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ARMY COCKPIT DELETHALIZATION PROGRAM (CDP)

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AVIATION APPLIED TECHNOLOGY DIRECTORATE POSITION STATEMENT

This report documents an investigation of occupant restraint concepts designed to provide improved crash protection to U.S. Army helicopter crewmen. Multiple approaches to mitigating injuries to the head and upper torso are presented through improvements to upper body restraint. These concepts are fabricated and tested with the results presented. The contractor's approach to the design and evaluation of these restraint concepts in considered valid and is concurred with. Results of this contract will be considered in the design of protective equipment and in formulating future programs for aircraft occupant crash protection.

Kent F. Smith of the Safety and Survivability Division served as project engineer for this effort.

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13. ABSTRACT (Maximum 200 words) Injury data indicate that secondary cockpit strikes to the head and upper torso account for approximately two-thirds of all major and fatal injuries in potentially survivable Army helicopter mishaps. A two-year program of research, biodynamic simulation, detail design, test and evaluation was performed to examine the head/upper torso strike problem and demonstrate potential olutions. This report describes the investigation and conceptual process leading to the development of ew protection designs, including an advanced harness geometry, a harness tensioner/retractor, and a ness mounted airbag that could be candidates for current as well as year 2000+ helicopter or light craft applications. The protective concepts were evaluated in a series of computer simulations and l[illegible]amic tests on a horizontal accelerator using a replication of an advanced attack helicopter [illegible]terior with a stroking crewseat. Overall effectiveness and physiological compatibility of t[illegible]ve concepts were evaluated under varying crash pulses and impact orientations. Results show signi[illegible]t improvement in reduction of head displacement and linear acceleration, torso displacement, inertia reel strap payout, and neck torque compared to a baseline conventional restraint.

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INTRODUCTION

BACKGROUND

Past aircraft crashworthiness programs have brought significant improvements in crash energy absorption, seat and aircraft high-mass component retention, and post-crash fire prevention. Energy absorbing seating systems, crashworthy fuel cells, and energy attenuating airframe structures and landing gear are just a few examples of improvements that have transitioned into operational use. Although these advancements have proven their effectiveness by reducing crash injuries and fatalities, little attention has been focused on reducing the cockpit environment hazards (i.e., head and upper torso secondary strikes) that have accounted for approximately two-thirds of all major and fatal injuries in potentially survivable Army aviation accidents (Reference 1). In the confines of the cockpit, equipment such as optical displays, gunsights, consoles, flight controls, and the surrounding seat structure are located in close proximity to the aircrew. Under the dynamics of a crash, violent contact between the aircrew and these structures is a distinct threat. Particularly vulnerable areas are the head/neck and upper torso which undergo forward and lateral movement and rotate into equipment. The Army Cockpit Delethalization Program (CDP) explored solutions to the problem of crewmember head/neck and upper torso injury caused by collisions with cockpit equipment (optical displays or gunsights) and structures (consoles, cyclic stick, or seat armor) during survivable crashes.

PROGRAM OBJECTIVES

The purpose of the CDP was to conceive, design and demonstrate effective and cost efficient methods to eliminate or reduce serious injuries from head/neck and upper torso strikes. These designs were to be retrofittable to current operational helicopters as well as applicable to future aircraft. Furthermore, the incorporation of this hardware into the cockpit environment could not degrade the aircrew's comfort and inflight mission effectiveness. To achieve the goal of reducing strike hazards in the cockpit, the following objectives were established:

a. Reduce the forward displacement of the crewmember to prevent head strikes on any cockpit structure. Although it is anticipated that cockpit-mounted target acquisition and sighting systems will be eliminated in future crewstation designs, the CDP objectives included reducing head strikes on existing locations of targeting systems in such rotorcraft as the AH-1 Cobra and AH-64 Apache.

b. Reduce the lateral displacement of the crewmember to prevent head and neck injury due to high G_y accelerations under crash impact conditions.

c. Reduce the secondary injury mechanism effects attributable to rebound impact of the crewmember's head after the initial crash impulse, and the high leg/foot load reactions on the foot rests during seat downward energy attenuating stroke.

PROGRAM APPROACH

The CDP involved four principal task areas - research, analysis, design, and testing - to provide more effective techniques for delethalizing the aircraft cockpit environment during survivable crash impacts. The program examined Army aircraft configurations and included both rotary-wing and fixed-wing cockpit arrangements as well as tandem and side-by-side crew seating configurations. The program was conducted in two phases.

The investigation and development of potential solutions for crewmember crash impact protection involved a thorough survey of advanced attack and utility helicopter cockpit design concepts. Both crewmember flight equipment and crewstation design specialists were surveyed in Phase I. This information on cockpit layouts and crew-mounted equipment defined boundary conditions of a potential year 2000+ crew station and crew equipment ensemble. Candidate cockpit design concepts which help minimize the injury potential during survivable crashes were incorporated into the overall crewstation design.

Mathematical models of the flight equipment and delethalization concepts were used in computer simulations to evaluate the dynamic and physiological effects of the delethalization concepts. Designs of the protective concepts were refined using the computer simulations to determine the optimum design approach and estimate the performance of several candidate protective concepts.

The selected delethalization concepts were translated into hardware designs which were fabricated for dynamic testing. Final protective configurations employed both passive and active delethalizing designs. They were integrated with the current five-point restraint harness mounted on an AH-64 Apache attack helicopter seat. A test platform representing a full scale envelope replication of an advanced attack helicopter forward crewstation was also designed and fabricated. This platform was mounted on a horizontal accelerator for the subsequent dynamic system testing. A total of eight dynamic crash tests were conducted in Phase I. The protective designs were evaluated under various crash conditions and fixture orientations.

In Phase II, the potential for retrofitting existing aircraft with the delethalization system designs was investigated by inspecting AH-1, AH-64, and UH-60 helicopters. A subjective assessment of delethalization system performance effectiveness was obtained from crewmembers of these same aircraft.

Design enhancements were implemented and new equipment was fabricated prior to Phase II testing. Improvement of an automatic strap retractor/tensioner, tested in Phase I, included changes to the mechanical operation, dimensional envelope, and seat interface. Changes in a harness-mounted airbag system developed and tested in Phase I were incorporated regarding the airbag geometry and fabric.

The newly fabricated hardware was subjected to a series of seven dynamic crash tests. Two additional tests were conducted in a baseline configuration for performance comparison. These Phase II tests focused on dynamic inflation/deflation of the automatic airbag and performance of the automatic strap retractor/tensioner and inertia reel (baseline) within the confines of a strike envelope (e.g., optical relay tube and cyclic stick) representative of an Apache crewstation geometry.

PHASE I TASKS

TECHNOLOGY SURVEY (PHASE I)

In order to establish a baseline for cockpit and crew-mounted protection effectiveness, a two-part survey was conducted. The goal was to obtain data representing advanced concepts of both crewstation configurations and crew-mounted equipment which might be useful in minimizing strike hazards in the cockpit. This data would be used both to build computer models and to design hardware for dynamic tests to determine the effectiveness of various protective concepts under crash conditions.

Cockpit Survey

Several cockpit configurations were surveyed for overall seating, console/display, control, and canopy arrangements. Interviews with airframe manufacturers and Department of Defense (DoD) research and development cockpit design agencies were conducted to identify features being considered feasible for year 2000+ tandem attack and side-by-side utility helicopter cockpits. The primary focus of this effort was directed toward equipment whose physical properties provided a potential strike hazard during crash conditions. As a result, details of certain displays and controls were not surveyed. Items of particular interest included hand and foot operated flight controls, main display panels, side consoles and seat mounted structures.

The survey focused on the advanced crewstation technology of the LH (now designated RAH-66 Comanche) attack helicopter with tandem seating and the V-22 utility helicopter with side-by-side seating. However, due to the then ongoing source selection competition that occurred from 1989-1991 (coinciding with this survey effort), no data for the LH were made available by either the competing vendors or the U.S. Army. The survey produced other key data, however, that were useful in the development of an overall representative future attack cockpit configuration.

Data were obtained from the following agencies during the cockpit survey phase of the program:

U.S. Army Aviation and Troop Command (ATCOM) - St. Louis, Missouri
- Accident Prevention Division, System Safety
- Mission Equipment - Advanced Crewstation Design
- Advanced Concepts
- Aeroflightdynamics Directorate (AFDD) - Moffett Field, California

U.S, Army Human Engineering Laboratory (HEL) - Aberdeen, Maryland

Boeing Vertol Helicopter Company - Philadelphia, Pennsylvania

While the generic future attack helicopter mock-up used at AFDD was a human factors engineering research tool, its features, as well as those of the AH-64 Apache attack helicopter, were useful in comparing design relationships with regard to crew-mission compatibility. The survey cross-checked current crewstation layouts (AH-64 displays and controls) with proposed layouts (like the AFDD model) to ensure that crew anthropometric accommodation guidelines of MIL-STD-1333 and MIL-STD-1472 were accurately incorporated. Results of the survey provided significant information regarding attack helicopter cockpit configurations that accurately replicated the design inputs of all LH airframe and cockpit layout designers. The dimensional layout of the crewstation mock-up residing at AFDD was used as the baseline model for the computer simulations. The generic mock-up design was nonproprietary and available for inspection even though it represented technology inputs from most LH design participants.

Using the survey results from all sources, the following configuration details were established for a year 2000+ attack helicopter crewstation layout (see Figure 1):

- Energy attenuating crew seat
- Five-point crew restraint harness
- Cockpit-mounted armor protection (not seat mounted)
- Side-arm flight controls (both sides of seat, including cyclic, collective, anti-torque and other secondary control functions)
- Helmet-mounted target acquisition system to be used in place of Telescopic Sight Unit (TSU) and Optical Relay Tube (ORT) targeting systems
- Foot rests to be used rather than foot pedals (due to fly-by-wire side-arm controls) with anti-entrapment features based upon the US Army Crash Survival Design Guide (Reference 2)
- Toggle switches to be replaced with low profile push buttons

Crew-Mounted Equipment Survey

The principal area of interest for projecting crew-mounted equipment designs to the year 2000+ involved the helmet and helmet-mounted devices/displays (HMD's). Replacement of the cockpit-mounted TSU target acquisition system with a helmet-mounted system eliminated a significant head strike hazard to the crew in survivable crash scenarios. However, the causal factor for injury now changed from the cockpit to the crewmember's own protective helmet. HMDs have long been realized as a source of potential severe head and neck injury due to the reactive crash loads generated by the adverse, off-set center of gravity (CG) effects of current advanced HMD systems.

Several existing and planned HMD configurations for attack and utility rotorcraft were reviewed. These included both target acquisition and night vision systems. Information obtained during visits to ATCOM, as well as other in-house research described below, led to establishment of a generic envelope, weight and CG baseline that would be used in the computer simulation model for the crewmember.

Optimum weight and CG boundaries for an ejection-safe HMD have been studied by the U.S. Navy. These boundaries approximately define a physiological safety of flight threshold that should be considered for any helmet system.

Acceptable HMD mass properties and physiological parameters were quantified by the US Navy under the Interim - Night Integrated Goggle and Head Tracking System (I-NIGHTS) program (see Reference 3). That study addressed a tactical fixed-wing aircraft crewmember ejecting under severe $-G_z$ accelerations. The head/neck dynamic response profile during ejection was judged comparable to a survivable crash impact biodynamic response of a rotorcraft crewmember. Adoption of the Navy parameters was considered reasonable since physiological considerations for safety of flight would be the principal requirement for future HMD systems during normal operations, combat, or emergency scenarios.

Further consideration was given to the overall design configurations of existing HMD's already in service. Optical elements in close proximity to the eye provide extreme hazards to the crewmember under crash impacts. Cockpit strikes involving the helmet HMD's and boom microphones can cause catastrophic eye and facial injuries. It was assumed that future HMD's would be designed not only to meet the weight and CG requirement thresholds but also to provide inherent impact protection by the elimination of intrusive hardware in close proximity to the crewmember's eye. In-the-ear microphone technology was one method surveyed that could eliminate the boom microphone as a facial strike hazard. Special requirements for

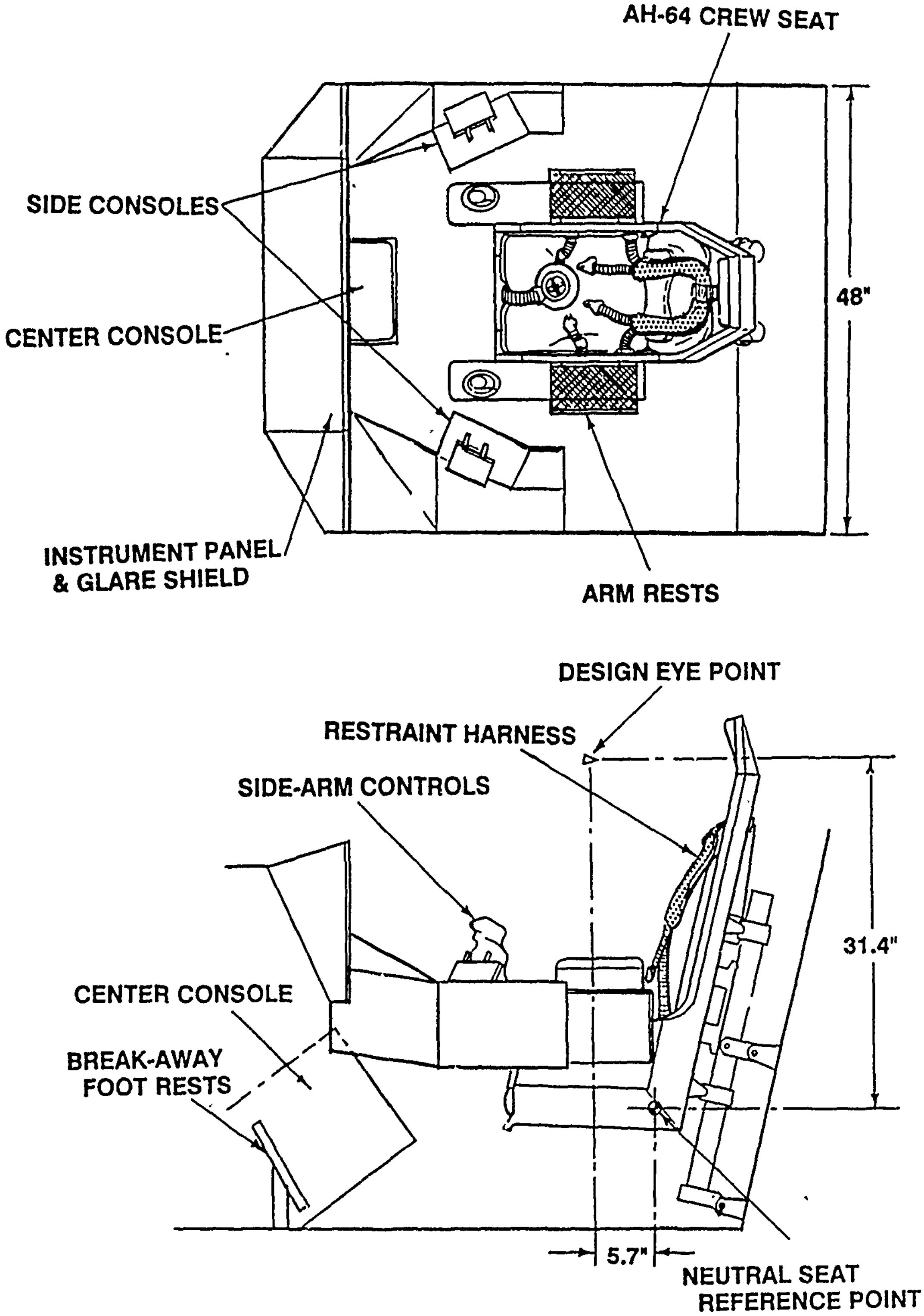


Figure 1. Advanced attack helicopter generic crewstation layout.

Nuclear, Biological, and Chemical (NBC) and laser protection helmet-mounted systems were also considered in the survey. However, for computer modeling purposes, the guidelines for not exceeding the weight and CG envelope evidenced from the Navy study were used.

At the completion of the survey, the mass properties (weight, CG, and principal moments of inertia) of a candidate configuration meeting these criteria were not immediately available. Rather than estimating mass properties somewhere within physiological acceptable boundaries, the concept of a detachable (break-away under crash loads) HMD - as currently employed with the integrated helmet and display sighting system (IHADSS) - was selected for use in the computer simulations. Details and mass properties of the aircrew ensemble and helmet system model are provided in the following section.

MATHEMATICAL MODELING / COMPUTER SIMULATION (PHASE I)

Dynaman simulation software (Copyright - General Engineering and Systems Analysis Corporation, 1989) version 1.0 was used to simulate crash impact scenarios to estimate performance of the delethalization concepts. Dynaman is a personal computer version of the Articulated Total Body (ATB) model with a pre- and post- processor to allow menu-driven interactive user input. The ATB has been validated against dynamic crash tests using both Part 572 and Hybrid III anthropomorphic dummies and against computer simulations using SOM-LA (Reference 4). (See References 5 and 6 for results of these comparisons.)

The ATB was adapted by the Air Force from the Crash Victim Simulator (CVS) model used in vehicle crash impact studies.

Three separate prctective system models were evaluated by computer simulation:

> Baseline - Current five-point restraint harness and stroking seat.
>
> Passive protection - Passive is defined as not requiring crewmember action beyond existing ingress and egress tasks. These devices react to or against the loads imposed by the crewmember, including in this case an improved restraint harness geometry, break-away foot rests, harness retractor/tensioner, and energy absorbing headrest pad.
>
> Active protection - Active is defined as requiring an external stimulus, such as auxiliary power, electronic sensing, signalling or pyrotechnic activation. These devices, in this case the airbag head restraint, apply a load to the crewmember. Computer simulations of the active protective systems also included all of the passive protective systems identified above.

Each protective model was subjected to three different crash loads. The mathematical models which comprised the computer simulations are described below.

Cockpit Model

The cockpit geometry used for the computer simulations represented the forward (copilot/gunner) crewstation of the advanced attack helicopter simulator at the U.S. Army, AFDD, Moffett Field, California. The seat model represented the geometry, energy absorbing characteristics, and five-belt restraint harness of the armored seat used in the AH-64 Apache. The planar surfaces and elliptical segments which comprise the model are listed below. The cockpit geometry is depicted in Figure 2.

> Seat: Bottom cushion, back cushion, head rest, armor
> Arm rests, side-arm controls
> Instrument panel, center display panel (between knees), side consoles

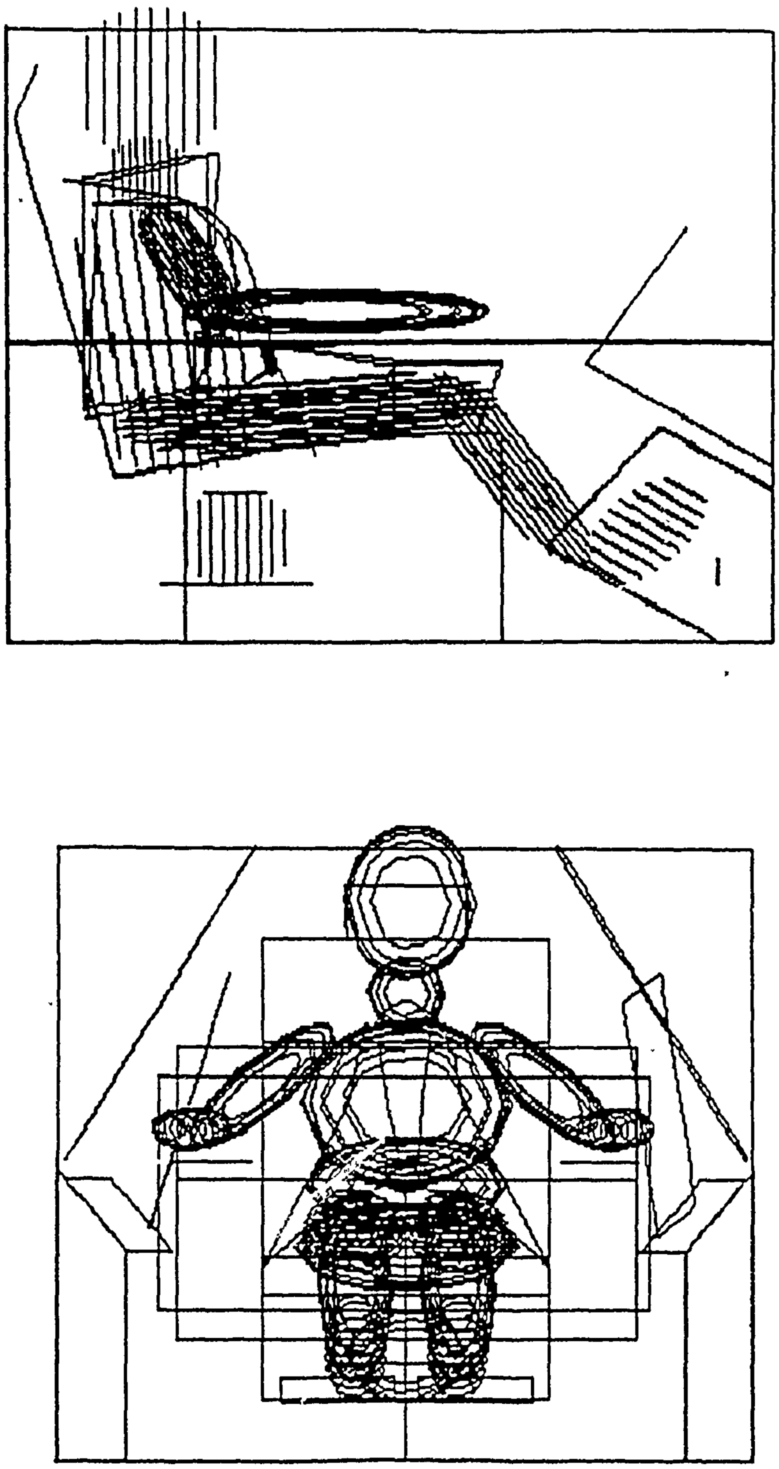


Figure 2. Cockpit geometry used for computer simulations.

Foot rests (anti-torque pedals)
Floor, bulkhead, side wall panels
Side, front and overhead canopy

The dynamic interface between the occupant and elements of the cockpit environment was described in terms of contact functions. Functions which describe the contact dynamics were force deflection (FDF), energy absorption (R-factor), permanent deformation (G-factor), and friction. These functions were defined via fifth degree polynomials, constants, or tabular functions.

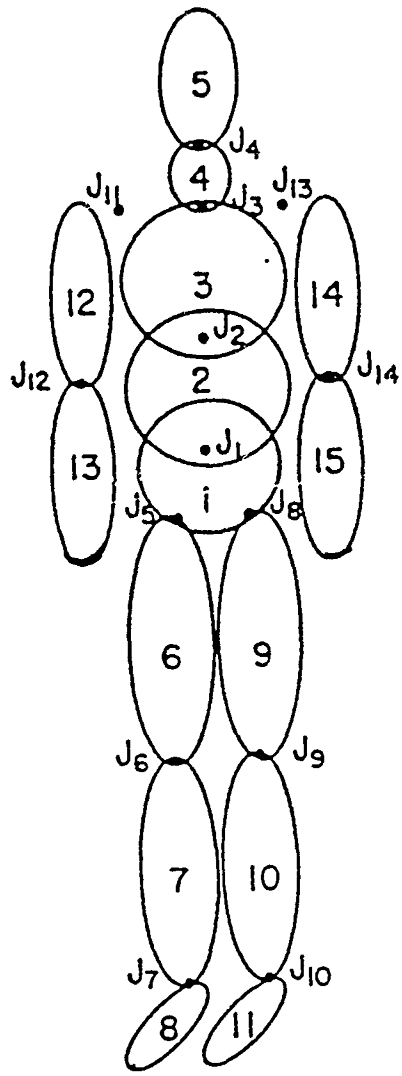
Occupant Model

The occupant was characterized by fifteen ellipsoidal segments. Height and weight were representative of the 95th percentile Army aviator. Body segment dimensions, weight, CG, principal moments of inertia and joint locations were generated using Generator of Body Data (GEBOD) obtained from the Modeling and Analysis Branch of the Armstrong Aerospace Medical Research Laboratory at Wright-Patterson AFB, Ohio (Reference 7). The mass properties and geometry of the occupant head and torso segments were modified to represent the additional size and weight of a helmet, Nuclear, Biological, Chemical (NBC) protective mask and armored survival vest. The occupant head was represented by data for a Hybrid III head, HGU-55/P helmet, and AR-5 mask (Reference 8). Mass properties of the Survival Armor Recovery Vest, Insert, and Packets (SARVIP) were calculated and used to supplement mass properties of the upper, middle, and lower torso body segments (Reference 9).

Joint characteristics represented measurements taken from a 50th percentile Hybrid III anthropomorphic dummy (Reference 10). The joint spring and viscous friction forces of the 50th percentile Hybrid III were increased by 26% to compensate for the increased weight of the 95th percentile aviator. The body segments and connecting joints are listed in Table 1 and are illustrated in Figure 3.

TABLE 1. BODY SEGMENTS AND CONNECTING JOINTS OF SIMULATION OCCUPANT MODEL

SEGMENT			JOINT	
ID	NAME	NUMBER	NAME	ID
lt	Lower Torso	1	Pelvis	p
mt	Middle Torso	2	Waist	w
ut	Upper Torso	3	Neck Pivot	np
n	Neck	4	Head Pivot	hp
h	Head	5	Right Hip	rh
rul	Right Upper Leg	6	Right Knee	rk
rll	Right Lower Leg	7	Right Ankle	ra
rf	Right Foot	8	Left Hip	lh
lul	Left Upper Leg	9	Left Knee	lk
lll	Left Lower Leg	10	Left Ankle	la
lf	Left Foot	11	Right Shoulder	rs
rua	Right Upper Arm	12	Right Elbow	re
rla	Right Lower Arm	13	Left Shoulder	ls
lua	Left Upper Arm	14	Left Elbow	le
lla	Left Lower Arm	15		



JOINT J CONNECTS SEGMENT N (J) WITH SEGMENT J + 1

J	=	1	2	3	4	5	6	7	8	9	10	11	12	13	14
N(J)	=	1	2	3	4	1	6	7	1	9	10	3	12	3	14

Figure 3. Occupant model segment and joint number scheme.

Vehicle Motion

Three different crash pulses were defined. Type I motion represented a vertical drop in a 15° nose-down attitude. Type II motion represented a vertical drop in a 15° roll-right and 15° nose-down attitude. For these two vertical drops, the 50 msec triangular deceleration profile peaked at 41.5 G's with a resulting change in vehicle velocity of approximately 30 ft/sec. Type III motion represented a horizontal crash in a 30° yaw-left attitude. The 95 msec triangular deceleration profile peaked at 32.9 G's with a resulting change in velocity of approximately 50 ft/sec.

Passive Delethalization Models

Two delethalization concepts were modeled for the passive simulations: an automatic G-sensing shoulder strap retractor/tensioner and an advanced crew restraint harness. The automatic strap retractor/tensioner was modeled in the simulation input file by reducing the shoulder harness belt slack from 3 to 0 inches. The 3 inches of slack used in the baseline simulation input file represented a nominal amount of packing down of webbing around the locked inertia reel. The advanced harness was modeled by adding two straps to the baseline five-point harness system. Each strap was attached at one end to either the left or right lap belt anchor point. Note: The computer restraint harness model does not allow one harness strap to slide through another, as would be necessary to replicate the mechanics of the Trans-Torsal Restraint Harness (TTRH) described later in this report. However, the restraint load paths illustrated in Figure 4 for the advanced crew restraint harness are accurately represented by the computer model described above.

Figure 4 illustrates a comparison of the restraint load paths of the baseline five-point restraint harness and the advanced crew restraint harness.

Active Delethalization Models

One additional delethalization concept, an inflatable bladder head restraint, was modeled for the active simulations. The bladder was modeled using two ellipsoidal segments attached to the upper torso. The anticipated inflation time of a production airbag system is 30 msec, which is less than the time between crash initiation and head contact with the bladder. Hence, the fact that the two segments are "pre-inflated" still accurately represents the state of the airbag at the moment of head first contact.

Results of Computer Simulations

The three protective system models (baseline, passive, and passive & active) were each subjected to the three (vertical pitch, vertical pitch and roll, and horizontal yaw) simulated crash pulses for a total of nine computer simulated tests. Results of these simulations are provided below.

Comparison of baseline versus passive simulation results indicated improvement in key measures of effectiveness for the passive delethalization designs. Most significant was the reduction in strike envelope of both the head and arms. Forward head displacement decreased an average of 1.1 inches (19%) for the passive simulation as shown in Figure 5. Arm strike against the instrument panel, which occurred during the baseline type III horizontal crash simulation, was eliminated in the passive simulations (see Figure 6).

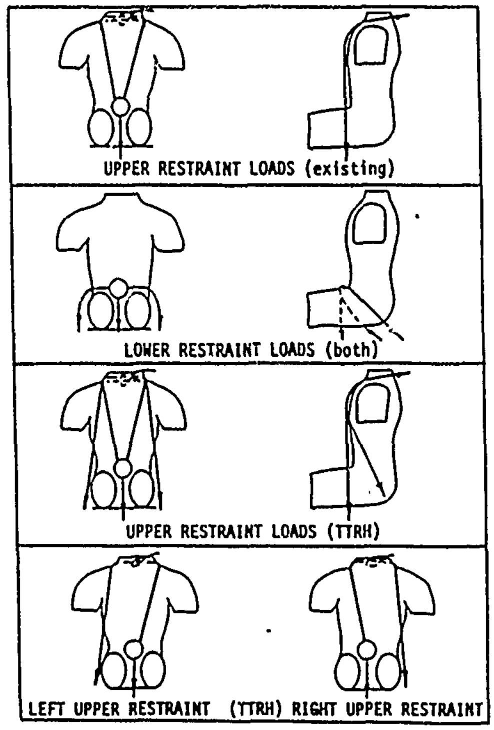


Figure 4. Restraint harness geometry and load paths used for computer simulation baseline (existing) models.

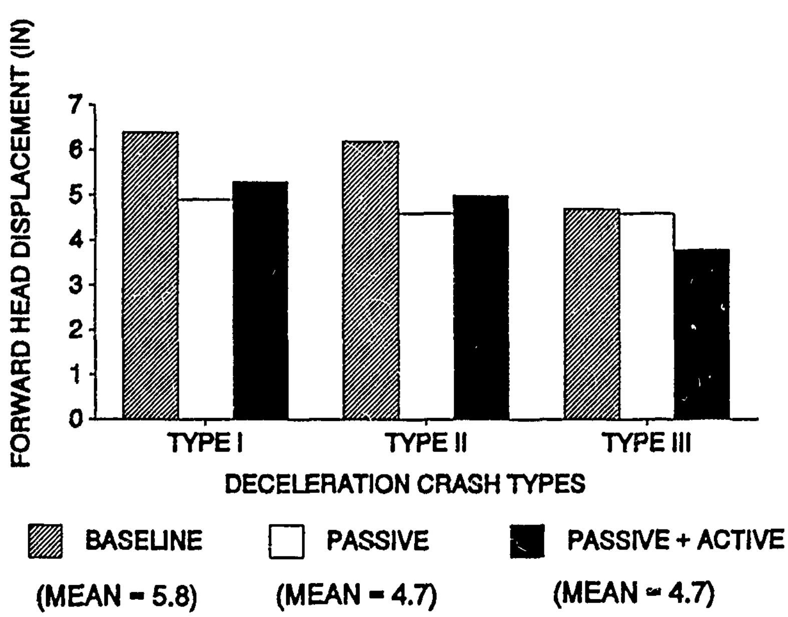
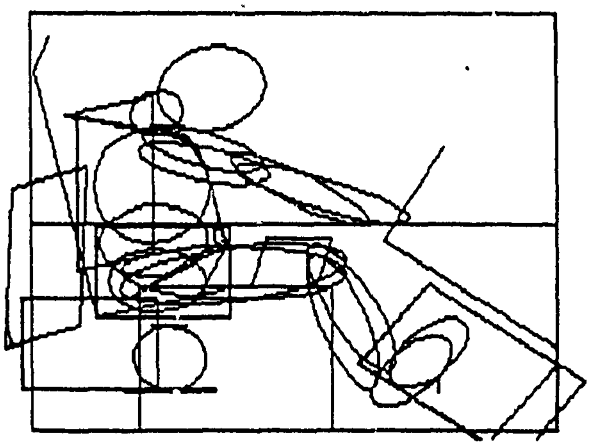


Figure 5. Maximum forward head displacement measured during computer simulations.

BASELINE TYPE III



PASSIVE TYPE III

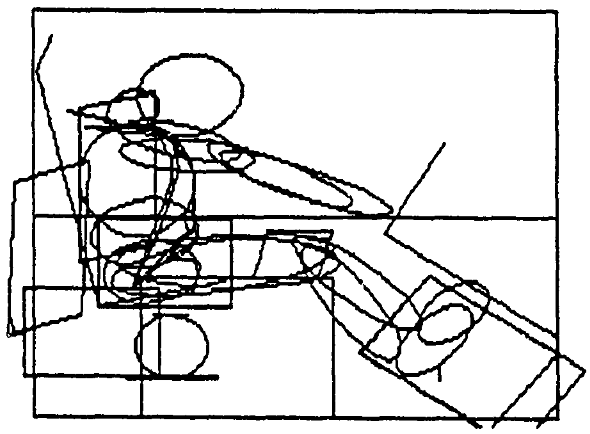


Figure 6. Maximum forward arm extension for baseline and passive designs during horizontal, 30° yaw crash simulations.

This reduction in strike envelope using the passive protection model was achieved at the expense of higher predicted head injury criteria (HIC) and Gadd severity index (GSI) values. The HIC values more than doubled in magnitude (see Figure 7). The tighter restraint used to reduce torso motion also caused the head to stop in a shorter lateral distance, although the change in velocity remained the same. The subsequent higher accelerations were reflected in higher HIC and GSI values. These HIC and GSI were still well within the safe bounds of human tolerance, although the validity of using these absolute criteria for data obtained using computer models of anthropomorphic mannequins is questionable (see Appendix A).

Subsequent simulations with passive & active systems showed similar reductions in head forward displacement as shown in Figure 5. Head angular deflection (forward rotation) was also reduced by an average of more than 10 degrees (10%) (see Figure 8). This was the most significant benefit of the airbag and indicated a potential to reduce neck injury. As with the passive simulations, the HIC values remained higher for the passive & active simulations than for the baseline simulations (see Figure 7).

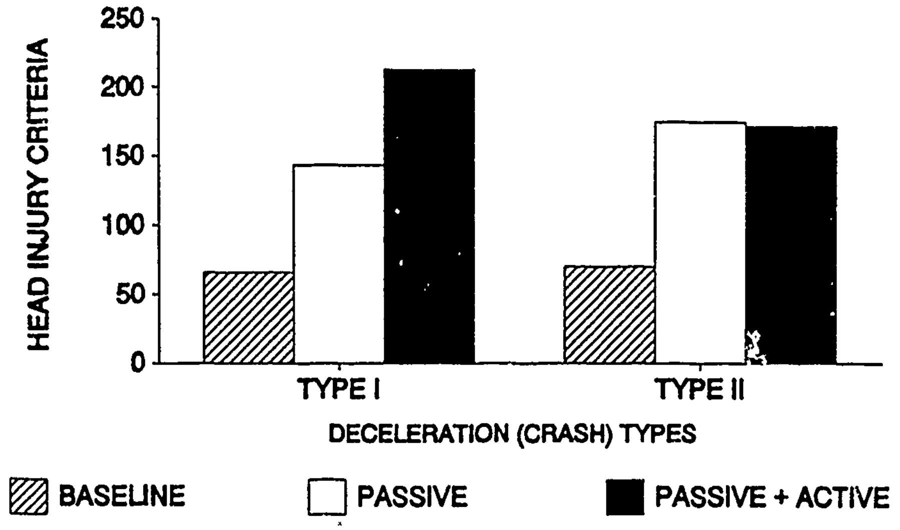


Figure 7. Head injury criteria (HIC) scores for types I and II computer simulations.

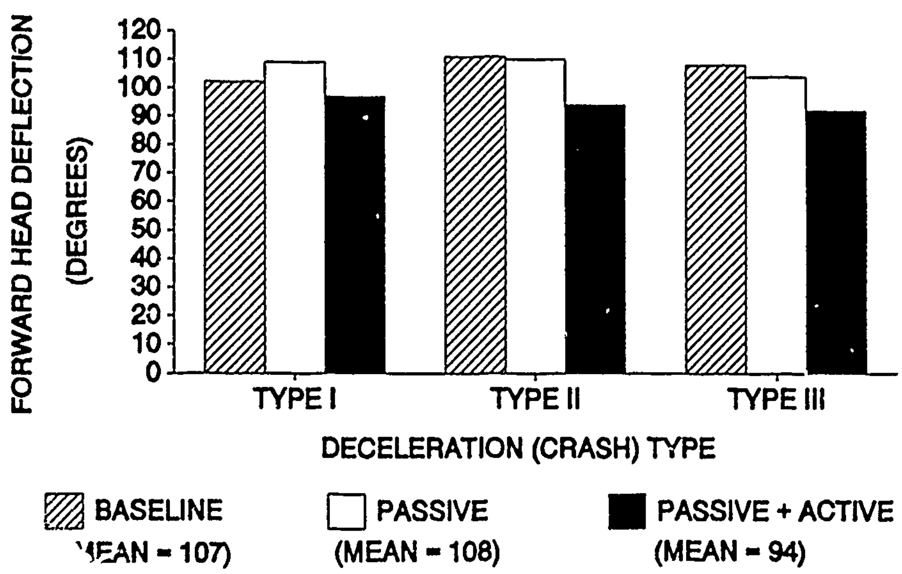


Figure 8. Head angular deflection measured during computer simulations.

HARDWARE DESIGN AND FABRICATION (PHASE I)

As a result of the computer simulations and trade study effort, a test configuration was proposed at the CDP Critical Design Review (CDR). A passive and active delethalization system in conjunction with an energy attenuating (stroking) crew seat was offered as an integrated system for detailed design, fabrication and testing. The approved Crewstation Protective System (CPS) was comprised of three main subsystems:

- o Automatic Strap Retractor and Tensioner (Passive system)
- o Trans-Torsal Restraint Harness (Passive system)
- o Harness Airbag (Active system)

The CPS elements are described in the following sections. Based on the information collected during the technology survey, design of the cockpit test fixture is also presented.

Automatic Strap Retractor/Tensioner (ASRT)

The ASRT is a passive mechanical device which pretensions the inertia reel strap at the onset of a crash impact. It is actuated by either G_x or G_z crash accelerations. The device removes up to 6 inches of slack from the restraint harness straps, thereby reducing forward and lateral motion of the crewmember's torso.

The ASRT (Figure 9) consists of a mechanical G-sensing release mechanism, a retractor, and a locking tensioner. The assembly is housed in a mounting frame which is attached to the seat back using extended mounting bolts on the inertia reel assembly. This mounting does not require modification of the existing Apache seat assembly.

The tensioner assembly of the ASRT acts as a redundant strap locking mechanism in case the inertia reel fails to lock under crash loads. It also is designed to prevent excess strap pay-out from the inertia reel that can result from strap pack down on the reel take-up roller.

The ASRT is activated when crash accelerations release spring tension on the piston which retracts the inertia reel strap. Motion of the strap releases the two wedges which lock the strap in position and prevent additional payout.

The ASRT may be safetied by inserting a standard ball-lock pin through two holes in the cylinder, just above the piston. If the device has been actuated, the safety pin cannot be inserted, the piston will be visible at the top of the cylinder, and the strap will not extend. A release handle has been designed to allow in-flight recycling of the ASRT by the crewmember in the event of an inadvertent actuation.

Trans-Torsal Restraint Harness (TTRH) Assembly

Design goals for development of the seat-mounted crewmember restraint system included reduction of forward and lateral upper torso displacement and the ability to retrofit into existing helicopter and fixed-wing seating configurations without requiring modifications to aircraft hardware.

The five-point restraint harness currently employed on the AH-64 Apache seat (supplied as GFE) was selected as a baseline configuration. The existing lap belts, center crotch strap, and quick release buckle assembly were not modified. The TTRH assembly elements were integrated into the five-point restraint geometry by replacing the existing shoulder restraint elements with a pair of transverse shoulder straps.

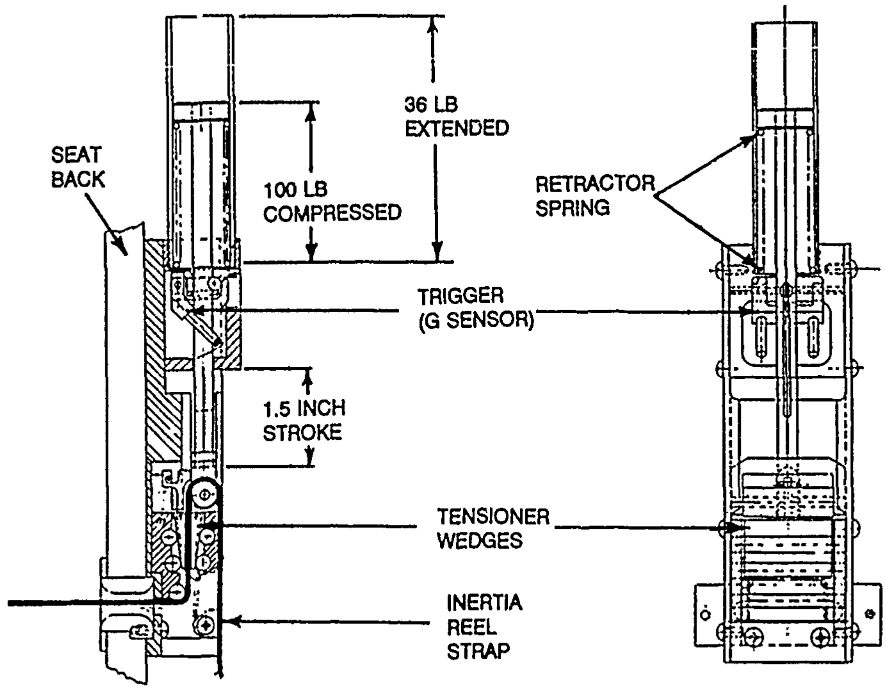


Figure 9. Automatic strap retractor/tensioner (ASRT) device.

The TTRH consists of an inertia reel strap with a collar assembly, through which pass the left and right harness straps. Each strap has an adjuster, an anchor attachment, and a quick release lug (see Figure 10). The left harness strap is affixed by the anchor attachment to an existing left lap belt attachment point on the seat. From the anchor attachment, a fixed strap section connects to the adjuster and an adjustable strap proceeds up the left side of the torso where it enters the collar assembly on the inertia reel strap. The collar assembly is a sleeve which guides the strap over the left shoulder, behind the neck, and over the right shoulder. The strap terminates at the quick release lug. The right harness strap is a mirror image of the left harness strap.

The harness straps are fabricated from latex-coated, low-elongation webbing. The collar assembly is fabricated from nylon webbing and velcro. The existing inertia reel strap is reinforced with additional nylon webbing. The adjusters, anchor attachments, and quick release lugs are all standard aeronautical hardware selected for compatibility with existing equipment.

The harness assembly collar connects directly to the inertia reel straps at the nape of the neck. The collar guides the two harness straps around the crewmember's shoulders, ensuring proper positioning of the harness. Since there is no hard attachment between straps and collar, the straps are free to slide when the crewmember turns from side to side, offering mobility in the cockpit yet firmly anchoring the torso to the seat. The straps end in quick release lugs which mate with an existing single-point release at the crewmember's waist. The collar also allows the straps to slide through for quick adjustment. Velcro affixed to the top of the collar assembly provides a mounting point for the stowed harness airbag system. The two harness adjusters allow accommodation of 1st through 99th percentile male crewmembers.

When combined with the existing AH-64 seat lap belt, lap tie-down strap and quick release buckle, the complete subsystem is formed.

Advantages of the TTRH configuration are:

- Reduced forward and lateral torso displacement due to transverse orientation of harness straps.
- Reduced arm flail excursion under crash loads due to torso strap orientation.
- No substantial degradation of mobility in comparison to existing AH-64 harness performance.
- No change in quick release emergency egress operation of buckle compared with AH-64. However, with TTRH, crewmember must doff in a motion similar to moving arms and shoulders out of 'pants suspenders'.

Static (under no dynamic load) bench test comparisons between the TTRH subsystem and the baseline AH-64 restraint harness demonstrated a reduction of forward and lateral torso displacements of approximately 50% when using the TTRH.

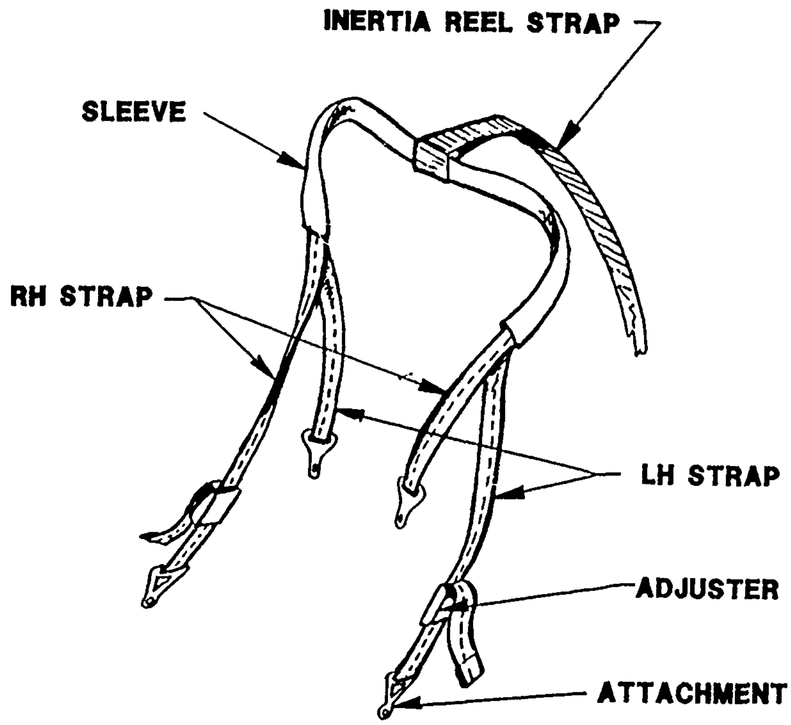


Figure 10. Trans-torsal restraint harness (TTRH) assembly.

Harness Airbag Subsystem (HAS)

The HAS is an inflatable device which attaches to the shoulder straps of the TTRH assembly. The inflated device reduces the hazard envelope by restraining the head and neck from uncontrolled forward motion. Compared to existing restraint systems, the HAS is designed to protect the crewmember from serious or fatal injury by preventing the head from whiplash and from striking items in the cockpit. Since the airbag completely encircles the neck, both forward and lateral head displacement is reduced.

The HAS consists of a sleeve assembly in which is stowed an airbag assembly. The sleeve assembly fits over the TTRH like a long collar. The airbag has a single "T" fitting at the nape of the neck to ensure symmetrical inflation from a single pressurization system. An operational airbag would not require any fitting since an integral cool gas generator would be used as the inflation source.

In normal flight, the collar and airbag are nonintrusive. They remain flat on the chest, shoulders, and behind the neck of the crewmember since they are attached to the TTRH. The airbag is designed to be pressurized to as much as 8 pounds per square inch, which is sufficient to retard head deflection.

In concept, G-sensors on the aircraft would provide the signal for airbag inflation upon impact. Airbag inflation would force open the hook-and-pile fasteners of the sleeve. Full inflation would occur in 0.03 second (see Figure 11).

Crash sensors and inflation sources were not employed during Phase I of the technology demonstration. However, the technical maturity of many such devices is known and judged to be compatible with the HAS design.

Figure 11. Harness airbag system (HAS).

DYNAMIC TESTS (PHASE I)

Test Methods

A total of eight tests were performed during Phase I at the Horizontal Accelerator Facility at the Naval Air Warfare Center in Warminster, Pennsylvania. The test hardware consisted of the following items:

Hybrid III anthropomorphic dummy - A 95th percentile Hybrid III dummy was used. The biodynamic response of the dummy closely resembles that of a human. The instrumentation package contained in the dummy measures accelerations, forces, and torques on the various body segments and joints. The dummy was outfitted in the basic summer aircrew flight ensemble, consisting of coverall, survival vest, gloves, boots and helmet. The estimated weight of the clothed 95th percentile dummy was 250 pounds.

AH-64 Apache crashworthy seat - The Apache seat utilizes energy absorbing elements in the vertical direction to reduce the severity of crash load impacts borne by the seat occupant. The energy absorbing elements were replaced after each test. Seat weight, with the armor removed, was estimated at 150 pounds.

Cockpit test fixture - The cockpit test fixture design was the product of the cockpit survey described previously in this report. It included crash protection enhancements to reduce the injury potential to the aircrewmember and to eliminate strike hazards seen in current helicopter cockpits. The test fixture frame was reinforced to withstand repeated dynamic testing and was provided with adapters to mate with the horizontal accelerator sled in the various test orientations. The estimated weight of the test fixture is 500 pounds.

Delethalization devices - The delethalization devices which were subjected to evaluation during the Phase I tests were the Trans-Torsal Restraint Harness (TTRH), the Automatic Strap Retractor/Tensioner (ASRT), and the Harness Airbag System (HAS). In addition, the test fixture contained breakaway foot rests, an energy absorbing head rest pad, and breakaway side-arm control grips.

Three different test configurations were used. Tests one, three and five used passive delethalization systems, including the TTRH in combination with the ASRT. Tests two, four, six and eight used both passive and active delethalization systems, including the HAS, in addition to the passive systems previously listed. Test seven used the baseline restraint system, consisting of the fielded AH-64 five-point restraint harness.

Three different cockpit orientations were used. Tests one through four used combined vertical orientations: tests one and two at 30° pitch down and tests three and four at 30° pitch down and 10° roll left. Tests five through eight were performed in a combined horizontal orientation of 30° yaw right. Figure 12 shows a typical pretest configuration.

The history of the two seats supplied by the Army and used during the testing was unknown. They had previously been used for other testing, as evidenced by some degree of damage on the seats prior to testing. Therefore, the pulses specified in MIL-S-58095 were modified to protect the seats from catastrophic failure. Appropriate crash accelerations (limited by a 12.6 inch limit on seat stroke) were calculated based on the total kinetic energy of the system, the total mass on the seat, and the vector of the applied force.

Five half-sinusoidal simulated crash pulses were used. Seat stroke distance during tests 1 and 2 was less than anticipated due to frictional binding on the seat rails. To increase the stroke length, the G-level was increased from 28.0G in Test 1 to 33.7G in Test 2, and again to 35.0G in Tests 3 and 4. These test pulse modifications preclude direct comparison of Tests 1 and 2 with Tests 3 and 4. Pulses for horizontal Tests 5 through 7 were at 24.0G and at 28.0G for Test 8. These simulated crash pulses, along with delethalization system configurations and crash orientations, are shown in Table 2.

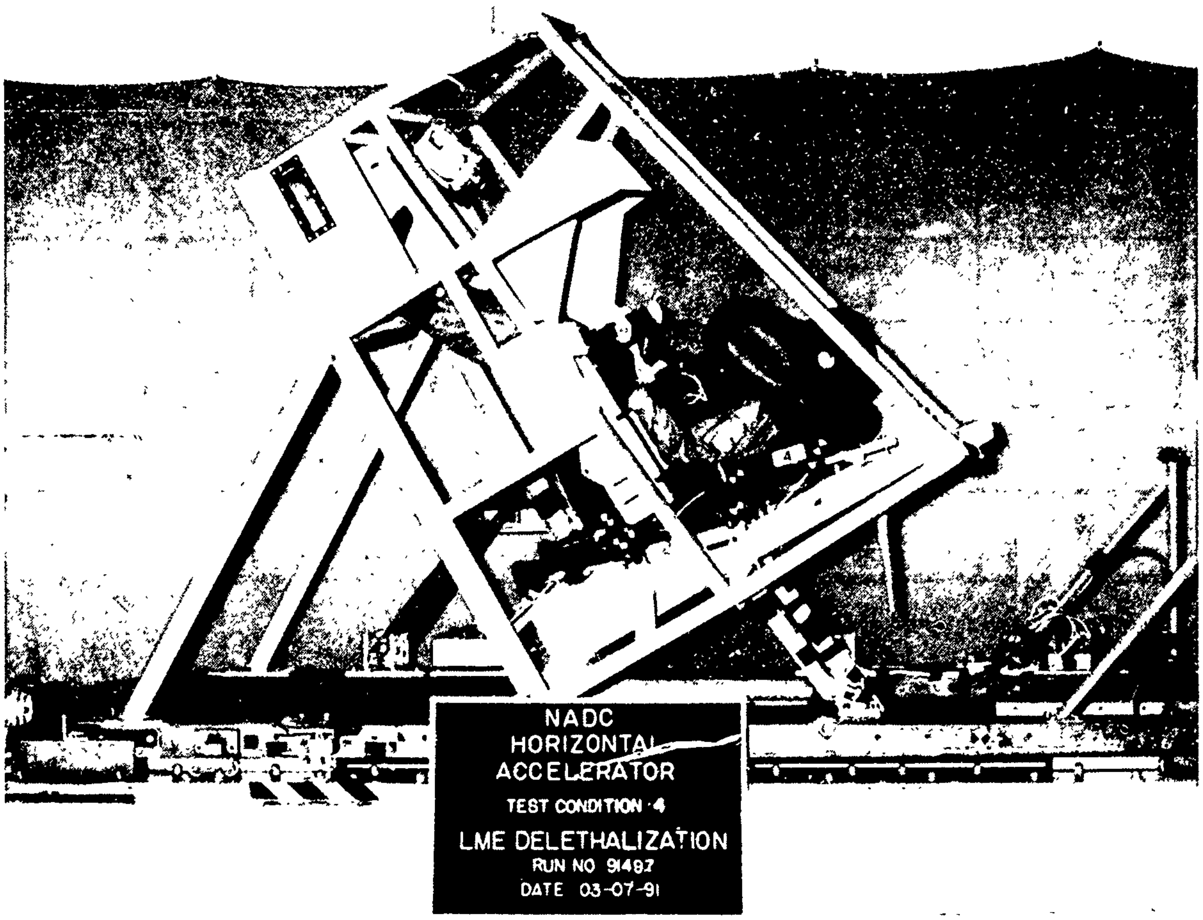


Figure 12. Horizontal accelerator pretest setup, 30° pitch down, 10° roll left.

TABLE 2. PHASE I TEST MATRIX

TEST	ORIENTATION	RESTRAINTS	PULSE
1	Vertical 30° Pitch Down	Passive Only	28.0G, 26.8 fps
2	Vertical 30° Pitch Down	Passive & Active	33.7G, 31.1 fps
3	Vertical 30° Pitch Down, 10° Roll Left	Passive Only	34.5G, 37.2 fps
4	Vertical 30° Pitch Down, 10° Roll Left	Passive & Active	34.9G, 37.3 fps
5	Horizontal 30° Yaw Right	Passive Only	24.3G, 39.6 fps
6	Horizontal 30° Yaw Right	Passive & Active	23.2G, 39.1 fps
7	Horizontal 30° Yaw Right	Standard AH-64	23.3G, 39.5 fps
8	Horizontal 30° Yaw Right	Passive & Active	27.7G, 40.8 fps

The following conditions were verified prior to each Phase I test:

- New energy absorbers were installed on the seat for each vertical test (numbers one through four only).

- The 95th percentile Hybrid III anthropomorphic dummy was installed in the seat. It was positioned by applying force to the shoulders to ensure that the buttocks were in firm contact with the seat bottom cushion. The dummy sitting height, being greater than that of a 95th percentile Army aviator, resulted in its helmet extending several (more than 6) inches above the top of the seat and headrest.

- The inertia reel was locked to prevent inadvertent strap payout. Inertia reel performance was not the subject of these tests.

- The seat was adjusted to the full-up position. This enabled use of the full stroking distance of the seat and ensured the seat would not bottom out.

- The harness airbag system was pre-inflated. A dynamic inflation device was not available for the Phase I tests. Inflation pressures are reported in the section entitled "Analysis of Test Results (Phase I)."

- The tensioner wedges were set in the closed position to demonstrate a level of performance that could be expected from a production-ready component.

Data Collection

The 95th percentile Hybrid III anthropomorphic dummy was restrained in the seat. Dummy instrumentation included head linear and angular accelerations, neck loading torque, and neck linear force. Additional instrumentation on the test sled included tensioner reaction time and seat acceleration (stroke axis). A list of instrumented and measured parameters collected during the tests is shown below.

Parameter	Direction/Location
Sled Linear Acceleration	Sled Stroke Axis
Seat Deflection	Seat Stroke Axis
Seat Linear Acceleration	Seat Stroke Axis
Head Angular Acceleration	X, Y, Z axes
Head Linear Acceleration	X, Y, Z axes
Neck Force	Z axis
Neck Torque	X, Y axes
Restraint Harness Tension	Outer shoulder straps (left and right) Inner shoulder straps (left and right)
Harness Retractor Activation Time	Piston

Photographic coverage consisted of three 400 fps motion picture cameras and three video cameras (two at 200 fps and one at 1000 fps). The cameras were mounted both on- and off-sled to provide front, rear, side and quarter angle views.

Seat stroke distance and inertia reel strap payout were also measured following each test.

ANALYSIS OF TEST RESULTS (PHASE I)

General

The simulated crash pulses used during the dynamic tests were different from those planned due to compensation for unanticipated seat stroking characteristics. Measured seat stroke on test 1 was approximately 3.5 inches, much less than the expected 8.0 inches. Initial calculations to predict seat stroke distance failed to account for the binding friction between the seat self-aligning rings and guide rails, and the absence of SARVIP body armor mass on the dummy. Test sled accelerations were increased on test 2 and again on test 3 until the desired seat stroke was attained (see Table 3). Initial pulse estimates were intentionally conservative to ensure that seat stroke limits would not be exceeded.

The seat used during the initial tests failed structurally during the sixth test and was replaced for the seventh and eighth tests. The second seat also failed structurally during the eighth test.

Reaction time of the ASRT spring-loaded retractor was measured using an electrical trip loop. The retractor fired in less than 30 msec on all tests except test 6 when there was not sufficient plunger stroke to open the trip wire connection. The inertia reel strap position was measured before and after each test to determine the payout distance of the strap. This was used to determine the effectiveness of the tensioner locking device. The tensioner locking device limited strap payout to 1/4 inch on all tests. On test 7, which did not use the ASRT, strap payout was measured using a string potentiometer. Even though the inertia reel was locked for this test, the strap payed out 5 inches (see Table 3).

Airbag pressure was measured prior to each test. Pressures are listed in Table 3.

TABLE 3. GENERAL TEST RESULTS, PHASE I

TEST NUMBER	VELOCITY (ft/sec)	SLED ACCELERATION (G's)	SEAT STROKE (In)	RETRACTOR REACTION TIME (msec)	TENSIONER STRAP PAYOUT (In)	AIRBAG PRESSURE (PSI)
1	26.8	28.0	3.5	≤30	0.25	N/A
2	31.1	33.7	6.0	≤30	0.25	2
3	37.2	34.5	8.0	≤30	0.25	N/A
4	37.3	34.9	8.5	≤30	0.25	2
5	39.6	24.3	N/A	≤30	0.25	N/A
6	39.1	23.2	N/A	See Note 1	0.25	4
7	39.5	23.3	N/A	N/A	5.00	N/A
8	40.8	27.7	N/A	≤30	0.25	3.5

NOTE 1. No reaction time was measured due to insufficient plunger stroke.

