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**Development of an Improved
SPH-4 Retention Assembly**

By

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April 1990

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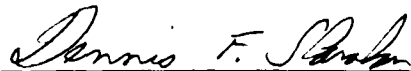
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Table of contents

	Page
List of figures.....	2
List of tables.....	2
Introduction.....	3
Materials.....	3
Methods.....	8
Results.....	13
Discussion.....	15
Conclusions.....	17
Recommendations.....	17
References.....	18
Appendix A. List of equipment manufacturers.....	19

List of tables

	Page
1. Pendulum tests results.....	15
2. Volunteer test results.....	15

List of figures

Figure

1. Final configuration of the USAARL yoke harness.....	5
2. The USAARL yoke harness mounted on headform.....	6
3. Photographs of Gentex swivel yoke harness.....	7
4. Right side view of the USAARL yoke harness in a skeletal helmet.....	8
5. Helmet retention harness pendulum tester.....	10
6. Typical pulse experienced by the "chest" of the pendulum tester.....	11
7. Typical helmet displacement on the Hybrid III headform in the pendulum tests.....	12
8. Chinstrap "pull" test on the standard, USAARL, and Gentex swivel yoke harnesses, all helmets equipped with a TPL™.....	13
9. Chinstrap "pull" test with standard, USAARL, and Gentex swivel yoke harnesses using a helmet liner without a TPL™.....	14

Introduction

Flight helmet stability and retention on the head during crashes have been, and continue to be, a source of concern for manufacturers and users of flight helmets. In use since 1970, the standard Sound Protective Helmet-4 (SPH-4) provides relatively good noise attenuation and impact protection, according to aircraft accident investigations. However, the retention assembly (integral napestrap and chinstrap) does not prevent the shell from undergoing excessive forward and rearward rotation when the head is exposed to crash induced acceleration(s) (Gruver and Haley, 1988) and, also, when visual enhancement devices are attached to the forward area of the helmet.

Previous work at the U.S. Army Aeromedical Research Laboratory (USAARL) has shown: (1) The double snap fasteners are inconsistent in attachment strength as determined by laboratory tests and actual failures in accidents (Vrynwy-Jones, Lanoue, and Pritts, 1988), (2) the cloth connection between the chinstrap/napestrap and shell permits excessive forward and rearward helmet displacement which may expose the cranium to impact, and (3) forward rotation of the shell has been identified as a concern when wearing night vision goggles due to the added weight and the forward position of the center-of-gravity (C.G.).

Palmer and Haley (1988) showed a simple modification of the current retention assembly significantly reduced elongation and increased the strength of the chinstrap. Recently, a new modified yoke harness incorporating the features described by Palmer and Haley (1988), was designed at USAARL and later constructed by Gentex Corporation. Gentex also designed a similar but different retention assembly having a swivel chinstrap. The objectives of this report were: (1) To compare the chinstrap strength and elongation of the USAARL yoke harness and the Gentex swivel yoke harness to that of the standard retention harness, (2) to compare the forward and rearward helmet rotation allowed by the two yoke harnesses to that allowed by the standard retention harness, and (3) to subjectively compare the wearing comfort of the USAARL yoke harness and the standard retention harness.

Materials

The final configuration of the USAARL yoke harness was obtained from the Gentex Corporation under the auspices of a written agreement dated 28 April 1989. It was constructed in a manner similar to a prototype assembly developed by Palmer and

Haley (1988). The Gentex swivel yoke harnesses* (Gentex Part no. 89D-7639) were provided by Gentex. The USAARL yoke harness shown in Figures 1 and 2 evolved from laboratory and field studies over a period of several months. The evaluation and testing of the USAARL yoke harness included a comfort wearing test in which pilots donned and doffed an SPH-4 with the USAARL yoke harness installed.

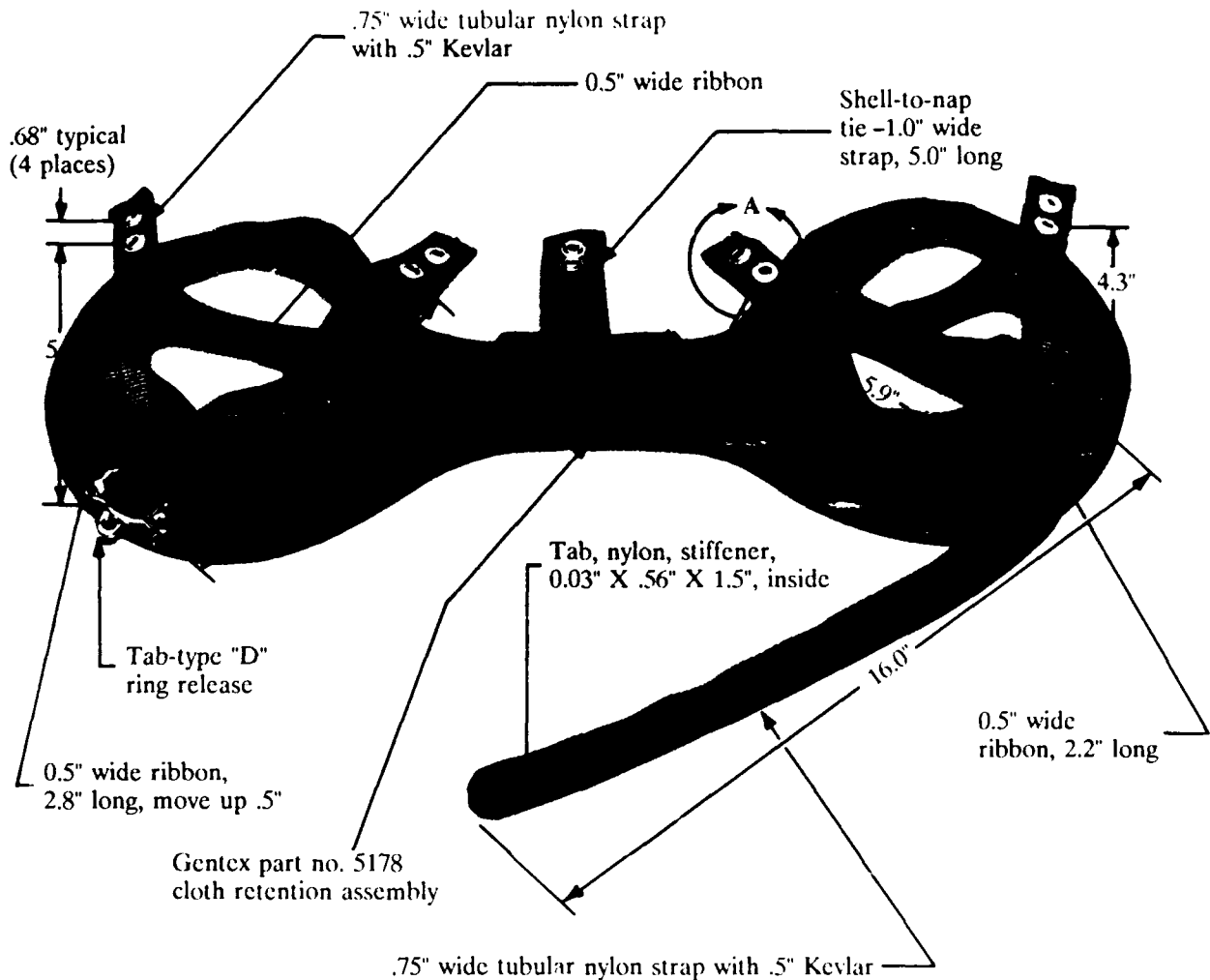
The USAARL yoke harness is a modified universal retention assembly with Gentex number 14AL crushable earcups* installed. The attachment points of the USAARL yoke harness are further apart than those of the current retention assembly and the Gentex swivel yoke harness (Figure 3) in order to increase the pitch rotational resistance of the assembly.

The forward mounting position of the USAARL yoke harness uses the lower visor hole (Figure 4) which is located 0.9 inches forward and 0.2 inches below the current harness attachment point. The rearward attachment point uses the headband clip hole located 1.1 inches rearward and 0.6 inches below the current rear attachment point.

The USAARL yoke harness was tied directly into the shell using 0.75-inch width tubular (existing chinstrap) webbing. Eyelets inserted into the tubular chinstrap webbing were reinforced with a stitch pattern as shown in Figure 1. Reinforcement of the eyelets in this fashion reduced deformation and allowed each attachment point to withstand loads of at least 150 pounds. This value is equal to the strength of the attachment points on motorcycle helmets. Also, it provides allowance for decrease of strength with age and usage. The chinstrap webbing was reinforced with 0.5-inch Kevlar™ tape which was added to minimize elongation of the chinstrap. A plastic (nylon) tab stiffener was sewn into the end of the chinstrap to ease the threading of the chinstrap through the double "D" ring release buckles. Diameter of the D-rings was 0.11 inches. A leather tab (1.75 inches x 0.19 inches, 50-lb strength) was affixed to the inner "D"-ring.

A shell-to-nape tie-down strap (1 inch wide x 5 inches long) was provided to limit the rotation of the shell away from the napestrap (see Figure 1). A 2-inch length of Velcro™ pile was sewn into the lower end of the tie-down strap so that it could be directly hooked into the Velcro™ of the adjustable napestrap. The tie-down strap concept was suggested and developed by Gentex Corporation development engineer Richard Long.

* See list of manufacturers



MIL-T-43636
 thread, nylon,
 FSN 8310-492-8397
 strength = 15 lb minimum

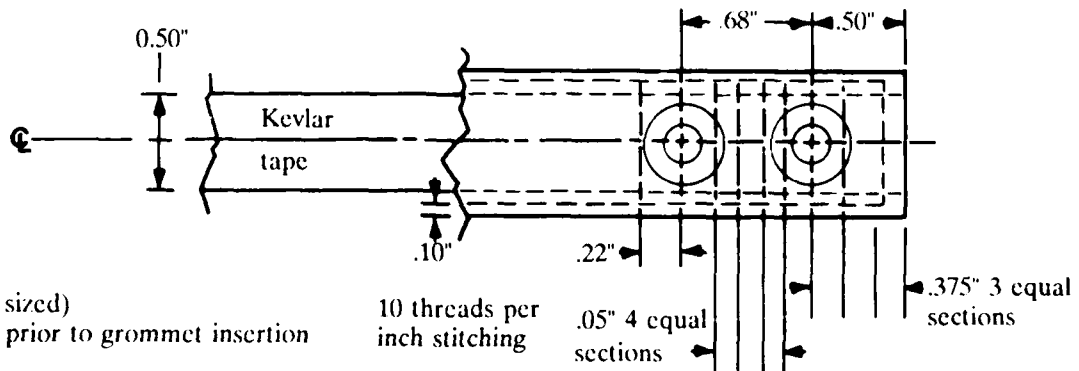
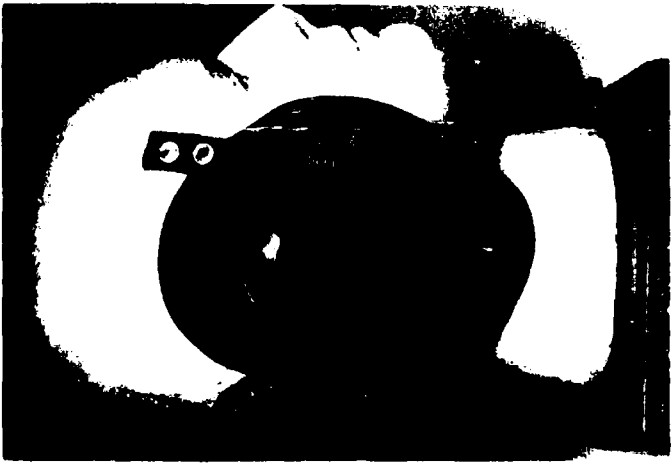


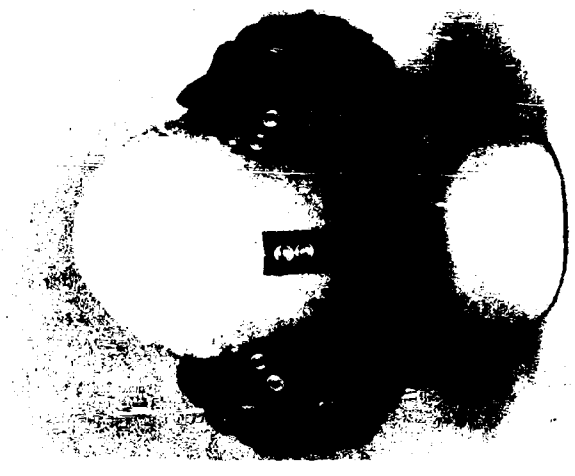
Figure 1. Final configuration of the USAARL yoke harness.



Right side view



Left side view



Rear view

Figure 2. The USAARL yoke harness mounted on headform.

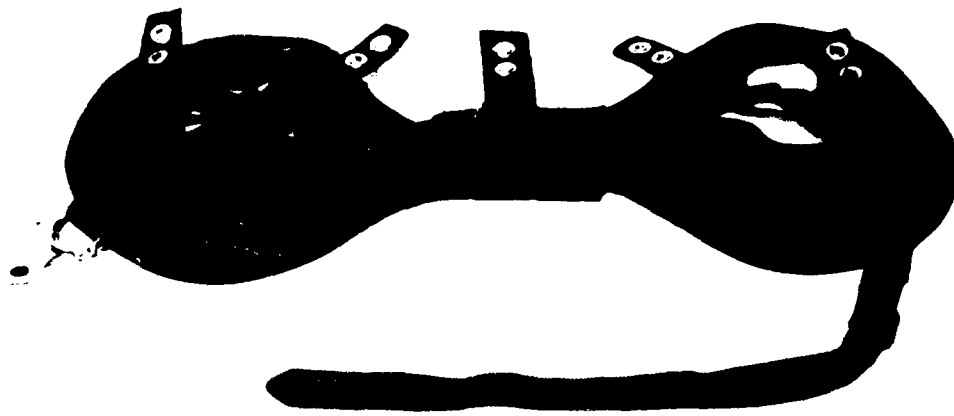


Figure 3. Photographs of Gentex swivel yoke harness.

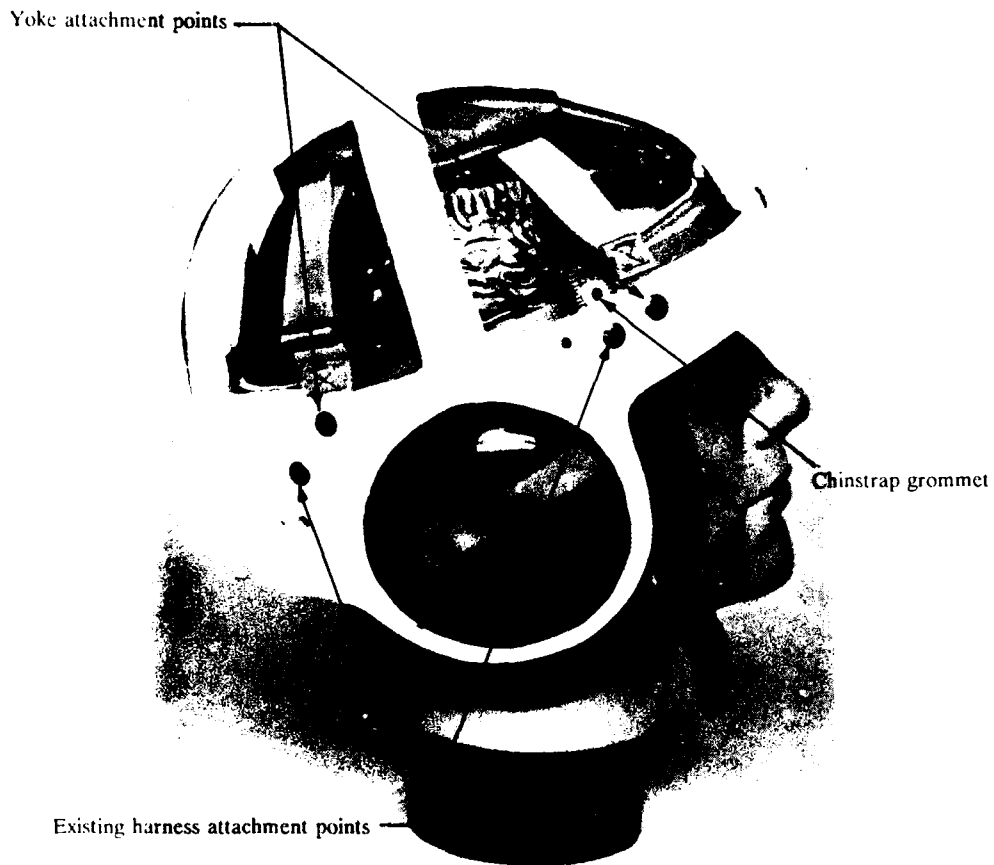


Figure 4. Right side view of the USAARL yoke harness in a skeletal helmet.

Methods

All testing was conducted with standard SPH-4 shells fitted with thermoplastic liners* (TPLTM). The USAARL yoke harness, Gentex swivel yoke harness, and the standard SPH-4 harness were tested for chinstrap strength, elongation, and helmet displacement using current USAARL testing methods. Only the standard harness and USAARL yoke harness were tested for wearer comfort.

The chinstrap tensile strength was measured according to MIL-H-43925 using a Tinius-Olson Locap testing machine*. A 600-lb Revere load cell* was used. Speed was 1.5 inches per minute.

A dynamic helmet retention harness testing device (Vyrnwy-Jones, Paschal, and Palmer, 1989) was used to measure helmet rotational displacement (Figure 5). This device consisted of a Hybrid III headform and neck assembly mounted on a pendulum beam. A simulated "crash" was created when the beam swung against a motion-arresting impact attenuator. The beam simulated an aviator's chest while the attenuator acted as the restraint harness. Upon impact, the "chest" velocity reduced to zero, but the head continued to move due to the humanoid (flexible) neck. The chest deceleration was provided by a 3-inch thick cardboard honeycomb pad and a 1-inch thick foam pad. The peak G provided by the honeycomb varied from 26 to 30 G. A typical example of deceleration experienced by the pendulum "chest" is shown in Figure 6 which shows a peak G value of 28 G. The approximate velocity was 16 fps at the headform C.G. Each test deceleration pulse was filtered at 1600 Hertz.

The simulated chest deceleration of 26-30 G peak is equal to the 95th percentile G level as stated in the Crash Survival Design Guide (Dynamic Science Engineering Corporation, 1971). However, the velocity of 16 fps is only the 10th percentile, a relatively short duration pulse, i.e., a moderate level "crash" pulse.

Helmets were fitted to the Hybrid III* headform and neck to simulate a "snug" fit on the wearer. Both the chin- and nape-straps were cinched to 10 lb to assure consistency. These values were reasonable, based on reported comfort from human trials. It should be emphasized that accident histories have shown that these straps frequently were worn more loosely than were tested.

The "chest" impact and resultant headform flail and helmet rotation were recorded by high speed video at 1,000 frames per second. Video data were digitized and reduced by computer. Mean values for forward and rearward rotational displacement were tested using one-way analysis of variance and the Student-Newman-Keuls multiple comparison test (Steel and Torrie, 1980).

Typical displacement of the standard SPH-4 helmet during a pendulum test is illustrated in Figure 7. Note the helmet displaced upward (lofted), then rotated forward and downward to the tip of the nose and rebounded enough to expose the frontal area of the head.

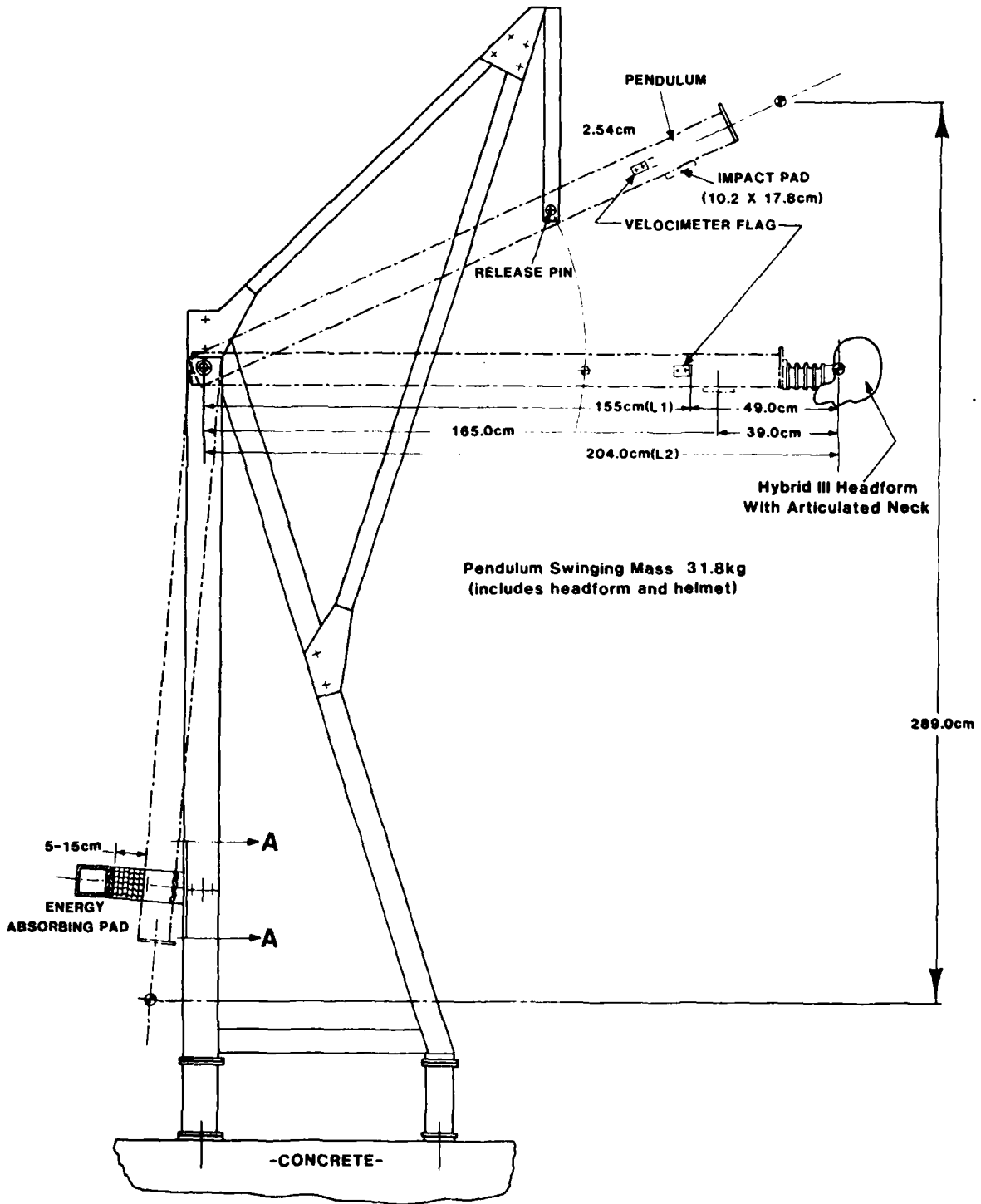


Figure 5. Helmet retention harness pendulum tester.

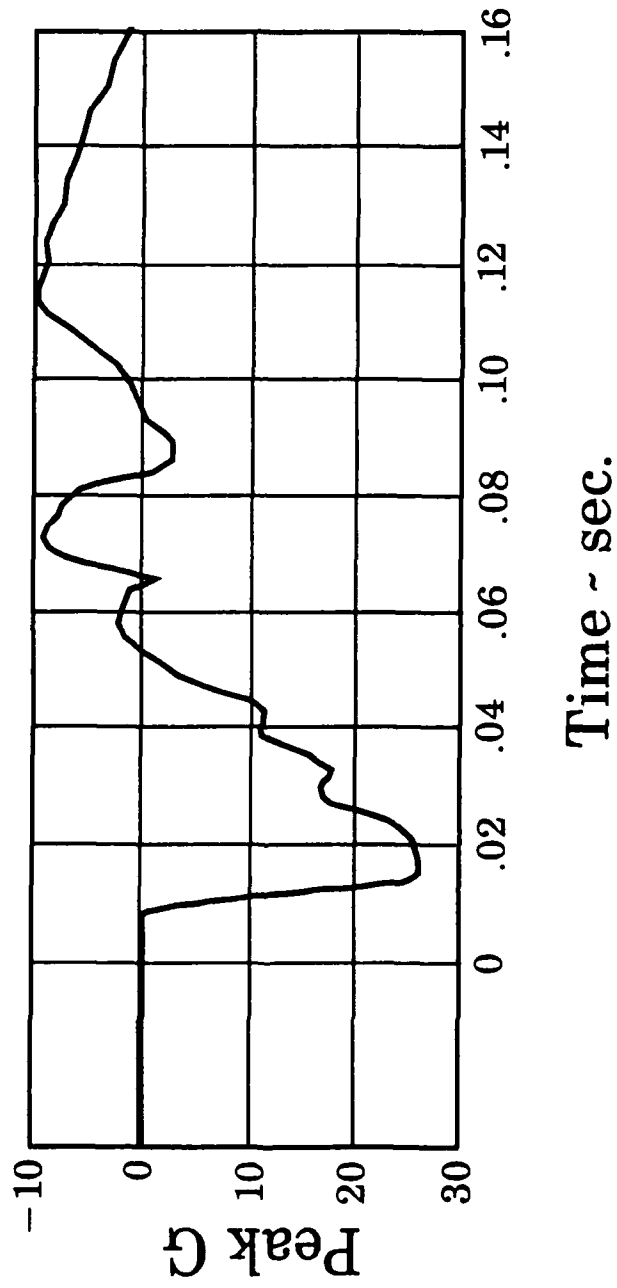


Figure 6. Typical pulse experienced by the "chest" of the pendulum tester.

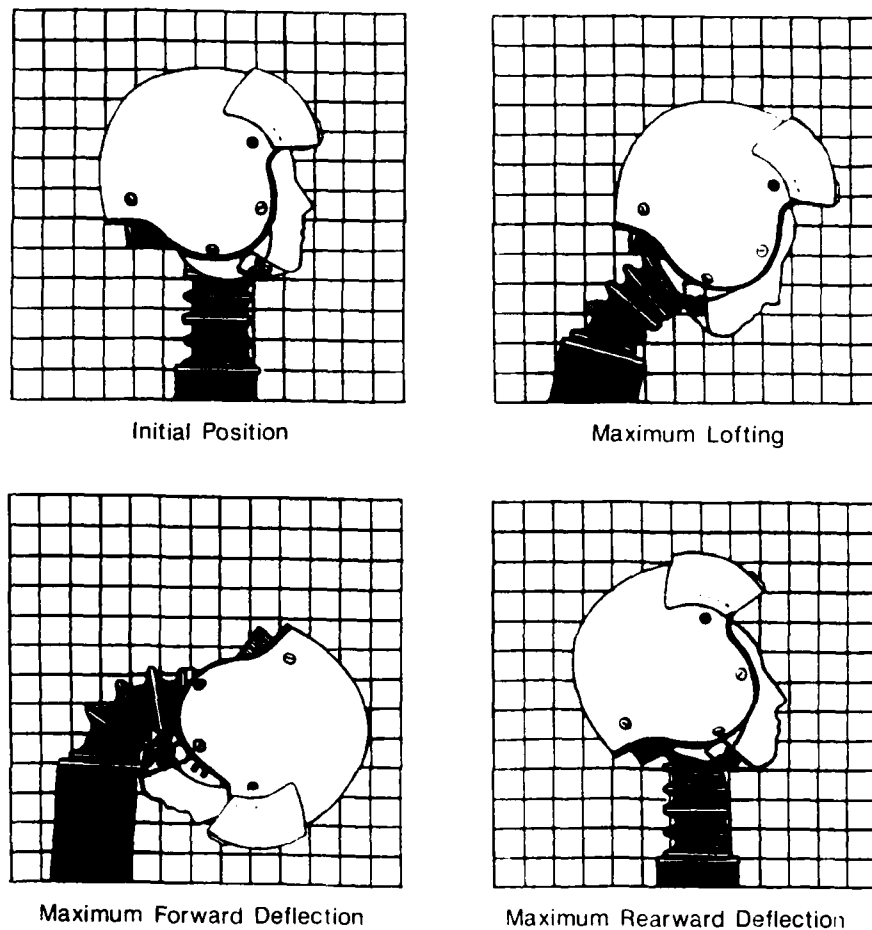


Figure 7. Typical helmet displacement on the Hybrid III headform in the pendulum tests.

To assess wearer comfort, a donning and doffing test was conducted using 29 aviators. This test compared two helmet configurations. The first helmet consisted of a TPL™ retrofit SPH-4 with a standard retention harness. (The TPL™ kit includes a 5/8-inch thick foam liner and the four-layer, pebbled plastic fitting pad). The second helmet consisted of a TPL™ retrofit SPH-4 with the USAARL yoke harness. The test subjects were instructed to don the helmet, wear it for 10 minutes, then remove the helmet. Immediately after removing the helmet, they answered a questionnaire relating to: (1) General overall comfort, (2) sound attenuation, (3) donning and doffing, (4) comfort of the double D-ring release buckle, and (5) preference.

Results

Chinstrap "pull test" results are shown in Figures 8 and 9. The USAARL yoke and the Gentex swivel yoke harnesses stretched less than the standard SPH-4 harness. The Gentex swivel yoke harness elongated more than the USAARL yoke harness when measured at the same load with or without the TPL™ installed. Both the USAARL yoke harness and the Gentex swivel yoke harness surpassed the HGU-56 strength requirement of 440 pounds.

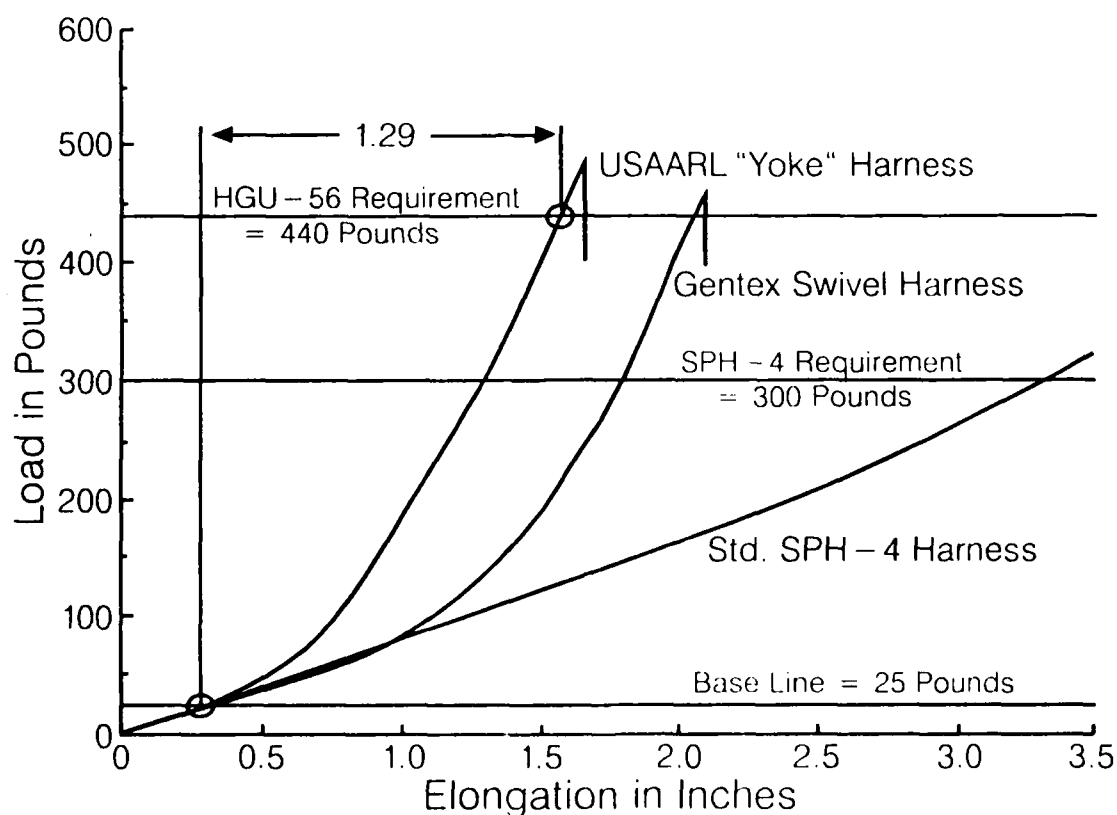


Figure 8. Chinstrap "pull" test on the standard, USAARL, and Gentex swivel yoke harnesses, all helmets equipped with a TPL™.

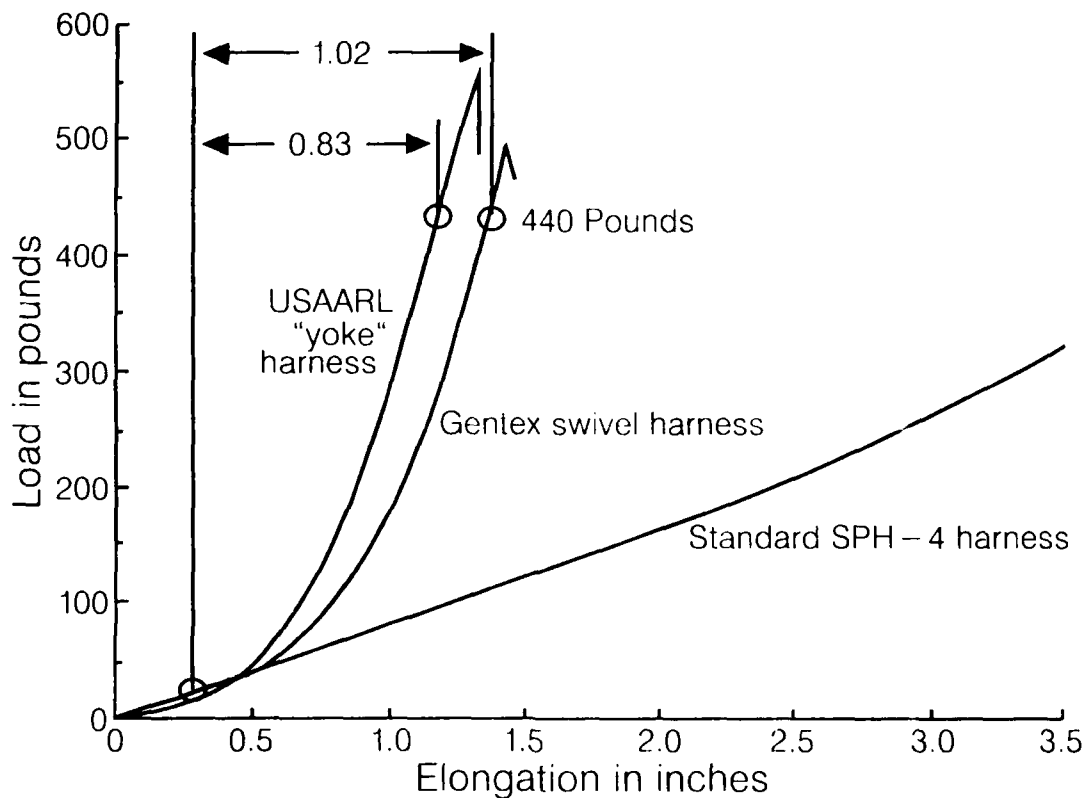


Figure 9. Chinstrap "pull" test with standard, USAARL, and Gentex swivel yoke harnesses using a helmet liner without a TPL™.

The pendulum test results are presented in Table 1. The standard retention assembly allowed more forward and rearward helmet rotation to occur than did either the USAARL yoke harness or the Gentex swivel yoke harness. Statistically, the USAARL yoke harness and the swivel yoke harness did not differ.

The results of the donning and doffing test with 29 aviators are shown in Table 2. Note a majority of the aviators critiqued the USAARL yoke harness as an improvement over the standard SPH-4 harness.

Table 1.

Forward and rearward rotations of the standard retention assembly, yoke retention assembly, and Gentex swivel yoke retention.

Assembly type	Number tests	Forward rotation (deg)	Rearward rotation (deg)
Standard SPH-4	8	16.3 ± 1.7 ^a	40.9 ± 3.3 ^a
USAARL yoke	8	9.0 ± 1.0 ^b	23.1 ± 3.3 ^b
Gentex swivel yoke	6	12.0 ± 1.3 ^b	19.3 ± 2.6 ^b

Note: Values are means ± standard error of mean (SEM). Different letters within a column indicate means differ (p=0.05).

Table 2.

Volunteer "don-doff" comparative critique of standard SPH-4 retention harness to the USAARL "yoke" retention harness.

	Improved	No difference	Decreased
Comfort	72.4%	17.2%	6.9%
Noise attenuation	79.3%	17.2%	3.5%
Ease of donning and doffing	0.0%	75.9%	24.1%
Comfort with D-ring	0.0%	86.2%	13.8%

Discussion

As mentioned in the introduction, the existing SPH-4 retention harness permits excessive helmet shell fore-aft rotation when the helmet is exposed to either operational torque caused by

visual enhancement devices or crash-induced inertial or tangential impact forces. Palmer and Haley theorized the rotational displacement could be reduced by reducing the chinstrap elongation and by providing a "yoke" shape chinstrap. The "yoke" shape, low elongation type retention harness was developed further in our laboratory trials to maximize its performance in the SPH-4 type helmet.

The preceding results have shown the USAARL yoke and the Gentex swivel yoke harnesses perform better than the standard SPH-4 harness because of the following: (1) The double snaps were replaced with tab-type "D" rings which provide higher strength and reliability ("D" rings have been used and proven effective in motorcycle helmets over the past 30 years), (2) the earcup retainer cloth was reinforced by a nylon-Kevlar™ "yoke" chinstrap which reduced the elongation of the assembly and reduced the rotational displacement of the helmet under inertial forces, (3) the current standard chinstrap sustained a load of 280 pounds, but the USAARL and Gentex yoke harnesses sustained 440 pounds (Figure 8) to ensure adequate resistance to asymmetric loads under tangential crash forces, (4) the USAARL yoke harness was judged by the 29 aviators to be slightly superior in sound attenuation because this type harness promotes a better earcup seal as the yoke chinstraps pull inward on the cups during tightening, and (5) the yoke harness offered enhanced stability and limited forward and rearward helmet displacement during normal wear in the cockpit.

When compared to the standard harness, both the USAARL and Gentex yoke harnesses stretched less than half as much. This stretch reduction is assumed to be the cause for the improved performance of the yoke harness over that of the standard harness on the pendulum device.

Although the Gentex swivel yoke harness and the USAARL yoke harness produced similar results in the pendulum tests, chinstrap pull tests definitely showed that less elongation occurred in the USAARL yoke harness than in the Gentex swivel yoke harness (Figures 8 and 9). Theoretically, the USAARL yoke should be superior to the Gentex swivel yoke because the lesser vertical displacement helped prevent forward or rearward rotation on the head.

Using the lowest visor hole for the forward attachment of the USAARL yoke to the shell requires a redesign of the TPL™ to include a depression in the foam liner to allow for the thickness of the anchor nut. The visor anchor nut should be increased in length by 0.10-in length to accommodate the addition of the 0.10-in thick chinstrap grommet (Figure 4). Insertion of the longer nut without causing damage to the TPL™ is a delicate task, but the procedure could be simplified by the use of a special anchor

nut gripping tool, or by the use of cement to hold the nut permanently.

The forward chinstrap anchorage point should be as far forward as is feasible, but if installation of the visor anchor nut simply is too tedious to consider for reasonably rapid production, the anchorage point can be moved rearward. For retrofit, the point can be the existing hole used for the forward anchor of the earcup cross strap; for new production SPH-4 helmets, the cross strap should be moved forward 0.4 inches and downward 0.2 inches. The new location would still function as the cross strap anchor hole, but provide the widest "yoke" possible for the chinstrap anchor point. Adequate flexibility exists in the yoke harness configuration to permit its usage in either location so that retrofit or production harnesses would be identical.

Conclusions

1. The USAARL yoke harness is stronger than the standard harness.
2. The USAARL yoke harness stretches less than the Gentex swivel yoke harness and the standard harness.
3. The USAARL yoke harness and the Gentex swivel yoke harness allow less helmet rotation than the standard harness.
4. The majority (72 percent) of aviators who wore the USAARL yoke harness preferred it over the standard harness.
5. The USAARL yoke harness easily sustains a 440-lb load (HGU-56 requirement).

Recommendations

1. Recommend replacing the standard SPH-4 harness with a "yoke" type harness as soon as possible.
2. The replacement yoke harness should be required to sustain a 440-lb load with less than 1.0-inch elongation between 25 and 440 pound loads.
3. Each of the four chinstrap attachments grommets should be tested to 150 pounds to ensure it does not loosen in the webbing after field use.

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Correspondence:

Cooperative Research Agreement between Gentex Corporation, Carbondale, PA, and U.S. Army Aeromedical Research Laboratory, Fort Rucker, AL, 28 April 1989.

Appendix A.

List of equipment manufacturers

Belding Corticelli Thread Company
1430 - T Broadway
New York, NY 10018

General Motors Corporation
3044-T West Grand Boulevard
Detroit, MI 48202

Gentex Corporation
P.O. Box 315
Carbondale, PA 18467

GHI Systems
Randros Palos Verdes, CA

Humanoid System
Division of Humanetics Corporation
17022 Montanero Street
Carson, CA 90746

John Chatillon and Sons
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Kew Gardens, NY 11415

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Winterthur, Switzerland

Nicolet Instrument Corporation
Oscilloscope Division
5225 Verona Road
Madison, WI 53711

Spin Physics 2000, Kodak
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San Diego, CA 92121-1011

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