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U.S. ARMY AVIATION
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HELICOPTER CREWSEAT CUSHION PROGRAM

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AVIATION APPLIED TECHNOLOGY DIRECTORATE POSITION STATEMENT

This report documents the results of a research effort to develop a more comfortable crewseat cushion without degrading seat system crashworthiness. The results of both static and dynamic testing indicate that a better crewseat cushion design is possible that will reduce the incidence of lower back pain. This approach is deemed to be worthy of consideration in conceptualizing new crewseat cushion designs and in making a retrofit decision for the AH-64 and UH-60 aircraft.

Kevin W. Nolan of the Safety and Survivability Division served as project engineer for this effort.

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A large proportion of Army helicopter pilots suffer back pain caused by flying. Extended missions required during Desert Shield/Desert Storm emphasized this problem. This pain could have an adverse impact on operational readiness, crew effectiveness, and flight safety. Poor posture during flight has been a contributing factor in pilot lower back pain. This program was performed to develop a seat cushion that improves comfort and reduces the incidence of lower back pain without adversely affecting crashworthiness. A literature survey and fact finding study analyzed the problem as it relates to AH-64 pilots. The knowledge and design, however, should be useful in all helicopters, especially in those with crashworthy stroking seats such as the UH-60 and AH-64 and in the future, the Comanche. Conceptual designs were developed which could help alleviate the problem. A survey of materials identified a few foams which were best suited to satisfy most of the requirements identified. Additional laboratory testing of foams was conducted to better compare the final candidates and aid in determining the optimal thickness and density to be used for the bottom cushion. A fit and function evaluation determined appropriate size and range of adjustment required for each postural/comfort aid (thigh, lumbar, and arm support). Prototype cushions were designed and fabricated and were used in dynamic crash test and in an Army-conducted comfort evaluation. Final design modifications were made prior to fabricating the twelve deliverable cushion assemblies.

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Thigh Support
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INTRODUCTION

Previous studies have shown that a large proportion of helicopter pilots suffer from back pain resulting from flying.[1-4] The pain has generally been confined to the lower back and, prior to any chronic symptoms developing, can be described as a dull ache. The problem drew more attention after extended missions required during Desert Shield/Desert Storm. This pain could have an adverse impact on operational readiness, crew effectiveness, and flight safety. Poor posture has been cited as the major contributing factor in pilot lower back pain.

The objective of this program was to develop a seat cushion that improves crew comfort and safety and reduces the incidence of lower back pain. Emphasis was placed on improving posture and on distributing weight over a larger area to reduce pressure point loading. These objectives were to be accomplished without compromising crash safety.

The following tasks were accomplished during this program:

- Literature survey and analysis
- Concept development
- Prototype design and fabrication
- Static and dynamic tests
- Final design and fabrication

FACT FINDING

The fact finding study conducted was comprised of three activities: 1) a survey of literature, 2) an on-site assessment of cockpit geometry and pilot posture at Ft. Eustis, VA, and 3) the survey of AH-64 pilots at Ft. Eustis, VA. A survey of literature in academic journals, government reports (both foreign and domestic), trade journals, and conference proceedings was conducted to gather information on postural effects, cushioning materials, seat geometry, vibrational effects, and crashworthiness and their relationship to lower back pain.

REVIEW OF LITERATURE: THE LOW BACK PAIN PROBLEM

Low back pain is well documented in aviators of many types of helicopter airframes[2-6] and in many countries (Netherlands, United States, Canada, Germany, Israel). A typical profile of low back pain in helicopter aircrew was compiled by Bowden:[7]

- Total flight hours: 300-1500
- Mission duration onset: 2-4 hours
- Pain duration: as little as 24 hours, but can exceed 48 hours in some pilots
- Location of pain: lumbar and buttocks

This profile is not peculiar to the helicopter community, nor to the AH-64 Apache. The low back pain problem is significant nonetheless because not only is it a widespread phenomenon, it can also be distracting to the accomplishment of the mission, and may eventually become chronic and disabling.

Most researchers attribute the low back pain in helicopter pilots to three factors: seated posture, vibration, and workload. Each factor is discussed separately below.

Posture

The typical seated posture of the helicopter pilot is the so-called "helicopter hunch". The primary driver for this posture is to stabilize and operate the cyclic control. The cyclic can be reached only by extension of the right arm, a fatiguing posture because of the long moment arm. By sitting hunched forward, pilots are able to bring the arm closer to the cyclic. The slouch is further exacerbated because pilots tend to use their right thighs as armrests to stabilize and rest the arm. Since anthropometrically, the elbow rest height is 3 to 5 inches above the thigh, the pilot must lean forward and laterally to make contact. This asymmetric hunching (see Figure 1) results in a loss of curvature, i.e., flattening of the lumbar vertebrae and increased loading of the back muscles due to forward displacement of the centers of gravity of the upper torso and head.

This lumbar flattening is undesirable for a number of reasons. The muscles, tendons, ligaments, and nerves of the lumbar spine are stressed. Also, the intervertebral disks (annulus fibrosi) are pinched anteriorly. This pinching bulges the disk posteriorly (see Figure 2) and stretches the posterior muscles and ligaments. The bulging disks also put pressure on the spinal nerves in that area, another source of discomfort.[8,9] The hunched posture further exacerbates the discomfort because the centers of gravity of the head and torso are forward of the spine, which concentrates the muscle load at the lumbar region. This was demonstrated by Anderson,[9] who found [higher] EMG activity was recorded in slouched postures. Osinga and Schuffel[10] recommended that in general, the head center of gravity should be directly above neck vertebrae. ANSI/HFS 100-1988, American National Standard for Human Factors Engineering of Visual Display Terminal Workstations, discourages seat designs that constrain the upper torso to a position forward of vertical. Flattening of the lumbar vertebrae can also increase the risk of spinal injury under crashloading.[11] Ewing et al[12] advocated increasing seat back angle to prevent injury due to impulse loads on vertebrae due to crash/ejection forces.

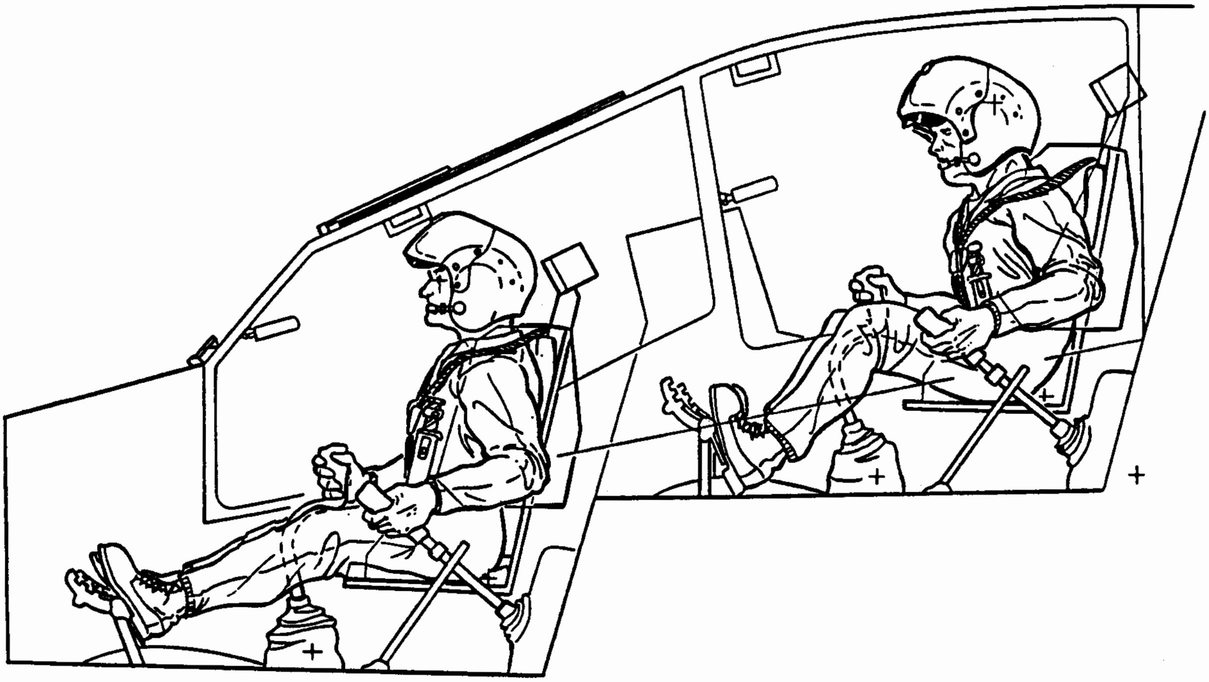


Figure 1. Helicopter aircrew posture, hunched (right), upright (left).

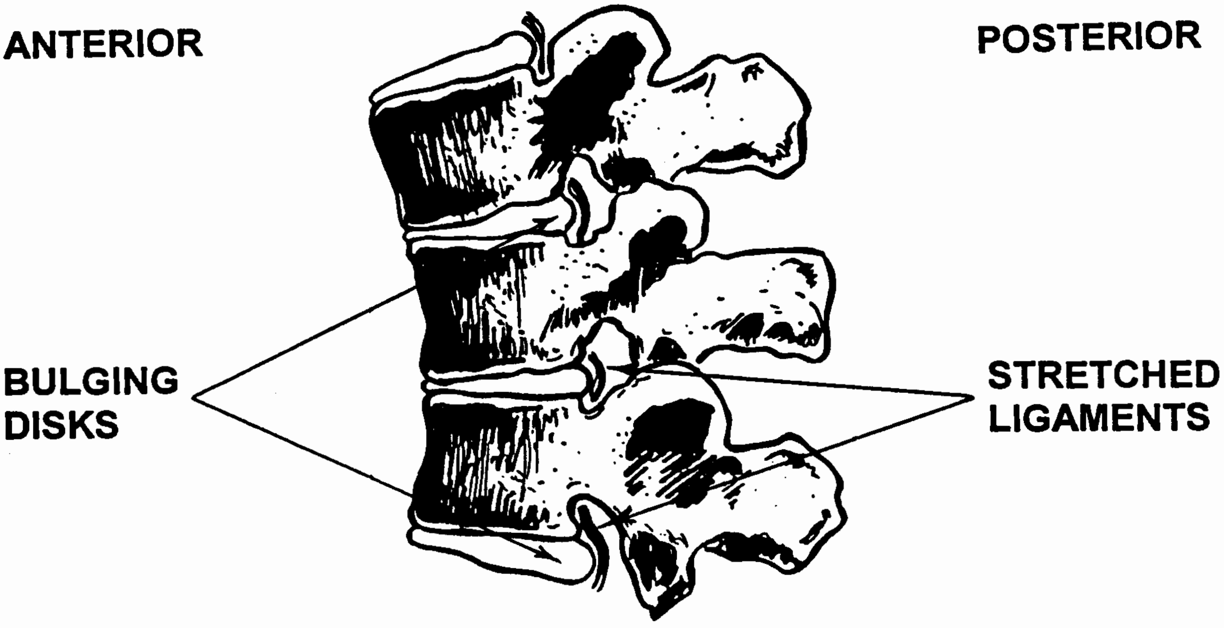


Figure 2. Bulging disks and stretched ligaments from lumbar kyphosis.

Vibration Transmission

Vibration transmission has also been identified as a possible factor in the etiology of low back pain of helicopter pilots. The debate over the significance of vibration as a factor hinges on the finding that low back pain develops whether or not vibration is present.[5,13] The relatively short duration of the low back pain reported by many pilots has led some researchers to discount vibration as a factor since vertebral microtrauma, which presumably would be the natural effect of vibration induced damage, would be associated with long-term back pain episodes.[5,2] However, these reported durations are subjective recollections which may be influenced by a fear of losing active flight status. Some researchers have found a bimodal distribution of pilots in terms of long-term and short-term back pain,[7] which may indicate that sampling may influence the duration of low back pain reported.

Some researchers suggest that evidence of spinal microtrauma implicates vibration as a factor in lower back pain: Wilder, Pope, & Frymoyer[14] found disc herniations were created in young calves subjected to vibration; and the prevalence of lytic spondylolisthesis (a forward displacement of the 5th lumbar vertebrae due to a fatigue fracture of the pars articularis) was discovered to be four times more prevalent in helicopter pilots than in fixed-wing cargo pilots or student pilots.[15] Both animal and human ligaments have been shown to become softer and weaker due to loading from vibration.[16]

Other findings implicating vibration as a causal factor include: the seat-to-head vibration transmitted in the helicopter has been measured at the natural resonant frequency of the head and spine, namely 4-8 Hz.[17,18] Bjurvald et al[19] found that whole body vibration elicited a general increase in EMG activity in the muscle groups of the back. The association between whole body vibration and low back pain has also been extensively studied; in particular, Magnusson, Wilder, and Pope[11] found that a long-term vibration exposure dose was significantly correlated to low back pain in truck drivers.

Determining the role of vibration in low back pain is difficult because a) it is difficult to isolate the physiological effects of vibration, b) the actual helicopter environment is difficult to simulate in the laboratory, and c) replicating and studying long-term exposure to vibration is untenable. The difficulty of measuring and assessing the physiological effects of vibration is central to the debate over the validity of the present International Standard for human response to whole-body vibration , ISO 2631.[20-23] Further, Wilder, Frymoyer, and Pope[24] concluded that a symbiotic relationship exists between posture and vibration in the etiology of low back pain. Evidence in support of this hypothesis was provided by Messenger and Griffith,[25] who found that adopting either posture - - anterior tilted pelvis with forward inclination of whole back (forward sloping seatpan) or posterior tilted pelvis with only an inclined upper back (backward sloping seat pan) - - reduced mean vibration transmissibility between 6-35Hz by 60 to 70%.

Workload

A third factor which contributes to low back pain is workload. Piloting a helicopter is a strenuous task: manipulation of the cyclic and rudder pedals is taxing both muscularly and cognitively due to the requisite fine motor control and coordination.[7] The necessity to acquire and maintain the proper field of view, static posture, and stability of controls further increases muscular and mental tension, which are intensified by the hunched posture.[6,10] Calisthenics have been suggested to strengthen back muscles to reduce fatigue due to workload,[6,3] but the benefits have not been verified.

ON-SITE ANALYSIS OF AH-64 PILOTS AT FT. EUSTIS, VIRGINIA

Additional fact finding was conducted during a trip to Fort Eustis, Virginia,to supplement the general findings of the surveys obtained in the literature and more specific to the AH-64 population. Two pilots were interviewed to obtain insight into individual aspects of the problem. Anthropometric measurements of the pilots were obtained to determine their relationship to the total population. Stature, sitting height, popliteal height, and buttock-popliteal length were recorded (see Figure 3). These measurements and their percentile rankings are shown in Table 1.

TABLE 1. PILOT ANTHROPOMETRIC DIMENSIONS AND PERCENTILES

	PILOT A		PILOT B	
DIMENSION	MEASUREMENT (cm)	PERCENTILE	MEASUREMENT (cm)	PERCENTILE
Stature	190.8	95	174.8	25
Buttock-Popliteal	61.5	50	56.4	2
Popliteal Height	47.2	75	42.7	10
Sitting Height	97.9	95	90.1	20
Weight	187 lb		150 lb	

A firsthand look at the problem was obtained with the pilots in the cockpit. Measurements of the cockpit were also obtained, including location, adjustment range, and range of motion of the cyclic, collective, and rudder pedals with respect to the seat. These data were used later for the computer accommodation study and for construction of the mock-up, used for the fit and function evaluation.

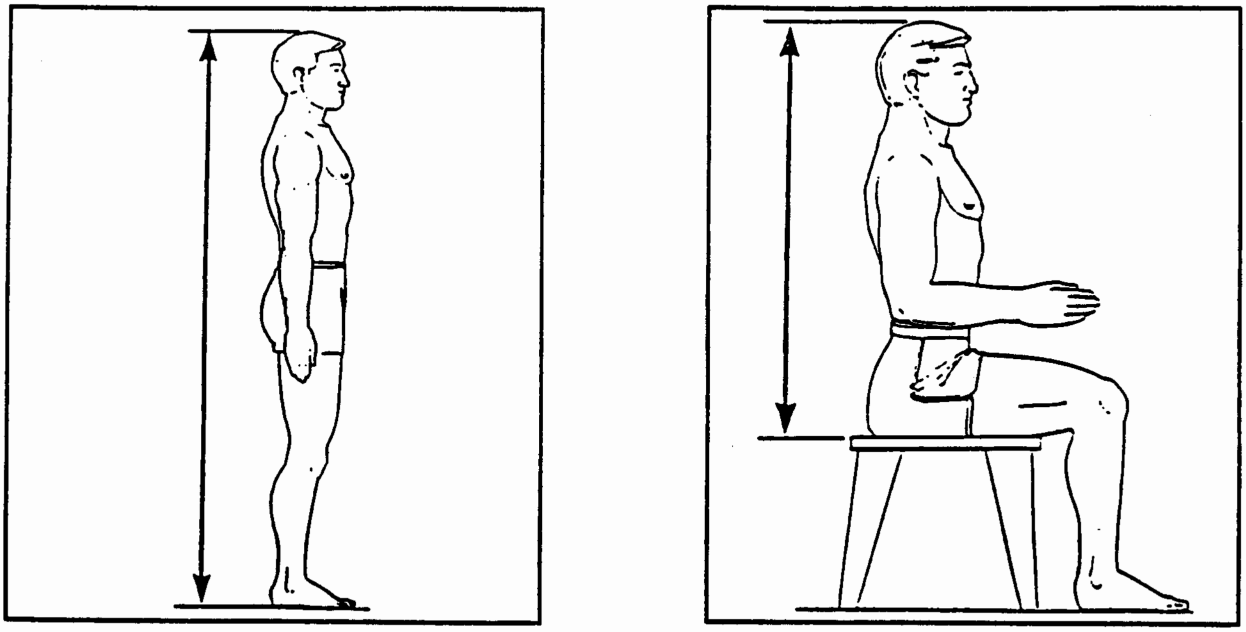
A questionnaire was also distributed to eleven additional AH-64 pilots to get a broader survey of pilot experience and insight into the problem and attributing variables. Pilot experience ranged from 40 to 1000 hours in the AH-64, with a mean time of 540 hours. Eight of the 11 experienced pain in the lower back region with pain beginning between 1 and 2 hours into a flight and persisting for some period after completion of the flight. Average mission duration was 2.8 hours.

