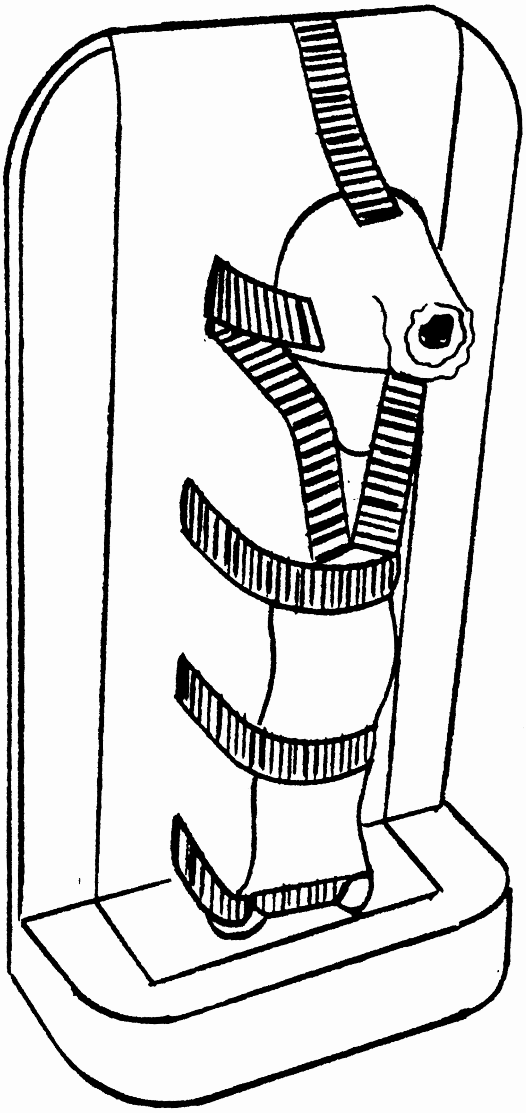

Fig. 8. An example of an advanced experimental restraint system providing protection to extreme impact forces (Lombard, 1964; 1966). Such restraint has been tested with quinea pigs and small primates. Guinea pigs have survived up to 240 g for 3 milliseconds duration at 100,000 g per second onset rate.

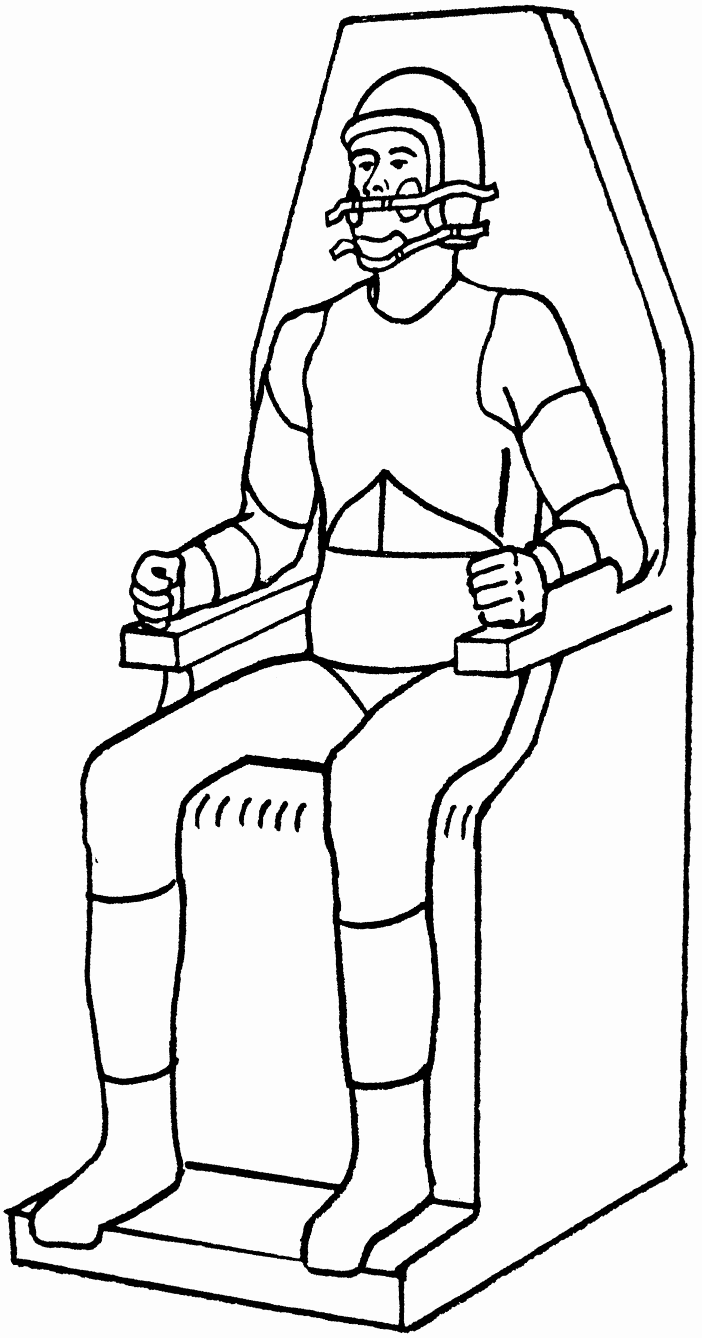

Fig. 9. Early space vehicle restraint concept incorporating restraint of the arms, legs and head, and upper body restraint (Ripley, 1966).

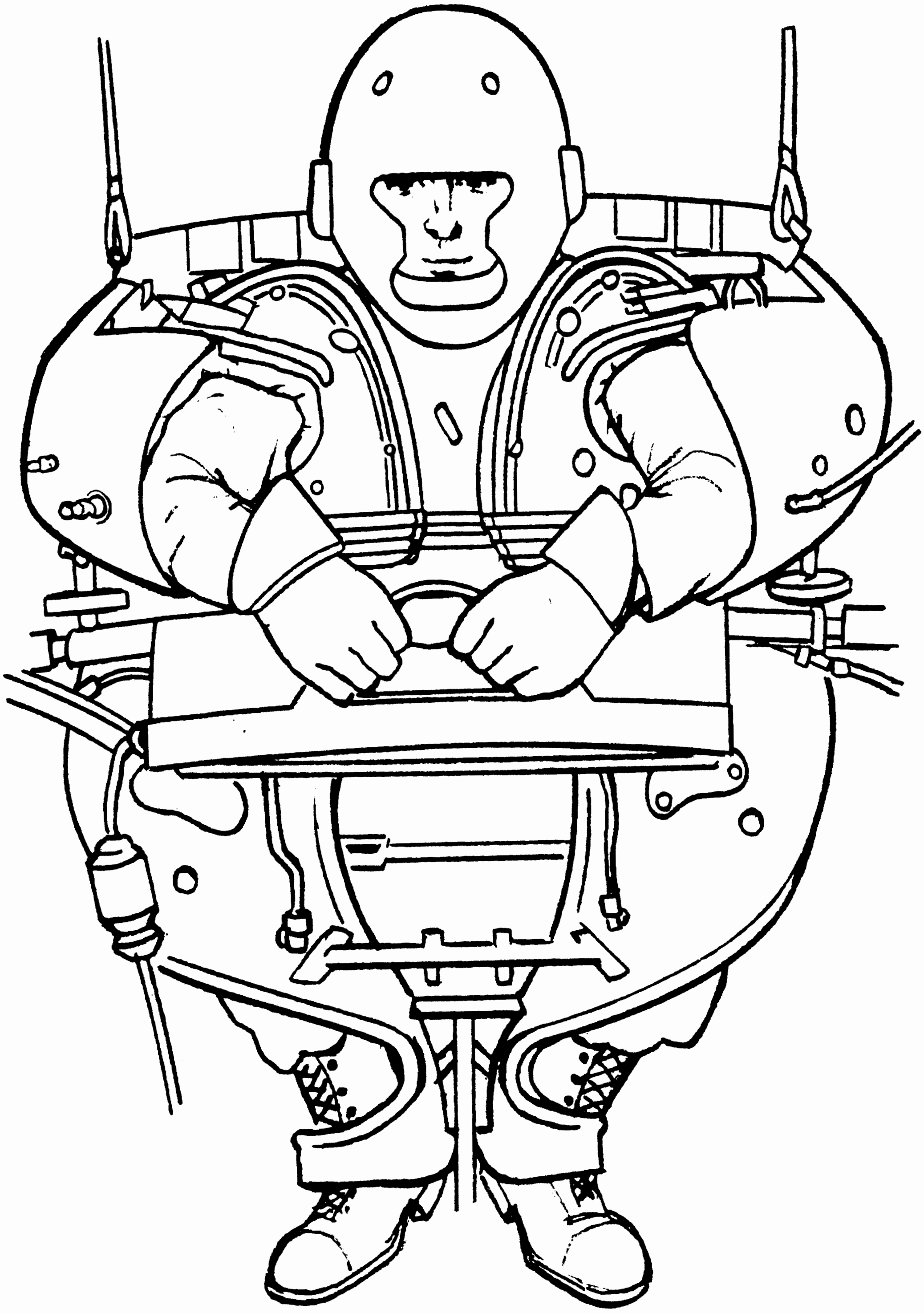

Fig. 10. Example of early "clamshell" experimental restraint for space crew, using hard-shell concept. The torso restraint is composed of shoulder, chest and abdomen hard shell units which are preloaded and restrained by cables tensioned by tak-up reels. The abdomen and chest units are lined with air bladders, and the shoulder pads lined with foam rubber. Space flight restraints have gravitated toward less bulky "shirtsleeve" environments (Ripley, 1966, p. 133).

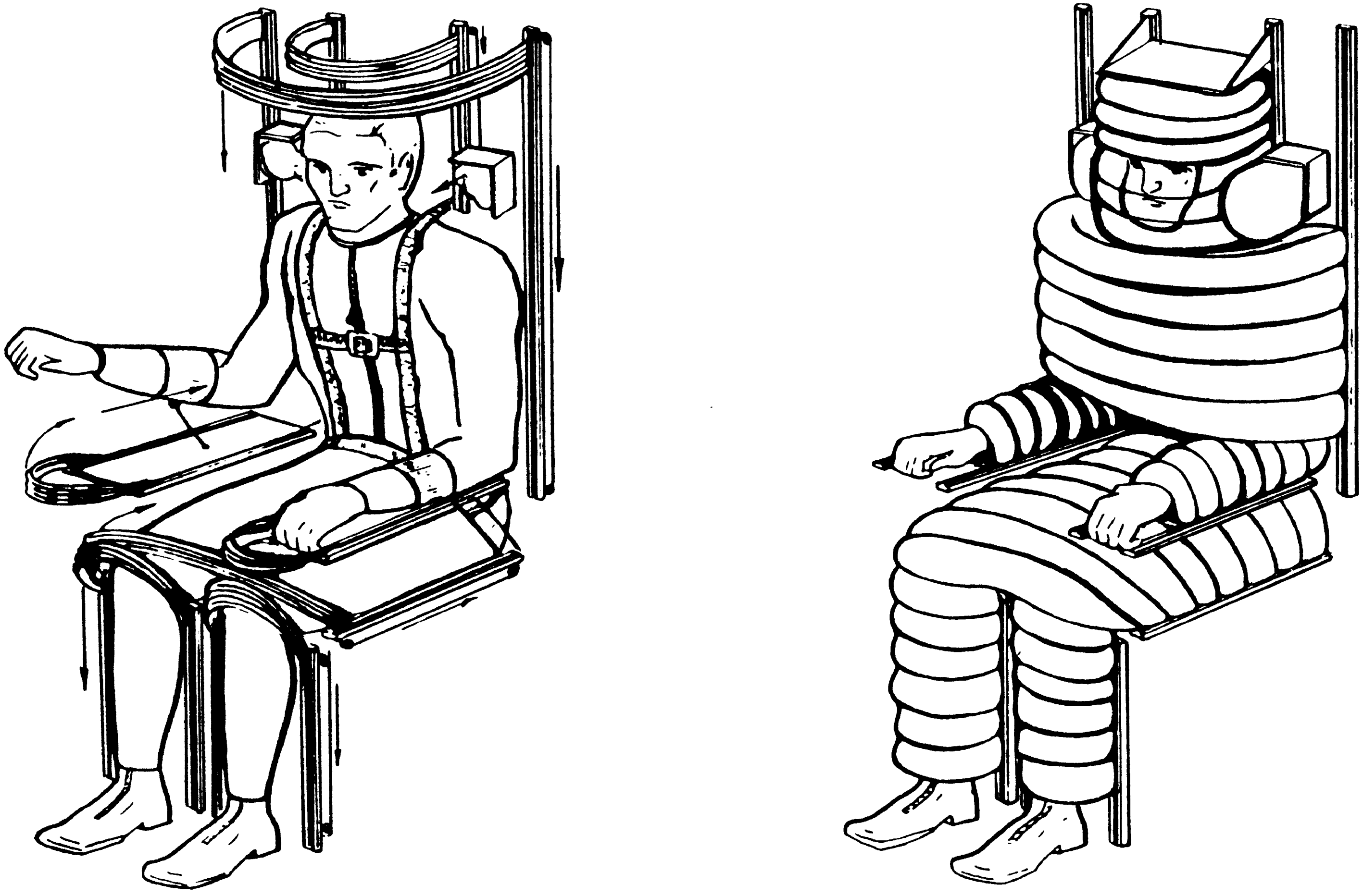

Fig. 11. "Caterpiller" advanced space restraint concept, showing basic retracted system or left, and activated full restraint system on right. The system employs inflatable fabric bags or bladders supported by semi-circular metal formers (Ripley, 1966, p.145).

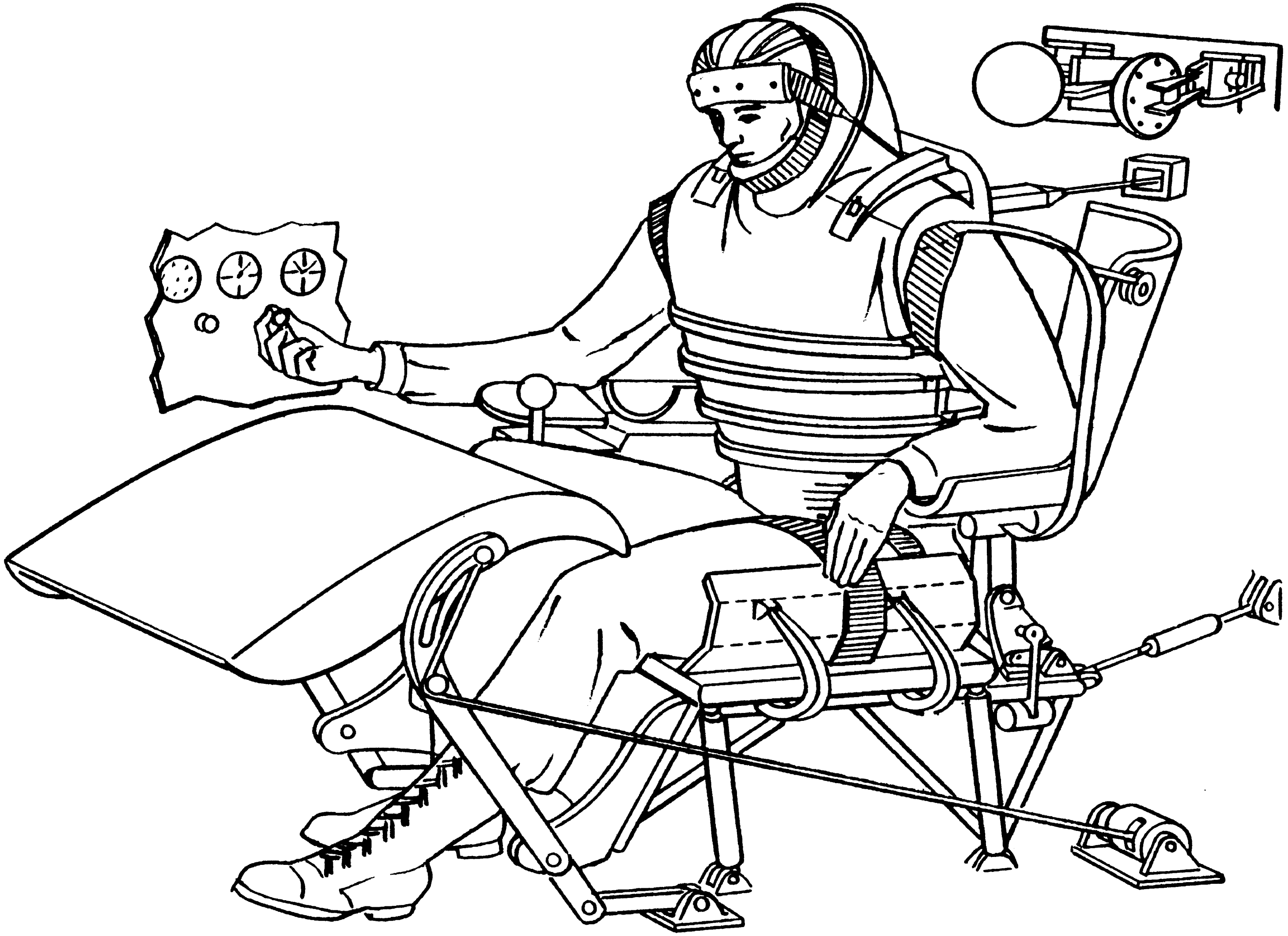

Fig. 12. Operational concept for optimal torso protection recommended by Northrup for space vehicles. Rigid form-fitting encasement of the body was found to offer "far greater protection" than any of the soft body-restraint systems. This system employed an intergral hard shell torso and seat back fitted to the occupant (Ripley, 1966, p.157).

