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# **Assessment of HGU-56/P Aircrew Integrated Helmet System (AIHS) Blunt Impact Protection after Liner Modifications**

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## **Military Relevance**

The U.S. Army's HGU-56/P AIHS performance standard was developed after a series of reviews of U.S. Army rotary-wing mishaps (Reading et al., 1984; Slobodnik, 1980; Vrynwy-Jones et al., 1988; Palmer, 1991) showed that aircrew lives were being lost to head injury in otherwise survivable accidents. Such cases included basilar skull fractures from both lateral and crown impacts, other skull fractures, intracranial hemorrhage, and concussions. The standard requires a helmet to be impacted at 4.9 meters per second (mps) for crown impacts and 6.0 mps for all other impact sites. Pass-fail headform acceleration thresholds of 150G for crown and lateral impacts and 175G for impacts to all other regions of the helmet. Particular attention is paid to lateral impact performance to minimize the risk of basilar skull fracture, which was prevalent with older helmet designs (Shanahan, 1983; Hundley & Haley, 1984). Currently, the HGU-56/P AIHS, initially fielded in 1995, and its variants, the HGU-56/P Apache Aircrew Integrated Helmet (AAIH) and the HGU-56/P Rotary Wing Helmet (RWH), are the only helmets to meet the AIHS performance standard. The HGU-56/P AIHS is currently in service with the U.S. Army, Air Force, Marine Corps, and Coast Guard. The HGU-56/P AAIH is a platform-specific variant of the HGU-56/P AIHS and is worn by pilots of the AH-64E. The HGU-56/P RWH is incrementally replacing the HGU-56/P AIHS in the U.S. Army.

## **Background**

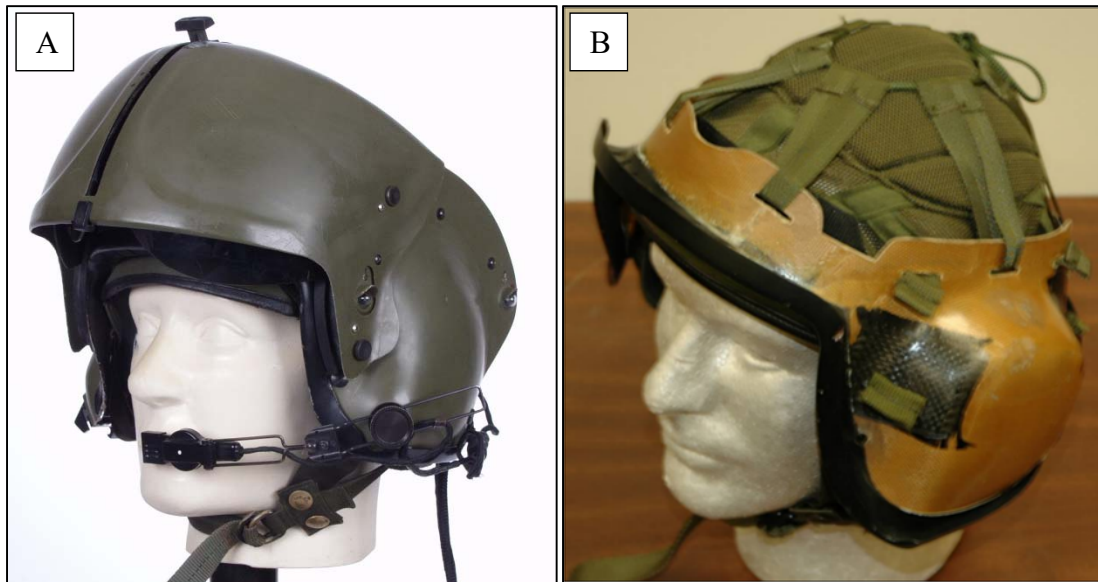
### **Helmet Fitting Evolution**

Over the last 50 years, aviation helmet fitting systems used by the U.S. Army have been refined and redesigned to improve wearer comfort while also keeping stability, retention, and protection at the apex of importance in design. Assets like the Aircrew Protection Helmet Number 5 (APH-5), an early hard-shell aviation helmet, utilized leather-covered foam pads of varying thicknesses in an effort to create a custom fit for the aviator with the aim of improving wearer comfort. In 1969, the Sound Protection Helmet Number 4 (SPH-4) was introduced into service and incorporated an adjustable sling suspension system (Figure 1). Additionally, the Integrated Helmet and Display Sighting System (IHADSS), used exclusively in the Apache Helicopter (AH-64), uses front and rear pads in conjunction with an inner basket assembly which can be vertically adjusted by the user (Figure 2); brow and nape pads are used to achieve a more custom fit for the fore-aft positioning of the helmet.

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*Figure 1.* SPH-4 helmet cross section exposing the sling suspension fitting system.



*Figure 2.* (A) Integrated Helmet & Display Sighting System (IHADSS) for the Apache Helicopter and (B) internal basket fitting system; not shown are the brow and nape pads.

In the mid-1980s, Gentex Corporation (Carbondale, PA) developed the ThermoPlastic Liner (TPL<sup>®</sup>) aimed to decrease headaches and hotspots and to improve helmet stability. The successor to the SPH-4, the SPH-4B, as well as the U.S. Army's current primary rotary-wing aviation helmet, the Head Gear Unit Number 56 Personal (HGU-56/P) Aircrew Integrated Helmet System (AIHS) (Gentex Corporation, Carbondale, PA), are equipped with the TPL<sup>®</sup> to provide individual aircrew members with a customized fit (Figure 3A).

The TPL<sup>®</sup> provides a majority of U.S. Army aircrew with a custom, comfortable, and stable helmet fit. However, the TPL<sup>®</sup> does not accommodate the entire U.S. Army aircrew population, particularly those individuals with atypical head anthropometry. In an effort to provide liners to a larger population alternative liners were developed: the Super Comfort Liner (SCL<sup>™</sup>) [Gentex Corporation, Carbondale, PA] and the Zeta II<sup>®</sup> (Oregon Aero, Inc., Scappoose, OR) [Figures 3B & 3C]. A limited number of current users have anecdotally cited the continued development of hot spots when using the standard or alternate liners. Hot spots are defined as areas on the wearer's head where helmet weight, retention tightness, head anthropometry, and other factors produce high pressure, thus causing discomfort.



Photos A and B: [www.gentexcorp.com](http://www.gentexcorp.com), photo C: USAARL

*Figure 3.* HGU-56/P AIHS comfort liners: (A) Gentex Corporation TPL<sup>®</sup>, (B) Gentex Corporation SCL<sup>™</sup>, and (C) Oregon Aero HGU-56/P-specific Zeta II<sup>®</sup>.

### **Helmet Fitting Issues**

Since the inception of protective headgear, a major challenge has been to design helmets that offer the required impact, penetration, abrasion, and hearing protection while providing a system that provides a comfortable fit. Although improvements have been made to enhance the comfort and functional helmet fit, there has never been a helmet or liner designed that satisfactorily fits the entire U.S. Army aircrew population.

Individual anthropometric variability is the primary source of discomfort. The use of head mounted visual displays and night vision systems are not compatible with the historically commonplace practice of helmet adjustment and/or shifting to relieve comfort/fitting problems. Additionally, the extended duration of the “normal flight mission” from the 2.5 hour duration to missions lasting 6 to 10 hours is another discomfort confounder. Discomfort could be directly correlated with difficulty concentrating on flight tasks and may lead to the cancellation of missions or contribute to accidents.

Despite continued efforts to improve the comfort of currently fielded helmets, a subset of U.S. Army aviators continue to have problems achieving a comfortable and safe helmet fit. These individuals are referred to the U.S. Army Aeromedical Research Laboratory (USAARL) Problem Fit (PROFIT) program by their local aviation life support equipment (ALSE) technicians. The USAARL PROFIT program has provided helmet fitting services in extreme cases for over 25 years (PEO-AVN, 1996). Since a safe and comfortable helmet fit is mission critical, the alternative to a liner modification could be as costly and extreme as rendering an aviator permanently unfit to fly.

USAARL PROFIT technicians are authorized to make minor modifications to TPLs<sup>®</sup> and SCLs<sup>™</sup> to achieve a custom fit based on the aviator's complaint and unique head anthropometry (ACIS, 1996). There are limited data available to determine what, if any, effect these modifications have on the impact performance of the HGU-56/P AIHS, and hence the head injury protection. It is important that these effects are quantified so that the risks associated with any modifications are fully understood by the PROFIT personnel performing the problem fit accommodation, the aviator requesting problem fit assistance, and the aviator's chain of command. The objective of this study was to quantify the effects of helmet liner modifications on the blunt impact protection provided by the HGU-56/P AIHS. The helmet liners, both the TPL<sup>®</sup> and SCL<sup>™</sup>, were modified to represent the worst-case scenario identified from the review of the PROFIT records and were evaluated by conducting impact performance tests following the specifications in the HGU-56/P AIHS purchase description (DOD, 1996).

## **Materials and Methods**

### **Experimental Equipment**

#### **Helmets**

The HGU-56/P AIHS flight helmet (Figure 4) is made up of a laminated composite (carbon fiber and Spectra) shell, expanded bead polystyrene energy-absorbing liner (EAL), comfort liner, energy attenuating earcups, integrated chin- and nape-straps, communications system, and dual visor assembly (clear and smoked visors). All sizes of HGU-56/P AIHS helmets are designed to provide the same level of blunt impact protection (DOD, 1996). For the purposes of this evaluation, the performance of the small size helmet was considered indicative of the performance of all helmet sizes. This evaluation required a quantity of 18 size small HGU-56/P AIHSs.

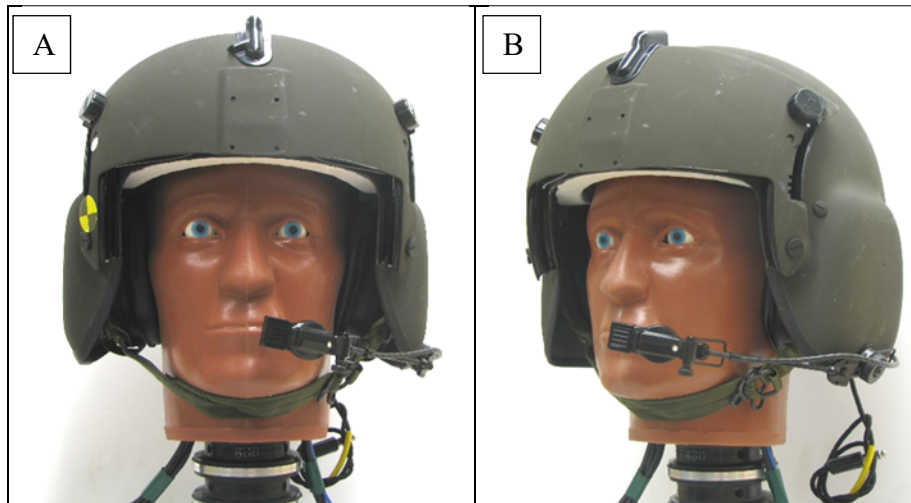


Figure 4. Head Gear Unit Number 56 Personal (HGU-56/P) Aircrew Integrated Helmet System (AIHS) donned on a FOCUS headform: (A) front and (B) isometric view.

### **Helmet Liners.**

USAARL PROFIT technicians modify TPLs<sup>®</sup> and SCLs<sup>™</sup> to provide wearers with customized, comfortable helmet fits. Zeta II liners were also used by PROFIT technicians to provide aviators with a comfortable helmet fit when modifications to the TPL<sup>®</sup> or SCL<sup>™</sup> did not alleviate the wearer's fitting issue. Zeta II liners were not modified in the same manner as TPLs<sup>®</sup> or SCLs<sup>™</sup> (i.e., having portions of the liner removed). For this reason, Zeta II liners were not included in this analysis. The impact protection provided by HGU-56/P AIHSs fitted with Zeta II liners was previously assessed by Brozoski et al. (2008).

### ***ThermoPlastic Liner<sup>®</sup>.***

ThermoPlastic Liner<sup>®</sup> (TPL<sup>®</sup>) [Figure 3A] is approved for use in the HGU-56/P AIHS. The TPL<sup>®</sup> is comprised of four-layers of thermoplastic sheets (each formed with egg carton-type dimples) covered with a removable, washable cloth cover. Individual fitting is accomplished by heating the TPL<sup>®</sup> until the thermoplastic layers become pliable, then having the individual don the TPL<sup>®</sup> and helmet until the thermoplastic sheets have cooled and formed to the shape of the wearer's head (McEntire, 1998).

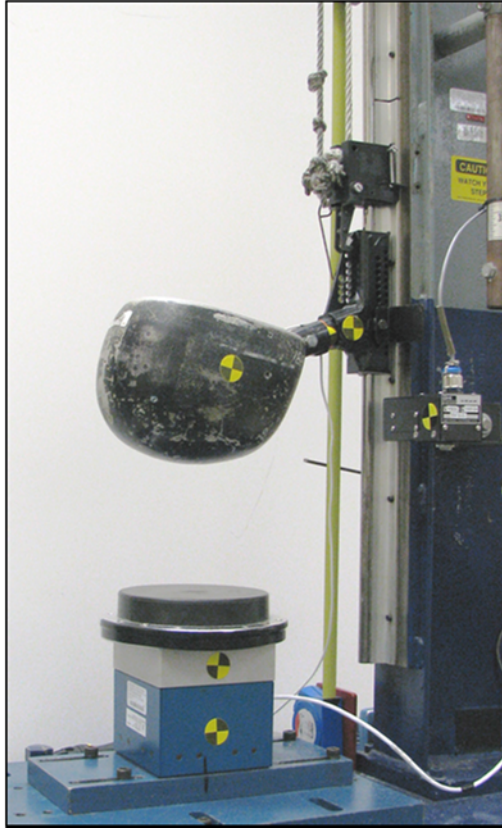
### ***Super Comfort Liner<sup>™</sup>.***

The Super Comfort Liner (SCL<sup>™</sup>) [Figure 3B] is also approved for use in the HGU-56/P AIHS. The construction is similar to the TPL<sup>®</sup> using the same four-layers of thermoplastic sheets used in the TPL<sup>®</sup> but with a plush visco-elastic foam padding incorporated into the removable, washable cloth cover. Individual fitting is accomplished following the same procedure as with the TPL<sup>®</sup>.

### **Monorail Drop Tower.**

Blunt impact attenuation tests were performed on a guided, free fall drop tower (Figure 5) conforming to Federal Motor Vehicle Safety Standard (FMVSS) 218 (Department of Transportation [DOT], 1992). The monorail drop tower was instrumented to collect four channels of data during blunt impact tests. A single-axis, linear accelerometer (model 7264C-2000; Meggitt Sensing Systems, San Juan Capistrano, CA) installed in the center of mass of the headform measured vertical deceleration of the headform. Transmitted force was measured using a barrier load cell (model 10490FL; Humanetics Innovative Solutions, Inc., Plymouth, MI) installed beneath the impact anvil. Vertical acceleration of the impact anvil was captured using a model 7264B-500 accelerometer for use in mass-compensating the impact force measurements. The velocity sensor (model VS300 Velocimeter; GHI Systems, Inc., San Pedro, CA) output voltage, used to trigger the data acquisition system, was also recorded. Data channels were recorded at 100 kilosamples-per-second using a Synergy data acquisition system (Hi-Techniques, Inc., Madison, WI). High-speed video of the impacts were recorded at 10,000 frames per second using a Phantom high-speed video camera (Vision Research, Inc., Wayne, NJ).

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*Figure 5.* Monorail drop tower. Shown is the blunt impact test equipment consisting of a guided, free-fall drop tower with the standard size C DOT headform installed.

## **Experimental Methods**

### **Liner Modification Selection.**

An audit of the PROFIT records was conducted with the assistance of PROFIT specialists. The most frequent modification recorded was the removal of the two inner-most layers of thermoplastic material from either the TPL<sup>®</sup> or the SCL<sup>™</sup>. Other documented modifications removed portions of either the first and second thermoplastic layers, or both. No modifications documented altered the 2 outer-most thermoplastic layers.

Based on the audit results, a single helmet liner modification was selected for evaluation to determine its effect on the blunt impact protection. TPLs<sup>®</sup> and SCLs<sup>™</sup> were modified by removing the two inner-most layers of thermoplastic material. This modification would also represent the worst-case scenario of documented PROFIT cases verses removing a portion of either the two inner-most layers.

## **Blunt Impact.**

### ***Methodology.***

The HGU-56/P AIHS performance specification (DOD, 1996) requires a helmet to be evaluated for blunt impact performance capabilities after a minimum of 4 hours conditioning at one of two environmental conditions: ambient laboratory conditions and an elevated (hot) temperature condition of 122°F. One set of blunt impact testing requires two helmets; one helmet is impacted in the front (FR), crown (CR), and rear (RR) and a second helmet in the left headband (LH), crown (CR), and right headband (RH). Earcup impacts can be performed on either helmet, but are typically done on the helmet tested in the front, crown, and rear to avoid any influence from the right and left headband impacts. Headband impacts are performed at 6.0 meters per second (mps) [19.7 feet per second (fps)] and crown impacts are performed at 4.9 mps (16.0 fps). Pass-fail headform acceleration criteria is 150G for crown impacts and 175G for headband impacts.

To maximize test assets, modifications were made to the standard methodology. Helmets were only impacted in 5 of the 7 locations: crown and the headband regions (front, rear, left headband, and right headband). The 2 earcup impacts were omitted as impacts to the earcup region do not directly engage the energy absorption capabilities of the comfort liners. In lieu of the purchase description requirement of 3 impacts per helmet, each helmet was impacted in 5 locations. While over 20 years of historical data that has shown the HGU-56/P AIHS capable of passing the headform acceleration performance requirement on impacts performed at all 5 impact locations on one helmet, impacts were still separated into “for record” and “supplemental” impacts. The “for record” impacts were completed first at the 3 impact locations defined in the purchase description. The “supplemental” impacts were completed second at the additional 2 locations.

Liner modification evaluations were divided into 2 series. Series 1 (Table 1) evaluated 12 helmets, 6 with modified TPLs<sup>®</sup> and 6 with modified SCLs<sup>™</sup>, conditioned in the hot condition for a minimum of 4 hours. The hot condition was evaluated first as this is considered the worst-case scenario for a comfort liner that is comprised of a temperature dependent, viscoelastic foam like that in the SCL<sup>™</sup>. Series 2 (Table 2) evaluated 6 helmets with modified liners in the ambient condition. The modified liners for Series 2 were selected based on the modified liner with the highest headform accelerations from Series 1.

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Table 1. Blunt impact test matrix for Series 1.

Helmet Identifier	Helmet	Size	Modified Liner	Conditioning	Impact Locations				
					Impacts for Record			Supplemental Impacts	
H1-ModTPL-H	HGU-56/P	Small	TPL®	HOT	FRONT HB	CROWN	REAR HB	LEFT HB	RIGHT HB
H2-ModTPL-H	HGU-56/P	Small	TPL®	HOT	LEFT HB	CROWN	RIGHT HB	FRONT HB	REAR HB
H3-ModTPL-H	HGU-56/P	Small	TPL®	HOT	FRONT HB	CROWN	REAR HB	LEFT HB	RIGHT HB
H4-ModTPL-H	HGU-56/P	Small	TPL®	HOT	LEFT HB	CROWN	RIGHT HB	FRONT HB	REAR HB
H5-ModTPL-H	HGU-56/P	Small	TPL®	HOT	FRONT HB	CROWN	REAR HB	LEFT HB	RIGHT HB
H6-ModTPL-H	HGU-56/P	Small	TPL®	HOT	LEFT HB	CROWN	RIGHT HB	FRONT HB	REAR HB
H7-ModSCL-H	HGU-56/P	Small	SCL™	HOT	FRONT HB	CROWN	REAR HB	LEFT HB	RIGHT HB
H8-ModSCL-H	HGU-56/P	Small	SCL™	HOT	LEFT HB	CROWN	RIGHT HB	FRONT HB	REAR HB
H9-ModSCL-H	HGU-56/P	Small	SCL™	HOT	FRONT HB	CROWN	REAR HB	LEFT HB	RIGHT HB
H10-ModSCL-H	HGU-56/P	Small	SCL™	HOT	LEFT HB	CROWN	RIGHT HB	FRONT HB	REAR HB
H11-ModSCL-H	HGU-56/P	Small	SCL™	HOT	FRONT HB	CROWN	REAR HB	LEFT HB	RIGHT HB
H12-ModSCL-H	HGU-56/P	Small	SCL™	HOT	LEFT HB	CROWN	RIGHT HB	FRONT HB	REAR HB

Table 2. Blunt impact test matrix for Series 2.

Helmet Identifier	Helmet	Size	Modified Liner	Conditioning	Impact Locations				
					Impacts for Record			Supplemental Impacts	
H13-ModTBD* -A	HGU-56/P	Small	TBD*	AMBIENT	FRONT HB	CROWN	REAR HB	LEFT HB	RIGHT HB
H14-ModTBD* -A	HGU-56/P	Small	TBD*	AMBIENT	LEFT HB	CROWN	RIGHT HB	FRONT HB	REAR HB
H15-ModTBD* -A	HGU-56/P	Small	TBD*	AMBIENT	FRONT HB	CROWN	REAR HB	LEFT HB	RIGHT HB
H16-ModTBD* -A	HGU-56/P	Small	TBD*	AMBIENT	LEFT HB	CROWN	RIGHT HB	FRONT HB	REAR HB
H17-ModTBD* -A	HGU-56/P	Small	TBD*	AMBIENT	FRONT HB	CROWN	REAR HB	LEFT HB	RIGHT HB
H18-ModTBD* -A	HGU-56/P	Small	TBD*	AMBIENT	LEFT HB	CROWN	RIGHT HB	FRONT HB	REAR HB

TBD\* - liner to be modified will be determined by the worst performing liner from Series 1

### *Procedure.*

Blunt impact testing was performed in accordance to the USAARL IBPG approved Helmet Evaluation Test Scope (2017-031) and the HGU-56/P AIHS purchase description (DOD, 1996) with previously described minor modifications.

The monorail drop height was adjusted prior to testing to determine the drop heights needed to achieve the desired impact velocity. While the theoretical drop height can be calculated based on the necessary impact velocity, additional drop height is typically needed to overcome the frictional drag of the tower rail. The headform and a representative helmet was dropped from successively higher drop heights, starting at the theoretical drop height. Headform impact velocity was measured at each drop height, and the process repeated until the desired impact velocity was achieved.

Pre- and post-test system integrity checks were performed before and after each set of tests, typically at the beginning and end of each day. During these checks, the bare DOT “C” headform was raised to a drop height of 12-inches (in.) and impacted on to a 1-in. thick, flat, modular elastomer programmer pad. Impactor acceleration, transmitted force, and impact velocity were recorded. The pre- and post- procedures were each performed a minimum of three times. The average of the peak headform accelerations measured for pre-tests were compared to the average peak headform accelerations measured post-test. A difference in the two averages of greater than 10 percent is indicative of test equipment or instrumentation damage occurring during the testing.

TPLs<sup>®</sup> and SCLs<sup>™</sup> were fitted to spare headforms following instructions documented in section 4-12 of the HGU-56/P AIHS operator’s manual (DA, 1996). The liners were placed in a 200°F oven with heating time reduced to 8 minutes. A PROFIT technician reduced the time based only using 2-layers of the thermoplastic material. Helmets were positioned upside down and the weight of headform was used in place of the downward pressure typically applied by the wearer. For Series 1, after liner fitting the helmets were conditioned for a minimum of 4 hours in 122°F. Heating the helmet for the hot environmental condition does not affect the fitting of the liners as it is lower than the transition temperature of the thermoplastic material. Series 2 helmets were tested at an ambient condition.

For each impact test, the helmet was mounted to the headform with the chin and nape straps adjusted to achieve a snug fit; helmets were not allowed to fit loosely or droop from the headform. The combined helmet/headform assembly was raised to the drop height necessary to achieve the desired impact velocity and released. The helmet/headform assembly then fell, impacting a flat steel anvil at the base of the drop tower. After each test, each helmet was thoroughly inspected for loose components and distorted hardware and the headform orientation was checked and adjusted as necessary.

All tests of environmentally conditioned helmets were conducted within 5 minutes of removing the helmets from the environmental chambers. If testing could not be completed within this time, the helmets were returned for a minimum of 15 minutes before resuming testing (DOD, 1996).

## **Data Analysis**

For both series, headform accelerations were filtered according to the Society of Automotive Engineers (SAE) Standard Practice J211-1 Part 1 (SAE, 1995). Peak headform accelerations were extracted from each filtered acceleration signal. Blunt impact protection was assessed by comparing the peak headform accelerations to the pass/fail criteria specified in the HGU-56/P AIHS purchase description (DOD, 1996).

Series 1 results were evaluated using a two-factor analysis of variance (ANOVA) with the Tukey multiple comparison method for the effects of helmet liner type and impact site on peak headform acceleration. The two-way ANOVA tested for the equality of the mean peak headform acceleration for each liner type and impact site. The Tukey multiple comparison method was used to determine statistical differences in mean peak headform acceleration for each liner type at each impact site. SigmaPlot for Windows version 12.5 (Systat Software, Inc., San Jose, CA) was used to perform the calculations. The ANOVA was designed to identify statistically significant differences with a power of 0.95, assuming an alpha of 0.05. The ANOVA results were used to determine which modified liner was used for Series 2.

## **Results**

The peak headform accelerations for helmets evaluated in the hot environment with the modified TPL<sup>®</sup> and SCL<sup>™</sup> are shown in Figure 6 and 7, respectively. Results were assessed against the peak headform acceleration pass/fail criteria specified in the HGU-56/P AIHS purchase description (DOD, 1996). Tables of average peak headform acceleration data are provided in the appendix.

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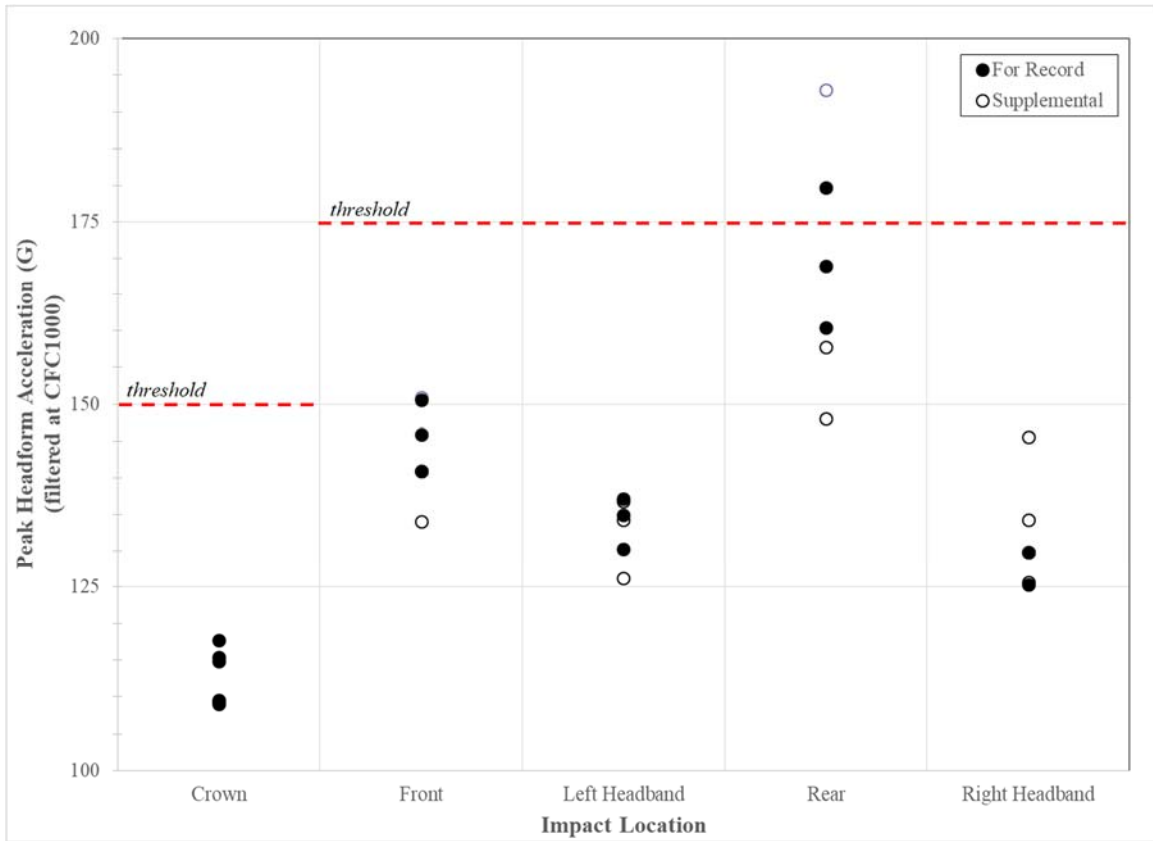


Figure 6. Peak headform accelerations by impact location for the HGU-56/P with the modified TPL<sup>®</sup> conditioned at 122°F; “for record” and “supplemental” impacts shown. The dotted line represents the HGU-56/P AIHS pass-fail threshold.

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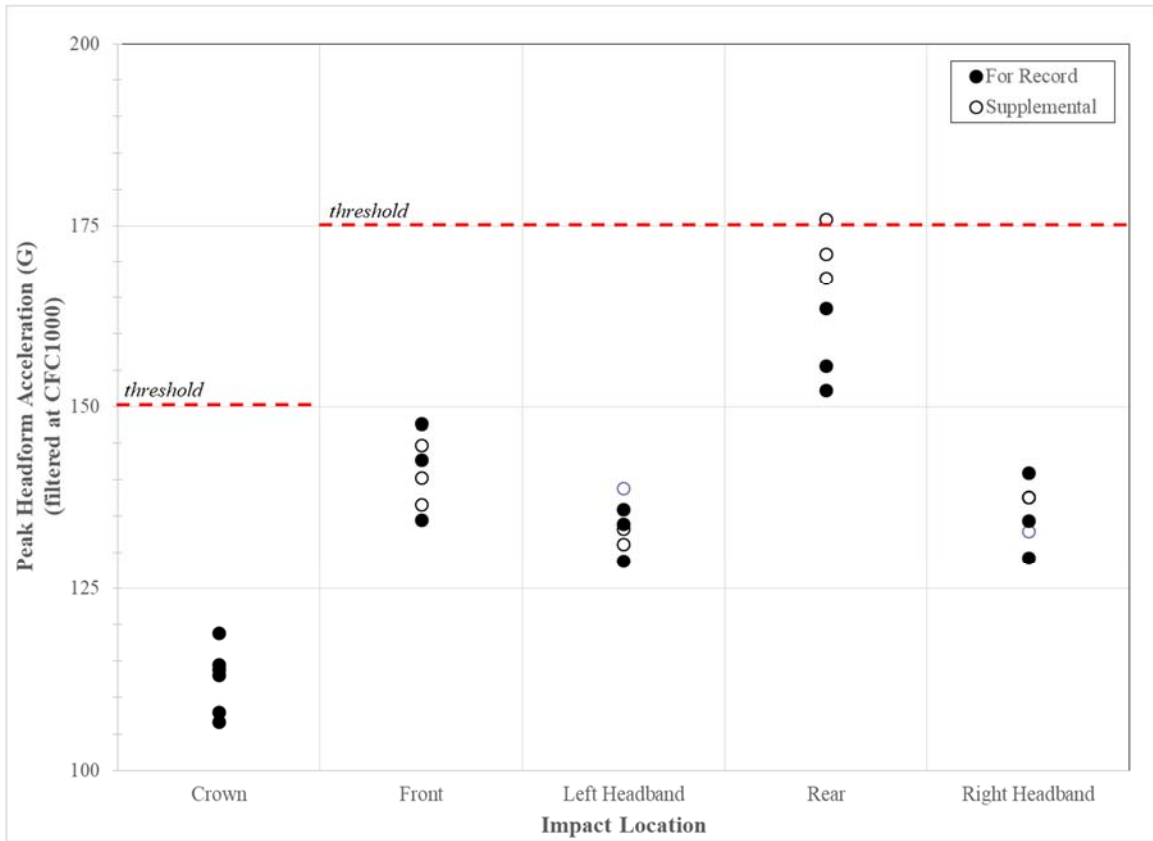


Figure 7. Peak headform accelerations by impact location for the HGU-56/P with the modified SCL™ conditioned at 122°F; “for record” and “supplemental” impacts shown. The dotted line represents the HGU-56/P AIHS pass-fail threshold.

A two way ANOVA ( $P < 0.05$ ) with a post-hoc Tukey Test was performed on the peak headform accelerations from the Series 1 hot conditioned impacts. The ANOVA results for both the “for record” and the combined “for record” and “supplemental” impacts showed no significant difference between the peak headform accelerations of the modified TPL® versus the modified SCL™ for all impact sites combined (Table 3). A pairwise multiple comparison (Tukey Test) was run on the “for record” headform accelerations for the modified liner types within each impact location. Only the rear impact location showed a significant difference between the mean peak headform accelerations measured with the TPL® versus the SCL™ ( $P = 0.006$ ). The TPL® was chosen for ambient blunt impact evaluation for Series 2.

Table 3. All Pairwise Multiple Comparison Procedures (Tukey Test) for Series 1 average peak headform accelerations.

Comparisons for factor: <b>Liner</b>						
<b>Comparison</b>	<b>Impact Type</b>	<b>Diff of Means</b>	<b>p</b>	<b>q</b>	<b>P</b>	<b>P&lt;0.050</b>
TPL <sup>®</sup> vs SCL <sup>™</sup>	“for record”	0.480	2	0.53	0.804	No
TPL <sup>®</sup> vs SCL <sup>™</sup>	“for record” and “supplemental”	2.308	2	1.824	0.209	No

The peak headform accelerations for helmets evaluated in the ambient environment with the modified TPL<sup>®</sup> are shown in Figure 8. Results were assessed against the peak headform acceleration pass/fail criteria specified in the HGU-56/P AIHS purchase description (DOD, 1996). Tables of average peak headform acceleration data are provided in the appendix.

One test (MDT0001107) evaluating the modified TPL<sup>®</sup> at ambient conditioning impacting to the rear impact location had an error in the data acquisition. The headform acceleration reported was calculated using tracking data from the high-speed video.

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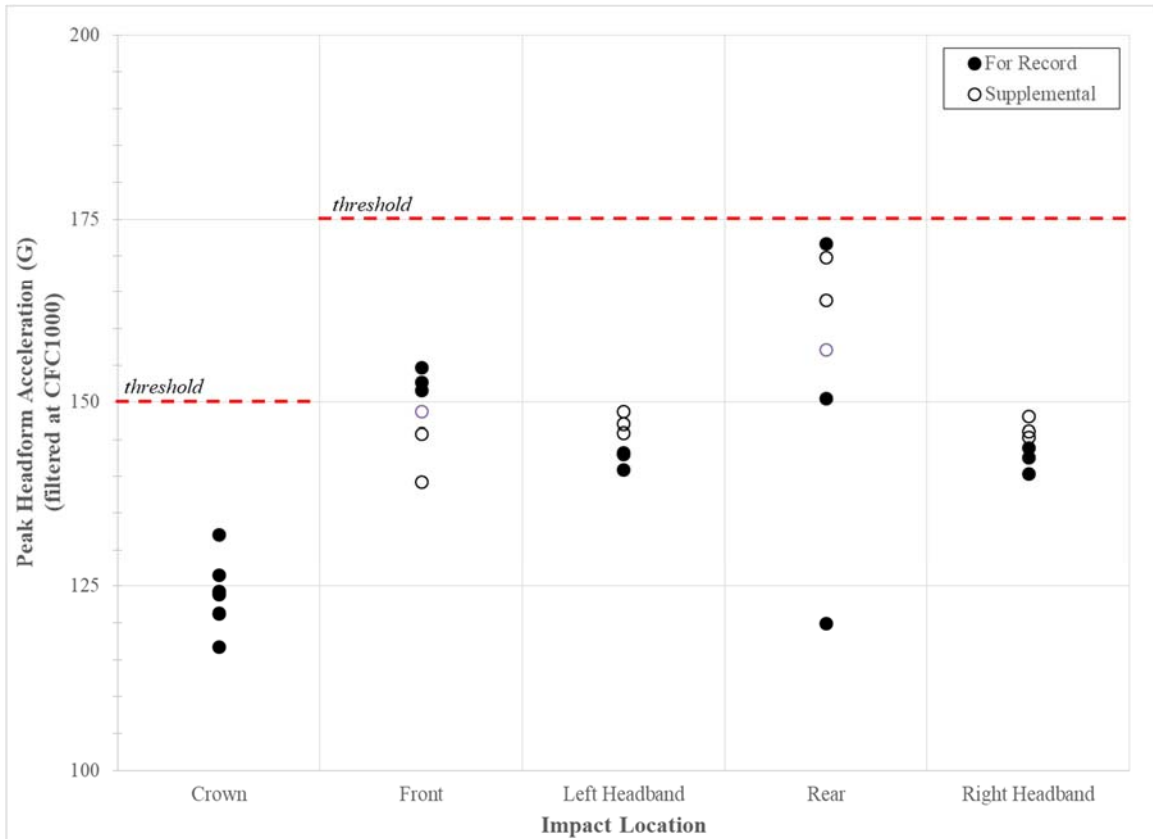


Figure 8. Peak headform accelerations by impact location for the HGU-56/P with the modified TPL<sup>®</sup> in the ambient condition; “for record” and “supplemental” impacts shown. The dotted line represents the HGU-56/P AIHS pass-fail threshold.

## Discussion

Helmet liners are intended to provide the wearer with a customized and comfortable helmet fit and not intended to be integral to the blunt impact protection of the HGU-56/P AIHS. However, previous research has shown that altering or substituting helmet liners can reduce blunt impact protection of the HGU-56/P AIHS. Qualification tests of the HGU-56/P AIHS were conducted with TPLs<sup>®</sup> consisting of two to four layers. These qualification tests indicated that the thickness of the TPLs<sup>®</sup> influenced helmet blunt impact performance, and HGU-56/P AIHSs were required to be fitted with only four-layer TPL<sup>®</sup> (DA, 1996). Unlike the SPH-4B helmet, which allowed unit-level aviation life support equipment (ALSE) technicians to remove up to two layers of thermoplastic material, when necessary, to provide a comfortable fit (DA, 1993), the HGU-56/P AIHS requires a USAARL PROFIT technician to perform modifications to the liners.

This evaluation has shown that removing the two inner-most layers of thermoplastic material from TPLs<sup>®</sup> and SCLs<sup>™</sup> should not compromise the impact protection provided by the HGU-56/P AIHS. These results indicate that, since the introduction of the HGU-56/P AIHS in 1995, the helmet manufacturer has likely refined manufacturing and quality control processes.

These improvements have improved the overall blunt impact protection of the helmet, reducing the influence of the helmet liner on the blunt impact protection provided by the HGU-56/P AIHS.

Removal of the two inner-most layers of thermoplastic material from TPL<sup>®</sup> and SCL<sup>™</sup> did not adversely affect the impact protection provided by the HGU-56/P AIHS. For both Series 1 and Series 2, mean peak headform accelerations measured during “for record” and the combined set of “for record” and “supplemental” tests remained below established pass-fail thresholds for each helmet impact site. Peak headform accelerations less than the specified pass-fail criterion (DOD, 1996) indicate that HGU-56/P AIHSs fitted with the modified helmet liners will provide the level of blunt impact protection required for US Army aviation operations (DOD, 1996).

Figure 6 shows that one rear “for record” impact of an HGU-56/P AIHS equipped with a modified TPL<sup>®</sup> and conditioned at 122°F resulted in a peak headform acceleration above the specified pass-fail criterion (DOD, 1996). In two of three supplemental rear impacts (i.e., rear impacts to helmets have been previously impacted in the crown, left headband, and right headband) resulted in peak headform accelerations below the 175 G pass-fail criterion (DOD, 1996). Results of these supplemental rear impacts indicate that the one peak headform acceleration exceeding 175 Gs may be an outlier, as even previously-damaged helmets fitted with modified TPLs<sup>®</sup> were shown to provide the required level of impact protection.

Current fitting guidance for the HGU-56/P AIHS requires that four-layer TPLs<sup>®</sup> and SCLs<sup>™</sup> be worn in the HGU-56/P AIHS (DOD, 1996). The results of this study show that removing the two inner-most thermoplastic layers of the TPL<sup>®</sup> and SCL<sup>™</sup> should not compromise the impact protection provided by the helmet. However, these modifications can still only be made by trained USAARL PROFIT Program technicians. Currently, unit-level ALSE technicians must follow published procedures for achieving a comfortable fit of the HGU-56/P AIHS (DA, 1996).

### **Caveats**

This was a limited evaluation intended to provide unbiased data on the performance of the modified TPL<sup>®</sup> or SCL<sup>™</sup> for the HGU-56/P AIHS. These data were intended to provide information to aid determining the effect of the PROFIT modifications to the blunt impact protection provided by the HGU-56/P AIHS.

The sample size used in this evaluation was small and limited to a single size. No more than three small helmets in each configuration were used for the blunt impact attenuation testing. The data gathered from this limited sample size should provide insight into the performance of all sizes of HGU-56/P AIHS with the modified TPL<sup>®</sup> or SCL<sup>™</sup>.



## Conclusions

The results of this evaluation indicate that HGU-56/P AIHSs fitted with two-layer TPL<sup>®</sup> and SCL<sup>™</sup> helmet liners will provide the required level of blunt impact protection as described in the HGU-56/P performance specification (DOD, 1996). When modified TPL<sup>®</sup> and SCL<sup>™</sup> helmet liners were installed in small HGU-56/P AIHSs, the helmets were shown to meet the blunt impact requirements prescribed in the HGU-56/P AIHS purchase description (DOD, 1996). As all sizes of HGU-56/P AIHS are designed to provide the same level of blunt impact protection, the results of this evaluation of small HGU-56/P AIHSs fitted with two-layer TPLs<sup>®</sup> and SCLs<sup>™</sup> are representative of the remaining sizes of the HGU-56/P AIHS.

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## References

- American National Standards Institute (ANSI). (1971). *Standard for protective headgear for vehicular users*. New York: American National Standards Institute, Inc. Z90.1-1971.
- Brozoski, F., Licina, J., Phelps, S., Padgett, K., Vasquez, K., Lindsey, J., & Harvey, A. (2008). Impact protection assessment of the redesigned Oregon Aero ZetaLiner fitting system in the HGU-56/P Aircrew Integrated Helmet System. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 2008-07.
- Department of the Army (DA). Operator's and Aviation Unit Maintenance Manual Including Repair Parts and Special Tools List for Helmet, Flyer's: SPH-4B HGU-56P. TM 1-8415-215-12&P. January 15, 1993.
- Department of the Army (DA). Operator's and Aviation Unit Maintenance Manual Including Repair Parts and Special Tools List. Helmet System, Aircrew Integrated, HGU-56P. TM 1-8415-216-12&P. December 13, 1996.
- Department of Defense (DOD). (1996). *Purchase description: Aircrew integrated helmet system, HGU-56/P (AIHS)*. FNS/PD 96-18. November 1, 1996.
- Department of Transportation (DOT). (2006). Federal Motor Vehicles Safety Standard 218. Motorcycle helmets. Title 49, Code of Federal Regulations Chapter V, Sub-section 571.218 (49CFR571.218), November 1, 2006.
- Hundley, T. A. (1984). *UH-60 shoulder harness lead-in stray failure analysis*. Fort Rucker, AL. U.S. Army Aeromedical Research Laboratory. USAARL Report No. 84-7.
- McEntire, B. J. (1998). *U.S. Army aircrew helmets: Head injury mitigation technology (reprint)*. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 98-12.
- Palmer, R. W. (1991). *SPH-4 aircrew helmet impact protection improvement 1970-1 990*. Fort Rucker, AL. U.S. Army Aeromedical Research Laboratory. USAARL Report No. 91-11.
- Program Executive Officer, Aviation (PEO-AVN). (1996). Aircrew integrated system advisory message on aviation life support equipment. Message number 10167. March 7, 1996.
- Reading, T. E., Haley, J. L., Jr., Sippo, A. C., Licina, J. R., & Schopper, A.W. (1984). SPH-4 U.S. Army flight helmet performance, 1972-1983. Report No. 85-1. Fort Rucker, AL. U.S. Army Aeromedical Research Laboratory.
- Shanahan, D. F. Basilar skull fracture in U.S. Army aircraft accidents. *Aviation Space and Environmental Medicine*, Vol. 54, No. 7, pp.628-63 1. July 1983.

Slobodnik, B. A. (1980). SPH-4 helmet damage and head injury correlation. Fort Rucker, AL. U.S. Army Aeromedical Research Laboratory. USAARL-80-7.

Society of Automotive Engineers. (1995). Recommended Practice J211-1. *Instrumentation for impact test – Part 1 – Electronic instrumentation*. Warrendale, PA. SAE J211-1. Revised March 1995.

Vyrnwy-Jones, P., Lanoue, B., & Pritts, D. (1988). SPH-4 U.S. Army flight helmet performance, 1983-1987. Report No. 88-15. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory.

## Abbreviations and Acronyms

<b>Abn</b>	<b>Airborne</b>
<b>AH</b>	<b>Attack Helicopter</b>
<b>AIHS</b>	<b>Aircrew Integrated Helmet System</b>
<b>ALSE</b>	<b>Aviation Life Support Equipment</b>
<b>ANSI</b>	<b>American National Standards Institute</b>
<b>APH</b>	
<b>ATD</b>	<b>Anthropomorphic Test Device</b>
<b>CFC</b>	<b>Channel Frequency Class</b>
<b>DOD</b>	<b>Department of Defense</b>
<b>DOT</b>	<b>Department of Transportation</b>
<b>fps</b>	<b>feet per second</b>
<b>FOCUS</b>	<b>Facial and Ocular CountermeasUre Safety</b>
<b>ft</b>	<b>foot</b>
<b>G</b>	<b>gravitational constant</b>
<b>HB</b>	<b>headband</b>
<b>HGU-56/P</b>	<b>Head Gear Unit, Number 56, Personal</b>
<b>Hz</b>	<b>Hertz</b>
<b>IHADSS</b>	<b>Integrated Helmet and Display Sighting System</b>
<b>in</b>	<b>inch</b>
<b>lb</b>	<b>pound</b>
<b>MEP</b>	<b>modular elastomer programmer</b>
<b>mps</b>	<b>meters per second</b>
<b>PROFIT</b>	<b>Problem Fit</b>
<b>SAE</b>	<b>Society of Automotive Engineers</b>
<b>SCL</b>	<b>Super Comfort Liner™</b>
<b>SOAR</b>	<b>Special Operations Aviation Regiment</b>
<b>SOP</b>	<b>Standard operating procedure</b>
<b>SPH-4B</b>	<b>Sound Protective Helmet Model 4B</b>
<b>TPL</b>	<b>Thermo Plastic Liner®</b>
<b>USAARL</b>	<b>U.S. Army Aeromedical Research Laboratory</b>

## Appendix.

*Table A1.* Average peak headform accelerations by impact location for the HGU-56/P with the modified TPL® in the hot and ambient conditions; “for record” and “supplemental” impacts shown.

Modified Liner	Conditioning	Test Type	Impact Location				
			Crown	Front	Rear	Left Headband	Right Headband
TPL®	Hot	"For Record"	112.69	145.78	169.66	134.13	128.30
		"Supplemental"	NA	141.93	166.24	132.41	135.15
		Combined*	112.69	143.86	167.95	133.27	131.73
	Ambient	"For Record"	124.15	153.04	197.67	142.44	142.30
		"Supplemental"	NA	144.66	163.59	147.26	146.54
		Combined*	124.15	148.85	180.63	144.85	144.42

*\*combined includes "for record" and "supplemental"*

*Table A2.* Average peak headform accelerations by impact location for the HGU-56/P with the modified SCL™ in the hot conditions; “for record” and “supplemental” impacts shown.

Modified Liner	Conditioning	Test Type	Impact Location				
			Crown	Front	Rear	Left Headband	Right Headband
SCL™	Hot	"For Record"	112.51	141.12	133.68	164.32	135.47
		"Supplemental"	NA	141.64	132.91	157.08	134.88
		Combined*	112.51	140.60	134.44	171.57	136.06

*\*combined includes "for record" and "supplemental"*



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