Head Linear Acceleration

Head linear accelerations were used to calculate GSI and HIC values for brain injury. Although these criteria were originally derived from laboratory studies in which skull fractures were produced by impacting the forehead against a "plane and unyielding surface", their use has been expanded to many other situations and empirically related to a variety of impact injuries.

None of the calculated GSI values reached a level where any kind of head injury would be expected. The same is also true for calculated HIC values. Not only were the magnitudes of these values below the concussive level of 1500 for non-contact blows (Reference 11), they were also below the injurious level of 1000 resulting from a direct blow to the head (Reference 12).

Figure 13 shows maximum values for GSI and HIC. The highest values for both GSI and HIC occurred in test 7, when the standard harness, as used in the Apache helicopter, restrained the dummy. It appears that the inflated airbag had no effect on the GSI and HIC values obtained in the vertical tests, while it decreased GSI by 27% and HIC by 41% for the horizontal tests.

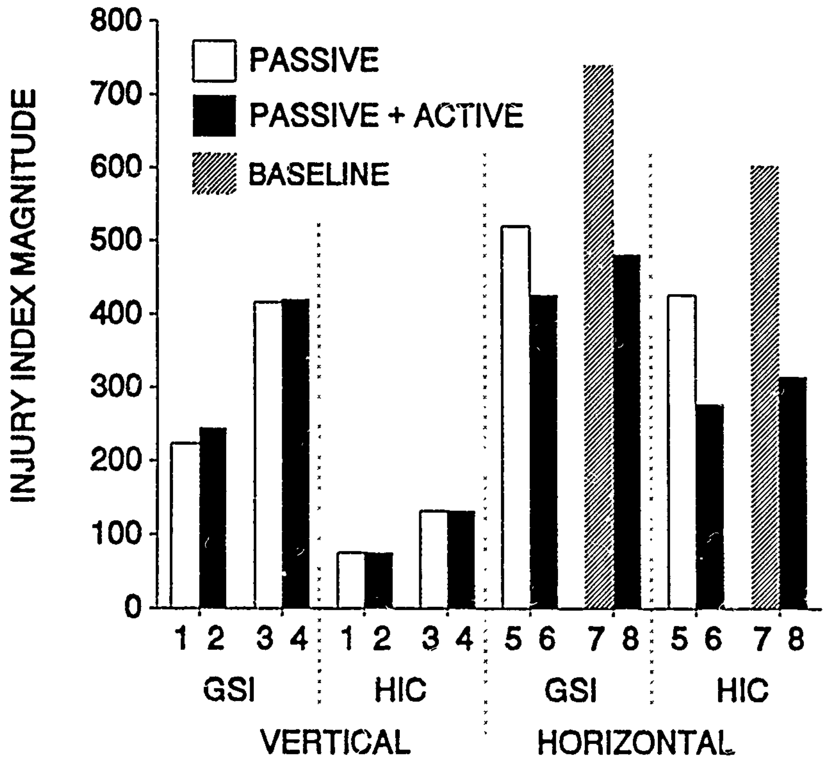


Figure 13. Head injury criteria (HIC) and Gadd (head) severity index (GSI) values.

Head Displacement

Head forward displacement was measured, as illustrated in Figure 14, from the high-speed film recordings of each test. [Note: The absolute magnitude of head displacement may be somewhat exaggerated due to slippage of the helmet on the mannequin head and seat back deflection, as this was clearly noticeable on the test film and video recordings. However, comparisons based on these magnitudes are unaffected by the slippage since it occurred in all test configurations.] Overall head displacement decreased 37% to an average of 14.2 inches for the passive only and 47% to an average of 12 inches for the passive & active configurations, respectively, from a maximum of 22.5 inches for the baseline configuration as can be seen in Figure 15. The reduction in body forward/lateral displacement afforded by the TTRH (passive only configuration) was accompanied by a 1.1 inch (15%) average increase in head displacement relative to the torso centerline (see Figure 16). A 2.75 inch (40%) average reduction in relative head displacement was achieved with the airbag (passive/active configuration). Maximum reduction of body displacements during a crash situation is obviously the goal sought in providing restraints, since injury results from impacting surrounding structures, as well as from relative movements between body parts.

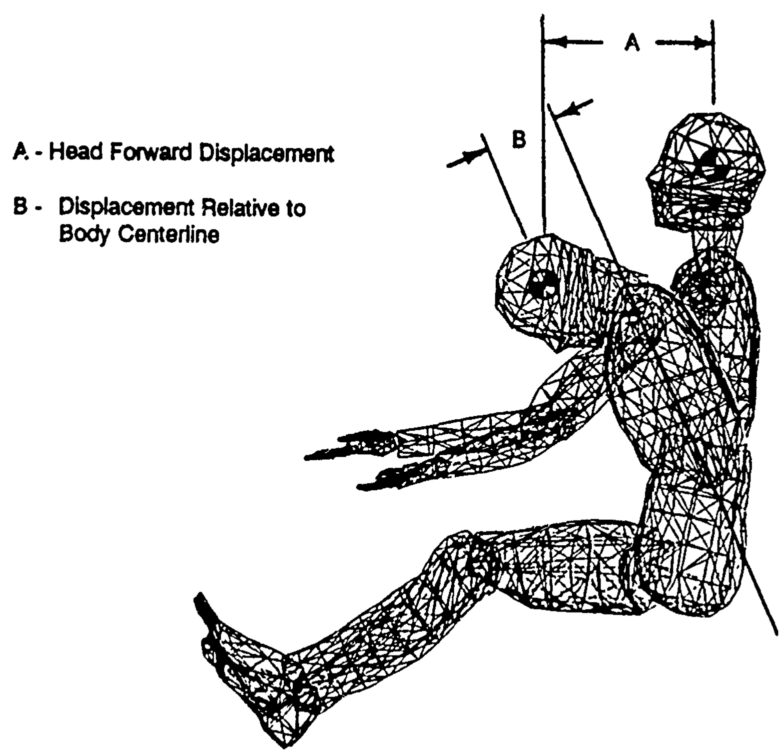


Figure 14. Measurement of maximum head displacement from high speed film.

Head Angular Acceleration

The threshold value for head rotational acceleration, measured by Ewing and Thomas on humans without producing concussion, was 2675 rad/sec^2 (Reference 13). This level of angular acceleration was exceeded during maximum forward head deflection only once - during baseline test 7. It was also exceeded during rebound against the seat back on Passive only test 3 and Passive & Active tests 2 and 4.

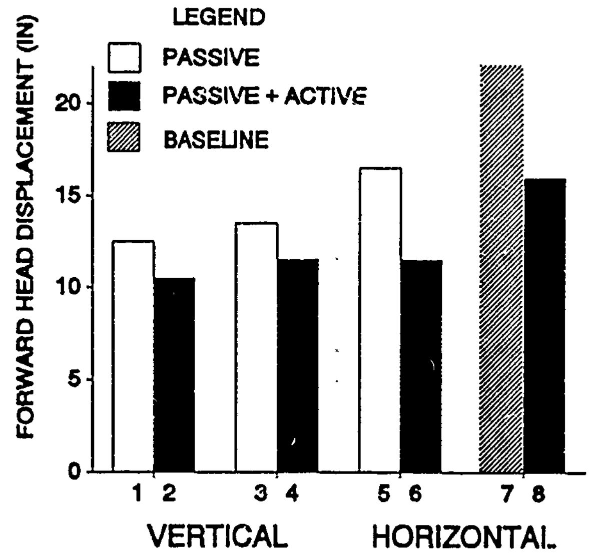


Figure 15. Total forward head displacement.

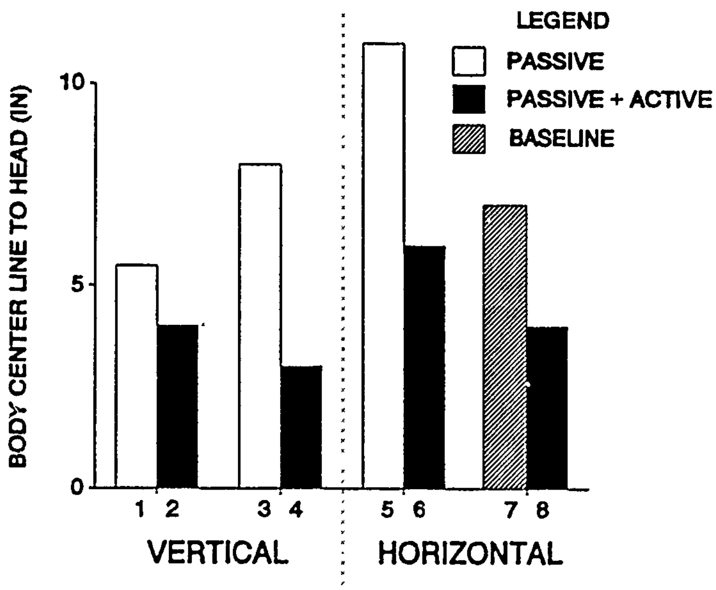


Figure 16. Head displacement relative to body center line.

Neck Torque

Neck bending torques causing injury at the cervical 7/thoracic 1 vertebrae junction cited in Reference 14 are 3360 in-lb (380 Nm) for flexion, 1009 in-lb (114 Nm) for extension, and between 1009 and 3360 in-lb (114 and 380 Nm) for lateral bending (see Appendix A). The maximum measured torque exceeded these limits in the folowing instances:

- Tests 3 (1330 in-lb), 5 (2390 in-lb), and 7 (1150 in-lb), lateral bending (x-axis) during forward deflection
- Tests 5 (4200 in-lb) and 7 (5000 in-lb), flexion (y-axis) during forward deflection
- Tests 3 (2000 in-lb) and 4 (1080 in-lb), extension (y-axis) during rebound

The protective capabilities of the airbag are evident, since six of the seven incidences just cited occurred when no inflated airbag was utilized. When the inflated airbag was utilized in test 4, the injurious level of neck loading torque probably occurred immediately before rebound of the head from the seat headrest, following maximum neck extension. In this case, the loading torque exceeded the level believed to cause injury by only about 7%.

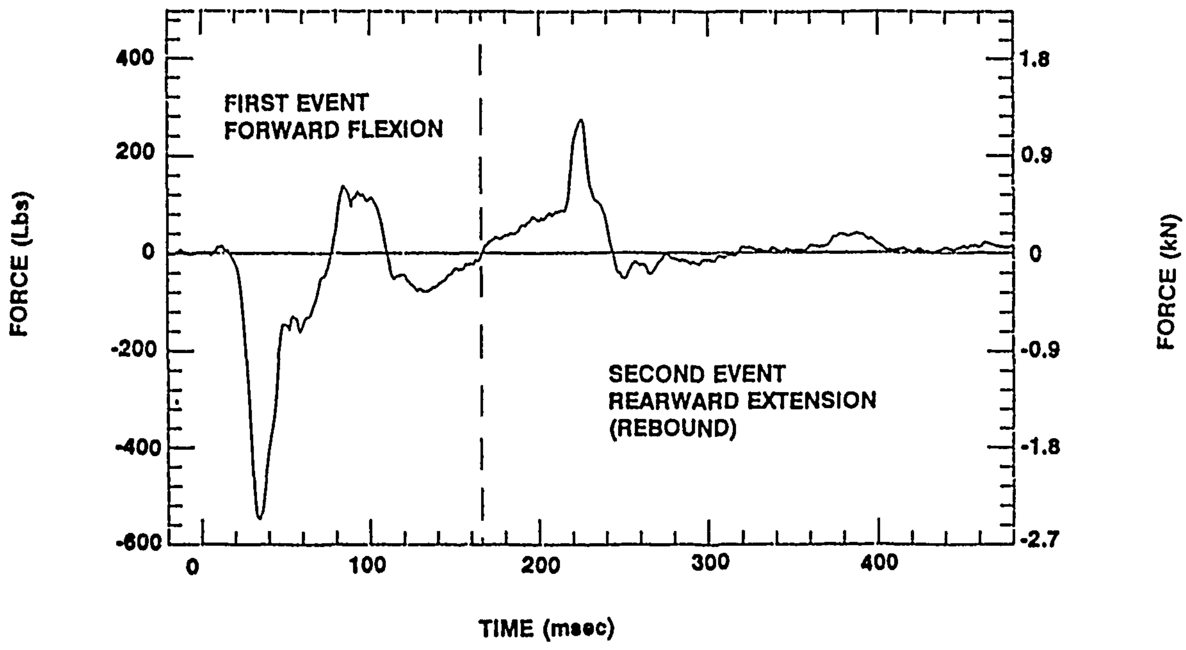
Neck Force

As expected, the first event records (e.g., during neck forward extension) of neck F_z forces were higher in the vertical group than those in the horizontal group, were quite similar in shape and magnitude among the former, and showed rather distinct pattern changes between vertical and horizontal groups (see Figure 17). In every case, the initial major loading consisted of a negative peak at about 35 msec for the vertical tests and an irregular positive peak at about 60-80 msec for the horizontal tests. Although the magnitudes of these vertical group peaks were sufficient to make major neck injury likely in compression, their very short durations precluded this possibility. The magnitudes were clearly insufficient to cause neck injury in tension. In contrast to the lack of any visible effect of the airbag on the first event vertical group peaks, the second event peaks (e.g., during neck rearward extension) showed a 42% increase in magnitude from test 1 to test 2 and a 37% increase in magnitude from test 3 to test 4. Even with apparent amplification due to the airbag, none of the second event peaks posed a neck injury threat. None of the first or second event peaks of the horizontal group were sufficient in magnitude/duration to produce any major neck injury per se, nor was the effect of the airbag apparent in the records.

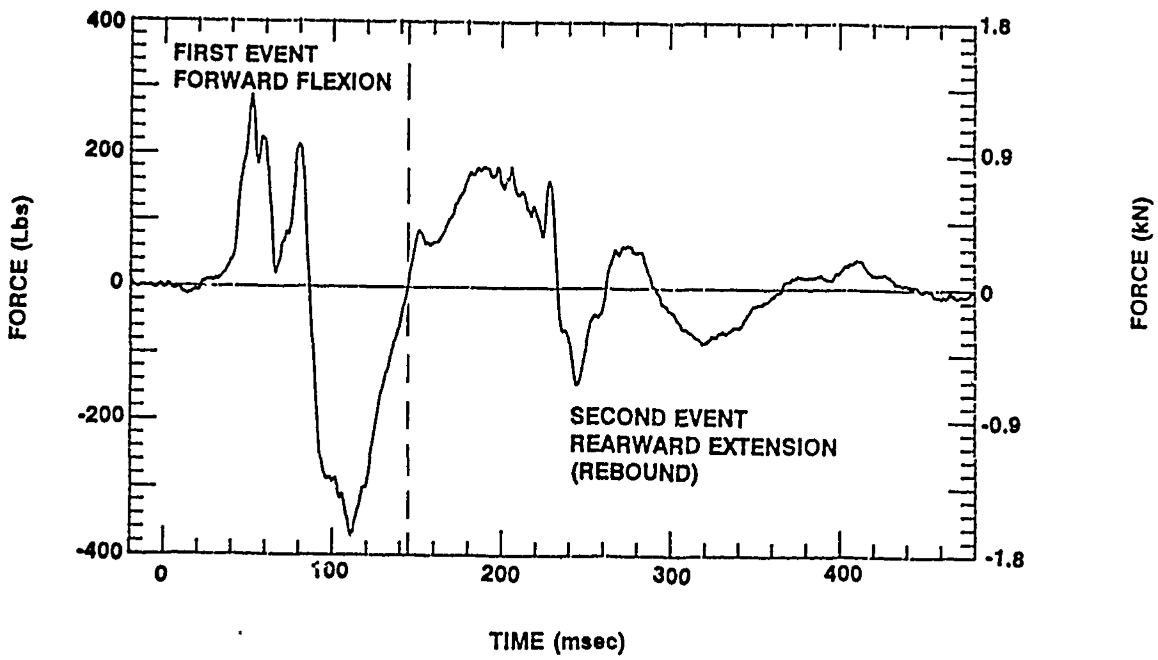
Passive Delethalization System Performance

Effectiveness of the passive delethalization systems (TTRH and ASRT) was evaluated based on comparison of test 5 (passive) and test 7 (baseline). Results showed significant improvement for the passive systems, with respect to the baseline test, in head strike envelope and head injury indices. The HIC and GSI both decreased 29% as shown on Figure 18. This improvement was not expected since computer simulations predicted higher head injury indices for the passive tests. The ASRT reduced the inertia reel strap payout by 95%. This, coupled with the improved geometry of the TTRH, yielded a 50% reduction of head total forward displacement. However, this was accompanied by a comparable increase in head displacement relative to body (see Figure 19). This appeared to exacerbate both head angular accelerations and neck loading torque.

The reduction of inertia reel strap payout offered by the tensioner/retractor, combined with the reduced torso displacement with the improved harness configuration, yielded a significant reduction of the head strike envelope. Neck torque during flexion (forward rotation about the y-axis) doubled for the passive only condition (test 5) (see Figure 20). While neck lateral torque (rotation about the x-axis) did decrease about 20% during this same period, the magnitudes exceeded suggested injury limits for both the passive and baseline conditions (see Appendix A). These results suggest the need to also restrain the head when upper torso movement is restricted with the ASRT and TTRH.



TEST 1 - VERTICAL



TEST 5 - HORIZONTAL

Figure 17. Typical neck force trace for vertical and horizontal tests.

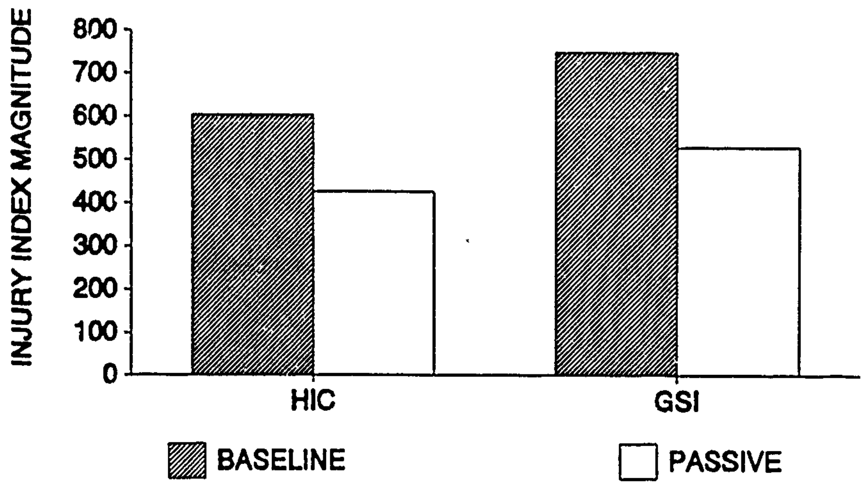


Figure 18. HIC and GSI values for baseline test 7 and passive test 5.

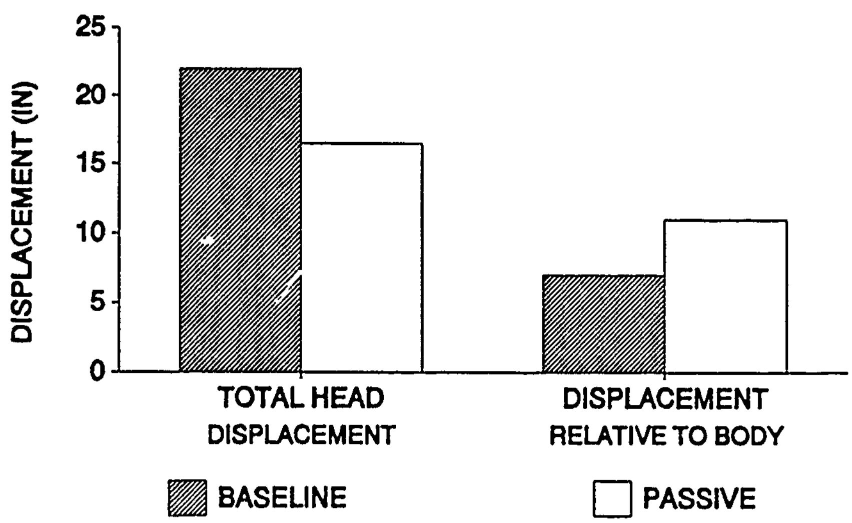


Figure 19. Head displacement, total and relative, for baseline test 7 and passive test 5.

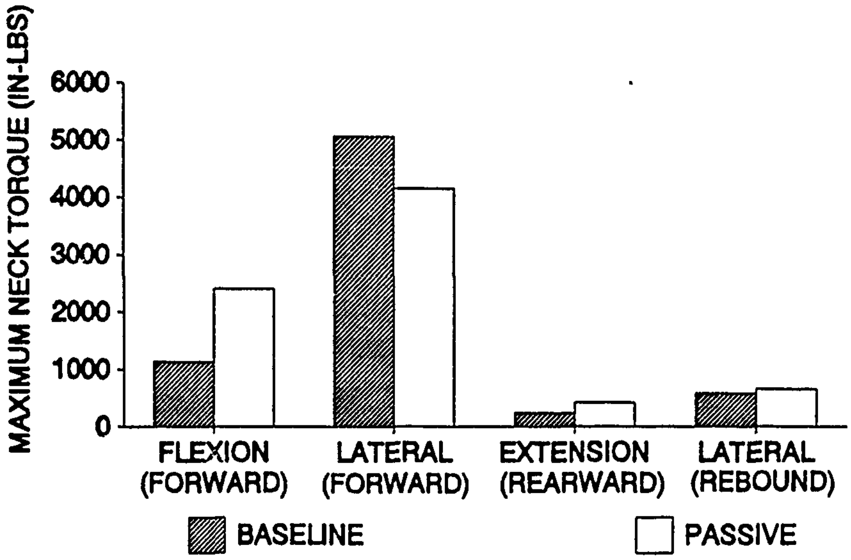


Figure 20. Maximum neck torque during head forward deflection and rebound for baseline test 7 and passive test 5.

Active Delethalization System Performance

Effectiveness of the active delethalization system (i.e., the HAS) was evaluated based upon comparison of passive test 3 (vertical) and test 5 (horizontal) with passive-active test 4 (vertical) and test 6 (horizontal). Results show improvement on several measures of effectiveness. The HIC and the GSI decreased 35% and 19%, respectively, on the active test, horizontal case, although both were the same in the vertical comparison (see Figure 21). Head displacement decreased 15% and 30% in absolute terms as well as 62% and 45% in relation to the upper torso for the vertical and horizontal cases, respectively (see Figure 22). This was accompanied by a significant reduction in neck torque for both vertical and horizontal cases, as shown on Figure 23. In fact, during forward neck flexion, neck torque never exceeded the suggested injury limit (see Appendix A) when the airbag was being used. These results indicate significant reduction in head strike envelope and head/neck injury potential.

Results during head rebound were not as encouraging, however. Neck torque during head rebound (second event) was generally greater for the passive-active (airbag) tests than for the passive tests (Figure 24), although in only one instance did the magnitude exceed the suggested injury limit. Similarly, maximum head linear acceleration (x-axis) during rebound increased for both vertical and horizontal test conditions (see Figure 25). In this case, the acceleration magnitude during rebound was significantly greater than during forward flexion. The peak acceleration duration during rebound, being significantly shorter than that during forward flexion, was not reflected in higher HIC or GSI values.

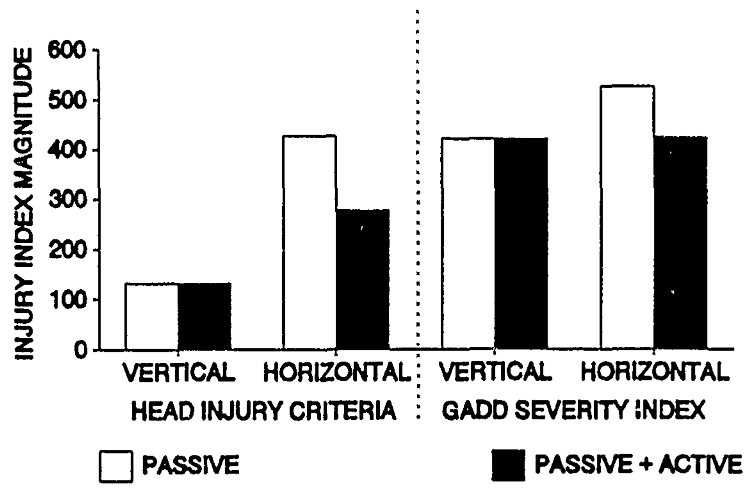


Figure 21. HIC and GSI values for passive only tests 3 and 5 and passive & active tests 4 and 6.

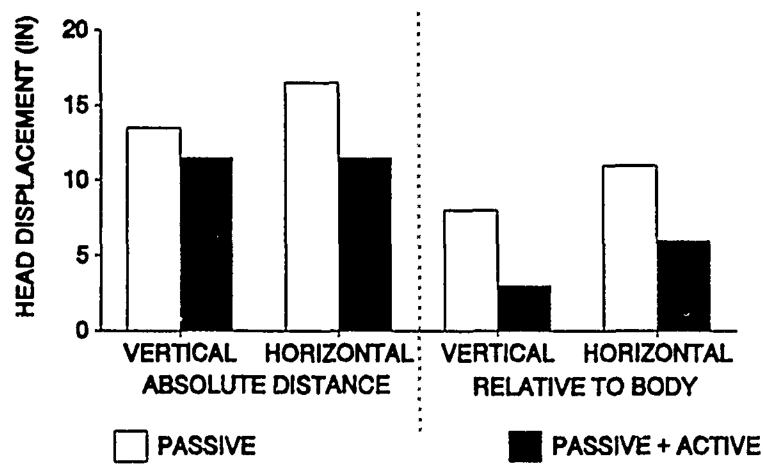
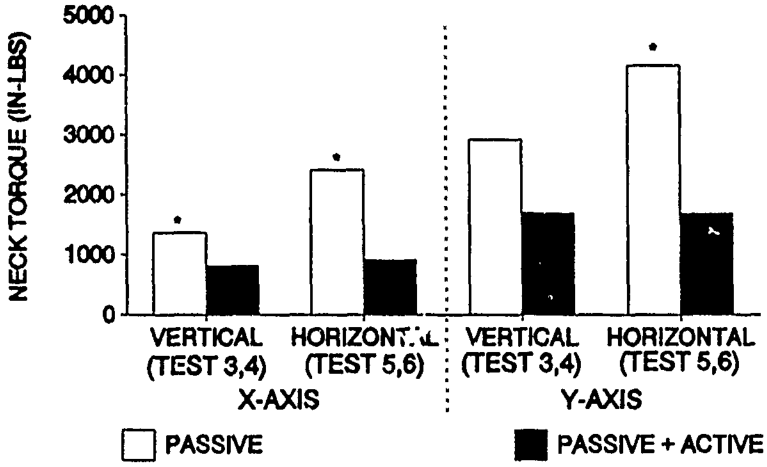
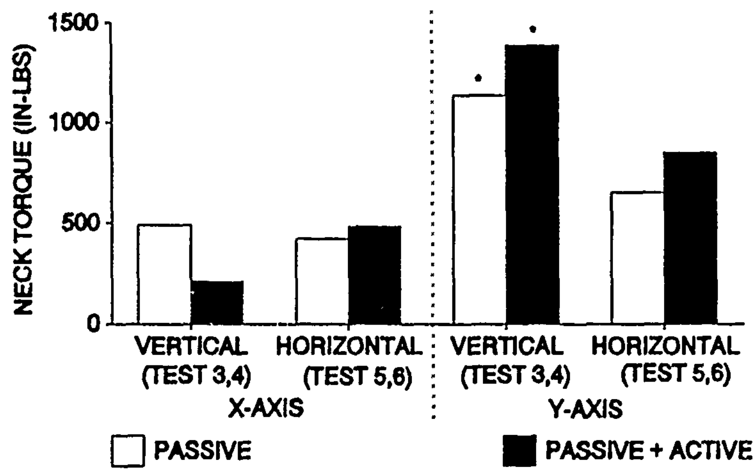


Figure 22. Head displacement, total and relative, for passive only tests 3 and 5 and passive & active tests 4 and 6.



* Magnitude x duration exceeded suggested injury limit.

Figure 23. Maximum neck torque during head forward deflection for passive only tests 3 and 5 and passive & active tests 4 and 6.



* Magnitude x duration exceeded suggested injury limit.

Figure 24. Maximum neck torque during head rebound for passive only tests 3 and 5 and passive & active tests 4 and 6.

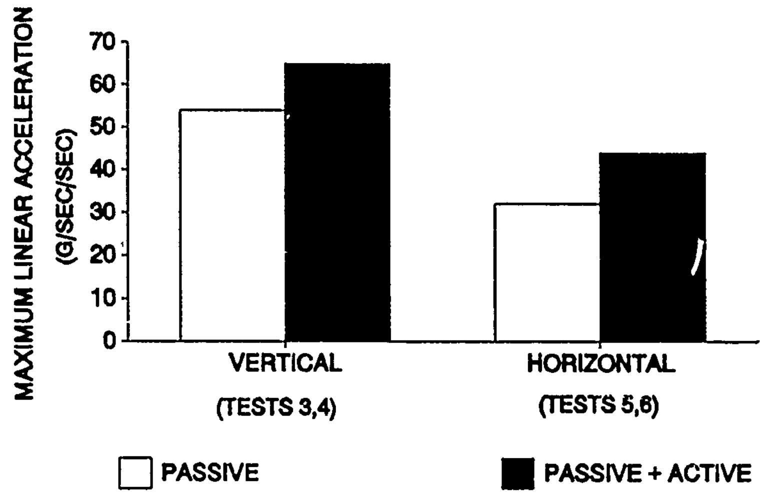


Figure 25. Maximum head acceleration (x-axis) during rebound for passive only tests 3 and 5 and passive & active tests 4 and 6.

The significant head accelerations during rebound were predicted since the airbag was not deflated upon head impact. Subsequently, energy stored by the airbag during head penetration forced the head rearward. The energy absorbing head rest pad might have absorbed this energy, but as shown in Figure 26, the head of the 95th percentile mannequin was much higher than the top of the seat back (which angles forward). This may have hindered effective energy absorption by the head rest cushion.

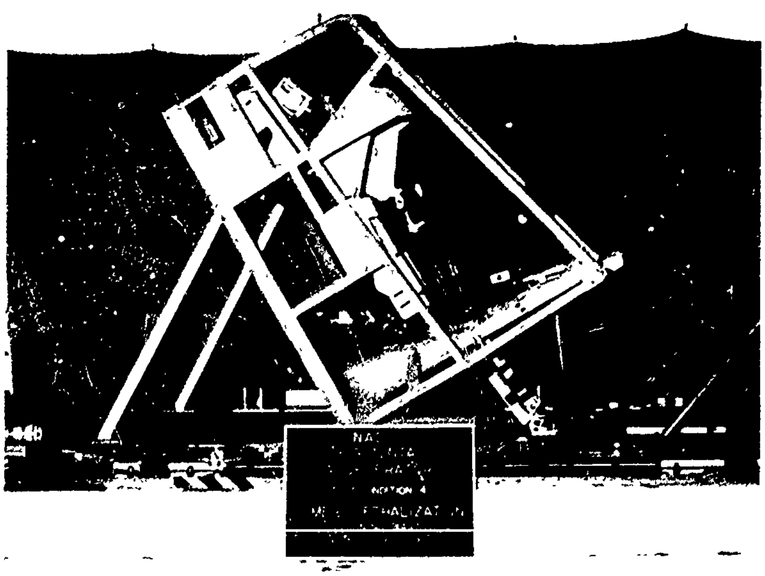


Figure 26. Illustration of 95th percentile dummy head protruding above the seat back and head rest.

PHASE II TASKS

Following completion of the Phase I concept feasibility tests, the basic CDP concepts were subjected to further analysis and testing. Phase II was comprised of three tasks: compatibility and retrofit study, hardware design refinement, and dynamic testing.

DESIGN COMPATIBILITY AND RETROFIT STUDY (PHASE II)

The design compatibility and retrofit study examined the retrofit feasibility of the prototype hardware designs in existing Army helicopter seating and restraint configurations. The study addressed the AH-1, AH-64 and UH-60 helicopters. These tests were conducted at the U.S. Army Aviation Applied Technology Directorate, Ft. Eustis, Virginia. Particular emphasis focused on crewstation compatibility, crash sensor and airbag integration. The results of this study, along with the Phase I test results, established objectives for the Phase II hardware design refinements.

Methodology

Both the pilot and copilot/gunner seats were evaluated in each helicopter. Objective data were obtained by taking physical measurements of the clearance envelope and interface/attachment points available for the installation of the protective systems. Clearance between the seat back and bulkhead was measured with the seat in the full-up and full-down positions. The size and location of inertia reel and strap guide attachment points were measured, as were other potential attachment points for the tensioner mounting plate, following removal of the reel and existing restraint harness hardware. The existing restraint system, mounting holes, and seat clearances were photographed.

The TTRH was installed to perform the subjective compatibility assessment. Each aircraft crew seat position was evaluated by two test subjects. All subjects were experienced pilots and/or gunners. They were briefed on the theory and operation of the CDP systems. Ingress, egress, mobility, flight control and weapons control tasks were performed. Videotape recordings were obtained during subject task performance. Subjects were debriefed and they completed the subject data sheet and questionnaire (Appendix C) following completion of the compatibility assessment.

Cockpit geometry measurements were also obtained to aid in locating the cyclic stick and ORT on the test fixture.

Results

AH-1. The AH-1 was excluded from the compatibility study because it uses a four-point harness which is incompatible with the CDP restraint system. Retrofittability, however, is achievable if a single-point release, five-strap harness is installed. The current inertia reel is usable but a custom length inertia reel strap is required. No potential tensioner mounting plate holes were identified, but some surmountable clearance problems between the seat and the bulkhead were obvious.

AH-64. Both compatibility and retrofittability were evaluated in the AH-64. Three subjects participated in this evaluation (one in the pilot's seat, one in the copilot's seat, and one in both seats).

The pilot's seat evaluation of the CDP harness yielded ratings of 3 or 4 on a scale of 1 to 6 for the following parameters:

Ease of ingress
Attachability/buckling
Adjustability

Inflight task performance
Ease of egress with the airbag deflated
Overall harness geometry acceptability
Overall harness comfort

The question evaluating the harness restraint capability received one 4 and one 6, indicating above average satisfaction for one subject.

The question evaluating egress with the airbag inflated yielded ratings of 1 and 2, clearly indicating dissatisfaction. Both subjects expressed concern with the increased time required to egress with the airbag inflated, especially in the event of a fire or an overwater mishap. Also, detachment of the communications cord was more difficult due to location of the inflated airbag, and water-wing hang-ups were expected.

The comparative evaluation between the standard harness system and the CDP system yielded ratings of 3 or 4 on a scale of 1 to 7 for all questions except one. The question evaluating the comparative ease of egress with the airbag inflated yielded ratings of 2.

Several other comments are listed below:

a. The communications cord can no longer be clipped to the harness or vest because of the stowed airbag location.

b. The inflated airbag may drive the IHADDS reticle into the eye.

c. The inflated airbag causes a pressure point at the base of the neck.

d. The lateral harness severely restricts the ability to look behind and above.

The gunner's seat evaluation of the CDP harness yielded ratings of 3 or 4 on a scale of 1 to 6 for the following parameters:

Ease of ingress
Adjustability
Inflight task performance
Ease of egress with the airbag deflated
Harness restraint capability

The question evaluating egress with the airbag inflated received ratings of 1 and 2, clearly indicating dissatisfaction. Both subjects expressed concern with the increased egress time, especially in an emergency situation.

The question evaluating the overall acceptability of the CDP restraint harness geometry received ratings of 2 and 4, indicating one subject's dissatisfaction. This was due to the lateral restraint which limited his motion envelope in and view from the cockpit. However, he found all controls accessible.

The question evaluating the overall comfort of the CDP restraint harness received ratings of 2 and 4, indicating one subject's dissatisfaction. No specific reason was given.

The comparative evaluation between the standard harness system and the CDP system yielded ratings of 3 and 4 on a scale of 1 to 7 for all questions except those related to egress.

The question evaluating comparative ease of egress with the airbag deflated received ratings of 2 and 3, while the question evaluating comparative ease of egress with the airbag inflated received ratings of 1 and 2. These ratings indicate higher levels of dissatisfaction with egressing with the airbag inflated than egressing with the airbag deflated.

Retrofittability problems were clear with the tensioner in both seats. The seat configurations were standard pilot and gunner. When installed on the pilot's seat, the tensioner spring housing contacted the bulkhead behind the seat in the 3/4 up position. When installed on the gunner's seat, the tensioner's g-sensing housing contacted a horizontal bulkhead in the 1/2-down position. However, this clearance problem was minor and the seat was cycled down with some contact on the housing face. A major problem with retrofittability is the inability to "recock" the tensioner without removing the upper seat tie-down pins in the case of an inadvertent actuation. The interface plate between the seat and the tensioner and inertia reel mounted satisfactorily. No physical problems with lateral strap or airbag retrofittability were encountered.

Several other comments are listed below:

a. The lateral restraints severely limit the body mobility required for inflight external visibility.

b. An inflated airbag is not acceptable during emergency egress.

c. The inertia reel strap creates discomfort at the base of the neck.

UH-60. Both compatibility and retrofittability were evaluated in the UH-60. Two subjects participated in the evaluation of the CDP system in the copilot's seat. The symmetry of the cockpit made evaluation in the pilot's seat unnecessary.

The copilot's seat evaluation yielded ratings of 3 or 4 on a scale of 1 to 6 for the following parameters:

Ease of ingress
Attachability/buckling
Adjustability
Inflight task performance
Ease of egress with the airbag deflated
Overall harness geometry acceptability
Overall harness comfort

The question evaluating the ease of attachment/buckling yielded ratings of 4 and 5, indicating above average satisfaction for one subject.

The question evaluating the harness restraint capability yielded ratings of 4 and 5, indicating above average satisfaction for one subject.

The question evaluating egress with the airbag inflated received a 1 and a 3, indicating the extreme dissatisfaction of one subject. Both subjects expressed concern with the increased time required to egress with the airbag inflated, especially in the event of a fire or an overwater mishap. Also, detachment of the communications cord is more difficult and water-wing hang-ups were expected.

The comparative evaluation between the standard harness system and the CDP system yielded ratings of 3 or 4 on a scale of 1 to 7 for all questions except one. The question evaluating comparative ease of egress with the airbag inflated yielded ratings of 1 and 2.

Several other comments are listed below:

a. With the inertia reel unlocked, the pilot cannot reach the caution advisory panel and the co-pilot cannot reach the blade de-ice switch due to the improved lateral restraint.

b. The circuit breakers mounted on the panel behind the pilot and copilot are difficult to reach with the improved lateral restraint.

c. The stitching on the shoulder strap guide must be made less stiff to improve harness comfort at the back of the neck.

d. An arm injury may hamper egress due to method of doffing the lateral restraint strap.

e. Removal of an unconscious pilot from the tilt-back seat may be hampered by the lateral straps.

f. By installing the lateral straps in inertia reels, current mobility would be retained in normal operations and limited mobility would be accomplished in a crash.

Retrofittability problems were clear for both the pilot's and copilot's seats. The horizontal strut of the seat frame located at head level, behind the seat, precludes tensioner mounting as desired when using the seat manufactured by Simula, Inc. No physical problems with lateral strap or airbag retrofittability were encountered. UH-60 aircraft equipped with ARA crewseats were not available for evaluation during the exercise and therefore were not evaluated.

These results are summarized in Table 4.

TABLE 4. SUMMARY OF DESIGN COMPATIBILITY AND RETROFIT STUDY RESULTS

Issue	Aircraft	Station	Discussion/ Solution
Egress with the airbag inflated	AH-64	Pilot & Gunner	Fabricating the airbag out of a more porous material or installing a poppet valve on the current airbag will permit airbag deflation.
Communication cord clip	AH-64	Pilot & Gunner	This is only a problem for the minority of aircrew who use the clip, and it is not considered a major problem by those aircrew.
Potential injury from IHADDS	AH-64	Pilot & Gunner	Discussions with ATCOM indicate that this may or may not be a problem. If the IHADDS is made detachable, this problem will cease to exist.
Neck discomfort due to prolonged airbag inflation	AH-64	Pilot & Gunner	This is not a problem because the airbag will not be inflated during normal operations.

TABLE 4. SUMMARY OF DESIGN COMPATIBILITY AND RETROFIT STUDY RESULTS (CONT'D)

Issue	Aircraft	Station	Discussion/ Solution
Neck discomfort due to the inertia reel strap	AH-64	Pilot & Gunner	Decreasing the stiffness of the inertia reel strap by changing the stitching pattern will alleviate the discomfort.
Lateral restraint restriction of mobility and view	AH-64	Pilot & Gunner	The restraint was designed to restrict lateral mobility. If the lateral restraints were loosened to permit more mobility, the tensioner would be able to remove the slack (up to 3 inches per strap).
Harness geometry	AH-64	Pilot & Gunner	The harness geometry causes the lateral restraint restriction of mobility and view which is addressed above.
Seat clearance problems	AH-64	Pilot & Gunner	Tensioner redesign is required to alleviate the clearance problems.
"Recocking" difficulty in the event of inadvertent actuation	AH-64	Pilot & Gunner	Tensioner redesign is required to alleviate the difficulty.
Egress with the airbag inflated	UH-60	Copilot & Pilot	Fabricating the airbag out of a more porous material or installing a poppet valve on the current airbag will permit airbag deflation.
Lateral restraint restriction of mobility	UH-60	Copilot & Pilot	The restraint was designed to restrict lateral mobility. If the lateral restraints were loosened to permit more mobility, the tensioner would be able to remove the slack (up to 3 inches per strap).
Egress from lateral strap with arm injury	UH-60	Copilot & Pilot	No testing was performed to determine whether this is an issue. Currently, the airman must loosen the strap manually if the single-point release is not sufficient.

TABLE 4. SUMMARY OF DESIGN COMPATIBILITY AND RETROFIT STUDY RESULTS (CONT'D)

Issue	Aircraft	Station	Discussion/ Solution
Unconscious flyer removal with tilt-back seat	UH-60	Copilot & Pilot	No testing was performed to determine whether this is an issue.
Tensioner mounting incompatibility	UH-60	Copilot & Pilot	This incompatibility occurs on the Simula seat and will require a tensioner redesign. The ARA seat was unavailable for evaluation.

Proposed Solutions. All of the issues and inputs described in the chart were examined and the following actions were taken pursuant to the survey analysis:

1. Airbag - An airbag comprised of a porous material was designed, fabricated and tested to eliminate the need to egress with a fully inflated airbag.

2. Harness - An inertia reel strap, with a different stitching pattern to decrease stiffness, was designed and fabricated to alleviate discomfort at the back of the neck.

3. Tensioner - An improved tensioner assembly was designed to afford easier recocking in the event of an inadvertent actuation. Means of eliminating seat clearance problems and mounting incompatibilities through tensioner redesign were examined.

HARDWARE DESIGN REFINEMENT AND FABRICATION (PHASE II)

As a result of Phase I testing, the design compatibility and retrofit study and component testing, design modifications were made to both the Harness Airbag System (HAS) and the Automatic Strap Retractor/Tensioner (ASRT).

Automatic Strap Retractor/Tensioner (ASRT)

The ASRT was redesigned to provide wedge adjustability and easier re-cocking procedures. A second redesign was performed at an assembly level. This redesign provides one-hand re-cocking capability in the event of inadvertent activation and reduces the overall ASRT size to eliminate problems identified in the Design Compatibility Study. Neither of these redesigned ASRTs was fabricated due to program budget constraints.

Component testing was performed to evaluate ASRT performance with both standard and low elongation webbing and to determine the reusability of wedges when subjected to fully dynamic situations. To perform this testing, a fixture was designed and fabricated. The ASRT and an inertia reel strap with an attached deadweight were permitted to free-fall until the desired velocity was reached. The ASRT free-fall was terminated while the weight continued, resulting in ASRT activation. This testing identified a minor problem with a wedge latching mechanism which was corrected.

Harness Airbag Subsystem (HAS)

The HAS was modified to permit dynamic inflation during Phase II dynamic system testing. Phase I testing was performed with the airbag pre-inflated. Due to the excessive cost of developing a gas generator system, a compressed gas source was selected as the means to inflate the HAS for Phase II testing. To achieve the high flow rates required for effective dynamic inflation, large inlet ports were installed in the HAS and large diameter hoses were utilized to interface the HAS to the source.

The HAS material was changed from a nonporous urethane-coated nylon to a porous neoprene-coated polyester to permit variation of inflation and deflation rates and durations, as well as to decrease head rebound accelerations due to the air spring effect created by the nonporous bag. Pressure transducers were added to the HAS to ensure accurate Pressure vs. Time measurements.

Component testing utilizing a data acquisition system was performed on the HAS to optimize inflation and deflation rates, durations and onset times. Compressed gas source pressures, and airbag porosities and pressures were varied to accomplish this optimization. The goal of the component testing was to refine the HAS to permit performance comparable to that of a HAS with a gas generator source. Pressure vs Time curves were obtained and analyzed to determine when to initiate the inflation system, as well as to determine airbag inflation peaks and durations.

DYNAMIC TESTS (PHASE II)

Test Methods

A total of nine tests were performed at the Horizontal Accelerator Facility at the Naval Air Warfare Center (NAWC) in Warminster, Pennsylvania, during Phase II. The test hardware consisted of the following items:

- 95th percentile Hybrid III dummy
- AH-64 Apache crashworthy seat
- LME cockpit test fixture

An AH-64 pilot's cyclic stick and AH-64 copilot/gunner's Optical Relay Tube (ORT) were added to the cockpit test fixture for the Phase II tests (see Figure 27). The cockpit was identical in all other ways to that used in the Phase I tests.

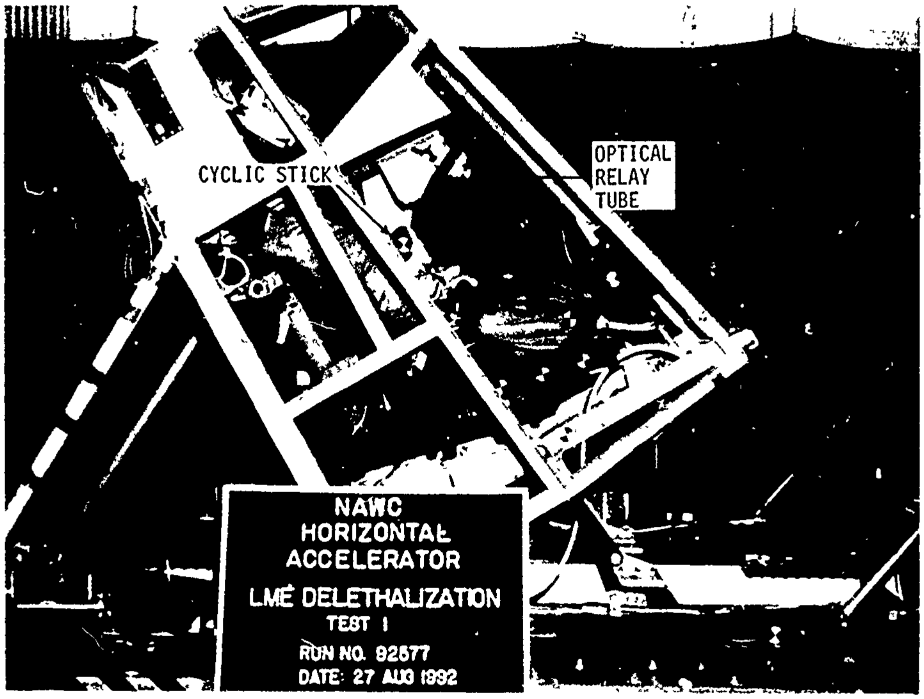


Figure 27. Cockpit test fixture showing cyclic stick and optical relay tube (ORT).

Four different test configurations were used. Tests four and eight were baseline tests, employing the standard Apache restraint harness. The inertia reel was locked and the inertia reel strap was adjusted with 1 in. of slack for these two tests only. This was a special request of the Crash Safety and Survival Systems Branch, NAWC, a co-participant in these tests. The remaining six tests employed the passive and active delethalization concepts - including the TTRH, ASRT, and HAS. The airbag inflation system was designed to provide dynamic inflation within 50 msec after pulse initiation. To accomplish this design goal, both cool gas generator and compressed gas sources were evaluated. Due to the prohibitive cost of developing a cool gas generator system, a compressed gas source was selected for the Phase II dynamic tests. The airbag inflation system consisted of a 96 cu. in. asset cylinder, a 3/4 in. solenoid valve and 3/4 in. I.D. hose. This system was initiated 100 msec prior to test pulse initiation due to mechanical delays in the system. (Note: A cool gas generator system would not require initiation prior to test pulse initiation.)

Two different cockpit orientations were used. Tests one through four used a 30° pitch down vertical orientation and tests five through eight used a combined 30° pitch down and 10° roll left vertical orientation. The test crash pulses were the same for all eight tests - with a change in velocity of 37 ft/sec and peak acceleration of 34.5 G's. Approximate duration of the half-sinusoidal crash pulses was 45 msec. The delethalization system configurations, crash orientations, and simulated crash pulses used are shown in Table 5.

TABLE 5. PHASE II TEST CONDITIONS/CONFIGURATIONS

TEST NUMBER	SLED PEAK ACCELERATION (G's)	SLED VELOCITY (ft/sec)	TEST ITEM ORIENTATION	RESTRAINTS EMPLOYED
1	34.4	39.3	30° Pitch Down	Passive & Active
2	34.4	36.5	30° Pitch Down	Passive & Active
3	35.3	37.7	30° Pitch Down	Passive & Active
4	35.4	37.3	30° Pitch Down	Baseline
5	34.9	37.2	30° Pitch Down 10° Roll Left	Passive & Active
6	34.4	37.0	30° Pitch Down 10° Roll Left	Passive & Active
7	34.7	37.0	30° Pitch Down 10° Roll Left	Passive & Active
8	34.8	37.1	30° Pitch Down 10° Roll Left	Baseline
9	34.8	37.2	30° Pitch Down 10° Roll Left	Passive & Active

Test 5 was initially declared a no-test due to a faulty critical data channel. Test 9 was performed to replicate the test 5 conditions. After concluding that the data in question were complete and accurate, the results for test 5 were declared valid. Test six was declared a no-test due to the failure of both film cameras, although the resultant data were declared valid.

Resultant sled velocity and peak acceleration were all within 5% of the target pulse with the exception of test 1 velocity, which was 6.2% (or 2.3 ft/sec) over the target velocity of 37.0 ft/sec and 5.9% (or 2.2 ft/sec) over the mean of the remaining eight tests.

The following conditions were verified prior to each test:

- New energy absorbers were installed on the seat.

- The seat was adjusted to the full-up position. This enabled use of the full stroking distance of the seat and ensured the seat would not bottom out.

- The inertia reel was unlocked (except on baseline tests 4 and 8).

Data Collection

A 95th percentile Hybrid III anthropomorphic dummy was positioned in the seat. Dummy instrumentation included head linear and angular accelerations, neck torque, neck force, and chest acceleration.

Additional instrumentation on the test sled included tensioner reaction time and seat acceleration (stroke axis). Seat stroke distance and inertia reel strap payout were measured following each test. A list of instrumented and measured data collected during the tests is shown on Table 6.

TABLE 6. TEST INSTRUMENTATION

ITEM NO.	MEASUREMENT	LOCATION
1	Carriage Acceleration (critical)	X-Axis
2	Carriage Redundant Acceleration	X-Axis
3	Seat Acceleration	Stroke Axis
4	Seat Displacement	Stroke Axis
5	Head Acceleration - Linear (critical)	X-, Y-, Z- Axes
6	Head Acceleration - Angular (critical)	X-, Y-, Z- Axes
7	Neck Torque (critical)	X-, Y- Axes
8	Neck Force (critical)	Z- Axis
9	Chest Acceleration - Linear	X-, Y-, Z- Axes
10	Airbag Pressure (critical)	Right Lobe
11	Airbag Trigger	External
12	Inertia Reel Strap Displacement	Between seat pass-through and shoulder harness
13	Inertia Reel Rotation	Shaft Axis

Photographic equipment and coverage consisted of the following:

1. Two sled-mounted 16mm motion picture cameras, each recording at 400 fps. One was mounted at an oblique front view and the other at a front view to record the dummy and restraint system.

2. One high-speed video camera, recording at 1000 fps, was mounted on the deck perpendicular to the direction of sled travel to record a side view.

3. Two high speed video cameras, recording at 200 fps, were mounted on the deck perpendicular to the direction of sled travel to provide an overall side view and an oblique side view.

4. A 35mm camera was used to obtain color stills for pre-test and post-test documentation.

ANALYSIS OF TEST RESULTS (PHASE II)

General

Seat stroke was electronically recorded during and physically measured following each test. Average stroke recorded and measured for each test was 7.6 and 8.3 inches, respectively. Results for individual tests are shown in Table 7.

TABLE 7. SEAT STROKE CHARACTERISTICS

TEST NUMBER	MEASURED STROKE (in)	MAX STROKE RECORDED (in)
1	7.75	7.75
2	8.0	9.75
3	8.0	8.75
4	7.25	7.5
5	7.5	7.75
6	7.5	no data
7	7.5	9.5
8	7.0	7.25
9	7.5	8.0

The seat is designed to protect the occupant from injurious peak G loads that occur during a crash. Ideally, the seat should limit the load imposed on the crewmember to less than 15 G's. The sled carriage loads imposed during these tests peaked at about 34 G's at 25 msec. Data recorded for the seat stroke axis accelerations indicate that the average peak load on the seat was almost equally as high. Seat accelerations were characterized by the typical double peak, the first preceding and the second following the sled carriage peak load. The magnitude of the first spike (the seat loading event) averaged about 33 G's and occurred at about 16 msec as the seat started to stroke. The second spike was less severe, averaging only 26 G's, and occurred at 67 msec as the seat stroking ended. In between these two peaks, the seat acceleration returned to 0 G's, with the typical slight dynamic overshoot. These characteristics suggest significant mechanical binding of the seat rollers and rails, possibly due to the off-axis direction of the sled acceleration, as well as the expected inertial interaction between the seat and dummy masses.

Pressure of the gas bottle used to inflate the airbag was recorded prior to each test. Airbag inflation was initiated prior to test initiation due to the relatively slow inflation rate using pressurized gas instead of a gas generator. The resulting airbag pressure was recorded during each test. Pretest bottle pressure, inflation trigger time, peak airbag pressure, and time that peak pressure was achieved are listed in Table 8.

TABLE 8. AIRBAG INFLATION PARAMETERS

TEST NUMBER	BOTTLE PRESSURE (PSIG)	TRIGGER TIME (msec)	PEAK AIRBAG PRESSURE (PSIG)	TIME OF PEAK PRESSURE (msec)
1	475	-120	10	230
2	475	-150	9.5	76[1]
3	450	-120	5.4	65[1]
4	-	-	-	-
5	475	-160	10	120
6	500	-190	8.4	88[2]
7	500	-164	12.4	136
8	-	-	-	-
9	500	-160	12.1	250

[1] Airbag bladder failed.
[2] Air inlet port detached during test.

On tests 2 and 3, the airbag ruptured on the interior edge along the left side of the neck. Similar failures were experienced during Phase I testing. Pressure recordings indicate rapid depressurization following those failures. This allowed the dummy head to pass unimpeded between the airbag lobes. On test 2, the dummy head contacted the ORT. In order to measure maximum head and torso deflection toward the cyclic stick, the ORT was removed for tests 3 through 8 with the concurrence of the Army Technical Representative. The airbag also experienced rapid depressurization on test 6 when the left inlet port detached from the bag.

The tensioner wedges were set in the open position prior to each test, with the exception of test 9 when they were closed (to replicate the predicted performance of the new design) and baseline tests 4 and 8 when the tensioner was not used. Strap payout was recorded during each test. Maximum payout recorded (during the period of maximum forward torso deflection) is shown in Table 9. Average tensioner payout was 2.9 inches. This compares to 5.7 inches payout on test 4 when the inertia reel was prelocked. (The string pot failed on test 8, so no data are available.) The inertia reel was unlocked prior to each test with the exception of baseline tests 4 and 8. Inertia reel rotation was recorded during each test. Maximum reel rotation is shown in Table 9.

TABLE 9. TENSIONER AND INERTIA REEL PERFORMANCE CHARACTERISTICS

TEST NUMBER	INERTIA REEL			TENSIONER	MAX. STRAP PAYOUT (in)
	SERIAL NUMBER	PRETEST CONDITION	MAX. ROTATION (deg)	PRETEST CONDITION	
1	11320	unlocked	1300[3]	open	17[3]
2	11321	unlocked	no data	open	3.6
3	11322	unlocked	840	open	3.4
4	11324	prelocked	-10[1]	not used	5.7
5	11325	unlocked	685	open	no data
6	11327	unlocked	721	open	0.8
7	11321	unlocked	400	open	3.8
8	11326	prelocked	-20[1]	not used	no data[2]
9	11322	unlocked	77	closed	2.7

[1] Inertia reel was prelocked, strap was preset with 1 in. slack.
[2] String pot failed at 56 msec.
[3] Locking devices in both the tensioner and inertia reel failed to operate; inertia reel rotation data clipped.

The following equipment and instrumentation anomalies were noted:

Test 1
- inertia reel did not lock
- tensioner wedges did not lock (it was subsequently determined that the tensioner was incorrectly assembled)
- resulted in dummy face and NVG impact on ORT

Test 2
- airbag ruptured at approximately 73 msec
- resulted in dummy head impact on ORT; ORT was removed for all subsequent testing
- inertia reel rotation channel failure

Test 3
- airbag ruptured at approximately 65 msec
- resulted in dummy head extending between and beyond the frontal lobes of the airbag
- incidental contact between helmet NVG mount and cyclic stick

Test 4
- no component failures
- dummy chest impacted cyclic stick

Test 5 - strap payout potentiometer failed at 56 msec
- head acceleration, Y-axis channel failure (critical for HIC calculation), no-test decision
- sled mounted camera failed
- analog Ektapro videotape failed

Test 6 - air supply hose detached from airbag at 88 msec
- inertia reel did not lock
- seat stroke string pot failed

Test 7 - inertia reel did not lock
- chest acceleration, Z-axis channel extremely low

Test 8 - dummy chest impacted cyclic stick
- fixture on rear of helmet contacted instrument panel
- strap payout potentiometer failed
- chest acceleration, Z-axis channel extremely low

Test 9 - chest acceleration, Z-axis channel extremely low
- inertia reel did not lock

The head rest cushion separated from the seat back during the initial sled acceleration pulse on all tests.

Head Linear Acceleration

HIC and GSI values were calculated from head linear acceleration data (see Figure 28). Both HIC and GSI values were greatest for the baseline conditions in tests 4 and 8 (with the exception of test 1 where neither the tensioner nor the inertia reel locked the restraint harness, thus allowing the dummy to impact the ORT unimpeded). Mean HIC and GSI values for tests using the airbag and tensioner were 235 and 245, respectively, while mean values for the baseline were 554 and 448, approximately double that of the former. Head injury indices did not exceed the criteria of 1500 for non-impact injury or 1000 for concussive blow for any of the test conditions.

Head rebound was rather severe on tests 3 and 8. Head accelerations during seat back impact accounted for 44% and 38%, respectively, of the total GSI value on these tests.

Torso Displacement

Forward displacement of the torso was measured from the high-speed film. Displacement was calculated by comparing the distance between targets placed on the dummy shoulder and on the seat back at initial test setup and at maximum torso forward deflection. Results are shown in Figure 29. A film recording was not available for test 3.

With the exception of test 1, displacement was generally less for the passive and active tests (mean - 15.2 inches) compared with the baseline tests (mean - 17.6 inches). This difference (2.4 inches) in mean torso displacement is roughly the same as the difference in mean inertia reel strap payout (2 inches) reported previously.

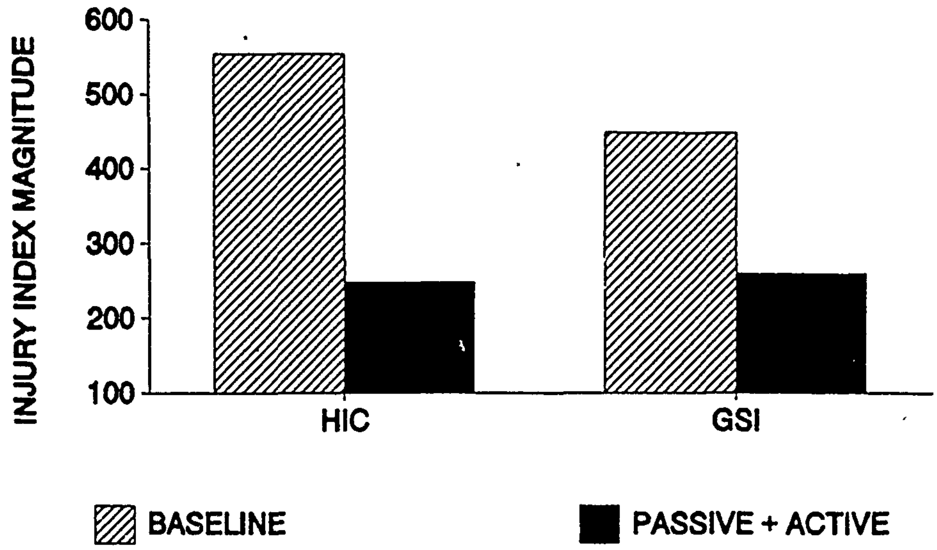
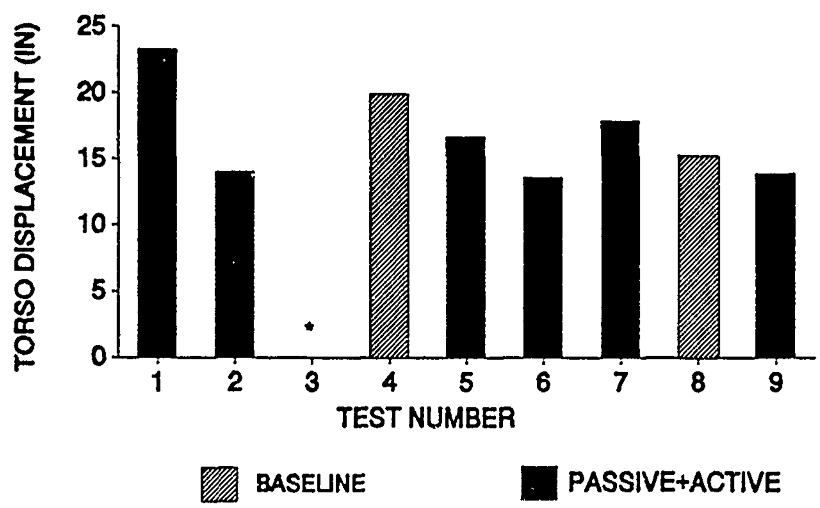


Figure 28. Mean HIC and GSI values, phase II tests.



* Camera failed.

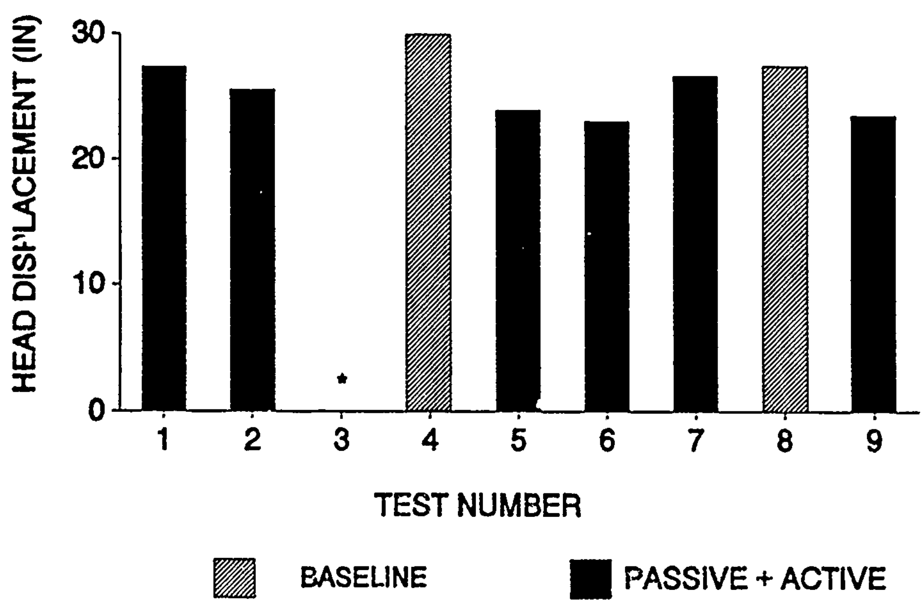
Figure 29. Maximum forward torso displacement.

Head Displacement

Head forward displacement was also measured from the high-speed film recordings. (Note: The magnitude of head displacement may be somewhat exaggerated due to slippage of the helmet on the mannequin head.) Head total displacement for each test is plotted in Figure 30. (The camera which recorded the side view used to make these measurements failed on test 3.) In general, total displacement was greater for the baseline tests (mean = 28.6 inches) than for the passive and active tests (mean = 24.5 inches). This is a greater difference than that demonstrated for torso displacement and inertia reel strap payout alone, suggesting that the airbag had some positive effect on head displacement.

Examination of head displacement relative to the torso (Figure 31) also suggests the benefits of the airbag. With the exception of test 2 where the airbag ruptured, head relative displacement was always less for the passive and active tests (mean = 8.5 inches, excluding tests 1, 2 and 6 or mean = 9.3 inches excluding test 1*) than for the baseline tests (mean = 11 inches).

*Note: Test 1 - inertia reel and tensioner both failed to lock.
Test 2 - airbag ruptured.
Test 6 - airbag deflated when inlet port separated.



* Camera failed.

Figure 30. Head forward displacement.

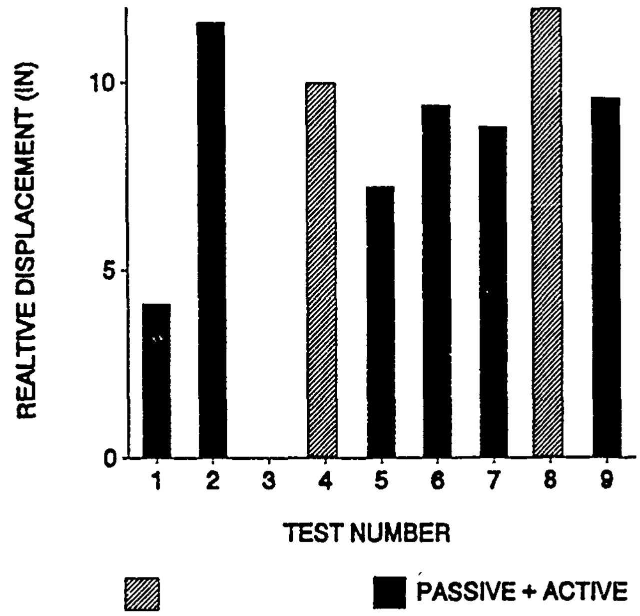


Figure 31. Head displacement relative to body center line.

Head Angular Acceleration

Head y-axis angular accelerations exceeded 2675 rad/s^2 (Appendix A) on Test 1 during seat binding forces at the end of seat stroking (second seat G spike) and during head impact on the ORT. The fact that in the former case the induced rotation was in the aft direction suggests that the initial head position and the 1G_x bias initial condition on the horizontal accelerator contributed significantly to this problem.

Neck Torque

Neck bending torques causing injury at the cervial 7/thoracic 1 vertebral junction cited in Reference 14 are 3360 in-lb (380 Nm) for flexion, 1009 in-lb (114 Nm) for extension, and between 1009 and 3360 in-lb for lateral bending (see Appendix A). The maximum measured torque exceeded these limits in the following instances:

- neck extension (aft rotation about y-axis) exceeded 1009 in-lb
  tests 1 (1300 in-lb) and 2 (1009 in-lb), during first seat G spike
  tests 3 (1200 in-lb), 4 (1550 in-lb), 5 (1550 in-lb), 6 (1009 in-lb), 7 (1590 in-lb), and 9 (1130 in-lb) during first seat G spike (momentary)
  test 8 (1150 in-lb), during second seat G spike (momentary)

- neck extension (aft rotation about y-axis) exceeded 1009 in-lb
  tests 1 (4450 in-lb) and 2 (2000 in-lb), during head impact with ORT

- neck flexion (forward rotation about y-axis) exceeded 3360 in-lb
  test 4 (4080 in-lb), during maximum forward head rotation

- neck lateral (rotation about x-axis) exceeded 1009 in-lb (114 Nm) but less than 3360 in-lb (380 Nm) tests 5 (2230 in-lb), 6 (1310 in-lb), 7 (1730 in-lb), and 9 (1460 in-lb) coincides with maximum forward rotation

Injurious neck extension coincided with seat G spikes on all tests. This injury mechanism appears to be related to initial posture of the dummy, in particular to the initial position of the head. This appears to be unrelated to the type of restraints employed since in most cases the extension occurs during the first G spike (less than 20 msec), long before any of the restraints can be of any benefit. Similar effects, correlated with seat binding and dynamic overshoot, were found in head G_z, head angular y-axis acceleration, and neck force data.

The benefits of the airbag are demonstrated by the fact that injurious neck flexion (forward rotation) occurred only once - on test 4 - when the airbag was not being used. The airbag did, however, increase the lateral rotation of the neck during all tests having a lateral acceleration in the crash load. Review of the test video recordings suggests that the right lobe of the airbag impacted the cyclic stick and subsequently caused the head to rotate to the left side.

Neck Force

Maximum neck forces recorded for each test are illustrated in Figure 32. Peak compression forces were not sufficiently different between passive and active tests (mean = 3.34 kN (752 lb)) and baseline tests (mean = 3.45 kN (775 lb)). However, peak tension forces were nearly 36% higher for the baseline tests (mean = 1.99 kN (448 lb)) than for the passive and active tests (mean = 1.46 kN (329 lb)). As similarly exhibited by chest G_z accelerations below, the peak neck compression force always immediately followed a spike in the seat G_z characteristic response. Though magnitudes of compression forces were sufficient to make injury likely, their very short duration precluded this possibility. Magnitudes were clearly insufficient to cause injury in tension.

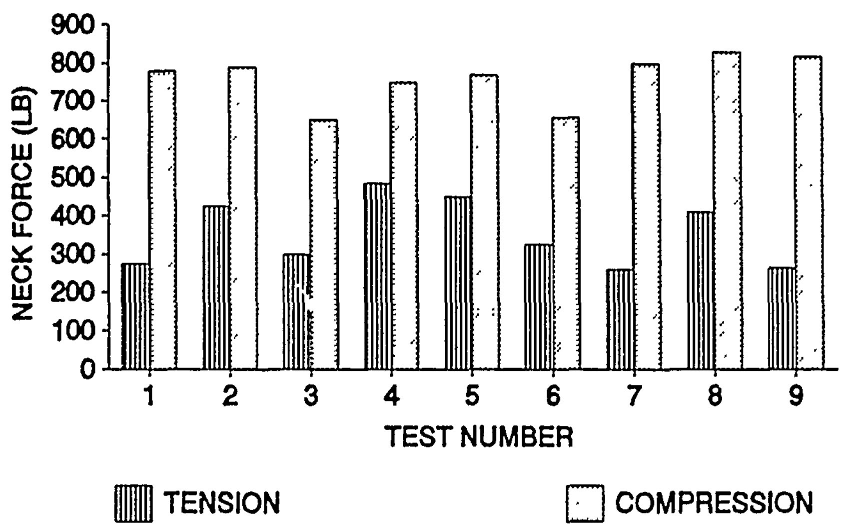


Figure 32. Peak neck forces; tension and compression.

Chest Acceleration

Peak chest accelerations ranged from 5 to 27 G's in the x-axis compared with 20 to 38 G's in the z-axis (see Figure 33). Mean peak accelerations for passive & active tests were 20 and 32 in the x- and z-axes, respectively, and for the baseline tests were 22 and 31, respectively. These calculations do not include data from either Test 1, x-axis since both the tensioner and inertia reel failed to lock, or from Tests 7 and 9 since a faulty accelerometer is suspected. The strong correlation between the time at which peak chest G_z and peak seat G_z loads occurred suggests that major forces imposed on the chest resulted from the vertical load transmitted via the seat and not from the horizontal load applied by the restraint harness. Chest severity index (CSI) was calculated to assess the injury potential. CSI values ranged from 23 to 138, far below the injury producing level of 1000. Mean CSI for baseline tests was 102 compared with 101 for the improved restraint system.

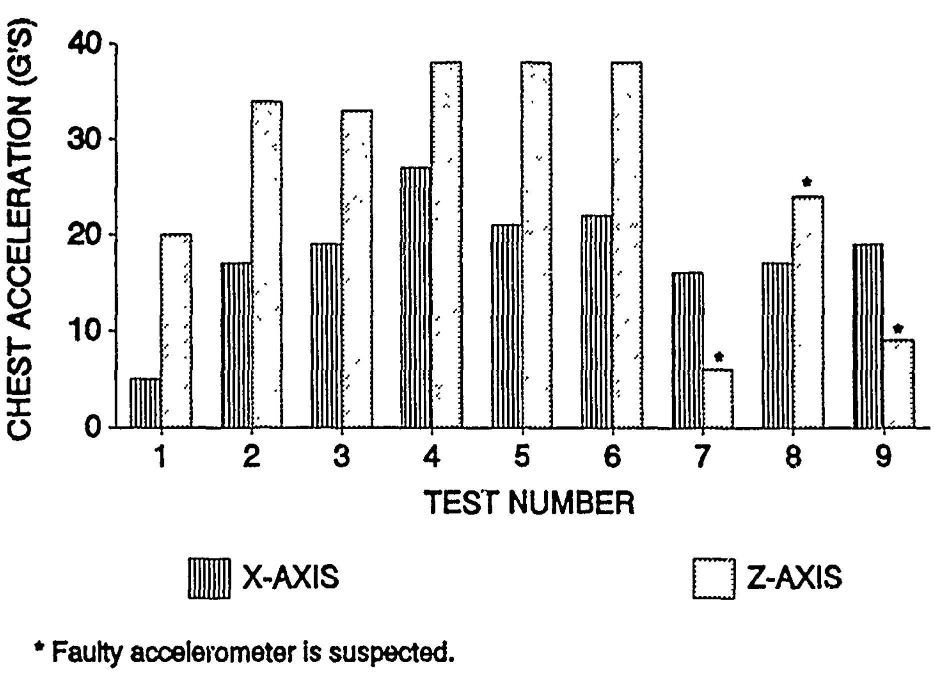


Figure 33. Peak chest acceleration; x-axis and z-axis.

Results indicate that the tensioner reduced the average strap payout by 50%. This is in spite of the fact that the inertia reel did not lock on five out of seven tests when the tensioner was used. (The inertia reel did lock on test 9 when the tensioner wedges were preset in the closed position. A faulty data channel prevented analysis of inertia reel rotation on test 3).

An average of 3.7 inches of strap payout was measured on the passive and active tests. (Data from test 1 are not included in this average since neither the tensioner nor the inertia reel locked.) This is significantly greater than the 0.5 inch observed in the Phase 1 tests (when the tensioner wedges were preset in the closed position) and in the component tests performed as part of the Phase II design and fabrication effort. One reason for this could be the dynamic overshoot during the typical oscillatory stroking characteristics of the seat which were previously described. Since the wedges are not held or locked into place once they are released to the closed position, they may not seat properly or may be shaken loose by strong vibrations or oscillations of the seat. The latest redesign of the tensioner includes features to better insure proper seating of the wedges, although fabrication and testing of this new tensioner design was not possible within the schedule and budget of this program.

The tensioner/harness combination offered better torso retention than the baseline restraint, as was evidenced by a 14% reduction in average torso displacement. (Again, test 1 data are not included in this average.) Tensioner/harness performance is best exemplified by the fact that the mannequin chest/neck impacted the cyclic stick on both baseline tests and did not on any of the passive and active tests (with the exception of test 1 where neither the tensioner nor the inertia reel performed properly). Cyclic stick contact was prevented on all but one passive & active test even though the airbag ruptured on tests 2 and 3 and the air inlet port separated on test 6 causing immediate airbag deflation. (Note: On test 6, a powder witness mark from the cyclic stick was noted on the helmet mask fitting, although the test films did not clearly demonstrate that a contact did occur.) The acceleration loads imposed on the chest were well below injury producing levels, as indicated by the CSI values.

Results also demonstrated that additional head retention was provided by the airbag. Total head displacement averaged 14% less for the passive & active tests. This resulted from a 23% reduction in head displacement relative to the body (shoulder) plus the 14% reduction in body (shoulder) displacement. By reducing forward head deflection, the airbag also reduced neck tension at maximum forward flexion.

The airbag reduced head linear accelerations, as was suggested by a 56% reduction in HIC and 42% reduction in GSI values. There was no evidence, however, that the airbag caused more severe rebound into the headrest, even though the airbag pressures were much greater in Phase II than in Phase I; however, a porus bag was used in Phase II tests.

Inspection of the film recordings suggests that the cyclic stick projected between the airbag lobes but did not contact the mannequin head on the vertical pitch tests. On the vertical pitch and roll tests, however, direct contact between the airbag right lobe and the cyclic stick resulted in extreme lateral rotation of the neck and increased the potential for neck injury.

CONCLUSIONS

Use of the ASRT resulted in an average 50% reduction in inertia reel strap payout. Strap payout could eventually be reduced as much as 95% with optimal ASRT performance, as demonstrated in Phase I when the tensioner wedges were set in the closed position. Less than optimal performance by the ASRT indicates the wedges did not remain seated in the closed position (there was no indication of strap slippage between the wedges). Design improvements were made but were not fabricated within the scope of this contract.

The ASRT and HAB combined to reduce forward head displacement by 14-15% on vertical tests (Phases I and II) and by 30% on horizontal tests (Phase I). In fact, head and body contact with the cyclic stick was prevented every time the ASRT and HAS operated properly. In comparison, the dummy chest/neck impacted the cyclic stick on both baseline tests (Phase II) even though the inertia reel was prelocked.

These strike envelope improvements were accomplished without subjecting the occupant to injurious physiological loads. Head linear accelerations (as indicated by HIC and GSI values), neck forward flexion, and neck compression/tension forces were all reduced. (All of the potentially injurious neck rearward extension torques were attributed to head initial position (tilted back due to the cockpit attitude on the horizontal accelerator) and dynamic overshoot of seat stroking.) Although lateral neck bending increased when the HAS was used (Phase II pitch and roll tests), the likelihood of injury is not certain since the injury criteria are not definitive (see Appendix A). Increased lateral support by the HAS is required to reduce the likelihood of lateral neck bending injury.

Caution must be exercised not to employ the TTRH without the HAS since Phase I demonstrated a 15% increase in head displacement relative to the torso for this passive only configuration.

RECOMMENDATIONS

The protective systems designed and evaluated under this program have demonstrated significant benefits toward delethalizing the helicopter cockpit. Further development and testing of these concepts promises to yield systems with higher fidelity, better performance, cockpit compatibility, and user acceptability.

Airbag lateral protection can be improved by raising the profile along the sides of the head. A cool gas generator whose supply rate is compatible with the porosity of the airbag fabric can be incorporated to provide optimal pressure characteristics. With proper inflation rates, crash sensors can be used to trigger the inflation sequence, thus demonstrating the full capability of this system.

Significant redesign work has already been done on the ASRT to improve performance of the wedges and to provide a smaller, more compact design for retrofit compatibility. However, this redesigned system was not fabricated and tested. The wedge redesign should provide more secure strap retention, even under negative G's during seat stroke dynamic overshoot. A one-handed capability to re-cock the device in flight will greatly improve user acceptability.

Finally, most of these design improvements can be refined and optimized using only laboratory bench testing which would be much more cost effective than testing at a horizontal accelerator or drop tower facility. The latter, more costly tests can be reserved for final validation of the system performance.

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APPENDIX A
COMMENTS AND BRIEF REVIEW OF IMPACT EFFECTS

The experience of conducting horizontal accelerator sled tests using restrained, volunteer, human subjects exposed to acceleration pulse velocity changes as high as 49 fps and peak accelerations of 20 G provided valuable insight on dynamic testing of restraint and support gear (Reference 15). The same may be said with respect to the ejection seat, where the use of human subjects played a critical role in its evaluation and acceptance at each stage in its development. One of the lessons learned here, and in other dynamic loading programs conducted on the Navy Drop Tower and Ejection Seat Tower, was that so-called anthropomorphic dummies may **look** like men, but they do not **react** like men. This is true in spite of great strides made in refining the design and construction of such dummies to more closely resemble their human counterparts.

This is not to say that such dummies do not play a very important role in the development of protective and survival equipment. Dynamic testing of such equipment is dependent upon the use of dummies, particularly in light of present safety regulations and legislation which significantly limit the conditions under which humans may serve as subjects. The point being made here is that although the use of dummies for dynamic testing is widespread and justified, one must not lose sight of their inherent limitations.

One of the difficulties encountered in trying to make more life-like dummies is the lack of hard data regarding the mechanical properties of human tissues. A concerted effort has been underway for the past three decades to support biomedical research in academic institutions and elsewhere to make up for this lack of information. While the necessary data are accruing, much more remains to be done. Even if all the biomechanical data were now available, translating them into practical terms so they could be implemented in dummy construction is a formidable job. Anthropomorphic dummies used in dynamic testing are expensive, bulky, and used in environments both friendly and hostile. Because of their cost, they must be designed to repeatedly withstand the rigors of rough handling under field test conditions. A series of compromises must therefore be made in producing a dummy which closely simulates the physical properties of the human body and, at the same time, is a cost-effective tool for use in dynamic testing.

The relation between gross movements and measurements of accelerations and loads measured in the dummy during dynamic tests, and prediction of injury in humans exposed to the same test conditions is highly tenuous. When acceleration or force is recorded in a dummy and fracture of an instrumented part occurs, the resulting change is quite unlike that seen with instrumented cadavers (or animals). In the latter case, an abrupt decrease in force occurs when a bone breaks, whereas the failure of a more ductile metal part presents an entirely different picture. When a human joint is rotated, resistance to such action gradually increases and failure is progressive; in a dummy, usually rotation continues largely unimpeded until a stop is struck, when sudden failure of the stop may occur. Metal to metal contact in dummy joints and other articulating parts frequently produces a resonating effect not seen in biological tissues. In addition, the human has much greater mobility between body parts than does the dummy. However, general trajectories of targeted body components, as revealed by the study of high-speed photography, can provide valuable information regarding impact with cockpit structures.

Because of these limitations in anthropomorphic dummies, and because of the restricted amount of instrumentation devoted to measuring variables associated with dummy accelerations and loads in the present program, it is believed that primary emphasis during analysis of the CDP testing should be based on a **comparative evaluation** of the passive and passive & active results. Although the limited number of tests for each condition will not permit much meaningful statistical treatment, differences between passive and passive & active variables, especially with regard to accelerations and load in the head and neck, will be large enough to be considered convincing.

Recently, in discussing guidelines for safe exposure of humans to impact accelerations for experimental purposes, Weiss et al listed acceptable and unacceptable injuries (Reference 14). In essence, injuries which result in disruption of tissues, such as bone fracture, herniation of vertebral discs, and ligament avulsion are unacceptable; reversible events such as muscle soreness, mild headache (qualified further as short-duration), and transient ECG arrhythmias are acceptable. Another event listed as acceptable is brief stunning or mild, uncomplicated concussion. From a military operational standpoint, concussion can be a very serious result of a vehicle crash, since alterations in the state of consciousness may prevent effective evasive action being taken. Particularly following an aircraft crash, an individual must be capable of extricating himself from the cockpit as quickly as possible in order to escape being burned or drowned. Typically, after concussion, there is a loss of reflexes and unresponsiveness to a number of auditory and visual stimuli, frequently followed by confusion and retrograde amnesia.

Holbourne postulated that head rotation cause by impact produces rotary distortion of the brain, which gives rise to high resultant shear stresses. These stresses were said to be the cause of cerebral concussion, contre-coup disruptions and other lesions, while distortions of the skull produce local contusions and skull fracture (Reference 16). Since the brain within the skull was pictured as a single degree of freedom spring-mass system, injury was said to be proportional to rotational velocity of the head for short-duration impacts, and to rotational acceleration for long-duration blows. Ommaya and Hirsch modified Holbourne's theory on the basis of their experiments, either striking primates on the occiput (direct impact) or striking the mobile chair on which the primate was seated (indirect impact) causing whiplash injury (Reference 17). Primate brain size varied from about 23 g (squirrel monkey) to 425 g (chimpanzee); using a scaling law, it was estimated that the critical values to produce concussion in man (brain weight approximately 1300 g) are 30 rad/s for rotational velocity and 1800 rad/s^2 for rotational acceleration. The value of 30 rad/s was later increased to 50 rad/s, and this, as well as 1800 rad/s^2, was said to have a 50 percent probability of producing concussion in man.

Weiss et al further recommended safe tolerance limits for torso-restrained humans exposed to impact G, based on **non-injurious** maximum exposures experienced by Naval Biodynamics Laboratory subjects (Reference 14). They stated that the value for rotational acceleration cited above as the threshold for concussion was reached in their -15Gx sled tests, without producing detectable concussion. For this reason, they stated that the values proposed by Ommaya and Hirsh are far too conservative, but they offered no alternative (Reference 17). However, Ewing stated that he had observed no adverse effects in subjects experiencing angular head accelerations of 2675 rad/s^2 and angular velocities of 38 rad/s. Weiss et al asserted that although the Gadd Severity Index (GSI) had been extended to cover cases of indirect impact, **acceleration** and **duration** may be better injury indicators. Occasional stunning was reported at 12 -G_x, onset rate of 226 G_x/s, and duration of 106 ms, severe stunning and disorientation lasting 10 to 15 s post-run occurred at 20 -G_x, and vertebral fractures and shock at 34 -G_x. With respect to bending and axial rotation of the neck (C1-T1), the following ranges of motion are not to be exceeded: 60° for extension, 52° for lateral flexion, + or - 47° for C1-C2 axial rotation, and + or - 94° for C1-C7 axial rotation. Torques causing injury at C1 are 190 Nm for flexion, 57 Nm for extension, and between 57 and 190 Nm for lateral bending; torques causing injury at C7/T1 are 380 Nm for flexion, 114 Nm for extension, and between 114 and 380 Nm for lateral bending. Shear, tension, and compression loads causing injury of the cervical spine are time dependent and are shown in Figure A-1.

The following material has been collected from a variety of publications and is presented without attribution in order to save time and space. The purpose of this presentation is to provide some supplementary information which may be of use in evaluating some of the data to be collected during the course of the CDP. The maximum tolerance of the human brain was given as 188 to 230 G lasting for 310 to 400 msec. The GSI was said to be associated with skull fracture and dangerous internal head injury when equal to 1000 for a concentrated head impact and 1500 for a distributed head impact. Linear fracture of the skull, which occurred after sustaining an average deceleration of 160 G, was usually found to be clinically associated with loss of consciousness or mild concussion. Such a fracture was found to be accompanied by values of GSI ranging from 390 to 1800, with a median value of 900. While the injury threshold to the head was established at a value of 1000 for the Head Injury Criterion (HIC), human subjects impacting an inflated airbag were reported to have experienced HIC values well over the critical value of 1000, but perceived the impact as a very mild rebound. Obviously, the nature of the impacted surface plays an important role in interpreting the meaning of calculated indices of injury. Based on resultant G measured at the CG of the upper thorax, GSI value of 1000 was taken as the injury threshold. Peak longitudinal impact loading of the femur at the knee of at least 1900 lb and 20 ft/s was sufficient to cause fracture. Lower leg impact tolerance for fracture of the tibia was found to be 967 lb. Finally, for the thoracic and spinal vertebrae, moderate injury occurred between 20 and 40 G_z applied for about 5 to 50 ms, increasing to over 100 G_z for 2.5 ms, and severe injury above 40 G_z applied for 7 to 50 ms, increasing to 100 G_z at 2.5 ms. For impacts lasting less than 70 ms, the body acts like a rigid mass, while for those impacts lasting longer, effects occur due to movements of organs and fluids. In general and regardless of duration, internal thoracic impact pressures from 45 to 55 psi result in 50 percent mortality, while those from about 28 to 32 psi cause shock.

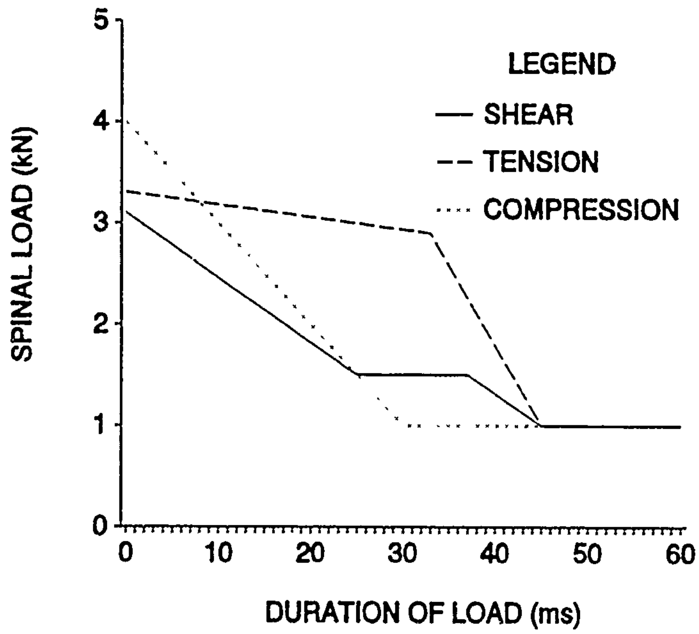

Figure A-1. Suggested spinal force-time limits for injury assessment.

APPENDIX B
OBSERVATIONS-DYNAMIC TESTS
(PHASE I)

TEST #1

Target Pulse:	Velocity = 25.0 fps, G-level = 31.0G
Actual Pulse:	Velocity = 26.8 fps, G-level = 28.0G
Seat Stroke:	3.5 in.
Test Results:	Both handgrips sheared Both footpedals sheared Tensioner fired successfully Inertia reel strap mark moved up approximately 1/4" (probably due to reel-packing and strap slack) Binding was evident on left, top seat rail (probably due to over-tight seat self-aligning ring) Seat stroke was lower than predicted (probably due to friction caused by binding and lack of armor for SARVIP) Head impacted top edge of headrest

TEST #2

Target Pulse:	Velocity = 30.0 fps, G-level = 31.0G
Actual Pulse:	Velocity = 31.1 fps, G-level = 33.7G
Seat Stroke:	6.0 in.
Test Results:	Both handgrips sheared Both footpedals sheared Tensioner fired successfully Inertia reel strap moved approximately 1/4" (probably due to reel-packing and strap slack) Binding was evident on left top seat rail (probably due to over-tight seat self-aligning ring) Seat stroke was lower than predicted (probably due to friction caused by binding) Probable right hand strike on right side console Head impacted top edge of headrest Airbag failed (probably due to overstressing the bag due to a combination of high bladder pressure and force exerted on the bag by harness and the bag tie-down straps)

TEST #3

Target Pulse: Velocity = 34.0 fps, G-level = 31.0G's

Actual Pulse: Velocity = 37.2 fps, G-level = 34.5G's

Seat Stroke: 8.0 in.

Test Results:

Both handgrips sheared
Both footpedals sheared
Tensioner fired successfully
Inertia reel strap moved approximately 1/4" (probably due to reel-packing and strap slack)
Probable right hand strike on right side console
Head impacted top edge of headrest
Probable right leg strike on outside of leg well

TEST #4

Target Pulse: Velocity = 34.0 fps, G-level = 31.0G

Actual Pulse: Velocity = 37.3 fps, G-level = 34.9G

Seat Stroke: 8.25 in.

Test Results:

Both handgrips sheared
Both footpedals sheared
Tensioner fired successfully
Inertia reel strap moved approximately 1/4" (probably due to reel packing and strap slack)
Probable right hand strike on right side console
Head impacted top edge of headrest
Probable right leg strike on outside of leg well
Airbag failed (probably due to overstressing the bag due to a combination of high bladder pressure and force exerted on bag by harness and the bag tie down straps
Right knee joint on dummy failed. Time and cause of failure is undetermined.

TEST #5

Target Pulse: Velocity = 40.0 fps, G-level = 24.0G

Actual Pulse: Velocity = 39.6 fps, G-level = 24.3G

Test Results:

Both handgrips and both foot pedals sheared
Tensioner fired successfully
Inertia reel strap mark moved up approximately 1/4" (probably due to reel packing and strap slack)
Headrest detached upon dummy motion forward and helmet impacted top of seat upon dummy rebound
Left elbow struck left console, breaking a piece off
Left shoulder joint weld failed. Time and cause of failure is undetermined.

TEST #6

Target Pulse: Velocity = 40.0 fps, G-level = 24.0G

Actual Pulse: Velocity = 39.1 fps, G-level = 23.2G

Test Results:

Both handgrips sheared
Both footpedals sheared
Tensioner activated fully or partially
Inertia reel strap moved up approximately 1/4" (probably due to reel-packing and strap slack)
Head impacted top edge of helmet
Probable hand strike on right front console
Airbag failed (probably due to overstressing the bag due to a combination of high bladder pressure (4 PSI) and force exerted on the bag by the harness and the bag tie-down straps
Partial seat failure occurred as indicated by seat delamination on both the left and right sides of the seat and broken ceramic armor on the sled. Without modification, the seat is no longer suitable for testing purposes.

TEST #7

Target Pulse: Velocity = 40.0 fps, G-level = 24.0G

Actual Pulse: Velocity = 39.5 fps, G-level = 23.3G

Test Results:

Both handgrips sheared
Both footpedals sheared
Inertia reel strap moved approximately 5 inches with 8° reel rotation
Head contacted overhead rails
Minor seat delamination was evident on left side of seat only. No ceramic armor damage was evident. Standard headrest detached upon dummy motion forward and helmet impacted top of seat upon dummy rebound.

TEST #8

Target Pulse: Velocity = 40.0 fps, G-level = 30.0G

Actual Pulse: Velocity = 40.8 fps, G-level = 27.7G

Test Results:

Both handgrips sheared
Both footpedals sheared
Inertia reel strap moved approximately 1/4" (probably due to reel-packing and strap slack)
Airbag failed (probably due to overstressing the bag due to a combination of high bladder pressure (3.5 PSI) and force exerted on the bag by the harness and the bag tie-down straps).
Partial seat failure occurred as indicated by seat delamination on both the right and left sides of the seat and broken ceramic armor on the sled. Without modification, the seat is no longer suitable for testing purposes.

APPENDIX C
PILOT DATA SHEET AND QUESTIONNAIRE
FOR THE
DESIGN COMPATIBILITY AND RETROFIT STUDY

Subject Profile

Name ____________________ Subject Number ______________

Rank ____________________ Crew Position ______________

Primary Aircraft ____________________ Flight Hours ______________

Other Aircraft ____________________ Flight Hours ______________

Height ____________________ Total Flight Hours ______________

Weight ____________________

Flight Coverall Size ____________________

1. How would you rate the ease of ingress for the CDP restraint harness?

Extremely Good	Very Good	Good	Poor	Very Poor	Extremely Poor
6	5	4	3	2	1

2. How would you compare the ease of ingress of the CDP restraint harness to that of the standard AH-1 restraint harness? The CDP restraint harness is:

Very Much More Easy	Much More Easy	Slightly More Easy	About the Same	Slightly More Difficult	Much More Difficult	Very Much More Difficult
7	6	5	4	3	2	1

3. How would you rate the ease of attachment/buckling for the CDP restraint harness?

Extremely Good	Very Good	Good	Poor	Very Poor	Extremely Poor
6	5	4	3	2	1

4. How would you compare the ease of attachment/buckling of the CDP restraint harness to that of the standard AH-1 restraint harness? The CDP restraint harness is:

Very Much More Easy	Much More Easy	Slightly More Easy	About the Same	Slightly More Difficult	Much More Difficult	Very Much More Difficult
7	6	5	4	3	2	1

5. How would you rate the ease of adjusting the shoulder harness strap length for the CDP restraint harness?

Extremely Good	Very Good	Good	Poor	Very Poor	Extremely Poor
6	5	4	3	2	1

6. How would you compare the ease of adjusting the shoulder harness strap length of the CDP restraint harness to that of the standard AH-1 restraint harness? The CDP restraint harness is:

Very Much More Easy	Much More Easy	Slightly More Easy	About the Same	Slightly More Difficult	Much More Difficult	Very Much More Difficult
7	6	5	4	3	2	1

7. Identify any interference or incompatibilities of the CDP restraint harness with your standard flight equipment ensemble.

____

____

____

____

8. Can you reach/operate the following controls with the inertia reel locked and unlocked?

	INERTIA REEL LOCKED	INERTIA REEL UNLOCKED
Cyclic	___ yes, ___ no	___ yes, ___ no
Collective	___ yes, ___ no	___ yes, ___ no
Throttle	___ yes, ___ no	___ yes, ___ no
Radio	___ yes, ___ no	___ yes, ___ no
Circuit Breakers	___ yes, ___ no	___ yes, ___ no
Others: ______	___ yes, ___ no	___ yes, ___ no
____________	___ yes, ___ no	___ yes, ___ no
____________	___ yes, ___ no	___ yes, ___ no
____________	___ yes, ___ no	___ yes, ___ no

9. How would you rate the compatibility with inflight task requirements of the CDP restraint harness?

Extremely Good	Very Good	Good	Poor	Very Poor	Extremely Poor
6	5	4	3	2	1

10. How would you compare the compatibility with inflight task requirements of the CDP restraint harness to that of the standard AH-1 restraint harness? The CDP restraint harness is:

Very Much Better	Moderately Better	Slightly Better	About the Same	Slightly Worse	Moderately Worse	Very Much Worse
7	6	5	4	3	2	1

11. How would you rate the ease of egress for the CDP restraint harness?

Extremely Good	Very Good	Good	Poor	Very Poor	Extremely Poor
6	5	4	3	2	1

12. How would you compare the ease of egress of the CDP restraint harness to that of the standard AH-1 restraint harness? The CDP harness is:

Very Much More Easy	Much More Easy	Slightly More Easy	About the Same	Slightly More Difficult	Much More Difficult	Very Much More Difficult
7	6	5	4	3	2	1

13. How would you rate the overall acceptability of the CDP restraint harness geometry?

Extremely Good	Very Good	Good	Poor	Very Poor	Extremely Poor
6	5	4	3	2	1

14. How would you rate the overall comfort of the CDP restraint harness?

Extremely Good	Very Good	Good	Poor	Very Poor	Extremely Poor
6	5	4	3	2	1

15. How would you rate the restraint capability of the CDP harness?

Extremely Good	Very Good	Good	Poor	Very Poor	Extremely Poor
6	5	4	3	2	1

16. General Comments: