AD 672 504

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Joseph L. Haley, Jr., et al

Aviation Safety Engineering and Research
Phoenix, Arizona

April 1968

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AD 672504

TECHNICAL REPORT
68-57-CM

# CRASHWORTHINESS OF AIRCREW PROTECTIVE ARMOR

by

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Natick, Massachusetts

Contract No. DAAG17-67-C-0138

Project Reference:
1F141812D154

Series: C&OM-47

April 1968

Clothing and Organic Materials Laboratory
U. S. ARMY NATICK LABORATORIES
Natick, Massachusetts 01760

## FOREWORD

This report covers the methods and results of various tests conducted to investigate the behavior of aircrew personnel body armor in an aircraft crash environment.

The report was prepared by the Aviation Safety Engineering and Research, A Division of Flight Safety Foundation, Inc., Phoenix, Arizona. The program was accomplished under Contract No. DAAG17-67-C-0138 for the U. S. Army Natick Laboratories, Natick, Massachusetts, 01760, with Edward R. Barron serving as Project Officer and Stanley Tanenholtz as Instrumentation Advisor.

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## ABSTRACT

The results of a test program conducted to determine the physiological effects of personnel armor on aircrew members exposed to an aircraft crash environment are presented. Emphasis has been placed on the effects of armor as worn by air crews in current military operations.

The program was divided into two major tasks. The first included a literature search to obtain design data on human injury simulation techniques, a conference to obtain information from a group of combat-experienced U. S. Army medical helicopter crewmen on the impact behavior of the armor in observed accidents, and modifications to anthropomorphic dummies to effect recordings of mechanical "injuries" to vital body areas. The second task consisted of three types of dynamic tests: vertical drop tower tests, horizontal accelerator tests, and a full-scale helicopter crash test.

Test results indicated that the potentially dangerous effects of the armor during a crash situation are relatively few. The most serious problem appears to be the possible collapse of the trachea following an impact of the upper edge of the armor with the front of the neck. Such injuries may be fatal. While such impacts occurred only once during the tests, sufficient chin and face impacts did occur (20 times in 30 tests) to indicate a potential for this type of body-armor contact. Simple modifications of existing armor such as a padded deflector in the neck area would be desirable.

Contact of the lower edge of the armor with the thighs resulted in loads of as much as 800 pounds. Specific modifications to the armor in this area are also recommended, although loads of this magnitude would not produce serious injury.

Some apparent advantages of the armor include resistance to concentrated loads on the front of the lower extremities and in the chest area when the appropriate armor is worn. There is also some indication that submarining of the occupant may be reduced in certain crashes when properly fitted and restrained chest armor is worn.

The practice of wearing a restraint system (lap belt and shoulder harness) loosely to allow the chest armor to be held away from the body and provide relief from thermal stress in hot/or humid climates is not recommended.

Sufficient seat failures occurred to warrant consideration of modifications to the seats.

CRASHWORTHINESS OF AIRCREW PROTECTIVE ARMOR

## 1. Introduction

Military operations in Southeast Asia have proved the value of the helicopter in close ground fire support and medical evacuation of wounded personnel under intense hostile ground fire. This new role of the helicopter as an active weapons system has required many aircraft modifications to provide protection from increased threat of hostile small arms fire.

In addition to decreasing the vulnerability of the aircraft to hostile small arms fire, parallel research has been conducted to provide increased ballistic protection for the aircrewmen. A major breakthrough was achieved in 1964 when a lightweight armor material was developed which provided significant protection against small arms fire. This new material, a ceramic fiberglass composite, was sufficiently light to be used in the design of new armored crew seats and personnel body armor.

New pilot and copilot seats for existing aircraft have been designed using this new armor material to provide ballistic protection on the back, bottom, and sides. An anatomically shaped chest armor worn in a canvas vest by the pilot and copilot was designed to complete the vital area body coverage. The duties of the helicopter crew chief and/or gunner, however, prevent adequate protection from a fixed seat; therefore, an armored seat has not been provided. The armor vest with an additional armor plate in the rear pocket is provided for the crew chief. Several types of full and partial leg armor have also been designed to increase the body coverage of the crew chief and/or gunner.

Large quantities of this type of body armor have been provided to military aircrewmen in Southeast Asia under an expedited program. The initial need for body armor has been met. However, new requirements are still being generated and it is now essential that the effect of the armor on personnel in an otherwise survivable crash situation be determined. The results of this study will be used with corollary research programs concerned with fitting, comfort, ease of donning and doffing to develop criteria for new designs and, if necessary, modifications to existing systems.

## 2. Analysis of the Problem

### a. General

Aircrewmen in aircraft accidents can be adversely affected by the body armor in these ways: (1) injuries may be directly or indirectly inflicted on the wearer by the armor, (2) the added armor mass may add to the loads carried by the seats and belts, causing failure, and (3) the armor may retard postcrash evacuation of the aircraft. Properly designed armor can result in beneficial effects by providing improved load distribution on the body and increased resistance to localized penetration and/or crushing.

The study of personnel armor as related to aircraft crashworthiness can therefore be divided into three major areas of concern:

(1) The effect of the armor on crewmen during the crash.

(2) The effect of armor on the design of personnel restraint systems.

(3) The effect of the crash and postcrash environments on the design of the armor.

This study is primarily concerned with the first area with consideration given to the overlap into the second and third areas.

### b. Injury Analysis

The most difficult task within the scope of this study was to correlate the mechanical damage sustained by anthropomorphic dummies used in the tests with the probability and degree of human injury under the same conditions. Accurate human tolerance data regarding specific injury levels in human body components are not well documented. Although considerable work has been done in medical research on wound ballistics, correlation of this work with crash injuries is difficult, if not impossible. It must be recognized that medical authorities cannot be expected to translate, without qualification, structural damage occurring in an anthropomorphic dummy into injuries which a human counterpart would have experienced. The combined judgment of medical and engineering research personnel appears to be the most practical approach to determining injury potential and/or probability in tests of this type. This approach was used in the analysis of the results of this test program.

c. Seat Considerations

Primary emphasis in this report is placed on the injury-producing effects of personnel armor on the aircrewman; however, it is necessary in this analysis to include consideration of the effects of the seats and restraint systems. Interaction between the wearer and his armor is dependent upon the response of his seat and restraint harness. The dynamic response of the seat and occupant restraint harness is determined to a large measure by the design of the seat, seat support structure, and the type of comfort cushion used. Therefore, evaluation of the armor components in representative types of seats was considered necessary to the successful completion of this study. The following listed seats typify the three types most commonly used in U. S. Army aircraft deployed in Vietnam:

(1) UH-1B/D armored crew seat - flexible in construction with a nylon net comfort cushion.

(2) CH-47 armored crew seat - more rigid than the UH-1B/D seat, with a sheet metal seat bucket and a resilient foam cushion.

(3) Bulkhead mounted troop seat - fabric cover stretched over a tubular support frame.

Each of these types of seats was used in one or more tests.

d. Impact Conditions

The crash environment simulated in the tests is characterized by:

(1) Acceleration levels and velocity changes corresponding to severe but potentially survivable rotary- and light fixed-wing aircraft accidents.

(2) Acceleration levels adequate to cause failure or near-failure in the seat structure in each test.

(3) Acceleration levels below the human survival limit but capable of producing injury.

3. Plan of Approach

a. General

The objective of this program was to conduct the necessary dynamic tests of present and future concepts in aircrew armor to determine the possible physical and physiological effects of crash loading on the crewmember wearing the armor and to develop recommendations for improving the crashworthiness of the armor.

To accomplish the objective, the program was divided into two major tasks as follows:

(1) Development of Human Injury Simulation Techniques.

(2) Performance of Dynamic Tests.

b. Human Injury Simulation

Review of Existing Data

A careful examination of the extensive crash-injury literature revealed that data on human injury simulation techniques were not recorded in sufficient detail to be of value in this program. However, during this review, five agencies* which have had research programs of similar objectivity were prominent. The lack of data available from the literature review necessitated a visit to these agencies to discuss the problem and to obtain any available data for better simulation or measurement of the degree of injury when using anthropomorphic dummies.

The problem of injury simulation in anthropomorphic dummies was discussed in detail at each of the agencies visited. Proposed methods for determining potential injuries were discussed and the consensus of opinion was that these should provide sufficient data for the purposes of this study. There was, in fact, very little data available from anyone contacted which would specify the tolerance of the body to localized blows

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such as could be expected from body armor in aircraft accident situations. Therefore, tests were conducted to gain such information.

(1) Anthropomorphic Dummy Modifications

Three body areas were determined to be the most susceptible to injury from the armor in a crash situation. These areas were the spinal column, the upper anterior thigh, and the face-neck.

It was postulated that the additional weight of the armor on the upper torso might cause injury to the spinal column under crash impact loading. Therefore, a load transducer was fabricated and was installed in place of one of the dummy's vertebral units (Figure 1). A comparison of the vertebral load with and without armor installed on the dummy then allowed an analysis of this potential problem area.

During the application of high vertical loads (parallel to the spine), it was anticipated that the personnel armor could impact the upper anterior thigh. To measure the force resulting from the contact, crushable foam-pads were fabricated to cover the predicted contact area (Figure 2). By measuring the indentations in these pads, the maximum force levels imposed by the armor were determined. These data would be used in the analysis of potential injuries by comparing the dummy test loads with measured human tolerance loads. Appendix F contains full technical data on the styrofoam pads.

The possibility of contact by the lower jaw and neck area of the dummy with the upper edge of the personnel armor under high vertical loading was considered to be a significant problem. To determine the contact force, a crushable foam-pad was mounted on the top edge of the personnel armor during each test (Figure 3). In addition, a high-speed camera was mounted on the drop jig to provide a closeup view of this area during the impact.

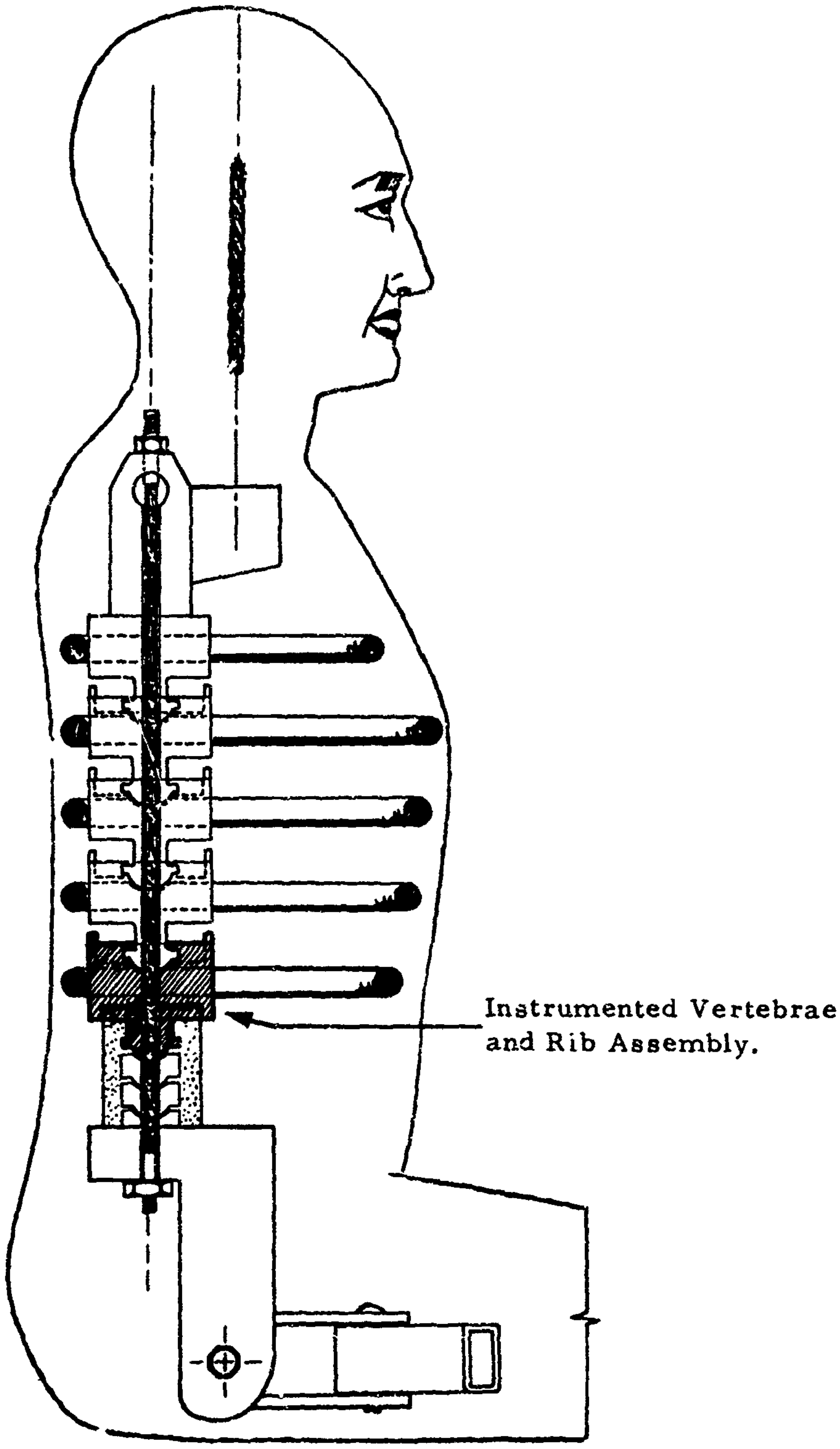



Figure 1. Location of Instrumented Vertebrae.

Figure 2. Thigh Pad Installation.

Figure 3. Chin Pad Installation.

(2) Aircrew Armor Conference

A conference was held in Phoenix, Arizona on 13 and 14 July 1967 between the AvSER staff, the Contracting Officer's technical representatives and U. S. Army Medical Evacuation personnel recently returned from Vietnam, to evaluate the proposed test procedures and methods for determining potential human injury and to obtain guidance for the dynamic test program.

The conference results proved beneficial to the overall test program by providing specific input for increasing the realism of the crash simulations and fixing the manner in which the armor should be installed on the dummies in the respective tests. A summary of the conference agenda is presented in Appendix D.

It was noted in the conference that there has been little evidence that the armor as now employed in Vietnam has produced significant injuries in crash situations. Minor injuries, however, had been observed.

During the conference, the specific modifications to the dummies to be used in test series were discussed. No additional modifications were suggested.

c. Dynamic Test Series

The armor was installed on anthropomorphic dummies in three typical helicopter seats and dynamically tested in three separate test phases as described below.

Phase I - Vertical Drop Tower Test Series

Drop tower tests were used to duplicate the high vertical accelerations characterisitic of helicopter accidents. The low longitudinal and lateral forces normally experienced were induced by altering the seat mounting an[illegible]le on the tower drop cage. A dual set-up was used to allow two seats [illegible] tested in each impact. This procedure allowed side-by-side com[illegible]n of dummies mounted both with, and without armor. A detailed re[illegible] on the drop tower tests is contained in Appendix A.

Phase II - Horizontal Accelerator Test Series

These tests were conducted to impose primarily longitudinal forces on the test dummies and seats which generally occur in fixed-wing impacts. The vertical and lateral impact conditions desired were obtained by changing the seat mounting angle to induce small lateral and vertical load components. Due to space limitations, only one seat was mounted in each of these tests. Appendix B contains the details on the accelerator tests.

Phase III - Full-Scale Aircraft Crash Test

A full-scale helicopter crash was simulated by mounting the test dummies, armor and seats on a relatively intact section of a salvaged UH-1 helicopter. The test vehicle was then suspended from the boom of a moving crane and dropped at prescribed longitudinal and vertical speeds onto a prepared impact area. See Appendix C for details on this test.

## 4. Biomedical Evaluation of Test Results

### a. General

In the biomedical evaluation of the dynamic tests, the body areas or segments subject to potential injury by the armor were categorized for analysis as follows:

(1) Head - Face

(2) Neck

(3) Chest

(4) Spine

(5) Pelvis and Upper Thigh

(6) Lower Leg and Feet

(7) Upper Extremities

This evaluation of the dynamic tests was conducted by a team of medical and engineering personnel using the electronic instrument data, posttest examination of injury indicators, and a single frame analysis of the high-speed motion picture films. Tables I, II and III, which are referenced in the discussion, will be found in the Appendices, pages 39, 73 and 94. They present a summary of the test conditions and results for each of the three test series.

### c. Head - Face Area

The occupant's head receives most of its protection in a crash from a properly fitted helmet. The face area receives minimal protection from the helmet and therefore is vulnerable to contact with the upper edge of the chest armor. For purposes of this study, the "face" area is defined as extending from the eyebrows to the angle of the jaw, as shown between 1 and 2 in Figure 4.

Although face/armor contact did not occur in some tests, a collision between the face and armor was present in all of the longitudinal acceleration tests and in those vertical acceleration tests in which longitudinal forces were present (see columns 8 and 9 of Tables I and II). This indicates that armor contact can be expected when significant

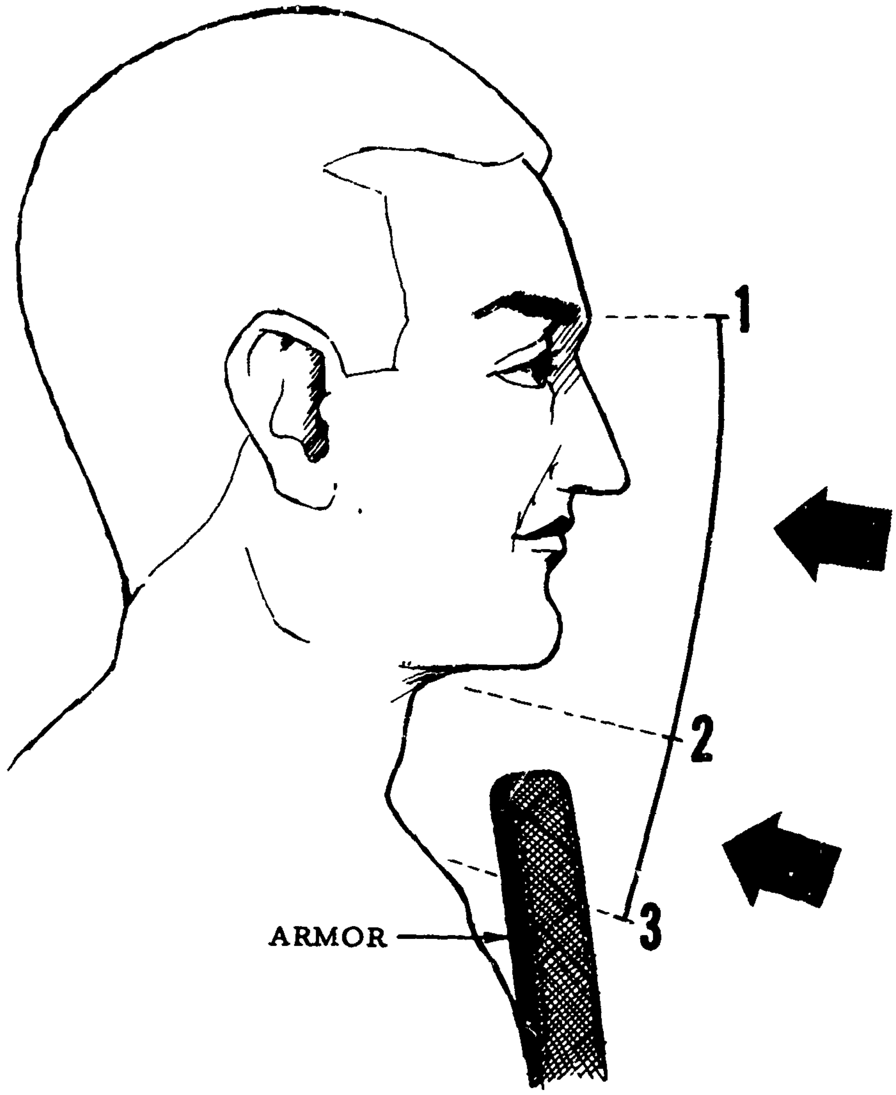



Figure 4. Face/Armor Contact Zones.

deceleration in the longitudinal direction occurs. In the full-scale dynamic tests, face/armor contact did not occur on any of the three armored crew seat occupants.

The point of contact on the face (i. e., chin, lips, nose, etc.) was not consistent in the tests. This indicates that a slight change in pitch and yaw can significantly influence the interaction between the dummy and armor.

The degree of deformation in the styrofoam impact pads placed on the top edge of the armor in the longitudinal acceleration tests, Tests 4 and 12, indicated force levels of 140-150 pounds. Examination of the 500 frames per second motion picture film has shown that this force was applied for a maximum of 0.1 second. At points of contact between 1 and 2, (Figure 4), impacts of this total impulse would produce lacerations, bruises, and could break some teeth, but these impacts are considered minor from a survival point of view[4].

The advantage of tightly worn armor and occupant restraint harness over loosely worn armor and restraint harness is considered to be significant based on the tests conducted during this program and previous experience with restraint systems at AvSER[9]. The tight, properly worn armor stayed closer to the dummy and did not flail around the neck and face area, especially during vertical impacts.

The necessity of shoulder harness restraint was dramatically illustrated by the dummy seated in the troop seat in the full-scale crash test. This dummy was restrained by a lap belt only and, from examination of the high-speed movies, apparently sustained a severe facial impact on the left corner of the armor. The addition of a shoulder harness to this location should reduce this danger and significantly increase the gunner's chances of survival in a crash.

c. Neck

The two potential injury hazards to the neck included in the following discussions were direct contact with the armor and whiplash.

Direct contact of the upper edge of the armor with the neck area along the arc from 2 to 3 in Figure 4 could produce serious damage, the most dangerous being fracture of the trachea, especially at the larynx. These are serious injuries, as the vocal cord spasm or collapse of the trachea associated with this trauma may occlude the airway long enough for death to result. The forces measured at the top of the armor were more than sufficient to cause this trauma[4]. In the test program, direct contact of the armor with the neck area occurred in only one test compared with 19 impacts to the face area in the remaining 29 tests (see Tables I and II for details). However, caution should be exercised in using these figures from which to draw the conclusion that the possibility of neck impact is low. It was recognized during the early planning that the neck area simulation of the anthropomorphic dummy was very poor. Several agencies visited are presently engaged in projects to increase the level of simulation; however, the improvements were not available for incorporation into this test program. What is significant here is the fact that sufficient force was recorded at the top of the armor to cause serious injury to the throat area. A practical modification of the armor-vest-carrier to avoid this occurrence would be to pad the neck area in some fashion. An energy-absorbing, fragment-deflecting, turtle-neck unit (Figure 5) would satisfy this requirement.

It was initially suspected, because the molded chest armor plate acts as an ideal total upper body restraint, that the head would decelerate more violently, with respect to the torso, than under similar crash pulses where the chest was restrained only by a shoulder harness. If this phenomenon were to occur, the whiplash potential as evidenced by both magnitude and rate of head deflection in the human could conceivably be increased by the resulting hyperextension and/or hyperflexion[2].

To investigate the whiplash potential induced by the presence of the chest armor on a live subject, the neck cable in the dummies used in both the drop tower and horizontal acceleration tests was adjusted to give head and neck motions approximating those of live subjects. To determine the adjustment required, both human subjects and dummies were restrained on a test table with a standard lap belt and shoulder harness (Figure 6). The range of motion of the head and neck in the forward and backward (flexion and extension, respectively) directions was recorded. Neck cable torque adjustments of 0, 20 and 40 foot pounds were made prior to tests with the dummy.

On the basis of the results of this experiment alone, a dummy neck cable torque adjustment of zero foot pounds would have been selected. However, had this value been used, then almost no resistance of the head to rotary motion would have been present in the range of ± 30 degrees from the normal vertical position. A neck cable torque adjustment of 20 foot pounds was found to reduce this range to approximately ± 10 degrees without greatly reducing the head rotational travel and was selected as a satisfactory compromise value. It is quite probable that the live subject provides some resistance to motion of the head through muscle tension in most accidents[1].

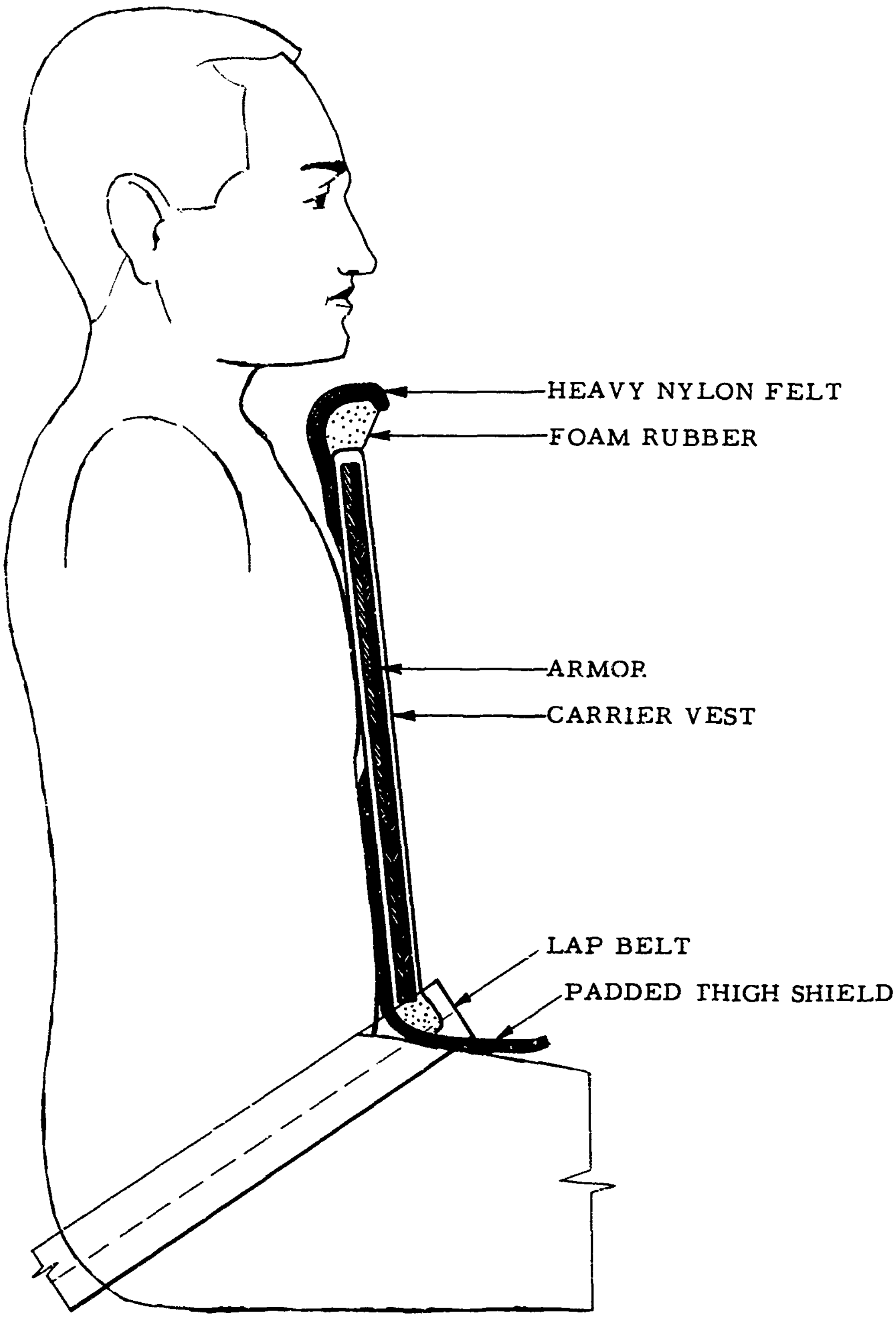



Figure 5. Recommended Padding for Upper and Lower Edge of Armor.

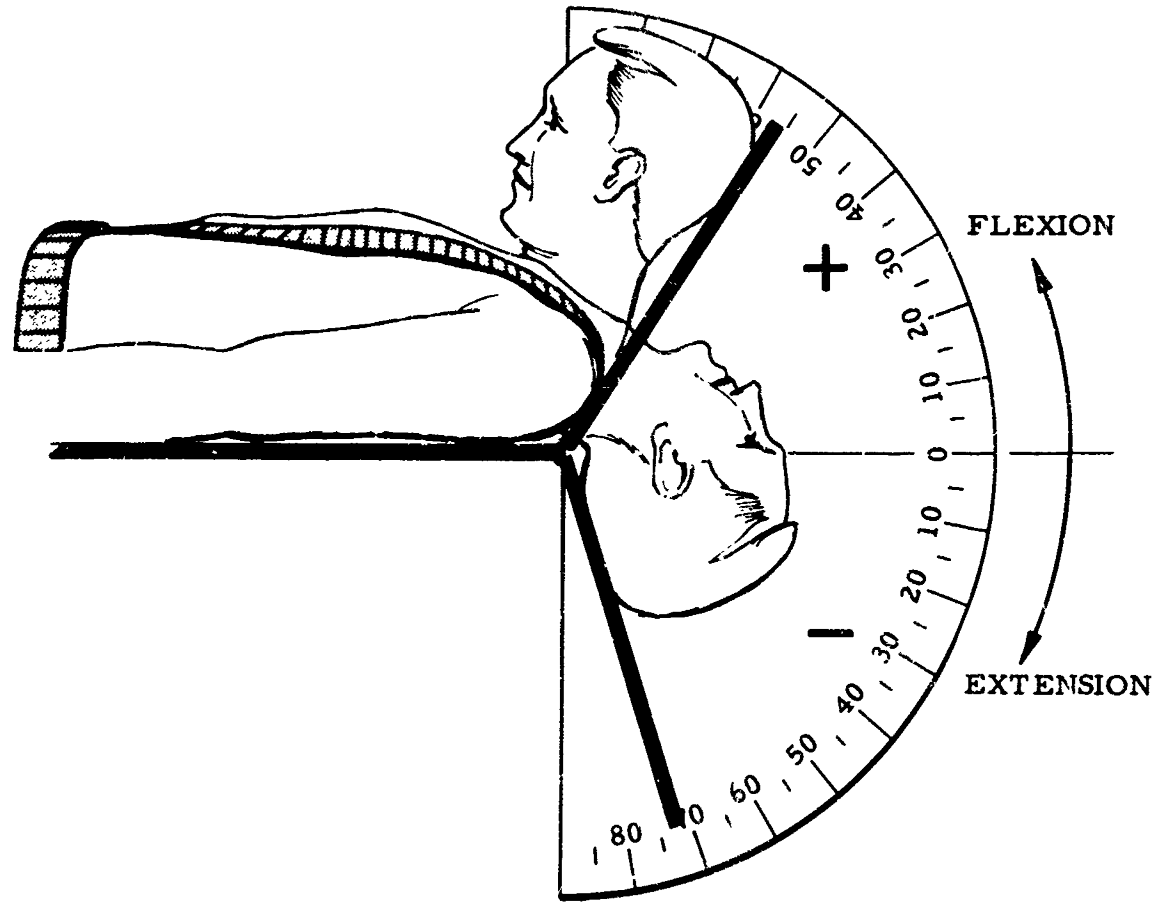



Figure 6. Method for Determining Neck Range of Motion in Live and Dummy Subjects.

Single frame examination of the test films did not substantiate the hypothesis of increased whiplash for the armored dummy. The elasticity of the shoulder harness apparently negates the anticipated increase in restraint due to the presence of the armor. On the other hand, the longitudinal head accelerations (see Table II, column 10) in the horizontal acceleration tests in every case were higher with the armor than without. This, however, may well be attributed to the fact that chin-armor contact occurred in every case in which the styrofoam chin pads were installed. In any event, the magnitude of the differences in head accelerations, with and without armor, is not considered medically significant[10].

The potential for injury evaluation in the head and neck due to oscillation, vibration or resonance is not within the scope of tests using dummies.

d. Chest

There was nothing observed from films or instrument data that would imply the armor increases chest injury during a crash. On the contrary, the armor should have a significant "shielding" effect on the front of the chest. The cyclic stick, for example, is a potentially dangerous instrument during a crash. The front armor plate provides definite protection against being impaled on this structure.

e. Spine

Military aircraft accident data indicate that the spine is particularly vulnerable to injury[3]. In the period 1 January 60 to 30 June 65, the U. S. Army reported 718 survivable rotary-wing aircraft accidents (exclusive of Republic of Vietnam) with 2,068 survivors[6]. In 13 percent (92) of these accidents the occupants suffered spinal injuries. The only other body areas receiving a higher percentage of injuries were the upper extremities (22 percent) and the legs (20 percent).

Studies done on the compressive strength of wet vertebrae (males, age 20-39 years), indicate strength ranges of 814 pounds for upper thoracic to 1606 pounds for lumbar vertebrae[4]. Present day standards for ejection seats are in the range of 20G for 0.5 sec (trapezoidal pulse)[5]. This would result in a mass acceleration product of about 2000 pounds based upon upper torso weight of 100 pounds. Although minor compression fractures of vertebral bodies are not uncommon following ejections, the human spinal column has built-in energy-absorbing discs. These discs (D) are shown between each vertebral "bone" (B) in Figure 7 which (depending upon the curvature of the spinal column at the moment the load is applied) serve to "cushion" the impact forces on individual bone unit.

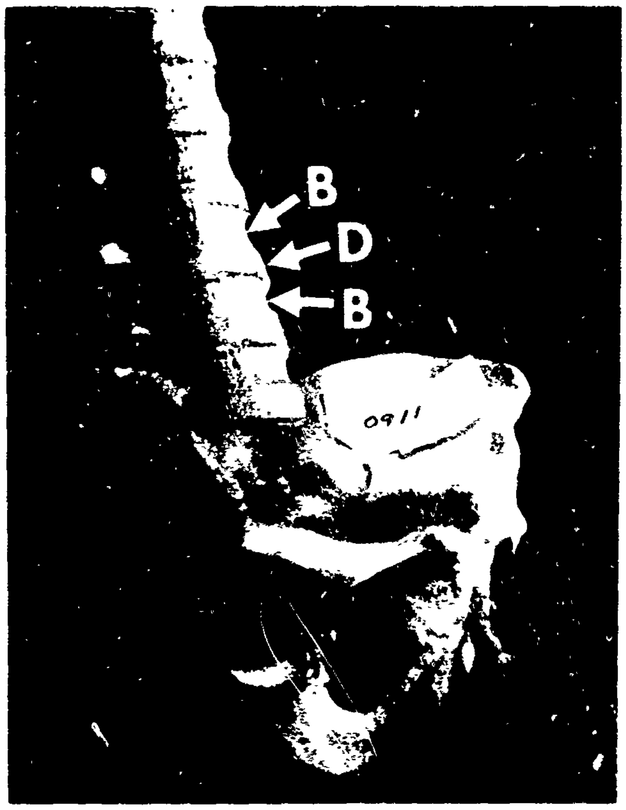



Figure 7. Typical Spinal Column Showing Discs (D) and Vertebral Bone (B).

A special effort was made to record the loads generated in the lumbar spine region of the dummy and to compare differences, if any, which would occur as a result of wearing the body armor chest plate. Special vertebral load cells were designed and installed (Figure 8). The upper portion of each dummy, (the mass "above" the load cell) was weighed by direct measurement. This upper segment weighed 101 pounds. From a purely mathematical viewpoint, the added weight of the armor vest (16 pounds) resting on the dummy's shoulders, would increase the vertebral loading (considering axial loading with no alternative load paths) by this same amount for each "G" of the "eyeballs down" acceleration. As an example, a 10G impact would be expected to increase the vertebral loading by 160 pounds, discounting overshoot, eccentric vertebral loading, etc.

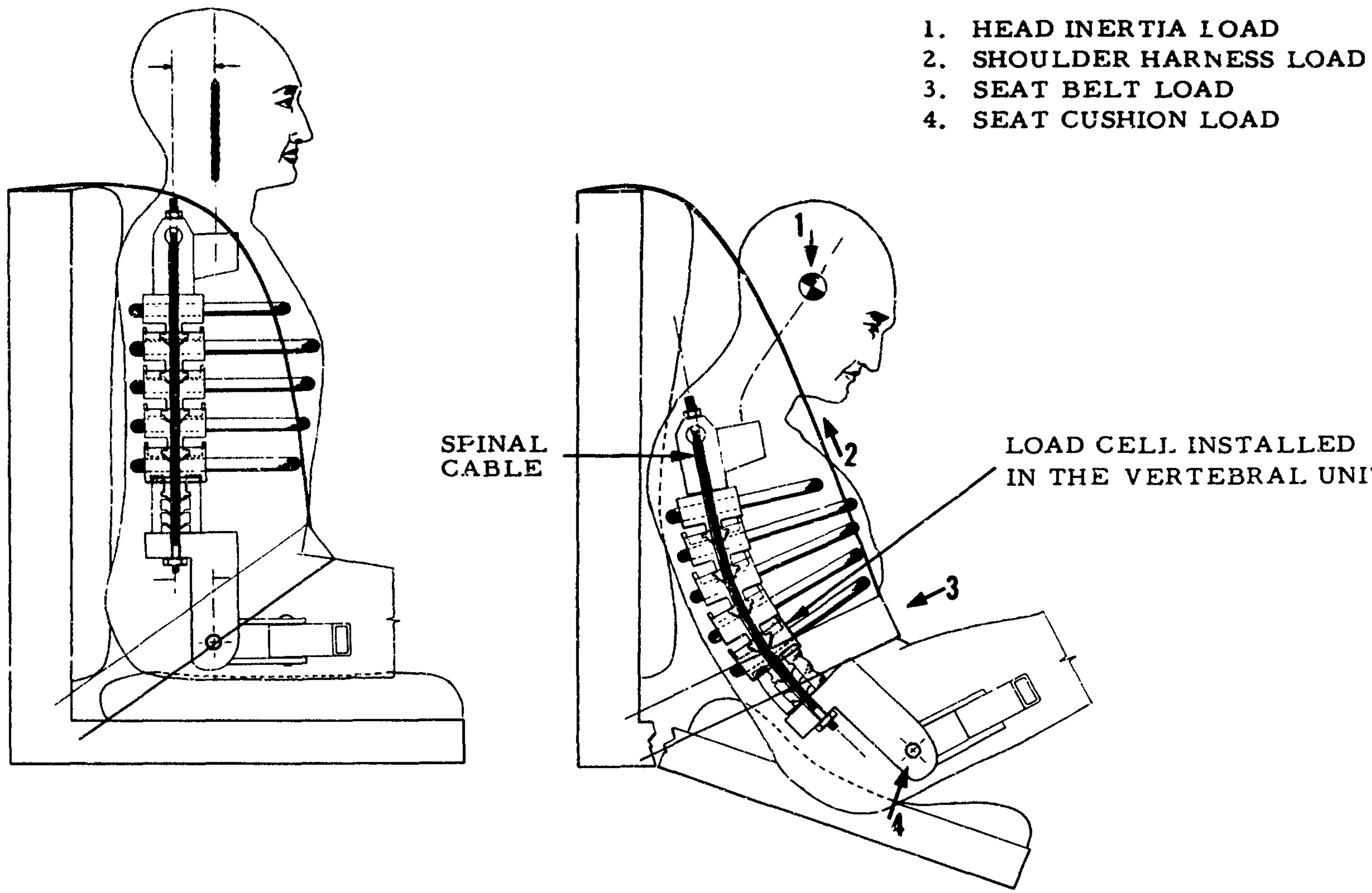



Figure 8. Flexion of Spine During Submarining.

In some of the tests, especially those in which the seats had a rearward tilt, Tests 23A, 6A, 18 (vertical drop) and Tests 4 and 6 (horizontal accelerator), there was agreement between the chest mass-acceleration product and the vertebral load cell readings (see Tables I and II for details). It was expected that in tests with identical seat orientations and crash pulses that the dummy with armor would show slightly higher vertebral loads than the unarmored dummy. However, this last assumption did not prove valid, and in the horizontal accelerator series the armored dummy consistently registered less vertebral load. Horizontal accelerator tests (3, 4, 7, 8, 11, 12) resulted in abnormally high vertebral load cell readings. In every one of these cases, the unarmored dummy experienced significantly higher vertebral loads than his armored counterpart.

The reasons for these large differences in vertebral readings (see Table II, column 17, for Tests No. 1 and 2, for example) have not been completely resolved. However, it is believed that the higher load readings were not indicative of vertical compressive load, but were associated with flexion of the spine due to either "submarining" or "jackknifing." It was clearly observed in the high-speed films taken during horizontal accelerator tests that the unarmored dummy in every case either submarined under the lap belt to a considerably greater degree than did the armored dummy, or jackknifed to a greater degree. This resulted in the unarmored dummy experiencing a more severe flexion in the lumbar region than the armored dummy. The mechanical design of the dummies used is such that bending of the spine beyond a certain limit will induce spurious load cell readings due to the tension induced in the cable which extends from the pelvis to the shoulders and ties the vertebrae of the dummy together, Figure 8. The vertebral load readings, in column 17 of both Tables I and II, which greatly exceed the product of the chest vertical acceleration and the chest mass (100 pounds x column 15 in Table I, and 100 pounds x column 17 of Table II), should be considered only as an indication of severe flexion.

The human spinal column is particularly susceptible to injury when it is forced to undergo acute flexion, and although the high loads recorded in acutely flexing dummies would not directly imply a similar loading situation in the human, the phenomenon responsible for producing the high load readings (acute flexion) could also be expected in the human[3, 6]. It is quite probable that if the chest armor acts to decrease vertebral loads in the dummy by limiting the range of acute spinal flexion, it would afford the same flexion protection to the spinal column of a human occupant.

It appears from the limited number of tests conducted that the use of the chest armor reduced submarining in those tests in which the crash pulse had a significant longitudinal component (horizontal accelerator tests), thus reducing the chance of injury to the spinal column. In the vertical drops, the vertebral loads occurred more randomly with respect to armor use and no strong evidence was found that the armor would contribute to increases in spinal injuries if the seat does not fail.

The single most apparent cause of high vertical loads (parallel to the long axis of the spine) and potential serious spinal injury is still collapse and "bottoming out" of the seat. Until protection against the uncontrolled mechanical failure of the seat is achieved, severe spinal injuries will continue to occur in occupants of "survivable" aircraft crashes.

f. Pelvis - Upper Thigh

A great deal of effort was made to establish realistic levels of tolerance to armor impact in the area where the upper thigh joins the pelvis. An experiment was conducted at the beginning of the program during which voluntary human test subjects tolerated forces in excess of 400 pounds for 5 seconds with ease (see Appendix E for details of this experiment). The styrofoam impact pads installed on the upper thigh of each dummy in the vertical drop series indicated average total thigh load of 514 pounds. A maximum total thigh load of 820 pounds was recorded in Test No. 8.*

Examples of typical pads are shown in Figures 18, 56 and 67 in Appendices A, B, and C, respectively. There was nothing in the tests to indicate that the armor has a serious effect in this area. The foregoing is not unqualified endorsement of the armor's crash response because several factors affect the behavior of the front armor plate. First, as the angle of forward bending (at the hips) becomes more acute, as in flexion due to a loose shoulder harness, the potential danger of the armor damaging the groin area increases.

*Styrofoam impact pads were also installed in all dummies on the horizontal accelerator series; however, no significant armor impact deformation occurred. The thigh loads received by the dummies in the dynamic crash test were similar to the loads recorded in the drop tower tests.

The addition of a thigh shield of heavy nylon felt or other cushioning materials below the armor vest carrier, as shown in Figure 5, would aid in padding the thigh-armor contact area and, as the human subject tests indicated so positively, can increase the tolerance to impacts in this area. The added ballistic protection from spall may also be beneficial. The shield would reduce stress concentrations on the thigh due to lap belt hardware and/or creasing of the belt under load. It would also help to anchor the lower edge of the armor and increase the comfort of the lap belt.

g. Lower Limbs and Feet

The position of the feet at impact seems to affect the response of the chest and spine under certain crash orientations; however, the body armor per se does not appear to affect the lower extremities in any way. The protective effects of leg armor, specifically that part protecting the shin, are obvious. In many crash situations the occupants survive the impact but are unable to exit the submerged or burning aircraft due to relatively minor injuries. One such injury is fracture of the lower shin and ankle area due to impact with seat structures, control pedals or dashboard. In fact, the most common major injury in Army rotary-wing aircraft is open fracture of the tibia (shin bone)[6].

Leg impact studies on cadavers to evaluate this specific type of injury showed that the maximum peak loading range of 1050 to 2000 pounds (the range in which fractures occurred) was considered realistic for test specimens ranging in age from 29 to 57 years of age[7]. The effect of sustaining such an impact while wearing a rigid armor "shin guard" would be to distribute these fracture level forces over the entire lower leg, and significantly reduce or eliminate the probability of leg and ankle fractures. The added mass of the leg armor would not predispose to fractures or dislocations of the femur (thigh bone) or hip under the crash conditions selected for this study.

h. Upper Extremities

The vertical and longitudinal crash force components did not cause any significant interaction between the chest armor and the upper extremities. It could be expected that a lateral crash force would exert some effects on the arms. However, within the range of lateral forces produced in these tests, there were no notable effects. The most severe lateral response was generated in the laterally seated dummy (troop seat installation) in the full-scale crash test. This dummy was restrained by a lap belt only, and the armor-vest-carrier moved upward (as if it were being removed over his head like an undershirt) without making appreciable contact with the arms, or compromising their normal range of ipsilateral motion.

Figure 9 shows the range of useful arm reach, by a seated and restrained individual, with and without armor. There is some compromise of the across body reach span with the armor but its potential significance to aircraft operation or evacuation is considered minimal.

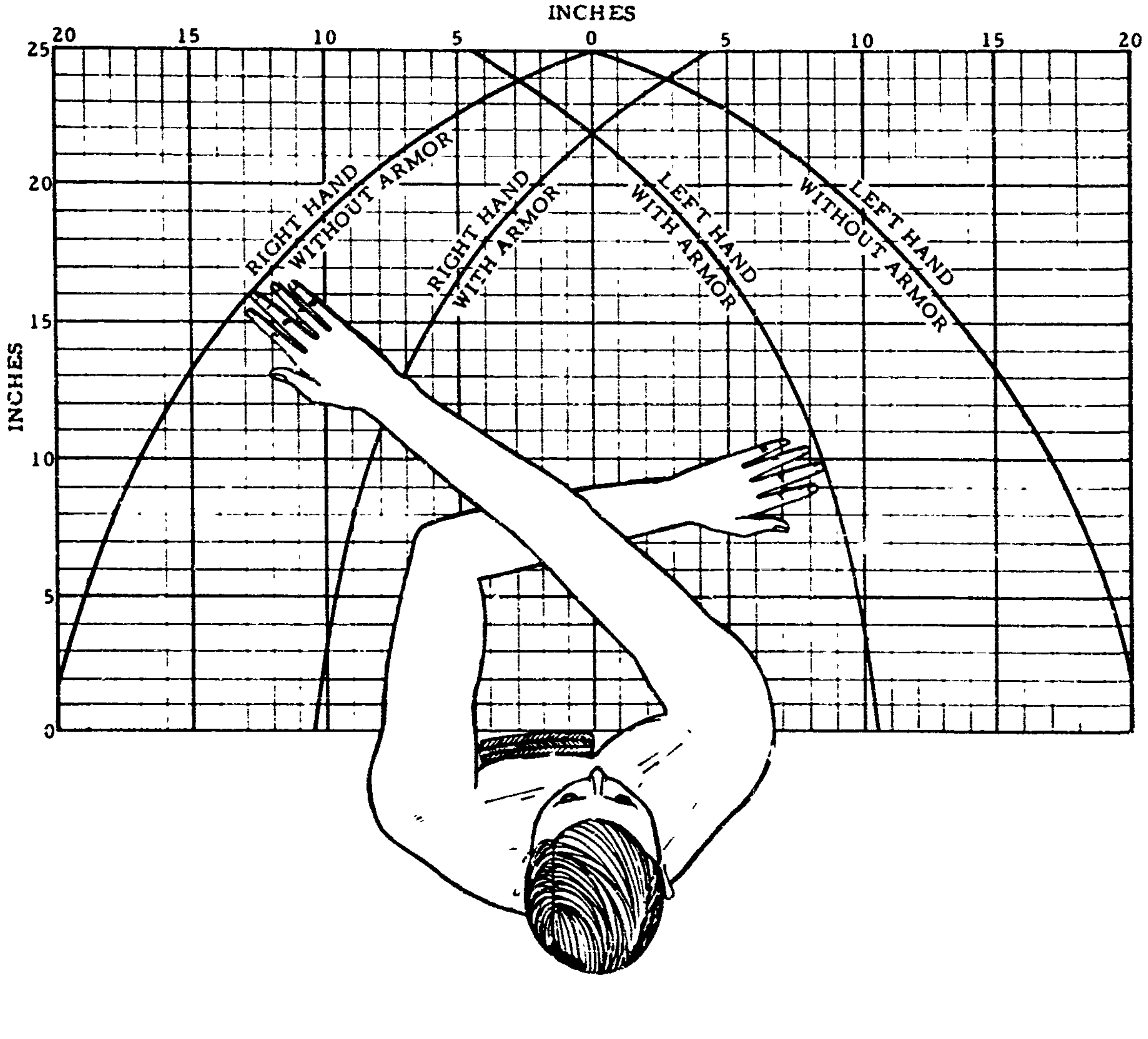



Figure 9. Cross Reach Restriction. (With and without front armor.)

5. Conclusions

As a result of the information obtained during this series of tests and the experience input provided by the Vietnam returnees, it is concluded that:

a. The potentially dangerous effects of the aircrew armor during a severe crash situation are relatively few and could probably be alleviated by minor modifications to the existing armor.

b. A potential for severe face and neck injuries due to contact with the upper edge of the chest armor does exist. Fatal injury could occur following fracture of the trachea.

c. The severity of upper thigh impacts by the armor is within the range of human tolerance; however, there appears to be advantages in adding a padded thigh shield to the bottom of the armor carrier vest in future designs. These advantages are:

(1) Improved retention of the carrier vest (Figure 5).

(2) Improved protection from spall and spatter.

(3) Reduction of impact severity between the lower edge of the armor and the thigh.

d. The armor serves to protect the chest and legs from direct contact injuries; and there is a strong implication that the chest armor may serve to limit the extent of injury-producing spinal flexion by providing a more distributed support against loads perpendicular to the spinal axes.

e. The collapse of the armored aircrew seats under a severe crash loading greatly increases the possibility of injury and poses a serious threat to occupant survival.

f. Loosely worn armor accompanied by a loose restraint system is potentially more dangerous in a crash situation than a properly worn armor-restraint system. In the loosely worn configuration, the occupant's deceleration profile is more subject to dynamic overshoot and random orientation with respect to both the armor and the resultant deceleration vector.

6. Recommendations

Based on the data presented in the report, the conclusions given in the previous section and other considerations, it is recommended that:

a. Systems for attenuating the contact force between the edge of the armor and the neck, face and thighs be developed.

b. The importance of wearing the armor and restraint harness properly be emphasized in the instructions provided the user.

c. Continued emphasis be placed on the improvement of aircrew seats and restraint harness. The failure of the seats used in this project indicate a need for modification of all seats.

d. All crew members of U. S. Army aircraft be provided shoulder harness in accordance with Figures 4-7 and 4-8 of USAAVLABS Technical Report 67-22 (8).

e. A study be made of postcrash evacuation problems of the armor wearer using live subjects, simulated injuries and actual crashed aircraft. Emphasis should be placed on the development of armor carriers and restraint systems which would minimize the effect of the armor on evacuation time.

f. Consideration be given to the inclusion of personnel armor in deceleration tests of live subjects, both humans and animals, at such facilities as the "Daisy" Track at Holloman Air Force Base. Such tests apparently have never been conducted and could lead to improved armor design.

g. An in-depth injury evaluation of accident experience in Southeast Asia be conducted to determine the after-the-fact crashworthiness of the aircrew armor. Equal emphasis should be placed on the study of direct injury and postcrash evacuation.

h. A study be made to determine pulse shape and a better estimate of the impact force on the chin, neck and thighs by utilizing load cells in place of the styrofoam pads. Such a study would provide more definitive information for the design of attenuation padding, redesign of armor shape and injury estimates.

## 7. References


1. Carroll, D. F., et al, Crashworthiness Study For Passenger Seat Design - Analysis and Testing of Aircraft Seats, AvSER Memorandum Report 67-4, NASA Contract NSR33-026-003, May 1967.

2. Selzer, M. L., et a., The Prevention of Highway Injury, A Symposium, Highway Safety Research Institute, University of Michigan, Ann Arbor, 1967.

3. Moseley, H. G. Col., USAF (MC), Aircraft Accident Injuries in the USAF, Aviation Medicine, April 1958.

4. Yamada, Hiroshi, Human Biomechanics, Kyoto Prefectural University of Medicine, Kyoto, Japan, 1963.

5. Webb, P., Bioastronautics Data Book, N.A.S.A., Washington, D.C., 1964.

6. Mattox, K. L., Injury Experience in Army Helicopter Accidents, USABAAR Technical Report HF 68-1, 1968.

7. Young, J. W., Applied Forces of Lower Leg Impact, Unpublished, Civil Aeromedical Institute, Oklahoma City, 1967.

8. Turnbow, J. W., et al, Crash Survival Design Guide, USAVLABS Technical Report 67-22, U. S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia, July 1967.

9. Haley, J. L., Jr., Personnel Restraint Systems Study Basic Concepts, USAAVLABS Technical Report 62-94, U. S. Army Aviation Materiel Laboratories (formerly TRECOM), Fort Eustis, Virginia, December 1962.

10. Haley, J. L., Jr., et al, Helmet Design Criteria For Improved Crash Survival, USAAVLABS Technical Report 65-44, U. S. Army Aviation Materiel Laboratories (formerly TRECOM), Fort Eustis, Virginia, January 1966.

## 8. Bibliography


1. von Gierke, H. E., Biomechanics of Impact Injury, Impact Acceleration Stress - Proceedings of a Symposium with a Comprehensive Chronological Bibliography, National Academy of Sciences, National Research Council Publication No. 977, 1962.

2. Lissner, H. R., et al, Experimental Studies on the Relation between Acceleration and Intracranial Pressure Changes in Man. Surgery, Cynecology and Obstetrics, pp. 329-338, September 1960.

3. Lissner, H. R., and Gurdjian, E. S., Experimental Cerebral Concussion, ASME Annual Meeting Paper No. 60-WA-273, November 27, 1960.

4. Eiband, A., Human Tolerance to Rapidly Applied Accelerations: A Summary of the Literature, NASA Memorandum 5-19-59E, June 1959.

5. See for example Human Tolerance to Impact Conditions as Related to Motor Vehicle Design, SAE Handbook Supplement J 885, 1964.

6. Swearingen, J. J., Tolerance of the Human Face to Crash Impact, Office of Aviation Medicine, F. A. A., Civil Aeromedical Research Institute, Oklahoma City, Oklahoma, July 1965.

7. Hodgson, V. R., Lange, W. A., and Talwalker, Injury to the Facial Bones, Proceedings of Ninth Stapp Car Crash Conference, University of Minnesota Publication, 1966.

8. Patrick, L. M., Kroell, C. K., and Mertz, H. J., Forces on the Human Body in Simulated Crashes, Proceedings on Ninth Stapp Car Crash Conference, University of Minnesota Publication, 1966.

9. Gadd, C. W., Criteria for Injury Potential, Proceedings of Impact Acceleration Stress Symposium, National Academy of Sciences, National Research Council, Publication No. 977, 1962.

10. Danforth, J. P., and Gadd, C. W., Use of a Weighted-Impulse Criterion for Estimating Injury Hazard, Proceedings of 10th Stapp Car Crash Conference, Society of Automotive Engineers, Inc., Publication No. 660793, December, 1966.

# APPENDIX A

## VERTICAL DROP TOWER TEST REPORT

Test Facility and Procedure
Description of Test Items
Instrumentation
Test Agenda
Test Data

## APPENDIX A
## VERTICAL DROP TOWER TEST REPORT

### Test Facility and Procedure

The drop tower used in these tests consists of two poles joined at the top by a steel cap beam (Figure 10). A concrete impact pad is positioned between the poles at the base. A winch provides lift for hoisting the drop cage. The drop cage is released by a pneumatic release hook from predetermined heights to give the desired velocity at impact. Two guide cables are attached to the cap beam at the top and secured at the base on the centerline between the two poles (Figures 10 and 11). These cables stabilize and guide the drop cage to the desired position at the tower base. A trailer parked adjacent to the tower serves as the control and instrumentation center.

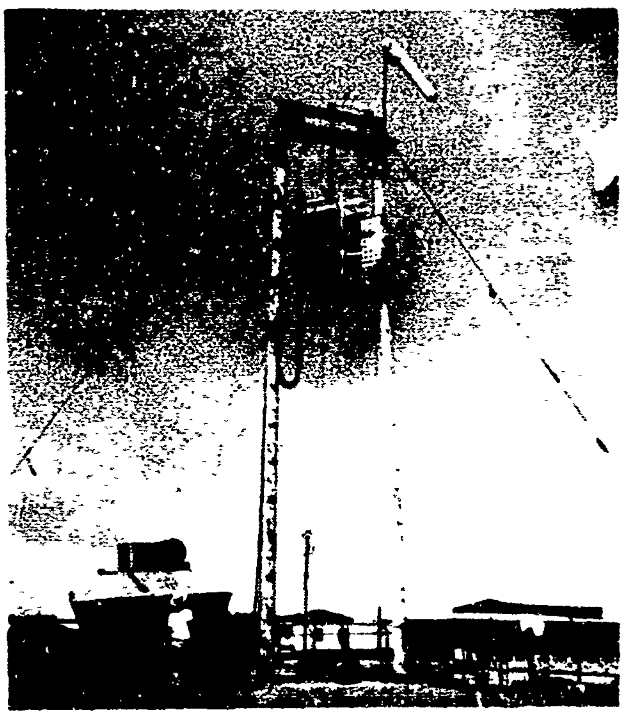


Figure 10. Drop Tower with Cage in Drop Position. (Crushable material to control the deceleration of the test subjects may be seen between the poles at ground level.)

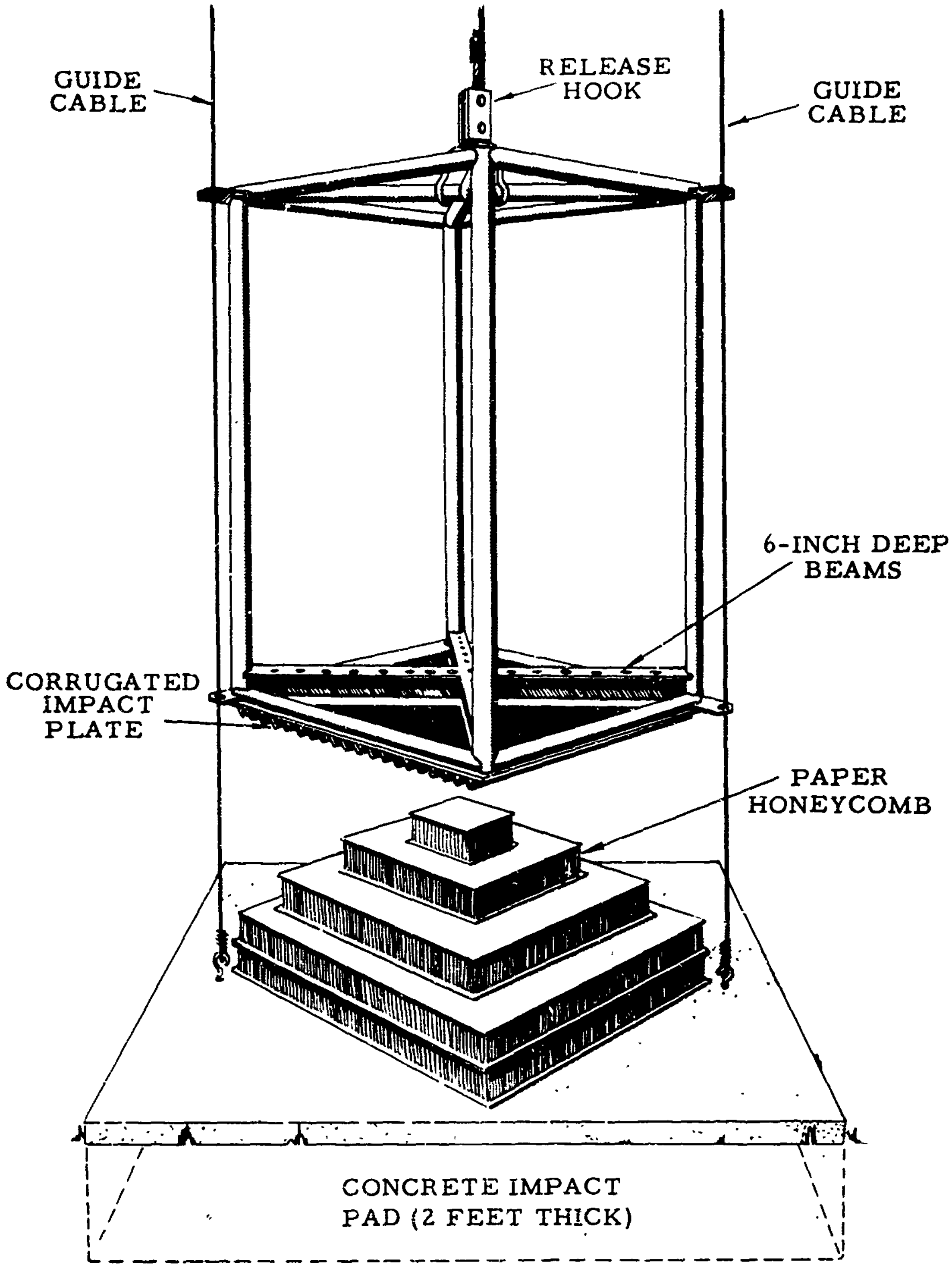



Figure 11. Drop Cage.

The drop cage used in this test series is an all-steel welded structure (Figure 11).

To aid in photographic analysis, a gridded backdrop is mounted on the cage and the vertical corner tubes are painted in an alternating black and white pattern.

The desired impact conditions are achieved by varying the height of the drop to achieve the desired impact velocity and using a crushable material at the base to provide acceleration pulses corresponding to those crash pulses which occur in the 70th and 80th percentile range of Army (fixed and rotary wing) accidents[8]. Paper honeycomb was used for this purpose. The honeycomb was positioned or "stacked" under the drop cage in various thicknesses, cross-sectional areas and stack shapes. These factors determine the acceleration pulse.

The seat installations in this test series were required to be either pure vertical or vertical with 15 degrees of forward, rearward, and/or lateral tilt. To achieve this, the seats were mounted on rigid frames made of 4-inch and 6-inch steel channel. These frames were so designed and constructed that, by adding or removing appropriate components, the seat orientation on the drop test platform could be changed from one configuration to another. Alderson F-95 (200 pound) dummies were used in the tests. Prior to the tests both dummies were disassembled and the joints were cleaned and lubricated. On reassembly the joints were torqued to the values shown below:

| | Torque Ft.-Lb. |
|---|---|
| Head Attachment Cable | 20 |
| Shoulder Joint (Vertical) | 80 |
| Shoulder Joint (Lateral) | 40 |
| Elbow | 60 |
| Wrist | 20 |
| Spine Cable | 25 |
| Knee | 60 |
| Ankle | 20 |

The torque values approximate the resistance to joint rotation found in live subject tests conducted at AvSER [1]. The dummies were painted to improve photographic analysis and special markings were used to assist in identifying the head center of gravity, body joint locations, and the axes of limbs and spine.

## Description of Test Items

The seats and armor tested in this program are of standard configuration in general use in Southeast Asia and other areas today. A brief description of the seats and armor follows:

UH-1B/D armored crew seat - consists of a nylon net-type cushion and back stretched over contoured aluminum tubes at each side of the seat. The seat has integral armor on the pan, back and sides. The seat comes in pilot and co-pilot configurations. The lap belt attaches to floor structure. Weight (with integral armor): 140 pounds.

CH-47 armored crew seat - CH-47 seats are made in at least two configurations, one having a sheet metal seatpan and back, the other having a plastic pan and back. Both have sheet metal bases. The sheet metal pan was used in the drop tower tests. A resilient foam comfort cushion is standard on both seats. The seat armor is a retrofitted kit installation. The pilot and co-pilot installations are made up by changing the outboard location of the side armor. The lap belt attaches to the seat. Weight (with armor): 120 pounds.

UH-1D troop seat - consists of a fabric cover stretched over a tubular frame. This seat folds back and attaches to a bulkhead when not in use. The seat armor is a retrofit kit installation on the seatpan only. It consists of a 3/4-inch armor plate with 3/8-inch of non-resilient foam rubber beneath it, a 1-inch piece of resilient foam rubber below that, and a 1-inch piece of resilient foam rubber above the armor. The armor and cushions are encased in a canvas cover. The occupant sits on the covered armor element. Weight of seat (less armor): 5 pounds.

The personnel armor components are discussed below. The respective weight for each piece is stated for the large size used on the 95th percentile, 200-pound dummy:

Armor Carrier (Figures 12, 13 and 14) is made of lightweight canvas The carrier comes in two pieces, a front and a back piece, joined together with straps over the shoulders. The back piece also has a strip on each side that joins in front of the chest piece to adjust the armor to

Figure 12. Vest Carrier with Front and Back Armor. (Back armor at bottom of picture.)

Figure 13. Front View of Personnel Armor Installation. (Note two-piece armor on right leg, one piece on left leg.)

Figure 14. Rear View of Personnel Armor Installation.

the body. "Velcro" fasteners are used for ease in adjustment and doffing. Weight: 2 pounds.

Chest Armor (Figures 12 and 13) - consists of a single p' ce that is anatomically molded. The edges are covered with a channel-shaped rubber stripping. Weight: 14 pounds.

Back Armor (Figures 12 and 14) - consists of a single piece that is anatomically molded. The edges are covered with channel-shaped rubber stripping. Weight: 15 pounds.

One-Piece Leg Armor (Figures 13 and 14) - this armor has a heel stirrup on the bottom which the wearer fits over his shoe heel. Hinging is allowed at the ankle. The armor is molded to the shape of the lower leg and has a wrap around strap with a "Velcro" fastener which secures it around the calf. A padded strap secures the armor over the shoe. The armor terminates at the knee cap level. Weight: 11 pounds.

Two-Piece Leg Armor (Figures 13 and 14) - the upper piece is molded to the anterior thigh and has a wrap around strap with a "Velcro" fastener. The assembly hinges at knee level. The lower piece covers the forward area from knee cap to ankle and is molded to the leg. It has oval-shaped steel plates along the sides of the feet. The armor hinges at the ankle and knee as the wearer walks. Weight: 23 pounds.

## Instrumentation

Figure 15 shows that, in addition to the force transducer installed in the spinal column of the dummy, accelerometers were installed in the head and chest. Triaxial accelerometers were used in the head.

A triaxial accelerometer was also installed on each seat between the rear seat legs at the seatpan level.

Acceleration of the drop cage was recorded by a vertical accelerometer placed between the two seats at the centerline on the drop cage structure.

A load link was installed in each shoulder harness between the inertia reel and the shoulder strap.

Still photographs of the test subjects were taken before and after each drop. Three high-speed movie cameras were positioned around the impact zone and one additional camera was mounted directly on the drop cage. Figure 15 shows the camera locations.

Instrumentation identification is shown in Appendix F.

## Test Agenda

Two identical armored seats with identically instrumented dummy occupants, one occupant with armor and one without, were installed on the drop cage for each test. Both of the seats were thus subjected to the same input acceleration pulse, providing an evaluation of the effect of the armor on the body response.

The troop seats were tested with only one dummy occupant. One test was made first without the armor. The test was then repeated with the armor for comparative purposes.

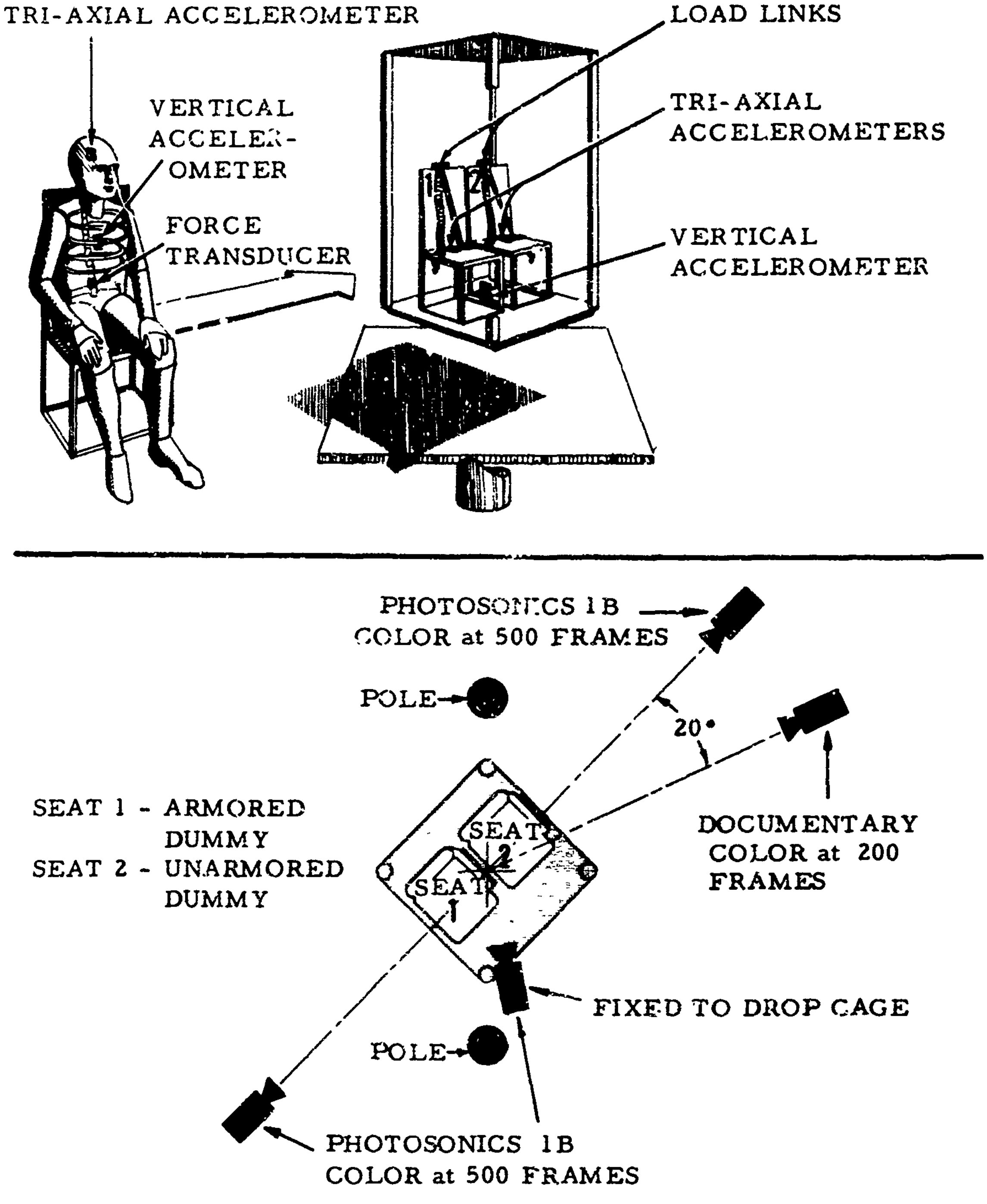



Figure 15. Drop Tower Instrumentation and Camera Coverage.

A total of 26 tests was conducted. A malfunction occurred in the magnetic tape recorder during six of these drops, resulting in a loss of electronic data. These six tests were conducted again to obtain the proper data. The repeated tests are identified by the suffix letter "A" in this section and are included because they do provide backup data on the chin and thigh impacts, seat failures, and body kinematics obtained from the high-speed films.

## TEST DATA

### General

In the following discussion of the drop tower series of tests, each test is referred to by the test number shown in the second column of Table I. Each Test Number relates to the test identity stated in the contract for this project, while each Drop Number (column 1, Table I, Appendix A), refers to the number appearing on the drop cage as shown in the high-speed films taken during testing.

Table I also includes information on armor application, seat type, acceleration pulse simulation, seat orientation, seat damage and significant load and acceleration data recorded during each test. Typical load and acceleration data traces are shown in Figures 16 and 17.

The drops were not conducted in the numerical order indicated in Table I. It was necessary to change the sequencing of the tests because sufficient seats were not available to repeat drops when seat failures occurred. The drop number sequence used was 1, 2, 3, 4, 5, 6, 8, 13, 12A, 8A, 9, 3A, 6A, 4A, 5A, 10, 16, 17, 12 and 15.

### Test Description

All crew seats were adjusted to the full-up position. The inertia reel shoulder harness control lever on the crew seats was placed in the "automatic" position for all tests. This was done since many helicopter accidents occur because of a sudden emergency in which little time is available for the pilot to switch the reel from the "automatic" to the "locked" position. Since the reel is designed to lock the shoulder strap before one-half inch of movement takes place, the reel setting probably has little effect on the failure or non-failure of the seats.

In all drop tests, the contact force levels between the armor and the dummy's thighs and chin were calculated from the imprints left by the chin and armor in crushable styrofoam pads installed on the top of the chest armor and on the upper thigh of the dummy. These imprints, when they appeared, were distinct and gave a good indication of the loads applied. Figure 18 shows a typical set of pads after testing. The areas circled in black are the imprints left by the chin and armor.

The significant events of each test are discussed below in the sequence shown in Appendix A, Table I, column 2.

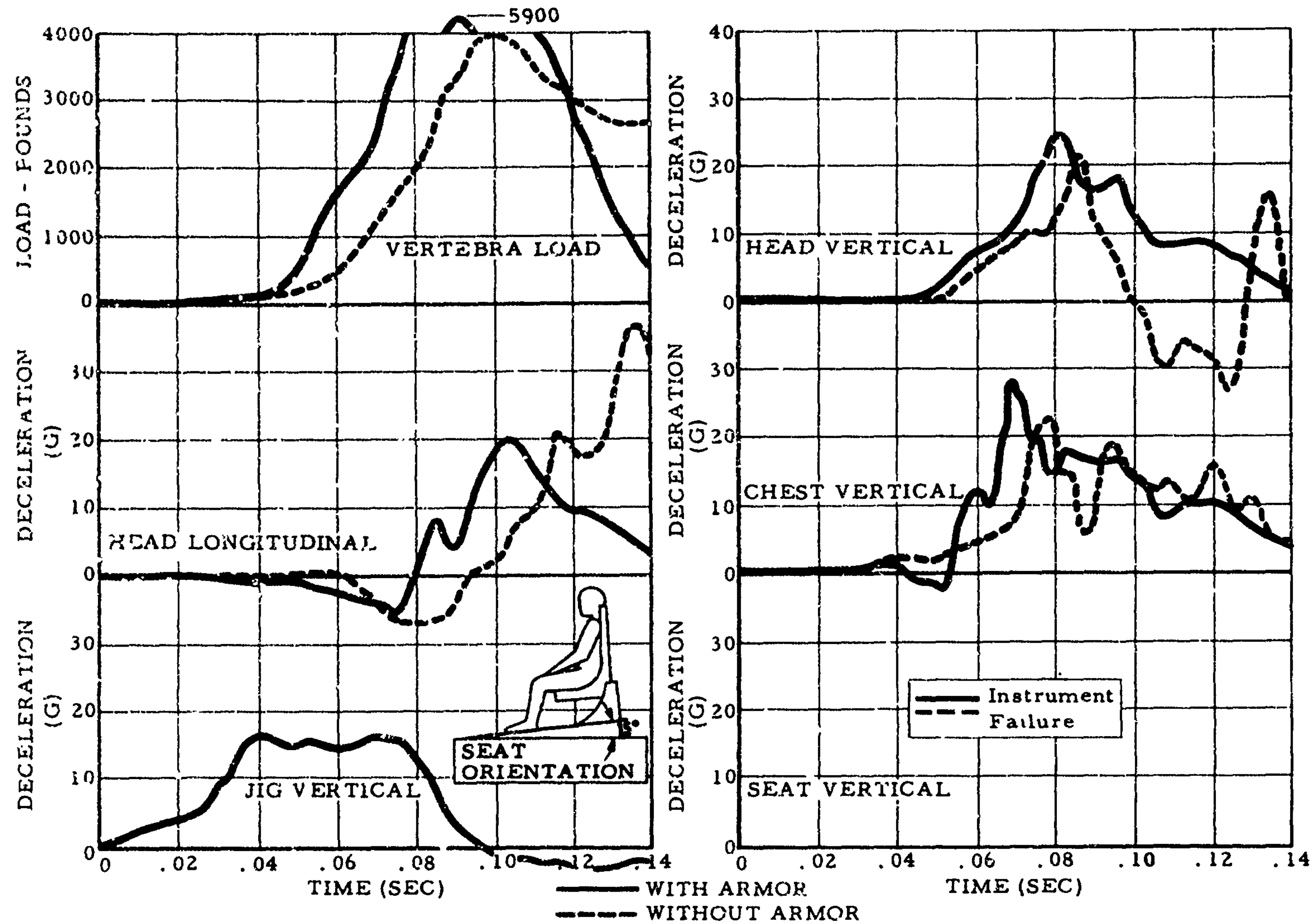



Figure 16. Typical Acceleration and Vertebra Load Traces - Tests 12A and 16A.

TABLE I

DROP TOWER TEST RESULTS - ARMORED CREW AND TI

| (1) DROP NO. | (2) TEST NO. | (3) CHEST ARMOR USED | (4) SEAT IDENTITY [c] | (5) SIMULATED ACCEL. PULSE | (6) SEAT ORIENTATION IN DROP JIG | (7) SEAT DAMAGE | (8) CHIN PAD CRUSH DEPTH (In.) | (9) CHIN PAD PEAK LOAD (Lb) | TI CRU LEFT |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | None | Armor UH-1D | 12G, 5G, ΔV 20fps; 0 .05 .10 TIME-SEC | Vertical | None | --- | --- | --- |
| | 2 | Chest | Armor UH-1D | | | | None | None | 0.2 |
| 2 | 3 | None | Armor UH-1D | 16G, 5G, ΔV 30fps; 0 .05 .10 TIME-SEC | DITTO | Seat side-armor deflected outward about six inches on both seats. | --- | --- | --- |
| | 4 | Chest | Armor UH-1D | | | | 0.2 | 15[1/] | 0.3 |
| 3 | 21 | None | Armor UH-1D | 25G, 5G, ΔV 20fps; 0 .05 .09 TIME-SEC | DITTO | Both seats tilted forward about two inches due to bending of support tubes. Net cushion failed on seat in Test 10. | --- | --- | --- |
| | 10 | Chest | Armor UH-1D | | | | None | None | 0.3 |
| 3 A [a] | 21 A | None | Armor UH-1D | DITTO | DITTO | Both seats tilted forward about two inches due to bending of support tubes. Net cushion failed on seat in Test 10A | --- | --- | --- |
| | 10 A | Chest | Armor UH-1D | | | | 0.1 | 20[4/] | 0.3 |
| 4 | 22 | None | Armor UH-1D | 16G, 5G, ΔV 30fps; 0 .05 .10 TIME-SEC | Vertical at 15° Forward | Both seats tilted forward about three inches at top due to bent support tube. | --- | --- | --- |
| | 5 | Chest | Armor UH-1D | | | | 0.4 | 80[3/] | 0.3 |
| 4 A [a] | 22 A | None | Armor UH-1D | DITTO | DITTO | Both seats tilted forward about three inches at top due to bent support tube. | --- | --- | --- |
| | 5 A | Chest | Armor UH-1D | | | | 0.4 | 100[1/] | 0.2 |
| 5 | 12 | None | Armor CH-47 [b] | DITTO | DITTO | Both seats cracked and bent downward about 15° - 20° at pan-to-back intersection. | --- | --- | --- |
| | 16 | Chest | Armor CH-47 [b] | | | | 0.5 | 130[2/] | 0.4 |
| 5 A [a] | 12 A | None | Armor CH-47 [b] | DITTO | DITTO | Both seats cracked and bent downward about 15° - 20° at pan-to-back intersection. | --- | --- | --- |
| | 16 A | Chest | Armor CH-47 [b] | | | | 0.4 | 85[1/] | 0.1 |
| 6 | 23 | None | Armor UH-1D | DITTO | Vertical at 15° Rear | No major damage to seat in Test 23, only 1 inch forward movement at top on seat in Test 6. | --- | --- | --- |
| | 6 | Chest | Armor UH-1D | | | | None | None | 0.1 |
| 6A [a] | 23A | None | Armor UH-1D | DITTO | DITTO | No major damage to seat minus chest armor, only 1 inch forward movement at top on seat in Test 6A. | --- | --- | --- |
| | 6A | Chest | Armor UH-1D | | | | None | None | 0.1 |

TABLE I

…ED CREW AND TROOP SEAT TESTS WITH PERSONNEL ARMOR

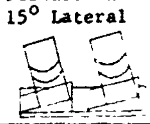
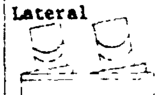
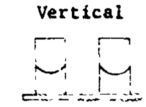
| (8) CHIN PAD CRUSH DEPTH (In.) | (9) CHIN PAD PEAK LOAD (Lb) | (10) THIGH PAD CRUSH DEPTH (In.) LEFT | (10) RIGHT | (11) THIGH PAD PEAK LOAD (Lb) LEFT | (11) RIGHT | (12) TOTAL THIGH PAD LOAD (LB) | (13) FLOOR VERT. ACCEL. (G) | (14) SEAT VERT ACCEL. (G) | (15) CHEST VERT. ACCEL. (G) | (16) HEAD VERT. ACCEL. (G) | (17) THORACIC VERTEBRA LOAD (LB) | (18) HEAD LONG. ACCEL. (G) | (19) HEAD LAT. ACCEL. (G) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| --- | --- | --- | --- | --- | --- | --- | 13 | 13 | Inst. Fail | 27 | Inst. Fail | 2 | 24 |
| None | None | 0.2 | 0.2 | 200 | 220 | 420 | | 14 | 30 | 30 | Inst. Fail | 3 | 4 |
| --- | --- | --- | --- | --- | --- | --- | 19 | 21 | 22 | 39 | 1200 | 7 | 5 |
| 0.2 | 15[1/] | 0.3 | 0.2 | 260 | 210 | 470 | | 23 | 22 | 40 | 1800 | 11 | 10 |
| --- | --- | --- | --- | --- | --- | --- | PHOTOGRAPHIC COVERAGE ONLY | | | | | | |
| None | None | 0.3 | 0.2 | 220 | 200 | 420 | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | 30 | 35 | 30 | 42 | 2700 | 15 | 5 |
| 0.1 | 20[4/] | 0.3 | 0.2 | 240 | 270 | 510 | | 35 | Inst. Fail | 40 | 3000 | 30 | 6 |
| --- | --- | --- | --- | --- | --- | --- | PHOTOGRAPHIC COVERAGE ONLY | | | | | | |
| 0.4 | 80[3/] | 0.3 | 0.1 | 240 | 170 | 410 | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | 17 | Inst. Fail | 28 | 23 | 3500 | 8 | 4 |
| 0.4 | 100[1/] | 0.2 | 0.1 | 240 | 160 | 400 | | 20 | 25 | 25 | 2000 | 25 | 17 |
| --- | --- | --- | --- | --- | --- | --- | PHOTOGRAPHIC COVERAGE ONLY | | | | | | |
| 0.5 | 130[2/] | 0.4 | 0.3 | 280 | 300 | 580 | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | 18 | Inst. Fail | 20 | 20 | 3900 | 34 | Inst. Fail |
| 0.4 | 85[1/] | 0.1 | 0.2 | 190 | 220 | 410 | | Inst. Fail | 20 | 24 | 5900 | 19 | 7 |
| --- | --- | --- | --- | --- | --- | --- | PHOTOGRAPHIC COVERAGE ONLY | | | | | | |
| None | None | 0.1 | 0.1 | 250 | 80 | 330 | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | 17 | 17 | 28 | 32 | 1500 | 17[e] | 4 |
| None | None | 0.1 | 0.2 | 160 | 280 | 340 | | 19 | 25 | 35 | 1800 | 23[c] | 12 |



B.

TABLE I (CONT'D.)

DROP TOWER TEST RESULTS - ARMORED CREW AND TROOP SEAT TE

| ① | ② | ③ | ④ | ⑤ | ⑥ | ⑦ | ⑧ | ⑨ | ⑩ | |
|---|---|---|---|---|---|---|---|---|---|---|
| DROP NO. | TEST NO. | CHEST ARMOR USED | SEAT IDENTITY [c] | SIMULATED ACCEL. PULSE | SEAT ORIENTATION IN DROP JIG | SEAT DAMAGE | CHIN PAD CRUSH DEPTH (IN.) | CHIN PAD PEAK LOAD (LB) | THIGH PAD CRUSH DEPTH (IN.) LEFT | RIGHT |
| 8 | 24 | None | Armor UH-1D | 16G; ΔV; 5G; 30 fps; 0 .05 .10 TIME-SEC | Vertical at 15° Lateral  | Both seats tilted forward four to six inches at top. Net cushion of seat in Test 7 torn longitudinal over a 5-inch length on right side. | | | | |
| | 7 | Chest | Armor UH-1D | | | | 0.1 | 50 1/ | 0.4 | 0.1 |
| 8A [a] | 24A | None | Armor UH-1D | DITTO | DITTO | Both seats tilted forward 4-6 inches at top. Net cushion of seat in Test 7A torn longitudinally along right side. | | | | |
| | 7A | Chest | Armor UH-1D | | | | 0.1 | 100 1/ | 0.2 | None |
| 9 | 11 | None | Armor CH-47 [b] | DITTO | DITTO | Both seat buckets displaced downward about 6 inches but dummies were still restrained. | | | | |
| | 15 | Chest | Armor CH-47 [b] | | | | None | None 1/ | 0.2 | 0.2 |
| 10 | 25 | None | Armor UH-1D | DITTO | Vertical at 15° Forward and 15° Lateral  | Seat side-armor deflected outward 6 inches in Test 25. Loose armor (2" slack). | | | | |
| | 8 | Chest [d] | Armor UH-1D | | | | 0.1 | 65 3/ | 0.3 | 0.3 |
| 12 | 13 | None | Armor CH-47 [b] | DITTO | DITTO | Both buckets deformed more severely than in Tests 11, 9, 15, but dummies were still restrained. | | | | |
| | 17 | Chest [d] | Armor CH-47 [b] | | | | 0.1 | 85 1/ | 0.6 | 0.3 |
| 13 | 26 | None | Armor UH-1D | DITTO | Vertical at 15° Rear and 15° Lateral  | Minor bend forward in both seats, net cushion torn over 4-inch length on right side of seat in Test 9. | | | | |
| | 9 | Chest [d] | Armor UH-1D | | | | None | None | 0.2 | 0.05 |
| 13A [a] | 26A | None | Armor UH-1D | DITTO | DITTO | Minor bend forward in both seats, net cushion torn over 4-inch length of right side of seat in Test 9A. | | | | |
| | 9A | Chest [d] | Armor UH-1D | | | | None | None | 0.2 | 0.3 |
| 15 | 14 | None | Armor CH-47 [b] | 25G; ΔV; 20 fps; 5G; 0 .05 .09 TIME-SEC | Vertical  | Forward edge of both seat pans deformed vertically about 1 inch. | | | | |
| | 18 | Chest | Armor CH-47 [b] | | | | None | None | 0.3 | 0.4 |
| 16 | 19 | None | Non-Armor Troop-Side Facing | 12G; 5G; ΔV; 20 fps; 0 .05 .10 TIME-SEC | Vertical  | Seat bottom webbing was torn through over one foot length | Not Applicable | Not Applicable | Not Applicable | Not Applicable |
| 17 | 20 | Chest Back, and Full Leg | Non-Armor Troop-Side Facing | DITTO | DITTO | Seat bottom webbing was torn through over one foot length. | 0.05 | 50 2/ | 0.1 | 0.1 |

a-Indicates rerun of test due to instrumentation error.
b-Early model CH-47 seats of sheet metal construction (1962-64 design).
c-Two (2) seats and dummies were used in each drop test and one dummy wore personnel chest armor with the exception of troop seat drops 16
d-Loosely fitted armor and restraint harness (2-inch slack provided on both sides of lap belt, shoulder strap, and armor straps).
e-Reversed (Aftward) Acceleration, i.e., head moved backward.
f-The peak accelerations given are those measured for 0.005 seconds or more. Spikes of shorter duration were neglected.

A.

TABLE I (CONT'D.)

ARMORED CREW AND TROOP SEAT TESTS WITH PERSONNEL ARMOR

| | (8) CHIN PAD CRUSH DEPTH (IN.) | (9) CHIN PAD PEAK LOAD (LB) | (10) THIGH PAD CRUSH DEPTH (IN.) | | (11) THIGH PAD PEAK LOAD (LB) | | (12) TOTAL THIGH PAD LOAD (LB) | (13) FLOOR VERT. ACCEL. (G) | (14) SEAT VERT. ACCEL. (G) | (15) CHEST VERT. ACCEL. (G) | (16) HEAD VERT. ACCEL. (G) | (17) THORACIC VERTEBRA LOAD (LB) | (18) HEAD LONG. ACCEL. (G) | (19) HEAD LAT. ACCEL. (G) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | LEFT | RIGHT | LEFT | RIGHT | | | | | | | | |
| to of | | | | | | | | --PHOTOGRAPHIC COVERAGE ONLY-- | | | | | | |
| l ide. | 0.1 | 50 1/ | 0.4 | 0.1 | 310 | 180 | 490 | | | | | | | |
| ches est 7A | | | | | | | | 16 | 17 | 25 | 32 | 1400 | 9 | 4 |
| side. | 0.1 | 100 1/ | 0.2 | None | 360 | None | 360 | | 18 | 22 | 26 | 2700 | 23 | 14 |
| n- | | | | | | | | 16 | 22 | 23 | 28 | 3000 | 15 | 3 |
| | None | None 1/ | 0.2 | 0.2 | 230 | 240 | 470 | | 22 | 22 | 26 | 2400 | 19 | 6 |
| rd mor | | | | | | | | 17 | Inst. Fail | 21 | 32 | 1600 | 16 | Inst. Fail |
| | 0.1 | 65 3/ | 0.3 | 0.3 | 420 | 380 | 800 | | Inst. Fail | 15 | 30 | 5000 | 22 | 7 |
| rely mies | | | | | | | | 18 | 24 | Inst. Fail | 10 | 1700 | 16 | Inst. Fail |
| | 0.1 | 85 1/ | 0.6 | 0.3 | 350 | 280 | 630 | | 30 | 26 | 25 | 3800 | 18 | 14 |
| s, ngth | | | | | | | | --PHOTOGRAPHIC COVERAGE ONLY-- | | | | | | |
| . | None | None | 0.2 | 0.05 | 310 | 140 | 450 | | | | | | | |
| s, net of | | | | | | | | 19 | 21 | 27 | 40 | 2100 | 12 | 6 |
| | None | None | 0.2 | 0.3 | 270 | 410 | 680 | | 25 | 23 | 25 | 1600 | 12 | 12 |
| de- | | | | | | | | 30 | 39 | 23 | 23 | 2200 | 7 | 2 |
| | None | None | 0.3 | 0.4 | 250 | 270 | 520 | | 35 | 26 | 22 | 3200 | 23 | 12 |
| | Not Applicable | Not Applicable | Not Applicable | Not Applicable | Not Applicable | Not Applicable | Not Applicable | 15 | Inst. Fail | 31 | 33 | 1800 | 3 | 2 |
| | 0.05 | 50 2/ | 0.1 | 0.1 | 140 | 80 | 220 | 14 | Inst. Fail | 22 | 24 | 4500 | 17 | 5 |

with the exception of troop seat drops 16 and 17.
houlder strap, and armor straps).

uration were neglected.

Chin Impact Location Code:
1/ Under chin
2/ At point of jaw
3/ Nose and mouth
4/ Trachea



B.

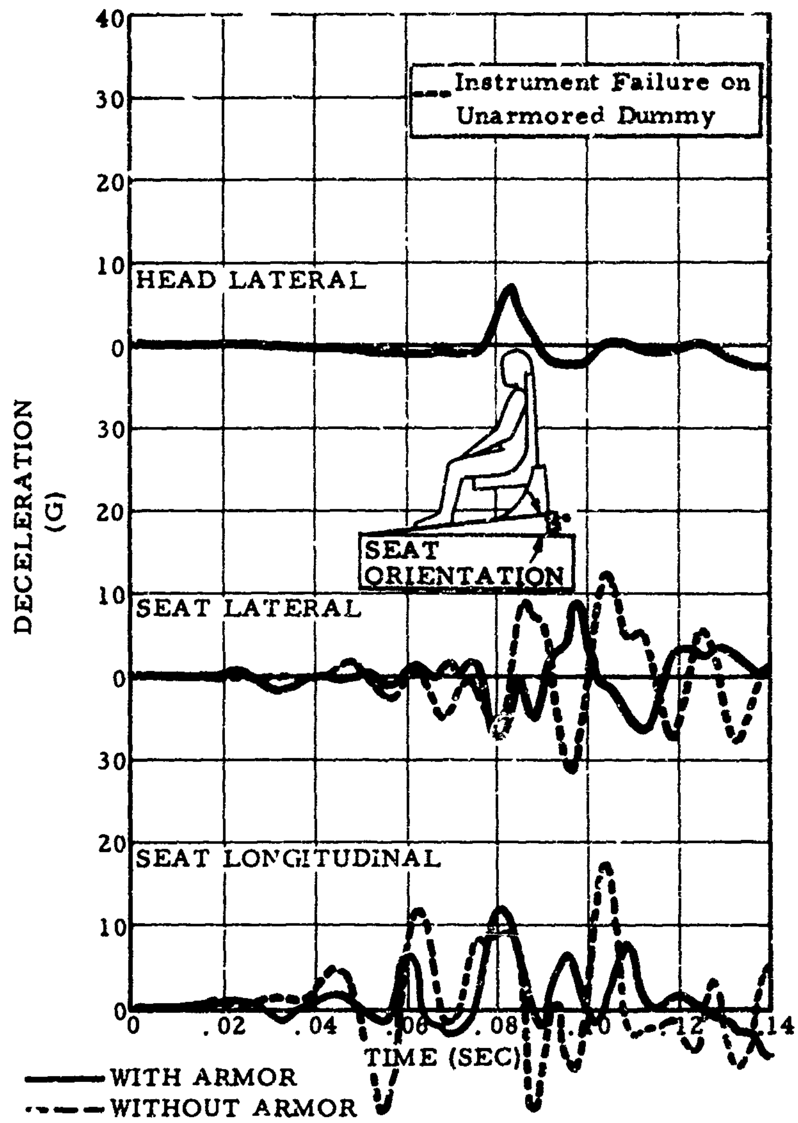



Figure 17. Typical Acceleration Traces - Tests 12A and 16A.

Figure 18. Styrofoam Load Pads Posttest View Showing Imprints of Chin and Armor.

## Tests 1, 2, 3, 4, 10, 10A, 21 and 21A

Figures 19, 20, 21 and 22 provide pretest views of Tests 10 and 21, typical of this group. These pure vertical tests did not result in significant damage to the UH-1D seats used. The dummy with the chest armor installed did exert enough force on the nylon net seat to tear a hole about 3 inches long on the right side of the tubular frame in Tests 10 and 10A. The seat shoulder armor also deflected downward enough to separate from its retainer at the upper edge and the armor rotated outward about its lower edge until stopped by contact with the adjacent seat. The shoulder armor in a UH-1D cockpit would probably rotate outward until contact occurred with the crew entry door. This movement would not likely result in a hazardous situation for the crew member. The chin did contact the armor chin pad in Test 4 and 10A; however, the maximum load did not exceed 20 pounds. The 20 pound force measured in Test 10A was in the trachea area, and was measured by forward crushing into the chin pad rather than by downward crushing into it. Thus, it is possible that the true load in the trachea area was greater than that recorded because the chin pad was designed to measure primarily downward loads. The average total thigh load for these tests was 455 pounds. The vertebral loads were higher in tests with armor than those without armor.

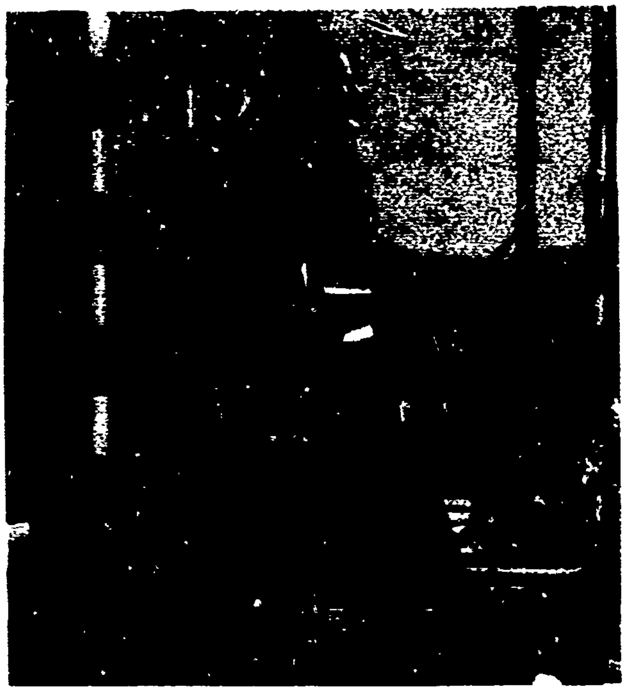


Figure 19. Pretest Sideview of Test 10 with Chest Armor Shown.

Figure 20. Pretest Front View of Tests 10 and 21.

Figure 21. Pretest Sideview for Test 21.
(Unarmored Dummy near Camera.)

Figure 22. Pretest Rear View Tests 10 and 21.
(Dummy with Chest Armor on Right.)

Tests 5, 5A, 22 and 22A

The 15-degree forward tilt in these tests caused more bending in the UH-1D rear seat support columns than the pure vertical loads applied in Tests 1, 2, 3, 4, 10, 10A, 21 and 21A. The top of the seat backs deflected forward and retained a permanent set of 3 inches compared to 2 inches in the pure vertical drops. The contact with the chin pads indicated 80 to 100 pound load which was near the maximum observed in all tests. The thigh contact loads averaged 405 pounds. The vertebral loads were higher without the armor (3500 pounds versus 2000 pounds). The 2000 pound value is in fair agreement with the mass-acceleration product (2500 pounds) of the chest (upper torso).

Tests 12, 12A, 16 and 16A

A side and frontal view is seen in Figures 23 and 24. The CH-47 seat was used. These tests resulted in a fracture of the seat pan for both the armored and unarmored dummy tests. In Tests 12 and 16, the pans fractured at their intersection with the seat back structure as shown in Figures 25 and 26. The seat damage shown in Figures 25 and 26 was about the same as that which occurred in Tests 12A and 16A. The downward deflection of the seat pan to 15-20 degrees resulted in the dummy sliding forward or "submarining" under the seat belt. The dummy's pelvis was deflected forward and "wedged" between the seat pan and the lap belt. This action resulted in severe bending in the dummy spinal column. The relatively high vertebral loads of 3900 and 5900 pounds for the unarmored and armored dummies, respectively, (recorded in Table I) are discussed further in Evaluation of Test Results. The peak loads on the thigh pads (580 pounds and 410 pounds) and chin pads (135 pounds and 85 pounds) were only slightly higher in these tests with the CH-47 seats than in the same tests with the UH-1D seats.

Tests 6, 6A, 23 and 23A

These tests did not result in a chin impact on the armor; this is probably due to the 15-degree aft orientation. Note the pretest installations shown in Figures 27 and 28. The thigh pad impacts were the least severe (average 335 pounds) of the drop test series. No seat damage was noted and the acceleration values and vertebral loads were less than those recorded for the 15-degree forward seat orientation discussed in the preceding two paragraphs.

Figure 23. Pretest View of Test 16.
(Dummy with Chest Armor Shown.)

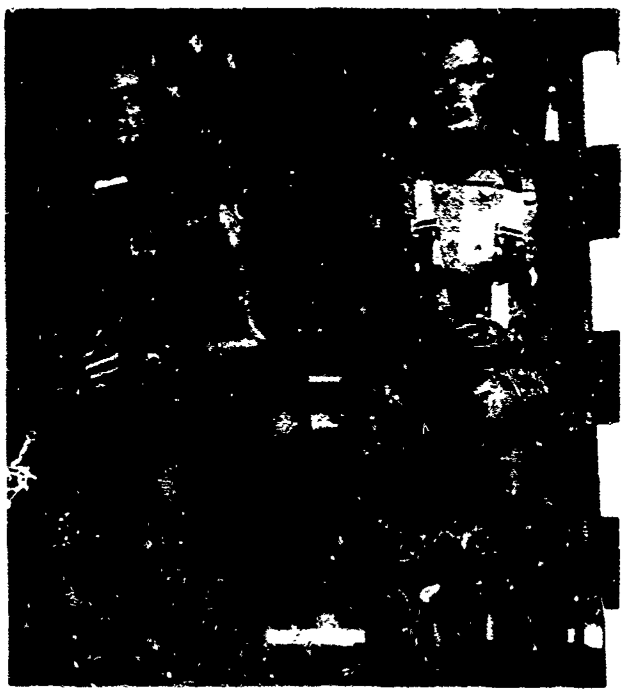


Figure 24. Pretest View of Tests 16 and 12.

Figure 25. Seat Pan Failure, Armored Dummy, Test 16.

Figure 26. Seat Pan Failure, Unarmored Dummy, Test 12.

Figure 27. Pretest Sideview Test 6 - 15-Degree Rearward Tilt, Dummy with Chest Armor Shown.

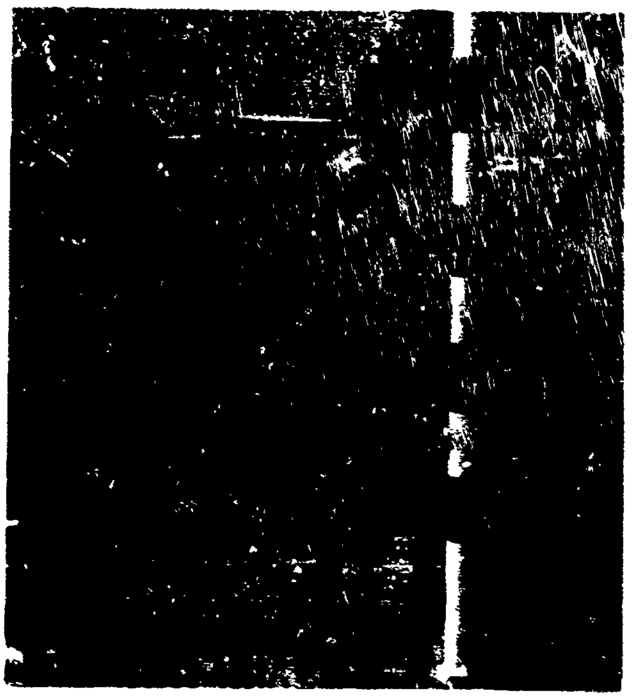


Figure 28. Pretest Front View, Tests 6A and 23A - 15-Degree Rearward Tilt.

## Tests 7, 7A, 24 and 24A

UH-1D seats were used and rotated laterally from the vertical by 15 degrees as shown in Figures 29 and 30.

These drops resulted in chin pad loads of 50 to 100 pounds and thigh pad loads of 490 and 360 pounds. The thigh pad loads were higher on the left thigh. The nylon net cushion was torn along the right side under the dummy with chest armor installed for both drops. The armored dummy appeared to translate laterally more than did the unarmored dummy; this difference may have contributed to the higher (2 to 1) vertebral loads in the armored dummy.

## Tests 11 and 15

CH-47 seats at 15-degree lateral tilt were used. The loading on the thigh pads was about the same in these tests as in the identical test with the UH-1D seat; however, no contact was made with the chin pad in this test. The entire seat bucket of both seats displaced vertically about 6 inches as can be seen by comparing Figures 31 and 32; however, the bucket was still restrained in the horizontal direction. The vertebral loads of 3000 and 2400 pounds are in fair agreement with the indicated chest accelerations.

## Tests 8 and 25

UH-1D seats were used at 15-degree forward and 15-degree lateral tilt. The armor straps, lap belt ends, and shoulder straps were loosened to provide 2 inches slack in these tests. The estimated chin pad contact load was 65 pounds. The total thigh pad load (Test 8) of 800 pounds was the highest noted in the drop test series. The vertebral load in the armored dummy was about three times that of the unarmored dummy. This difference in vertebral load may be the result of more spinal flexion by the armored dummy as noted in the high-speed film. It is also possible that the right hip joint of the armored dummy contacted the tubular frame (due to lateral movement) of the seat while the unarmored dummy hip joint may have just cleared the tube frame and deflected downward into the net cushion.

## Tests 13 and 17

The CH-47 seat was used at 15-degree forward and 15-degree lateral tilt as shown in Figures 33 and 34. The armor straps, lap belt ends, and shoulder straps were loosened to provide 2 inches slack in these tests.

Figure 29. Pretest Sideview, Test 7 - 15-Degree Lateral Tilt, Dummy with Chest Armor Shown.

Figure 30. Front View, Tests 7 and 24 - 15-Degree Lateral Tilt.

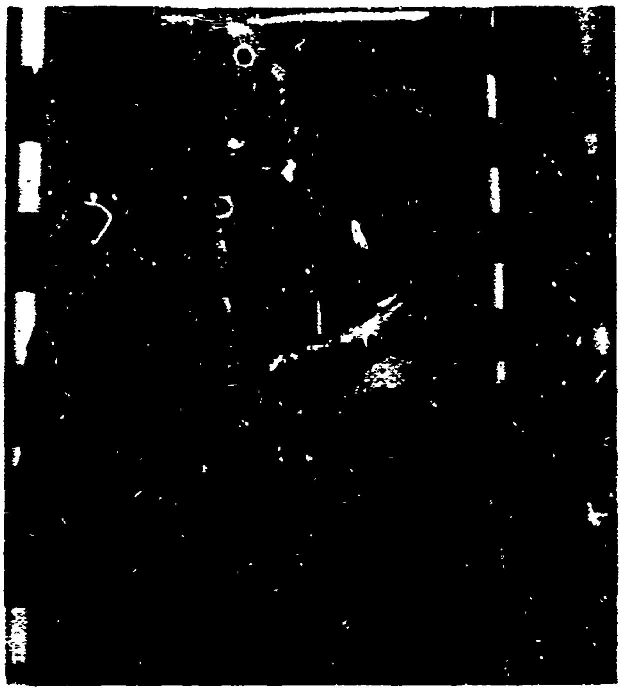


Figure 31. Pretest Sideview Test 15.

Figure 32. Posttest View, Test 15 - CH-47 Seat Bucket Displacement.

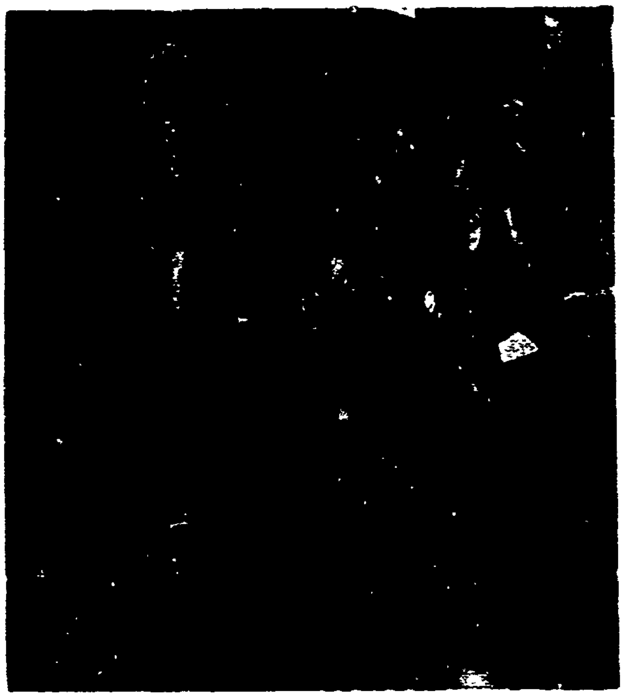


Figure 33. Pretest Sideview - Test 17 - 15-Degree Forward and Lateral Tilt. Dummy with Chest Armor Shown.

Figure 34. Pretest View Tests 17 and 13 - 15-Degree Forward and 15-Degree Lateral Tilt.

The forward and downward movement of the unarmored dummy's seat can be seen in Figure 35. The movement of the armored dummy's seat can be seen by comparing Figure 33 with Figure 36. The armored dummy's seat fractured at the pan intersection to the seat back (see arrow, Figure 36). This resulted in more severe "submarining" of the seat occupant than occurred with the unarmored dummy. The chin impact load was 85 pounds in Test 17. The total thigh load was 630 pounds.

Tests 9, 9A, 26 and 26A

UH-1D seats were used with 15-degree rearward and 15-degree lateral tilt. The armor straps, lap belt ends, and shoulder straps were loosened to provide 2 inches slack in these tests. Side and rear views of this test set-up are shown in Figures 37 and 38. These tests did not reveal any radically different results from the previous tests with the 15-degree rearward tilt (6, 6A, 23, 23A); however, the thigh loads (450 pounds and 680 pounds) were slightly higher.

In Tests 26A and 9A, however, both seat buckets sheared their retaining pins and slid down the right rear support columns as shown in Figure 39. This action caused both dummies to be deflected further laterally than was the case in Tests 24, 7, 24A, 7A, 25, 8, 13, and 17 in which a 15-degree lateral seat tilt was also used. The lateral movement was also greater because of the loose restraint harness. The vertebral loads were low (2100 pounds and 1600 pounds). No chin contact occurred.

Tests 14 and 18

CH-47 seats were used in a pure vertical drop. The effect of the armor on the dummy in these tests was very similar to Tests 21, 10, 21A, and 10A with the UH-1D seat. No contact of the chin pad occurred and the thigh pad loads ranged from 420 to 520 pounds. Vertebral loads were about the same as the loads in Tests 21A and 10A; however, they were of longer duration. Vertical acceleration values in the head and chest were all lower than the 30G input floor acceleration.

No more seat damage occurred in this 30G test than occurred in the higher velocity change 17 to 19G tests (12, 16, 12A, 16A, 11, 15, 13 and 17) involving a tilt either 15 degrees forward or 15 degrees lateral, or both.

Figure 35. Posttest Sideview, Test 13. CH-47 Seat at 15-Degree Forward and Lateral Tilt.

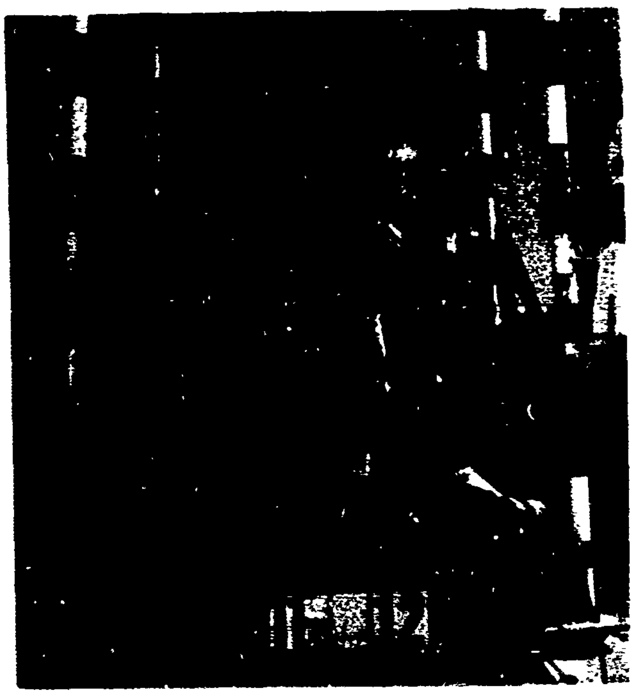


Figure 36. Posttest Sideview, Test 17. CH-47 Seat at 15-Degree Forward and Lateral Tilt. (Seat Pan Failure at Arrow.)

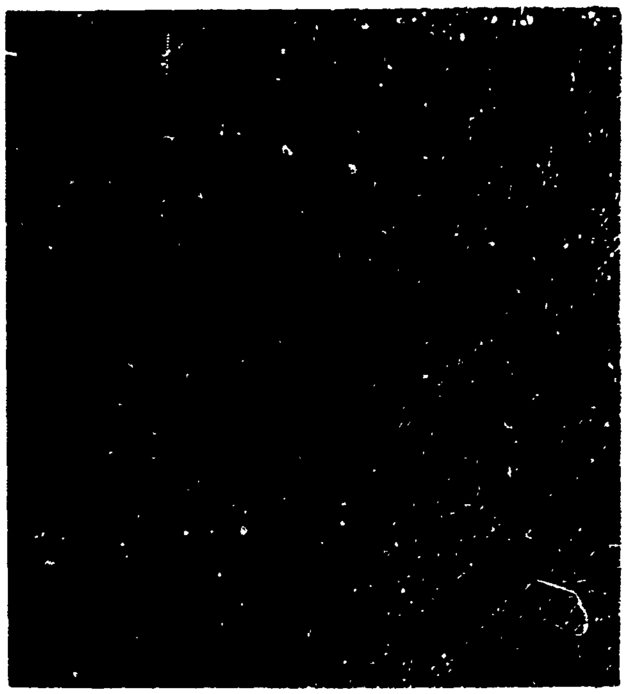


Figure 37. Pretest Sideview, Test 9A - 15-Degree Rearward and Lateral Tilt.

Figure 38. Pretest Rearview Tests 9A and 26A - 15-Degree Rearward and Lateral Tilt.

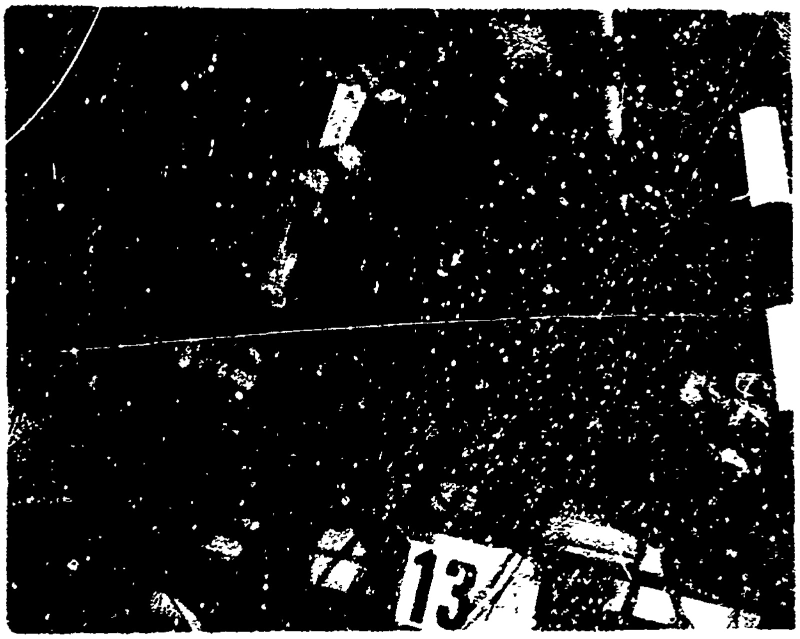


Figure 39. Posttest View Tests 9A and 26A Vertical and Lateral Deformation of UH-1D Seats (Note "bottoming" of bucket at right support column).

## Tests 19 and 20

Pretest photographs of the troop seat used are shown as Figures 40, 41, 42 and 43. These tests with an unarmored and an armored dummy resulted in a tearing failure of the nylon canvas seat pan at the intersection with the nylon canvas back. This failure allowed the dummy's buttocks to move downward to a point about 6 inches above the floor in Test 19 with the unarmored dummy and down to about 4 inches above the floor with the armored dummy in Test 20. The armored dummy's final position is shown in Figures 44 and 45.

The vertebrae load is slightly more than twice as high for the armored dummy as for the unarmored dummy. The thigh and chin loads were minimal.

## Other Observations from the Drop Tests

Examination of the high-speed films shows that the head and chest do not move significantly until after the input pulse is completed. It is thus possible to make a direct comparison of the vertical accelerations

Figure 40. Pretest Sideview, Test 19 - UH-1D Troop Seat, Unarmored Dummy.

Figure 41. Pretest Front View, Test 19 - UH-1D Troop Seat, Unarmored Dummy.

Figure 42. Pretest Sideview, Test 20 - Troop Seat, Armored Dummy.

Figure 43. Pretest Front View, Test 20 - UH-1D Troop Seat, Armored Dummy.

Figure 44. Posttest Position of Armored Dummy in Test 20. (Note position of lap belt at midline of chest armor.)

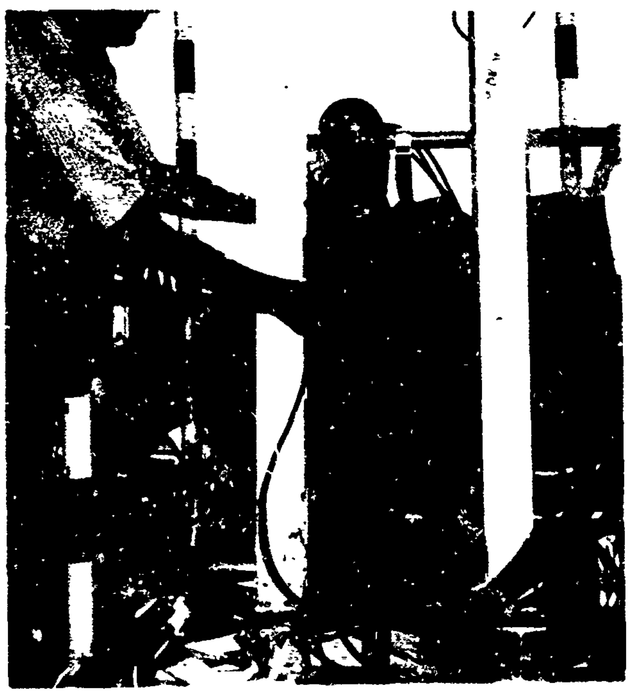


Figure 45. Posttest Position of Armored Dummy in Test 20 - Rear View.

of the floor and the dummy chest and head. Such a comparison indicates that, with few exceptions, a head and chest acceleration up to twice as large as the floor input acceleration is typical.

The shoulder armor of the UH-1D seat will break free at its upper edge and rotate laterally about its lower attachment. This movement, however, is not believed to be detrimental because of the proximity of the UH-1D crew entry door which would serve as a stop for the armor.

The shoulder-harness guide-bracket, attached to the upper edge of the UH-1D seat back, is very weak. This 3/8-inch O. D. aluminum tube was broken through the weld to the attachment bracket because of handling during shipping. The aluminum tube is welded on one side only. It should be welded on both sides as a minimum to sustain normal handling loads.

## APPENDIX B

## HORIZONTAL ACCELERATOR TEST REPORT

Test Facility and Procedure
Description of Test Items
Instrumentation
Test Agenda
Test Data

## APPENDIX B
## HORIZONTAL ACCELERATOR TEST REPORT

### General

The horizontal accelerator was used to simulate those accidents in which the acceleration is predominantly perpendicular to the spine. This condition often occurs in fixed-wing accidents in impacts where the descent rate is low as opposed to the high sinking-rate accidents of helicopters. The seat mounting angle on the accelerator was altered to introduce the required lateral and vertical loading components. Acceleration pulses were chosen to correspond to the 70th to 85th percentile range for accidents in this type aircraft.

### Test Facility and Procedure

The accelerator (Figure 46) was constructed by modifying the drop tower used in the vertical drop tests and pouring a concrete impact barrier and rail bed.

The sled which serves as the platform on which the seat experiments are mounted is made of 6-inch steel channels with longitudinal and lateral braces of the same material. A 1/2-inch steel plate is fixed to the impact end of the sled. The surface of this plate is "corrugated" with 1-inch x 1-inch steel angle lengths welded to the face of the plate. This corrugated surface contacts the paper honeycomb energy absorber and initiates the crushing of the honeycomb. The sled rides on four wheels attached to the frame. These wheels are kept on the tracks by steel plates that extend below the wheels and under the rail top on the outboard sides. The pneumatic release hook is transported on a sliding support, positioned behind the sled, that is not shown in Figure 46. The hook is attached to the rear of the sled and when the sled is released, the support prevents the hook from being damaged by falling on the track bed.

A gridded backdrop made of plywood sheets and aluminum framing was installed on one side of the sled to aid in the photographic analysis.

The seats were mounted on sections of standard track identical to that used in current aircraft. These tracks were in turn attached to a base plate attached to the sled. The desired various pitch and yaw angles for the seats were achieved by elevating one side of the base plate or rotating the base plate assembly on the sled. Figure 47 shows a typical seat installation.

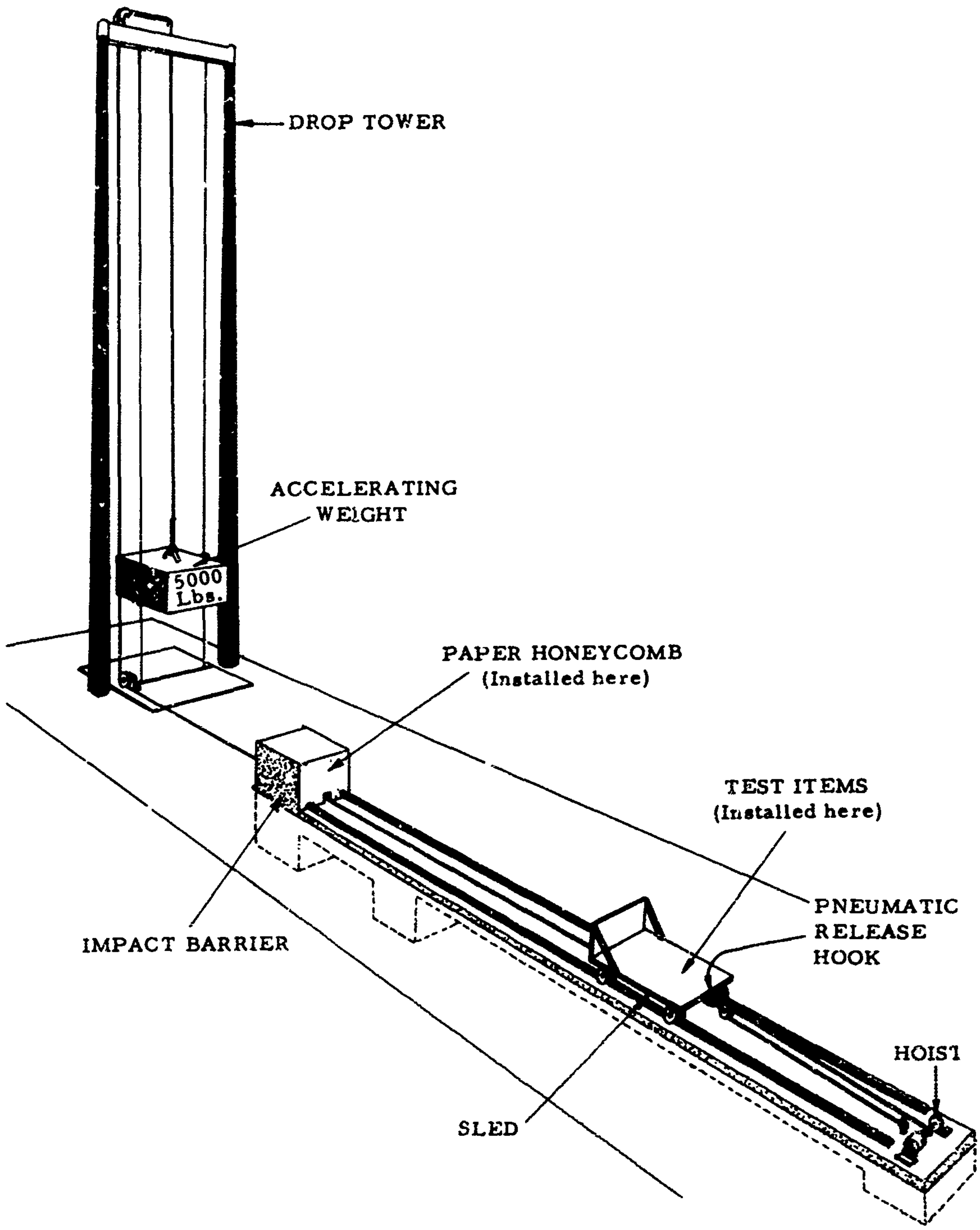



Figure 46. Drop Tower and Horizontal Accelerator Installation.

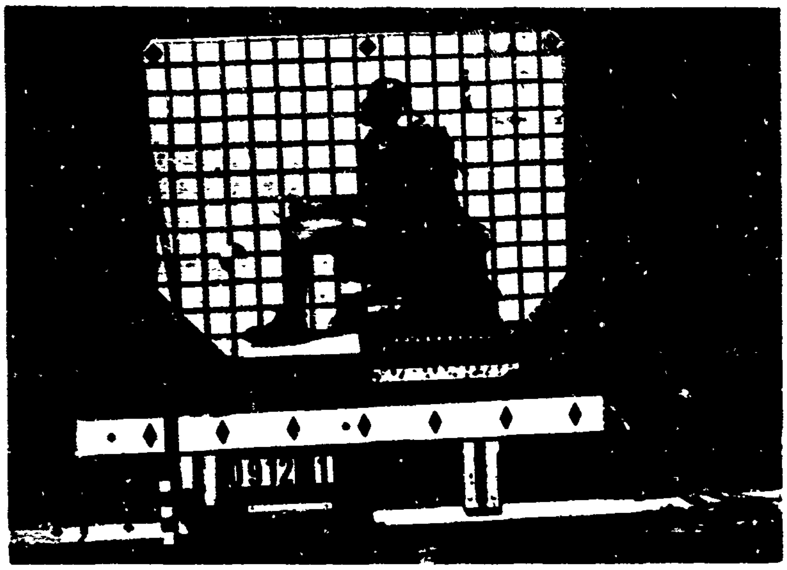


Figure 47. Typical Seat Installation (CH-47) Horizontal Accelerator Tests.

The stacks of paper honeycomb were attached to the face of the impact barrier shown in Figure 46. The honeycomb used has a 45 psi crushing strength.

One of the Alderson F-95 dummies used in the vertical drop tests was also used in the horizontal accelerator tests. The joints were torqued to the values as follows:

| | Torque Ft. - Lb. |
|---|---|
| Head Attachment Cable | 20 |
| Shoulder Joint Clamp (Vertical) | 24 (each) |
| Clavical Breast Plate (Sphere) | 40 |
| Shoulder Joint (Lateral) | 40 (each) |
| Biceps Rotation | 10 (each) |
| Elbow (Vertical) | 60 (each) |
| Wrist (Vertical and Lateral) | 10 (each) |
| Spine Cable | 25 |
| Pelvic (Hip) Joint (Vertical) | 80 (each) |
| Pelvic (Hip) Joint (Lateral) | 40 (each) |
| Femur (Upper Leg Bone) Rotation | 20 (each) |
| Knee | 60 (each) |
| Ankle | 20 (each) |

The limbs and sides of the dummy's body were marked as shown in Figure 47 to identify hinge points, head center of gravity, and centerlines of the limbs and spine. Styrofoam pads were installed on each upper thigh and on the top center of the chest armor to record blows by the armor.

## Description of Test Items

The seats and armor tested on the horizontal accelerator were the same as tested on the drop tower (Phase I) except that the fabric troop seat was not tested. Basic characteristics of the test items are restated below:

UH-1B/D armored crew seat - flexible construction - integral armor (back, pan and sides) - net comfort cushion - lap belt attaches to floor structure. Weight: 140 pounds.

CH-47 armored crew seat - rigid sheet metal frame - plastic seat pan - foam cushion - armor kit installation - lap belt attaches to seat structure. Weight (with armor): 120 pounds.

Body armor for these tests consisted only of chest armor in the canvas carrier. Weight: 16 pounds.

## Instrumentation

Figure 48 illustrates the complete instrumentation installation.

The dummy instrumentation consisted of:

(1) The spinal column load transducer.

(2) Tri-axial accelerometers in the head.

(3) Tri-axial accelerometers in the chest.

Each seat was instrumented with:

(1) One tri-axial accelerometer on the bucket.

(2) A load link in each half of the lap belt.

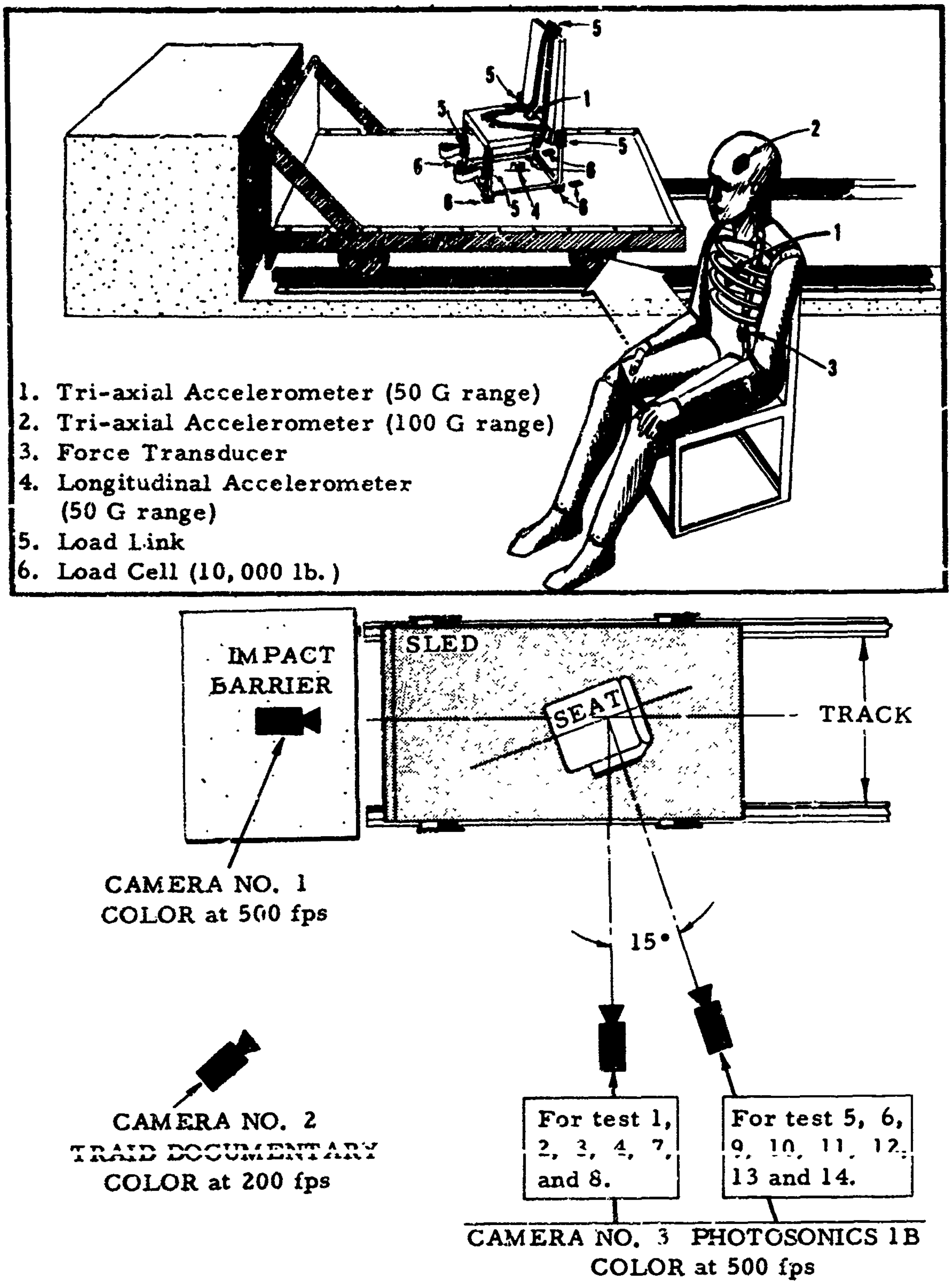



Figure 48. Horizontal Accelerator Instrumentation and Camera Layout.

(3) A load link in the shoulder harness between the inertia reel and neck yoke.

(4) A load cell under each seat leg.

(5) A load cell behind each rear seat leg to measure the shear (horizontal) load at the floor.

An accelerometer mount was installed on the sled at the center of gravity for measurement of longitudinal acceleration.

In addition to the still photographs taken before and after each test, three motion cameras were located around the impact barrier. Figure 48 shows the location of each and identifies the equipment used.

All instrumentation is identified by type and manufacturer in Appendix F.

Test Agenda

As shown in Table II, eight tests were conducted with the UH-1B/D armored crew seat and six tests were conducted with the CH-47 armored crew seat. Seven tests were conducted with the personnel armor installed and seven corresponding tests were conducted without armor.

# TEST DATA

## General

In the following discussion of the horizontal accelerator tests, the tests will be referred to by number and the acceleration pulses will be referred to by type. Table II presents information concerning armor applications, seat type, acceleration pulse simulation, seat orientation, seat damage, and significant load and acceleration data as recorded during each test.

Since tests were required on both seats at the same orientation, and further since seat failures were encountered early in the test series, the tests were not run in numerical order. The order of testing was: 1, 7, 8, 14, 13, 9, 10, 11, 12, 5, 6, 4, 3, 2.

Three seat orientations were used during this series of tests: longitudinal with zero pitch and zero yaw, longitudinal with 30-degree pitch and zero yaw, and longitudinal with 15-degree pitch and 15-degree left yaw. Figures 49 through 51 show these orientations.

Test 1, the first of the series, was performed using a Type A pulse (see the lower right corner of Table II for details). In this test the rear legs of the CH-47 seat failed completely, allowing the seat to pivot forward about the front leg attachment points until the seat pan bottomed on the sled floor. This allowed the occupant's head to displace forward approximately 3 feet. Figure 52 shows the seat after this test. This is apparently the characteristic failure pattern for this seat since all subsequent failures experienced were virtually identical.

To determine the effect of a Type A pulse on the UH-1 seat, Test 7 was performed next. In this test the seat carrier slides failed at the front leg attachment fittings, releasing the front legs and allowing the seat to pivot about the rear leg attachments until the seat pan bottomed on the sled floor. The seat then rebounded, pivoting 90 degrees about the rear attachments. This failure is apparently characteristic of this seat, since subsequent failures were virtually identical to this. Figure 53 shows the results of this test.

Since it was apparent that the Type A pulse would result in seat failure that would have greatly complicated the evaluation of the personnel armor injury effects, a Type B pulse was adopted for Tests 9, 10, 13 and 14. Tests 11 and 12 used a Type D pulse as originally planned.

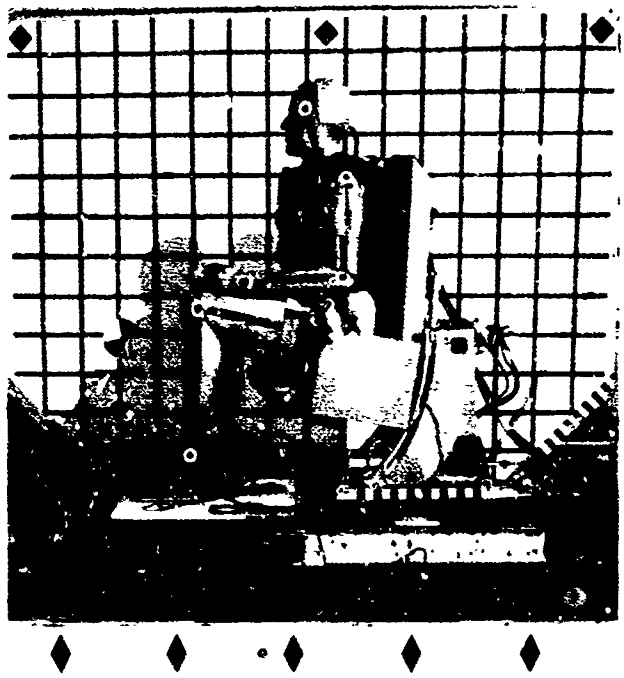


Figure 49. Longitudinal Mount (Zero Pitch, Zero Yaw).

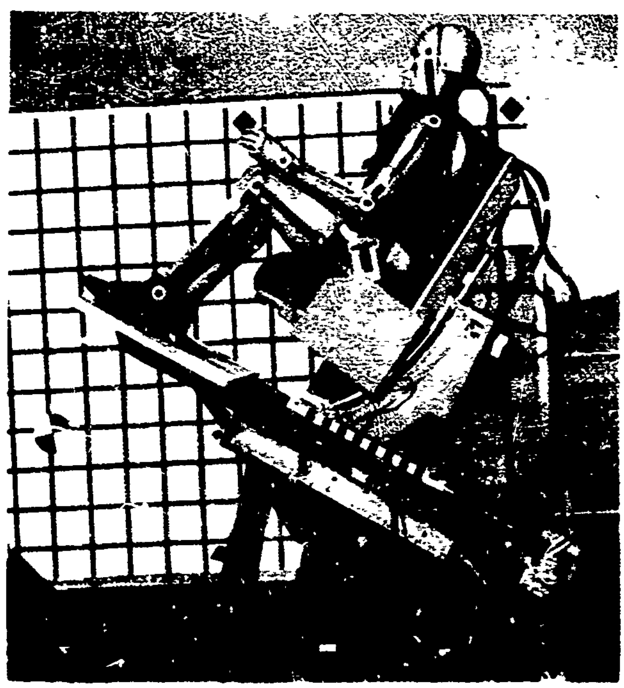


Figure 50. Longitudinal Mount (30-Degree Pitch, Zero Yaw).

Figure 51. Longitudinal Mount (15-Degree Pitch, 15-Degree Yaw).

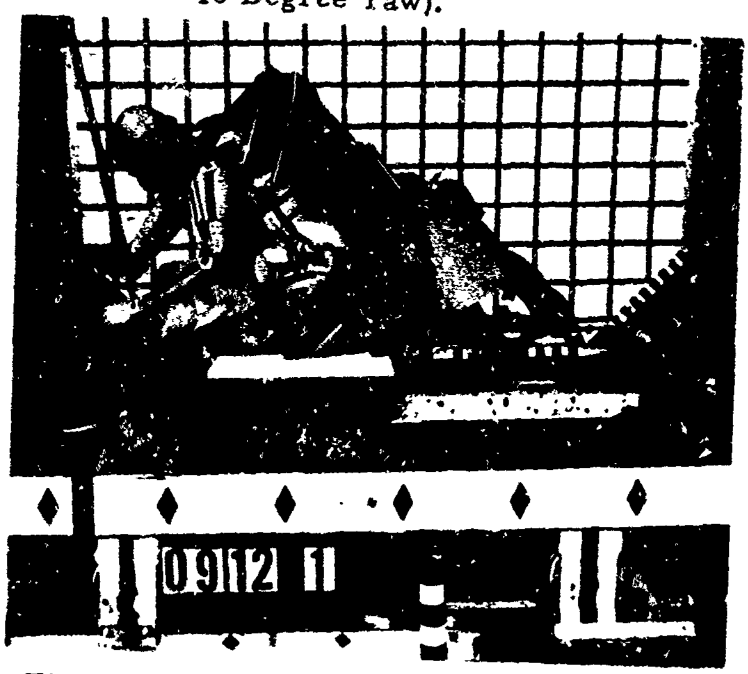



Figure 52. CH-47 Seat Failure, Test 1.

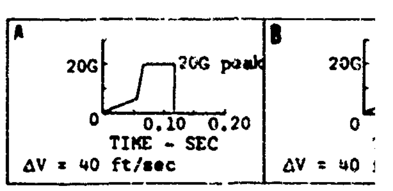
## TABLE II
## HORIZONTAL ACCELERATOR TEST RESULTS - PERSONNEL ARMOR

| (1) TEST NO. | (2) CHEST ARMOR USED | (3) SEAT TYPE | (4) CRASH PULSE TYPE | (5) SEAT ORIENTATION PITCH (Degree) | (6) SEAT ORIENTATION YAW (Degree) | (7) SEAT DAMAGE | (8) CHIN PAD CRUSH (IN.) | (9) CHIN PAD LOAD (LBS) | (10) ACCELERATIONS (G) HEAD LONG. | (11) HEAD VERT. | (12) CHEST LONG. | (13) CHEST VERT. | (14…) SE… LO… |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | NO | CH-47 | A | 0 | 0 | Failure of rear leg tiedown resulted in rotation about front leg tiedown until seat pan contacted floor. | N/A | N/A | 17 | 16 | 22 | 17 | 1 |
| 2 | YES | CH-47 | A | 0 | 0 | Failure of rear leg tiedown resulted in rotation about front leg tiedown until seat pan contacted floor. | 0.2 | 140 3/ | 33 | 19 | 18 | 18 | [illegible] |
| 3 | NO | CH-47 (Mod 2) | C | 30 | 0 | Minor deformation of front seat tube at upper seat bucket attachment fitting. | N/A | N/A | 29 | 19 | 18 | 9 | 1 |
| 4 | YES | CH-47 (Mod 2) | C | 30 | 0 | Failure of upper seat bucket attachment fitting. Seat pan rotated forward 20 degrees. | 0.2 | 140 1/ | 34 | 10 | 14 | 7 | 1 |
| 5 | NO | CH-47 | C | 15 | 15 | Failure of rear leg tiedown resulted in rotation about front leg tiedown until seat pan contacted floor. | N/A | N/A | 12 | 12 | 20 | 10 | [illegible] |
| 6 | YES | CH-47 (Mod 1) | C | 15 | 15 | Failure of seat track attachment slide. Complete loss of seat at seat/test jig retention. | 0.1 | 110 1/ | 15 | 6 | 10 | 7 | [illegible] |
| 7 | NO | UH-1D | A | 30 | 0 | Failure of front leg tiedown resulted in rotation about the rear leg tiedown until seat pan contacted floor. | N/A | N/A | 29 | 48 | 29 | 5 | [illegible] |
| 8 | YES | UH-1D | A | 30 | 0 | Failure of front leg tiedown resulted in rotation about the rear leg tiedown until seat pan contacted floor. | UNK | UNK 2/ | 40 | 42 | 27 | 22 | [illegible] |
| 9 | NO | UH-1D | B | 15 | 15 | Minor fracture of front seat track attachment slide. | N/A | N/A | 24 | 25 | 20 | 10 | 1 |
| 10 | YES | UH-1D | B | 15 | 15 | Minor fracture of front seat track attachment slide. | 0.3 | 240 1/ | 48 | 24 | 17 | 7 | 1 |
| 11 | NO | UH-1D | D | 15 | 15 | Minor fracture of front seat track attachment slide. | N/A | N/A | 32 | 22 | 28 | 18 | [illegible] |
| 12 | YES | UH-1D | D | 15 | 15 | Minor fracture of front seat track attachment slide. | 0.1 | [illegible] 1/ | 48 | 24 | 30 | 16 | [illegible] |
| 13* | NO | UH-1D | B | 15 | 15 | Failure of front leg tiedown resulted in rotation about the rear leg tiedown until seat pan contacted floor. | N/A | N/A | 28 | 37 | 28 | 14 | [illegible] |
| 14* | YES | UH-1D | B | 15 | 15 | Failure of front leg tiedown resulted in rotation about the rear leg tiedown until seat pan contacted floor. | 0.1 | 170 1/ | 42 | 28 | 22 | 10 | [illegible] |

* Two inches of slack in restraint harness and armor carrier vest.

** When seat failure occurs peak seat accelerations were taken just prior to failure. All other accelerations are taken at seat failure. Where sharp spikes occur in the traces, peaks were taken at the point where the duration was 0.005 sec.

Location of Impact:
1/ Under chin.
2/ Under nose.
3/ Unknown.




A.

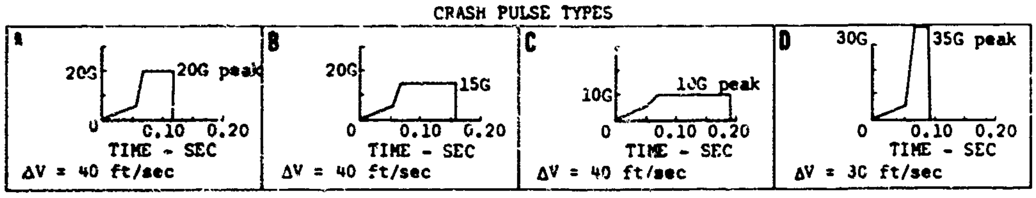
TABLE II

HORIZONTAL ACCELERATOR TEST RESULTS - PERSONNEL ARMOR

| ⑦ | ⑧ | ⑨ | ⑩ | ⑪ | ⑫ | ⑬ | ⑭ | ⑮ | ⑯ | ⑰ | ⑱ | ⑲ | ⑳ | ㉑ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T DAMAGE | CHIN PAD CRUSH (IN.) | CHIN PAD LOAD (LBS) | ACCELERATIONS (G) ** | | | | | | | LOADS (LBS.) | | | | |
| | | | HEAD LONG. | HEAD VERT. | CHEST LONG. | CHEST VERT. | SEAT LONG. | SEAT VERT. | SLED LONG. | VERTEBRA | LAP BELT RIGHT | LAP BELT LEFT | LAP BELT TOTAL | SHOULDER HARNESS |
| leg tiedown resulted t front leg tiedown contacted floor. | N/A | N/A | 17 | 16 | 22 | 17 | 15.6 | 3 | 15 | 5000 | 1600 | 1500 | 3100 | 600 |
| leg tiedown resulted t front leg tiedown in ...ted floor. | 0.2 | 140 3/ | 33 | 19 | 18 | 18 | 21 | 0 | 19 | 2800 | 2300 | 1600 | 3900 | 800 |
| n of front seat at bucket ing. | N/A | N/A | 29 | 19 | 18 | 9 | 13 | 6 | 10 | 7300 | 1400 | 1200 | 2600 | 600 |
| seat bucket ng. Seat pan 20 degrees. | 0.2 | 140 1/ | 34 | 10 | 14 | 7 | 13 | 10 | 10 | 1100 | 1200 | 1200 | 2400 | 600 |
| leg tiedown resulted t front leg tiedown contacted floor. | N/A | N/A | 12 | 12 | 20 | 10 | 14 | 4 | 12 | 3000 | 1400 | 1700 | 3100 | 900 |
| track attachment loss of seat at tention. | 0.1 | 110 1/ | 15 | 6 | 10 | 7 | 13 | 4 | 12 | 500 | 700 | 1300 | 2000 | 400 |
| leg tiedown resulted t the rear leg tie- pan contacted floor. | N/A | N/A | 29 | 48 | 29 | 5 | 17 | 10 | 19 | 5400 | 1700 | 1600 | 3300 | 700 |
| leg tiedown resulted t the rear leg tie- pan contacted floor. | UNK | UNK 2/ | 40 | 62 | 27 | 22 | 19 | 9 | 20 | 3800 | 1400 | 1500 | 2900 | 500 |
| f front seat track . | N/A | N/A | 24 | 25 | 20 | 10 | 13 | 5 | 12 | 3600 | 800 | 1600 | 2400 | 1200 |
| f front seat track . | 0.3 | 240 1/ | 48 | 24 | 17 | 7 | 16 | 7 | 14 | 2200 | 600 | 1700 | 2300 | 1100 |
| f front seat track . | N/A | N/A | 32 | 22 | 28 | 18 | 34 | 8 | 30 | 4100 | 1800 | 2300 | 4100 | 700 |
| f front seat track . | 0.1 | 150 1/ | 43 | 24 | 30 | 16 | 30 | 6 | 33 | 2100 | 1200 | 1900 | 3100 | 1000 |
| leg tiedown resulted t the rear leg tie- pan contacted floor. | N/A | N/A | 28 | 37 | 28 | 14 | 18 | 8 | 18 | 3200 | 1900 | 2600 | 4500 | 700 |
| leg tiedown resulted t the rear leg tie- pan contacted floor. | 0.1 | 170 1/ | 42 | 28 | 22 | 10 | 14 | 10 | 15 | 3100 | 1100 | 2000 | 3100 | 700 |

vest.
just prior to failure. All other ac-
occur in the traces, peaks were taken

CRASH PULSE TYPES






B.

Figure 53. Failure of UH-1 Seat, Test 7, (View looking aft with seat rotated backward about rear leg attachment points.)

Test 8 was performed with a Type A pulse in order to yield a test with armor comparable to Test 7.

The CH-47 seat was known to be of lower strength than the UH-1 seat, so a Type C pulse was adopted for Tests 3 through 6. Even with this reduced pulse, it was necessary to reinforce the seat to prevent failures. Test 2 with personnel armor was performed with a Type A pulse to be comparable to Test 1.

Action of Personnel Armor

The armor remained in place in all tests and no damage occurred to the armor, the carrier vest, or the restraint harness.

Estimates of the loads applied to the thighs and chin of the occupant were obtained from crushable foam pads installed on the dummy and on the top of the armor. These pads were made of a material having a known crushing strength which remained approximately constant throughout the range of loads experienced. Figure 54 shows a typical chin installation after crushing by the chin impacting on the top of the armor. Figure 55 shows a posttest view of the thigh pad installation.


Figure 54. Chin Pad Installation.

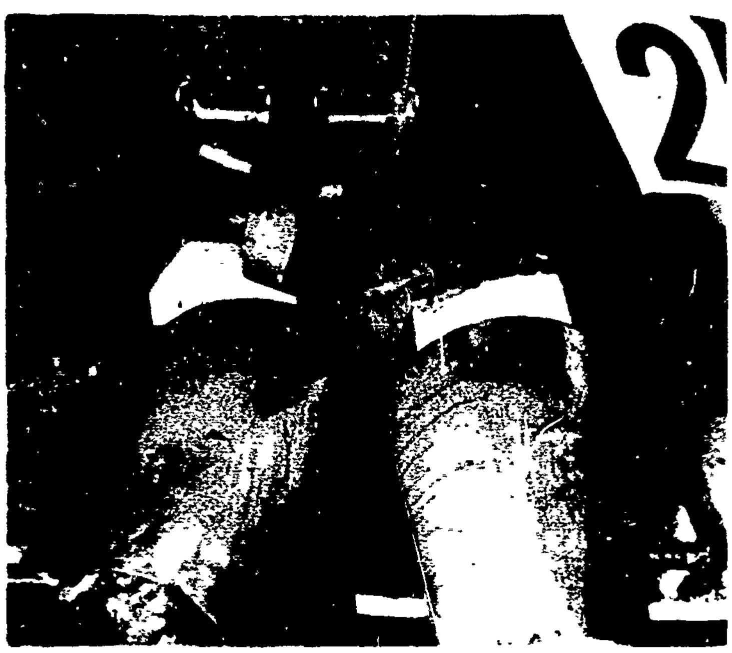


Figure 55. Thigh Pad Installation.

In this series of tests, the thigh pads suffered heavy damage, especially those involving the chest armor. Examination of the thigh pads showed that the damage consisted primarily of shearing failure of the styrofoam caused by the lap belt. Close examination of the pad did not reveal any damage which might have been caused by the armor. The increased damage in the tests involving chest armor was due to the fact that when the armor is worn, the lap belt is farther forward and comes in contact with more of the thigh pad. Figure 56 shows a posttest view of a typical set of pads.

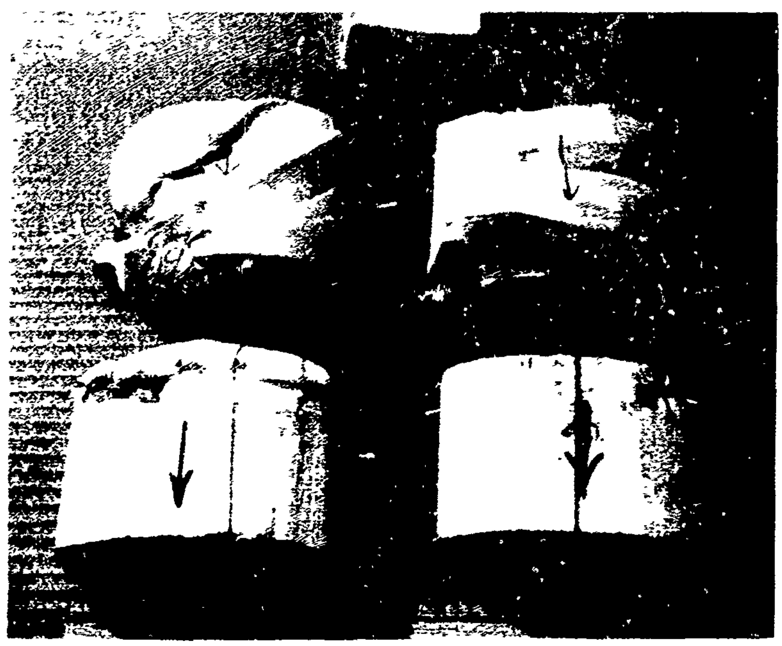


Figure 56. Styrofoam Load Pads. Posttest View Showing Shearing Failure Caused by Lap Belt.

The chin pads showed varying degrees of crushing. The estimated impact loads imposed by the armor on the chin are given in Table II, column 9, with footnotes to indicate location of the impact. In general, the loads were more severe when the seats remained in place, or when the restraint harness was slack.

Table II also presents the peak values of the loads and accelerations measured in each test. The lateral accelerations have been omitted since they were consistently below 10G in all tests. Typical data traces from Tests 9 and 10 are shown in Figures 57 through 60.

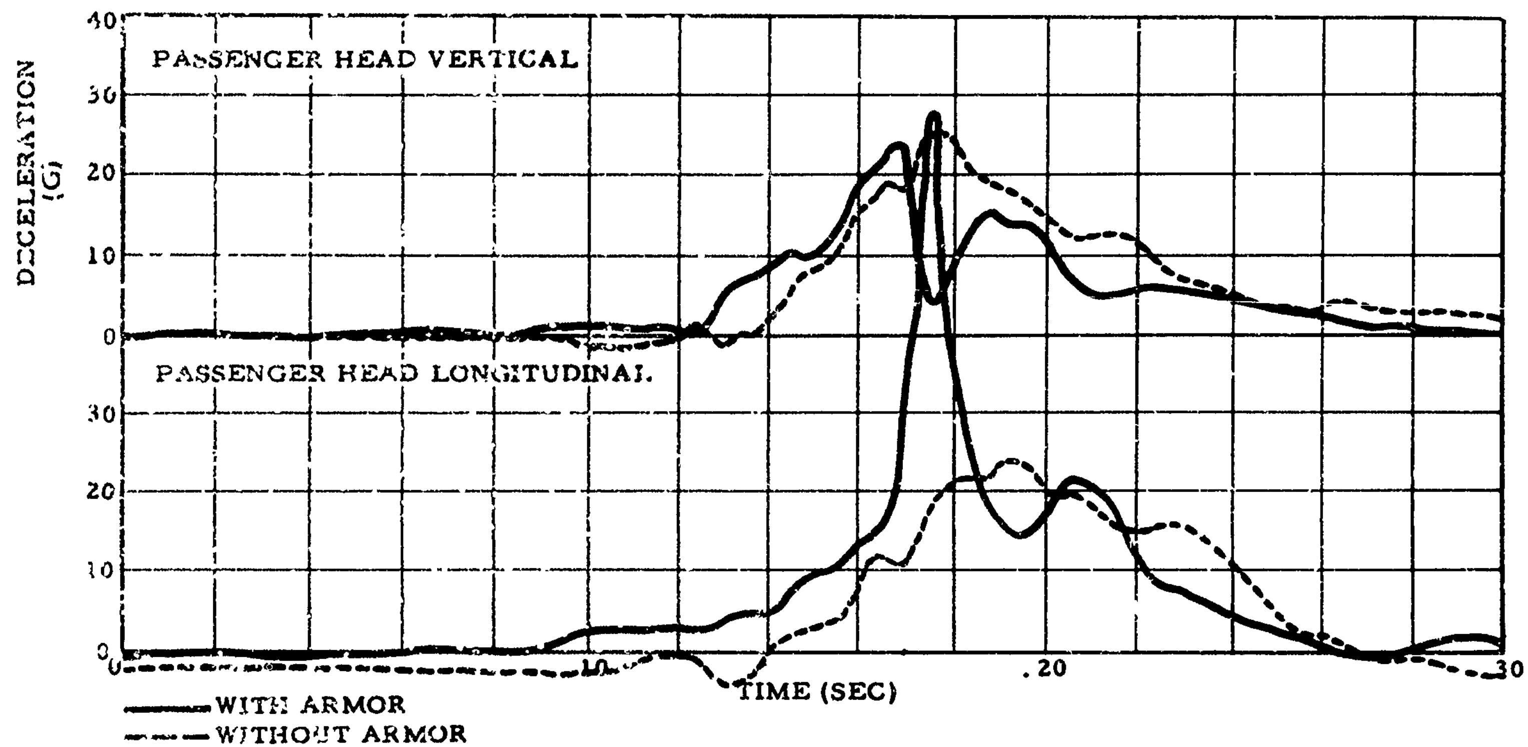



Figure 57. Typical Dummy Head Data - Accelerator Tests 9 and 10.

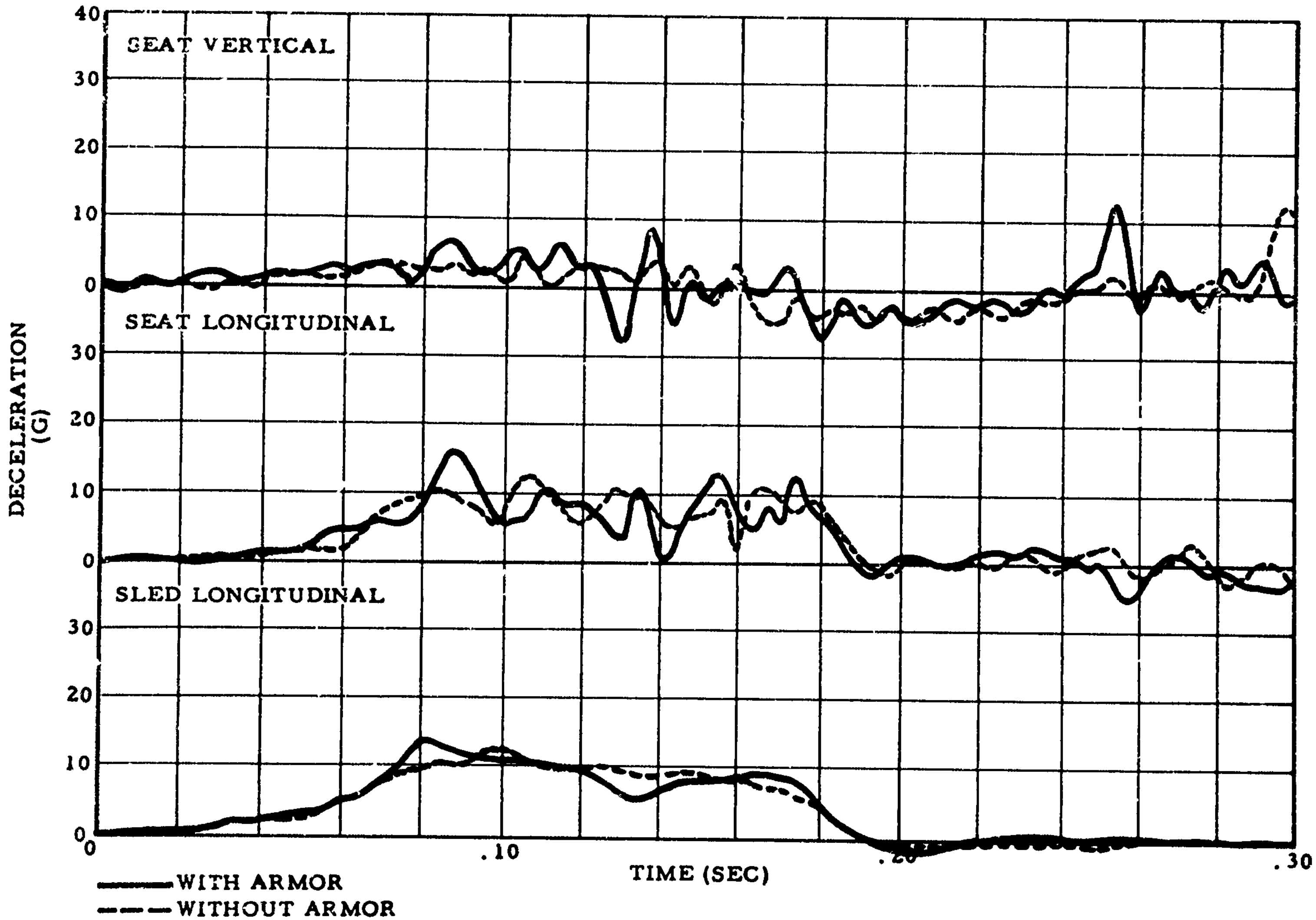



Figure 58. Typical Seat and Sled Data - Accelerator Tests 9 and 10.

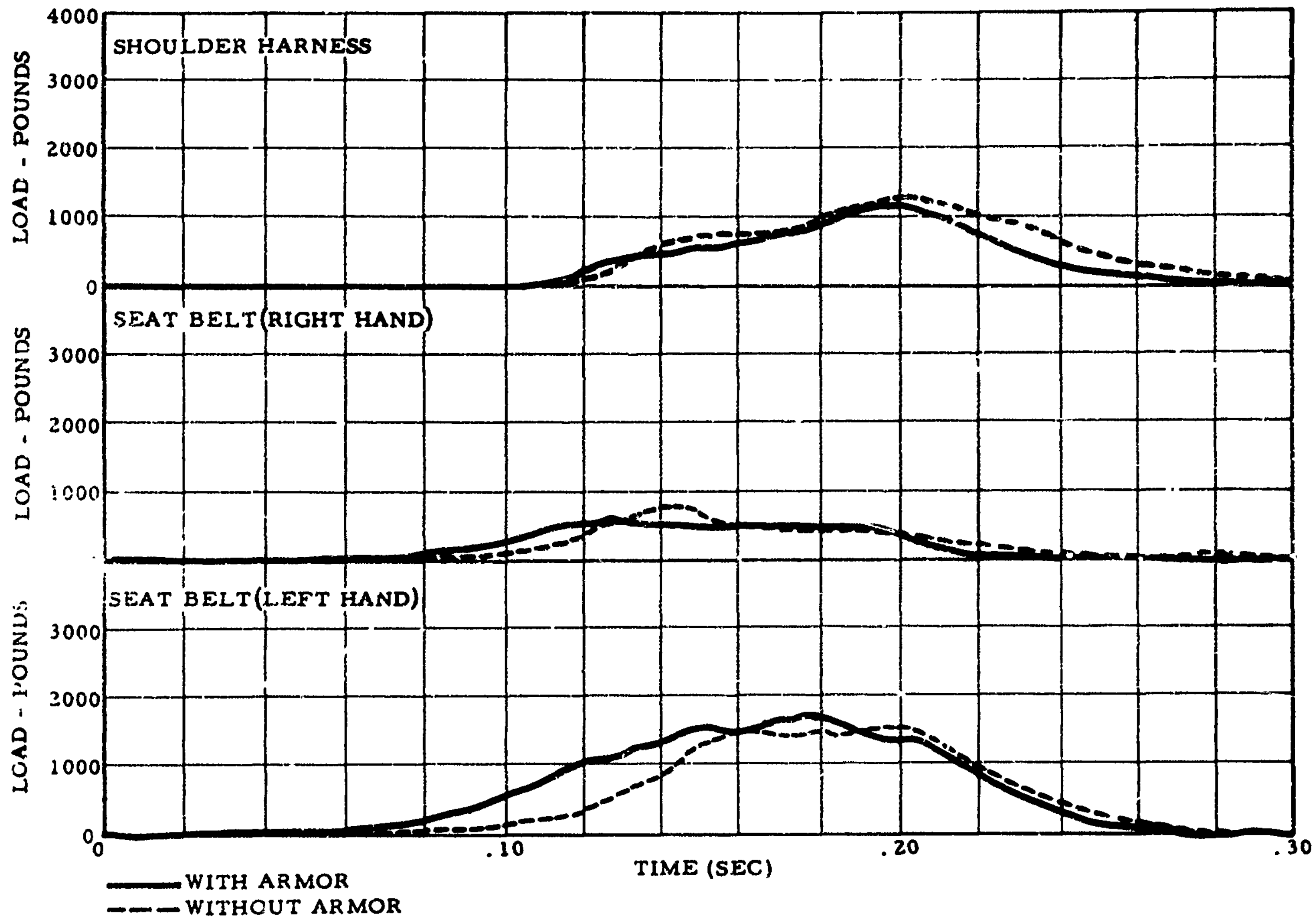



Figure 59. Typical Restraint Harness Data - Accelerator Tests 9 and 10.

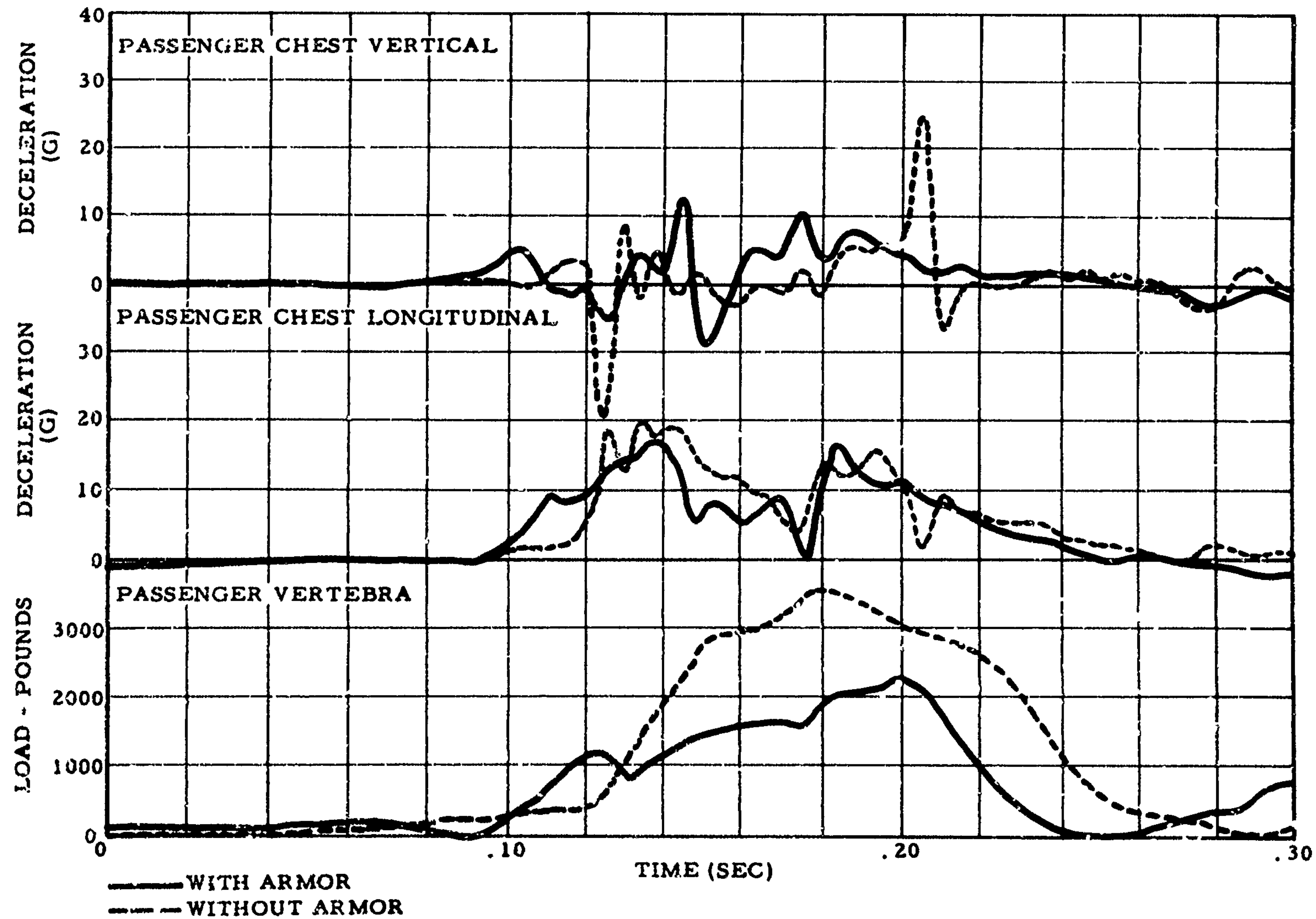



Figure 60. Typical Dummy Chest and Vertebra Data - Accelerator Tests 9 and 10.

Tests 1 and 2

The CH-47 seat failed in both tests, allowing the seat pan to bottom on the sled floor. This fact accounts for the high seat accelerations shown, since these peaks all occur after seat failure.

The passenger head and chest accelerations also reached their maximum values after seat failure (Table II). There is no significant difference between the two tests in the seat and passenger accelerations experienced except for the seat vertical acceleration and the passenger head longitudinal acceleration. The difference in the seat vertical accelerations is due, at least in part, to the fact that seat loads measured during the test show that the seat failed at a lower load in Test 1, thus allowing the seat to impact the floor at a higher velocity. The difference in the head longitudinal acceleration is probably due to the chin impacting the chest armor after the seat bottoms on the floor.

The restraint harness loads for the two tests show slightly higher loads for the test involving the chest armor. This is to be expected, since this seat failed at a higher load. The loads experienced were well within the design limits of the harness. The vertebral load is lower with the personnel armor in place.

Tests 3 and 4

These tests used the longitudinal seat mount with 30-degree pitch and zero yaw. The CH-47 seats suffered only minor bending of the rear tubes.

In comparing the data, the only significant difference observed is in the vertebral load.

Tests 5 and 6

These tests utilized the longitudinal seat mount with 15-degree pitch and 15-degree left yaw. The CH-47 seats failed in both tests, with the failure in Test 6 being especially severe. The seat carrier slides failed, completely releasing the seat from the tracks. Both accelerations and loads measured in Test 6 are lower than in Test 5 because of the seat failure. The large reduction in vertebral load is again evident in the test involving armor, and this is probably due, at least in part, to the failure of the seat in Test 6.

Tests 7 and 8

These tests utilized the longitudinal seat mount with 30-degree pitch and zero yaw. The UH-1D seats failed in both tests. The only major difference to be noted in the data from these two tests is in the longitudinal head acceleration and the vertebral load. The higher longitudinal head acceleration in the armor test is probably due to the chin striking the armor; however, the chin pad was inadvertently omitted in this test so no load data are available. The vertical head acceleration is very high (40G+) in both tests. The vertebral load with armor is again lower than without armor.

Tests 9 and 10

These tests with UH-1D seats utilized the longitudinal seat mount with 15-degree pitch and 15-degree left yaw. No major failures occurred. Again, the only significant difference in the data for the two tests lies in the longitudinal head accelerations and the vertebral loads. The higher longitudinal head acceleration in the armor test is probably due to the impact of the chin on the armor. The impact in this test was the most severe experienced in the series. The vertebral load is again lower for the armor test.

Tests 11 and 12

These tests used the same seat mount (UH-1D) as Tests 9 and 10. The seats remained in place. The characteristic higher longitudinal head acceleration and lower vertical load was again present in the test involving armor.

Tests 13 and 14

These tests used the seat mount (UH-1D) from the previous four tests. The tests were the same as Tests 9 and 10 except that two inches of slack was left in the restraint harness and the armor carrier vest was installed loosely. The seats failed in these tests due to excess loading induced by the dynamic overshoot experienced. The higher longitudinal head acceleration was present; however, the vertebral loads were more nearly equal in these tests.

## APPENDIX C

## FULL-SCALE AIRCRAFT CRASH TEST REPORT

Test Facility and Procedure
Description of Test Items
Instrumentation
Test Agenda
Test Data

## APPENDIX C
## FULL-SCALE AIRCRAFT CRASH TEST REPORT

### General

This mode of testing provided a realistic crash environment in which the impact velocity was made consistent with the 60th percentile accident for U. S. Army rotary-wing aircraft[8].

### Test Vehicle, Facility and Procedure

The test vehicle consisted of the lower fuselage portion of a salvaged UH-1 helicopter. All structure forward of the aft bulkhead and above the floor line was removed to improve camera coverage. The transmission, engine, and rotor head had been removed before the airframe was shipped to the contractor's facility. Fuel cells were filled with 174 gallons of water to simulate a 1443-pound full fuel load. A four-point hoisting rig was fabricated from steel cable to maintain the test vehicle in level flight attitude prior to release from the crane shown in Figure 61.

The test vehicle was suspended behind the mobile crane with the boom elevated 60 degrees and rotated 15 degrees to the left to give a yawed condition at impact.

The conditions at impact were:

| | | |
|---|---|---|
| Horizontal velocity | = | 30 fps (20.5 mph) |
| Vertical velocity | = | 30 fps (14 feet drop height) |
| Fuselage yaw | = | 15 degrees nose left |
| Fuselage pitch | = | 0 degrees nose down |

### Description of Test Item

Although the aircraft used in the test had previously been damaged, the floor and substructure were relatively intact. The original seat mounting tracks in the cockpit area and the fuel cells and adjacent spaces were intact.

Two UH-1B/D integrally armored seats were installed on the original tracks in the cockpit area (Figure 62). The seat configuration (pilot and copilot) was reversed so that the side armor plates would both be inboard and not interfere with camera coverage. A P-95 dummy was

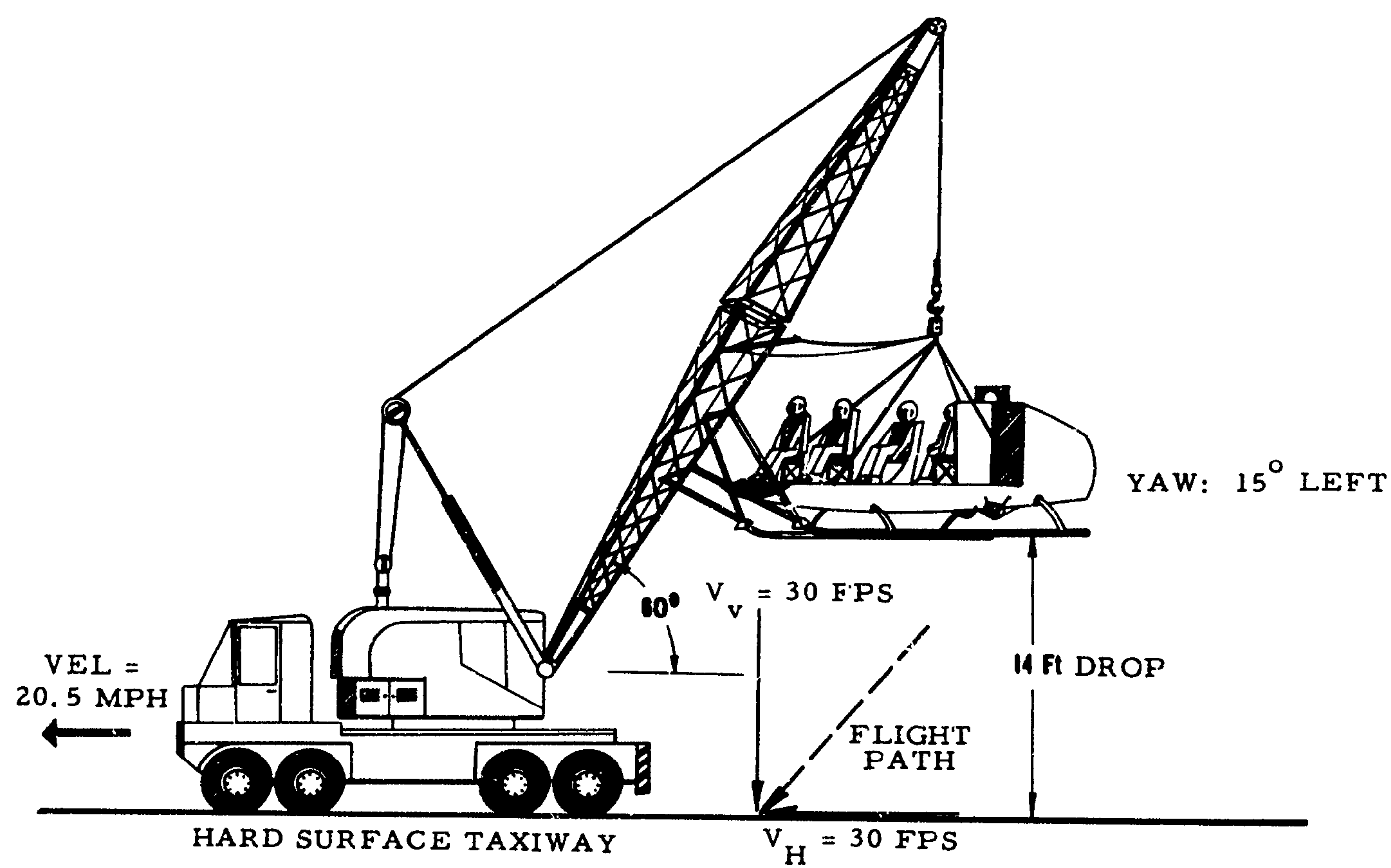



Figure 61. Test Setup - Full-Scale Crash Test.

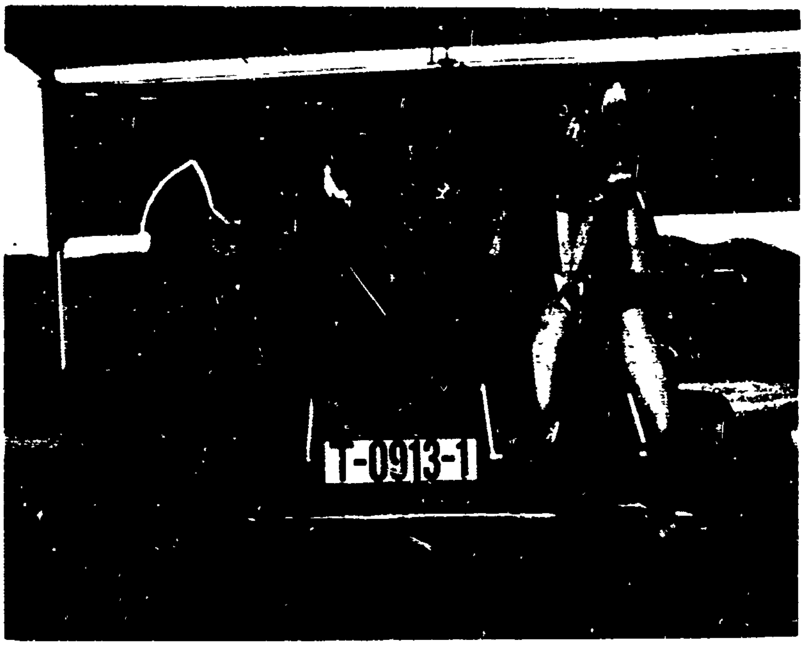



Figure 62. Rearward View of UH-1 Seat Installations (in foreground) and CH-47 Seat Installation (on fuselage centerline).

installed in the copilot seat (left side) and an F-95 dummy in the pilot side (right side). The existing floor tie-points were used for the lap belts and the existing seat shoulder-restraint-system was used. Each dummy in the UH-1 seats wore the armor carrier vest with the chest armor only - the normal pilot and copilot armor arrangement.

A single CH-47 armored seat was installed 40-inches behind the UH-1 seats on the fuselage centerline (Figures 62 and 63). Since there are no mounting tracks in this position, a mount was fabricated of 4-inch aluminum channels (5/16-inch web). The mount bridged two longerons and was securely anchored to the basic airframe. A P-95 dummy, wearing the carrier and chest armor, was seated here and restrained with conventional harness over the shoulders and across the lap. The lap belt was attached to existing tie-points on the seat structure.

Immediately behind the CH-47 seat, a floor-to-ceiling plywood bulkhead was installed running fore and aft (Figure 64). This bulkhead was rigidly attached to the structure which originally held a bulkhead in the same position. A standard two-mar troop seat was attached to this bulkhead, facing outboard on thc right side of the test vehicle (Figure 64).

Figure 63. Side View of CH-47 Seat Installation.

Figure 64. Troop Seat Installation.

The two seat legs were attached over existing "buttons" on the floor. An F-95 dummy was installed in the forward (aircraft orientation) half of the seat and restrained only by a standard lap belt. The dummy carried both front and back armor in the carrier vest. The carrier vest was applied tightly to the dummy's torso. The single-piece leg armor was worn on the left leg and the two-piece armor on the right leg. The dummy's body was positioned in the crouched stance of a gunner.

The gross weight of the test vehicle with its full fuel load, four seats and dummies, and recording equipment, was 4,500 pounds. An overall side view taken prior to the test is shown in Figure 65.

Figure 65. Side View of Test Vehicle.

## Instrumentation

The F-95 dummies in the pilot seat and in the troop seat contained instrumented vertebrae. The P-95 dummies in the copilot seat and in the CH-47 seat had tri-axial accelerometer mounts in the heads. Tri-axial accelerometers were also installed in the chests of all dummies.

The joints of all dummies were torqued as follows:

| | Torque Ft. - Lb. |
|---|---|
| Head Attachment Cable | 20 |
| Shoulder Joint Clamp (Vertical) | 20 (each) |
| Clavical Breast Plate (Sphere) | 40 |
| Shoulder Joint (Lateral) | 40 (each) |
| Biceps Rotation | 10 (each) |
| Elbow (Vertical) | 40 (each) |
| Wrist (Vertical and Lateral) | 10 (each) |
| Spine Cable | 25 |
| Pelvic (Hip) Joint (Vertical) | 60 (each) |
| Pelvic (Hip) Joint (Lateral) | 40 (each) |
| Femur (Upper Leg Bone) Rotation | 20 (each) |
| Knee | 40 (each) |
| Ankle | 20 (each) |

The limbs, joints and body sides of the dummies were all marked for photographic coverage.

Styrofoam pads were installed on each dummy's upper thighs and on the top of the chest armor.

Load links were installed in all the seat belts and in the shoulder harnesses except for the F-95 dummy in the troop seat. No shoulder harness was used on this dummy.

Fuselage accelerations at floor level were recorded by tri-axial accelerometer mounts installed on the floor between the two UH-1B/D seats and between the CH-47 seat and the troop seat.

Still photographs were taken of the test items during test preparations, just before and immediately following the crash. Motion coverage was provided by 13 cameras located on the crane and around the impact zone (Figure 66).

Appendix F further identifies the instrumentation by type and manufacturer.

| CAMERA | SPEED | TYPE | LENS |
|---|---|---|---|
| 1 | 500 F.P.S. | PHOTOSONICS 1B | 3" |
| 2 | 500 F.P.S. | PHOTOSONICS 1B | 3" |
| 3 | 500 F.P.S. | PHOTOSONICS 1B | 2" |
| 4 | 500 F.P.S. | PHOTOSONICS 1B | 2" |
| 5 | 500 F.P.S. | PHOTOSONICS 1B | 2" |
| 6 | 500 F.P.S. | PHOTOSONICS 1B | ½" |
| 7 | 200 F.P.S. | TRAID 200 V | 1" |
| 8 | 500 F.P.S. | PHOTOSONICS 1B | 1" |
| 9 | 500 F.P.S. | PHOTOSONICS 1B | 4" |
| 10 | 500 F.P.S. | PHOTOSONICS 1B | ½" |
| 11 | 32 F.P.S. | BELL & HOWELL 70 KM | 3" |
| 12 | 500 F.P.S. | PHOTOSONICS 1B | 3" |
| 13 | 24 F.P.S. | BOLEX | ZOOM |

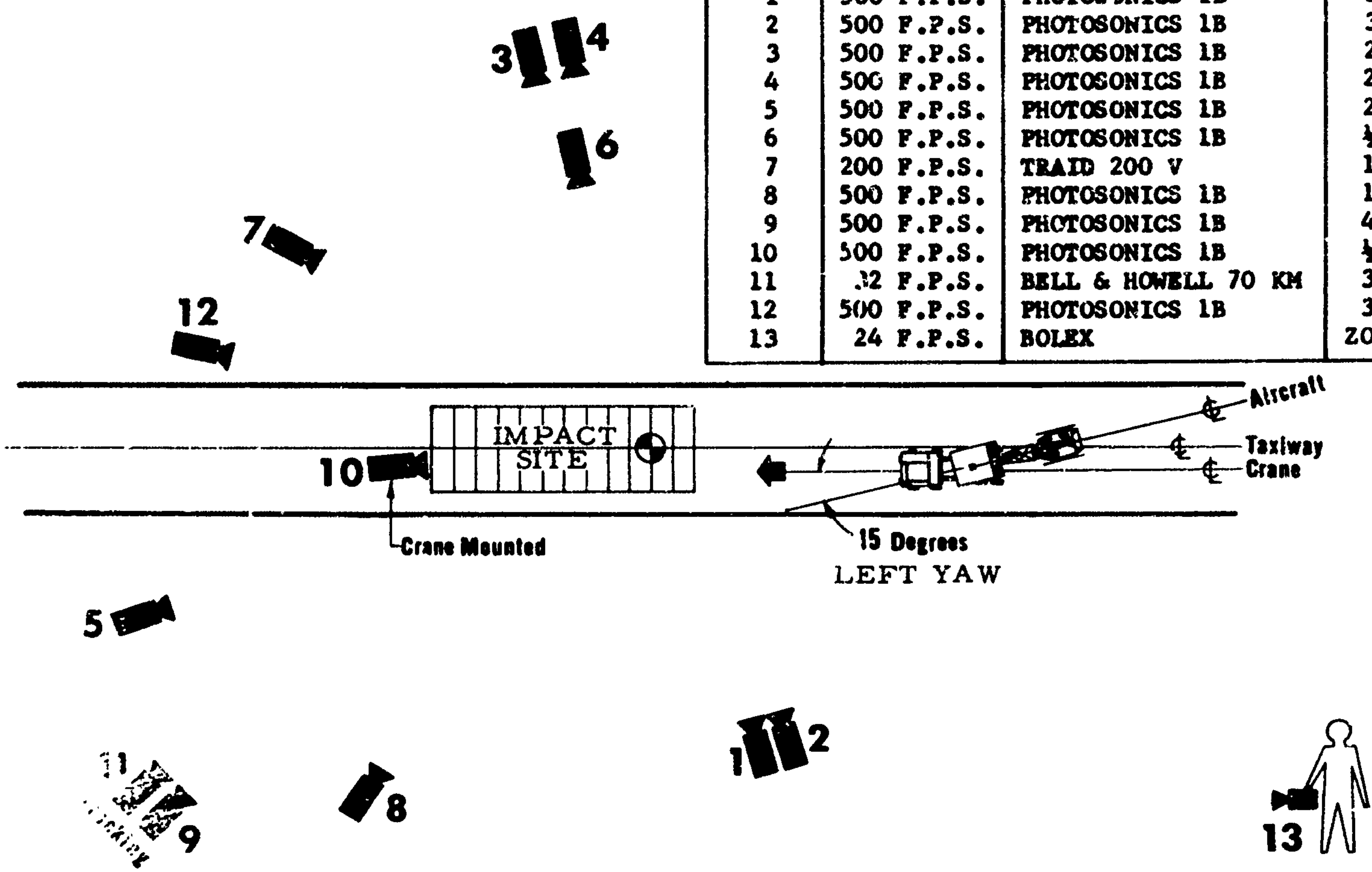



Figure 66. Test Site Layout - Full-Scale Crash Test.

## TEST DATA

### General

In the discussion that follows, all references to direction, such as left and right, are given from the viewpoint of the aircraft occupant. A summary of test results is given in Table III.

All seats except the canvas troop seat remained in place with no major failures. The troop seat failed rather severely as will be discussed later. No significant damage was noted to any of the personnel armor, carrier vests or restraint harness. The straps holding the seat armor to the troop seat failed when the seat failed.

As in previous tests involving chest armor, the loads imposed on the thighs and chin were calculated from imprints on the styrofoam pads installed on the dummies. Figure 67 shows a typical set of pads after the test. Notice that the indentations in the thigh pads are similar to those experienced in the drop tower tests, indicating that the acceleration was predominantly vertical.

Figures 68 through 70 show the positions of all dummies after impact.

### Pilot Position - UH-1 Seat (Right Side)

As previously mentioned, this seat was actually a copilot's seat, but was placed in this position so that the side armor would be inboard to avoid interfering with photographic coverage. The seat bucket stroked 5 inches vertically due to failure of the positioning pins in the seat height adjustment tubes. A partial failure of the weld on the support bracket for the side armor allowed the armor to deflect downward. Indentations in the foam thigh pads indicated that the chest armor impacted the right thigh with a force of 500 pounds. No appreciable crushing was found in either the left thigh pad or the chin pad. Analysis of the high-speed film indicates that the chin did not strike the armor. Figures 71 and 72 show front and side views of the final position of seat and dummy. Notice the extremely high position of the lap belt buckle. This is a result of the slack induced by the vertical movement of the bucket.

TABLE III
SUMMARY OF FULL-SCALE CRASH TEST RESULTS

| (1) Seat and Position | (2) Armor | (3) Chin Load | (4) Thigh Load Right | (5) Thigh Load Left | (6) Thigh Load Total | (7) Final Armor Position | (8) Seat Damage |
|---|---|---|---|---|---|---|---|
| UH-1 Pilot (Right) | Chest only | 0 | 500 | 0 | 500 | Normal | Vertical adjustment failed. Seat displaced vertically 4 inches. |
| UH-1 Co-Pilot (left) | Chest only | 0 | 200 | 300 | 500 | Normal | Vertical adjustment failed. Seat displaced vertically 4½ inches. |
| CH-47 | Chest only | 0 | 0 | 0 | 0 | Normal | Vertical adjustment failed. Seat bottomed on floor. |
| UH-1 Troop | Chest Back Legs | 40 | 370 1/ | 430 | 800 | Chest and Back armor slid up on dummy. | Canvas seat pan tore. Forward outboard leg attachment failed. Seat rotated forward and down. |

1/ Probably caused by thigh portion of full length armor rather than chest armor.

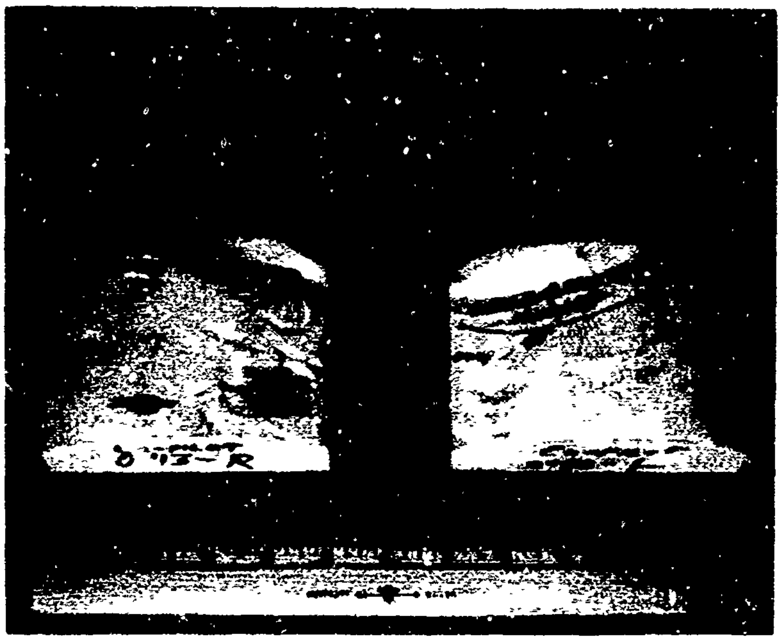


Figure 67. Styrofoam Pads Posttest View Showing Armor Damage.

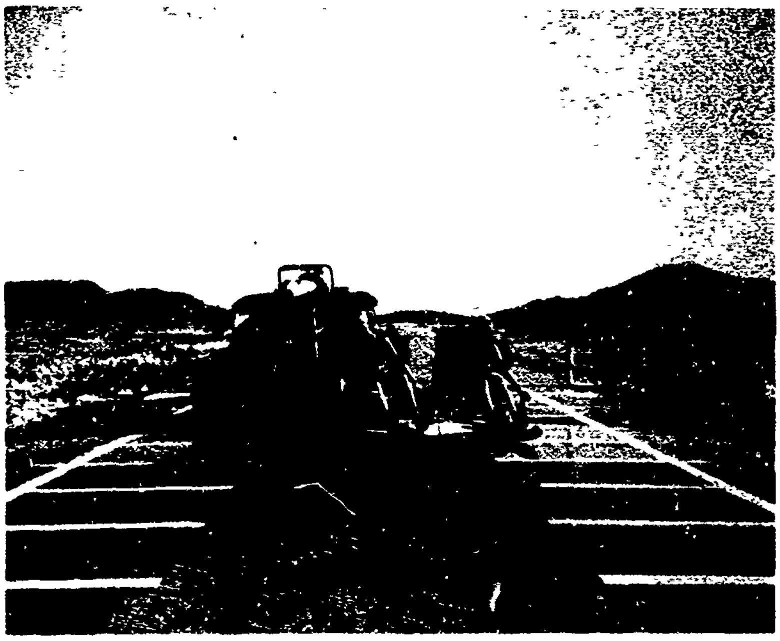


Figure 68. Front View - Postcrash.

Figure 69. Side View - Postcrash.

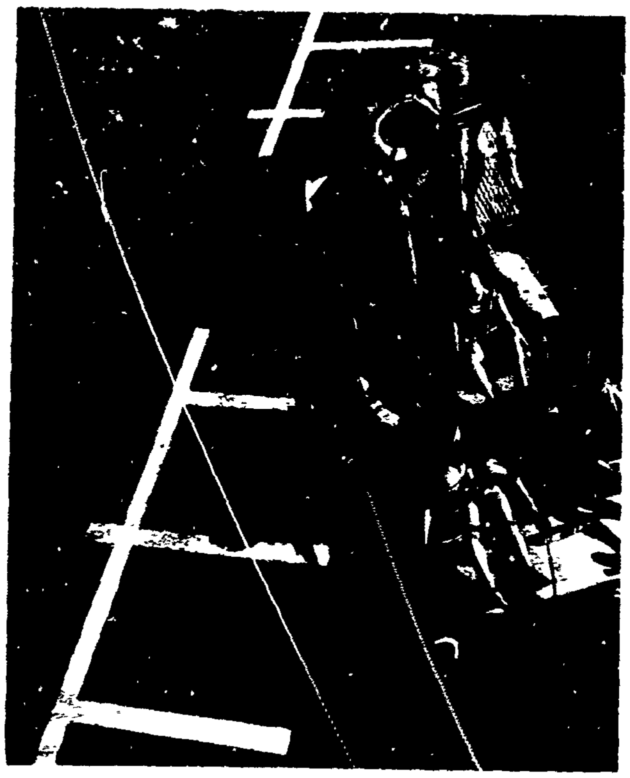


Figure 70. Overhead View - Postcrash.

Figure 71. Postcrash Front View - Pilot Position.

Figure 72. Postcrash Side View - Pilot Position.

Copilot Position - UH-1 (Left Side)

This seat was a pilot seat, but was placed in this position to allow better photographic coverage. The seat reacted to the crash in much the same manner as the other UH-1 seat. Vertical deflection of the seat bucket was approximately 4-1/2- inches due to failure of the retaining pins in the vertical adjustment tubes. The support bracket for the side armor failed, releasing the armor panel. This is the only complete failure of this bracket that occurred during the entire test program.

Indentations in the thigh pads indicated that the chest armor applied loads of 200 pounds to the right thigh and 300 pounds to the left.

No visible crushing was observed on the chin pad. The high-speed film shows that the chin did not strike the armor.

Figures 73 and 74 show the final position of this seat and dummy. Notice again the extremely high position of the lap belt buckle caused by slack that was induced by the vertical displacement of the seat bucket.


Figure 73. Postcrash Front View - Copilot Position.

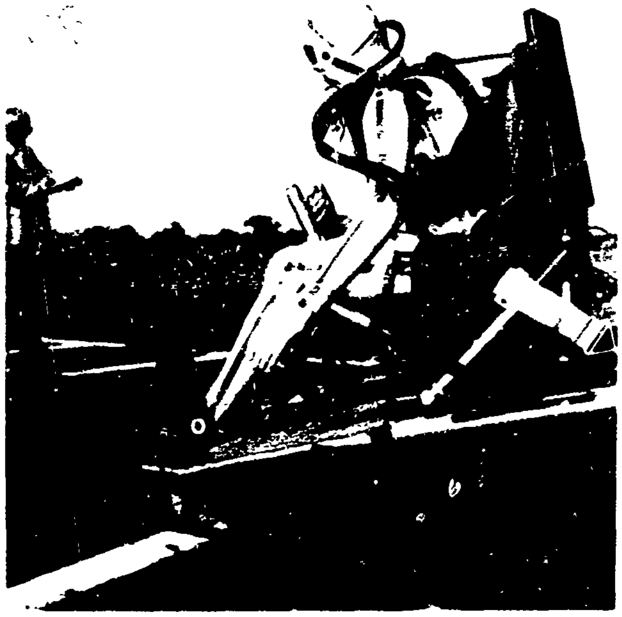


Figure 74. Postcrash Side View - Copilot Position.

## CH-47 Seat

This seat also displaced vertically due to failure of the height adjusting mechanism. The seat bottomed severely on the seat mount; however, no crushing was observed in the thigh pads or chin pad. This would indicate that the armor did not strike the thighs or chin with any appreciable force. Figures 75 and 76 show the final position of this seat and dummy. Note that the lap belt has remained in place. No slack was introduced by the vertical displacement since the belt is fastened to the seat.

## UH-1 Troop Seat

This seat was the only seat in the test to completely collapse. The front outboard support leg pushed its floor attachment fitting through the floor and into the fuel cell area (Figure 77). The dummy moved forward and outward on the seat, failing the canvas seat pan and causing the outboard longitudinal support-tube to rotate forward and down as illustrated in Figure 78. This rotation pulled the rear leg free from its floor attachment. Sufficient load was then transferred through the canvas to fail the

Figure 75. Postcrash Front View - CH-47 Seat.

Figure 76. Postcrash Side View - CH-47 Seat.

Figure 77. Postcrash 3/4 Side View UH-1 Troop Seat.

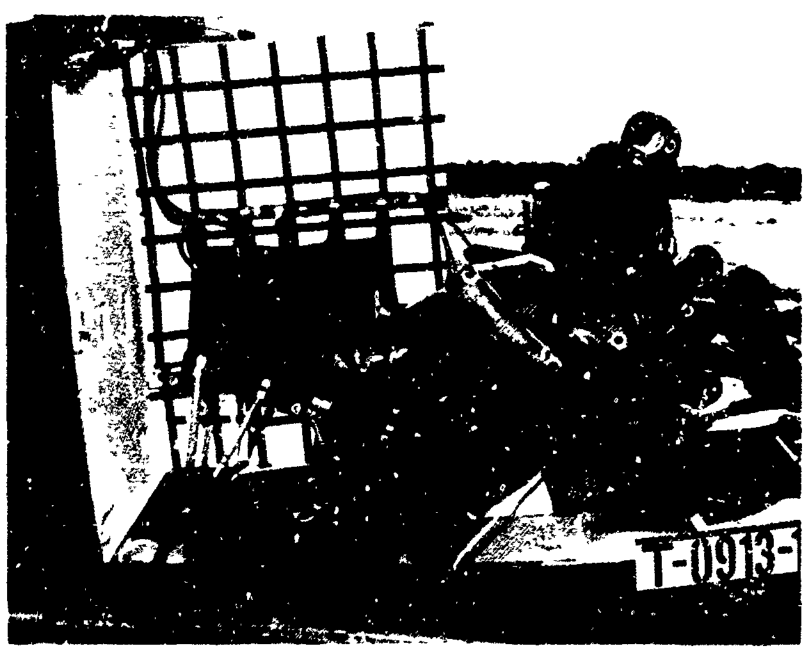



Figure 78. Postcrash Front View UH-1 Troop Seat.

rear inboard longitudinal support bracket. The dummy, restrained only by a lap belt, jackknifed over the belt. The chest armor impacted the left thigh with a force calculated at 430 pounds.

The pad on the right thigh showed an indentation produced by a load of 370 pounds. However, this is believed to have been caused by the upper edge of the thigh armor as the dummy jackknifed. The final position of this armor can be seen in Figure 78. The chin impacted the top of the armor with a force calculated at 40 pounds. As the dummy moved down and forward, the armor rebounded and moved up the torso until it was restrained by the lower portion of the arm opening in the carrier vest (Figure 77). The snaps on the shoulder straps connecting the front and rear carriers pulled loose on the right shoulder. There was no damage in this separation - the snaps simply separated in their normal manner.

## Instrumentation

The high-speed camera coverage of this test was excellent. All cameras operated as planned, producing good quality film.

The electronic instrumentation data recording package operated properly except for a 0.1 second period during the impact. Data recording during this 0.1 second period was not considered valid due to the recorder malfunction. The cause of the malfunction is being investigated.

## APPENDIX D

## AIRCREW ARMOR CONFERENCE PROCEEDINGS

## APPENDIX D
## AIRCREW ARMOR CONFERENCE PROCEEDINGS

The conference agenda took the form of a problem and discussion forum. Problems were presented orally to the group and the responses were recorded. The combined knowledge and experience of the participants served to clarify the following specific problems and to provide tentative solutions.

PROBLEM: The data from the dynamic testing of personnel armor, seats and restraint systems, although scientifically valid, was obtained through the use of anthropomorphic dummies. Transference of this data to meaningful descriptions and predictions of human injury under identical conditions has, historically, been less than satisfactory.

SOLUTION: By a thorough and detailed search of the current literature in the medical and engineering (mostly automotive) fields, much of this gap has been narrowed (see Bibliography). Foreign literature has contributed significantly to our knowledge. AvSER has done a great deal of after-the-fact aircraft crash injury research and this is available. This body of factual knowledge and data will be analyzed in several different ways to predict actual human injury. One of the methods proposed for use is that of an exponential weighting factor for appraising the deceleration or force impulses registered on the dummy's heads, in conjunction with an impulse-integration procedure. The use of this method was not practical in view of the magnitude of head accelerations measured.

PROBLEM: Experimental crash testing should be conducted so that the inferences can be made as to the effects, if any, which might be expected when the armor is worn in the following "improper" ways:

a) small man - long vest

b) loosely worn chest armor, resting on thighs but under the shoulder harness

SOLUTION: The test plan has been expanded to include testing for evaluation of the two "improper" situations noted above. If significant differences are noted during the drop tower and sled tests, an improperly worn armor system can be incorporated into the actual helicopter crash test.

PROBLEM: Particular attention should be given to the door gunner position so that this position is simulated accurately during the full-scale dynamic crash test. The orientation of a medical corps crew member, by contrast, would be in a (random) standing position.

SOLUTION: It was generally agreed that little useful information could be gained by a test of a dummy in a standing position for obvious reasons; that is, it is impossible to provide crash protection for an essentially unrestrained standing individual. Thus, testing will be limited to the door gunner in the seated position.

PROBLEM: Should the chest armor be grossly modified so that it could be instrumented with strain gage loaded contact areas; should we instrument the dummy at the anticipated points of contact; or should we seek an alternate method which would allow us to use the armor exactly as worn by the pilot?

SOLUTION: Use the armor exactly as issued, without modification and use special styrofoam-type energy-absorbing strips that will give an approximate peak force profile (by permanent reproducible deformation). This will not interfere with the interaction between the dummy and the armor.

PROBLEM: In the final helicopter crash, should there be a "roll" (rotational) component purposely introduced prior to impact?

SOLUTION: The review of our past crash tests and actual crash data from USABAAR show that the introduction of this additional component into the crash situation will add little significance to the test data. Hence, the helicopter will be crashed without a pre-crash rotational component.

The following statements are representative of the general feelings of the conferees, based upon their combined knowledge and experience:

1. The present ceramic armor, if worn properly, probably does not contribute to increase the severity of injury experienced by the aircrewman in a potentially survivable rotary-wing aircraft crash.

2. There have been several cases where the chest armor may well have protected the wearer from more serious injury in a crash situation.

3. There were no known cases of the ceramic armor shattering during crash impact.

4. The few known anterior thigh injuries due to the armor were all of a minor nature. The two reported cases of facial injuries due to contact with chest armor during a crash were also considered minor*.

5. Any unattached (loose) armor becomes a potentially dangerous missile during a crash.

6. The most common serious rotary-wing crash injury seems to be trauma of the spine and coccyx.

7. The "short-form" aircraft accident report, used in RVN, is not ideal for a statistical analysis of the role of aircrew armor in crash injury.

*Subsequent to the conference, a telephone call from one of the participants indicated that one UH-1D pilot lost several teeth in a hard vertical impact due to contact with chest armor. This information was obtained from reviewing 500 questionnaires completed by Vietnam returnees.

## APPENDIX E

## HUMAN TOLERANCE TEST REPORT

## APPENDIX E
## HUMAN TOLERANCE TEST REPORT

Observation and analysis of previous rotary-wing crash experience (both controlled dynamic tests and actual postcrash investigations) indicates that there is a significant vertical force component present in these crashes[6]. The front segment (chest) of the personnel armor would then be expected to exert a significant force on the anterior (front) portion of the upper thighs of any seated crew member during crash situations. To gain some insight into the magnitude of forces which can be comfortably and/or safely endured by humans, the following static-load human tolerance tests were performed.

The testing device is shown in detail in Figure 79. The seat and occupant were raised with a forklift, thus progressively forcing the chest armor, which was attached to the weight as shown in the photograph, into the upper portion of the subject's thighs. A standard seat belt and shoulder harness restraint was used. A calibrated load link was placed between the armor plate and the weight (W). The deflection of the flesh of the anterior upper thigh at the point of contact with the armor plate was measured with the deflection pointer (DP). The test set-up limited the total load applied to the thighs to no more than the value of the weight (W), 755 pounds.

The initial tests were performed with a minus 5-degree seat-back angle which is standard for most military aircraft seating configurations. To simulate the position of the pilot and copilot during crash situations in which there is some longitudinal velocity change, two tests were run with subjects using a plus 25-degree seat-back angle. Arbitrary end points for terminating the test, as progressive pressure was applied, was disappearance of the dorsalis pedis pulse (indicating occlusion of the femoral artery in the area of contact with the bottom of the armor plate); or subjective evidence of discomfort at the point of contact of the armor and the upper thighs.

> The femoral artery (accompanied by the femoral vein and nerve), as it leaves the pelvis and goes into the leg, passes just beneath the point where the armor contacts the thigh of a seated individual. As the femoral artery continues down the leg toward the foot, it branches into several smaller vessels. One of these smaller arteries, the dorsalis pedis, is readily palpable along the top of the

foot and is commonly used as a "pulse." Consequently, if the femoral artery is compressed or blocked at any point in the leg, the dorsalis pedis pulses will disappear. All the test subjects had readily palpable dorsalis pedis pulses prior to the application of the load to the armor, and as the load increased to the point where the bottom of the armor pressed down with sufficient force to occlude the femoral artery, the dorsalis pedis pulse ceased.

Figure 79. Human Tolerance Test Device.

Test subjects were five healthy adult males with general physical size and condition which would meet the standards set for Army Aviators, see Table IV. All five subjects had strong, easily palpable dorsalis pedis pulses at the initiation of each test run.

| TABLE IV | | | | | |
|---|---|---|---|---|---|
| **ANTHROPOMETRY – TEST SUBJECTS** | | | | | |
| SUBJECT | HEIGHT | WEIGHT | WAIST | CHEST | MID THIGH |
| JH | 6-0 | 165 | 30 | 37 | 18 |
| LT | 6-0 | 180 | 38 | 39 | 19 |
| LF | 6-4 | 220 | 37 | 45 | 23 |
| JS | 5-11 | 160 | 33 | 38 | 20 |
| DC | 5-11 | 175 | 34 | 38 | 22 |

All subjects while on the standard-minus-5-degree seat configuration experienced moderate discomfort and complete disappearance of the dorsalis pedis pulse (see Table V) in the 350-400 pound range. In the plus 25-degree seating configuration, subject JS had disappearance of the dorsalis pedis at less than 300 pounds and discomfort was severe at 300. Subject LT was only permitted to reach the pressure reading of 200 pounds because of the intense discomfort which subject JS had noted at levels in excess of this. The subject DC using styrofoam protection pads on the bottom of the armor, Figure 80, was able to tolerate a force of 600 pounds comfortably and without disappearance of the dorsalis pedis pulse. Without the styrofoam pads he tolerated 370 pounds and the dorsalis pedis pulse disappeared at 350 pounds. Two load deflection curves are shown in Figure 81. Occlusion of the femoral arteries (as measured by the disappearance of the dorsalis pedis pulse) seems to be related more to the absolute pressure (total load) than to the size of the upper thigh and/or the amount of deflection. The maximum pressures were universally sustained for three to five seconds.

On the basis of these results, aircrewmen should be able to tolerate a decelerative force generated by this armor (by a vertical crash component) for short periods of time in the 25 to 30 "G" range. With some padding on the bottom of the armor, much greater vertical "G" forces may be sustained with no serious consequences.

| TABLE V | | | | | |
|---|---|---|---|---|---|
| **VERTICAL LOADING TESTS: ARMOR/THIGH** | | | | | |
| SUBJECT | MAXIMUM DEFLECTION Inches | MAXIMUM LOAD Lbs. | MAXIMUM LOAD G* | SEAT BACK ANGLE Deg. | COMMENTS |
| JH | 1-1/8 | 400 | 28 | -5 | Pain<br>Pulse loss |
| LT | 1-1/2<br>N/A** | 400<br>200 | 28<br>24 | -5<br>+25 | Pulse loss at 350#<br>Severe pain, test stopped before pulse loss occurred |
| LF | 1 | 400 | 28 | -5 | Pain<br>Pulse loss |
| JS | 1<br>N/A** | 390<br>300 | 28<br>21 | -5<br>+25 | Pain, pulse loss<br>Severe pain, pulse loss, hematoma |
| DC | 1-7/8 | 370 | 26 | -5 | Pain, pulse loss |
| DC | N/A | 600 | 43 | -5 | STYROFOAM PADS<br>No pulse loss, moderate discomfort, hematoma |

* Based on armor weight of 14 pounds.

** Deflection could not be accurately measured in this test due to the acutely flexed position of the subject.

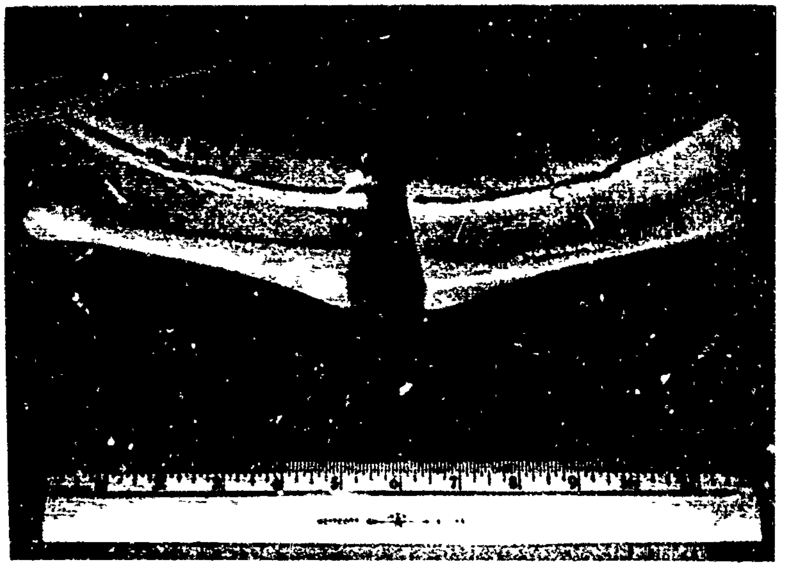


Figure 80. Styrofoan. Padding of Armor.

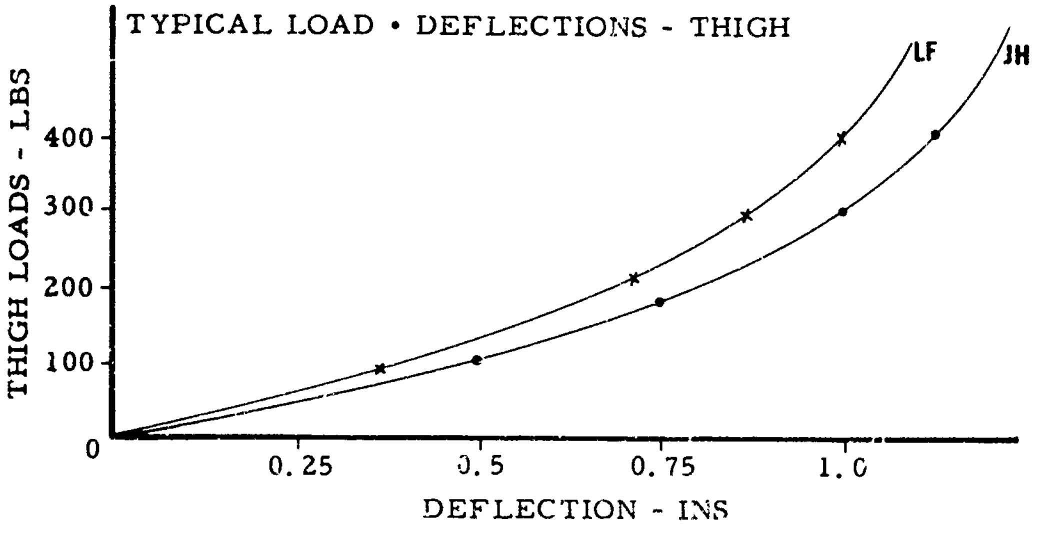



Figure 81. Load Deflection Curves for Minus 5 Degrees Seat-Back Angle.

## APPENDIX F

## INSTRUMENTATION

Data Recording System
Styrofoam Impact Pads

## TABLE VI
## INSTRUMENTATION

| End Items | | | | Test Phase* | | |
|---|---|---|---|---|---|---|
| Instrument | Type or Model | Manufacturer | Location | I | II | III |
| Transducer | 10,000 lb. | AvSER | Vertebrae | X | X | X |
| Accelerometer | A-6-20, -50, -100 | Statham | Dummy Head | X | X | X |
| Accelerometer | A-5-25, -50, -100, -200 | Statham | Dummy Chest | X | X | X |
| | | | Dummy Head | | | X |
| | | | Dummy Cage | X | | |
| | | | Sled | | X | |
| | | | Fuselage | | | X |
| | | | Seat Bucket | X | X | |
| Load Link | 4,000 lb. | AvSER | Shoulder Harness | X | X | X |
| | | | Lap Belt | | X | X |
| Camera | 1B | Photosonics | Drop Cage | X | | |
| | | | Drop Zone | X | | |
| | | | Impact Barrier | | X | |
| | | | Impact Area | | | X |
| Camera | 200V | Traid | Drop Zone | X | | |
| | | | Impact Barrier | | X | |
| | | | Impact Area | | | X |
| Camera | 70KM | Bell & Howell | Impact Area | | | X |
| Camera | H-16-M4 | Bolex | Impact Area | | | X |

*I - Drop Tower Tests, II - Horizontal Accelerator Tests, III - Full-scale Crash Test.

The end instruments listed in the preceding table, exclusive of the cameras, are the input media for the magnetic tape recording system that consists of the following components:

| Item | Manufacturer and Model |
|---|---|
| Tape Transport | Weber 10-110 |
| Electronic Module Housing | Weber 60-117 |
| Voltage Regulator | Weber 43-106 |
| Inverter | Weber 41-111 |
| Bias Oscillator | Weber 30-109 |
| Record Amplifiers | Weber 20-108 |
| Balance and Sensitivity Calibration Equipment | AvSER |
| Timing Signal Generator | AvSER |
| Ni-Cad Batteries | Sonotone |

The signals from the end instruments are fed into the self-contained signal-conditioning circuits and then recorded on 1-inch magnetic tape at 60-inches per second. Each signal is recorded on two tracks for reliability. Timing and correlation are also recorded.

For the drop tower and horizontal accelerator tests, the instrument recording system is bench mounted in a trailer parked by the test facility. The system is "packaged" within a specially constructed housing and mounted on the test vehicle for the crane drop tests (Figure 82).

## Styrofoam Impact Pads

Impact loads produced by contact between the personnel armor and the thighs and chin of the dummy were estimated by using impact pads of styrofoam in the interface. This material was a locally purchased, commercial grade styrofoam intended for use as insulation. Two densities were utilized. The thigh pads were made of 2-inch thick styrofoam having a density of 2.25 pounds per cubic foot, while the chin pad

Figure 82. Instrumentation Recorder Package Installed on Test Vehicle.

material was 1-inch thick and had a density of 1.96 pounds per cubic foot. The crushing strength of these materials was determined by crushing a sample in the Dillon test machine and recording load and deflection data. From these data, force-deflection curves were plotted. These curves are presented as Figures 83 and 84. Within the range of deflections experienced during the tests, the crush strength of both materials was essentially a constant.

In estimating loads from these pads, the limit of the crushed area was traced onto paper and the area thus enclosed was measured with a planimeter. Since the crush strength was essentially constant, the product of the area and the crush strength yields the estimated load. These estimates are believed to be accurate to within ± 20 percent of the load.

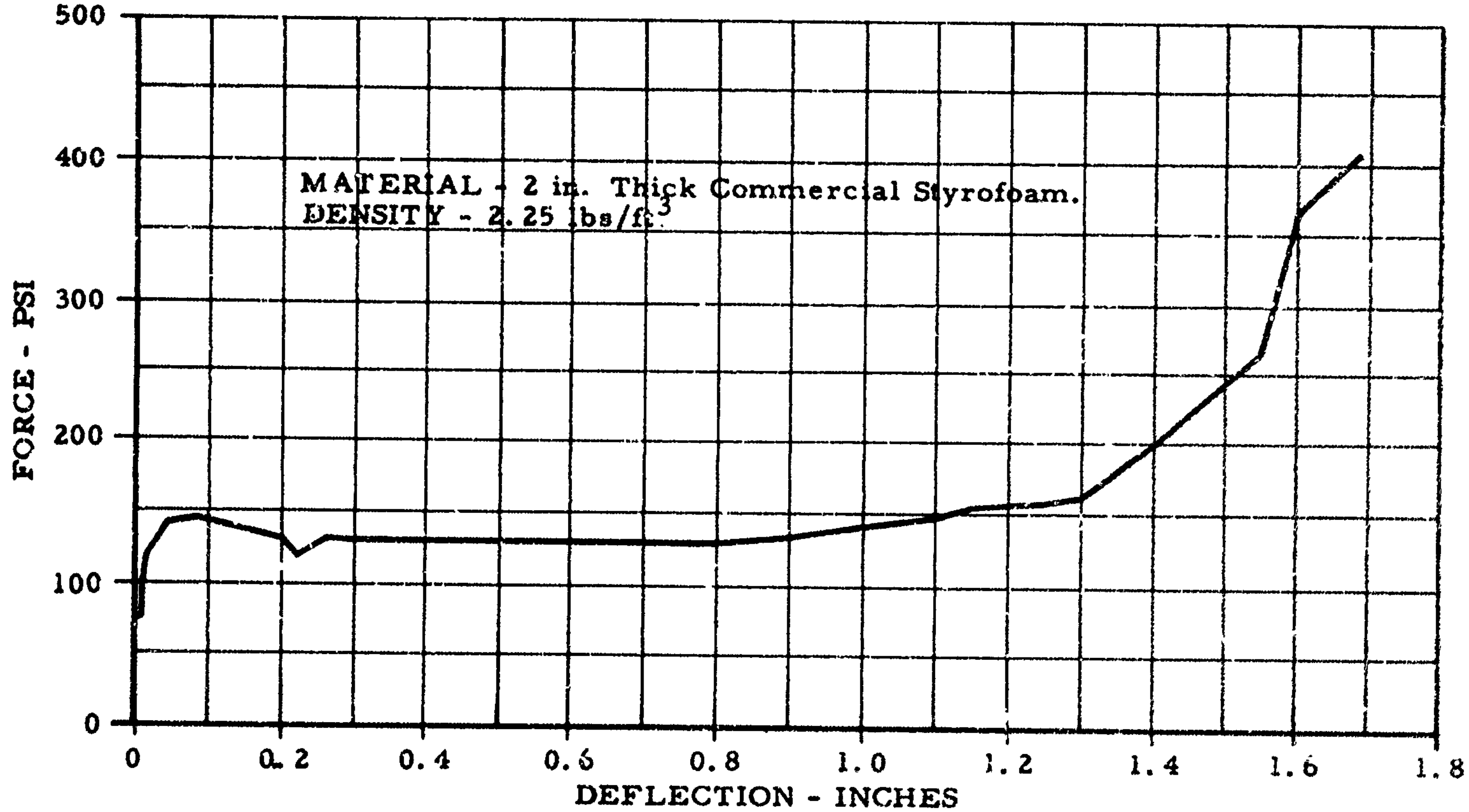



Figure 83. Force Deflection Curve (Thigh Impact Pads).

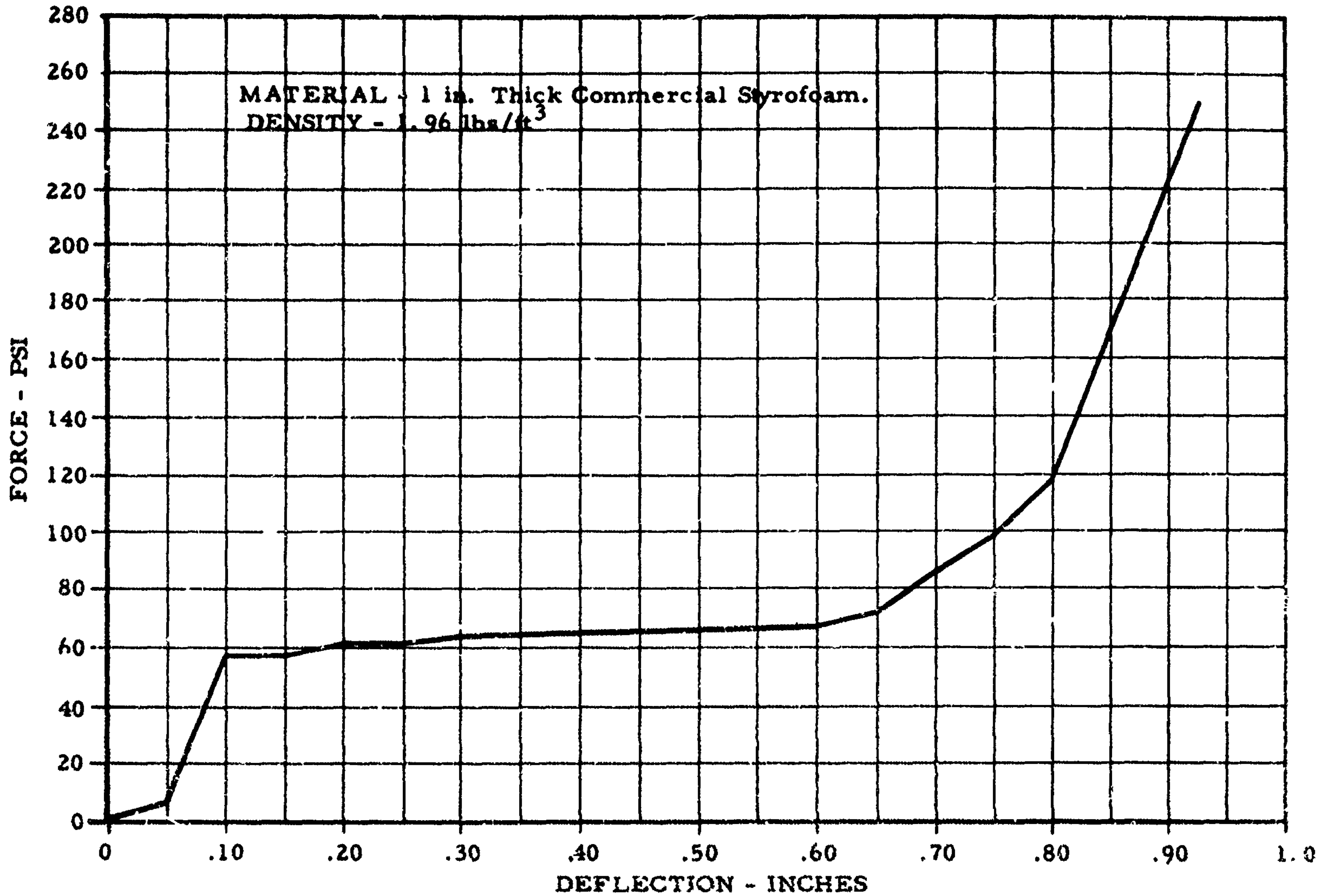



Figure 84. Force - Deflection Curve (Chin Impact Pads).

an impact of the upper edge of the armor with the front of the neck. Such injuries may be fatal. While such impacts occurred only once during the tests, sufficient chin and face impacts did occur (20 times in 30 tests) to indicate a potential for this type of body-armor contact. Simple modifications of existing armor, such as a padded deflector in the neck area would be desirable.

Contact of the lower edge of the armor with the thighs resulted in loads of as much as 800 pounds. Specific modifications to the armor in this area are also recommended, although loads of this magnitude would not produce serious injury.

Some apparent advantages of the armor include resistance to concentrated loads on the front of the lower extremities and in the chest area when the appropriate armor is worn. There is also some indication that submarining of the occupant may be reduced in certain crashes when properly fitted and restrained chest armor is worn.

The practice of wearing a restraint system (lap belt and shoulder harness) loosely to allow the chest armor to be held away from the body and provide relief from thermal stress in hot/or humid climates is not recommended.

Sufficient seat failures occurred to warrant consideration of modifications of the seats.

UNCLASSIFIED
Security Classification

**DOCUMENT CONTROL DATA - R & D**

*(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)*

| | |
|---|---|
| 1. ORIGINATING ACTIVITY (Corporate author)<br>Aviation Safety Engineering and Research<br>Flight Safety Foundation, Inc.<br>Phoenix, Arizona 85027 | 2a. REPORT SECURITY CLASSIFICATION<br>UNCLASSIFIED<br>2b. GROUP |

3. REPORT TITLE
Crashworthiness of Aircrew Protective Armor

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Final Report

5. AUTHOR(S) (First name, middle initial, last name)
Joseph L. Haley, Jr., Clifford I. Gatlin, James L. Schamadan, James W. Turnbow, Edward R. Barron and Stanley Tanenholtz

| 6. REPORT DATE | 7a. TOTAL NO. OF PAGES | 7b. NO. OF REFS |
|---|---|---|
| April 1968 | 118 | 10 |

| | |
|---|---|
| 8a. CONTRACT OR GRANT NO.<br>DAAG17-67-C-0138<br>b. PROJECT NO.<br>1F141812D154<br>c.<br>d. | 9a. ORIGINATOR'S REPORT NUMBER(S)<br><br>9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)<br>68-57-[illegible]; C&[illegible]-47 |

10. DISTRIBUTION STATEMENT
This document has been approved for public release and sale; its distribution is unlimited.

| | |
|---|---|
| 11. SUPPLEMENTARY NOTES | 12. SPONSORING MILITARY ACTIVITY<br>US Army Natick Laboratories<br>Natick, Massachusetts 01760 |

13. ABSTRACT


The results of a test program conducted to determine the physiological effects of personnel armor on aircrew members exposed to an aircraft crash environment are presented. Emphasis has been placed on the effects of armor as worn by air crews in current military operations.

The program was divided into two major tasks. The first included a literature search to obtain design data on human injury simulation techniques, a conference to obtain information from a group of combat-experienced US Army medical helicopter crewmen on the impact behavior of the armor in observed accidents, and modifications to anthropomorphic dummies to effect recordings of mechanical "injuries" to vital body areas. The second task consisted of three types of dynamic tests: vertical drop tower tests, horizontal accelerator, tests, and a full-scale helicopter crash test.

Test results indicated that the potentially dangerous effects of the armor during a crash situation are relatively few. The most serious problem appears to be the possible collapse of the trachea following


DD FORM 1 NOV 65 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

Unclassified
Security Classification

UNCLASSIFIED

Security Classification

| 14. KEY WORDS | LINK A | | LINK B | | LINK C | |
|---|---|---|---|---|---|---|
| | ROLE | WT | ROLE | WT | ROLE | WT |
| Armor, Aircrew<br>Protective Clothing<br>Small Arms Protective<br>Dynamic, Static, Air Crash Tests | | | | | | |

Unclassified

Security Classification