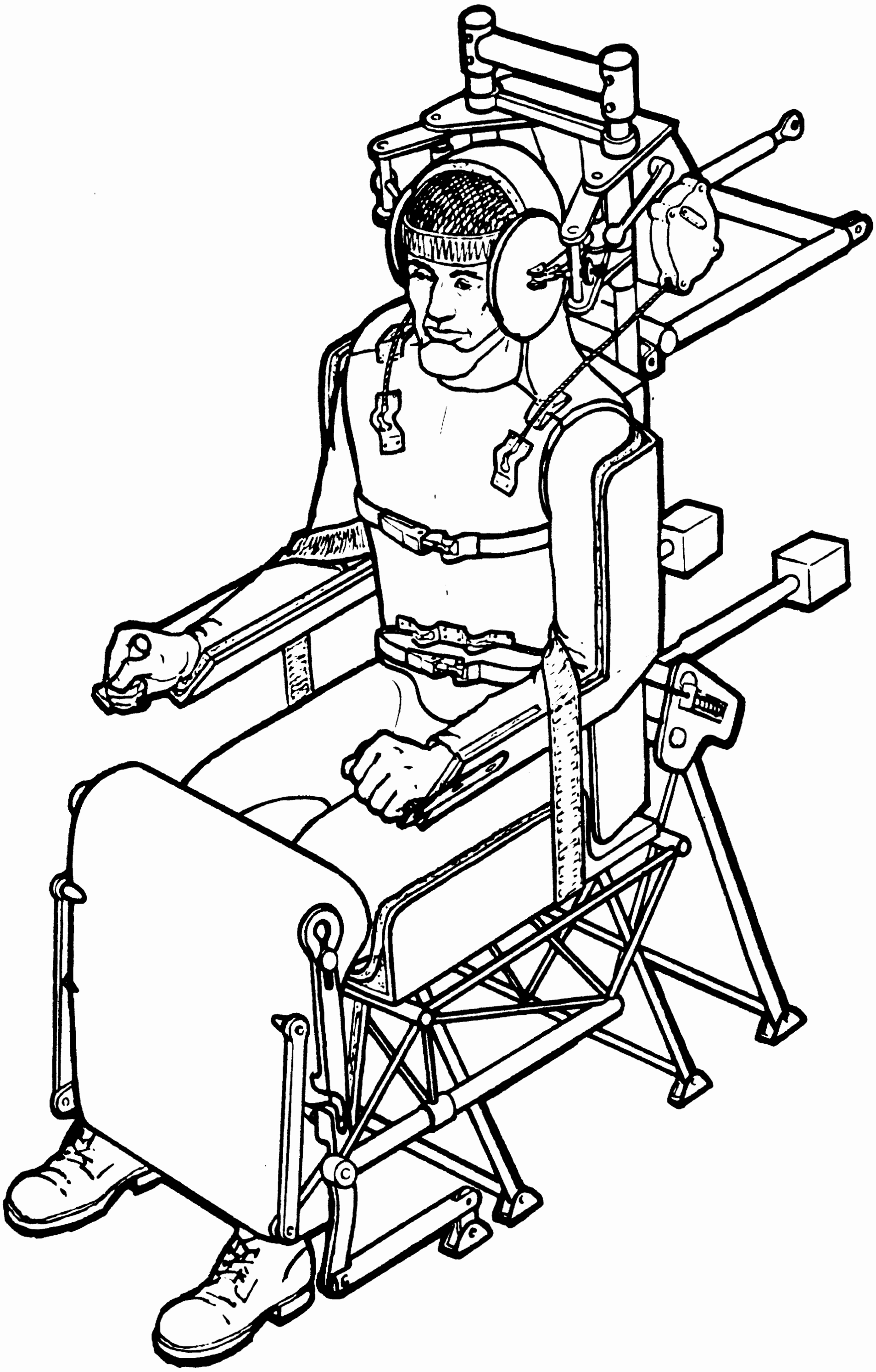

Fig. 13. Same system as in Fig. 10, in fully restrained position (Ripley, 1966).

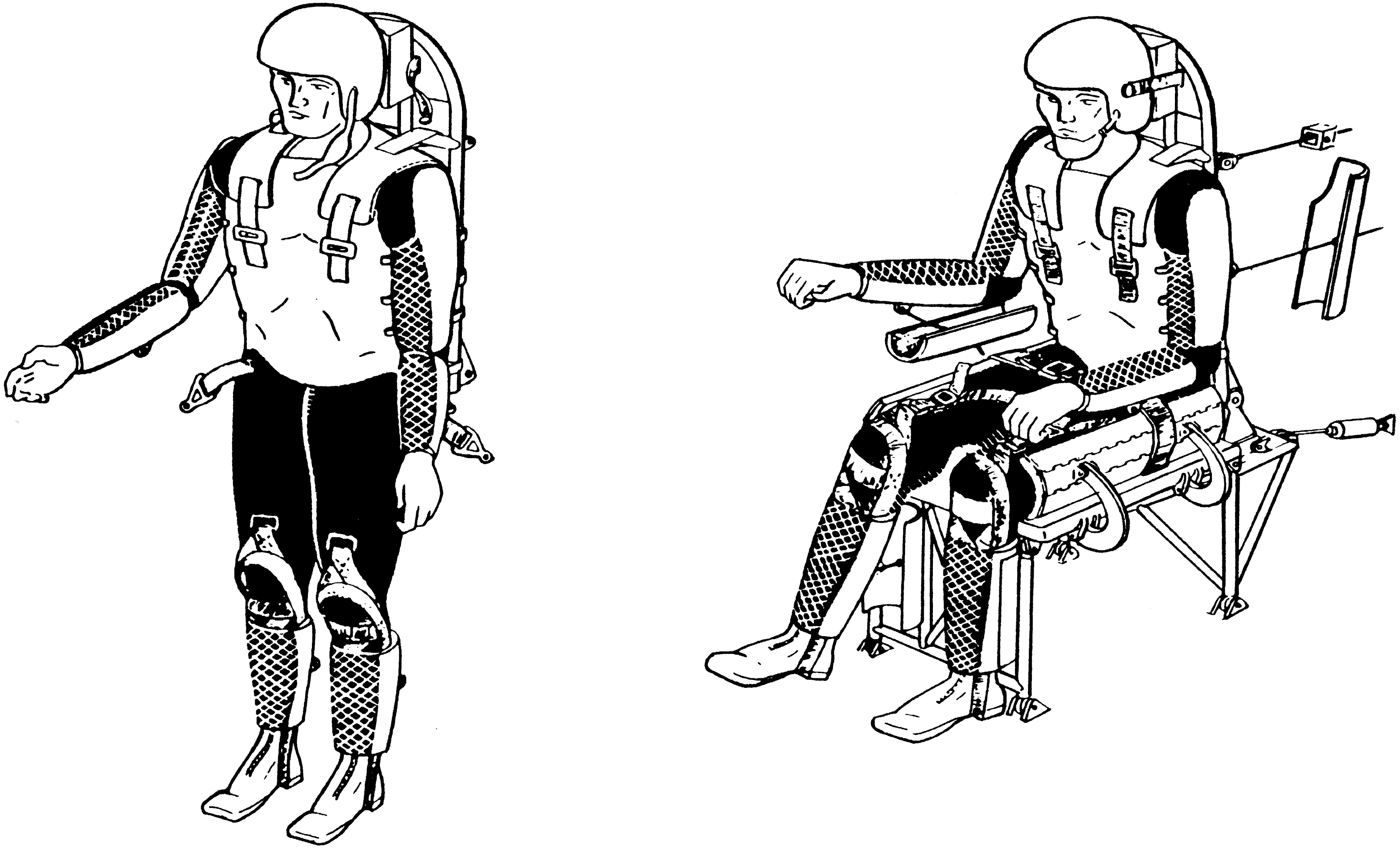

Fig. 14. Hard-shell spacecraft restraint system. On left crewman is between stations, and on right restraint is shown in seated position. Note vest torso protection (Ripley, 1966).

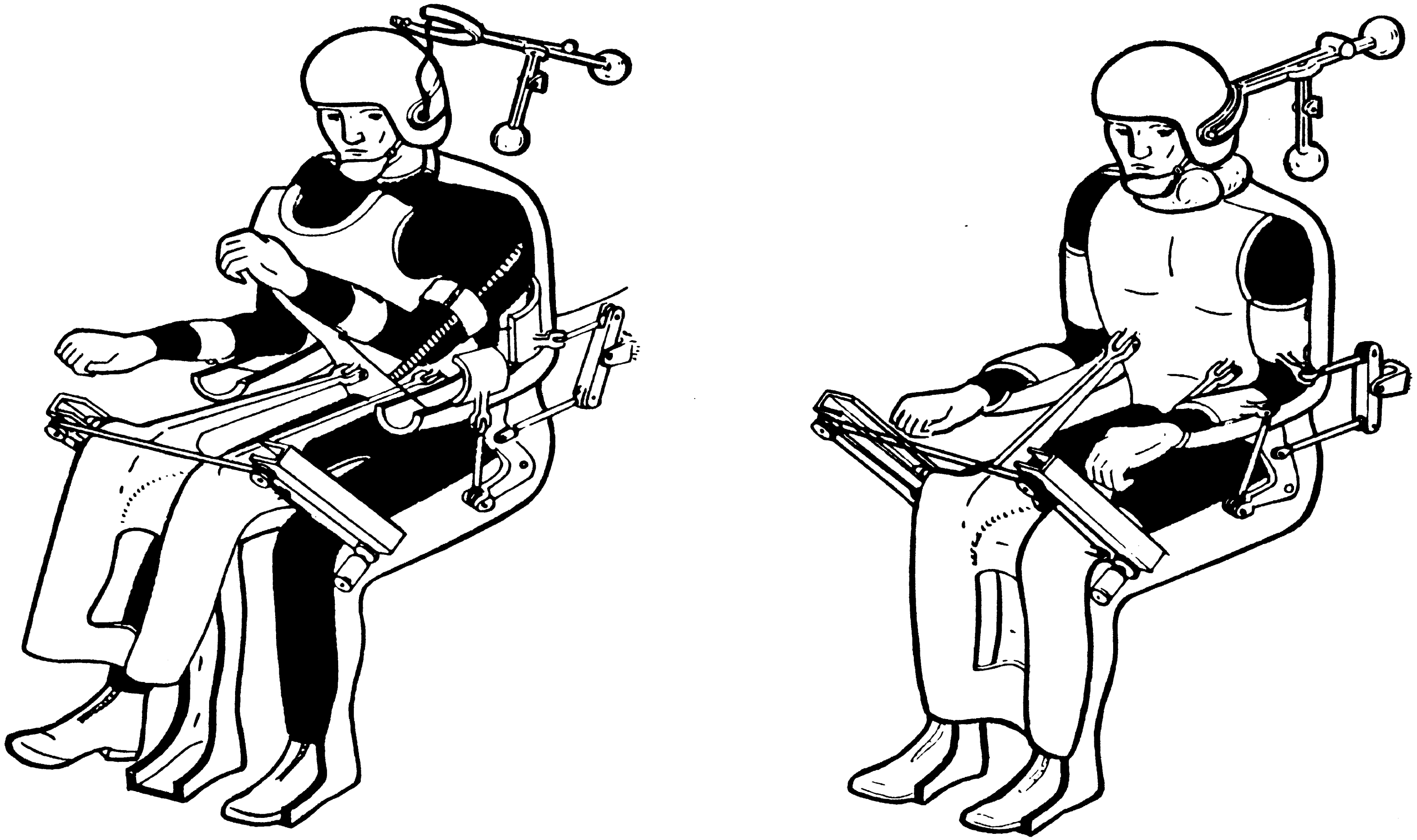

Fig. 15. Seat-mounted clamshell restraint system, in normal position on left, and in full restraint activation on right. This was designed to provide a crewman maximum protection and mobility using a Mercury molded couch. This employs a thorax shell (Ripley, 1966; p.151).

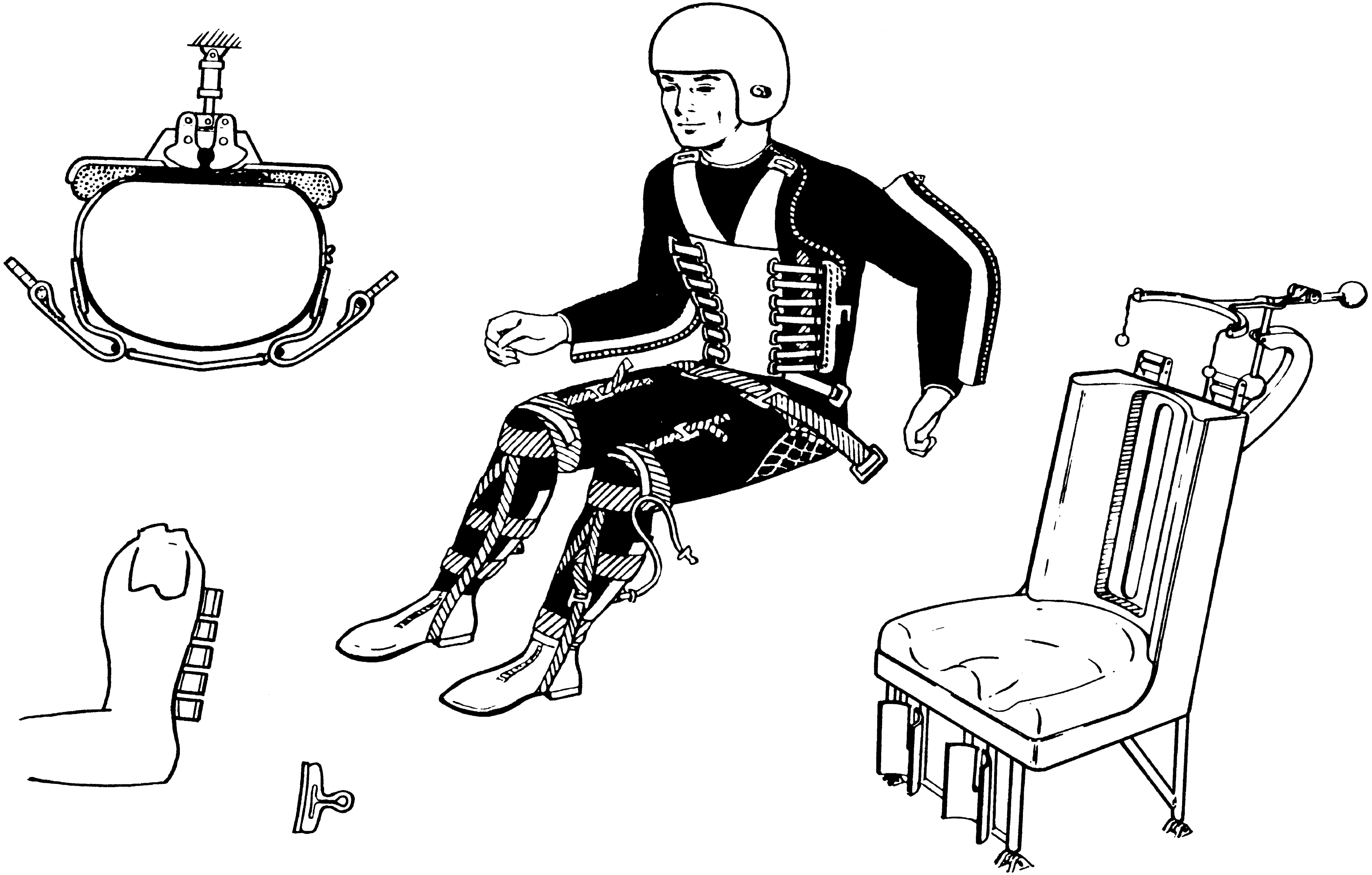

Fig. 16. Integrated soft harness restraint system. Torso protection is provided by the nylon coveralls reinforced with straps and dacron net. Lacings on each side squeeze the torso when the two torso hold-back straps are tightened. This is a 60 g restraint system (Ripley, 1966; p.149).

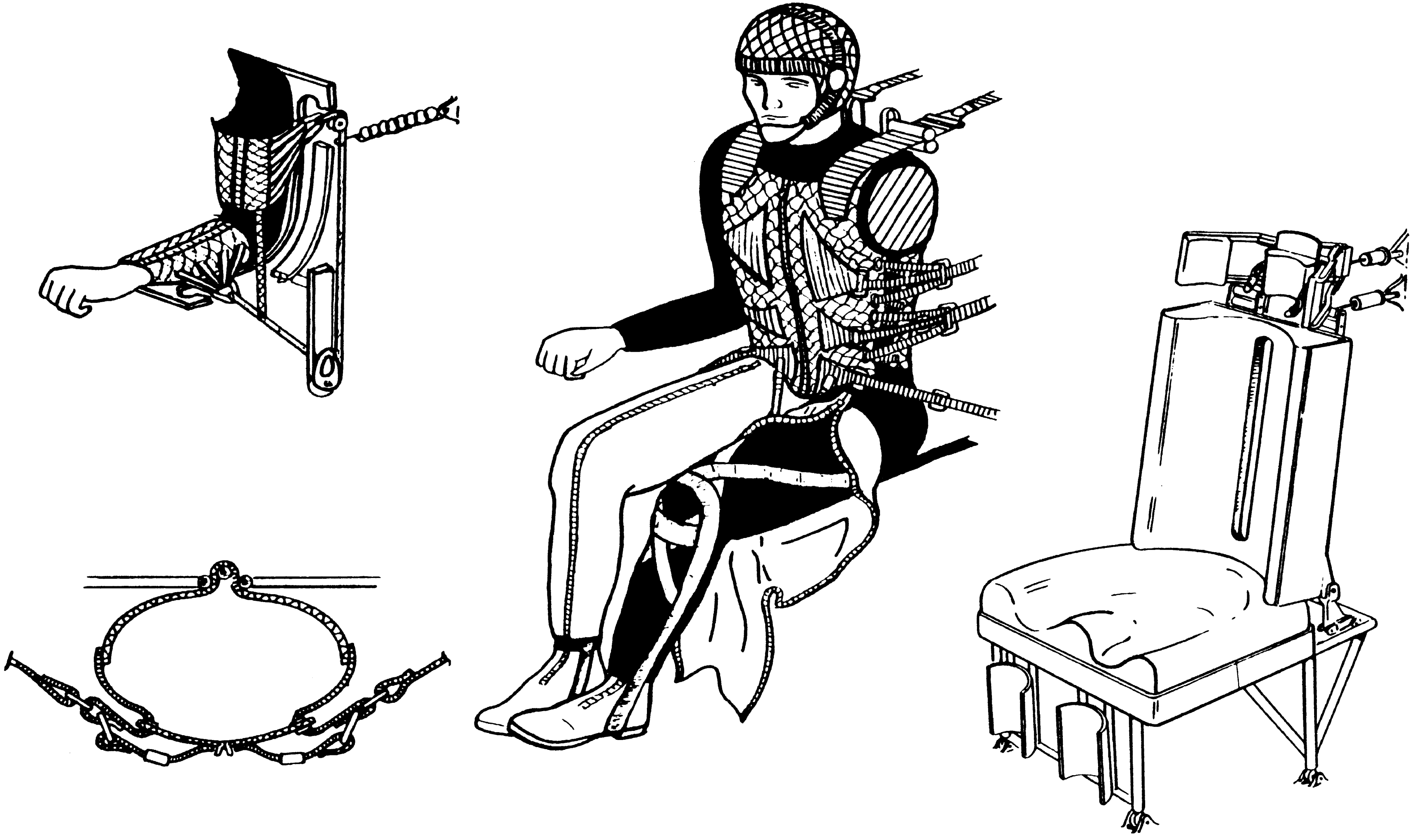

Fig. 17. Universal fit seat mounted soft harness. Torso protection is provided by a nylon net garment extending from the top of the thighs to the armpits. It has a zipper front closure and a lacing system that tightens the net around the torso (Ripley, 1966; p.147).

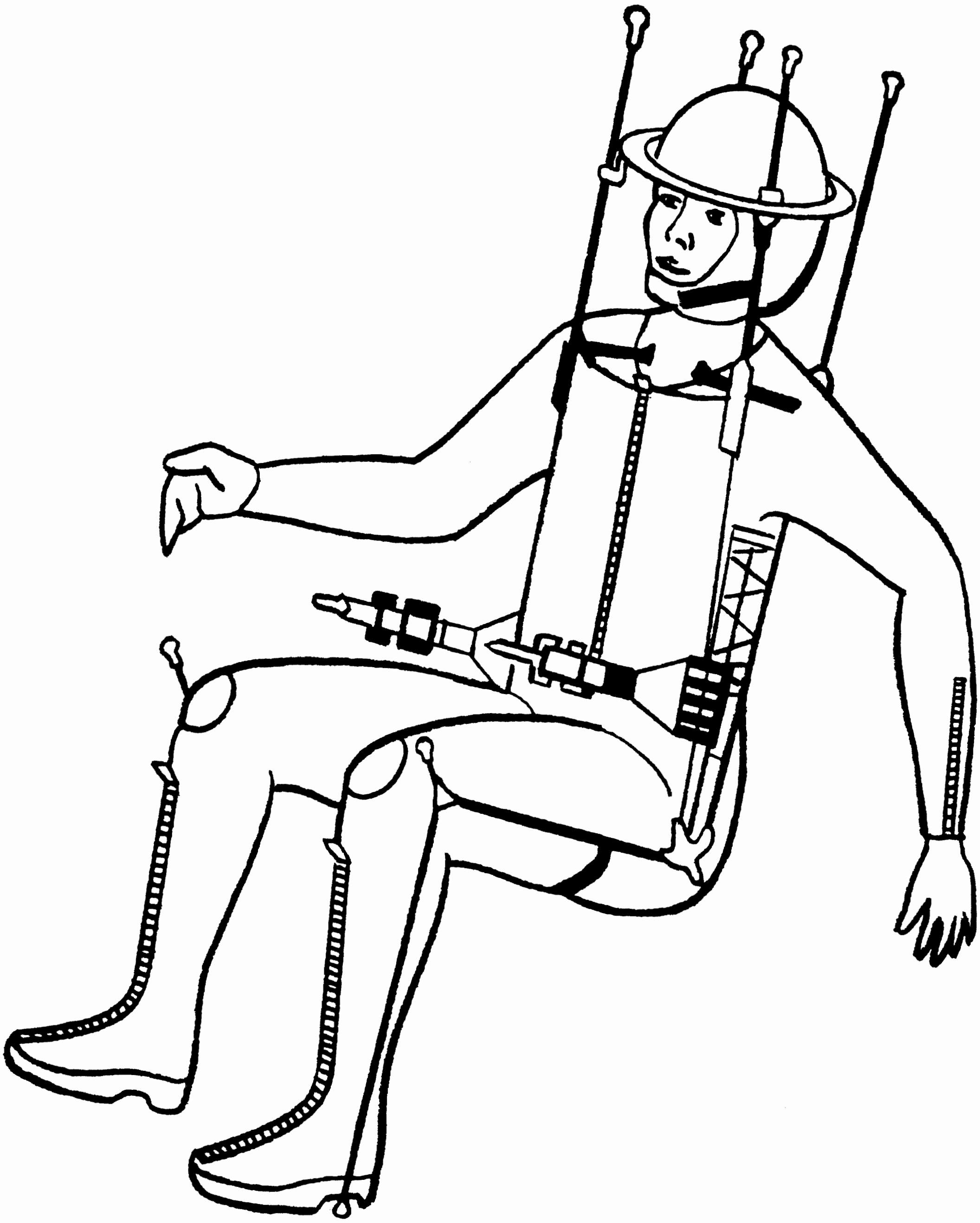

Fig. 18. The Boeing Hammock full body restraint is an all-net restraint system suspended on cables. The torso is restrained by a net vest attached to the "V" cables. The vest is zippered in front and uses ensolite for shoulder pads (Boeing, 1959).

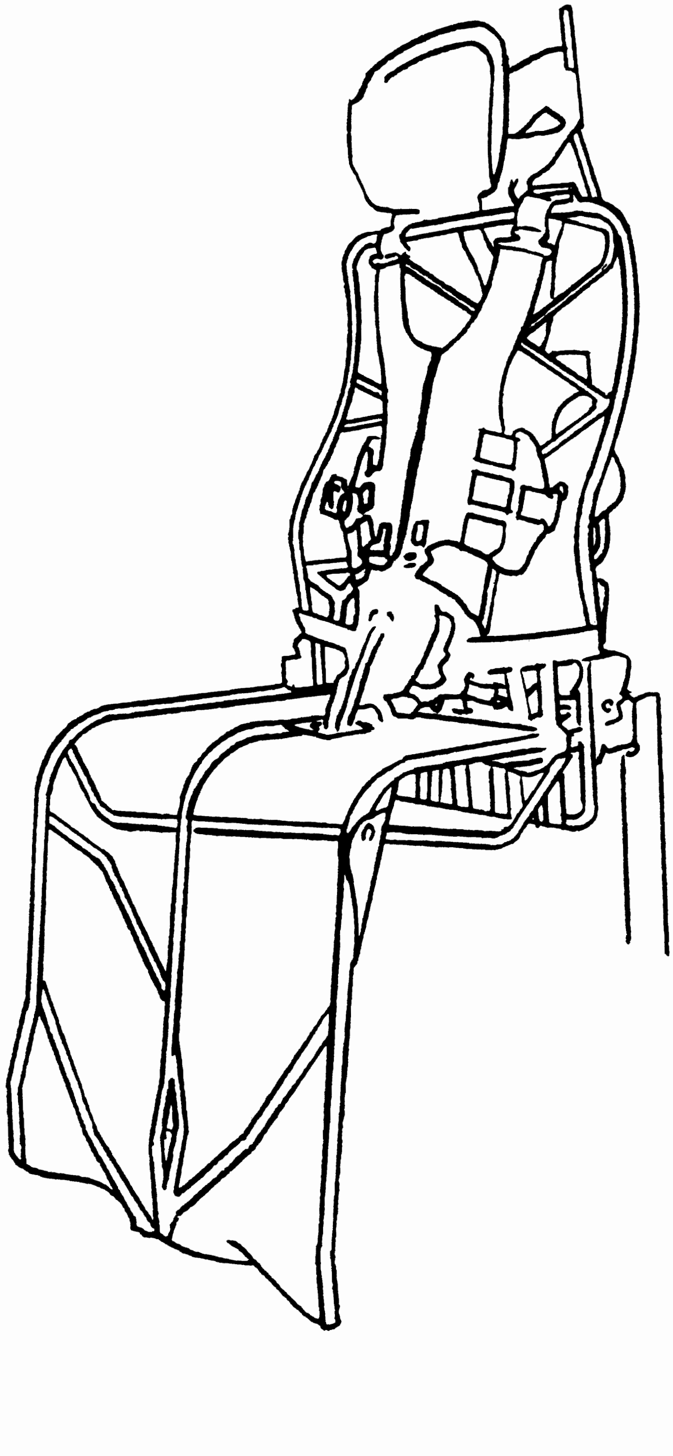

Fig. 19. Net crew seat restraint concept consists of bonded aluminum honeycomb backrest and welded tubular steel truss seat pan. Full body restraint includes torso vest (U.S. Air Force, 1962).

Fig. 20. Dacron vest restraint in full restraint position (Ripley, 1966, p.64).

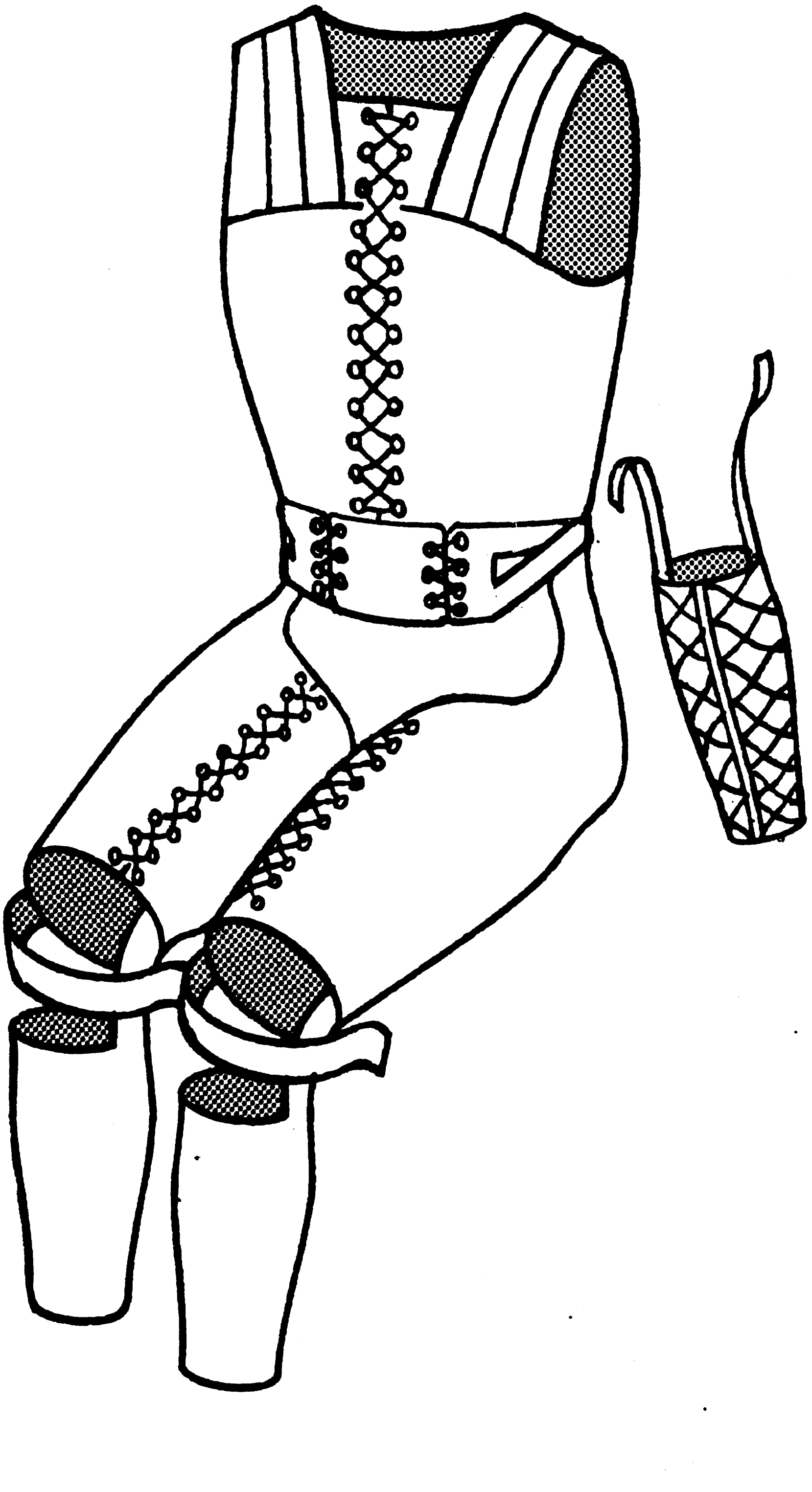

Fig. 21. Full restraint system based upon G-suit concept.

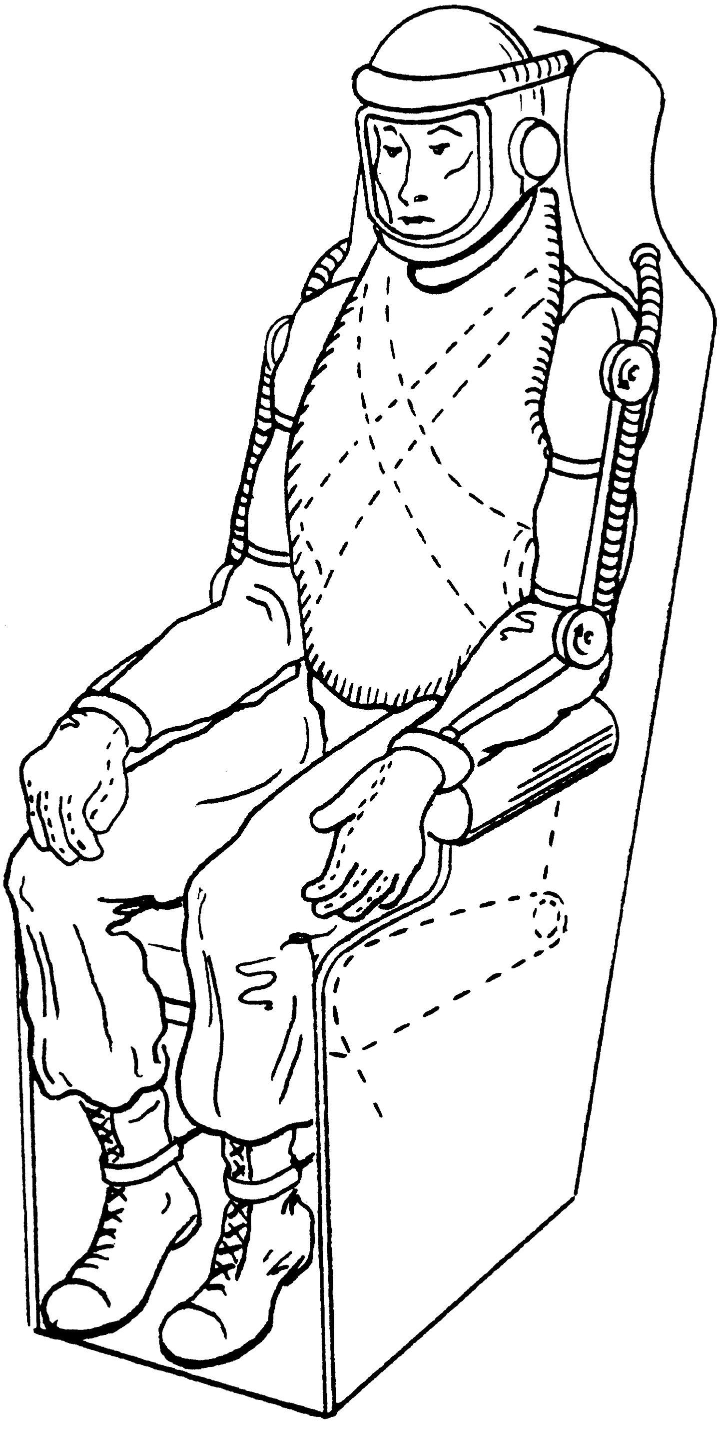

Fig. 22. Early space crew restraint system designed at University of Arizona in 1959. Note vest-type torso restraint incorporating crossed shoulder straps (Snyder, 1960).

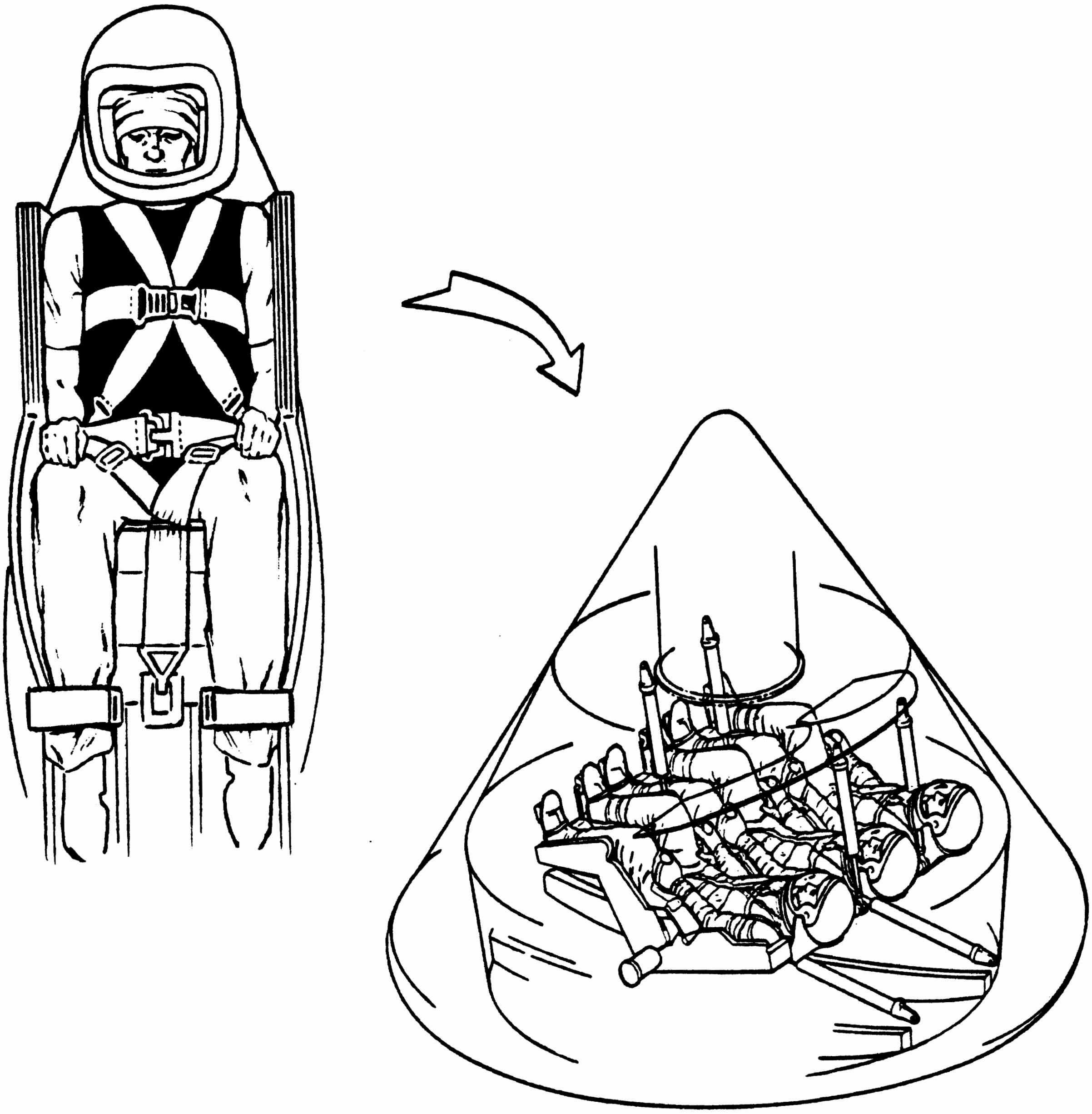

Fig. 23. Apollo spacecraft crew restraint system.

needs of race-drivers and spacecraft aircrew and represent unique applications for heavy equipment operators.

An exception is a vest-type restraint designed for child and infant protection. An unpublished study was found of tests conducted in 1976 by the Federal Aviation Administration evaluating on experimental vest-type child and infant restraint systems. In this design webbing straps were held in position on the child by a cloth vest of unknown material. Four dynamic sled tests were conducted at 11 to 25 g sled deceleration and 44.3 to 44.6 ft/sec impact velocity. Infant dummy weights was 17.4 lbs, simulating a 6-month old, and child dummy weight was 32.6 lbs., simulating a 3-year-old child. A system failure occurred in all four tests.

These tests may be of some importance to the present study, since they seem to represent the only prior dynamic sled deceleration tests which we have been able to locate employing a vest restraint system. The FAA test systems used a conventional seat belt for primary attachment. Adjustment for size was accomplished by means of adjusters located on the belt and shoulder straps, but no adjustment was provided on the vest.

An interesting test simulated turbulence, however it was created by inverting the passenger seat. During simulated crash conditions the vest restraint system allowed the dummy to move to the far edge of the seat. In more severe tests, the restraint system failed through tears in stitching and material, and allowed the dummy to move off the seat onto the floor. In the most severe tests run the restraint system failed (FAA, 1976).

IV. ACCIDENT DATA

Knowledge of previous accident experience is essential to understanding the nature of the problems and environmental conditions requiring protection of the occupant. In this regard, a second task involved review of accident data of drivers of heavy equipment to determine the nature, site, severity and frequency of injuries and identify occupant protection problems. These data were obtained from two major sources and while neither source provided necessary medical information, the general accident environmental information was useful in determining the nature of the injury. These data were particularly helpful in identifying major risk factors.

1. Nationwide Data

To obtain information on the nationwide incidence and nature of vehicular injuries the National Institute for Occupational Safety and Health (NIOSH) was requested to provide statistical information from the worker's compensation data files relative to vehicle accidents in the iron ore industry. These data were generously provided by Roger C. Jensen, Chief, Accident and Epidemiology Branch.

The Bureau of Labor Statistics of the U.S. Department of Labor, which has been delegated responsibility for collecting data to assist the Occupational Safety and Health Administration (OSHA) in standards and compliance areas, has developed a program to supplement the Bureau's Annual Survey of Occupational Injuries and Illnesses. This is called the Supplementary Data System (SDS). The basis source document for the SDS is the first report of injury or illness submitted by employees and insurance carriers to state workers compensation agencies. This system has been described in detail by Root and McCaffrey (1978), and forms the basis for the following computer analysis.

The resultant output received was based upon several specifications. Only the iron ores industry (SIC 1011) was selected, as described in the Standard Industrial Classification Manual for 1972 (page 32). The iron ores mining group is classified as "Establishments primarily engaged in mining, beneficiating, or otherwise preparing iron ores and manganiferous ores valued chiefly for their iron content. This industry includes production of sinter and other agglomerates except those associated with blast furnace operations..." The establishments include brown ore mining; hematite mining; iron agglomerate and pellet production; iron ore, blocked; iron ore dressing (beneficiation) plants; iron ore mining; limonite mining; magnetite mining; manganiferous ore mining, values chiefly for iron content; siderite mining; sintering of iron ore at the mine, and taconite mining (Appendix C).

Data from 31 states for 1979 (Fig. 25) for five occupations were searched. These included truck driver, motormen mine, fork lift operator, and road machine operator. There were 120 cases (52%) of worker compensation claims for the category of truck driver in the iron ore mining industry for 1979, and 230 total cases for all five classifications. These statistics are shown in Table I.

Of the 31 states only seven states had claims, with 135 (58.7%) originating from Minnesota, and 55 (23.9%) from Michigan. These data, are shown in Table II, providing the number of claims in 1979 (for each of these occupations shown in Table I.).

The NIOSH search tabulated only those cases in the iron ore industry that involved a worker in one of the five occupations listed in

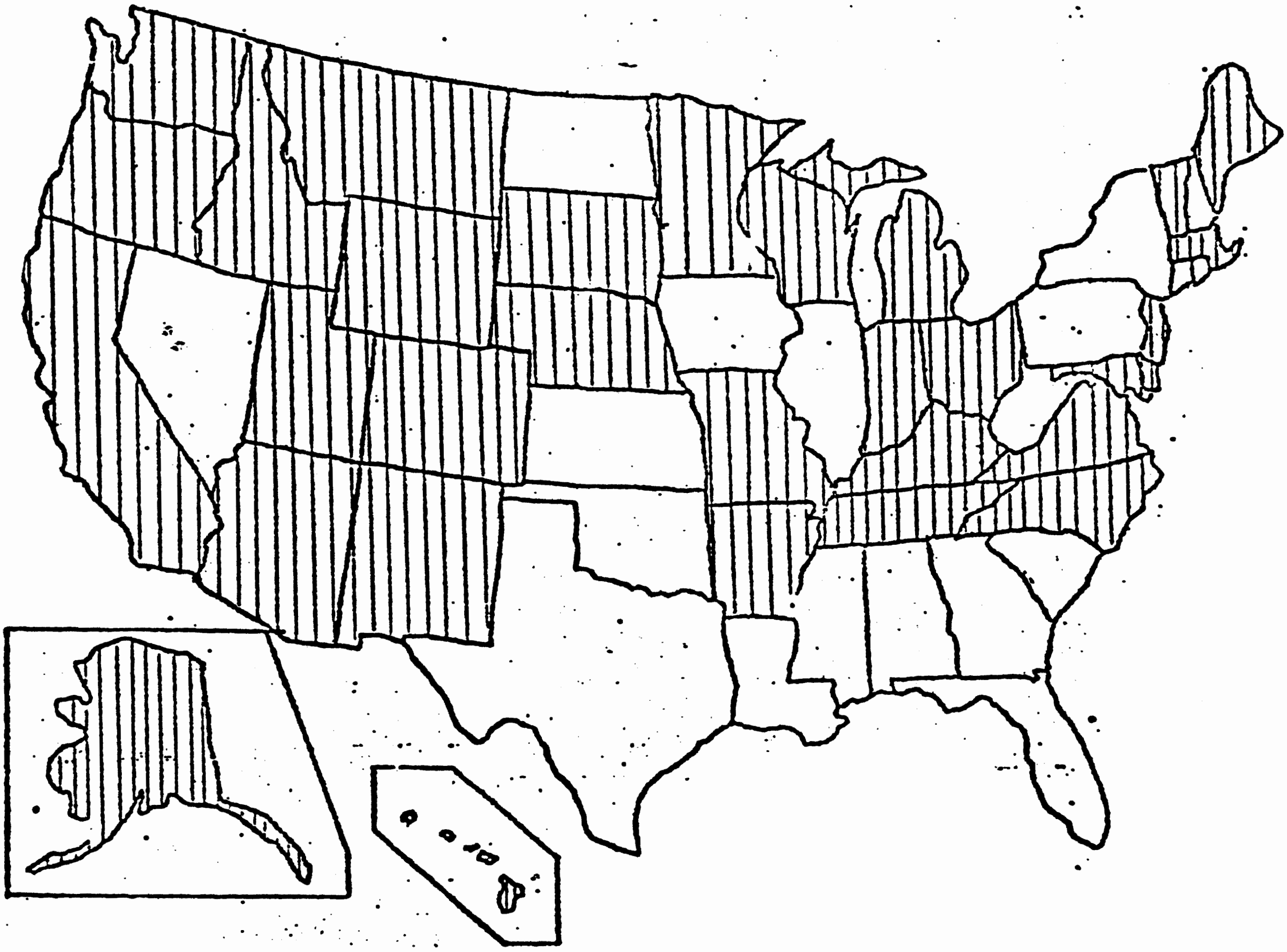

Fig. 24. Map of United States showing (vertical lines) those states which provided the data used in the 1979 SDS analysis.

TABLE !.
FREQUENCY DISTRIBUTIONS FOR 1979 SDS DATA
INDUSTRY=IRON ORES (1011) BY OCCUPATION
WEIGHTED VALUES

OCCUPATION	FREQ.	CUM. FREQ.	PERCENT	CUM. PERCENT
Road Mach Oper 436*	13	13	5.652	5.652
Mine Oper 640	82	95	35.652	41.304
Fork Lift Oper 706	11	106	4.783	46.087
Motormen Mine 710	4	110	1.739	47.826
Truck Driver 715	120	230	52.174	100.000

*Numbers refer to occupational codes listed in SDS book.

TABLE II.
FREQUENCY DISTRIBUTIONS FOR 1979 SDS DATA
INDUSTRY=IRON ORES (1011) BY STATE
WEIGHTED VALUES

STATE	FREQ.	CUM. FREQ.	PERCENT	CUM. PERCENT
Colorado	1	1	0.435	0.435
Michigan	55	56	23.913	24.348
Minnesota	135	191	58.696	83.043
Missouri	28	219	12.174	95.217
Utah	7	226	3.043	98.261
Virginia	2	228	0.870	99.130
Wisconsin	2	230	0.870	100.000

Table I. A frequency distribution of the type of compensation claim by occupation is given in Table III. For truck drivers this shows that many cases of injury were not classified (27). The greatest frequency of injury was listed as striking a stationary object (13), struck by vehicle (11), involuntary motions (11) and hot objects (11). This information is not detailed enough for further comment.

TABLE III.
FREQUENCY DISTRIBUTIONS FOR 1979 SDS DATA INDUSTRY=IRON ORES (1011) BY OCCUPATION WEIGHTED VALUES

TYPE FREQUENCY	ROAD MACH OPER	MINE OPER	FORK LIFT OPER	MOTORMEN OPER	TRUCK DRIVER	TOTAL
Stationary Obj	0	23	0	0	13	36
Falling Obj	0	7	0	1	1	9
Flying Obj	0	2	0	0	0	2
Struck by N*	0	11	0	0	0	11
Ladders	1	0	0	0	1	2
Vehicles	1	4	0	0	11	16
Working Surface	2	3	0	0	0	5
Against Obj	0	2	0	0	0	2
Same Level N	0	1	0	0	9	10
Move & Stat Obj	0	1	0	0	0	1
Caught in N	1	4	0	0	0	5
Frgn Mat Eyes	0	6	0	0	0	6
Invol Motions	1	2	0	0	11	14
Vol Motions	0	0	0	0	10	10
Lifting Obj	0	8	1	2	10	21
Pulling Obj	0	2	1	0	2	5
Throw Obj	0	3	0	0	1	4
Overexert N	0	0	0	1	1	2
Hot Obj	4	0	0	0	11	15
By Inhalation	0	1	0	0	0	1
By Absorption	0	1	0	0	0	1
Oth N	2	0	0	0	0	2
Standing Veh	0	0	0	0	1	1
Run Into/Off Rd	0	0	0	0	1	1
Stop/Start	0	0	9	0	1	10
Oth	0	1	0	0	1	2
Acc Type N	1	0	0	0	9	10
Nonclass	0	0	0	0	27	27
Total	13	82	11	4	120	230

*Not elsewhere classified.

The source of injury is a coding category which indicates the object, substance, exposure, or bodily motion which directly produced or inflicted the injury. Table IV is a cross-listing of source by occupation. The frequency distribution suggests that "bodily motion," "ground," and "highway vehicle" are the three major factors.

TABLE IV.
FREQUENCY DISTRIBUTIONS FOR 1979 SDS DATA
INDUSTRY=IRON ORES (1011) BY OCCUPATION
WEIGHTED VALUES

SOURCE FREQUENCY	ROAD MACH OPER	MINE OPER	FORK LIFT OPER ·	MOTORMEN MINE	TRUCK DRIVER	TOTAL
Bodily Motion	1	2	0	0	21	24
Barrel	0	2	0	0	9	11
Bundle	0	1	0	0	0	1
Container N	0	0	1	1	0	2
Acid	0	1	0	0	0	1
Chemical N	0	0	0	0	9	9
Coal/Oil N	0	1	0	0	0	1
Powered Convey	0	1	0	0	0	1
Flame/Fire/Smok	0	0	0	0	2	2
Crowbar	0	3	0	0	0	3
Knife	0	1	0	0	0	1
Pick	0	1	0	0	0	1
Shovel	0	1	0	0	0	1
Chain Hoist	0	1	0	0	0	1
Const Mch N	4	1	0	0	0	5
Mining Mach N	0	2	0	0	0	2
Mach N	0	2	0	1	0	3
Chain/Rope	0	1	1	0	4	6
Beam/Bar	0	5	0	1	0	6
Nail/Spike	0	1	0	0	0	1
Metal Item N	2	24	0	1	0	27
Mineral (ore)	0	1	0	0	0	1
Sprain Strain	6	19	11	2	58	96
Mult Injuries	0	0	0	0	9	9
Mental Disorder	0	0	0	0	9	9
Oth Injury N	0	2	0	0	18	20
Total	13	82	11	4	120	230

Significantly, for truck drivers (48.3%), road machine operators (46%), mine motormen (50%) and fork lift (100%) operators the most prevalent injury reported was "sprain or strain." It was the only type of injury reported for fork lift operators. For mine operators "contusion" was the most frequent type of injury, comprising 67 percent of reported injuries. Contusions were the second most frequent injury to truck drivers as well.

Next, source of occupation was listed for those workmen compensation claims in which the type of injury is coded against the "struck against" category. Table V shows that all injuries listed for truck drivers were due to striking against a highway vehicle (as were the majority of injuries to mine operators).

TABLE V.
FREQUENCY DISTRIBUTIONS FOR 1979 SDS DATA
INDUSTRY=IRON ORES (1011) BY OCCUPATION
TYPE=STRUCK AGAINST
WEIGHTED VALUES

SOURCE FREQUENCY	MINE OPER	TRUCK DRIVER	TOTAL
Crowbar	2	0	2
Knife	1	0	1
Nail/Spike	1	0	1
Metal Item N	9	0	9
Highway Veh	9	13	22
Log	1	0	1
Total	23	13	36

Finally, the data were tabulated by a means of a cross-listing of source by occupation for those claims in which the type of injury is coded in the "struck by" category (Table VI). This was not very productive and the N of 22 was very small. It indicated that mine operators were chiefly struck by metal items.

TABLE VI.
FREQUENCY DISTRIBUTIONS FOR 1979 SDS DATA
INDUSTRY=IRON ORES (1011) BY OCCUPATION
TYPE=STRUCK BY
WEIGHTED VALUES

SOURCE FREQUENCY	MINE OPER	MOTORMEN MINE	TRUCK DRIVER	TOTAL
Bundle	1	0	0	1
Mining Mach N	2	0	0	2
Chain/Rope	0	0	1	1
Metal Item N	11	1	0	12
Mineral (ore)	1	0	0	1
Mineral (dirt)	3	0	0	3
Misc N	2	0	0	2
Total	20	1	1	22

In general, the SDS data from workers compensation files relative to vehicle accidents in the iron ore industry did not provide information in sufficient detail to be very conclusive.

2. Typical Mining Operations

Accident reports involving operators of heavy vehicles were reviewed from a typical mining operation. These data consisted of 161 reported accidents over a 5-1/3 year peroid, from January 1977 to April 1982, in which an injury was reported involving a heavy vehicle driver at this single mining operation.

During this period four female drivers (2.5% of accidents reported) and 157 (97.5%) male drivers were involved. Age of the female drivers ranged from 19-1/2 to 25 (mean 22-1/4 years), but unfortunately height and weight information was not available. All were injured while driving trucks, three being jolted in driving into holes on the road and one jarred while being loaded.

Ages of the injured drivers ranged from 19.5 to 64 years, with a mean age of 29.8 years. The frequency distribution of injured drivers ages showed the majority (61.5%) to be between 19 and 29 years, with 24.2% between 30-39 years of age

Experience of the injured drivers ranged from one month to 23 years.

Review of the accident reports indicates that the most prevalent type of injury occurred from vertical impacts of vehicles hitting holes in the road, followed closely by vehicles hitting solid objects (rocks, other vehicles). Rough ground, running off a rock or ledge, hit by or into shovel bucket while loading, and the vehicle being hit by a falling rock while loading were also frequently attributed as causes of the driver injuries. These conditions accounted for 76.4 percent of the injuries described.

Determination of the nature and direction of force on the occupant is important in order to understand what occupant protection is necessary in the heavy vehicle accident environment. Over half the accidents reported (55.6%) involved vertical loadings (+Gz) on the driver, resulting from bumps, jolts, and vertical impacts. Some 15.7 percent involved a collision or front impact with the vehicle and some object in -Gx deceleration. Lateral forces (±Gy) were reported in 13.5 percent (24 cases) and are not as easily protected against by a lap belt system alone. This shows the most prevalent directions of loading on the driver, and in particular that the use of belt restraints could be effective in preventing these type of injuries in most accidents that occur.

Seatbelt use is an important factor and in only eight cases (5%) in this accident series was it indicated whether a seatbelt was installed in the vehicle and whether it was being worn. In four cases it was reported that the belt was not used.

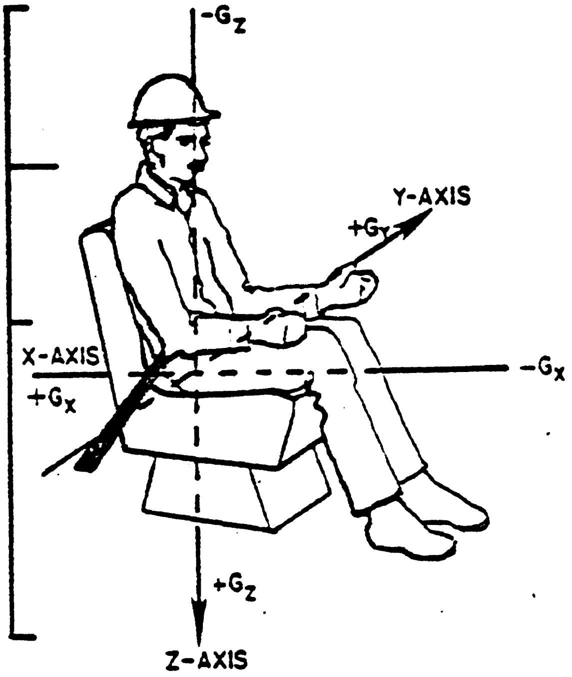

Fig. 25. Illustration of uni-axial acceleration vectors used to describe direction of force on the seated operator.

V. WORK ENVIRONMENT

1. General Background

Heavy vehicles in use in mining operations include load hauling trucks, in addition to a variety of water trucks, large loaders, scrapers and tractors. A visit by the investigators to a heavy vehicle mining operation could not be conducted due to mine closings during this period, however some general observations from a prior visit are noted.

Haulers most often being operated included the Euclid (Model 302HD, manufactured by Euclid Canada, Inc.),. with a 200,000 lb (100 ton) rated maximum payload and 51.33 cubic yard capacity (Fig. 26). The ones examined were equipped with anchorlok air ride seats and two inch wide lap belts. The Wabco Haulpak (Fig. 27) is the major hauler, with a 240,000 lb (120 ton) rated capacity. The models examined utilized the Bostrom Viking T-Bar seat and were equipped with three-inch lap belts. A third hauler, was the Unit Rig Model M100, manufactured by Unit Rig and Equipment Company of Tulsa, Oklahoma.

Other vehicles observed included the Caterpiller 992C, the Caterpiller D10 with 20 foot blade, and three-inch lap belt, and Dorf oil wagon, the Clark 46 equipped with rubber tires and used for cleanup and high mobility, and the Grove hydraulic crane model RT-751S, manufactured by the Grove Manufacturing Company of Shady Grove, PA. Graders, although inspected, were not included, since the driver primarily stands to operate.

Collective observations by the investigators related to the problems of seat belt usage both from the driver's operational viewpoint and that of safety management were drawn upon from an earlier

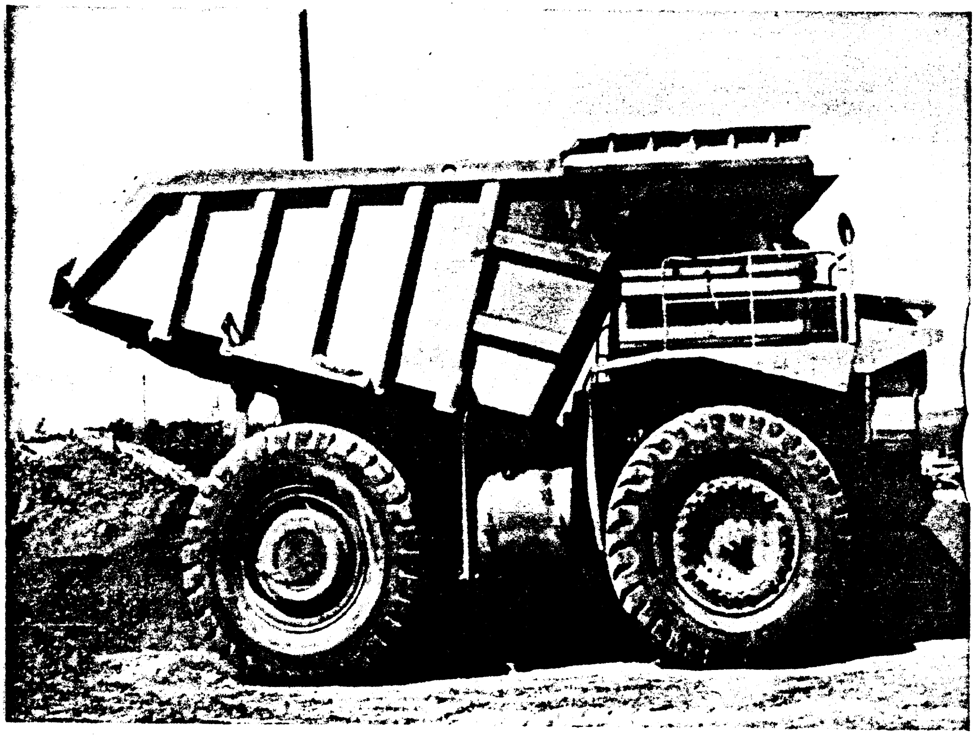

Fig. 26. Euclid load hauling truck, with 100 ton rated maximum payload.

Fig. 27. Wabco Haulpak is another load hauling truck in use, with 120 ton capacity (loaded).

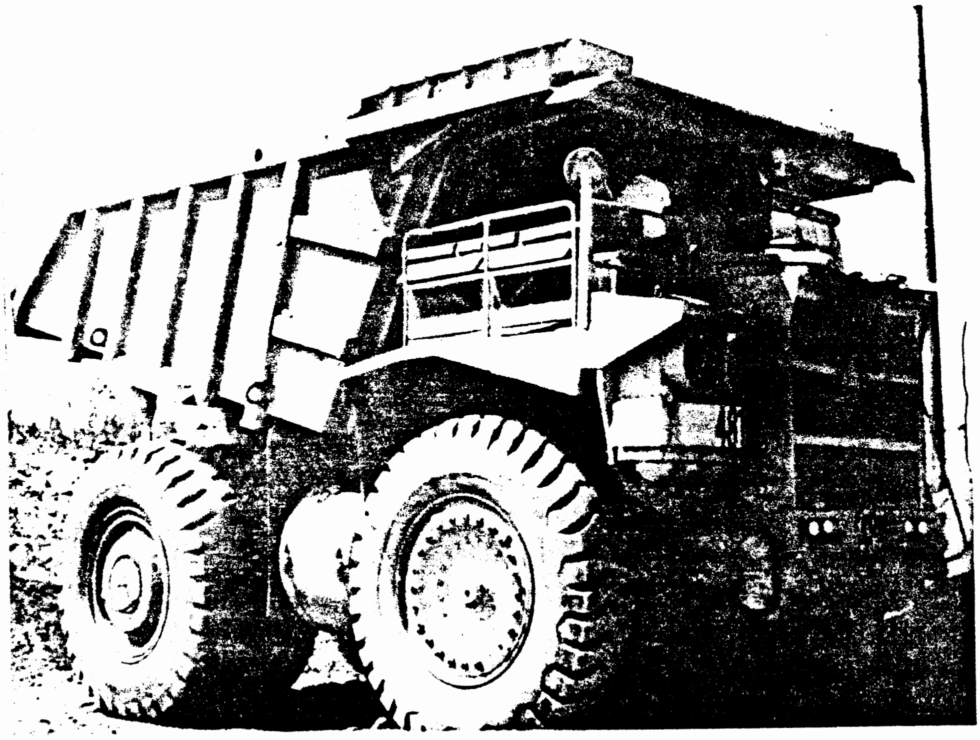

Fig. 28. Quartering view of Euclid truck.

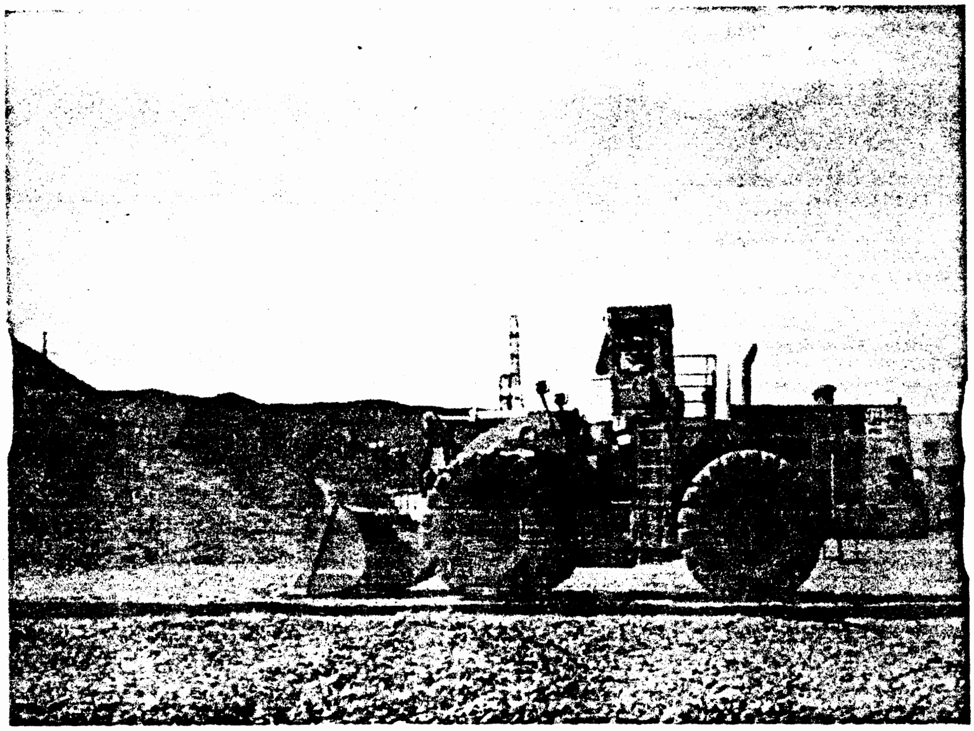

Fig. 29. CAT used to move taconite to conveyer belt for crushing and processing into concentrate (and pelletizing) and tailings.

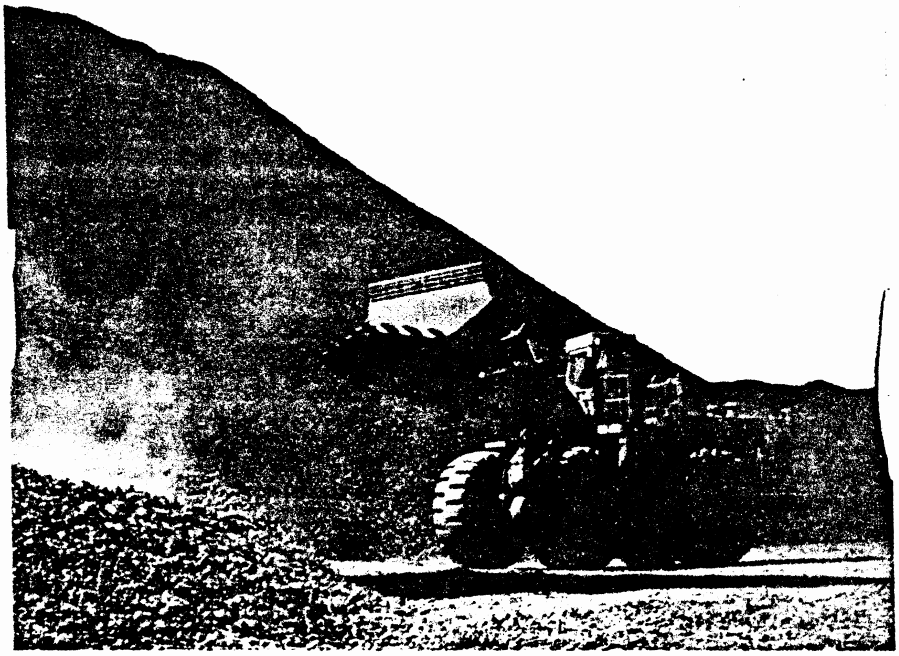

Fig. 30. CAT in action with scoop raised when loaded and raised. This changes the C.G. forward.

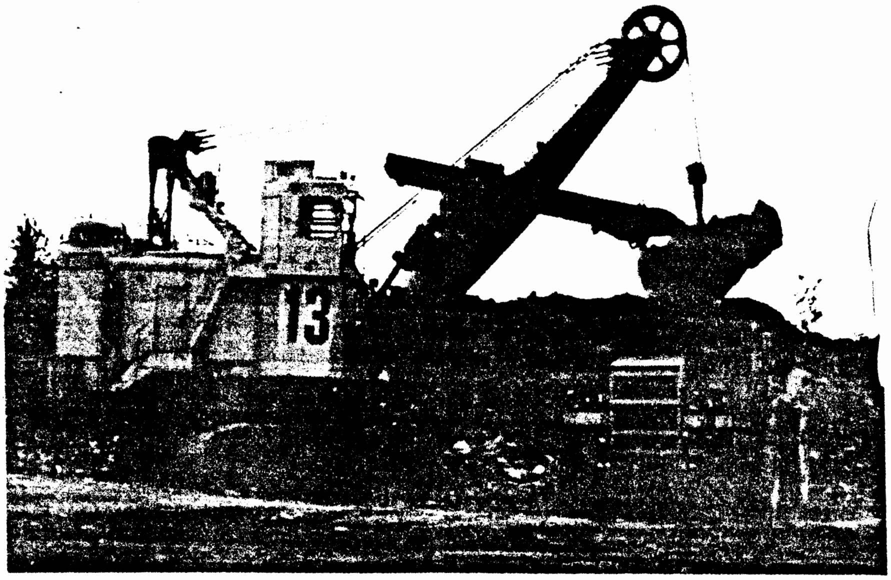

Fig. 31. Large shovel loading load hauling truck.

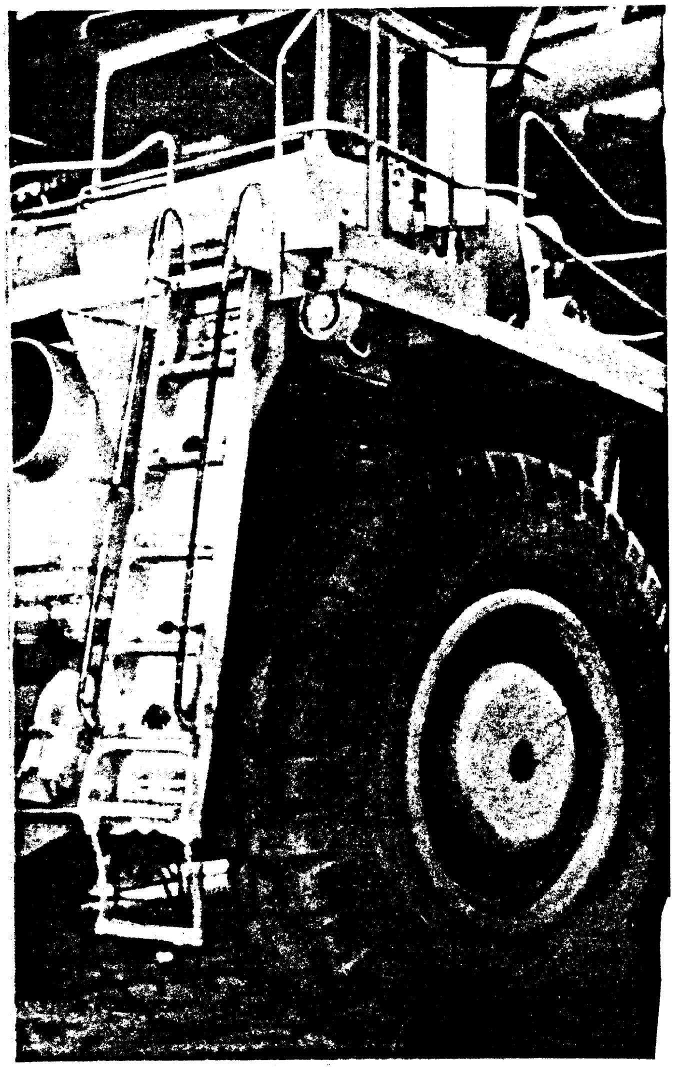

Fig. 32. Cab ingress and egress of the load hauling truck involves climbing a ladder about 10 feet to a platform before entering the cab.

visit. Specific comments and discussion are outlined in the following sections.

2. Ergonomics Factors

An Ergonomics assessment of restraint use and problems by heavy equipment operators in surface mines provided by Professor Thomas J. Armstrong, both from a Human Factors and Industrial Engineering viewpoint, as follows:

(a) Cab Ingress and Egress

Operators must climb up a ladder to a platform or catwalk, open the door and enter the cab (Figure 33). Cab floors are approximately ten feet (measured 10'8" unloaded) above ground level, so a fall could result in serious injury. The risk of a fall might be particularly high when the ladder is wet or icy. Also cold days might be expected to increase the risk of a fall because of reduced tactual sensitivity and probable use of gloves. A worker en route to the cab could be pulled off balance by snagging loose fitting clothes on a number of possible catch points. Cab entry requires use of both hands and feet, so carrying personal belongings, tools, or supplies to the cab would increase the risk of an accident.

(b) In the Cab

The cab environments vary from truck to loader, truck to truck, and loader to loader. All of the cabs are built from a heavy steel frame. All have many hard sharp edges on the edges of instrument panels, steering wheel brackets, control boxes, etc. Some of these edges are associated with modifications such as water bottle boxes (Figure 34). Minor injuries could be caused by bumping these surfaces in the course of normal reach and move activities required to enter, exit, and operate the vehicle (Figure 35). Serious injuries could be produced when one of these surfaces is contacted forcibly as when the vehicle goes over a bump, stops suddenly, or rolls over. Aside from the seat and armrests there is very little padding in most cabs.

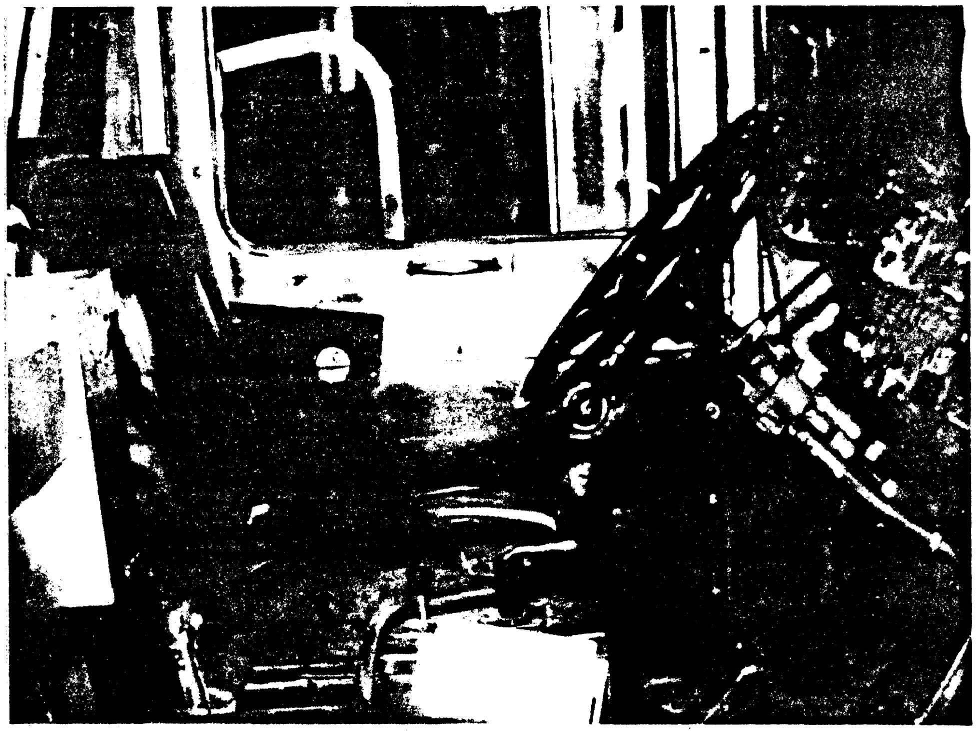

Fig. 33. The truck cab has many surfaces hostile to the driver in an impact. Note the sharp steel edges of the instrument panel, along the door, and of the steel water box to the rear of the driver.

Operating the vehicles requires movements of the upper and lower extremities to reach and operate the controls. More movement is required to operate the scoop than the truck. The scoop is used to transport materials short distances; the scoop must be cycled once each trip and shifting may be required. Because scoops tend to be operated in the vicinity of other equipment the operators tend to move around in their seat so that they can see their wheels and bucket. Also there is probably more jarring of the scoop operator because of the way they drive into piles of material to load the bucket.

Use of the proposed restraint vest system could be expected to reduce risk of serious injuries due to ejection or bouncing against the ceiling. It does not restrain the upper torso from jackknifing in frontal impact however, and serious injuries could still be produced by contact with hostile cab surfaces in a collision.

Observations of selected operators and the condition of selected belts suggested that the existing belts are seldom used. Some workers complained that the belts were dirty, hard to fit, and in poor mechanical condition. The proposed personal restraint system which would be assigned to each worker as personal equipment, should in theory overcome the problems with the belts being dirty and hard to find. They still would require action to put them on and creation and enforcement of a seat belt rule would still be required. Seat belts should be designed so that they can be quickly hooked and unhooked with gloved hands and with bare hands in a cold environment.

Both the existing and proposed designs could be expected to interfere with operator movements forward in the seat. This could reduce operator visibility and increase the risk of an accident, especially for the scoops.

(c) Auxiliary Tasks

Operators of trucks and scoops are responsible for auxiliary tasks such as checking the fuel level with dipsticks. These tasks should be further inventoried and studied. It appears that they require maneuvering on the vehicle outside the cab and would be subject to the same concerns discussed under CAB INGRESS AND EGRESS.

3. Biomechanical Factors

Most of vehicles have lap belts installed, except for the graders in which the operator primarily stands. As shown in Figure 36, belts often use nylon webbing conforming to SAE and DOT FMVSS standards with metal-to-metal type buckles, and provided a reasonable belt angle (45-55°). The WABCO Haulpak and CATS such as the D10 and 992C are equipped with 3-inch wide belts, while the other vehicles use 2-inch wide belts. Belts are generally attached to floor structure rather than to seats, providing good anchorages. Some, such as the 992 CAT, use a steel cable between the seat and floor.

Fig. 34. Example of steel projections within operator's kinematic envelope in an impact.

The main current problem appears to be that drivers are not wearing belts where provided. While various reasons are given by drivers, the most common reason given is that the belts were dirty and greasy. And most of those which have been examined are indeed filthy, having been left on the dirty floor, rather than being worn. It would seem that simply replacing dirty belts will not solve the problem if the driver won't wear it. One possible solution for current belts, suggested by a driver, is to provide a device (hook?) to hang up the belt ends when not in use. However this would require driver cooperation or enforcement to be effective. Another solution would be to use retractors so that when not in use the belt is protected and out of the way.

From a potential injury point of view the truck, tractor, and loader cabs present generally hazardous impact environments. The heavy non-yielding and sharp steel edges of the instrument panels present injurious contact points to the driver in a jolt or impact situation, as do the door side panels, cab roof structures, and rear of the cab. In particular the metal boxes and water containers are located where injury could result. The CAT 992, for example, has a steel box with sharp edges to the left of the rear of the head, as well as sharp metal surfaces on the right door such as the window opener. The truck cabs usually have an open metal box attached to the rear of the right side of the driver's seat (Figure 35). Some more recent models of the same make truck have improved panels, although much more could be done to provide driver protection. The latest model WABCO truck was observed to have a much better panel from an impact point of view than the previous model; sharp metal edges had been rounded and metal boxes removed.

In case of a jolt or collision the driver may be thrown into abrupt contact with sharp metal surfaces. An illustration is shown in Figures 12-14, of the positions a driver may be thrown into in the cab of a Unit Rig truck (Model M100) (Figure 37). Figure 38 shows impact points of an unrestrained driver leaning forward into the steering wheel, panel and windshield area. Figure 39 illustrates a side impact and the driver impacting the side door window frame with his head. Note that the safety helmet might not offer adequate protection in this situation.

Since it is unlikely that energy-absorption devices, crash padding, and improved cab impact design are possible without some major retrofit or redesign, the simplest and most effective driver protection for the current vehicle operation is to ensure that all drivers (even those operating from a standing position) are provided and wear a restraint system which will prevent them from contacting hazardous structures during a jolt or impact.

While there appears to be adequate headroom in the various cabs the variation in physical size of drivers is not known. Small individuals or females may have reach and accommodation problems. Heavy or large males over the 95th percentile may also have problems. Previous studies of the physical size of truck driver populations, as well as other populations such as air traffic controllers, airline stewardesses, law enforcement officers, or military pilots, have shown that such occupations may consist of individuals varying greatly in size from that of the general population. It is important to know more about the body sizes of the heavy equipment truck driver population in order to provide an objective assessment of the relationship between the drivers and the

Fig. 35. The driver in position relative to the cab environment.

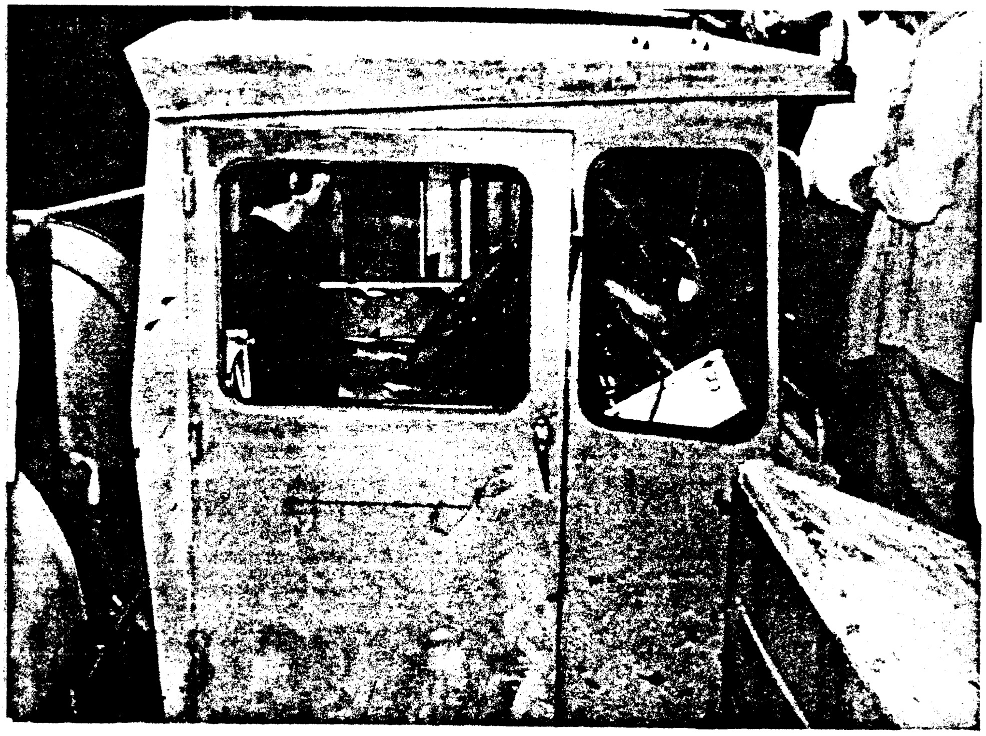

Fig. 36. View of Model M100 Unit Rig truck cab.

Fig. 37. An unrestrained driver could be thrown forward.

cab environments, and an anthropometric survey should be conducted to provide this information.

Fig. 38. In a side impact the driver can have his head thrown into sharp metal edges.

VI. EVALUATION OF PROPOSED RESTRAINT SYSTEM

The intent of the proposed vest restraint is to provide a personal restraint system which could be issued as personal equipment to each driver. This belt is designed to be worn all the time and can simply be snapped onto the existing restraint tie-down hardware of any truck the driver may be assigned to. An attractive feature is the notion that as personal equipment the belts will be kept clean, in good condition, and receive more use.

The idea of personal equipment works effectively in many other occupations. For example, most deep sea divers (hard hat) have their own personal diving helmet and other equipment. This is a matter of safety, preference, and tradition, since the diver maintains his own equipment as his life depends upon it daily. Sky divers and military parachutists pack their own chutes for similar reasons. Pilots and race drivers also maintain their own personal equipment. The list of occupations where personal equipment is important to the individual is extensive. There are a number of occupations including telephone linesmen, law enforcement officers, tree-climbers, and carpenters where belts are worn for carrying special equipment necessary to the job.

Thus, although this concept appears to be unique for drivers, it has been effectively used and accepted by other occupational groups. The question of acceptance by the drivers may depend to a large extent on how the concept is presented. It probably will meet less resistance once drivers experience wearing the restraint and find to what degree it is comfortable, accessible, allows individual freedom, and is convenient. The need for protection would be expected to be difficult for them to perceive, but if it can be shown that wearing the belt makes the ride more comfortable by reducing jolts and fatigue it might receive more acceptance.

The proposed vest restraint system, experimentally fabricated by Kaiser Mfg. Co. of Minneapolis, consists of an layer of orange colored canvas material and outer layer of high visibility bright orange material. A series of straps go over the shoulders and waist and are integral with the vest body. The front was fastened in the prototype version with five metal snaps. Net webbing forms an under-layer for the shoulder straps and a sewn dacron bond at the top of each shoulder holds the straps in place. The vest belts in the prototype may be adjusted at five locations. The lap belt buckle (manufactured by IMM Inc, stamped part no. 59810) is the metal tongue with push button release type, and the top belt can be easily adjusted on the tongue (left) side. Each shoulder harness can also be easily adjusted by tightening (pulling down) on the strap in front. A flap in the rear, held by four velcro straps, can be easily released or closed, and protects two horizontal belts, which are tightened by pulling the ends.

In order to appraise donning, three individuals, one female and two males, of differing body sizes were asked to put on the vest, adjust it, and wear it in both seated and standing positions. No attempt was made to utilize a larger sample and no heavy equipment was available to make trials in an operational mode. The following photographs illustrate some of our findings.

Figure 40 shows the vest restraint worn by a male approximately the 95th percentile U.S. male, based upon National Health Examination Survey (HANES) anthropomorphic data. This individual weighed 210 lbs. and is 72 inches in stature (the U.S. 95th percentile male weighs 224 lbs. and is

72 inches tall). A closeup of the front of the vest is shown in Figure 40.

For comparison, note the fit for an average sized male (Fig. 41) (165 lbs., 70"), and for small female (Fig. 42) (118 lbs., 63").

To don this restraint there are several steps that must be gone through. Holding it in front in both hands (Fig. 43) the right-handed subject puts his right arm through the right shoulder strap (Fig. 44) and adjusts the collar, then brings his left arm through the left shoulder strap (Fig. 45), snaps the center snaps closed (Fig. 46), releases the velcro attachment to the rear flap at the right side (Fig. 47), and adjusts the two rear horizontal straps by pulling the straps tight (Fig. 48). The rear flap is then closed, and the right (Fig. 49) and left (Fig. 50) shoulder straps are adjusted. Steps 9-12 may occur in a different sequence with some individuals. That is, the shoulder straps may be adjusted before the rear straps, or the lap belt in front may be adjusted first. The strap adjustments may not be necessary in order to don in subsequent usage.

Some things may occur for the first-time uninstructed donner that probably would not in subsequent donnings, or that could be perceived and corrected by the individual. An example is shown in Figs. 51 and 52, illustrating the possibility of not properly getting the arm through both shoulder straps. This individual got his arm through the shoulder strap on the right side, but the shoulder webbing remained tucked under his arm. Because he could feel the shoulder strap, he did not realize the vest was not on properly even after adjusting all straps. This apparently can occur in the present design due to the space between the dacron vest and top-of-shoulder attachment.

Fig. 39. Large (95th%ile) male with restraint adjusted by the wearer.

Fig. 40. Closeup of frontal view of vest restraint. Note closure snaps in front and adjustment straps for horizontal strap (with buckle) and two shoulder straps in front.

Fig. 41. Vest restraint worn by average-sized male.

Fig. 42. Vest restraint worn by small female subject.

Fig. 43. To don, the vest is held to the front with both hands.

Fig. 44. For right-handed persons the right arm is thrust through the right shoulder. There may be a need to straighten the shoulder strap with the left hand.

Fig. 45. Next, the left arm is placed through the left shoulder strap.

Fig. 46. The vest is closed with snaps at the front.

Fig. 47. The velcro fasteners are released at the right side to open the backflap.

Fig. 48. Two rear horizontal straps can be adjusted by pulling on the belt ends. This must be accomplished by feel.

Fig. 49. The left shoulder belt is adjusted with a strap in front.

Fig. 50. The right shoulder belt is also adjusted with a strap end and metal release.

Proper fit may be a problem with the present configuration for both large males and small females. In the case of large males a problem may be encountered in snapping the front of the vest closed (Fig. 53). In this case the subject had to exhale and pull together both sides of the vest at the center and had great difficulty in closing the snaps. A velcro or other arrangement may be more satisfactory.[1]

On the other hand, small female (or male) subjects do not fit this vest well since there is too much slack in the material at both the shoulders (webbing) and vest itself (Fig. 54). This looseness is particularly evident about the armpits (Figs. 55-58).

In summary, from this limited donning experience several points appear to need further design modification if fit satisfactory to the wearer is to be achieved.

- The metal snaps in front were found to be particularly difficult to close for a large individual. Perhaps a velcro fastener would be easier to use.
- The net over the shoulders was loose on both large male and small female when the straps were tightened. Besides resulting in an uncomfortable fit, possibly reducing the effectiveness of the overall restraint, this also results in a "baggy" look which is not very attractive for personal equipment. Female wearers in particular may object to the present fit.
- The vest itself presents fit problems for the small individual and the comments above equally apply to the vest.

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[1] Velcro fasteners have been utilized successfully in subsequent modifications to the prototype vest discussed here.

Fig. 51. This individual is completing adjustment of the lower belt unaware that his right shoulder webbing is under his arm.

Fig. 52. Closeup showing the problem encountered by this individual in a first-use.

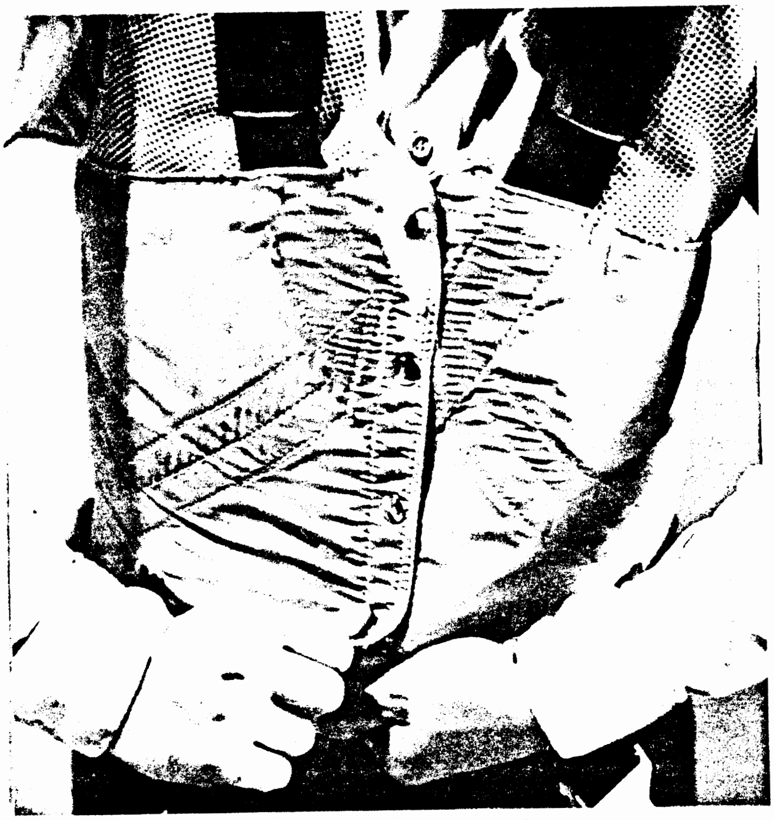

Fig. 53. Difficulty in snapping the vest closed was encountered by this large male.

Fig. 54. Too loose a closure is evident with this female.

Fig. 55. Note looseness of restraint on this female, particularly around armpits.

Fig. 56. Shoulder webbing is far too loose when shoulder straps have been adjusted on this subject.

Fig. 57. Here the looseness is evident as the front is being fastened.

Fig. 58. Note loose fit after all straps are adjusted.

- It was suggested that pockets should be added to the front of the vest; and that matching bright orange shoulder straps might be considered.

Despite these subjective faults in the prototype the vest system offers a number of advantages. The straps were all easily reached and adjusted. From an impact protection point of view the over-the-shoulder features would be predicted to offer substantial protection to jolts and vertical motion. While comfort during driving was not evaluated, the vest system would seem to be a viable design. The problems of donning over heavy clothing, or in very cold weather while wearing gloves, snapping the vest restraint to the vehicle, or comfort during very hot weather are also factors that should be considered. The use of bright highly visible color is both an excellent safety feature and may serve to encourage wearing for hunting or other activities, and result in better acceptance and usage on the job. On balance, the conclusions of the subjective evaluation are that this restraint offers considerable promise, but would benefit from design modifications requiring further study.

VII. DISCUSSION OF PHASE II TEST PROGRAM

The primary factors related to developing a protocol for testing the operator restraint system are:

1. Accident environment
2. Vehicle physical characteristics
3. Operator ergonomics and body size factors.

These factors have been discussed in the previous sections with regard to the extent of available information. As noted, there is a lack of definitive information in many of the areas represented by the above factors. With due consideration of this state of affairs, the following test protocol is recommended for evaluating the performance of the operator restraint system.

The accident environment data indicate that for actual collisions (as opposed to jolts and bumps) the frontal collision is slightly more common than the lateral collision. Thus, it would appear reasonable to test the occupant restraining ability of the proposed restraint system in both frontal crash simulations and in lateral crash simulations. The vehicle deceleration characteristics in such events are virtually unknown. However, a frontal crash velocity change of 20 mph with an average deceleration of 30 G would provide a test condition which reflects both the low speed of vehicle operation and the stiff nature of the vehicle structures involved. Similarly, a side crash velocity change of 10 mph with an average deceleration of 20 G would appear to be appropriate.

The vertical jolt environment, which produces over half the reported injuries, is not truly on impact in the collision sense. However, appreciable accelerations can be delivered to the occupant in the vertical direction during such events. A vertical velocity change of about 7 mph with a peak acceleration of 6 G would represent a 6-inch sinusoidal displacement at a frequency of 3 Hz.

The impact tests would be conducted on the UMTRI Impact Sled with a 50th percentile male anthropomorphic dummy. The dummy will have head and chest accelerometers mounted and will be seated in a conventional bucket seat. The seat and dummy will be oriented on the sled to produce the desired impact condition (i.e., frontal or side). The vertical jolt tests will require the seat and dummy to be mounted on a seat vibration test machine.

Following the tests with the proposed restraint system a second set of tests should be run using a conventional lap belt for comparative purposes and in the case of vertical jolt tests a comparative test with no restraint should also be run. As a final step in the evaluation a single frontal test with a suspension seat system should be run to check the total system response to the restraint system/seat structure interactions.

In none of the tests will a mock-up of surrounding cab structures be used. This is due to the great variability of such structures in the field and the arbitrariness of choosing any one structure. The tests will serve solely to evaluate the restraint capabilities of the proposed restraint system.

VIII. PRELIMINARY DYNAMIC TEST

One dynamic deceleration test (Test 82M001) was conducted on 29 September as a preliminary evaluation of the prototype restraint system. This test was not scheduled in the original research protocol, however since the restraint failed, with broken stitching at a number of strap locations, it enabled modifications to be made prior to the Phase II tests and may have resulted in a saving of time in the long run.

A 50th percentile Part 572 male dummy was seated upon a forklift seat which was mounted to the sled by a fabricated steel frame. The dummy was restrained by the prototype harness which was attached to the sled frame through seatbelt fabric segments. The arrangement is shown in Figures 59 through 62. The lower seatbelt segments had load cells applied to them, as did the right shoulder harness of the prototype restraint. All belts were tightened snugly.

The sled was subjected to a 22 mph velocity change with an average deceleration of 32 G. The dynamic belt loads, dummy head and chest center of gravity triaxial accelerations, sled deceleration and velocity were recorded on magnetic tape. Side and overhead view 16 mm movies at 1000 frames/sec nominal film speed and a side view Polaroid sequence camera photograph (Figure 63) were taken of the impact event.

As shown in Figure 63 the dummy translated forward and the restraint system was loaded, tearing the jacket. This allowed the straps of the restraint system to move free of the dummy in such a way that the dummy moved under the abdominal strap and dropped off the front of the seat. Peak belt attachment loads were; right side - 1091 lb., left side - 942 lb., while the shoulder strap load reached a peak of 650 lb. Head and chest accelerations were low with a Head Injury Criterion

(HIC) value of 248 and a peak resultant head acceleration of 38 G. The peak resultant chest acceleration was also 38 G.

The final post-test configuration is shown in Figures 64 through 66 and the details of the failed restraint vest are shown in Figures 67 through 69.

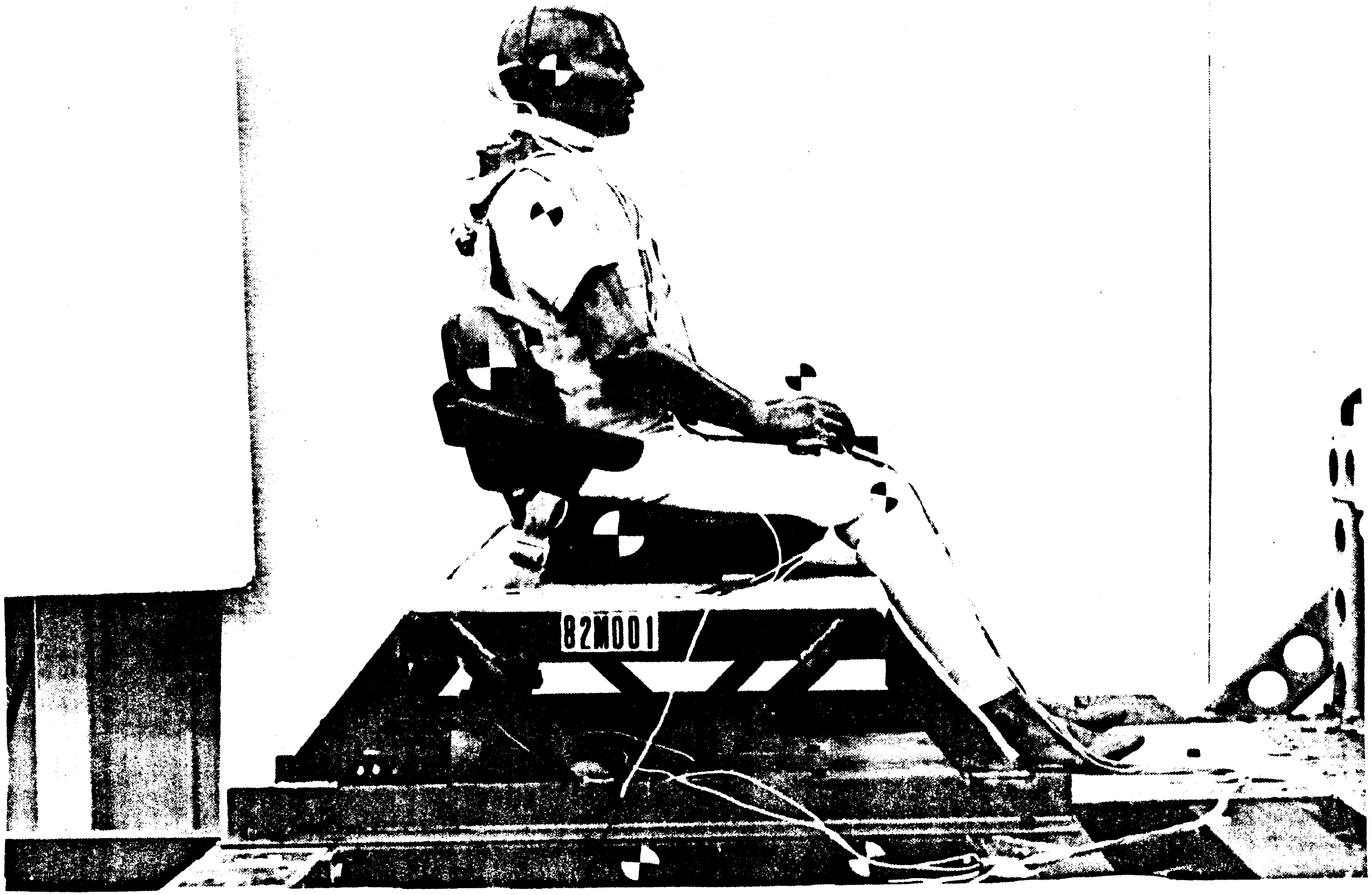

Fig. 59. Side view of 50th percentile Part 572 male dummy wearing prototype vest restraint prior to dynamic Test No. 82M001.

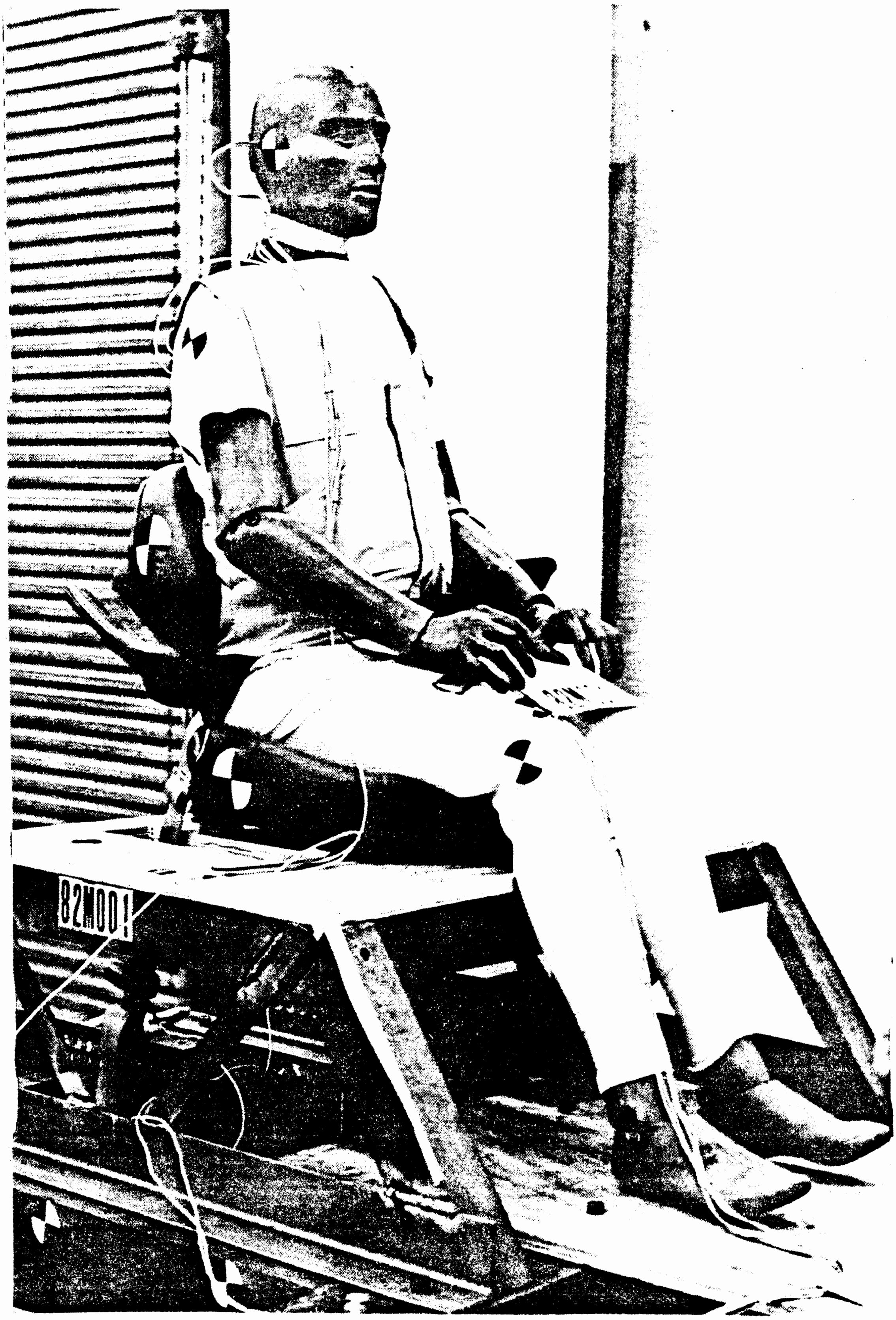

Fig. 60. Quartering view of dummy wearing prototype vest restraint system.

Fig. 61. Frontal view of prototype vest restraint.

Fig. 62. Left side view of restraint prior to test.

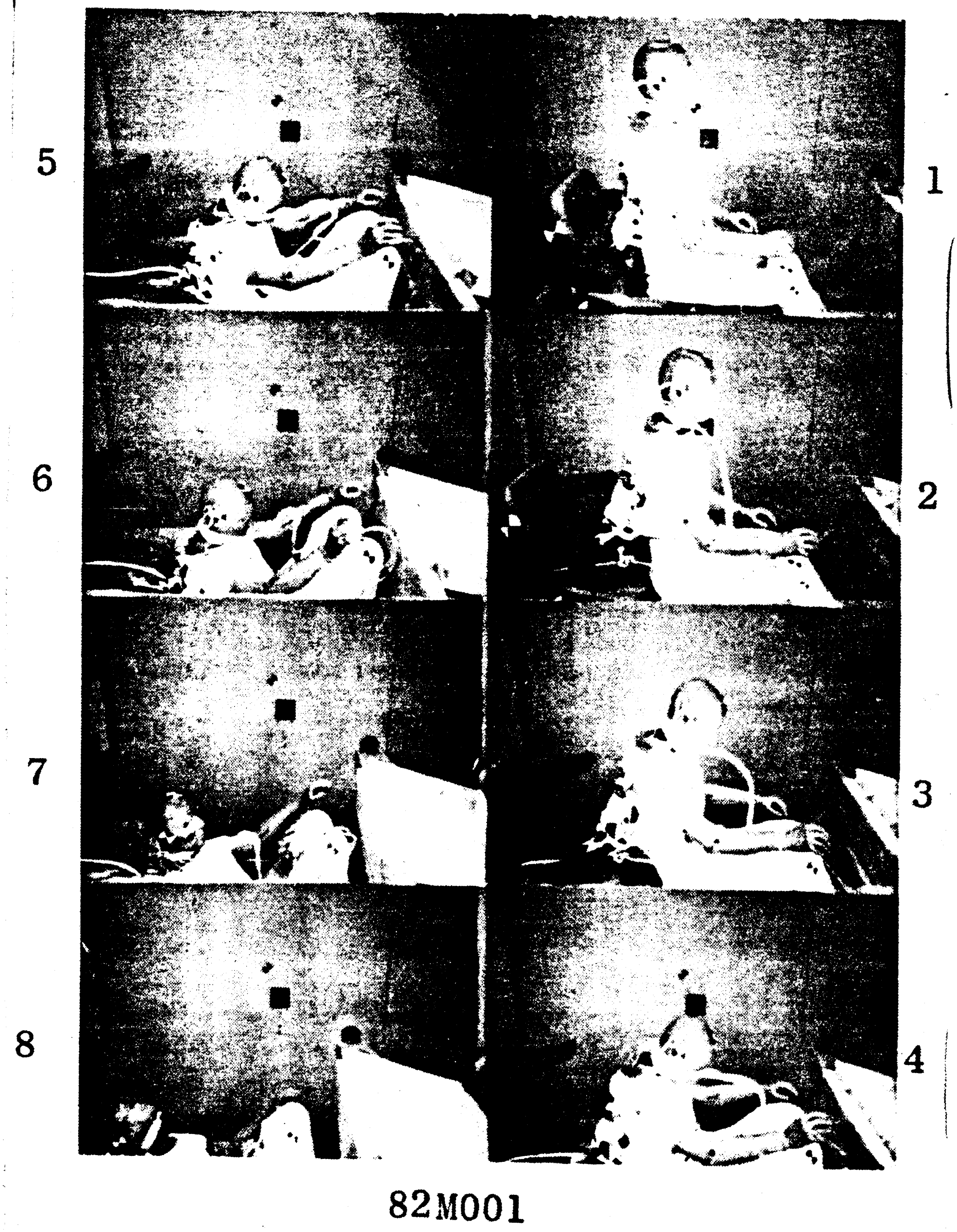

Fig. 63. Side view Polaroid sequence camera showing eight frames during the impact.

Fig. 64. Post-impact view showing dummy on floor in front of seat.

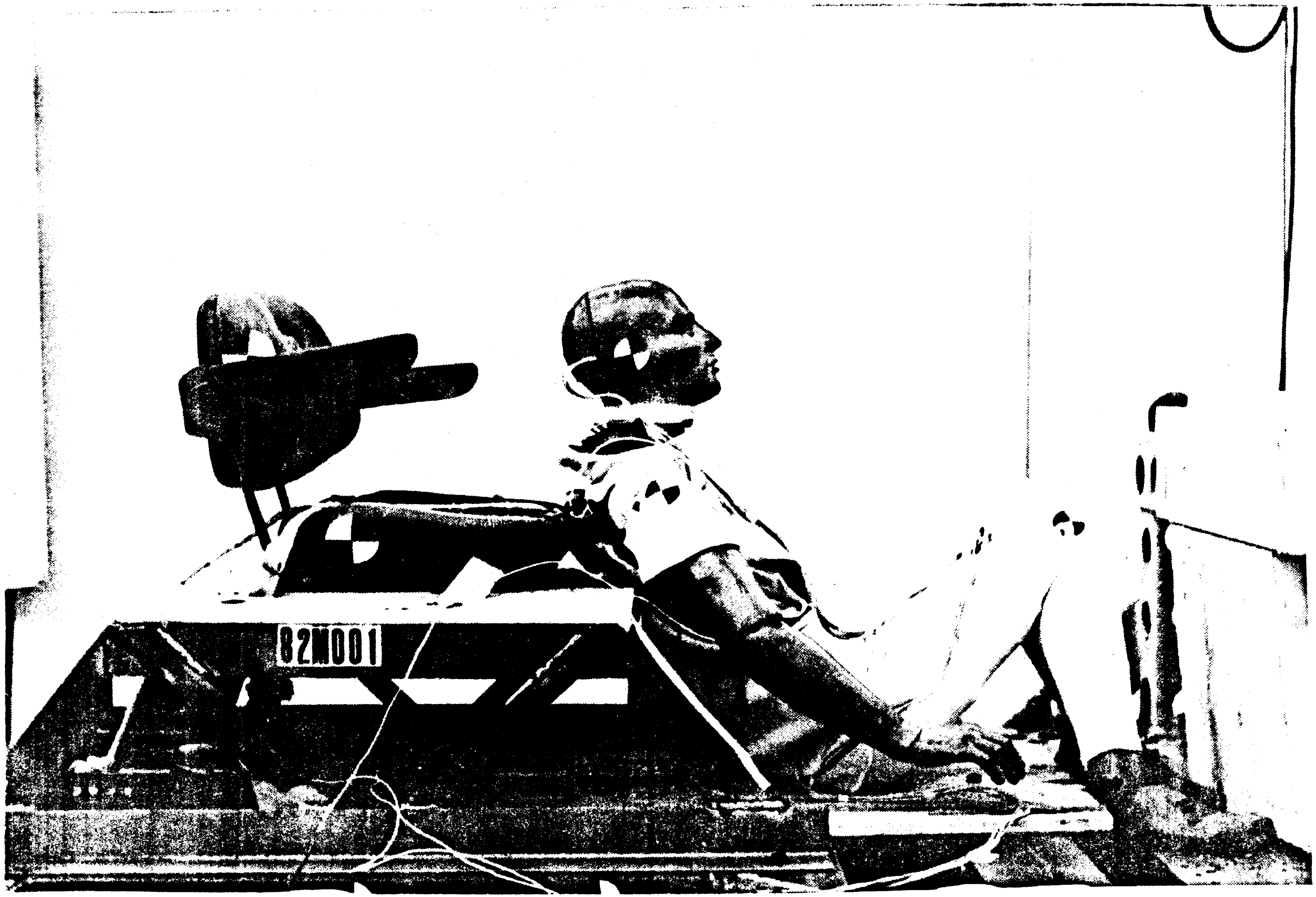

Fig. 65. Side view showing dummy position post-impact.

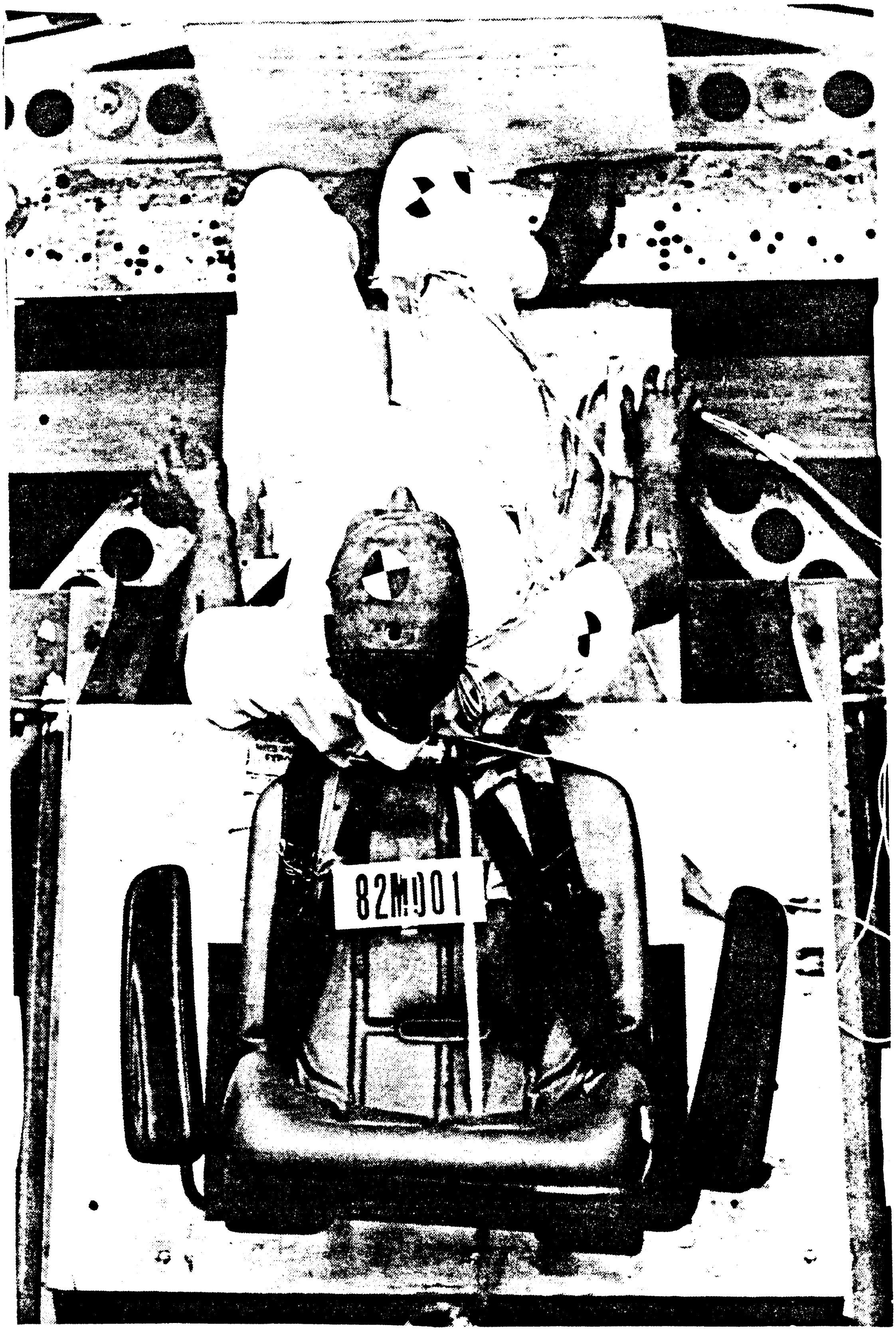

Fig. 66. Overhead view. Note that dummy has slid completely off seat.

Fig. 67. The straps came unstitched in the impact and the vest failed to restrain the dummy.

Fig. 68. Details of tears in the vest and strap failures.

Fig. 69. Another view, from inside, showing failure points.

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APPENDIX A.
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