Results of the interviews and survey are summarized below.

The Postural Problem

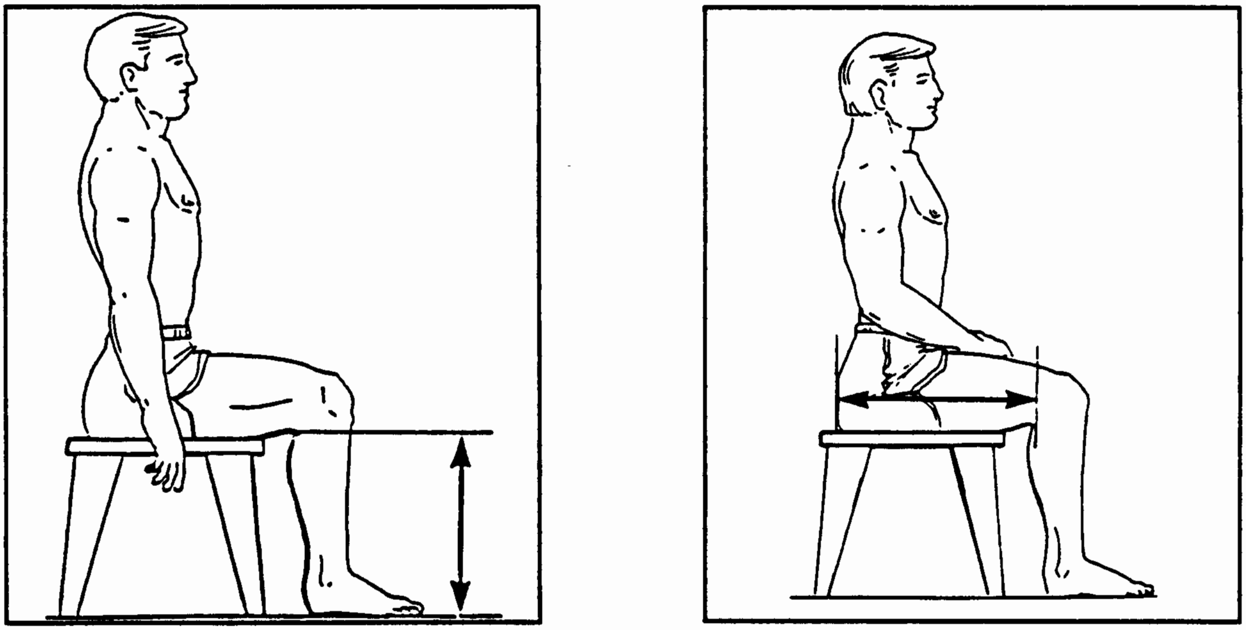
The primary factors leading to the hunched posture can be attributed to the following pilot goals: a) to improve forward visibility, b) to stabilize and maintain fine control of cyclic and rudder pedals, and c) to stabilize seated position. Posture is also significantly constrained by seat position, individual anthropometry, and the cockpit geometry.

Field of View. In the AH-64, external vision from the pilot position is obstructed by the structural beams of the canopy in front and slightly upward and to the sides, and by the gunner's head/helmet directly in front and slightly downward. The pilot seat also appears to provide less legroom and less head clearance to the canopy; hence, the crouching is more extreme than in the gunner's seat. A taller pilot will tend to crouch so that his view is unobstructed by the lateral canopy beam and also to ensure enough headroom for other scanning head movements. A taller pilot will also tend to have more flexed knees, due to limited forward adjustment of the rudder pedals, and will thus have higher, more unsupported thighs. Shorter pilots tend to adjust the seat up to attain a better field of view but then must lean down farther to reach the cyclic. Some of the latter use the



STATURE

SITTING HEIGHT



POPLITEAL HEIGHT

BUTTOCK-POPLITEAL LENGTH

Figure 3. Measurement of anthropometric dimensions.

lumbar support doubled over to shift the body forward to reach the cyclic. In the pilot position, a shorter aircrew has more of a problem with obstruction from the gunner's head, and will typically attempt to sit up straighter to see over the gunner's head.

Stabilization of Cyclic and Rudder Pedals. The cyclic, a floor-mounted control stick, is positioned between the thighs and curves toward the seat. Pilots tend to use their thighs as armrests to stabilize their right arms and to enable fine control using the wrist and forearm muscles. Since anthropometrically, the elbow rest height can be anywhere from 3 to 5 inches above the thigh, the pilot must lean down to support the forearm. This causes a distinct lateral bending of the pilot's torso to the right. Some pilots have used their kneeboards as armrests, but this is generally unsatisfactory since the kneeboard tends to roll to either side, destabilizing the forearm. Similarly, in an attempt to reduce the downward lean, pilots sometimes increase their knee flexion, which raises the thigh up off the seat pan and provides a comfortable platform for the forearm. This concentrates the pilot's weight on the ischial tuberosities, since the thighs are unsupported by the seat cushion.

Knee flexion is also increased due to the aircrew's tendency to pull their heels back so that they are braced on the floor with only the toes resting on the rudder pedals. Foot stability attained in this manner is important since flying, and especially hovering, requires fine and constant manipulation of the rudder pedals. If pilots raise their heels off the floor to place the balls of their feet on the pedals, the legs and feet are unsupported and have no local fulcrum about which to pivot, and instead must use the longer moment arm at the knees and hips to operate the rudder pedals. [The quadriceps muscle group controlling pivoting from the hip and knee are too gross and powerful to enable fine control of the pedals as needed in hovering]. Stabilizing the heels on the floor increases flexion of the knees, raises the thighs up off the seat, and tilts the pelvic girdle posteriorly, all of which contribute toward both flattening of the lumbar vertebrae and increasing pressure concentrated at the ischial tuberosities.

Stabilization of the Seated Posture. The pilots attempt to maintain a stable seated position by slouching, a mechanically stable yet uncomfortable posture. When the pilots slouch, the back curves, forming an arch. This slouching posture is more stable because more of the back and buttock surface areas are in contact with the seat, allowing less rocking and shifting of the pelvis. In particular, the posterior tilting of the pelvic girdle rolls the weight of the body onto the more shallow convexities of the ischial tuberosities, imposing a posterior torque to keep the posture static. Bracing the heels on the floor and arms against the thighs further rotates the pelvis posteriorly against the backrest to keep the pilot in a stable seated posture. It is not known whether seat-to-head vibrational transmission is an added inducement to maintain stability. While this is a stable position when the spine reaches its bending limit; the bending moment imposed on the spine by the vertical component of head and trunk weight, which are forward of the lumbar spine, results in fatigue and pain over time.

The adoption of the slouched posture may also be a habit learned from training or formed in another helicopter cockpit. To illustrate, in the UH-1, the cyclic is rather low and necessitates slouching in order to operate it. In the OH-58, the cyclic is comparatively farther forward and requires a slouched posture to grasp. When a new pilot trains with an experienced instructor, he may mimic the posture of his instructor, regardless of whether that posture is appropriate for him.

The Cockpit Geometry Problem

In the Apache, the gunner and pilot sit in tandem, with the gunner in front and the pilot behind and slightly above. The gunner has more legroom than the pilot and although the gunner also has more headroom, there is the appearance of less due to the steep slope of the canopy, when one assumes a hunched forward posture. In addition to the visual obstructions of the airframe and gunner, the position of the rudder pedals, and the height of the cyclic, the interior dimensions of the cockpit predispose certain anthropometric dimensions as more desirable for each station. The aircrew we interviewed stated that they prefer to have shorter aircrew (that is those with shorter sitting height and functional leg length) sit in the gunner position, even though taller aircrew fit the geometry there better. The taller aircrew (those with greater sitting heights and functional leg length) tend to prefer sitting in the pilot position because of the appearance of greater head room, which is still inadequate for some, but conversely prefer the increased legroom of the gunner position. In the pilot position, taller aircrew tend to have a problem with banged shins as the clearance between the lower edge of the instrument panel and the floor is less than in the gunner's position.

The Seat Cushion Problem

The current seat cushion suffers from a degradation of contouring and of the cushioning properties over time from hard use (cushions are often stepped on to enable ingress and egress). The seat pan is generally too short, leaving thighs unsupported for most of their length. The leading edge of the seat cushion does not have a waterfall contour. This may also contribute to discomfort for those who have legs short enough to allow them to extend their legs to reach the pedals and to rest their thighs on the cushion. The seat back cushion, although slightly contoured, is rather thin and flat. The Velcro-attached lumbar support is too thin in the middle section where support is most needed. The 13-degree seat back angle (18 degrees when hovering due to the additional 5-degree pitch attitude) itself should encourage a comfortable seated posture by allowing an open trunk-to-thigh angle. However, the position of the cyclic control, limited adjustment of the rudder pedals, and visibility requirements previously discussed all contribute to prevent increasing the trunk-to-thigh angle to a comfortable posture. Observation of pilots revealed that the thoracic portion of the seat back as well as the head rest are seldom used, and indeed, show little evidence of wear.

REVIEW OF LITERATURE: SEAT DESIGN

General Recommendations

Most recommendations from the literature regarding seat design addressed office and automotive applications. A great many researchers advocate encouraging lumbar lordosis by increasing the thigh to trunk angle either by reclining the seat back[26-28] or by sloping the seat pan toward the front.[29-31] Postural adjuncts (lumbar pads, headrests, armrests, footrests) and contouring have been found to distribute seated loads over greater surface areas, eliminating some pressure points.[10,32-35] Standards exist for comfortable postural angles (e.g., ANSI, CEN, DIN, BS standards) but do not consider the peculiar seated environment of the helicopter; however, Osinga and Schuffel[10] proposed new postural angles for helicopter pilots to replace those in the current MIL-STD-1333 Aircrew Station Geometry for Military Aircraft. Specific recommendations for seat design are:

Seat Pan. Seat pans should mold to the buttock contour, including lateral support, with a slight lowering with respect to the thigh, of the area supporting the ischial tuberosities and widening of seat toward front for thigh spread.[32] Seat depth should encourage lumbar and sacral contact with backrest. An optimal pressure distribution of 1.5 to 4.4 lb/in^2 (1 to 3 N/cm^2) pressure directly beneath ischial tuberosities, and 1.2 to 2.2 lb/in^2 (0.8 to 1.5 N/cm^2) for the remaining boundary area was suggested by Kurz et al[34] and by Weichenrieder and Haldenwanger.[36] The front edge of the seat should offer minimal resistance to reduce effort needed to operate pedals[37] and to avoid pressure on popliteal area by using a waterfall contour (ANSI/HFS 100-1988).

Backrest. Many researchers advocate the incorporation of lumbar support to backrests. Suggested locations range from the first sacral vertebrae (S1) to the fifth lumbar vertebrae (L5),[26] L4 to L5,[8] and at L3.[28,38] Bridger[30] advises supporting the top of sacrum in forward sloping seats to stabilize posture by resisting pelvic rotation. Contouring of the backrest should also follow the concavity in the shoulder region below the scapula (ANSI/HFS 100-1988). Kurz et al[34] recommends adjustable height and depth support of the iliac crest, lumbar lordosis, and cervical lordosis to adjust for differences in human torso lengths.

Armrests. Osinga and Schuffel[10] suggest stowable armrests to allow for convenient ingress and egress, and adjustable 15-25 cm above sitting surface. For the bent-forward sitting posture, they found armrests reduced the muscular activity in the neck-shoulder region.

Recommendations for Materials

Foams. Foams are used in seating applications to provide comfort (by distributing seated loads more evenly) and structure. Desirable comfort attributes include softness, conformability, water vapor permeability, durability, and good recovery after compression. Foams typically used in commercial furniture are not generally applicable in the helicopter environment which must also provide protection against fire, crashloads, and harsh environment. Rigid foams have been found to exhibit more desirable crashloading response than softer foams[18] and are recommend over honeycomb structures for that purpose. Rigid foams do not conform to the contours of the human body and create uncomfortable pressure points. Soft foams, such as foam rubbers, increase comfort by distributing pressure over a larger surface area,but as the thickness increases, the risk of spinal injury in crashes increases due to the phenomenon of dynamic overshoot. Viscoelastic or rate sensitive foams have been explored as a solution to the comfort/ crashloading dilemma, and found to exhibit good crashloading response as well as comfort.[18] Beach[6] using the Dynamic Response Index, found, however, that some viscoelastic foams may amplify some forces on the spine. An advantage of the high density foams, like viscoelastics, is that higher density is associated with greater tensile strength, elongation, cushioning, durability and lower compression set, which are all desirable attributes for a seating cushion.[39] A disadvantage is that as density increases, water vapor permeability decreases, which means that sweat vapor does not dissipate as easily, creating discomfort for the pilot. Kurz et al[34] have found that increasing the percent of perforation and bore/separation increases the water vapor permeability.

To address the vibration factor, Foley & Allemang[40] recommend using viscoelastics designed to vibrate at approximately the same frequency as that of the seat back to dampen vibration transmission. Courtney et al[41] assert that full foam seats dampen vibrations to the occupant better than steel spring seats because of the higher frictional resistance and lower resiliency of the foam matrix. Bead-filled foams were compared to spongy rubber foams in terms of vibration transmission,[42] but results were inconclusive.

Upholstery Fabrics. Kurz et al[34] provide a comprehensive list of desirable attributes for upholstery fabrics: should offer sufficient frictional resistance to prevent sliding, permit air circulation, be permeable to water vapor, and be tactually pleasant to the skin. Additional requirements for the helicopter environment include flame resistance and durability.

CONCEPT DEVELOPMENT

As the preceding review of literature indicates, the etiology of low back pain can be attributed to posture, vibration, and workload, all of which are influenced by the seat design, seat materials, and individual anthropometry. Resolving one factor in discomfort may exacerbate another: the use of a lumbar support to increase comfort through better posture may increase vibration transmitted through the seat back, which may degrade a pilot's performance,[21,24] and the transmissibility is a function of the materials of which the support is made, and the posture the pilot assumes. The dependent relationship of these variables requires an approach to concept development that considers the effect of each on the other.

In general, the results of the fact finding effort suggest that an improved seat cushion should:

> support a more correct posture, that is, eliminate the "helicopter hunch" by resisting rearward pelvic tilt, correcting the asymmetric tilt, resisting forward slump, and encouraging lumbar lordosis.
>
> be more comfortable by distributing pressure more evenly across the buttocks and thighs, and by accommodating a wider anthropometric range of thigh angles and lumbar curvatures.
>
> be compatible with the seat bucket, crewstation, crew tasks, and crewstation environment (extremes of temperature and humidity, oil and hydraulic fluid contamination, and frequency of use).
>
> be acceptable to the user by being easy to use and by not interfering with aircrew tasks, cyclic and rudder control stabilization, or normal ingress/egress.
>
> not adversely affect safety, including emergency egress and crashworthiness.

Eliminating the need to assume the lumbar-flattening slouched posture and encouraging an upright supported posture with lumbar lordosis would solve the postural problem of AH-64 pilots. Lumbar lordosis can be induced by increasing the trunk-to-thigh angle to about 105 degrees. Traditional approaches accomplish this objective by increasing the negative slope of the seat back, or by increasing the forward tilt of the seat pan. A computer accommodation study was conducted and found both approaches to be infeasible.

The measurements obtained from the AH-64 at Fort Eustis, Virginia, were used to create a three-dimensional computer model of the cockpit. Fifth and 95th percentile (stature) manikins were seated in that environment with appropriate positioning of the seat and rudder pedals. Right forearm position (cyclic control) and thigh clearance deviated greatly as the seat was adjusted to accommodate the two extreme aircrew sizes (see Figure 4).

Were it physically possible to tilt the seat back rearward, it would create an undesirable field of view. Tilting the seat pan forward, while actually improving field of view, is also not feasible because the seat bottom posterior would need to be built up, compromising both crashworthiness and headroom. Raising the seat higher and pushing the pedals forward improves lumbar posture, yet also creates incompatibilities: if the pilot is induced to sit higher and upright, eye position is moved away from the design eye point and headroom is consequently reduced, impeding the movement of the helmeted head and likely obstructing vision by the canopy structural beams. Thus, the crewstation geometry, hardware limitations of the current seats, and the pilot task requirements render seat angle changes infeasible.

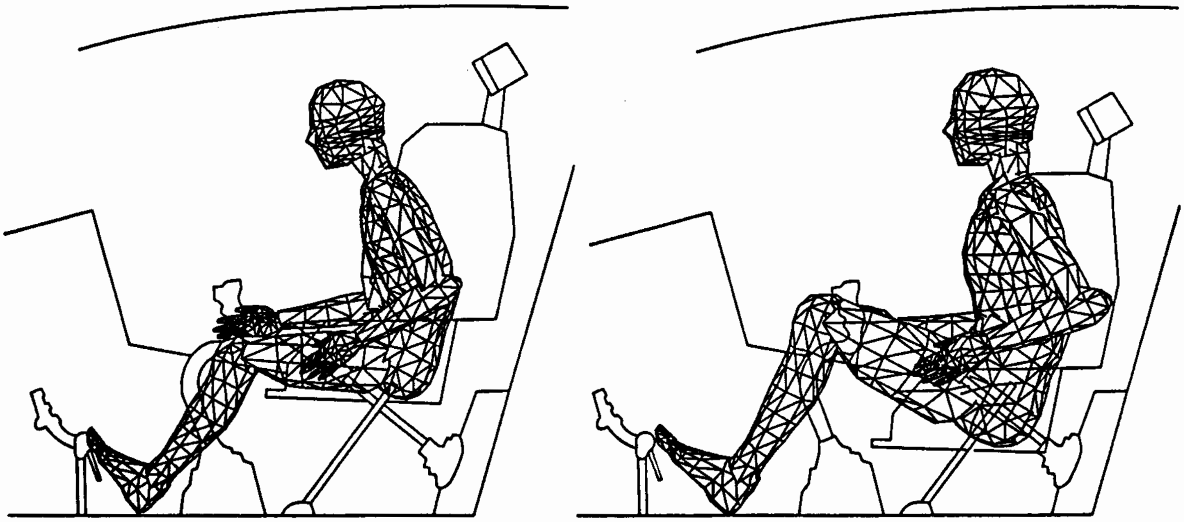


Figure 4. Aircrew accommodation study, 5th percentile (left), 95th percentile (right).

Since attempting to change the seat angle appears to create as many problems as it solves, a strategy of providing better support for the current posture and encouraging lumbar lordosis by means of a lumbar support should be adopted. The seat back should be contoured to provide lateral support and should provide an adjustable lumbar pad. Lumbar support location should be adjustable to accommodate central 90% of the pilot population. The seat pan should be contoured to evenly distribute pressure over the buttock and thigh area, and extended in length to support the lower thighs. An armrest should be provided to alleviate lateral trunk tilting, to cushion the forearm's pressure on the thigh, and to lessen the need for the thigh to be raised off the seat pan.

PRELIMINARY CONCEPTS

Postural Aids

To encourage a more correct posture for the aircrew, the following improvements to the seat cushion were proposed:

- an improved thigh support to reduce the pressure concentrations around the ischial tuberosities and distribute the weight across a wider area

- an improved lumbar support to encourage lumbar lordosis

- an arm rest to eliminate the lateral tilt on the spine and provide a stable platform for the forearm to maintain cyclic control.

Several variations of each component were considered, including (see Figures 5 through 7):

THIGH SUPPORT
- fixed contour
- inflatable bladder
- mechanical adjustment
- removable / invertible wedges

LUMBAR SUPPORT
- fixed contour, foam
- movable contour, foam; increased firmness and thickness compared with existing support
- inflatable, movable
- inflatable, fixed position; integrated within back cushion

ARM REST
- inflatable
- foam
- "bean bag"

Concepts proposed for initial fabrication and testing were selected based upon their accommodation of anthropometric extremes, ease of fabrication and integration with the seat and crewstation, safety (non-interference with ingress and egress), and non-duplication of concepts already being developed under other Army programs.

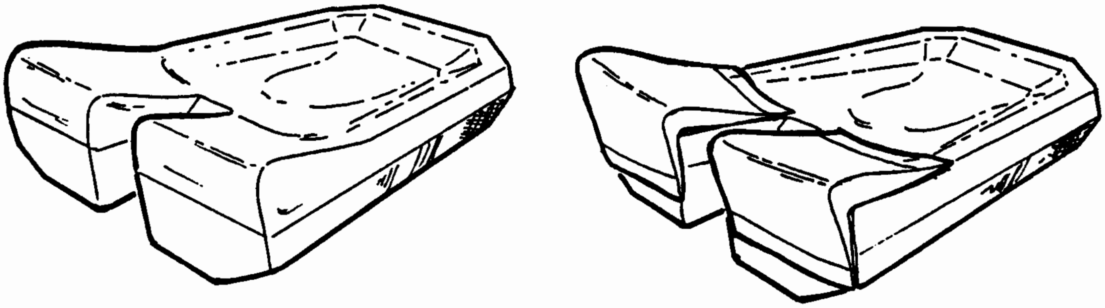
Bottom Cushion Composition

It was a practice throughout this program to change cushion properties, attributes, and materials only when improvements in comfort performance could be expected. Changes were made in the materials of the bottom cushion to improve pressure distribution, retain air and moisture permeability performance, and avoid compromising crashworthiness properties. However, the basic composition of the bottom cushion remained the same (see Figure 8). The top foam layer aided transport of air and moisture vapor between the top cover material and the middle foam layer. The energy absorbing middle foam layer assisted in evening pressure distribution by conforming to the shape of the thighs and buttocks and was perforated to assist in air and moisture vapor transport. The hard foam bottom layer provided a contour shape to minimize the thickness of the middle foam layer, and was grooved to allow air and moisture passing through the middle foam layer to escape. The following features were targeted for improving performance of the bottom cushion:

- Improve the thermal comfort properties (air and moisture permeability) of the cover fabric.

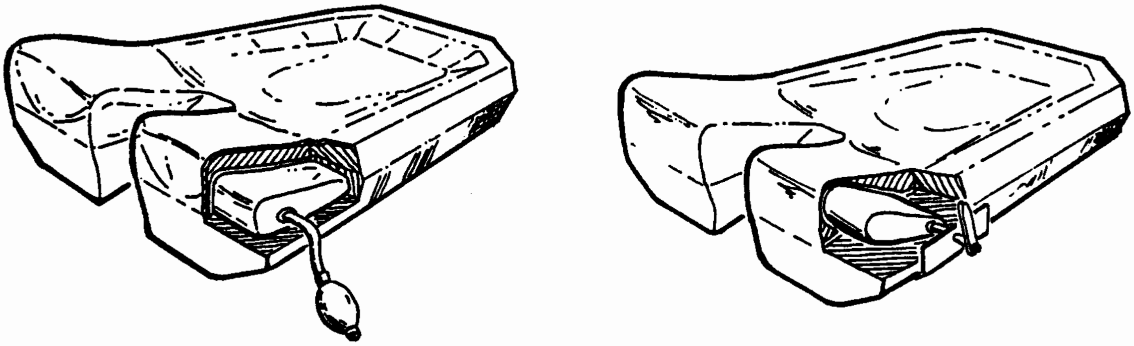
- Increase the thickness of the energy absorbing layer of foam to improve pressure distribution without compromising crash protection.

- Increase the hardness of the bottom contouring foam to compensate for any loss in crash protection caused by increasing the thickness of the middle layer of foam.



FIXED CONTOUR

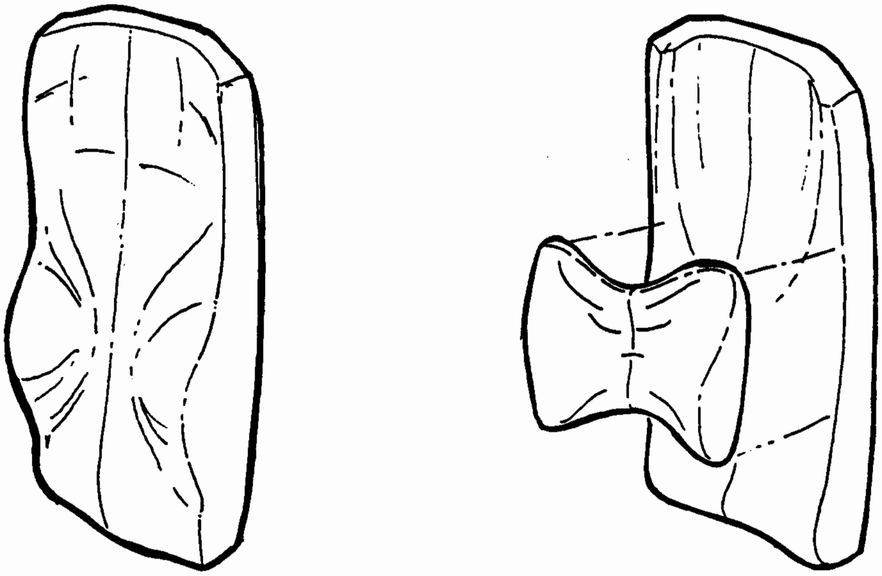
REMOVABLE/INVERTIBLE WEDGES



INFLATABLE ADJUSTMENT

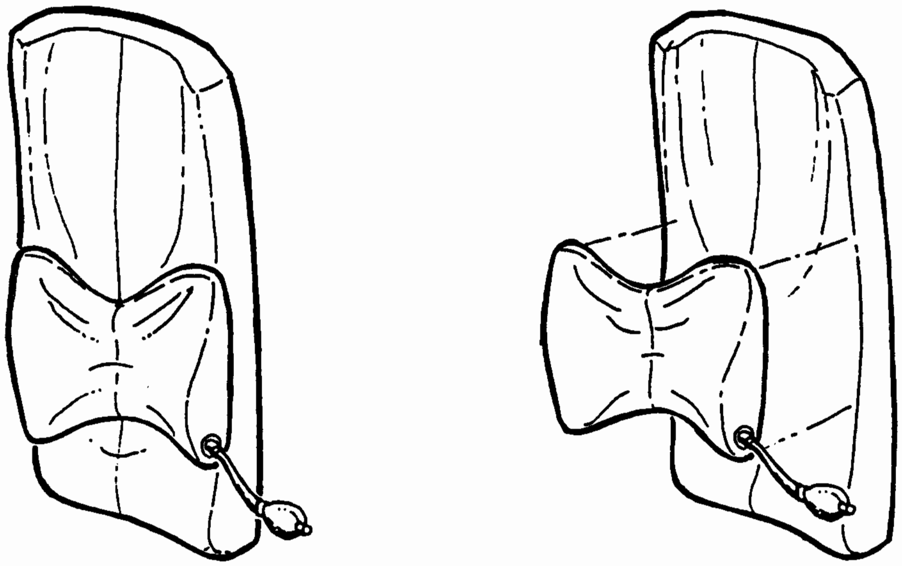
MECHANICAL ADJUSTMENT

Figure 5. Seat bottom / thigh support preliminary concepts.



FIXED LUMBAR CONTOUR

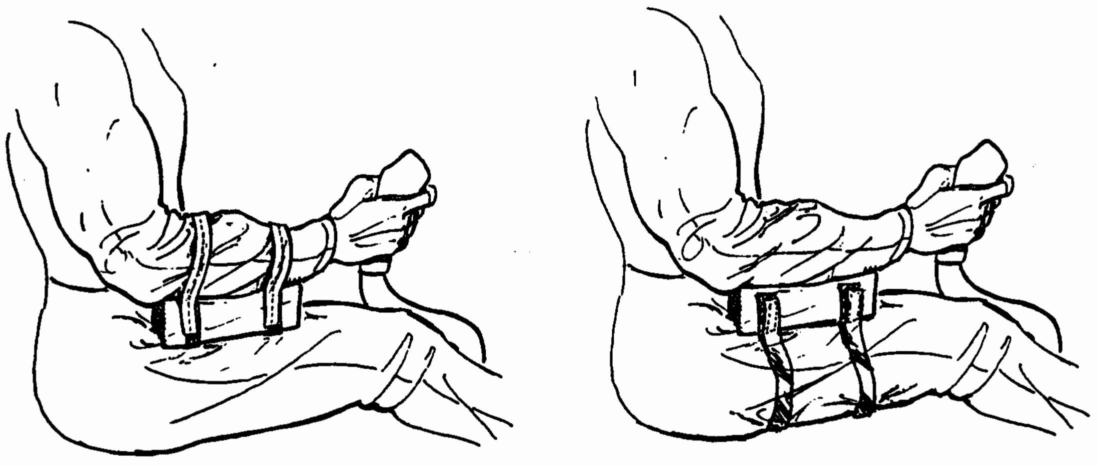
ADJUSTABLE LUMBAR CONTOUR



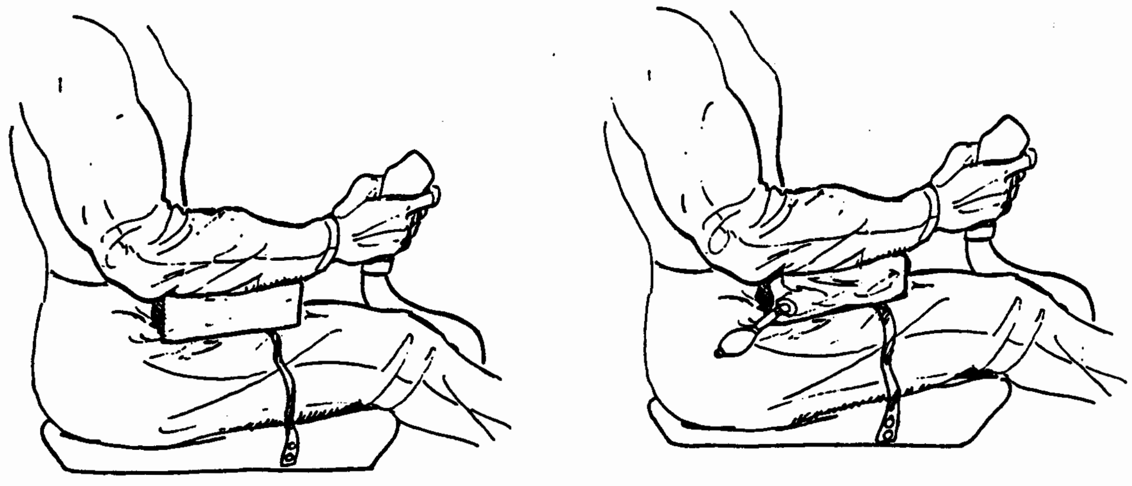
INFLATABLE LUMBAR (FIXED)

INFLATABLE LUMBAR (ADJUSTABLE)

Figure 6. Seat back / lumbar support preliminary concepts.

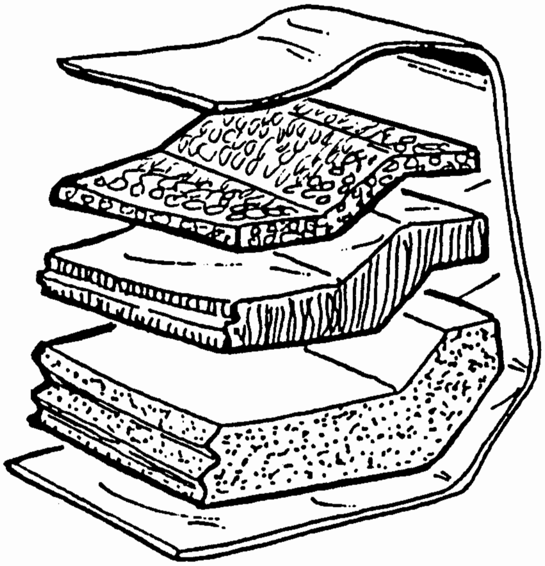


FOAM SUPPORT ON ARM **FOAM SUPPORT ON LEG**



BEAN BAG SUPPORT ON SEAT **INFLATABLE SUPPORT ON LEG**

Figure 7. Arm support preliminary concepts.



DURABLE FABRIC
BREATHABLE/WICKING

SOFT FOAM FOR
CUSHIONING COMFORT

PLIABLE FOAM FOR
ENERGY ABSORPTION

RIGID FOAM FOR
SUPPORT AND CONTOUR

Figure 8. Seat bottom cushion composition.

MATERIAL SURVEY / SELECTION

Soft Foam Top Layer

The purpose of the top foam layer is to facilitate air and moisture vapor transport away from the cover and through to the middle foam layer. A thickness of 1/4 to 3/4 inch should be sufficient to resist tearing without adding bulk to the cushion which may increase the overall compressed thickness measurement. A generic polyurethane open-cell foam with a 25% indentation force deflection of 30 to 50 pounds is considered adequate to satisfy these requirements as demonstrated by the existing cushions in the AH-64 Apache and UH-60 Blackhawk helicopters.

Soft Foam Middle Layer

It was determined that desirable characteristics of the soft foam to be used in the construction of seat cushion components include comfort, durability, safety, and crashworthiness. Over 20 vendors were contacted for samples and literature on foams and the properties of approximately 30 product lines were compared. Force deflection, strength, and energy absorption properties were used as initial screening criteria, and many foams were eliminated from further consideration. The remaining soft foams were characterized in more detail according to the following parameters:

COMFORT:
- force/load deflection (within comfort range for specified thickness)
- compression set (low)
- moisture vapor permeability (high)
- air permeability (high)
- vibration absorption (high)

ENVIRONMENTAL:
- durability (high tear strength, high tensile strength, low fatigue, and high density)
- thermal stability (high at low and high temperature extremes)
- chemical (petroleum, oil, lubricants) resistance (high)
- fungus/microorganism resistance (high)

SAFETY:
- flammability (low off-gassing and melt/drip)
- crashworthiness (high energy absorption, rate sensitive force deflection, and low rebound resilience)

Since the test methods used by the various vendors vary considerably, a qualitative assessment of each foam's properties was made for comparison purposes. Results of this assessment of the foams remaining after the initial scanning are provided in Table 2. Following comparison of the available data, the two leading candidates (Sun Mate and Confor) were subjected to further testing and evaluation. Final selection of foam variety and grade was based upon analysis of laboratory tests and measurements, the fit and function evaluation, the comfort evaluation, and the drop tests.

Hard Foam Bottom Layer

Desirable characteristics of the hard/structural foam for the bottom contour layer focused primarily on safety and environmental resistance. One candidate was examined from each of three different classes of polyurethane foams (rigid, linear, and modified). A qualitative comparison of their characteristics was made based upon the following properties (see Table 3):

SAFETY:
- compression/load deflection (high)
- resiliency/ elasticity (low)
- flammability (low)

ENVIRONMENTAL:
- durability (high)
- thermal stability (high at high temperatures)
- chemical (petroleum, oil, lubricants) resistance (high)
- fungus/microorganism resistance (high)
- humidity resistance (high)

Following inspection of foam samples, it was determined that Last-a-foam was too brittle and did not recover its shape after small dents and bumps, and the Illbruck foam was difficult to bond to the soft foams. Hence, Sun Mate T50E was selected for fabrication of the prototype bottom cushions.

Cover Fabrics

Desirable characteristics of fabrics for the cushion components focused primarily on comfort, safety, and environmental resistance. Most of the synthetic fabrics sampled and examined had either poor friction, air/moisture permeability, or flammability properties. A qualitative comparison of final candidate materials was made based upon the following properties (see Table 4):

COMFORT:
- vapor permeability (high)
- air permeability (high)

ENVIRONMENTAL:
- durability (high)
- chemical (petroleum, oil, lubricants) resistance (high)
- fungus/microorganism resistance (high)

SAFETY:
- thickness (low; overly thick could exacerbate dynamic overshoot in crash situations)
- friction (high; low friction could facilitate pelvic rotation and submarining beneath lap belt)
- flammability (low)

Due to program emphasis on comfort factors, sheepskin and wool honeycomb were chosen for fabrication of the prototype cushions.

TABLE 2. COMPARISON OF CANDIDATE SOFT FOAM PROPERTIES

CANDIDATES ATTRIBUTES	CONFOR CF-40	CONFOR CF-42	FOAMEX M180-39	E200/U POLYURETHANE ETHER	SUN-MATE POLYURETHANE ELASTOMERIC	PUDGEE
COMFORT						
Indentation Load Deflection	4 IFD	8 IFD	36± 3 ILD	28± 3 ILD	3-5 IFD (est)	2-4IFD (est)
Vibration Absorption	GOOD	GOOD	POOR	POOR	GOOD	GOOD
Vapor Permeability	MODERATE	MODERATE	GOOD	VERY GOOD	MODERATE	POOR
Air Permeability	GOOD	GOOD	VERY GOOD	VERY GOOD	MODERATE	POOR
Compression Set	2.4%	1.0%	10%	7%	Varies w/Grade	UNKNOWN
SAFETY						
Energy Absorption	99%	99%	55% (est)	55%	90%	90% (est)
Flammability	VERY GOOD	VERY GOOD	VERY GOOD	GOOD	GOOD	UNKNOWN
ENVIRONMENTAL						
Durability	MODERATE	GOOD	MODERATE	UNKNOWN	VERY GOOD	UNKNOWN
Thermal Stability	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	GOOD	GOOD
Chemical Resistance	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN
Fungus/Microorganism Resistance	GOOD	GOOD	UNKNOWN	UNKNOWN	UNKNOWN	GOOD
DENSITY/WEIGHT	5.8 PCF	5.7 PCF	1.7 PCF (min)	2.0 PCF	5.5 PCF	20 PCF

IFD = Indentation Force Deflection
ILD = Indentation Load Deflection
SF = Square Foot
PCF = Pounds Per Cubic Foot

TABLE 3. COMPARISON OF CANDIDATE HARD FOAM PROPERTIES

ATTRIBUTES / CONCEPTS	LAST-A-FOAM FM-3706 RIGID POLYURETHANE	ILLBRUCK D-400 LINEAR POLYURETHANE	SUN MATE T 50E MODIFIED POLYURETHANE
SAFETY			
Compression/Load Deflection	VERY GOOD	GOOD	GOOD
Resilience/Elasticity	VERY GOOD	GOOD	GOOD
Flammability	GOOD	UNKNOWN	GOOD
ENVIRONMENTAL			
Durability	MODERATE	VERY GOOD	GOOD
Thermal Stability	VERY GOOD	GOOD	VERY GOOD
Chemical Resistance	VERY GOOD	UNKNOWN	UNKNOWN
Fungus/Microorganism Resistance	VERY GOOD	VERY GOOD	UNKNOWN
Humidity Resistance	GOOD	VERY GOOD	GOOD
DENSITY/WEIGHT	GOOD	VERY GOOD	GOOD

TABLE 4. COMPARISON OF CANDIDATE FABRIC PROPERTIES

ATTRIBUTES / CANDIDATES	NOMEX HONEYCOMB	WOOL HONEYCOMB	SHEEPSKIN SHORT
COMFORT			
Vapor Permeability	MODERATE	GOOD	GOOD
Air Permeability	MODERATE	MODERATE	GOOD
ENVIRONMENTAL			
Durability	VERY GOOD	VERY GOOD	GOOD
Chemical Resistance	GOOD	UNKNOWN	UNKNOWN
Fungus/Microorganism Resistance	GOOD	UNKNOWN	UNKNOWN
SAFETY			
Thickness	GOOD	GOOD	GOOD
Friction	GOOD	GOOD	GOOD
Flammability	VERY GOOD	GOOD	GOOD

MATERIALS TESTING / MEASUREMENTS

Not all foam vendors were able to provide the data specific to our selection criteria, and many vendors chose different testing methods to quantify the characteristics of their foams. In order to provide a more comprehensive and equitable comparison of the candidate foam properties, additional tests were performed. The three candidate foams selected from the trade study were subjected to laboratory tests to compare their durability properties. Force deflection properties were also measured to select appropriate densities from each family of foam and to aid in determining the appropriate final cushion thickness. Finally, mock-up cushions of varying densities were compressed under a 95th percentile weight anthropomorphic manikin to measure the compressed cushion thickness for comparison with MIL-S-58095 criteria. Details of these tests and measurements are provided below.

DURABILITY

Durability tests were conducted by the United States Testing Company, Inc., Fairfield, New Jersey. Force deflection, roller shear, and heat aging tests were conducted in accordance with ASTM D3574-91. The samples tested were 15 x 15 x 1 inches in size. The following three foams were tested:

Foamex M180-30
Sun Mate T38E (soft)
Confor CF 40

Tests were conducted in the following order:

Test B_1 - Indentation Force Deflection (IFD) at 25%, 45%, and 65% deflection

Test K - Dry Heat Aging, 22 hours at 140C

Test B_1 - IFD at 25%, 45%, and 65% deflection

Test I_2 - Dynamic Fatigue by Roller Shear, 8,000 cycles

Test B_1 - IFD at 25%, 45%, and 65% deflection

The percent decrease in IFD was calculated after heat aging and after roller shear. Results are summarized in Figures 9 and 10. The figures indicate that although Foamex showed little loss in IFD following heat aging, the combined effect of heat aging and roller shear was greatest for that foam. Combined effects were less for both Confor and Sun Mate foams, with Sun Mate performing best overall.

All foam samples suffered tears during the roller shear test (see Figure 11). Tearing was most severe for the Confor foam (7 inch tear).

FORCE DEFLECTION CURVES

Force deflection was measured by compressing a 2-inch-thick (6 x 6 inch square) foam sample with a 10-square-inch circular disk. Force was measured at 55%, 65%, 75%, and 85% compression using a Chatillon force gauge. Pressure versus percent compression was calculated and plotted for each foam. Results are shown in Figure 12. Softer foams are characterized by lower force deflection curves.

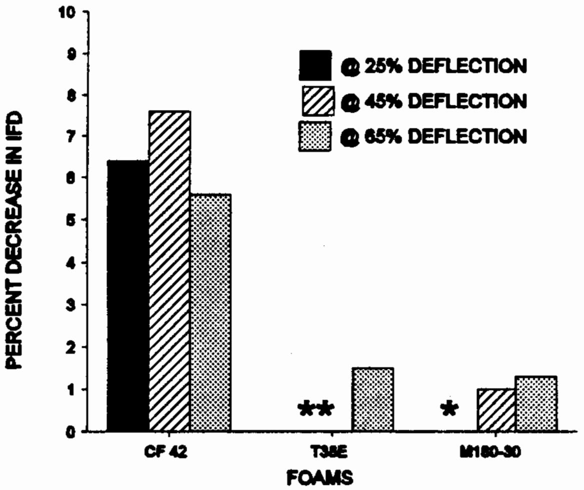


Figure 9. Percent loss in IFD following heat aging.

*Decrease in IFD was 0%.

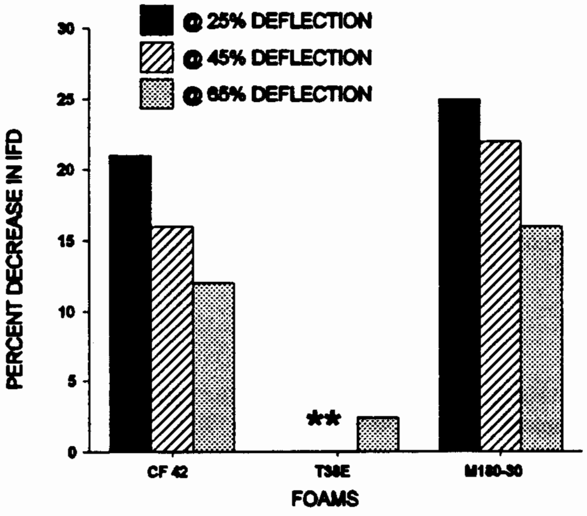
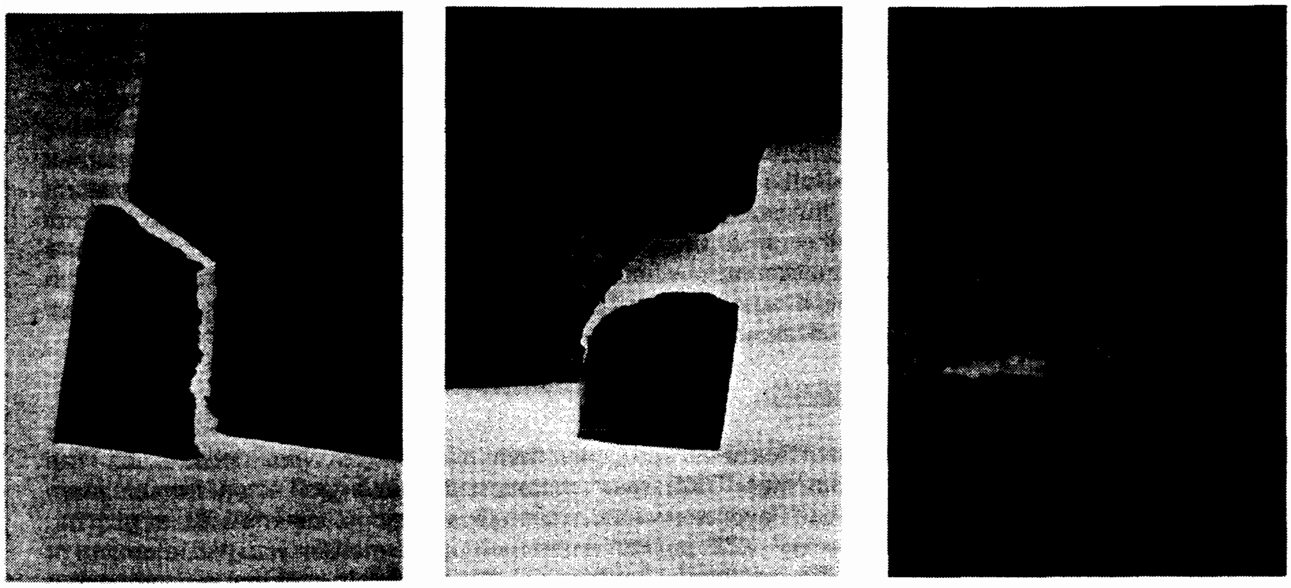


Figure 10. Percent loss in IFD following heat aging and roller shear.

* Decrease in IFD was 0%.



FOAMEX
M180 - 30

SUN MATE
T38E

CONFOR
CF 40

Figure 11. Post-test photographs of foam samples.

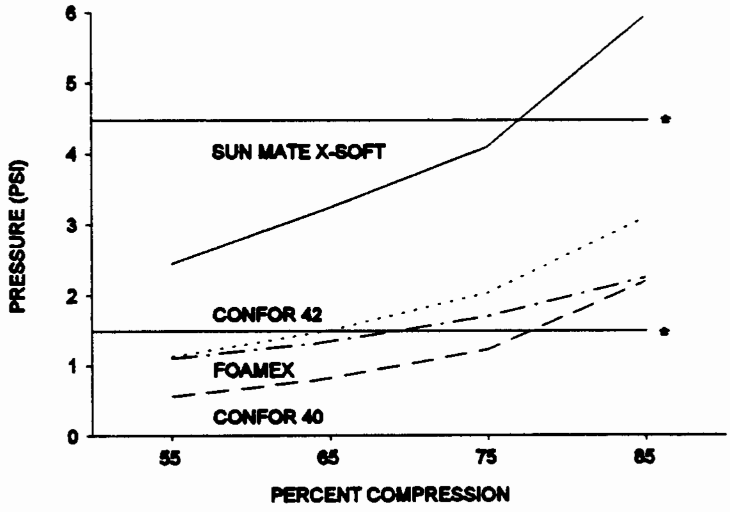


Figure 12. Force deflection curves for varioius density foams.

*1.5 to 4.4 psi is suggested pressure beneath ischial tuberosities for comfort.[34,36]

Obviously a very thick, very soft foam bottom cushion would be comfortable, but this would either raise the location of the seat reference point or reduce air and moisture permeability due to overcompression. To avoid too thick a cushion, a balanced trade-off between foam density and thickness is required. Limiting foam thickness to some reasonable amount requires increasing the density to avoid bottoming-out and overcompressing the foam. When a foam is too soft, it will be overcompressed, pressure will build up beneath the points of deepest penetration and the foam may not provide support at surrounding peripheral areas of the buttocks and thighs. Two of the foams here exhibit load deflection properties which satisfy two important criteria: 1) 1.5 to 4.4 psi beneath the ischial tuberosities and 2) maximum 75% compression to retain moisture and vapor permeability properties. Given the variance of body contours and weight of seat occupants, it is not feasible to analytically determine whether all of the density, pressure, and thickness characteristics are concurrently satisfied. It still remains a question as to whether a 1.5-inch thickness is sufficient to support the peripheral areas of the buttocks and thighs at a pressure of 1.2 to 2.2 psi. Of course the bottom contour layer and the thigh support both should aid in distributing the weight/pressure in this way.

COMPRESSION THICKNESS (MIL-S-58095)

Seat bottom cushion prototypes comprised of Sun Mate and Confor foam middle layers were constructed. The prototype cushions consisted of a rigid (Sun Mate T50E) foam contour bottom layer and a conformable foam upper layer. The thickness of the upper foam layer was varied systematically and no cover fabrics or bonding adhesives were used. A 95th percentile weight (223 pounds) anthropomorphic manikin was placed on top of each cushion in an Apache seat bucket. The height of a landmark on the manikin lower torso was measured with and without the prototype cushion in place. The net compressed thickness of each cushion was determined by averaging the height difference on three successive trials. The rigid bottom contour layer and the baseline existing Apache seat bottom cushion were also measured. The compressed thickness of each cushion is shown in Table 5.

TABLE 5. COMPRESSED THICKNESS OF PROTOTYPE BOTTOM CUSHION FOAMS

FOAM TYPE	FOAM THICKNESS (in)	COMPRESSED THICKNESS (in)[a]
Confor CF42	2.0 2.0 plus Foamex (1 in) 1.0 plus Foamex (1 in)	1.0 1.0 0.75[b]
Sun Mate T36E (x-soft)	1.0 1.5 1.5 plus Foamex (1 in)	0.75 0.875 0.95[b]
Apache (existing)	Actual	0.75
Sun Mate T50E (Contour Only)	N/A	0.63

a MIL-S-58095 criterion for compressed thickness is 0.5 to 0.75 inch.

b The effect of adding a 1-inch layer of Foamex M180-44 foam to either the Sun Mate or Confor foam was found to be minimal.

The compressed thickness of all foam combinations was greater than or equal to 0.75 inch. This exceeds MIL-L-58095 criteria of 0.5 to 0.75 inch; however, this difference was caused primarily by the geometry of the manikin pelvis/buttocks area. The anthropomorphic manikin used had a 7-inch separation of the ischial tuberosities with a radius of curvature of 5 inches, whereas MIL-S-58095 specifies a separation of 4 inches and a radius of 3 inches. The difference in separation and radius combined causes the buttock contour to make maximum compression at a distance of 3.5 inch rather than 2 inches from the center line. The rigid foam contour bottom layer is 0.25 inch thicker at 3.5 inches from the center line compared with 2 inches from center line. The use of a standard body block would have resulted in compression thickness of all foam combinations being within acceptable 0.5 to 0.75 inch thickness.

FIT AND FUNCTION EVALUATION

INTRODUCTION

A fit and function evaluation was conducted to (1) determine the appropriate size(s) for each of the seat cushion components and (2) obtain subject matter expert (SME) inputs regarding helicopter crewseat cushion component designs in terms of functionality and compatibility.

Various sizes of prototype thigh supports, arm supports and lumbar supports were examined, along with associated seat cushions and back cushions, and were compared with the current seat cushion components in an iterative fashion, to assess proposed designs in a comparative manner. Subjective and objective data were collected using test subjects who ranged greatly in key body dimensions.

METHOD

Ten individuals, eight male and two female, served as test subjects for this evaluation. Two of the males were also experienced helicopter pilots and served as SMEs. Test subjects were selected so as to span the anthropometric range of the 1988 U.S. Army Aviator population.[43]

The following test equipment was used:

A. Test Fixture - A crewstation mock-up was fabricated for this evaluation and included a cyclic, collective, rudder pedals, and seat with single point release harness. All items represented actual AH-64 components in terms of geometry and adjustment range. Seat and cyclic hardware were actual AH-64 helicopter hardware. Other test fixture components were reproduced to full scale. The existing lumbar pad and seat cushion were included in the evaluation for comparison with prototype components.

B. Anthropometric Measuring Equipment - An anthropometer (convertible for use as a sliding caliper) and a digital scale were used for making anthropometric measurements of test subjects prior to testing.

C. Prototype Components- including four sizes of thigh supports, five sizes of arm supports and two sizes of lumbar supports as described:

Each thigh support consisted of a hard foam wedge covered by a soft foam leading edge waterfall. The resultant height above the seat buttock reference point (MIL-STD-1333) and the steepness of each wedge are shown in Table 6.

Both lumbar supports were made of a firm foam with a 10-inch radius of curvature. The small support was 1 inch thick and the large support was 1.5 inches thick.

Each arm support consisted of a thigh contour made of firm foam, an arm contour made of extra-soft foam, and a wedge insert made of hard foam. The thickness and taper angles of each insert are listed in Table 7.

TABLE 6. HEIGHT AND THICKNESS OF THIGH SUPPORT WEDGES

WEDGE	HEIGHT ABOVE BUTTOCK REFERENCE POINT (in)	STEEPNESS ANGLE (deg)
LOW	4.8	15
MED-LOW	5.3	21
MED-HIGH	5.8	28
HIGH	6.3	34

TABLE 7. THICKNESS AND TAPER OF ARM SUPPORT INSERTS

		TAPER	
INSERT	HEIGHT (in)*	FORE-AFT (in)	LEFT-RIGHT (in)
1	1.0	0.5	0.25
2	1.5	0.75	0.5
3	1.75	0.75	1.25
4	1.75	1.25	0.75
5	2.5	1.5	1.5

*Height is combined of all layers.

The following procedures were utilized during each test session:

1. At the start of each session the test subject's anthropometric dimensions were physically measured in accordance with the procedures of Gordon and Donelson,[43] and other necessary parameters (e.g., gender, age) were recorded.
2. Seat ingress and donning of the harness were performed.
3. Subject was positioned to the Design Eye Position.
4. Rudder pedals were adjusted to an appropriate position.
5. Seat position and rudder pedal position were recorded.
6. Prototype thigh supports, arm supports and lumbar supports were sequentially presented, with each test subject asked to subjectively evaluate several design characteristics of each component and identify each characteristic as acceptable or unacceptable. Following presentation of all prototypes of a component, each subject was asked to rank-order their preference of the prototypes. The questionnaire shown as Appendix A was administered during each test session.
7. Video recordings and stills photos were made during each test session.

RESULTS

Test subject anthropometric data and associated percentile equivalents are contained in Table 8. All data recorded on questionnaires were summarized and entered into a spreadsheet for data reduction and analysis. Anthropometric measurements, initially recorded in centimeters, were converted to the nearest tenth-inch.

Data collected during the test sessions are summarized in Table 9 and further detailed in Tables 10 through 12. Tables 10 through 12 each address a specific component and contain information pertaining to subject ID and gender, related anthropometric data, seat and pedal position data, and each subject's preferences regarding specific design parameters. The prototype rankings are shown by subject for each component.

TABLE 8. TEST SUBJECT ANTHROPOMETRY
(Dimensions in inches, weight in pounds)

SUBJECT ID	1	PERCENTILE[a]	2	PERCENTILE[a]	3	PERCENTILE	4	PERCENTILE
GENDER	F		F		M		M	
STATURE	61.4	<1 (<1M)	64.3	14 (2M)	74.2	96	72.3	84
WEIGHT	119	8 (<1M)	144	54 (6M)	177	54	206.5	91
SITTING EYE HEIGHT	28	2 (1M)	30.6	62 (15M)	33.3	87	32.1	56
ELBOW REST HEIGHT	7.7	6 (4M)	9.8	78 (61M)	8.3	10	8	7
BUTTOCK-POPLITEAL LENGTH	18.3	7 (4M)	19.1	37 (26M)	21.3	92	20.2	68
POPLITEAL HEIGHT	14.9	8 (1M)	14.8	5 (<1M)	18.6	94	17.6	81
BUTTOCK-LEG LENGTH	38.8	b	40.9	b	49.3	b	45.6	b
SEAT POSITION + Up (Distance from Neutral) - Down	2.53		0.63		-1.9		-1.27	
PEDAL POSITION (Distance from Full Aft)	Full Aft		+1		Full Fwd		Full Fwd	

SUBJECT ID	5	PERCENTILE	6	PERCENTILE	7	PERCENTILE	8	PERCENTILE
GENDER	M		M		M		M	
STATURE	64	2	68.3	29	64.9	3	67.4	19
WEIGHT	149	9	238	99	171.5	44	200.5	86
SITTING EYE HEIGHT	29.8	6	30.8	18	29.4	4	31.1	25
ELBOW REST HEIGHT	10.1	73	9.3	39	8.1	8	9.7	57
BUTTOCK-POPLITEAL LENGTH	18.1	3	20	61	17.8	1	19	22
POPLITEAL HEIGHT	14.9	1	16.7	39	14.8	<1	15.6	5
BUTTOCK-LEG LENGTH	39.6	b	43.6	b	41.5	b	42.1	b
SEAT POSITION + Up (Distance from Neutral) - Down	2.53		-0.63		1.27		-0.63	
PEDAL POSITION (Distance from Full Aft)	+4.25		Full Fwd		+2		+1	

TABLE 8. TEST SUBJECT ANTHROPOMETRY (CONT'D)
(Dimensions in inches, weight in pounds)

SUBJECT ID	9	PERCENTILE	10	PERCENTILE	1988 ARMY ANTHROPOMETRIC SURVEY[43]		
GENDER	M		M		5% Female	5% Male	95% Male
STATURE	70.6	63	71.7	78	63.45	65.49	73.92
WEIGHT	192	77	183	64	115.81	143.7	213.77
SITTING EYE HEIGHT	31.7	43	33.3	87	28.46	29.71	33.95
ELBOW REST HEIGHT	9.7	57	8.6	16	7.67	7.91	11.1
BUTTOCK-POPLITEAL LENGTH	20.8	84	19.1	26	18.23	18.32	21.53
POPLITEAL HEIGHT	17.7	78	17.8	81	14.8	15.61	18.63
BUTTOCK-LEG LENGTH	45.7	b	45.4	b			
SEAT POSITION + Up (Distance from Neutral) - Down	-0.63		-1.27				
PEDAL POSITION (Distance from full Aft)	Full Fwd		Full Fwd				

[a] Male equivalent percentile shown in parentheses.

[b] Buttock-Leg length not included in the 1988 Army Anthropometric Survey.[43]

TABLE 9. SUBJECT PREFERENCES

SUBJECT ID	1	2	3	4	5	6[a]	7[a]	8	9	10
THIGH SUPPORT										
HEIGHT	MED-HIGH	MED-LOW	MED-LOW	HIGH	LOW	MED-HIGH	LOW	MED-LOW	MED-HIGH	MED-LOW
ANGLE	MED-HIGH	MED-HIGH	MED-LOW	HIGH	MED-LOW	MED-HIGH	LOW	MED-LOW	MED-HICH	MED-LOW
ARM SUPPORT										
HEIGHT	MED-LOW	LOW	LOW	LOW	HIGH	ALL TOO HIGH	LOW	MED-HIGH	MEDIUM	ALL TOO HIGH
TAPER	MED-HIGH	LOW	LOW	LOW	HIGH	MED-HIGH	LOW	MED-HIGH	MED-HIGH	MEDIUM
LUMBAR SUPPORT										
THICKNESS	LARGE	BASE	SMALL	LARGE	LARGE	BASE	SMALL	BASE	SMALL	SMALL
WIDTH	LARGE	BASE	SMALL	SMALL	LARGE	BASE	BASE	BASE	SMALL	SMALL
POSITION[b]	10	14.5	8.75	13	9.25	12	10.5	12	15	10.75

[a] Subject Matter Expert.
[b] Inches above seat bucket.

TABLE 10. THIGH SUPPORT RANKINGS
(1 = best)

SUBJECT ID	1	2	3	4	5	6	7	8	9	10
HEIGHT										
LOW (4.8 in)	4	2	3	4	1	3	1	4	3[a]	4
MED-LOW (5.3 in)	2	1	1	3	3[b]	2	2[b]	1	2	1
MED-HIGH (5.8 in)	1	3	2	2	4	1	3	3	1	2
HIGH (6.3 in)	5[b]	4	4	1	5[b]	4	4[b]	2	4	3
STANDARD (3.6 in)	3	5	5	5	2	5	5	5	5	5[a]
ANGLE										
LOW (15 DEGREES)	3	3	3	4	2	3	1	4	4[c]	4
MED-LOW (12 DEGREES)	2	4	1	3	1[d]	2	2[d]	1	3	1
MED-HIGH (28 DEGREES)	1	1	2	2	3	1	4	3	1[c]	2
HIGH (34 DEGREES)	4[d]	2	4	1	4[d]	4	3[d]	2	2	3

[a] Unacceptably low
[b] Unacceptably high
[c] Unacceptably shallow
[d] Unacceptably steep

TABLE 11. ARM SUPPORT RANKINGS
(1 = best)

SUBJECT ID	1	2	3	4	5	6	7	8	9	10
HEIGHT										
LOW	4	1	1[a]	1	5[b]	1[a]	1	2	5	1[a]
MED-LOW	1	2	2[a]	2	3[b]	2[a]	3	4	2	2[a]
MED	3	3	3[a]	3	4[b]	3[a]	2	3	1	3[a]
MED-HIGH	2	4	4[a]	4	2	4[a]	4[a]	1	3	4[a]
HIGH	5	5	5[a]	5[a]	1	5[a]	5[a]	5	4[a]	5[a]
TAPER[e]										
LOW	3	1	1	1	4	2	1	2	4	4
MED-LOW	2	2	2	2	3	3[d]	2	4[d]	3	5[d]
MED	4	3	3	3	5	4[c]	3[c]	3	2	1
MED-HIGH	1	4	4	4	2	1	4[c]	1	1[c]	3
HIGH	5	5[c]	5[d]	5[c]	1	5[c]	5[c]	5	5[c]	2

[a] Unacceptably high
[b] Unacceptably low
[c] Unacceptably steep
[d] Unacceptably shallow
[e] See Table 7

TABLE 12. LUMBAR SUPPORT RANKINGS

SUBJECT ID	1	2	3	4	5	6	7	8	9	10
THICKNESS										
LARGE	1	3[a]	2[a]	1	1	3[a]	3[a]	3[a]	2	2[a]
SMALL	2	2[a]	1	2	2	2	1	2	1	1
STANDARD[a]	3[b]	1	3	3	3	1	2[b]	1	3[b]	3
WIDTH										
LARGE	1	3	2	3[d]	1	2	3[c]	3[c]	3[c]	2
SMALL	2	2	1	1[d]	2	3	2[c]	2	1	1
STANDARD[a]	3	1	3	2	3	1	1	1	2[d]	3

[a] Dimension varies with shape of the lumbar support. Component is wide and thick at the ends and narrow / thin in the center.

ANALYSIS

Although the data shown in Tables 10 through 12 meet the minimum requirements for the Analysis of Variance Fixed Effects model, these type of analyses are of limited value in this application. With each data set being bounded and containing objective rank data consisting of discrete integer values, the analyses do not possess the characteristics associated with data collected using objective measures. The standard deviations associated with the prototype mean ranks for the design parameters of interest were generally high and dispersed due to the limits on rank responses. However, the data do provide the designer with the necessary feedback from comparative analyses for making design decisions.

Thigh Supports

Review of Table 10 shows that subject preference centered around the medium-low and medium-high prototypes for both height and angle. Of the ten subjects, nine ranked one of these two prototypes as their first or second choice for height, while all ten selected one of them as their first or second choice for angle. The existing seat cushion was ranked last for height by eight subjects. However, two of the three small (stature and leg length) test subjects did not rank it last, but found the high prototype to be the worst for both height and angle and all three subjects found the height and angle of the high prototype to be unacceptable. Analysis of variance performed on the data shows a significant effect of thigh support height ($p<.05$). Post-hoc Newman-Keuls testing further identified the data pertaining to the medium-low and medium-high prototypes to be different from the other three.

The medium-low and medium-high prototype thigh supports, when combined with the new seat bottom cushion, provide 1.2 to 1.7 inches more cushion height at the forward edges of the seat pan than the existing seat cushion, enhancing comfort and posture while minimizing the possibility of blood pooling.

Arm Supports

Review of Table 11 shows that the low prototype arm support was the predominant choice in terms of height, as five of the six subjects with longer upper arms ranked this first, while also identifying the high prototype as unacceptably high. Three subjects found the height of **all** prototype arm supports to be unacceptably high. Average rank of the arm support height grows worse as prototypes of increasing height are considered. Although an analysis of variance shows that arm support height is significant, post-hoc testing shows only that the high prototype is different from the other four. This is most likely a result of the high standard deviations that are associated with the mean ranks and the insensitivity of the subjects to height differences. This phenomenon may also equally be the result of using a discrete ordinal scale in evaluating the prototypes in a comparative fashion, rather than a continuous scale in an objective manner whereby responses using fractional values between whole numbers would be permitted.

The data suggest that the target height for the arm support should be around 1.25 inches to provide 90% of the **subjects** with their first or second choice. However, selection of a target dimension to provide 90% **population** accommodation is more difficult in view of the results of the post-hoc analysis. It appears that an adjustable height ranging from 0.5 inch - 1.75 inches would provide better accommodation in view of SME comments and anthropometric range of the user population .

An analysis of variance performed on the arm support *taper* data showed taper to be significant ($p<.05$). However, most subjects experienced a great deal of difficulty in noticing differences among the various tapers, which is evident when viewing post-hoc test data. Once again post-hoc testing shows only that the high prototype is different from the other four, with the standard deviations ranging from 1.03 to 1.49. Half of the test subjects found the taper of the high prototype to be unacceptably steep. Review of the taper data of Table 11 shows little general agreement as to preferred taper, although the low prototype had the best mean rank. Subjects with lower elbow rest heights preferred the taper of the low and medium-high prototypes, while the subjects with larger elbow rest heights tended to judge the taper of the medium-high and high prototypes more favorably. The data also suggest that the subjects were insensitive to the dimensional differences among prototypes.

Arm contour and leg contour widths of the arm supports were judged as acceptable by 90% of the subjects. Opinions about the offset angle of the leg contour were mixed, with four subjects judging it as unacceptably large, while four felt that it was acceptable, and two felt it was unacceptably small.

Lumbar Supports

Table 12 contains the data relating to the lumbar supports. The thickness of the small lumbar support was most preferred, as all subjects rated it as their first or second choice. The average rank of the large prototype was slightly better than that of the baseline lumbar support; the large prototype was judged unacceptable in terms of thickness consistently by the subjects. The small prototype was most preferred for width, followed by the baseline lumbar support and then the large prototype, judged by three subjects to be unacceptably wide. The small lumbar support was able to provide 90% of the test subjects with their first or second choice for width. Analysis of variance shows that although the mean ranks indicate the small lumbar support is preferred, neither width nor height proved to be significant. Again this shows the possible insensitivity to dimensional differences, the effects of a small sample size, and limitations of rank statistics.

Cushion Hardness

The baseline seat cushion, the prototype seat back, and the prototype lumbar support were most frequently cited as being too hard, suggesting that softer materials would provide better comfort. Only three components were judged as too soft, with none of the three being cited more than twice.

Subject Matter Expert Comments

While providing numerous significant comments, there was little general agreement between the two SMEs, suggesting the need for review of the components by additional SMEs. Differences in the anthropometry of these two subjects led to differences in preferred seat posture and divergence in responses to questionnaire items. Both individuals concurred that the arm support interfered with control of the cyclic and the smaller SME stated that the high thigh support wedge would interfere with full and normal cyclic travel due to increased thigh contact, especially when the cyclic is moved laterally.

CONCLUSIONS AND RECOMMENDATIONS

Analysis of test results suggests that in order to accommodate 90% of the user population (5th through 95th percentile), the following sizes of postural aids are recommended:

Arm Support - 0.5 to 1.75 inches thick (height)

Thigh Support - up to 2.2 inches high at the leading edge of the bottom cushion

Lumbar Support - up to 1.5 inches thick with less than 10 inch radius.

DESIGN OF TEST ARTICLES

Cushion components of each of the approved conceptual designs were designed and fabricated for use in dynamic testing. Level I development drawings are listed in Appendix B. Details of the component designs are provided below.

BOTTOM CUSHION

The bottom cushion was comprised of a hard foam contour base, an energy absorbing foam middle layer, a generic polyurethane foam top layer, and a cover made of sheepskin and wool honeycomb fabric.

The hard contour base was made of Sun Mate T50E foam. The contour differed from the existing Apache cushion in that the leading edge was cut lower to accommodate the lower thigh angles of the 5th percentile occupants. Grooves on the top surface of the hard contour layer allow moisture vapor and air to pass through the soft foams to escape from the cushion. A mesh fabric covers the grooves to prevent the soft foam above from filling the grooves. The energy absorbing layer was either Sun Mate T36E or Confor CF42 foam. Wool honeycomb was used on the sides and bottom of the cover and sheepskin was used on the top. Moisture vapor transport was facilitated by perforations in both the energy absorbing foam and the sheepskin cover and by the large, open-cell structure of the top polyurethane foam.

An opened pocket in the front of the cover permitted insertion of thigh supports between the hard contour and energy absorbing foam layers. Foam thigh supports were made of Sun Mate T50E wedges (to retain shape) with a Sun Mate T36E contoured waterfall for comfort. The wedges were covered with a black cotton fabric. Inflatable thigh supports were made of a coated fabric that was heat sealed to retain pressure. Baffles inside the bladder created a wedge shape when inflated, and an elastic cover fabric allowed for expansion of the bladder. Inflation was accomplished using a bulb-type hand pump.

BACK CUSHION

The back cushion was comprised of a soft foam cut to the angle of the seat bucket and a cover made of sheepskin and wool honeycomb fabric.

The foam used was 1-1/2-inch thick Sun Mate T36E. The sides were angled forward to match the contour of the seat back. The front cover was sheepskin and the back and sides were wool honeycomb fabric. Hook and pile fastener tape was used to attach either of the two movable lumbar supports to the front cover. The third lumbar support could be inserted in a pocket cut into the back of the cover.

The adjustable foam lumbar support was made of Sun Mate T47E foam that was approximately 7-5/8 inches wide by 3/4 inch thick with a 10-inch radius of curvature.

The inflatable lumbar supports were made of a coated fabric and were heat sealed to maintain pressure. When fully inflated, the supports measured approximately 9 inches wide by 3 inches thick. Baffles inside the inflatables created a contoured shape. Inflation was accomplished using a bulb-type hand pump.

The movable inflatable and foam lumbar supports were covered by sheepskin in front and cotton fabric in back. The inflatable support integrated within the back cushion was held in place by an elastic fabric pocket inside the back cushion cover.

ARM SUPPORT

The arm supports measured approximately 4 inches wide by 7 inches long and were between 1-1/2 inches and 2-1/2 inches thick. They were all covered with cotton fabric. A 1 inch wide nylon strap was used to attach them to either the thigh or the seat bottom cushion.

At the middle of the inflatable arm support was a small bladder made of a coated fabric and heat sealed to maintain pressure. Baffles were used inside the inflatables to maintain a flat shape. When fully inflated, the bladder measured approximately 4 inches wide x 7 inches long x 2 inches thick. The bottom layer was a contoured piece of Sun Mate T47E foam used to assist in maintaining shape and to provide added stability on the thigh. The top layer was a 1/2-inch layer of generic polyurethane foam used to provide a soft interface for the forearm and to prevent perspiration buildup. Inflation was accomplished using a bulb-type hand pump.

The "bean bag" effect was accomplished using a sealed bag of drafting powder inside the arm support cover. The bag of drafting powder could be mounded to provide loftier support or flattened to provide less support. The top layer was a 1/2-inch layer of generic polyurethane foam used to prevent perspiration buildup.

COMFORT EVALUATION

METHOD

A comfort evaluation was conducted by the U. S. Army Aeromedical Research Laboratory (USAARL) at Fort Rucker, Alabama. The seat cushions were evaluated by twelve AH-64 Apache helicopter instructor pilots on a Multi-Axis Ride Simulator (MARS). The MARS contained an AH-64 seat with cyclic, collective and rudder pedals configured consistent with AH-64 flight control geometry. Subjects were exposed to a simulated helicopter ride by reproducing field recorded AH-64 triaxial accelerations, in the range of 2 to 40 Hertz, on the MARS.

Accelerations were measured on the seat bucket and on the seat cushions at both the seat bottom and seat back locations. Transfer functions were obtained to determine the effect of the intervening seat cushions on transmitted vibrations. Results from inflatable and foam cushion configurations were compared with those from a standard AH-64 cushion configuration. A questionnaire was administered following each test to obtain subjective opinions about the comfort and vibration transmission and following all tests to evaluate user acceptance of the postural aids.

ANALYSIS OF RESULTS

Vibration transfer function data was processed by integrating z-axis frequency responses in the ranges of 4-8 Hz (the maximum sensitive region for human spine vertical response) and 20-40 Hz (to assess high frequency attenuation).

Low Frequency Response

Comparison of low frequency transfer function (integrated response) shows a significant difference in the back cushion response. The baseline cushion amplified the z-axis vibration more than either inflatable or foam lumbar supports. The small difference in low frequency transfer function for the bottom cushion was not statistically significant.

High Frequency Response

Comparison of high frequency transfer functions shows a significant difference in the bottom cushion response, with both test cushions (either foam or inflatable thigh support) having a greater attenuation than the baseline existing cushion. The small difference in transfer function for back cushions was not statistically significant.

Subjective Responses

Subjective responses for the seat bottom cushion show statistically significant differences between the test cushion and the baseline in three areas. Both test cushions (with either foam or inflatable thigh support) were rated more acceptable than the baseline for thickness of seat cushion, vibration absorption, and overall comfort. Subjective responses for seat back cushion also show a statistically significant difference in three areas. Pilots indicated a preference for the test cushions (with either the foam or inflatable lumbar support) over the baseline existing back cushion for thickness of lumbar support, cover material thickness, and overall comfort.

With regard to design of the postural aids, subjects disliked the arm support when attached to the thigh, disliked the foam lumbar support, and found no interference between the foam thigh support wedges and cyclic control.

A complete description of this test program and discussion of results can be found in USAARL Report No. 94-32.[44]

DYNAMIC TESTING

Dynamic testing was conducted using the Vertical Deceleration Tower (VDT) at the Armstrong Laboratory by the Biodynamics and Biocommunications Division at Wright-Patterson Air Force Base, Ohio.

METHOD

Test Materials

The cushion components tested on the VDT consisted of the following concepts approved by the AATD:

a. Seat bottom cushion with inflatable thigh support. Bottom cushion was constructed of either Confor and/or Sun Mate foam.

b. Seat bottom cushion with invertible foam wedge thigh support. Bottom cushion was constructed of either Confor and/or Sun Mate foam.

c. Foam seat back cushion with inflatable lumbar support, adjustable in height.

d. Foam seat back cushion with inflatable lumbar support, integrated with seat back cushion.

e. Foam seat back cushion with foam lumbar support, adjustable in height.

f. Inflatable with foam arm support, tethered to seat bottom cushion.

g. Inflatable with foam arm support, attached to thigh.

h. "Bean bag" arm support, tethered to seat bottom.

Facilities and Equipment

The VDT is a man-rated impact test facility which can produce +Z-axis impact accelerations representing upward ejections or vertical crashes. A carriage guided by vertical rails is accelerated from a predetermined drop height and a plunger on the bottom of the carriage enters a water-filled cylinder to determine the shape and duration of the acceleration pulse. Sine, triangular, square, and ramp impact acceleration shapes are achievable using different plunger shapes. Deceleration pulse durations of 40 to 180 msec, peak accelerations up to 80 Gs, 150 - 5000 G/sec onset rates, and maximum 56 ft/sec velocity are possible with a payload of 500 lb.

Advanced Dynamic Anthropomorphic Manikin (ADAM)

The ADAM was used to represent the human dynamic response. It is capable of processing 128 channels of sensor information at up to 1000 samples per second per channel. The model used was 74.3 inches tall, weighed 217 pounds, and was clothed in flight coveralls, boots, gloves, and an SPH-4 helmet.

AH-64 Crew Seat

An AH-64 Apache crew seat with side armor panels was used for the tests. The seat provides enhanced crash survival capability using energy absorbing members that allow the seat to stroke under vertical crash loads.

TEST CONDITIONS

Eight tests were conducted on the VDT. The cushion configurations tested are shown in Table 13.

TABLE 13. CUSHION CONFIGURATIONS

TEST NUMBER	THIGH SUPPORT/ BOTTOM CUSHION	LUMBAR SUPPORT/ BACK CUSHION	ARM SUPPORT
1	Baseline[1]	Baseline[1]	None
2	Inflatable/Confor	Inflatable/Adjustable	Inflatable, tethered to seat bottom
3	Foam wedge/Sun Mate	Inflatable/Integrated	Inflatable, attached to thigh
4	Inflatable/Sun Mate	Foam/Adjustable	"Bean bag", tethered to seat bottom
5	Foam wedge/Confor	Inflatable/Adjustable	"Bean bag", tethered to seat bottom
6	Inflatable/Confor	Inflatable/Integrated	Inflatable, tethered to seat bottom
7	Foam wedge/Sun Mate	Foam/Adjustable	Inflatable, attached to thigh
8	Baseline[1]	Baseline[1]	None

[1] Baseline cushions used were the current AH-64 configuration.

Tests were conducted in a 0° pitch, 0° roll attitude per MIL-S-58095. The target pulse was 41.5 G peak acceleration, 36.0 ft/sec velocity change, with an onset rate between 1520 and 1956 G/sec. The carriage drop height necessary to produce the target pulse was calculated to be 19.5 feet.

DATA RECORDING

Instrumentation

Electronic data that were recorded on the ADAM and on the VDT include:

- Seat Stroke Axis Acceleration
- Seat Cushion Z Acceleration
- Carriage Z Acceleration
- Carriage Z Acceleration (redundant)
- Carriage Velocity
- Seat Stroke Axis Acceleration
- Pelvic Z Acceleration
- Chest X, Y, Z Acceleration
- Pelvic Y Angular Acceleration
- Neck Y Moment
- Neck Z Load
- Lumbar X, Y, Z Load
- Lumbar X, Y Moment

Photographic Documentation

The photographic equipment used included:

- Three deck-mounted high-speed 16mm film cameras, each recording at 500 fps, were positioned to record front and side views of the seat and ADAM.
- One deck-mounted high-speed video camera, recording at 500 fps, was positioned to record an overall view of the seat and ADAM.
- One 35mm camera was used for color documentation of pre-test and post-test setup.

Test Procedure

The following procedure was followed during the conduct of all tests:

- Initiate tasks on pre-test checklist (see Appendix C).
- Secure seat on VDT carriage.
- Install new Energy Absorbers (EAs) on seat.
- Install test cushions.
- Place dressed ADAM in seat.
- Secure desired protective restraint systems.
- Connect, continuity-check and calibrate data acquisition system .
- Ensure photo documentation equipment is functional.
- Take color still photographs of pre-test setup and cushion configuration.
- Complete pre-test checklist.
- Clear the test area.
- Perform test.
- Take post-test color still photographs.
- Complete post-test checklist for hardware and data review (see Appendix C).

ANALYSIS OF TEST RESULTS

Although anthropomorphic manikin dynamic performance may parallel that of humans, it does not necessarily replicate that of humans, especially in response to vertical accelerations. Therefore, analysis of these test results will be comparative in nature rather than judging them against human physiological injury criteria.

Test Impulse Parameters

The impulse parameters and seat response are presented in Table 14 for each test. On test number 1, the stroking seat bottomed out, even though the impulse parameters of the carriage were within expected limits. To prevent this from recurring, a new drop height was calculated and the drop height for test number 2 was adjusted an amount proportional to the energy remaining in the seat just prior to the seat reaching its stroke limit. The resulting impulse parameters and seat response were far below acceptable levels for evaluating seat cushion performance. However, seat performance was more in line (than was test number 1) with what would be expected for the given impulse parameters. The drop height was increased for test number 3, while still maintaining a comfortable safety margin from the effects of test number 1. The resulting impulse parameters and seat response were within theoretical expectations, but still below that required to adequately test cushion performance. The drop height was again increased for test number 4, to achieve higher impulse parameters and more seat stroke. No further adjustment of drop height was made in order to maintain consistent impulse parameters on the remaining tests. Hence, comparable conditions were achieved on test numbers 4 through 8 to allow comparison of two tests each of Confor and Sun Mate seat bottom cushions and one test of the baseline cushion.

TABLE 14. IMPULSE PARAMETERS AND SEAT RESPONSE

TEST NO.	DROP HEIGHT (ft)	PEAK G CARRIAGE (Gs)	VELOCITY CHANGE (ft/sec)	PEAK G SEAT (Gs)	SEAT STROKE (in)
1	19.25	39.57	32.39	46.24	11.9
2	11.5	23.69	25.59	16.47	5.5
3	14.5	29.85	27.78	15.03	7.4
4	16.5	34.56	29.73	18.59	8.4
5	16.5	35.88	30.02	23.20	9.38
6	16.5	35.32	29.72	17.97	9.25
7	16.5	35.34	30.75	25.53	8.91
8	16.5	35.29	30.86	23.09	9.2

Carriage Acceleration

Acceleration of the VDT carriage for test numbers 1 through 4 is shown in Figure 13. These responses, based upon different drop heights, are not sufficiently similar to allow comparison of the seat cushion dynamic response. Figure 14 shows the carriage acceleration response for test numbers 4 through 8. This similarity of response demonstrates consistent performance of the VDT for the tests having the same drop height and suggests that differences in ADAM responses can be attributed to the effects of the various seat cushions that were tested.

Pelvic Acceleration, G_z

Peak pelvic acceleration in the z-axis is shown on Figure 15 for test numbers 4 through 8. Results indicate the highest peak acceleration occurred on test number 8, which was 10% greater than the average peak acceleration of test numbers 4 through 7. Although the differences are very small, similar trends were also noted in comparison of Root Mean Square (RMS) values (see Figure 16). The small magnitude of the differences precludes drawing any inferences between performance of the two test bottom cushions.

Lumbar Loads, F_z

Peak lumbar load in the z-axis is shown on Figure 16 for test numbers 4 through 8. Results indicate the highest peak load occurred on test number 8, which was 19% higher than the average peak of tests 4 through 7. Peak loads were lowest for the Sun Mate foam bottom cushions used on test numbers 4 and 7, where the average peak loads were 8% less than those for the Confor foam bottom cushions used on test numbers 5 and 6. Similarly, the highest RMS value occurred on test number 8 (see Figure 17), which was 7% higher than the average RMS value for test numbers 4 through 7. The lowest RMS value occurred on test number 7, although the average RMS value for tests 4 and 7 of that bottom cushion was not significantly different than the average value for test numbers 5 and 6 of the Confor foam bottom cushion.

Peak lumbar shear forces are shown on Figure 18. Results indicate that shear y-axis forces were greatest for test number 4, and were least for test numbers 5 and 6. Results also indicate that shear x-axis forces were greatest for the baseline bottom cushion.

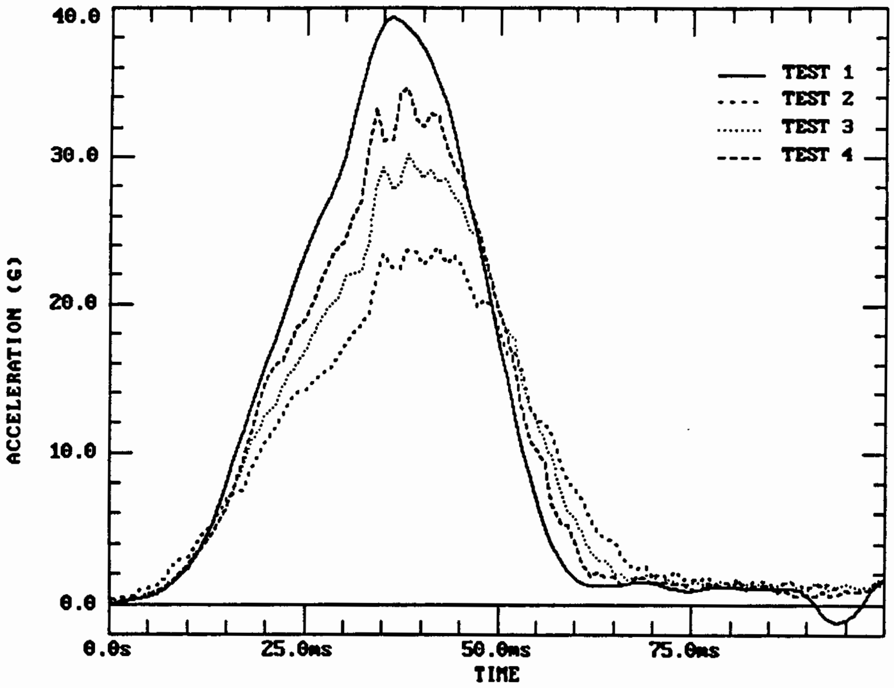


Figure 13. Carriage acceleration, test numbers 1 through 4.

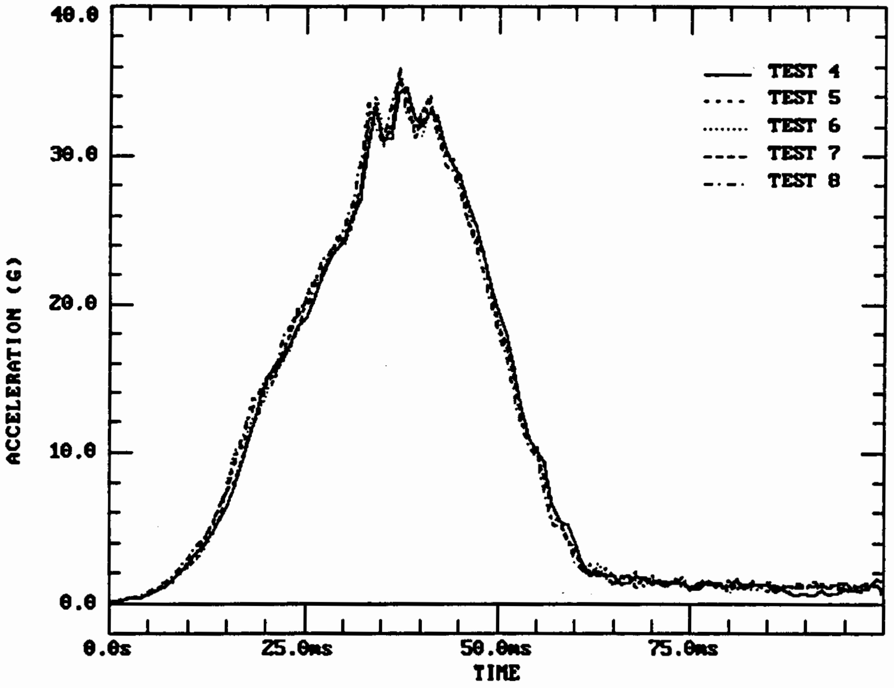


Figure 14. Carriage acceleration, test numbers 4 through 8.

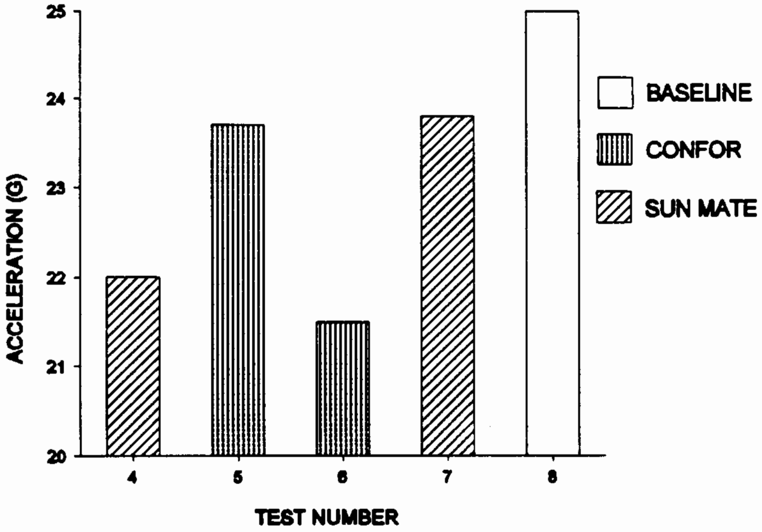


Figure 15. Peak pelvic acceleration, z-axis.

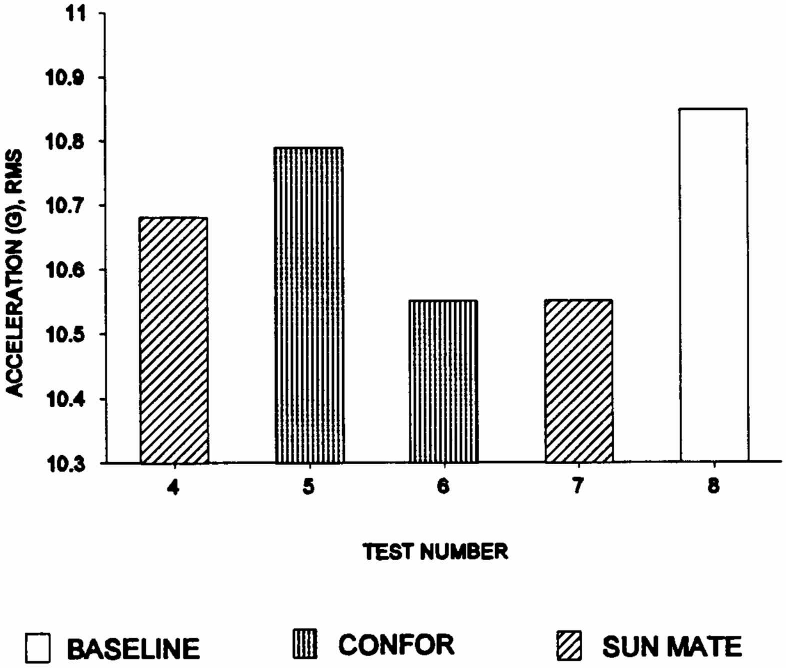


Figure 16. Root mean square pelvic acceleration, z-axis.

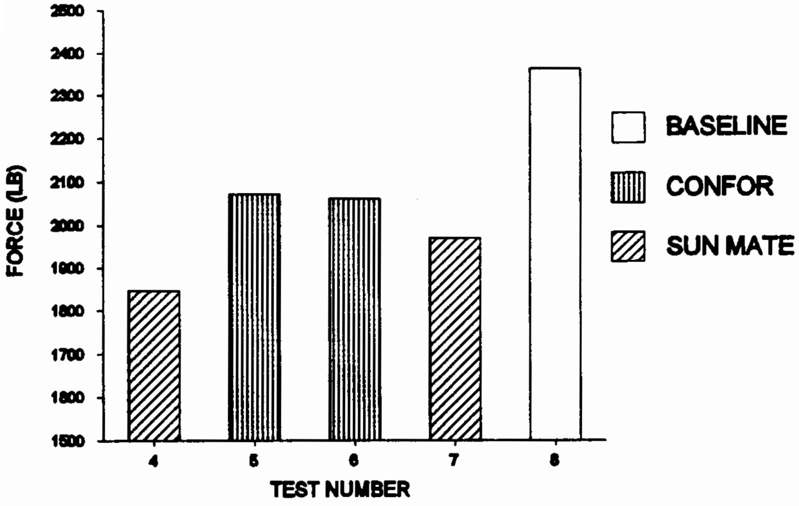


Figure 17. Peak lumbar load, z-axis.

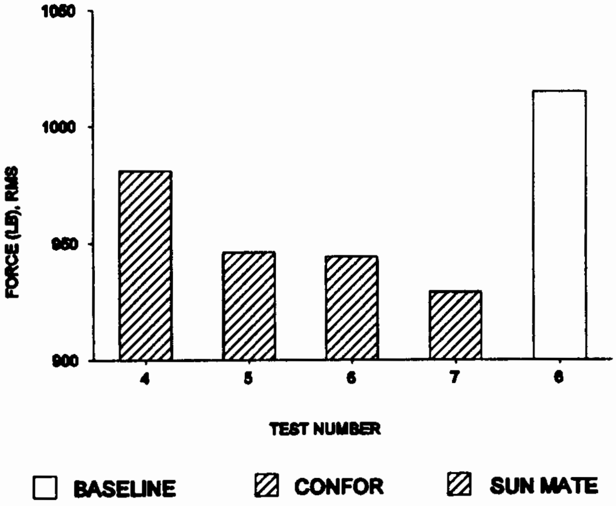


Figure 18. Root mean square lumbar load, z-axis.

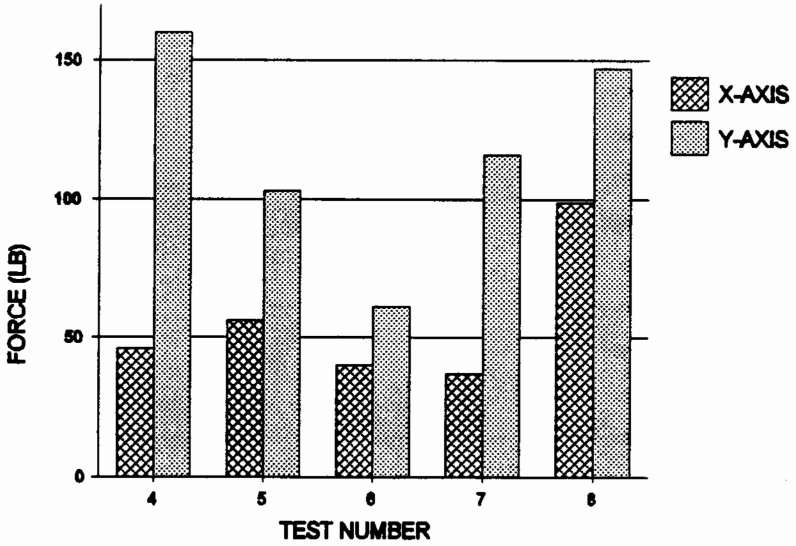


Figure 19. Peak lumbar shear load, x and y-axes.

Chest Acceleration, G_z

Peak chest z-axis accelerations are shown on Figure 20. Results indicate that the highest z-axis peak accelerations occurred on test number 8, which was 19% greater than the average peak accelerations on test numbers 4 through 7. Similarly, the highest z-axis RMS value occurred on test number 8 (see Figure 21). Peak z-axis acceleration was least on test number 4, although the RMS value for that test was greater than all but the baseline bottom cushion. The average peak accelerations were 5% less for test numbers 4 and 7 than for test numbers 5 and 6.

Neck Load, F_z

Peak z-axis neck loads are shown on Figure 22. Results indicate that the highest peak loads occurred on test number 8, which was 20% greater than the average of the peak loads of test numbers 4 through 7. Similarly, the highest RMS value occurred on test number 8 (see Figure 23), which was 7% greater than the average peak value on test numbers 4 through 7. Peak loads were lowest on test numbers 5 and 6, where the average peak was 5% less than test numbers 4 and 7. The small difference (less than 1%) in RMS values of the Sun Mate and Confor bottom cushion foams precludes drawing any inferences between the two.

Lumbar Torque, M_y

Peak y-axis lumbar torque is shown on Figure 24. Results indicate that the highest peak torque occurred on test number 8, which was 56% greater than the average of the peak torques of test numbers 4 through 7. Comparison of the two test bottom cushion foams shows that although the lowest peak torque occurred on test number 6, the average peak torque for that foam was 3% higher than that of the Sun Mate foam cushion.

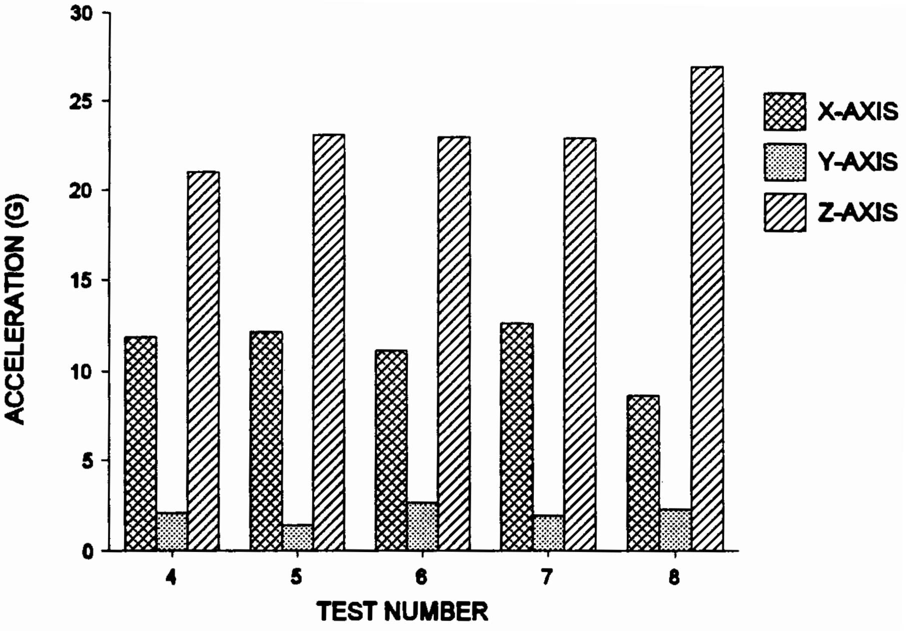


Figure 20. Peak chest acceleration, x, y and z-axes.

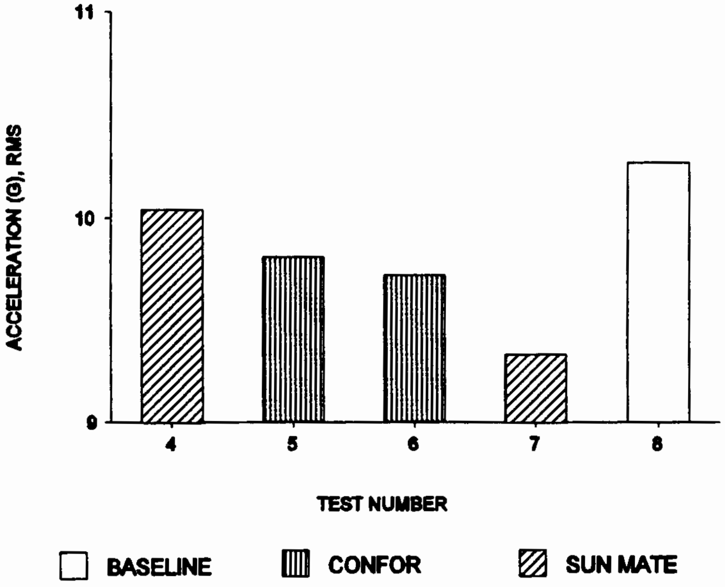


Figure 21. Root mean square chest acceleration, z-axis.

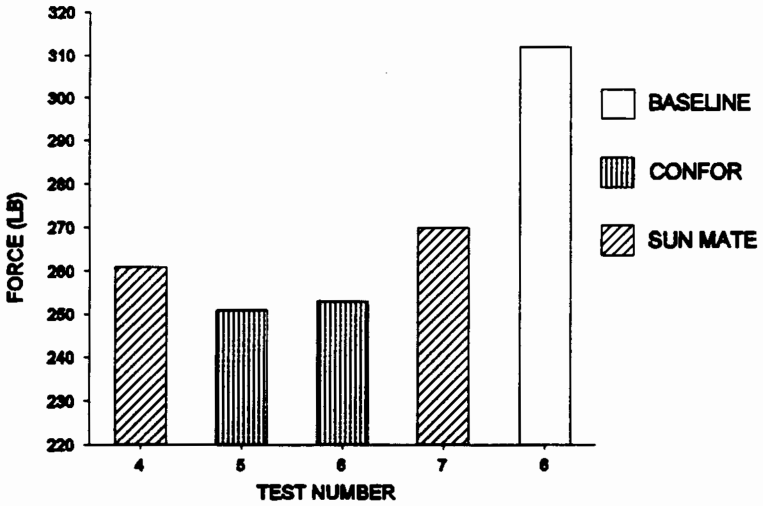


Figure 22. Peak neck load, z-axis.

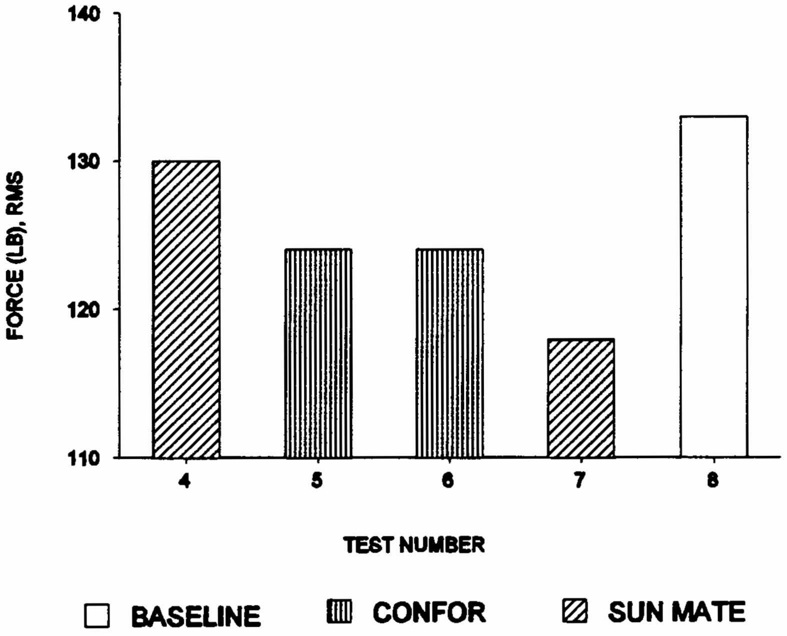


Figure 23. Root mean square neck load, z-axis.

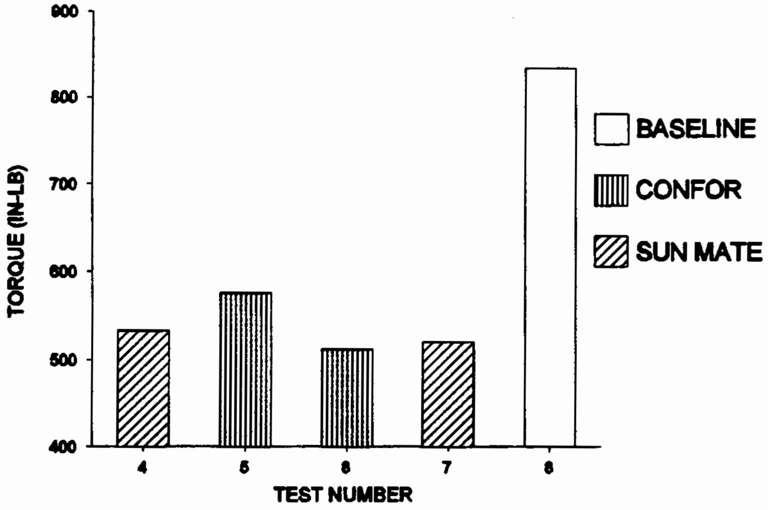


Figure 24. Peak lumbar torque, y-axis.

Pelvic Angular Acceleration, A_y

Peak y-axis pelvic angular acceleration is shown on Figure 25. Results indicate that the highest peak acceleration occurred on test numbers 5 and 6 and the lowest peak acceleration occurred on test number 7. Average peak angular acceleration for tests 4 and 7 was 17% less than that of the baseline bottom cushion.

Neck Torque, M_y

Peak y-axis neck torque is shown on Figure 26. Results indicate that the greatest torques occurred on test numbers 4 and 7, while the lowest torques occurred on test number 8. This result is most likely attributable to the shape of the ADAM lumbar/back and its interaction with the foam lumbar support rather than to any difference in the bottom cushion foam. It is possible that the thickness of the foam lumbar support forced the upper torso of the ADAM off of the seat back cushion, since the ADAM back does not have a concave curvature in the lumbar region as does a human. This out-of-position initial condition would promote excessive upper torso fore-aft motion dynamics during the test and subsequently result in higher neck torques. If these results were due solely to the bottom cushion foams, similar trends would be expected in some or all of the instrumented measurements on the lower torso/pelvic region.

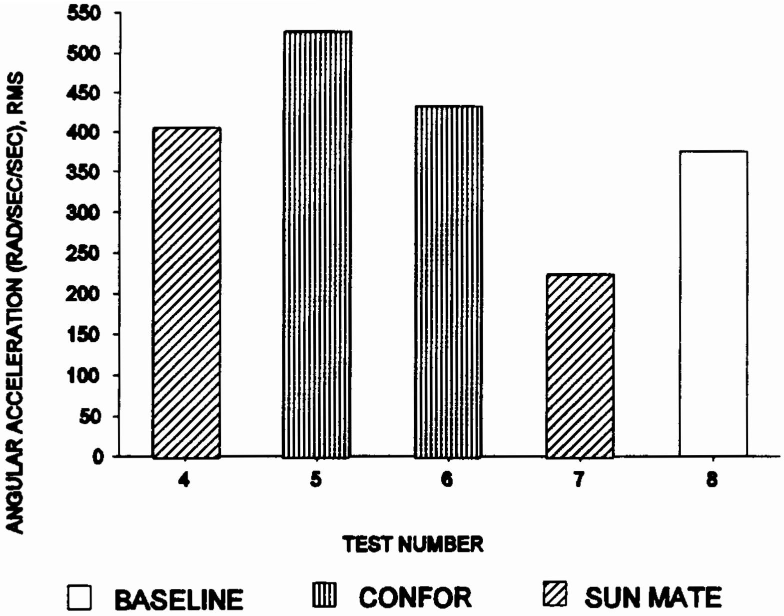


Figure 25. Peak pelvic angular acceleration, y-axis.

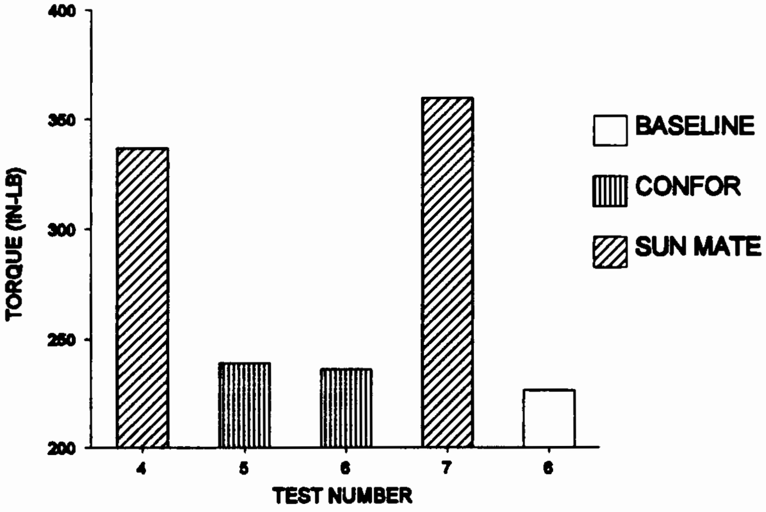


Figure 26. Peak neck torque, y-axis.

FINAL ANALYSIS AND DESIGN

PROPOSED FINAL DESIGN CONCEPTS

The wide variation in anthropometry of the user population can best be accommodated using inflatable components. Inflatable thigh and lumbar supports can be easily adjusted in flight to compensate for changes in sitting posture which become more likely on extended durations. Inflatable adjustment is not recommended for the arm support, however, since this could reduce cyclic control stability, and the hand pump inflator would make the arm support more likely to impede ingress/egress. In order to accommodate the range of user population anthropometry, two sizes of arm support are recommended. By flattening or fluffing to suit the user's needs, the small "bean bag" arm support can provide 0.5 to 1.0 inch of lift beneath the forearm, and the large size arm support can provide 1.25 to 1.75 inches of lift (as determined necessary by the fit and function evaluation). The arm support should be tethered to the seat bottom cushion, as pilot opinion is strongly against its being attached to the thigh.

FOAMS

Both Confor and Sun Mate foam cushions performed better than the baseline existing cushion on both the dynamic drop tests and the Army-conducted comfort evaluation. Sun Mate was selected for the final design since it performed much better than the Confor foam in the durability tests and slightly better on most instrumented measurements on the dynamic crash tests.

DESIGN CHANGES

The final design incorporates the inflatable thigh support completely within the seat bottom cover. (The test articles were fabricated with a pocket in the front of the bottom cushion to permit using the inflatable and foam thigh supports interchangeably.) The width of the inflatable lumbar support has been reduced to 4 inches. Subjective comments during both the comfort and the fit and function evaluations suggested that a wide lumbar support tends to push the body forward in the seat rather than supporting the lumbar curvature. A layer of less dense (softer) foam has been added to the front of the back cushion and the base foam layer has been made thinner to give it a softer feel. Comments during both the comfort and the fit and function evaluations suggested that even the softest grade of Sun Mate foam was too firm. The overall thickness of the back cushion was minimized to prevent moving the back tangent line and subsequently the seat reference point. The initial "bean bag" arm support contained 12 ounces of drafting powder and provided 1.25 to 1.75 inches of support. The smaller size will contain 8 ounces and provide 0.5 to 1.0 inch of support.

CONCLUSIONS AND RECOMMENDATIONS

It is not practical to alter the crewstation geometry to allow the aircrew to adopt a better posture. In this program it has been necessary to support a more appropriate posture within the geometric constraints of the AH-64 crewstation. The following are significant conclusions drawn during this program:

- The slumped forward, lateral tilt posture adopted by many helicopter aircrews is not conducive to a healthy back. Lower back pain can be reduced by adopting a good posture. The arm support is the single most important feature in promoting good posture.

- Limited seat and pedal adjustment do not allow most aircrews to achieve a trunk-to-thigh angle that naturally permits a good spinal curvature. A good back support is necessary to promote lumbar lordosis.

- Seat cushion comfort is achieved by distributing weight across the buttocks and thighs. Thigh-to-seat angle can vary from 0° to over 25°. A variable height thigh support is necessary to accommodate the wide variation in thigh-to-seat angle of the aircrew population.

The seat cushions that were designed and fabricated demonstrated accomplishment of the goals of this program. Improved comfort and vibration transfer characteristics were both demonstrated during the Army-conducted comfort evaluation.[44] Improved crash protection was demonstrated during the dynamic crash tests. Superior durability was demonstrated by laboratory material tests of the foams.

The results of this program recommend the following:

- Seat cushions which incorporate the arm support, thigh support and lumbar support postural aids described herein should be provided in helicopter crew seats to help alleviate back pain.

- A user assessment of the components developed herein should be conducted to evaluate the size and range of adjustment of the postural aids, to make a direct comparison of the cushion comfort with the existing cushions during extended missions, and to determine the best location for affixing the inflator hand pumps to the seat.

- Additional testing should be conducted to determine the ability of the materials selected to withstand the extreme conditions of the operational environment and to compare their performance with that of military qualified materials.

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SPECIFICATIONS AND STANDARDS

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APPENDIX A

HELICOPTER CREWSEAT CUSHION
FIT AND FUNCTION EVALUATION
QUESTIONNAIRE AND DATA SHEET

NAME________________________________ DATE______________________

ANTHROPOMETRY

STATURE__________________________cm,_________________________ percentile
WEIGHT___________________________kg, _________________________ percentile
SITTING EYE HEIGHT_________________cm,_________________________ percentile
FUNCTIONAL LEG LENGTH____________cm,_________________________ percentile
ELBOW REST HEIGHT_________________cm,_________________________ percentile
BUTTOCK-POPLITEAL LENGTH__________cm,_________________________ percentile
POPLITEAL HEIGHT__________________cm,_________________________ percentile

PEDAL POSITION _______cm from full forward
SEAT POSITION _______cm above full down

THIGH SUPPORT WEDGES

1. Identify the thigh support wedges that are <u>unacceptably high</u>. (Check all that apply)
low _______, med-low _______, med-high _______, high _______, standard _______
Explain why.

2. Identify the thigh support wedges that are <u>unacceptably low</u>. (Check all that apply)
low _______, med-low _______, med-high _______, high _______, standard _______
Explain why.

3. Please rank order the thigh support wedges in terms of <u>height</u> (1 = best, 5 = worst)
low _______, med-low _______, med-high _______, high _______

4. Identify the thigh support wedges that have an angle that is <u>unacceptably shallow</u>. (Check all that apply)
low _______, med-low _______, med-high _______, high _______
Explain why.

5. Identify the thigh support wedges that have an angle that is <u>unacceptably steep</u>. (Check all that apply)
low _______, med-low _______, med-high _______, high _______
Explain why.

6. Please rank order the thigh support wedges in terms of <u>angle</u> (1 = best, 5 = worst)
low _______, med-low _______, med-high _______, high _______

<u>Questions 7 through 9 to be answered by subject pilots only</u>.

7. Identify the thigh support wedges that interfere with <u>full cyclic travel</u>.
low _______, med-low _______, med-high _______, high _______, standard _______
Explain why.

8. Identify the thigh support wedges that interfere with <u>normal cyclic travel</u>.
low _______, med-low _______, med-high _______, high _______, standard _______
Explain why.

9. Identify the thigh support wedges that interfere with <u>normal pedal (yaw) travel</u>.
low _______, med-low _______, med-high _______, high _______, standard _______
Explain why.

ARM SUPPORT

10. The <u>arm contour</u> on the arm support is...
unacceptably wide_______, OK _______, unacceptably narrow _______
Explain why.

11. The <u>leg contour</u> on the arm support is...
unacceptably wide_______, OK _______, unacceptably narrow _______
Explain why.

12. The <u>offset angle</u> of the leg contour is...
unacceptably large_______, OK _______, unacceptably small _______
Explain why.

13. Identify the arm supports that are <u>unacceptably high</u>. (Check all that apply)
low _______, med-low _______, med _______, med-high _______, high _______
Explain why.

14. Identify the arm supports that are <u>unacceptably low</u>. (Check all that apply)
low _______, med-low _______, med _______, med-high _______, high _______
Explain why.

15. Please rank order the arm rests in terms of <u>height</u> (1 = best, 5 = worst).
low _______, med-low _______, med _______, med-high _______, high _______
Explain why.

16. Identify any arm rest <u>taper</u> that is <u>unacceptably steep</u>. (Check all that apply)
low _______, med-low _______, med _______, med-high _______, high _______
Explain why.

17. Identify any arm rest <u>taper</u> that is <u>unacceptably flat</u>. (Check all that apply)
low _______, med-low _______, med _______, med-high _______, high _______
Explain why.

18. Please rank order the arm rests in terms of <u>taper</u> (1 = best, 5 = worst).
low _______, med-low _______, med _______, med-high _______, high _______
Explain why.

<u>Questions 19 through 22 to be answered by subject pilots only</u>.

19. Does the arm support <u>interfere with control of the cyclic</u>?
yes _______, no _______
Explain why.

20. Does the arm support interfere with other cockpit tasks?
yes ________, no ________
Explain why.

21. Does the arm support help you to stabilize the cyclic?
yes ________, no ________
Explain why.

22. Does the arm support improve your posture?
yes ________, no ________
Explain why.

LUMBAR SUPPORT

23. Identify the lumbar supports that are unacceptably thick. (Check all that apply)
large ________, small ________, standard ________
Explain why.

24. Identify the lumbar supports that are unacceptably thin. (Check all that apply)
large ________, small ________, standard ________
Explain why.

25. Please rank order the lumbar supports in terms of thickness (1 = best, 3 = worst).
large ________, small ________, standard ________

26. Identify the lumbar supports that are unacceptably tall. (Check all that apply)
large ________, small ________, standard ________
Explain why.

27. Identify the lumbar supports that are unacceptably short. (Check all that apply)
large ________, small ________, standard ________
Explain why.

28. Please rank order the lumbar supports in terms of height (1 = best, 3 = worst)
large ________, small ________, standard ________

29. Measure the preferred position of the lumbar support.
__________ inches above the seat bucket

GENERAL

30. Identify any cushion surfaces that are too hard (or too soft).

	too hard	too soft
a. seat bottom	______	______
b. baseline bottom	______	______
c. seat back	______	______
d. arm support	______	______
e. thigh support	______	______
f. lumbar support	______	______
g. baseline lumbar	______	______

Explain why.

APPENDIX B

DRAWINGS, ENGINEERING AND ASSOCIATED LISTS - LEVEL 1, REVIEW HELICOPTER CREWSEAT CUSHION

I. BOTTOM CUSHION CONFIGURATIONS

A. Inflatable Thigh Support

94HCC111	Cover Assembly, Seat Bottom
94HCC121	Cushion Subassembly, Seat Bottom
94HCC141	Cover Assembly, Thigh Support - Inflatable
94HCC142	Support Subassembly, Thigh - Inflatable

B. Foam Wedge Thigh Support

94HCC111	Cover Assembly, Seat Bottom
94HCC121	Cushion Subassembly, Seat Bottom
94HCC131	Cover Assembly, Thigh Support - Foam
94HCC132	Support Subassembly, Thigh-Foam

II. BACK CUSHION CONFIGURATIONS

A. Foam Lumbar Support

94HCC211	Cover Assembly, Cushion - Seat Back
94HCC221	Cushion Subassmbly, Seat Back
94HCC231	Cover Assembly, Lumbar Support - Foam
94HCC232	Cushion Subassembly, Lumbar Support

B. Inflatable, Adjustable Lumbar Support

94HCC211	Cover Assembly, Cushion - Seat Back
94HCC221	Cushion Subassembly, Seat Back
94HCC243	Cover Assembly, Bladder-Lumbar-Fwd
94HCC244	Support Assembly, Lumbar - Inflatable

C. Inflatable, Integrated Lumbar Support

94HCC211	Cover Assembly, Cushion - Seat Back
94HCC221	Cushion Subassembly, Seat Back
94HCC241	Cover Assembly, Bladder - Lumbar - Aft
94HCC244	Support Assembly, Lumbar - Inflatable

III. ARM SUPPORT CONFIGURATIONS

A. Bean Bag Tethered to Seat

94HCC311	Cover Assembly, Arm Rest

B. Foam with Inflatable Tethered to Seat

94HCC321	Cover Assembly, Arm Rest - Inflatable
94HCC322	Thigh Contour, Arm Rest - Inflatable
94HCC323	Support Assembly, Arm - Inflatable

C. Foam with Inflatable Tethered to Leg

94HCC321	Cover Assembly, Arm Rest - Inflatable
94HCC322	Thigh Contour, Arm Rest - Inflatable
94HCC323	Support Assembly, Arm-Inflatable

APPENDIX C

PRE-TEST CHECKLIST

Test Number: ____________________ Date: ____________________

Time: ____________________ Test Engineer: ____________________

Bottom Cushion: ____________________ Thigh Support: ____________________

Lumbar Support: ____________________ Arm Support: ____________________

________ 1. Install appropriate seat cushion components on seat and record types and numbers above.

________ 2. Record the serial numbers of new energy absorbers on the crashworthy seat.
S/N: Right ______, Left ______

________ 3. Record the serial numbers of the inertia reel on the crashworthy seat. S/N: __________

________ 4. Adjust the crashworthy seat to the full up and locked position.

________ 5. Place the fully-instrumented, 95th percentile ADAM manikin into the crashworthy seat.

________ 6. Adjust the seat cushions and inflate bladders; secure inflator bulbs.

________ 7. Fasten lap belt straps and adjust tension evenly.

________ 8. Lock the inertia reel.

________ 9. Pull both shoulder straps to pack the webbing around the inertia reel.

________ 10. Fasten shoulder straps and adjust tension evenly.

________ 11. Place marks on shoulder and lap belt straps at adjustors.

________ 12. Place marks on inertia reel strap.

________ 13. Position the manikin's hands and feet as desired and secure them with ordnance tape.

________ 14. Place targets on the test item where desired.

________ 15. Take still photographs including the following items:

- Test set-up
- Thigh clearance
- Arm support position
- Inflator bulb position
- Lumbar cushion position

________ 16. Install the safety strap on the manikin.

________ 17. Sight cameras.

NOTES:

POST-TEST CHECKLIST

Test Number: ______________________ Date: ______________________

________ 1. Remove safety strap from the manikin.

________ 2. Take still photographs.

- Overall condition of the test set-up
- Position of test items: cushions and inflator bulbs
- Stroke distance

________ 3. Measure seat stroke.

________ 4. Measure inertia reel strap slip/packing.

________ 5. Examine the harness assembly for signs of wear. Replace as necessary.

________ 6. Remove ADAM manikin from seat.

________ 7. Remove and examine cushion components for damage and wear.

________ 8. Remove the used energy absorbers from seat and install new energy absorbers.

________ 9. Obtain electronic data from critical channels immediately following each test. Review this data prior to performing any subsequent tests.

________ 10. Obtain copies of video data from all video cameras immediately following each test. Review this data prior to performing any subsequent tests.

NOTES: