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**ARMSTRONG**

**FEASIBILITY OF REDUCING INCIDENCE OF LOW BACK PAIN IN HELICOPTER PILOTS USING IMPROVED CREWSEAT CUSHIONS**

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FOR THE COMMANDER



THOMAS J. MOORE, Chief  
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## PROJECT SUMMARY

This effort included a literature search to review the most current research related to seating and back pain. A pilot survey was also conducted to obtain direct information on the occurrence of low back pain in Black Hawk helicopter pilots. The natural frequencies and durability properties of 18 cushion foam materials were experimentally determined; stiffness and density properties were measured. With the results from the literature search and pilot survey, and the information on foams, a number of concepts were developed for cushions that reduce the incidence of low back pain.

Prototypes of four of these cushion concepts were fabricated: cushion with nonadjustable lumbar support incorporated into back contour; cushion with mechanical lumbar support adjustment; cushion with inflatable lumbar support adjustment; and pivoting fiberglass seat pan and back contour with cushion. The pivoting fiberglass contour with cushion prototype did not provide a satisfactory combination of low back support and comfort, therefore, only the first three cushion prototypes were evaluated for short-term comfort. Thirteen volunteers (5th-, 50th-, and 95th-percentile occupants) were asked to evaluate the three prototype cushions for short-term comfort. The cushion with a nonadjustable lumbar support was ranked the highest. This highest-ranked cushion was then further evaluated for long-term comfort by one volunteer (50th-percentile).

The three prototype cushions evaluated for short-term comfort demonstrated improved comfort over the original Black Hawk cushion. Compared to the original Black Hawk cushion, the highest-ranked, nonadjustable cushion demonstrated reduced incidence of low back pain during the long-term comfort evaluation. This program effort concluded that a cushion can be designed to improve comfort, and reduce the incidence of low back pain in helicopter pilots.

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## 1.0 INTRODUCTION

The intent of this Phase I effort was to demonstrate the feasibility of designing a cushion to help reduce the incidence of low back pain in helicopter pilots. Helicopter pilots are currently subjected to uncomfortable conditions such as high vibrations and uncomfortable seating postures while flying, for periods up to 13 hours. Nonergonomic design features, such as the location of the pedals and the angle between the seat back and pan, aggravate the situation. Many of these ergonomic deficiencies are imposed by the cockpit layout, which would be costly to change. Fortunately, crewseat cushion designs can be improved through material changes and contour enhancements without affecting the cockpit layout. Therefore, designing cushions to help reduce the incidence of back pain is feasible.

To demonstrate the feasibility of designing a cushion to reduce back pain, this program had four objectives. The first was to determine the relationship between cushions and back pain through a literature search and a pilot survey. The second was to determine the durability and vibration characteristics of materials through testing. The third was to develop and select improved cushion concepts. The last objective was to fabricate cushion prototypes and evaluate their effect on comfort and back pain. This comprehensive study concluded that a cushion can be designed to effectively reduce back pain in helicopter pilots.

## 2.0. IDENTIFICATION AND SIGNIFICANCE OF THE PROBLEM

Chronic lower back pain in helicopter pilots is a significant problem. The task of controlling a helicopter, whether it is hovering or moving strategically in flight, is both physically and mentally taxing (Reference 1). While the helicopter is valued in military and civilian operations for its maneuverability, it is this attribute which puts such physical demands on the pilot. Consequently, the incidence of backache in helicopter pilots is more severe than in pilots of other aircraft (Reference 2).

During flight, the pilot is subjected to high vibrations from the helicopter and, to properly control the aircraft, is required to assume an uncomfortable posture. In particular, the right arm, which grasps the control stick, is rested on the right thigh. To do this, the pilot must bend forward slightly and tilt to the right, which is believed to cause pain in the right shoulder blade. Pressing the feet on the rudder pedals decreases the pelvic tilt because the force transmitted by the legs pushes the upper part of the pelvis rearwards. Decreasing the pelvic tilt increases the discomfort since more body weight is placed on the ischial tuberosities (IT's), the large, lower bony projections of the pelvis on which one sits. Meanwhile, the left hand controls the collective lever; the act of reaching for and lifting the lever causes the spine to rotate to the left. This twist of the spine is believed to produce pain on the left side, at the junction of the thoracic and lumbar vertebrae. Finally, the nose-down attitude of the helicopter in flight tends to further distort the spinal curve (Reference 2).

Subjected to such uncomfortable seating postures, the helicopter pilot suffers from chronic low back pain. The high incidence of pilot low back pain is directly related to lower performance in flight and increased health and medical costs (Reference 3).

Pilot performance is decreased by a dull ache in the lower back that is often associated with a tired feeling; this condition may become debilitating if the pilot continues to fly (Reference 4). The pain usually starts within two hours of flight and normally lasts the remainder of the mission, often increasing in intensity. Many pilots seek professional treatment from a flight surgeon, and require rest for relief. The pilot's time off from work and the time required of the medical staff is costly. Therefore, by eliminating back pain in helicopter pilots, on-the-job performance would be significantly improved and more consistent, while the number of off-duty hours with resultant costs would be substantially decreased.

The purpose of this program, therefore, is to identify ways to reduce or eliminate the ailment by designing cushions with ergonomic contours and fabricating them with vibration-absorbing materials.

### 3.0 PHASE I TECHNICAL OBJECTIVES

The primary goal of the Phase I effort was to develop a cushion that effectively demonstrates improved comfort and consequently reduces back pain relative to the existing Black Hawk cushion. The cushion was to include contours that improved support of the lower back and buttocks, as well as isolating the seat vibrations imposed by the helicopter. The objectives required to achieve this goal were:

- Identify problem areas related to low back pain among helicopter pilots, such as posture, vibration, and seat design
- Identify vibration-absorbing and durable materials for use in seat cushions
- Determine cushion contours and develop cushion concepts which increase comfort and consequently minimize low back pain
- Fabricate prototype cushions of selected concepts
- Evaluate the effect of the prototype cushion configurations on comfort and low back pain.

## 4.0 STUDY OF CUSHION EFFECT ON BACK PAIN

Low back pain may be caused by any combination of the following variables: aircraft vibration, pilot posture during aircraft control, pilot muscle fatigue, cockpit ergonomics, and the pilot's general physical fitness and medical history. However, the exact combination of these causes of discomfort has not yet been isolated. It is evident that current helicopter ergonomics contribute to the pilot's abnormal posture while flying the aircraft, and cause undue discomfort and back pain. Further aggravating the pilot's pain is the poor construction of and the lack of back support in existing cushions. A literature search and a pilot survey were conducted to help identify the weaknesses of the existing Black Hawk cushion and possible cushion improvements that could be made to reduce the incidence of low back pain.

### 4.1 LITERATURE SEARCH

The purpose of the literature search was to study the available information related to cushions, seating, and back pain; for example, typical buttock pressures and lumbar curvature, causes of low back pain, and seat comfort requirements. This section summarizes the literature that was reviewed (Section 4.1.1) and lists the pertinent information used in the program (Section 4.1.2).

#### 4.1.1 Information Summary

Over 20 references were reviewed. The information obtained from these papers was separated into the following topics:

- Human sitting characteristics
- Optimum seat positions
- Causes of low back pain
  - Vibration
  - Posture
  - Workload
- Description of discomfort and pain
- Recommended cushion comfort requirements.

**4.1.1.1 Human Sitting Characteristics.** When the occupant is in a seated position, the normal lumbar curve is flattened, causing added pressure to the anterior portion of the intervertebral discs (Reference 2). This flattening is more severe in males than in females (Reference 5). The lumbar curve also flattens as the thigh-trunk angle gets smaller (Reference 5). It has been found that the pressure on the intervertebral discs is highest in the unsupported spine during sitting and that muscle fatigue develops in the back muscles as a result of not being able to change positions while flying (Reference 6).

During sitting, the body weight displaces and spreads the flesh of the buttocks and thighs. The flesh cells become compressed under the IT's, impeding blood flow and nerve conduction (Reference 7). Although the skin over the IT's is especially adapted for weight bearing, the load can be tolerated for a maximum of one hour. In tall, heavy-boned men with very thick gluteal musculature, pressures may rise up to 60 psi, whereas in leaner men with less flesh beneath the IT's, the pressure can rise even higher (Reference 7).

The loading of the tuberosities differs depending on the lumbar curvature which in turn is dependent on the seat back angle (with respect to vertical) of the sitting occupant. When the normal lumbar curve is maintained, the pelvis tilts forward and most of the weight is applied to the small front portion of the tuberosities (Reference 3). Tuberosity loading is reduced when the pelvis is tilted backward and the rearmost point of the IT's are loaded (Reference 7). This desirable condition occurs when the seat back angle (with respect to horizontal) is 105 degrees and the seat pan is horizontal.

**4.1.1.2 Seat Positions.** The lumbar curve is in its most normal and comfortable position while the individual is standing. To achieve a lumbar curve similar to that during standing, both the thigh-trunk and thigh-knee angles should be 135 degrees. Seat back angles, therefore, play a significant role in the comfort of the seated occupant (References 2 and 8). Unfortunately, the most comfortable thigh-trunk angle is not necessarily the most practical for the pilot flying an aircraft as it may impede forward vision. Therefore, to maintain forward vision, the thigh-trunk angle should be reduced to 95 to 110 degrees (Reference 8). Keegan suggests that the minimum thigh-trunk angle should be 105 degrees to help preserve the lumbar curve (Reference 5). Reader, on the other hand, suggests that to provide both comfort and sufficient vision, the seat back angle should be between 100 degrees and 105 degrees with respect to horizontal (Reference 9). Also, the lumbar curve should be supported by a low back rest or muscle support.

**4.1.1.3 Factors Affecting Low Back Pain.** The factors affecting low back pain were grouped into four categories: workload, posture, vibration, and exercise.

**Workload.** The typical scenario of a pilot who acquires back pain includes two to four hours flying time and 300 to 1,500 hours flight experience, although one author suggests that less than 100 hours is all that is needed to acquire back pain (Reference 8). After the onset of low back pain during flight, the pain tends to become chronic and is related to frequency, duration, and the nature of the flight mission (Reference 10). In the CH13 Labrador helicopter, it has been found that the average back pain threshold values include:

- 500 total rotary wing hours
- 30 to 40 flying hours/month
- 3-4 flying hours/day
- 1.5 hours continuous flight (Reference 4).

**Posture.** To manage helicopter controls which are inconveniently positioned, most pilots assume a slumped and assymmetric posture for an extended period of time (Reference 10). This poor sitting posture straightens out the normally curved spine increasing pressure on the anterior portion of the vertebrae and causing back pain (Reference 10). Since the pilot often has to lean forward while flying, he receives no back support to help relieve the pain. Nevertheless, a small percentage of pilots reporting back pain do not lean forward while flying and therefore do not subject the spine to additional load concentrations (Reference 4). This suggests that there may be another cause, besides poor posture, that produces back pain. For helicopter pilots, another factor affecting back pain is vibration.

**Vibration.** Occupants are subjected to a range of helicopter vibrations that include the resonant frequency of the spinal system which causes unnecessary discomfort for the occupant (Reference 10). Consequently, pilots avoid leaning on the back cushion to alleviate the potential increase in vibration transmission to the head which causes reduced vision (Reference 8). Pope conducted a vibration study and found that the vibration environment of the UH-1H helicopter produced significant subjective discomfort not only in the lower back, but also in the buttocks (Reference 11).

**Exercise.** Exercise plays an important role in reducing the incidence of backache (Reference 4). A regular exercise program aimed at improving the strength, endurance, and flexibility of the lower back and abdomen muscles decreases the incidence of low back pain.

**4.1.1.4 Types of Pain or Discomfort.** Pilots have reported a dull ache associated with a tired feeling in the lumbar region. This discomfort can grow to excruciating intensity if the pilot continues to fly (Reference 8). Severe, acute, and sometimes debilitating backaches have been reported by helicopter pilots (Reference 12). Pilots often attempt to alleviate their pain with a number of methods including:

- Shifting positions
- Relinquishing the controls
- Stuffing an extra lumbar cushion between the seat and lower back
- Loosening the seat belt (Reference 3).

**4.1.1.5 Cushion Comfort Requirements.** The British Royal Air Force has done extensive research on back pain and attempted to correct the problem with individually molded lumbar support pads (Reference 8). These pads were successful although they did not offer support of the upper back. The Canadian Air Force has also used these contoured support pads.

A correctly contoured surface will permit the occupant to sit longer without the discomfort found while sitting on a flat seat. The contoured surface spreads the load that is normally on the IT's to some of the surrounding tissue, reducing the peak pressures at the IT's (Reference 7).

Beach recommends that the contour, especially the lumbar support, be made adjustable to accommodate the range of pilot sizes and shapes (Reference 4). An adjustable lumbar support would allow the pilot to shift his sitting position and maintain a high degree of comfort (Reference 4).

Reader suggested that the rear portion of the seat pan be flattened rather than curved upward to avoid coccygeal (tail bone) discomfort and allow contact between the sacrum and seat back. He also suggested that the width of the lumbar support from the upper part of the lumbar spine to the lower part be 12.5 in. long and the point of maximum curvature no more than 0.4 in. forward of the main back cushion plane. Also, the point of maximum location should be located not higher than 9.4 in. above the upper surface of the compressed seat cushion (Reference 9). It was also emphasized that the lumbar support should not be so contoured that it would press into the spine, reintroducing back pain due to local pressure (Reference 2).

#### **4.1.2 Results of Literature Search**

The literature search provided useful information on sitting characteristics, back pain, and cushions. Recommendations from the literature used in the program are listed below:

- Reduce the transfer of vibration to allow the pilot to lean against the seat back without impeding his/her vision
- Use foams that result in resonant frequencies that do not coincide with the human body's natural frequencies (Reference 10)
- Distribute the vertical load of the body over the entire buttocks to prevent load concentrations on the IT's (Reference 7)
- Provide durable cushions to prevent bottoming out and increased pressure on the IT's
- Provide lower back support especially when the pilot hunches forward in the seat to operate the controls
- Provide an open or recessive space for the sacrum and buttock that project on the posterior, permitting constant contact with the primary lower lumbar back support (Reference 5)
- Curve front edge of seat downward (Reference 5).

These principles reaffirmed the importance of conducting durability and vibration tests on sample cushion foams, as well as the importance of providing ergonomic contours in both the back and bottom cushions.

#### **4.2 PILOT SURVEY**

The purpose of the survey was to obtain firsthand information from Black Hawk helicopter pilots on back pain, comfort, and posture and correlate it to the information provided on Black Hawk cushions.

Approximately 200 surveys were distributed to two Air Force and two Army bases: Kirkland Air Force Base (10 sent, 10 received), Eglin Air Force Base (40 sent, one received), Fort Bragg (100 sent, 19 received), and Fort Campbell (50 sent, four received). The responses to this survey helped to identify the current back pain and comfort problem.

The pilot survey addressed the issue of the pilot's perception of comfort in the Black Hawk crewseat. A sample survey is shown in Appendix A. Of the 34 surveys received, 10 (of the 10 sent) were received from Kirkland Air Force Base and reflected the opinions of pilots with less than 500 hours of flying time. A majority of the pilots with the most flight time and experience are at Fort Campbell; however, only four of the 50 surveys sent there were received. Therefore, the results may be somewhat slanted since a smaller-than-actual percentage of experienced Black Hawk pilots responded. The survey results are summarized as follows:

- Fifty-nine percent of the respondents had a total of 500 hours or less total flying time in the Black Hawk .
- The maximum length of time flown in the Black Hawk without a rest period ranged from 2-13 hours, with an average time of 6 hours. The average height, weight, and age of the respondents is 70.8 in., 177 lb, and 32.4 years, respectively.
- None of the pilots felt that the Black Hawk seat was comfortable on extended missions. Fifty-three percent of the respondents flew in seats manufactured by ARA and Simula; 35 percent flew in ARA seats only, and 12 percent flew in Simula seats only. Most preferred the sheepskin-covered cushions primarily for the extra cushioning they provided. However, some complained about the sheepskin covers being too hot, especially in the summer.
- The worst level of pain indicated by each pilot occurred, on the average, after 4.125 hours of flying. The average of what the pilots perceived to be the worst level of pain was 3.3 on a scale of 0 to 5, where 0 is no discomfort and 5 is most severe back pain. Many of the lower levels of pain were indicated after less than four hours of flying time since many pilots had never flown for more than four hours (the average length of one mission was 6 hours).
- The two most severe levels of pain (4 and 5) occurred after four and six hours of flying, respectively.
- The average amount of time that it takes for a pilot's pain to disappear was two hours, 40 minutes, with some pain disappearing immediately, and some taking up to five days.
- Neither height nor weight affected the level of discomfort, when it occurred, and when it disappeared.
- There was no correlation between mission length, or total number of hours flown in the Black Hawk, with level of pain, when it occurred or when it disappeared.
- Methods to alleviate discomfort ranged from placing a cushion behind the lower back, or adjusting the position of the lumbar support, to changing position and posture.

- Most of the pilots, regardless of size, positioned their seat full aft, and midway between the full up and down positions. One pilot commented that he repositioned his seat higher than normal due to the high position of the glare shield.
- Comments on the bottom cushion suggested that the cushion was too thin (19 responses), that there was load concentration on the IT's (19 responses), and that there was not enough thigh support (17 responses).
- Comments on the back cushion suggested that there was a lack of lumbar support (16 responses) as well as a limited amount of adjustment (seven responses).
- The contours for both the back and bottom cushions were generally received favorably. The discomfort, therefore, seemed to stem from the lack of durability and support provided by the foam used in the cushion.

A summary of the comments on both the bottom and back cushions is shown in Table 1. These comments are ranked by the number of related comments made with respect to the total number of comments received.

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TABLE 1. SUMMARY OF SURVEY RESULTS REGARDING  
BACK AND BOTTOM CUSHIONS

---

<u>Bottom Cushion</u>	<u>Percentage of Total Responses</u>
Hard and thin Load Concentration on IT's	42
<u>Lumbar Support</u>	31
Not enough Lacks adjustment	
<u>Thigh Support</u>	
Not enough	16
<u>Back Cushion</u>	
Hard and thin	11

---

## 5.0 MATERIALS EVALUATION

A series of tests on various cushion foams was performed to help identify the most appropriate foams for use in seat cushions designed to alleviate back pain. Eighteen different foams were selected from existing literature and tested for durability and vibration, and measured for stiffness and density.

### 5.1 DURABILITY TEST

The durability of each foam was determined by measuring the change in thickness of a sample subjected to cyclic shearing under a constant compressive load. Samples 2.75 x 2.75 x 1.00 in. in size were bonded between two aluminum plates and subjected to a compressive stress of 3 lb/in.<sup>2</sup>.

A cyclic shear displacement at a frequency of 60 Hz and an amplitude of  $\pm 0.10$  in. was applied to the bottom plate while the top plate remained fixed. This application of shear stress on the cushion represents the occupant's motions on a seat cushion in a vibrating helicopter. Prior to testing, each sample thickness was measured. After 60 minutes of testing, and one minute of rest, the change in thickness was measured; after 60 more minutes of rest, the change in thickness was measured again. Similar measurements were taken after 11 hours of testing. The results show which foams are better able to endure the stresses imposed by an occupant sitting on a vibrating cushion. If the foam was able to recover its original thickness, then major breakdown of its cellular structure did not occur during the test. If, however, the foam did not recover to its original thickness, then damage to the cell structure occurred, indicating lack of durability. Table 2 lists the materials tested with the average change in sample thickness after each of the four stages.

Foams exhibiting a change in thickness less than the average of 0.041 in., after a total of 12 hours of testing and 60 minutes rest, were determined to be resilient and were considered as design candidates. These foams are indicated by an asterisk in Table 2.

### 5.2 VIBRATION TEST

Different samples (8 x 8 x 2 in.) of the same foam types tested for durability were measured for their vibration-attenuating properties. Each foam was subjected to  $\pm 0.1$  G acceleration through a frequency range from 2 to 60 Hz. A cylindrical metal block, 4.5 in. diameter by 5.5 in. high, and weighing approximately 25 lb, was placed on each foam sample during the test, imposing a pressure of 1.5 lb/in.<sup>2</sup> to represent the seated occupant's effect on the cushion. An MB C-60/MB4200 Vibration Table, controlled by an HP-5427A Digital Control System, was used for the test.

The transmissibility ratio of each foam/mass system, i.e., output acceleration on the metal block divided by input acceleration to the cushion, was measured. Every foam transmitted some vibration, although Confor Foam exhibited the lowest transmissibility ratio. The peak transmissibility ratio for each foam/mass system, and the resonant frequency at which it occurs, are listed in Table 3. Foam/mass systems that exhibited resonant frequencies coinciding with those of the whole body (4 - 14 Hz), and the helicopter main (4 Hz, 16 Hz) and tail (19.6 Hz) rotors, were considered to be less desirable

TABLE 2. AVERAGE CHANGE IN THICKNESS (IN.) OF FOAM SAMPLES SUBJECTED TO COMBINED COMPRESSIVE AND CYCLIC SHEAR LOADS

No.	Material	After 1 hr Testing		After 11 more hr Testing	
		1 min. rest	60 min. rest	1 min. rest	60 min. rest
1	1233X	0.127	0.076	.172	.114
2	Aero*	0.048	.013	.127	.039
3	HR2511	0.053	.025	.074	.049
4	1826X	.090	.057	.117	.080
5	Minicell*	.025	.007	.059	.034
6	24100	.050	.036	.089	.057
7	Ethafoam® XFS 4101	.035	.012	**	**
8	Black Ionomer	.031	.021	.052	.046
9	CU 3341*	.057	.039	.055	.038
10	Evazote*	.011	.002	.024	.008
11	CU 3360	.058	.041	.065	.043
12	HR3031	.054	.030	.072	.047
13	Recticel (small)	.042	.023	.075	.042
14	Recticel (large)*	.025	.005	.055	.020
15	Recticel (wire)*	.036	.016	.073	.035
16	Confor Foam C-45®*	.033	.020	.047	.038
17	Ensolite*	.004	.001	.013	.007
18	F12 Chorlastic*	.003	.003	.003	.001
	Average	.043	.023	.065	.041

\*Candidate materials.

\*\*Test apparatus failed.

®Ethafoam is a registered trademark of Dow Chemical Company.

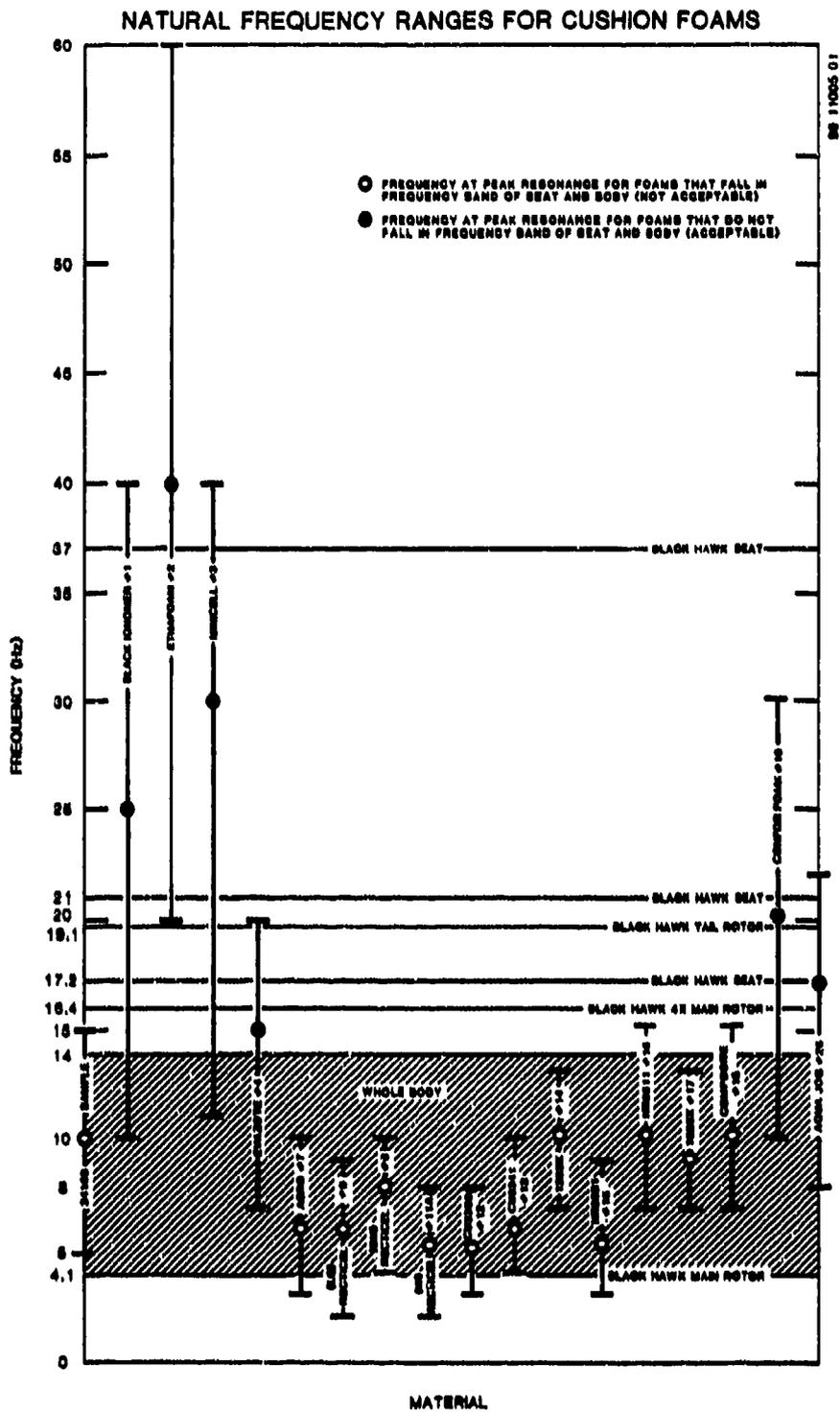
®Confor Foam is a registered trademark of EAR Specialty Composites.

for this program. It is interesting to note that of all the soft foams tested, Confor Foam is the only one to fall within a desirable resonant frequency range. Soft foams with lower transmissibility ratios therefore were not eliminated as candidate cushion materials, even though their natural frequencies fell outside the acceptable frequency range. Like Confor Foam, the stiffer foams fell in the acceptable frequency range. However, the transmissibility ratios of the stiffer foams were much higher than those of the softer foams. Confor Foam, a soft foam with low transmissibility ratio and acceptable resonant frequency, was selected as the number one foam candidate. Figure 1 illustrates the frequency range through which each foam resonates, and the frequency at which the peak transmissibility for each foam occurs. Figure 1 also highlights the resonant frequencies for the body and helicopter.

TABLE 3. RESULTS OF FOAM VIBRATION TESTS

No.	Material	Resonant Frequency (Hz)	Peak Transmissibility Ratio	Material Frequency Coincident with Body & Helicopter Frequencies*
1	1233X	10	5.0	X
2	Aero*	6	3.5	
3	HR2511	10	2.5	X
4	1826X	9	5.0	X
5	Minicell	30	6.5	
6	24100	10	4.5	X
7	Ethafoam XFS 4101	40	6.4	
8	Black Ionomer	25	7.0	
9	CU 3341	6	4.5	X
10	Evazote	15	6.5	
11	CU 3360	5.3	5.0	X
12	HR3031	5.5	4.5	X
13	Recticel (small)	8	5.0	X
14	Recticel (large)	6	3.0	X
15	Recticel (wire)	5.5	2.0	X
16	Confor Foam C-45	20	1.4	
17	Ensolite	-	-	
18	F12 Chorlastic	-	-	
	Average		4.5	

\*Whole: Body frequency range 4 - 14 Hz  
Mean rotor frequency range 4.1 - 4.3 Hz  
4x main rotor frequency range 16.4 - 17.2 Hz  
Tail rotor frequency range 19.0 - 19.9 Hz  
Seat frequencies 17.2, 21.0, 37.0 Hz.



**FIGURE 1. FREQUENCY RANGE WHERE RESONANCE OCCURS FOR DIFFERENT FOAMS SUBJECTED TO  $\pm 0.1$  G THROUGH 2-60 Hz FREQUENCY RANGE.**

### 5.3 FOAM STIFFNESS AND DENSITY

The densities and stiffnesses of the foams were measured and are listed in Table 4. The foam stiffness is indicated by the 25-percent Indentation Load Deflection (ILD) number in pounds. The 25-percent ILD is the number of pounds required to compress a 4-in. thick piece of foam 25 percent. There is no optimum ILD number; however, one can be selected as the optimum for a specific cushion design. The stiffness measured for each foam was used to establish a desired level of comfort, and density was taken into consideration because weight is a primary concern of the aerospace industry.

TABLE 4. MATERIAL STIFFNESS AND DENSITY

No.	Material	Density lb/ft <sup>3</sup>	ILD (lb)
1	1233X	1.1	30
2	Aero	1.41	50
3	HR2511	1.52	25
4	1826X	1.57	27
5	Minicell	1.91	>100
6	24100	2.13	100
7	Ethafoam XFS 4101	2.16	>100
8	Black Ionomer	2.78	>100
9	CU 3341	2.78	33
10	Evazote	2.83	>100
11	CU 3360	3.02	55
12	HR3031	3.18	33
13	Recticel (small)	3.30	53
14	Recticel (large)	4.20	65
15	Recticel (wire)	4.56	55
16	Confor Foam C-45	5.77	45
17	Ensolite	6.56	>100
18	F12 Chorlastic	12.59	>100

### 5.4 MATERIAL SELECTION

The acceptable foams are listed in Table 5. A foam with acceptable durability properties was defined to have a change in sample thickness less than 0.041 in. An acceptable density was defined to be less than 3.52 lb/ft<sup>3</sup>. Foams exhibiting an ILD greater than 100 lb were defined as too stiff to be used to interface the seated occupant. However, a stiff foam may be contoured and used as the base layer in a sandwich-constructed cushion.

The selection of foam for the cushion design was based on the results shown in Table 5. However, some foams were selected on a slightly more subjective basis to meet the demands of the occupant. For example, Evazote meets both the durability and vibration requirements; however, it exhibits a stiffness greater than 100 lb (ILD) which suggests that it would not serve as a comfortable interface between the body and the seat. However, it could be very effective as a contoured base layer of a sandwich cushion structure similar to the Black Hawk cushion.

TABLE 5. CANDIDATE FOAM MATERIALS

Foam	Durability: Change in Thickness (in.)	Vibration: Peak Transmissibility Ratio	Density (lb/ft.)	ILD Stiff- ness, (lb) <sup>2</sup>
F12 Chorlastic	.001	-	12.59	>100
Ensolite	.007	-	6.56	>100
Recticel (Large)	.020	3.0	4.20	55
Evazote	.008	-6.5(1)(3)	2.83	>100
Aero	.039	3.5	1.41	50
Minicell	.034	-6.5(1)(3)	1.91	>100
Ethafoam	-	-6.4(1)(3)	2.16	>100
Black Ionomer	.046(2)	-7.0(1)(3)	2.78	>100
CU 3341	.038	4.5	2.78	33
CU 3360	.043(2)	5.0(3)	3.02	55
HR 3031	.047(2)	4.5	3.18	33
Recticel (wire)	.035	2.0	4.56	55
Confor Foam	.038	-1.4(1)	5.77	45

Notes:

- (1) Foams with acceptable frequencies: they do not coincide with natural frequencies of body and helicopter.
- (2) Average change in thickness is higher than the average (0.041 in.) for all the foams tested (see Table 2).
- (3) Peak transmissibility ratio is higher than the average (4.5) for all the foams tested (see Table 3).

Confor Foam was selected for the bottom cushion because it has exceptional dampening characteristics (indicated by a low transmissibility ratio), and reasonable durability properties. In addition to durability and dampening, Confor foam is also recognized for its rate sensitivity. As a rate-sensitive foam, Confor foam has the ability to stiffen when compressed quickly, facilitating crashworthiness. Confor Foam also conforms to the body contour when compressed slowly, providing optimum comfort. Therefore, Confor Foam not only exhibits excellent dampening properties, but it also enhances comfort and crashworthiness.

Confor Foam was not selected for the back cushion because this foam exhibits initial stiffness that is reduced only by direct loading. For example, used as a bottom cushion, the rate-sensitive Confor Foam conforms to the body's contour in response to the pressure applied by the seated occupant. Since the body does not apply very large loads to the back cushion, the occupant would continue to experience a higher stiffness in the back cushion than desired. Therefore, a softer foam was more desirable for the back cushion. As already noted, the soft foams all exhibited unacceptable resonant frequencies. Therefore, the back cushion foam had to be selected carefully, since a soft foam with acceptable resonant frequency was not available.

The foam selected (CU1818) for the back cushion was both softer and had a lower density than the CU foams tested (CU 3341 and CU 3360). CU 3341 had the lowest stiffness of all the foams tested and was determined to have slightly more durability and higher dampening properties than CU 3360. When CU 3341 foam was measured for comfort, however, it was determined that an even softer foam would be more desirable. CU 1818, which has a lower ILD (18) and a lower density (1.8 lb/ft<sup>3</sup>) than the CU 3360 and CU 3341 tested, demonstrated improved comfort. The durability and higher damping characteristics of CU 1818 were not tested. However, following the trend shown between CU 3341 and CU 3360, the reduction of CU 1818 should improve the durability and damping characteristics.

## 6.0 CUSHION DEVELOPMENT

After the completion of the literature search, pilot survey, and materials tests, the cushion development process began. First, several concepts were established based on the recommendations from the literature and pilot survey, and the most promising concepts were selected. Second, after evaluating existing cushion contours, improved back and bottom contours were designed. And third, fabrication of prototype cushions completed the cushion development process. These three subtasks are described below.

### 6.1 ESTABLISH CONCEPTS

Several brainstorming sessions were conducted to produce a set of cushion concepts. Suggestions include:

- Provide seat pan contour that supports the sides of the buttocks and reduces pressure on the IT's (Figure 2)
- Consider inner thigh support (high in front center, low in back center) (Figure 3)
- Provide seat pan contour with downturning back end (Figure 4)
- Provide cushion with ridges for ventilation (Figure 5).

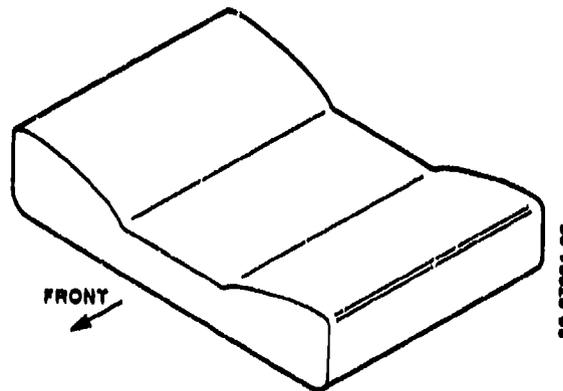
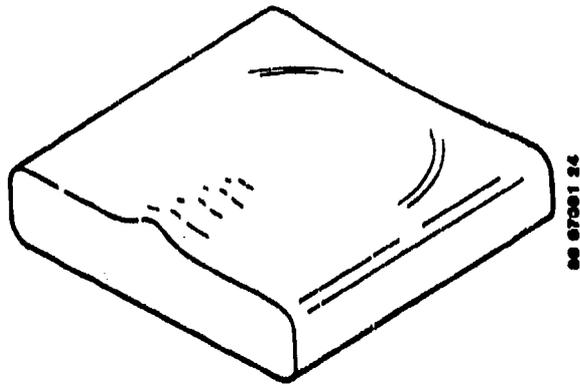
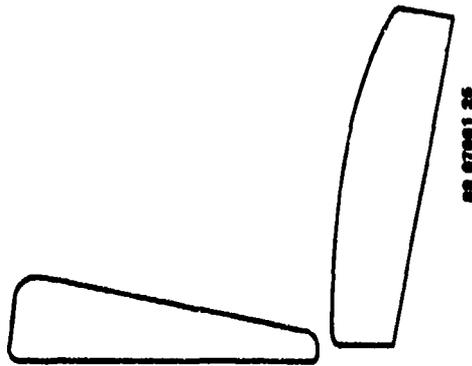


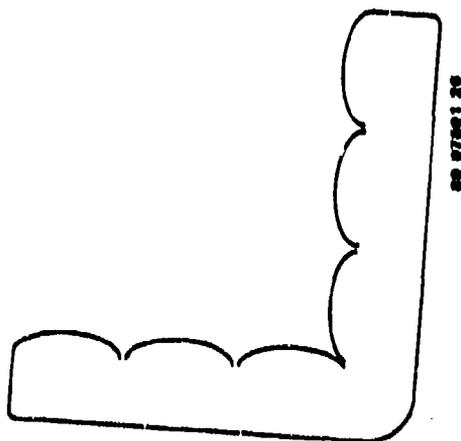
FIGURE 2. CUSHION THAT SUPPORTS THE SIDES OF THE BUTTOCKS.



**FIGURE 3. CUSHION PROVIDING INNER THIGH SUPPORT.**



**FIGURE 4. BOTTOM CUSHION WITH DOWNTURNING BACK END.**



**FIGURE 5. CUSHION WITH RIDGES FOR VENTILATION.**

Second, commercially available seat attachments, advertised as devices designed specifically to reduce back pain and increase comfort, were evaluated for possible incorporation in cushion concepts. Three of the advertised seat attachments were purchased and analyzed. They are:

- Back Friend<sup>™</sup> (Figure 6)  
Contoured seat pan and back hinged together to allow continuous support at any angle
- Back Joy<sup>™</sup> (Figure 7)  
Small, contoured seat pan designed to support the buttocks and tail bone
- Back Machine<sup>™</sup> (Figure 8)  
Back cushion designed with roller bar to provide adjustable lumbar support for any size occupant.

And finally, using the suggestions and the back devices, together with the information gathered from the literature search and pilot surveys, eight concepts were produced:

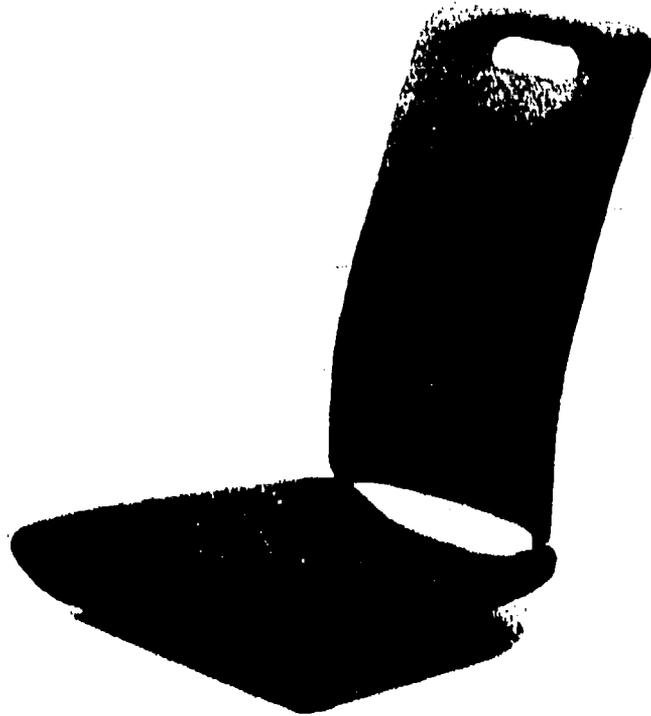
1. Concept No. 1: Combined pivoting seat pan/back fiberglass contour (Figure 9).
2. Concept No. 2: Inflatable thigh support with cross bleed (Figure 10).
3. Concept No. 3: Torso support (Figure 11).
4. Concept No. 4: Combined pivoting cushion and torso support (Figure 12).
5. Concept No. 5: Combined pivoting fiberglass contour with torso and adjustable lumbar support (Figure 13).
6. Concept No. 6: Mechanical vertical adjustment mechanism for lumbar support (Figure 14).
7. Concept No. 7: Mechanical horizontal adjustment mechanism for lumbar support (Figure 15).
8. Concept No. 8: Inflatable adjustment mechanism for lumbar support (Figure 16).
9. Concept No. 9: Separate seat pan and back cushions with key features listed in Section 4.1.2.

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<sup>™</sup>Back Friend is a trademark of ME Design, Ltd.

<sup>™</sup>Back Joy is a trademark of Back Joy, Inc.

<sup>™</sup>Back Machine is a trademark of Kingstar International America, Inc.

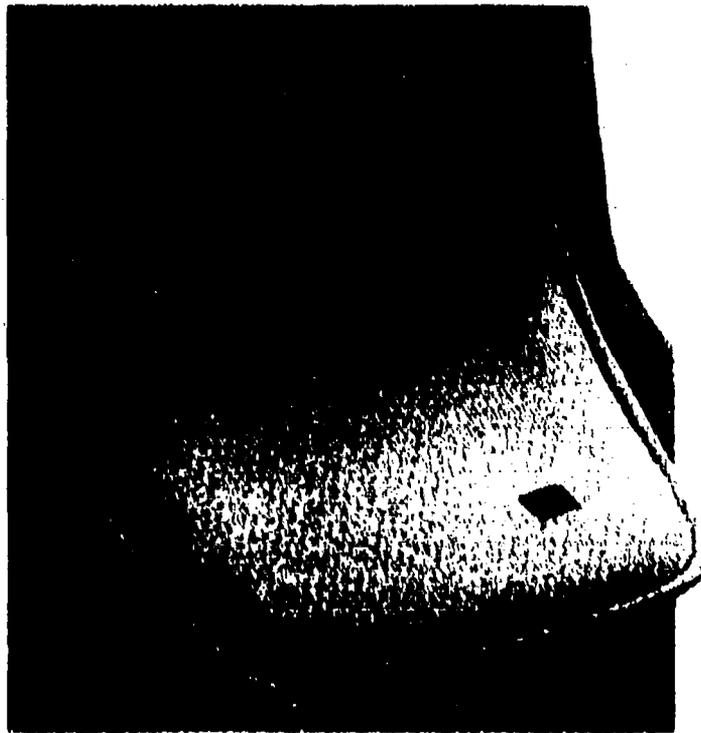


**FIGURE 6. BACK FRIEND.**

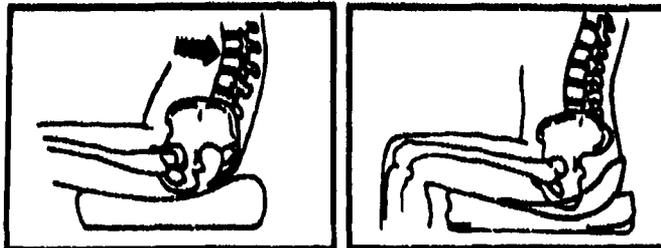
Of these nine concepts, four were selected for prototype fabrication on the basis that they could most easily be designed to satisfy the criteria listed in Section 4.1.2. The four selected concepts are listed here and are shown with greater detail in Figures 17 through 20.

1. Concept No. 1: Pivoting Contoured Seat Back and Bottom (Figure 17).
2. Concept No. 6: Mechanical Adjustable Lumbar Support (Figure 18).
3. Concept No. 8: Air Bag Adjustable Lumbar Support (Figure 19).
4. Concept No. 9: Contoured Back and Bottom Cushions (Figure 20).

Cushion Concept No. 1 was designed and fabricated but it did not provide the desired level of comfort. Therefore, the development process of Concept Nos. 6, 8, and 9 is discussed in Sections 6.2 and 6.3.



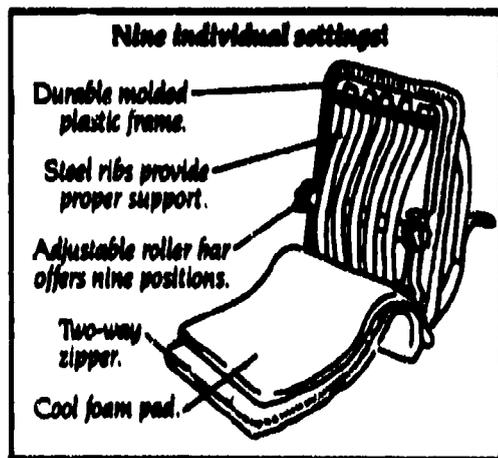
*If you sit a lot. Back joy will help prevent poor posture, and in turn, help prevent lower back trouble*



**FIGURE 7. BACK JOY.**

## **6.2 DEVELOP CONTOURS**

The development of the contours took place in three basic tasks. First, existing contours were evaluated for comfort and compared with the list of criteria gathered for each concept. Second, a baseline design was made which combined the most comfortable features of the evaluated contours with the other features believed to add to comfort. Finally, a contour was fabricated and then modified as required to maximize comfort. All evaluations were conducted by a group of four individuals ranging in size from the 5th- to 98th-percentile male aviator (referred to as "Group").



**FIGURE 8. BACK MACHINE.**

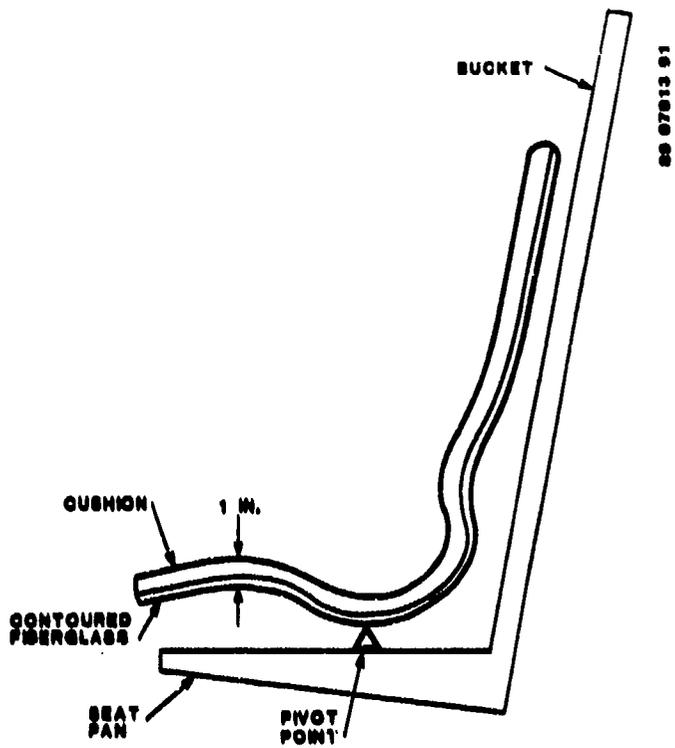


FIGURE 9. PIVOTING FIBERGLASS CONTOUR WITH CUSHION (CONCEPT NO. 1).

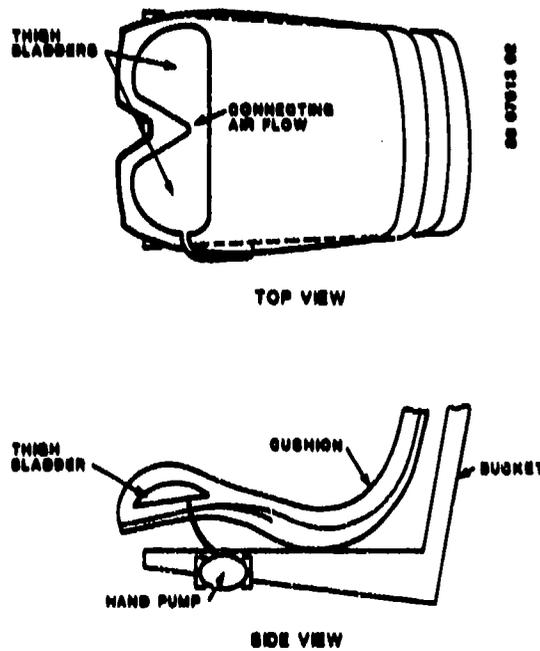
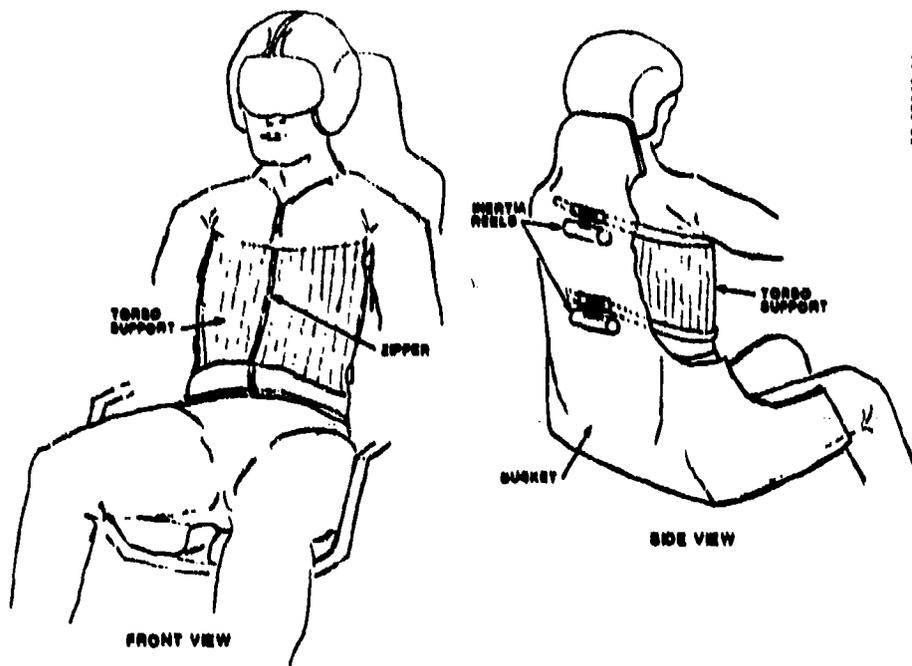
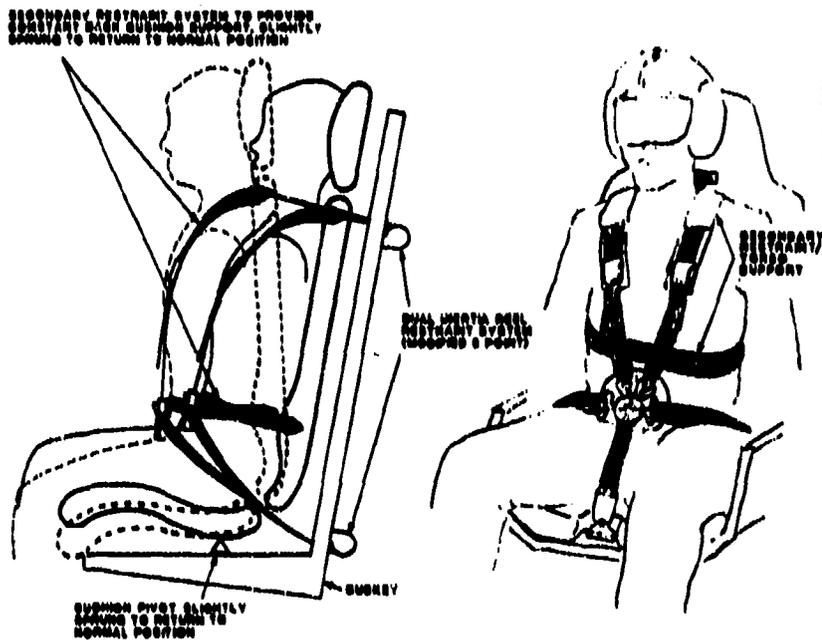


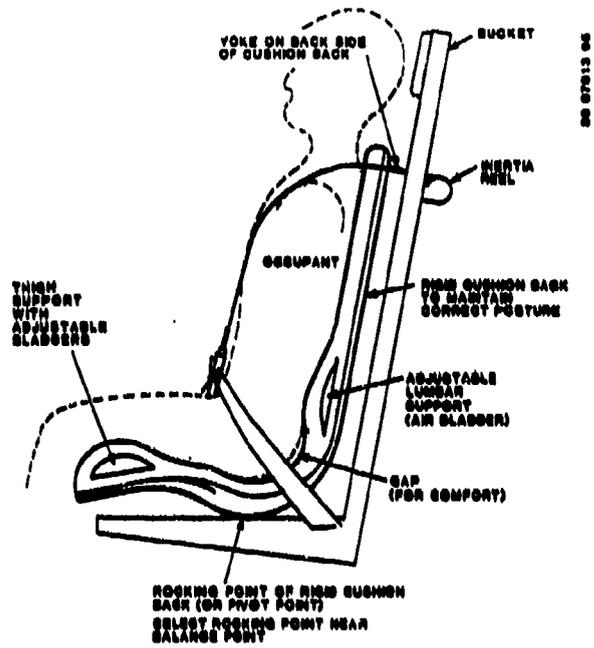
FIGURE 10. INFLATABLE THIGH SUPPORTS WITH CROSS BLEED (CONCEPT NO. 2).



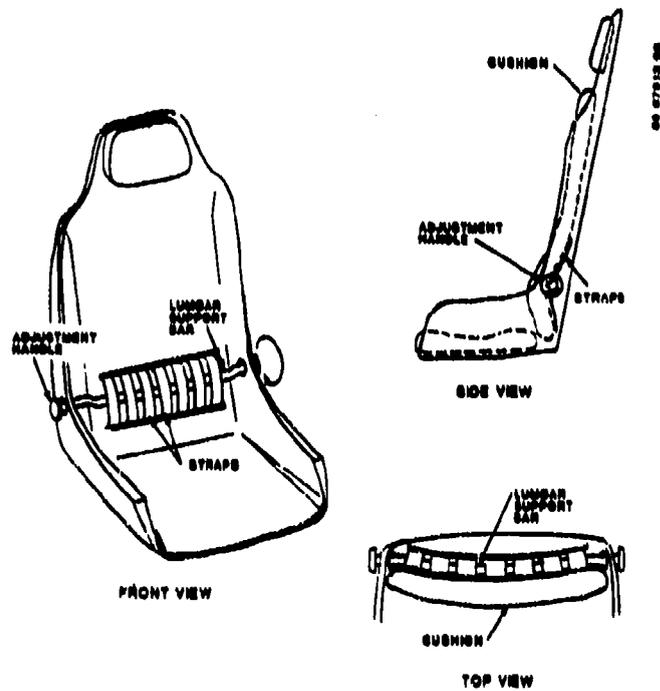
**FIGURE 11. TORSO SUPPORT (CONCEPT NO. 3).**



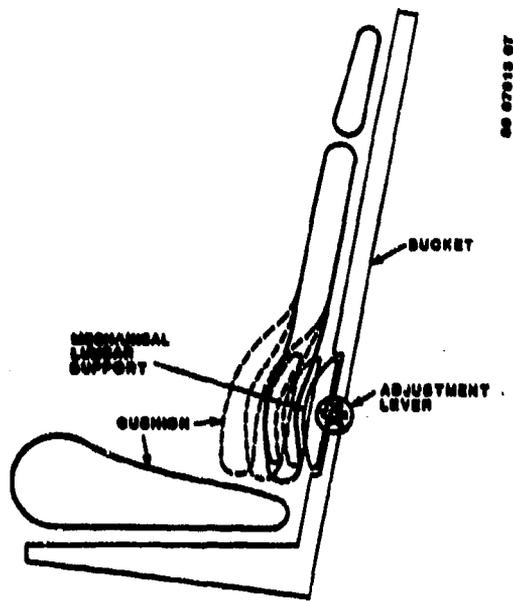
**FIGURE 12. COMBINED PIVOTING CUSHION AND TORSO SUPPORT (CONCEPT NO. 4).**



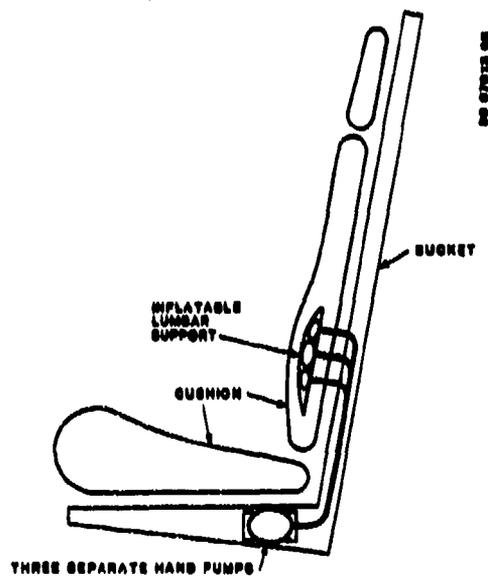
**FIGURE 13. COMBINED PIVOTING FIBERGLASS CONTOUR TORSO SUPPORT AND ADJUSTABLE LUMBAR SUPPORT (CONCEPT NO. 5).**



**FIGURE 14. LUMBAR SUPPORT ADJUSTMENT - MECHANICAL (CONCEPT NO. 6).**

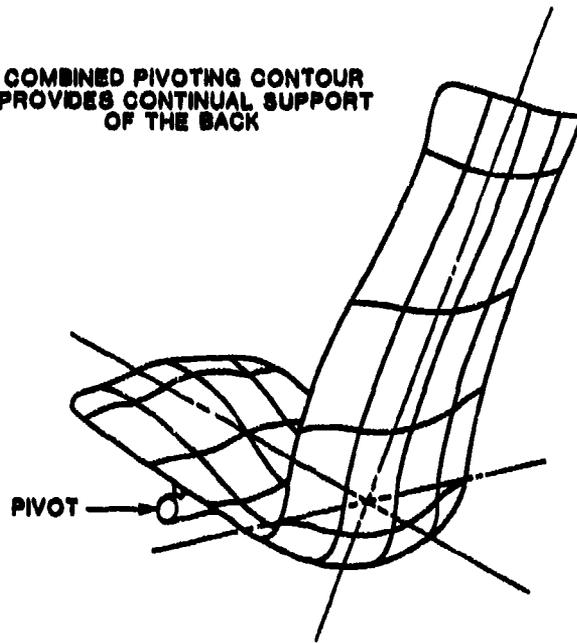


**FIGURE 15. HORIZONTAL LUMBAR SUPPORT ADJUSTMENT - MECHANICAL (CONCEPT NO. 7).**



**FIGURE 16. VERTICAL AND HORIZONTAL LUMBAR SUPPORT ADJUSTMENT - INFLATABLE (CONCEPT NO. 8).**

COMBINED PIVOTING CONTOUR  
PROVIDES CONTINUAL SUPPORT  
OF THE BACK

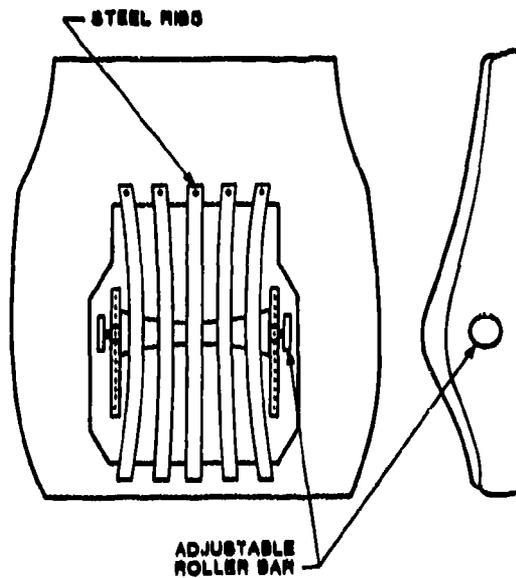


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FIGURE 17. PIVOTING CONTOURED SEAT BACK AND BOTTOM.

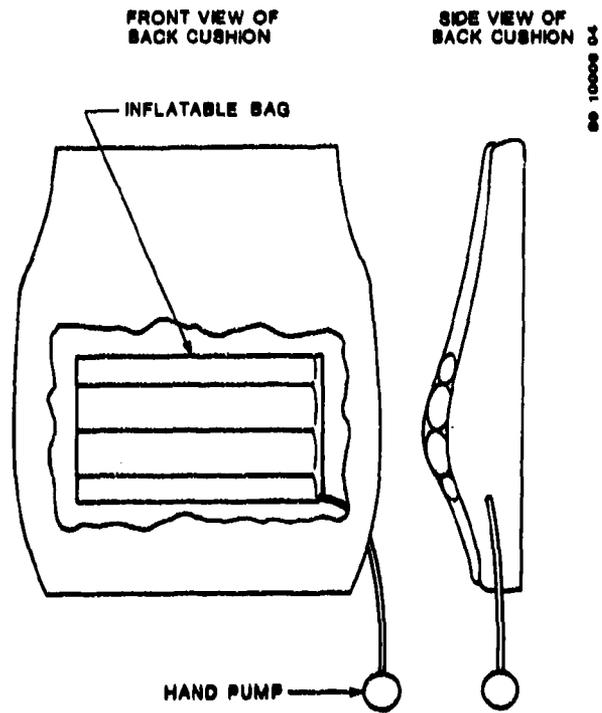
FRONT VIEW OF  
BACK CUSHION  
(UPHOLSTERY FOAM REMOVED)

SIDE VIEW OF  
BACK CUSHION

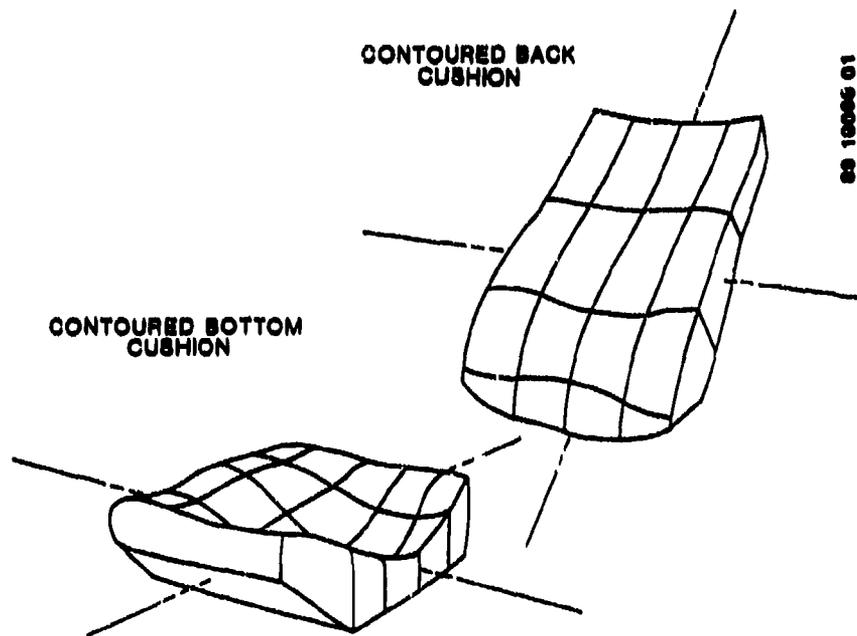


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FIGURE 18. MECHANICAL ADJUSTABLE LUMBAR SUPPORT.



**FIGURE 19. AIR BAG ADJUSTABLE LUMBAR SUPPORT.**



**FIGURE 20. CONTOURED BACK AND BOTTOM CUSHIONS.**

### 6.2.1 Back Contour

The first phase of the development was evaluation of existing back contours. The evaluation process consisted of sitting in a dozen existing cushions and comparing them to the desired characteristics listed from the literature search in Section 4.1.2, as well as comparing for comfort. The contours evaluated included five helicopter seats, four automotive seats, and three commercially available seat attachments, which were advertised as devices designed specifically to reduce back pain and increase comfort. Of these contours, the one selected for best lower lumbar support was that of the Back Machine (Figure 8), and for lateral and upper back support, the Back Friend (Figure 6). These attachments were rated best and most comparable to the given criteria.

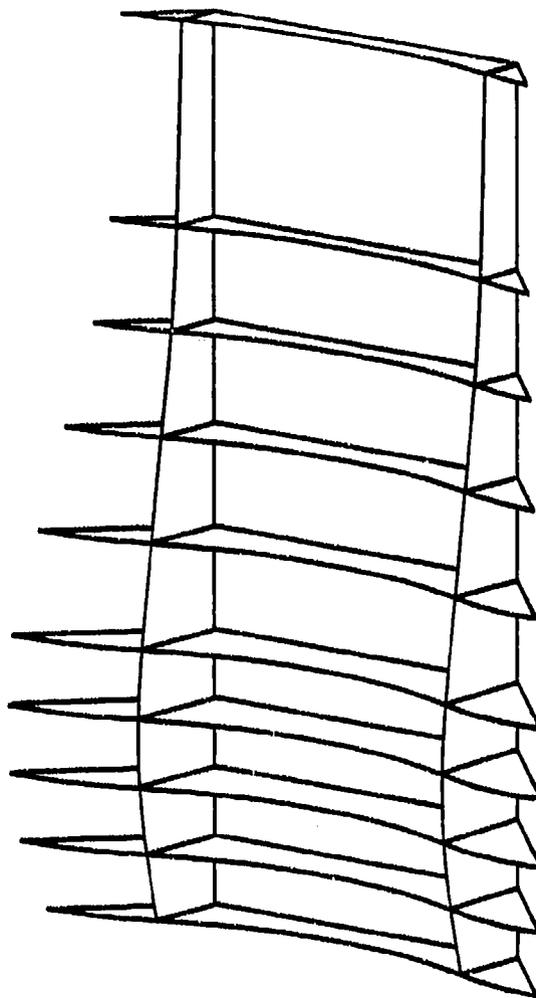
The next phase of development was producing drawings which combined the features of the Back Machine and Back Friend that would interface with the Black Hawk bucket. To do this, templates were cut to fit the contours at various spacings and then measured. These measurements were then used to produce a three-dimensional coordinate grid, which was input to a Computer-Aided Design (CAD) system. Finally, a three-dimensional surface was developed on the CAD which blended all the points into a single symmetrical contour. The contour was then "sliced up" at various locations, and a template drawing was made for each section.

To fabricate the baseline contour, the templates were plotted at full scale and laid out on 0.060-in. thick aluminum sheet stock. The aluminum was then cut out, notched, and assembled as shown in Figure 21. The template grid was then placed in the bucket with backing film, and the gaps in the template were filled with expandable polyurethane foam. After the foam set, the excess foam was sanded down flush with the aluminum grid. The contour was then placed in a bucket and evaluated by the Group without any upholstery foam installed. The contour was quite comfortable and the only modification performed was removal of material near the base so that the occupant could move back into the cushion for added lumbar support. The rigid contour was then sealed with filler and a master fiberglass mold was made so that several rigid contours could be fabricated.

The remaining step was the development of the upholstery foam contour. The first foam selected for the back was CU 3341, which has good vibration isolation and durability, as discussed in Section 5.1 and 5.2. After experimenting with several foam stiffnesses, it was determined that a thicker, softer foam was more desirable than a thin, stiff foam. A softer foam was selected (CU 1818) allowing larger relative movement without appreciably changing the pressure and also allowing the seat occupant to bend forward slightly and still maintain back support.

The shape of the foam was also determined experimentally. It was found that the most comfortable arrangement was having the foam thickness proportionate to the base contour (Figure 22). Thus the lumbar support area had the maximum thickness, as desired. Additional thickness was also added toward the outer edges in the lumbar support area for lateral support similar to that found in newer automotive bucket seats.

The end result of this development was a very comfortable back contour that provided the proper support of the lumbar spine. The foam contour was developed to accentuate the rigid contour and allow slight forward movement (common for helicopter pilots) while still providing good support.

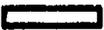


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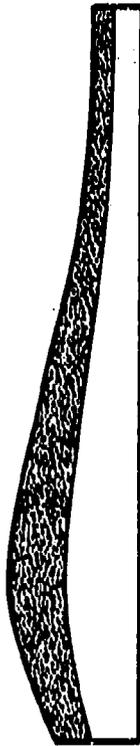
FIGURE 21. TEMPLATE GRID REPRESENTING THE BACK CUSHION CONTOUR.

### 6.2.2 Bottom Contour

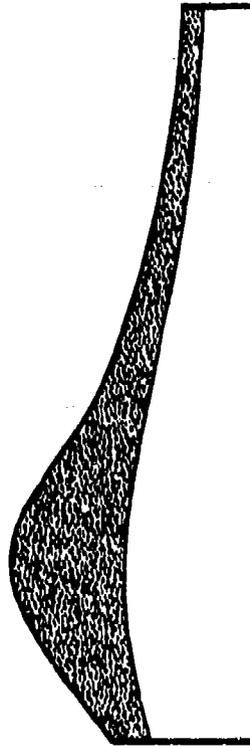
The bottom contour development was more restricted since both crashworthiness and comfort requirements had to be satisfied. In general, bottom cushions use relatively thick foam pads and/or springs to achieve comfort, but this is not acceptable for a crashworthy helicopter seat. In a crash situation, thick cushions can be easily and quickly compressed causing significant occupant downward motion in a short time frame. The result is dynamic overshoot, or severe loads on the quickly decelerating occupant, and loosening of the shoulder harness. The best bottom cushion from a crashworthiness standpoint would have no soft foam at all, and would rely on a shaped contour to provide comfort. Therefore, it was decided that the best way to develop the bottom contour would be to provide the most comfortable contour for various-sized occupants using a relatively thin layer of rate-sensitive foam such as Confor foam, to maximize comfort.

UPHOLSTERY FOAM   
RIGID BASE 

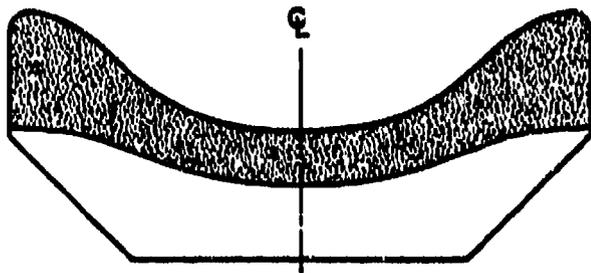
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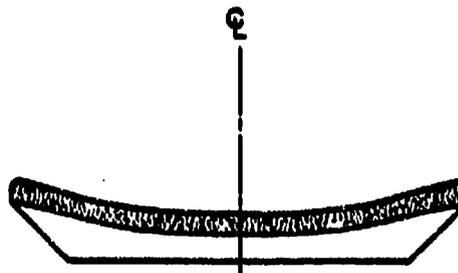
a. CENTERLINE SECTION



b. OUTER EDGE SECTION



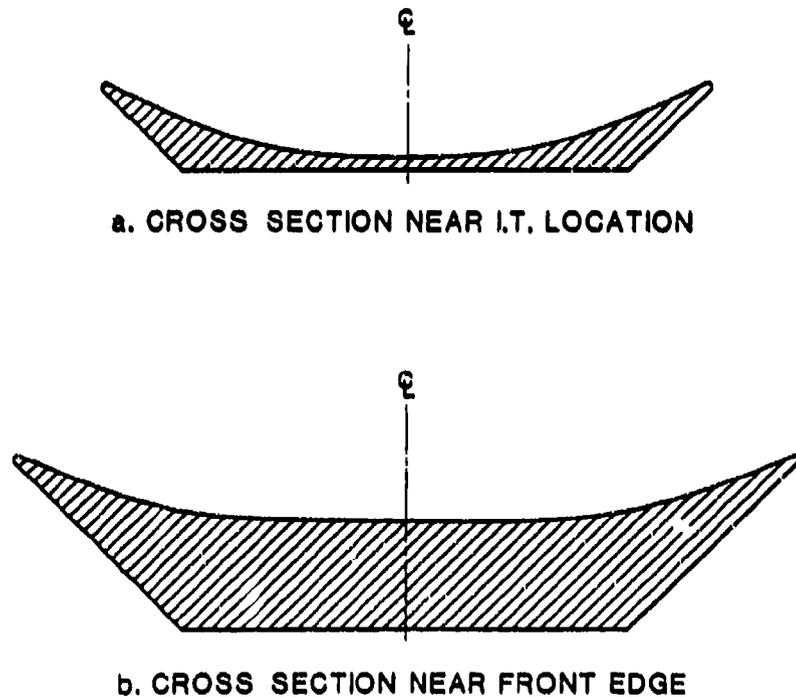
c. LUMBAR LEVEL SECTION



d. TOP EDGE SECTION

FIGURE 22. BACK CUSHION FOAM CONTOUR.

As with development of the back contour, the first phase of development was to evaluate the comfort of existing seats by sitting in them. The contours of existing bottom cushions are similar, having a cupped shape with a flat to relatively large radius of curvature near the centerline and a smaller radius of curvature near the outside edges, as shown in Figure 23. When sitting on a semirigid base contour of an existing cushion with the foam removed, it was found that after approximately 10 minutes, discomfort and high pressure were noted under the IT's. This high pressure was caused by two main factors. First, there was limited lateral support and very little thigh support, causing the occupant weight to be supported over a relatively small area (high average pressure). Second, there were no recesses cut out for the IT's.



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**FIGURE 23. EXISTING HELICOPTER SEAT BOTTOM CUSHION BASE PROFILE.**

Several actions were taken to develop an improved contour which would optimize the supporting area and also have recessed locations for the IT's. First, the thigh angle was increased and the contour was "built up" in the front between the thighs. This gave the contour the general shape of the old style, all-metal (no padding) tractor seats (Figure 3). The sides and rear contours of the existing cushions favor larger occupants as they fill in the entire contour to take advantage of the lateral support available. The curved edges could have been narrowed to support the smaller occupant, but this would produce unacceptable discomfort to the large occupant. Instead, the curved areas were replaced with a nearly straight profile originating from the IT locations for a large occupant (maximum width). This enhancement

of the contour provided all the occupants with the same lateral support. Very slight recesses for the IT's were incorporated in the bottom cushion to help alleviate the pressure buildup on the IT's.

As with the back cushion contour, template drawings were developed on the CAD and the profile was fabricated using rigid expandable polyurethane foam. After sanding the foam to shape, the contour was evaluated by the Group, and in this case, modifications were conducted to maximize comfort. The IT locations were lowered further and it was also found that slightly rounded side and back buttock support was more comfortable for all sizes of occupants than the straight sides. The final contour was relatively deep, giving support around the full buttock circumference with no high pressure points.

The final step of the bottom contour development was the selection of upholstery foam. For crashworthiness and vibration dampening, Confor foam, which is a highly damped and rate-sensitive foam (stiffens when compressed quickly) was selected. After experimenting with several different stiffnesses and thicknesses, it was found that maximum comfort was obtained using a base layer of 0.375-in. thick medium foam (Confor Foam P/N C-45) followed with one layer of 0.375-in. soft foam (Confor Foam P/N C-42). Figure 24 compares the prototype bottom cushion (final selected contour) and the existing Black Hawk bottom cushion front and back views.

### **6.3 FABRICATE CUSHIONS**

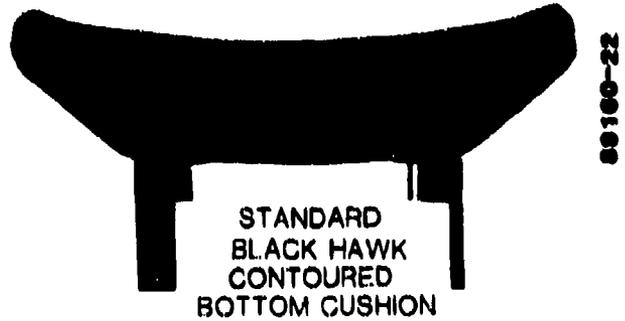
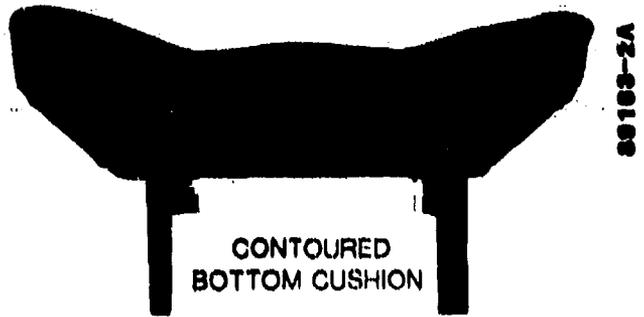
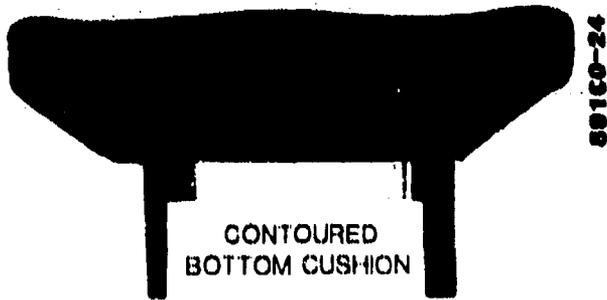
The fabrication and evaluation of three cushion concepts is discussed here. These concepts are a nonadjustable back cushion with bottom cushion (Cushion No. 1), a back cushion with mechanical lumbar adjustment and bottom cushion (Cushion No. 2), and a back contour with inflatable lumbar adjustment and bottom cushion (Cushion No. 3). All three back cushions had the same contour shape with the same amount of foam padding, as discussed in Section 6.2. One bottom cushion was used for all three sets.

#### **6.3.1 Cushion Without Adjustment (Cushion No. 1)**

Fabrication of the cushion back without adjustment was the simplest of the three concepts. First, a relatively thin (0.8 in.) fiberglass part was laid up on the master mold and removed. The part was then trimmed around the edges to the proper shape. Next, the part was placed in a mockup bucket liner with plastic lining so that the gap between the part and the bucket liner could be filled with expandable polyurethane foam. Standoffs were placed between the part and the liner to ensure proper spacing as the foam set. After the foam set the part was removed from the liner and excess foam was trimmed. Finally, the developed upholstery foam contour was bonded to the part and the entire cushion was covered with fabric. Loop fastening tape was also attached to the back of the cushion to hold it in place during the final evaluation process. The prototype cushion without adjustment is shown in Figure 25.

#### **6.3.2 Cushion with Mechanical Adjustment (Cushion No. 2)**

Similar to the cushion without adjustment, a relatively thin fiberglass part was made off the master mold. A hole was then cut in the part so that modified components from the Back Machine could be installed inside the contour as shown in Figure 26.



**FIGURE 24. COMPARISON OF CONTOURS BETWEEN PROTOTYPE AND EXISTING BLACK HAWK BOTTOM CUSHIONS.**



FRONT VIEW OF  
BACK CUSHION  
(UPHOLSTERY FOAM REMOVED)

SIDE VIEW OF  
BACK CUSHION

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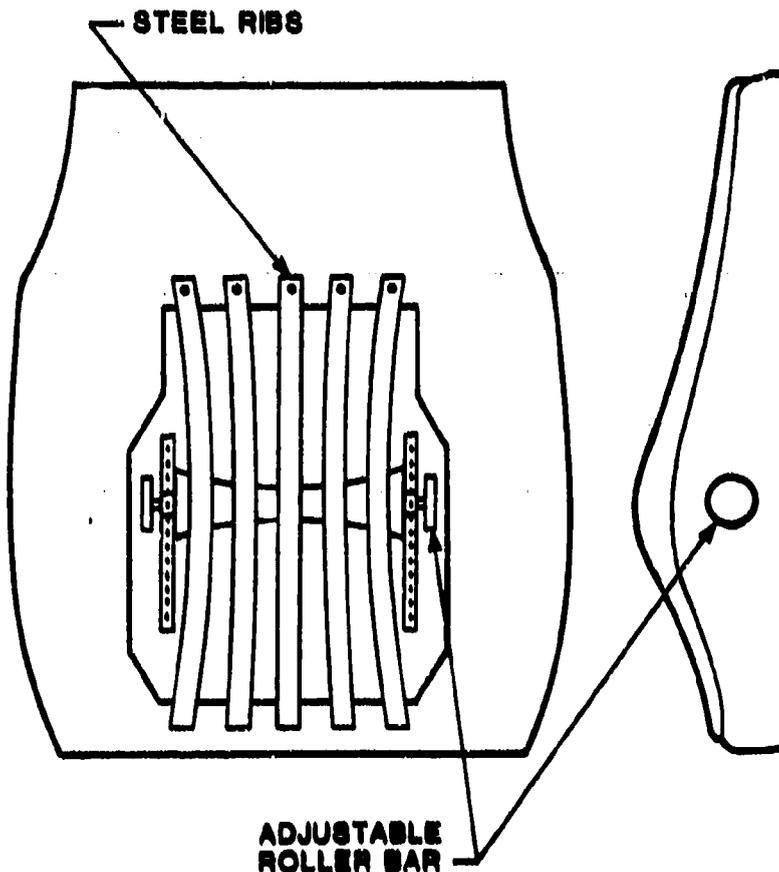


FIGURE 26. INSTALLATION OF MODIFIED COMPONENTS ON CUSHION WITH MECHANICAL LUMBAR ADJUSTMENT.

assembly from the bucket for adjustments. Finally, the developed upholstery cushion profile was bonded to the back and covered with material similar to the cushion without adjustment. The prototype cushion with mechanical adjustment is shown in Figure 27.

### 6.3.3 Cushion with Inflatable Adjustment (Cushion No. 3)

As with the other two cushions, a fiberglass part was fabricated and the back surface was filled in with expandable foam. The optimum inflatable bag shape was determined experimentally.



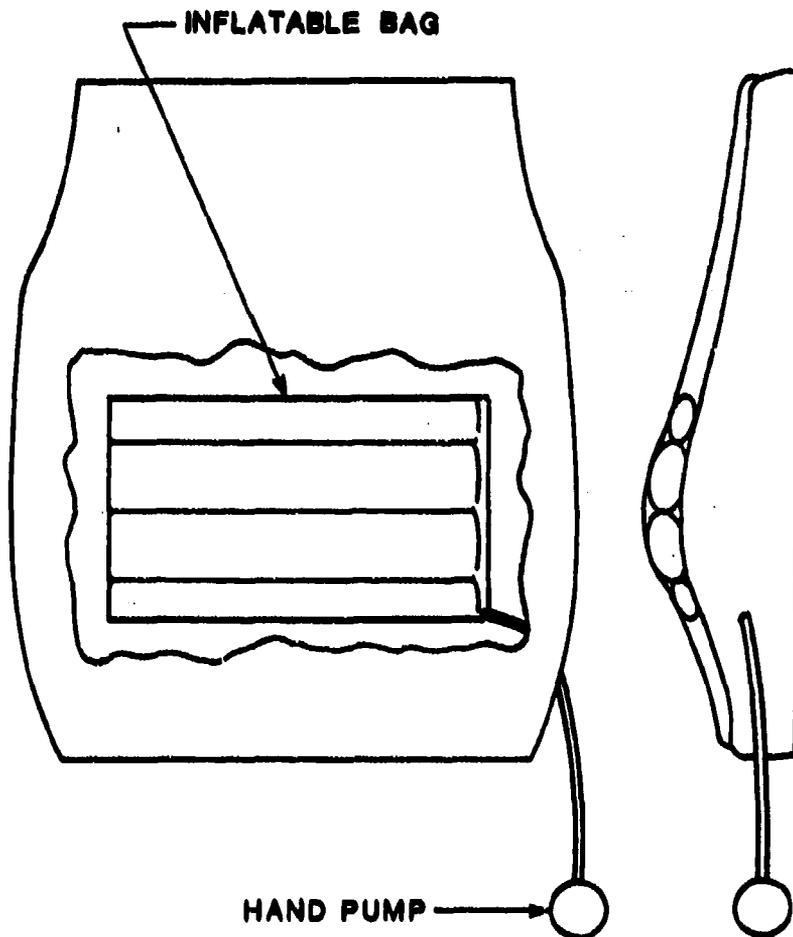
**FIGURE 27. PROTOTYPE CUSHION WITH MECHANICAL ADJUSTMENT  
(CUSHION NO. 2) (a) FRONT VIEW, (b) SIDE VIEW.**

The experimental inflatable bags were fabricated from high stretch vacuum bag material, normally used during composite fabrication. To build a bag, two sheets of the material were cut to shape, and the perimeter was sealed using hot melt glue. Tubing was also installed to fill the bag with air. A new bag could be fabricated in a matter of minutes, which allowed numerous bag shapes to be evaluated. These shapes included basic rectangles, bow tie shapes, and multiple chamber bags. Evaluation was conducted by the Group with upholstery foam installed. A multiple chamber concept, as shown in Figure 28, was selected as being the most comfortable.

**FRONT VIEW OF  
BACK CUSHION**

**SIDE VIEW OF  
BACK CUSHION**

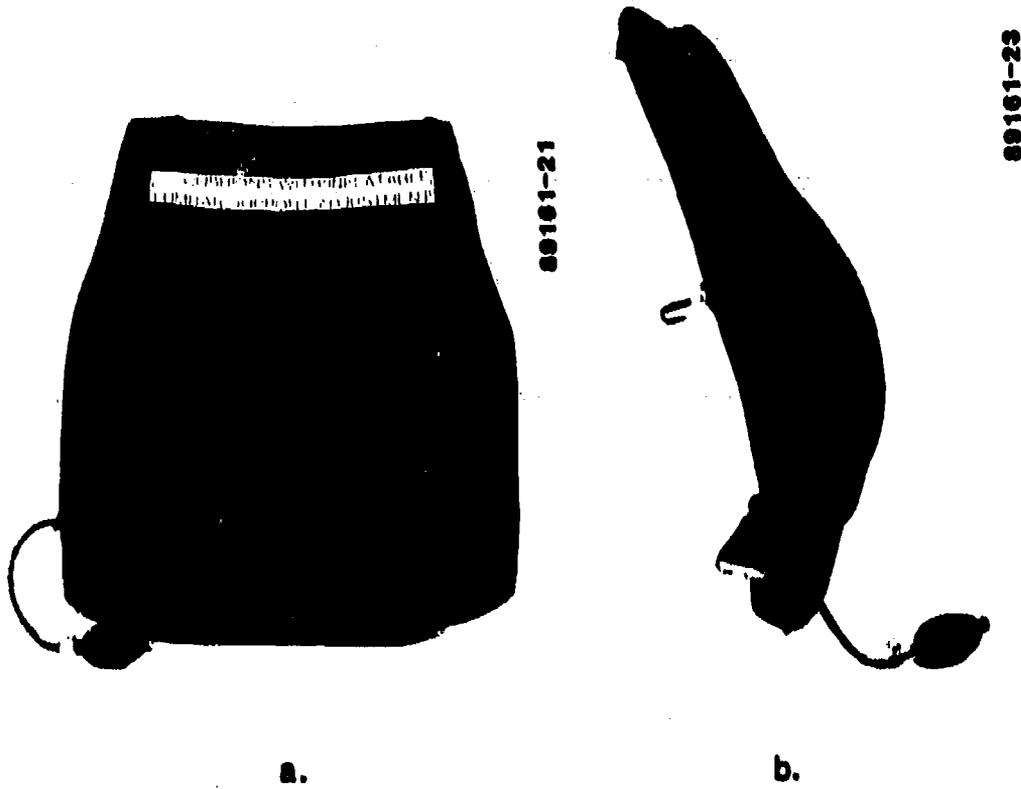
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**FIGURE 28. MULTIPLE CHAMBER CONCEPT FOR INFLATABLE LUMBAR SUPPORT.**

The selected bag concept had four interconnected chambers with the smallest chamber on the top and bottom and the largest chambers near the center. This shape provides more deflection at the center where it is needed for maximum comfort.

The selected bag was bonded to the rigid contour and the upholstery foam was installed. Fabric was also stretched over the foam and pleats were provided near the bag area to allow free movement of the cushions during bag inflation. A hand pump taken from a blood pressure bag was installed for simple air pressure adjustment. The prototype cushion with inflatable adjustment is shown in Figure 29.



**FIGURE 29. PROTOTYPE CUSHION WITH INFLATABLE ADJUSTMENT  
(CUSHION NO. 3) (a) FRONT VIEW, (b) SIDE VIEW.**

## 7.0 CUSHION EVALUATION

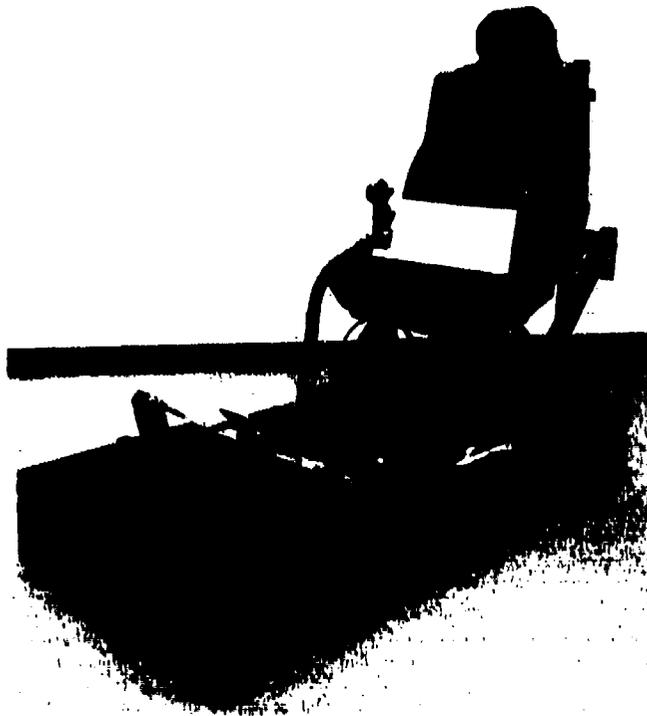
The three back cushion prototypes and the bottom cushion prototype were all evaluated for short-term comfort based on the hypothesis that improved comfort is related to a reduced incidence of back pain.

The short-term comfort evaluations were conducted in a mockup Black Hawk cockpit shown in Figures 30 and 31 with the original Black Hawk cushion and the mechanically-adjustable cushion, respectively. Twelve occupants representing 5th-, 50th-, and 95th-percentile males (four each), and one experienced Apache helicopter test pilot (95th-percentile male) from McDonnell Douglas Helicopter Company (MDHC), were selected for the evaluation. Each cushion was evaluated separately while sitting in the Black Hawk crewseat with the feet located on accurately-positioned rudder pedals, and the right hand on the cyclic stick (Figure 32). Comments on each cushion were made throughout the evaluation and are summarized in Appendix B. The experienced pilot from MDHC provided valuable comments and suggestions based on his extensive flying experience as a test pilot.



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**FIGURE 30. MOCKUP COCKPIT WITH ORIGINAL BLACK HAWK CUSHION IN CREWSEAT.**



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**FIGURE 31. MOCKUP COCKPIT WITH MECHANICALLY ADJUSTABLE CUSHION PROTOTYPE IN CREWSEAT.**



89155-11

**FIGURE 32. VOLUNTEER (5TH-PERCENTILE MALE) EVALUATING CUSHION IN MOCKUP BLACK HAWK COCKPIT.**

In addition to their comments, each occupant was asked to evaluate four aspects of each cushion set (different backs, but same bottom) on a scale of one to five (five being the best). The four aspects that were evaluated are:

- Bottom cushion, general
- Back cushion, general
- Lumbar support, specific
- Thigh support, specific.

Each aspect of the cushions was evaluated three times during a 10-minute sitting interval: immediately upon sitting, after four minutes of sitting, and again after another four minutes of sitting. Comments were taken throughout the evaluation. The results of this short-term comfort evaluation are shown in Table 6 which lists the averages of all the rankings.

The results shown in Table 6 indicate that the cushion preferred by all the occupants, on the average, was the cushion that provided no adjustment (Cushion No. 1). Both the 5th- and 95th-percentile occupants indicated, on the average, their preference for the nonadjustable cushion, whereas the 50th-percentile group indicated their preference to be, on the average, the cushion with the mechanical adjustment. These results indicate a unique situation since both the 5th- and 95th-percentile occupant, the population extremes, preferred the same cushion. All occupants preferred the prototype cushions over the original Black Hawk cushion which suggests that these cushions were designed effectively to improve comfort.

Although this program was only contracted to conduct a short-term comfort evaluation, an additional assessment was made to evaluate the long-term effect of the preferred cushion (Cushion No. 1) on back pain and compare it to the original Black Hawk cushion. These two cushions were evaluated in the mockup Black Hawk crewseat, but to simulate the pilot flying a helicopter, the selected occupant was asked to perform tasks on a computer screen, which required him to lean slightly forward to reach the keyboard and to maintain a high level of concentration (as a pilot does while flying an aircraft). One occupant (50th-percentile) was selected to do the long-term evaluation. First, he sat in the Black Hawk cushion until he began to feel some indication of aching or discomfort in his lower back. Then, after a day of rest, he evaluated Cushion No. 1.

The occupant was asked to record his level of discomfort at certain intervals and also to rate the four aspects of each cushion (bottom, back, lumbar, and thigh support). The length of time for some discomfort to develop during the test and disappear after the test was also recorded.

Table 7 lists the occupant's discomfort levels at various intervals, with 0 indicating no discomfort and 5 indicating severe discomfort. The results show that the level of occupant discomfort imposed by the new cushion (0.5) is much lower than that imposed by the original Black Hawk cushion (2.375). The outcome of this long-term evaluation indicates that cushions can feasibly be designed to reduce the incidence of low back pain.

TABLE 6. RESULTS OF SHORT-TERM CUSHION COMFORT EVALUATION FOR ALL OCCUPANTS

*Cushion No.	Aspects Evaluated**				Average
	Bottom	Back	Lumbar	Thigh	
<b>Total</b>					
1	3.83	4.04	4.18	3.27	3.83
2	3.84	3.86	3.62	3.25	3.64
3	3.70	3.46	3.57	3.22	3.49
BH	2.96	3.21	2.58	2.54	2.82
<b>5th-Percentile</b>					
1	3.94	4.48	3.67	3.86	3.99
2	3.37	3.86	3.01	3.56	3.45
3	3.56	3.38	3.28	3.72	3.49
BH	3.38	3.19	2.63	2.75	2.99
<b>50th-Percentile</b>					
1	3.88	4.00	4.59	3.75	4.06
2	4.25	4.21	4.23	3.84	4.13
3	3.88	3.75	3.79	3.79	3.80
BH	2.75	3.00	3.00	2.75	2.88
<b>95th-Percentile</b>					
1	3.70	3.73	4.27	2.42	3.53
2	3.90	3.57	3.62	2.53	3.41
3	3.68	3.30	3.63	2.37	3.25
BH	2.80	3.40	2.20	2.20	2.65

\*Cushion No. 1 - No adjustment  
 2 - Mechanical adjustment  
 3 - Inflatable adjustment  
 BH - Original Black Hawk cushion.

\*\*Evaluations for each cushion aspect ranged from 1 to 5; 1 least favorable, 5 most favorable.

TABLE 7. DISCOMFORT LEVELS IMPOSED ON OCCUPANT BY ORIGINAL BLACK HAWK CUSHION AND CUSHION NO. 1 DURING LONG-TERM EVALUATION\*

<u>Cushion</u>	<u>Interval</u>				<u>Average of Four Intervals</u>
	<u>Immediately Upon Sitting</u>	<u>After 30 Min</u>	<u>After 1 Hr</u>	<u>After 2 Hr</u>	
Original Black Hawk	1	2	3	3.5	2.375
Cushion No. 1	0	0	1	1	.5

\*0 - no discomfort.  
5 - severe pain.

Table 8 rates the cushion concepts by aspect. An aspect was most favored if it had a high rating (max. 5) and least favored (min. 1) if it had a low rating. Overall, Cushion No. 1 indicated improved comfort (3.625) over the original Black Hawk cushion (2.5).

TABLE 8. RATINGS OF ORIGINAL BLACK HAWK CUSHION AND CUSHION NO. 1 ASPECTS\*

<u>Cushion</u>	<u>Characteristic</u>				<u>Average</u>
	<u>Bottom</u>	<u>Back</u>	<u>Lumbar</u>	<u>Thigh</u>	
Original Black Hawk	3	2	1.5	3.5	2.5
Cushion No. 1	4	3	4	3.5	3.625

\*1 - least favorable.  
5 - most favorable.

## 8.0 FEASIBILITY ANALYSIS

In addition to the comfort evaluation, each of the three cushion prototypes was evaluated in terms of cost, weight, and manufacturing potential. A simple analysis was conducted to provide an estimate of these characteristics. The results are discussed in the following sections.

### 8.1 COST

The cost for fabricating production cushions for each of the three developed cushion concepts would be similar to the cost of fabricating the existing Black Hawk cushion. The only difference would be in the cost of adding the adjustment mechanisms to two of the back cushions. A breakdown of the components for each back cushion and the cost (and weight) impact of each component on the cushion is shown in Table 9.

The arrows used in the table indicate the direction of the cost impact for each respective part in the cushion. Both of the adjustable back cushions are impacted more heavily by the cost of the added materials and the labor required to produce the adjustment. The nonadjustable back cushion, however, has relatively no added cost since the contoured Ethafoam base alone provides the lumbar support that is provided separately in the original Black Hawk cushion. The cost for providing the separate lumbar support would be equivalent to the cost of providing a contoured Ethafoam base. Although Ethafoam is slightly more expensive than polyurethane foam, the cost of covering a separate lumbar support would be greater. Since the results of the comfort evaluation indicate that the adjustable back cushions are not the most favorable of the cushions evaluated, greater detail in this cost analysis is not included in this report.

Table 10 compares the relative cost (and weight) for the bottom cushions. Although Confor foam costs more than the foam used for the original Black Hawk cushion (16 times more), the cost of using Confor foam in the modified cushion is only 20 percent more than the use of Confor foam with the foam in the original Black Hawk cushion. These results indicate that a small cost increase is required to provide additional comfort and reduced back pain.

### 8.2 WEIGHT

The potential weight impact for fabricated production cushions of each of the developed concepts is similar to the cost impact shown in Tables 9 and 10. The preferred back cushion (nonadjustable, Cushion No. 1) is only impacted by a very small weight increase due to the additional weight of the Ethafoam base. The other two back cushions are impacted by a larger weight increase with Cushion No.2, the mechanically adjustable cushion, bearing the largest weight increase. The weight impact of the bottom cushion is small since it is constructed similar to the original Black Hawk bottom cushion which has a contoured base bonded with layers of foam. The difference between the two cushions lies in the foam types. The original cushion (16 x 18 in.) has a 1.0-in. thick layer of rate-sensitive foam (density 6.2 lb/ft<sup>3</sup>) and a 0.5-in. thick layer of foam (density 1.8 lb/ft<sup>3</sup>). The modified cushion (16 x 18 in.) has a combined total thickness of 0.75 in. from two

TABLE 9. COST AND WEIGHT IMPACT, BY COMPONENT, OF MODIFIED CUSHIONS RELATIVE TO ORIGINAL BLACK HAWK CUSHION\*

Black Hawk Back Cushion	Nonadjustable Back Cushion No. 1		Mechanically Adjustable Back Cushion No. 2		Inflatable Adjustable Back Cushion No. 3					
	Ct	Wt	Ct	Wt	Ct	Wt	Ct	Wt		
Separate Lumbar Support	-	-	Contoured Ethafoam Base	- ↑	Contoured Ethafoam With Fiberglass Cavity	↑	↑	Contoured Ethafoam Base with Cavity	↑	↑
Contoured Foam	-	-	Contoured Polyurethane Foam	-	Contoured Polyurethane Foam	-	-	Contoured Polyurethane Foam	-	-
					Roller Bar With Rack	↑	↑	Multi-Bay Bladder	↑	↑
					Metal Ribs Attached to Fiberglass Cavity with Rivets	↑	↑	Hand Air-Pump and Tube	↑	↑
					Adjustable Handle	↑	↑			

Summary

Baseline Cost and Weight

No increase in cost and slight increase in weight due to Ethafoam base

Largest increase in cost and weight

Large increase in cost and weight

\*Ct = Cost Impact.

Wt = Weight Impact.

↑ = Cost or weight increase.

↓ = Cost or weight decrease.

- = No change in cost or weight relative to baseline.

TABLE 10. COST AND WEIGHT IMPACT, BY COMPONENT, OF MODIFIED BOTTOM CUSHION RELATIVE TO ORIGINAL BLACK HAWK BOTTOM CUSHION

Black Hawk Bottom Cushion		Modified Bottom Cushion			
	Ct	Wt			
Contoured Base	-	-	Contoured Ethafoam Base	-	-
0.5-in. thick Rate-Sensitive Foam	-	-	0.375-in. thick C-45 Confor Foam	↓	⇓
1.0-in. thick Foam	-	-	0.375-in. thick C-42 Confor Foam	↑↑	↑
Baseline Cost and Weight			Small decrease in weight (5%) and small increase in cost		

layers of Confor foam. The weight of the two Confor foam layers is approximately 5 percent less than the weight of the combined foam layers in the original cushion. Although the modified foam would cost more than the original, it would weigh less.

### 8.3 MANUFACTURING

The manufacturing requirements for Cushion No. 1 compared to the original Black Hawk cushion are relatively similar. One advantage of the modified Cushion No. 1 is that it does not require separate fabrication of the lumbar support, which in the original Black Hawk cushion is a separate piece. Manufacture of the adjustable back Cushions No. 2 and No. 3 would require some significant additions to the production effort. For example, a fiberglass insert would need to be made for Cushion No. 2 to provide a base for the adjustment rack and the roller. The steel ribs would also have to be riveted on. Cushion No. 3 would require careful placement of the air bladder with some method of attachment. The connection of the hand air pump would also take more time. The bottom cushion would not require any additional fabrication techniques over those for the original bottom cushion since they are both simply constructed of bonded foam layers.

## 9.0 SUMMARY AND CONCLUSIONS

A literature search and pilot survey were conducted. Recommendations from the literature included:

- Reduce the transfer of vibration to allow the pilot to lean against the seat back without impeding his/her vision
- Use foams that result in resonant frequencies that do not coincide with the human body's or helicopter's natural frequencies
- Distribute the vertical load of the body over the entire buttocks to prevent load concentrations on the IT's
- Provide durable cushions to prevent bottoming out and increased pressure on the IT's
- Provide lower back support especially when the pilot hunches forward in the seat to operate the controls
- Provide an open or recessive space for the sacrum and buttock that project on the posterior, permitting constant contact with the primary lower lumbar back support
- Curve front edge of seat downward.

Results of the pilot survey pertaining to back pain indicated that:

- The average amount of time that it takes for a pilot's pain to disappear was two hours, 40 minutes, with some pain disappearing immediately, and some taking up to five days
- Neither height nor weight affected the level of discomfort, when it occurred, and when it disappeared
- There was no correlation between minimum flight duration, or total number of flight hours, with the level of pain, when it occurred, and when it disappeared.

Results of the pilot survey pertaining to Black Hawk cushions indicated that:

- The bottom cushion was too thin, there was irritation under the IT's, and there was not enough thigh support
- The back cushion lacked adequate lumbar support and had limited adjustment capability
- The lack of durability and support provided by the foams used in the original Black Hawk cushion contributes to pilot discomfort.

Three prototype Black Hawk crewseat back cushions and one prototype bottom cushion were fabricated and demonstrated that they all improved the occupant's comfort during a short-term evaluation when compared with the original Black Hawk back and bottom cushions.

The prototype back cushion with the nonadjustable lumbar support was ranked the highest over the prototype back cushion with a mechanical lumbar adjustment and the prototype back cushion with an inflatable lumbar adjustment during a short-term comfort evaluation.

The nonadjustable prototype cushion demonstrated that the incidence of back pain was reduced over the original Black Hawk cushion during a long-term comfort evaluation.

The nonadjustable prototype back cushion was designed with an improved lumbar support incorporated into the back contour, and bonded with a polyurethane foam. The foam was tested to have an acceptable natural frequency and high durability.

The prototype bottom cushion was designed with improved buttock support to relieve pressure on the IT's and with an increased thigh angle to improve thigh support.

The bottom cushion prototype was fabricated with a contoured base, bonded with two 0.375-in. layers of different stiffness Confor foams. The foams were tested to have exceptional dampening properties and acceptable durability.

The nonadjustable back cushion is predicted to cost the same as the original Black Hawk cushion, and weighs slightly more than the original due to the addition of the contoured Ethafoam base, whereas the two adjustable back cushions are predicted to cost and weigh much more than the Black Hawk original.

The prototype bottom cushion is predicted to weigh slightly less (5 percent) and cost slightly more than the original Black Hawk bottom cushion.

The conclusions are:

- Low back comfort was improved by integrating a contoured lumbar support with the back cushion. It was determined that both adjustable and nonadjustable lumbar supports enhanced low back support and comfort when compared to the original Black Hawk back cushion.
- Buttock support was improved by providing a contoured bottom cushion with greater thigh support and cushioning it with a 0.75-in. layer of rate-sensitive foam.
- Improved comfort appears to reduce low back pain.
- Low back pain was reduced relative to that experienced in the existing Black Hawk cushions. This was accomplished by combining a contoured bottom cushion providing more thigh support and with a contoured back cushion designed with an integral lumbar support.

## 10.0 RECOMMENDATIONS

The following items are recommended to optimize the design of a Black Hawk crewseat cushion and demonstrate its effect on improving comfort and reducing back pain:

- The lumbar support, incorporated in the prototype back cushions, should also be evaluated as a separate component of the back cushion. As a unit, the lumbar support provides a snug fit for the occupant unencumbered by gear; however, it also reduces fundamental space and comfort for the occupant wearing life-support gear. As a separate piece, and when removed, the lumbar support would provide more room for a pilot encumbered with life-saving equipment during a flying mission, and when it is in place, the pilot without extra gear on his body would be well-supported in the lower back. Further comparison between adjustable and nonadjustable lumbar supports should be conducted.
- An adjustable thigh support should be designed and evaluated for incorporation into the bottom cushion to improve the support and comfort for a wider range of occupant sizes. The concepts used to provide adjustable lumbar supports could be modified for incorporation into thigh supports.
- The long-term effect of an optimum cushion (with features such as thigh support and lumbar support) on the incidence of low back pain should be evaluated by conducting tests with pilots on daily flying missions for at least two weeks (or simulation thereof).
- The durability of the foam used to fabricate the cushions should be evaluated by conducting long-term flight tests (or simulation thereof).
- A tradeoff between comfort and crashworthiness should be conducted with a cushion designed for a helicopter crashworthy crewseat. A dynamic drop test could be conducted to evaluate the crashworthiness of the cushion.

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**APPENDIX A**  
**SAMPLE PILOT SURVEY**  
**BLACK HAWK CREWSEAT COMFORT**

SURVEY  
BLACK HAWK CREWSEAT COMFORT

Simula Inc. under contract to the U.S. Air Force Aerospace Medical Research Laboratory is collecting information to determine the feasibility of reducing the incidence of low back pain in helicopter pilots. Although the crewseats in the Black Hawk (UH-60A) may not be responsible for the major incidences of low back pain, pilots of this aircraft have been selected for this survey.

Please answer all the questions to the best of your ability and add any comments that you feel will contribute to the effort to reduce the incidence of back pain that can be a serious problem for helicopter pilots.

1. Aircraft Qualifications: UH-60A, UH-1, CH-3, HH-3, HH-53, others: \_\_\_\_\_  
\_\_\_\_\_

2. Hours in UH-60A: 100, 200, 300, 400, 500, More, Less

3. Maximum length of time flown in the UH-60A cockpit without rest period:  
\_\_\_\_\_

4. Height: \_\_\_\_\_ Weight: \_\_\_\_\_ Age: \_\_\_\_\_

5. Do you feel the UH-60A crewseat is comfortable on extended missions? \_\_\_\_\_  
\_\_\_\_\_

6. Does the UH-60A you fly have crewseat cushion covers made of sheepskin or of a black material with white dots? Which seats do you fly in the most?  
\_\_\_\_\_  
\_\_\_\_\_

Does one cushion type cause more discomfort than the other? \_\_\_\_\_  
If so, which one? \_\_\_\_\_

7. Rate the level of discomfort, from 0 (for no discomfort) to 5 (severe back pain), for each of the following time intervals in the cockpit:

\_\_\_\_\_ immediately upon getting situated in the crewseat  
\_\_\_\_\_ immediately upon takeoff  
\_\_\_\_\_ after 30 minutes of flying  
\_\_\_\_\_ after 1 hour of flying  
\_\_\_\_\_ after 2 hours of flying  
\_\_\_\_\_ after 4 hours of flying  
\_\_\_\_\_ after 6 hours of flying

8. When does this back pain usually disappear?

\_\_\_\_\_ immediately upon disembarking aircraft  
\_\_\_\_\_ minutes after leaving aircraft (specify number of minutes)  
\_\_\_\_\_ hours after leaving aircraft (specify number of hours)  
\_\_\_\_\_ days after leaving aircraft (specify number of days)

9. Do auto-rotation landings cause back pain? If so, do you feel they are the major cause of the pain you may have? \_\_\_\_\_  
 \_\_\_\_\_
10. What do you do or use to alleviate discomfort? Remove lumbar support, add more support in the lumbar area, change posture, etc.? \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
11. What position is the seat normally adjusted to when you fly?  
 Fore/Aft:  Full Forward  Middle  Full Aft  Other (Specify)  
 Up/Down:  Full Forward  Middle  Full Aft  Other (Specify)
12. What posture do you normally assume while flying the Black Hawk? (Lower back against back cushion; upper back away from back cushion; right forearm on right knee; shoulder relaxed or hunched; thighs resting on front edge of cushion; thighs angled forward and above cushion; etc.)  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
13. Is the posture you assume while flying the Black Hawk different from that assumed in other helicopters? If so, why? \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_
14. Please comment on possible contributing causes of discomfort in the bottom cushion.  
 Cushion Contour (too wide, too narrow, fits well, etc.): \_\_\_\_\_  
 \_\_\_\_\_  
 Thigh Support (not enough, too much, etc.): \_\_\_\_\_  
 \_\_\_\_\_  
 "Hot" Points (under IT's (sitting bones), under thighs, etc.): \_\_\_\_\_  
 \_\_\_\_\_  
 Cushioning (too soft, too hard, too thin, too thick, vibrates, etc.): \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

Cushion cover (causes difficulty in adjusting body position, leaves imprint on body, etc.): \_\_\_\_\_

\_\_\_\_\_

Thermal comfort: \_\_\_\_\_

\_\_\_\_\_

15. Please comment on possible contributing causes of discomfort in the back cushion.

Cushion Contour (too wide, too narrow, fits well, etc.): \_\_\_\_\_

\_\_\_\_\_

Lumbar Support (too much, too little, too wide, too narrow, limited adjustment): \_\_\_\_\_

\_\_\_\_\_

"Hot" Points: \_\_\_\_\_

\_\_\_\_\_

Cushioning: \_\_\_\_\_

\_\_\_\_\_

Cushion cover: \_\_\_\_\_

\_\_\_\_\_

16. What else, if anything, do you consider to be a contributing cause of discomfort? (vibration, posture, workload, seat back angle, limited seat adjustment, personal gear, etc.): \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

17. Any other comments: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

**APPENDIX B**  
**SUMMARY OF COMMENTS FROM COMFORT EVALUATION**

Comments from 5th-, 50th-, and 95th-percentile occupants as well as the 95th-percentile pilot were made on each of the cushions during the evaluation and are summarized here.

**B-1. ORIGINAL BLACK HAWK CUSHION**

**5th-Percentile**

- Back cushion needs more lateral support

**50th-Percentile**

- Back cushion lacks adequate thigh support
- Bottom cushion is solid and stiff

**95th-Percentile**

- Back cushion lacks adequate lumbar support and provides too much lateral support
- Bottom cushion lateral contour is too narrow around the IT's, squeezes buttocks together
- Bottom cushion lacks adequate thigh support

**Pilot**

- Bottom cushion causes discomfort under the IT's
- Bottom cushion enables use of bucket sides for lateral thigh support

**B-2. NONADJUSTABLE CUSHION NO. 1**

**5th-Percentile**

- Bottom cushion firm but comfortable
- Bottom cushion applies some pressure on sides of buttocks
- Bottom cushion provides too much thigh support
- Lumbar support is too high

**50th-Percentile**

- Bottom cushion firm but comfortable
- Bottom cushion Conforms well to buttocks
- Bottom cushion contour too deep--provides too much thigh support
- Back cushion provides good lumbar support

- Unable to lean against upper part of back cushion without significant arch
- Back cushion is comfortable

95th-Percentile

- Bottom cushion needs more side thigh support
- Bottom cushion contour too narrow
- Back cushion provides poor lumbar support
- Lumbar support is too high
- Back cushion provides good upper back support

Pilot

- Bottom cushion contour too deep
- Back cushion lacks upper back support

**B-3. MECHANICALLY ADJUSTABLE CUSHION NO. 2**

5th-Percentile

- Bottom cushion contour too deep, full pressure under thighs
- Back cushion lacks adequate lumbar support, side support
- Adjustable roller in back cushion can be felt through cushion

50th-Percentile

- Bottom cushion contour too deep
- Back cushion lumbar support is good/is uneven/lacks side support
- Unable to lean against upper part of back cushion

95th-Percentile

- Back cushion not as comfortable as other two modified cushions
- Back cushion lumbar support is inadequate/uneven/lacking in side support
- Adjustable roller in back cushion can be felt through cushion

Pilot

- Upper back support is improved; back arch is reduced
- Lumbar support is less contoured

#### **B-4. INFLATABLE ADJUSTABLE CUSHION NO. 3**

##### **5th-Percentile**

- Bottom cushion contour too deep
- Bottom cushion supports buttocks as well
- Pressure buildup under thighs
- Back cushion lumbar support is too high/uncomfortable when full of air/provides good lateral support
- Unable to lean against upper part of back cushion

##### **50th-Percentile**

- Back cushion lumbar support is good/provides good lateral support/is too high
- Air in lumbar support distributes well as body moves
- Unable to lean against upper back without severe arching of back

##### **95th-Percentile**

- Bottom cushion firm but comfortable
- Back cushion lumbar support is too high/side support is too low/has uncomfortable shape
- Back cushion lacks upper back support

##### **Pilot**

- Bottom contour is too deep
- Hand air pump is inconvenient for a busy pilot and not conducive to system safety.

This list of comments emphasizes that there are a vast number of opinions on this subject and that it is difficult to satisfy every pilot's wishes. However, there are two comments that are worth noting. The first is that the bottom cushion contour was designed too deep, providing more than the desired thigh support, where thigh support is a much-needed characteristic of the bottom cushion. An adjustable thigh support may prove to be the answer to this need.

The second comment is the inability to lean against the upper portion of the back cushion without severely arching the lower back. The lumbar support was designed to support the lower back while the pilot was operating the aircraft, that is, with a slightly hunched back. Although the lumbar support provides much improved support over that in the original Black Hawk cushion,

it is more than is needed. The pilot who helped in this evaluation also suggested that, although the lumbar support is effective, it may be intrusive on missions that require the pilot to wear a significant amount of equipment. During these missions, it would be desirable to make room for this equipment by removing the lumbar support as is possible on the original Black Hawk cushion.

These comments are a significant contribution to the comfort evaluation and will be used to recommend further enhancements to cushions designed to reduce back pain. Meanwhile, it has been concluded that the modified cushions do improve the pilot's comfort and, as a result of the long-term evaluation, reduce the incidence of low back pain.