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## **Assessment of Aircrew Head Injury Protection After Helmet Liner Modification**

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**14. ABSTRACT**  
U.S. Army aviators experiencing difficulty attaining a comfortable helmet fit are referred to the U.S. Army Aeromedical Research Laboratory's ProblemFit (PROFIT) program. USAARL PROFIT personnel make modifications to the comfort liner to accommodate atypical head anthropometry to achieve a more user-specific fit. Effects of these modifications on blunt impact performance of the HGU-56/P Aircrew Integrated Helmet System (AIHS) and head injury protection are unknown. It is important for these effects to be quantified and the risks associated with modifications to be understood by USAARL PROFIT personnel, the aviator, and aviation leadership. Through a USAARL PROFIT records audit, two approved comfort liners were selected for modification in the HGU-56/P AIHS: Super Comfort Liner™ (SCL) and Thermal Plastic Liner® (TPL). In order to evaluate a "worst-case scenario" modification the two inner-most layers of thermoplastic material were removed from each liner. Helmets were tested according to HGU-56/P AIHS Purchase Description (DoD, 1996) using a monorail drop tower (ANSI, 1966).

**15. SUBJECT TERMS**  
HGU-56/P, AIHS, ThermoPlastic Liner, TPL®, Super Comfort Liner, SCL™, helmet problem fit, modified comfort liner, blunt impact protection

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14. Abstract (continued)

The monorail drop tower was instrumented to collect three channels of data: impact velocity, headform acceleration, and impact force. Helmet blunt impact performance was assessed using the peak headform acceleration for each impact. Two test series were conducted. Series one consisted of six helmets each of the modified SCL™ and modified TPL® tested in the hot environmental condition. Series two consisted of six helmets with the modified TPL® tested in the ambient condition. In series one, the modified SCL™ helmets tested in the hot environmental condition peak headform accelerations averaged 112.51G at the crown and 141.63G at the headband. The modified TPL® helmets peak headform accelerations averaged 112.69G at the crown and 144.71G at the headband. In series two, the modified TPL® helmets peak headform accelerations averaged 124.16G at the crown and 148.65G at the headband. Results indicated the removal of the two inner-most layers of the SCL™ or TPL® does not degrade the blunt impact protection of the helmet below the pass-fail threshold of 150G and 175G for crown and headband impacts, respectively. In an isolated incident, a single helmet failed on rear impact. Helmet orientation and liner installation are possible contributing factors.

## **Acknowledgements**

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# Assessment of Aircrew Head Injury Protection after Helmet Liner Modifications

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# The Evolution of Helmet Fitting



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## 1960s: Aircrew Protection Helmet Number 5 (APH-5)

- Hard shell aviation helmet
- Leather-covered foam pads

## 1969: Sound Protection Helmet Number 4 (SPH-4)

- Sling suspension system

## 1984: Integrated Helmet and Display Sighting System (IHADSS)

- Front and rear pads
- Inner basket assembly, vertically adjusted
- Brow and nape pads



Photo A: [www.worthpoint.com](http://www.worthpoint.com), Photos B-E: USAARL



# The Evolution of Helmet Fitting (Continued)



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## Mid-1980s: SPH-4 Conversion Kits

- Kit to modify to sling suspension
- Gentex ThermoPlastic Liner (TPL<sup>®</sup>) introduced
  - Decrease headaches and hotspots
  - Improve helmet stability

TPL<sup>®</sup>



## 1989: SPH-4B

- Standard issue with TPL<sup>®</sup>

SCL<sup>™</sup>



## 1995: Head Gear Unit Number 56 Personal (HGU-56/P) Aircrew Integrated Helmet System (AIHS)

- Standard issue with TPL<sup>®</sup>

## Alternative Liners

- Gentex Super Comfort Liner (SCL<sup>™</sup>)
- 2008: Oregon Aero Zeta II<sup>®</sup>

Zeta II<sup>®</sup>



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



# Helmet Fitting Issues



- Among aviators, individual anthropometric variability incongruent with standard helmet fitting is the primary source of discomfort.
- Extended duration of the “normal flight mission”
  - Creates expected discomfort from head-borne mass
  - Exacerbates pre-existing discomfort
- Subset of U.S. Army aviators continue to have problems achieving a comfortable and safe helmet fit even with standard adjustments or helmet liners.



- A safe and comfortable fit is considered mission critical in aviation.
- U.S. Army Aeromedical Research Laboratory (USAARL) Problem Fit (PROFIT) program
  - Helmet fitting services for helmet fitting issues for the last 25+ years (Program Executive Officer Aviation [PEO-AVN], 1996)
- If unit Aviation Life Support Equipment (ALSE) technicians cannot resolve issues with basic modifications, aviators are referred to the USAARL PROFIT program for evaluation.
- USAARL PROFIT technicians are authorized to make minor modifications to TPLs<sup>®</sup> and SCLs<sup>™</sup>.
  - Unique head anthropometry and specific complaint (e.g., hotspots, headaches) are considered in PROFIT assessments for liner modification.
    - Examples: Removing portions of one or multiple layers, removing a whole layer
- There are limited data available to determine if these modification influence blunt impact protection.



# Study Objective



- Quantify the effects of helmet liner modifications on the blunt impact protection provided by the HGU-56/P AIHS
- Comparing blunt impact attenuation testing results of helmets with modified TPL<sup>®</sup> and SCL<sup>™</sup> liners to standard pass/fail criteria



- An audit of PROFIT records was conducted.
- Researchers identified the most common PROFIT modification techniques used in the program:
  - Removal of the two inner-most layers of thermoplastic material from either the TPL<sup>®</sup> or the SCL<sup>™</sup> was the most frequent modification.
- Other documented modifications removed portions of either the first or second thermoplastic layers, or both.
- No modifications were documented where the two outer-most thermoplastic layers were altered.



- A single helmet liner modification was selected for evaluation.
  - Removed the two inner-most layers of the TPL<sup>®</sup> and SCL<sup>™</sup> liners.
    - This modification represented the most frequent and “worst-case” scenario.
  - Custom fitting instructions from section 4-12 of the HGU-56/P AIHS operator’s manual (Department of the Army [DA], 1996) were modified:
    - Modified TPLs<sup>®</sup> and SCLs<sup>™</sup> liners were heated in a 200<sup>o</sup> Fahrenheit (F) oven.
    - Heating time was reduced from 10 minutes to 8 minutes based on the reduced number of layers.
    - Liners were installed in new HGU-56/P AIHSs.
    - Helmets were donned on a spare headform and positioned upside down. The weight of the headform simulated the downward pressure typically applied by the wearer.



- To maximize test assets, modifications were made to the standard methodology.
  - Each helmet was impacted in 5 of the 7 locations:
    - Crown
    - Headband regions (front, rear, left headband, and right headband).
  - Earcup impacts were omitted.
  - The 5 impacts were separated into “For Record” and “Supplemental.”
    - “For Record impacts” – first 3 impacts to each helmet defined in the purchase description (DOD, 1996)
    - “Supplemental” – the additional 2 impacts to each helmet



- Liner modification evaluations were divided into 2 series.
  - Series 1: 12 size small HGU-56/P AIHSs were tested after hot conditioning (122° F) for a minimum of 4 hours. *Results were used to down-select for series 2.*
    - Six helmets with modified TPL®
    - Six helmets with modified SCL™
  - Series 2: 6 size small HGU-56/P AIHSs were tested in ambient conditions (60° to 80° F) with a modified TPL® only.

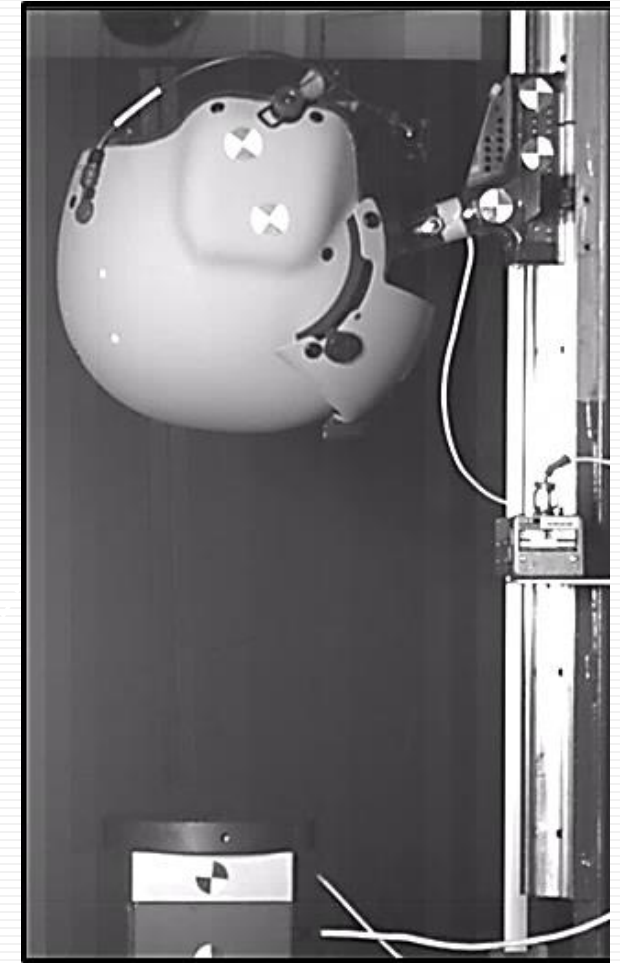


# Blunt Impact Attenuation Testing



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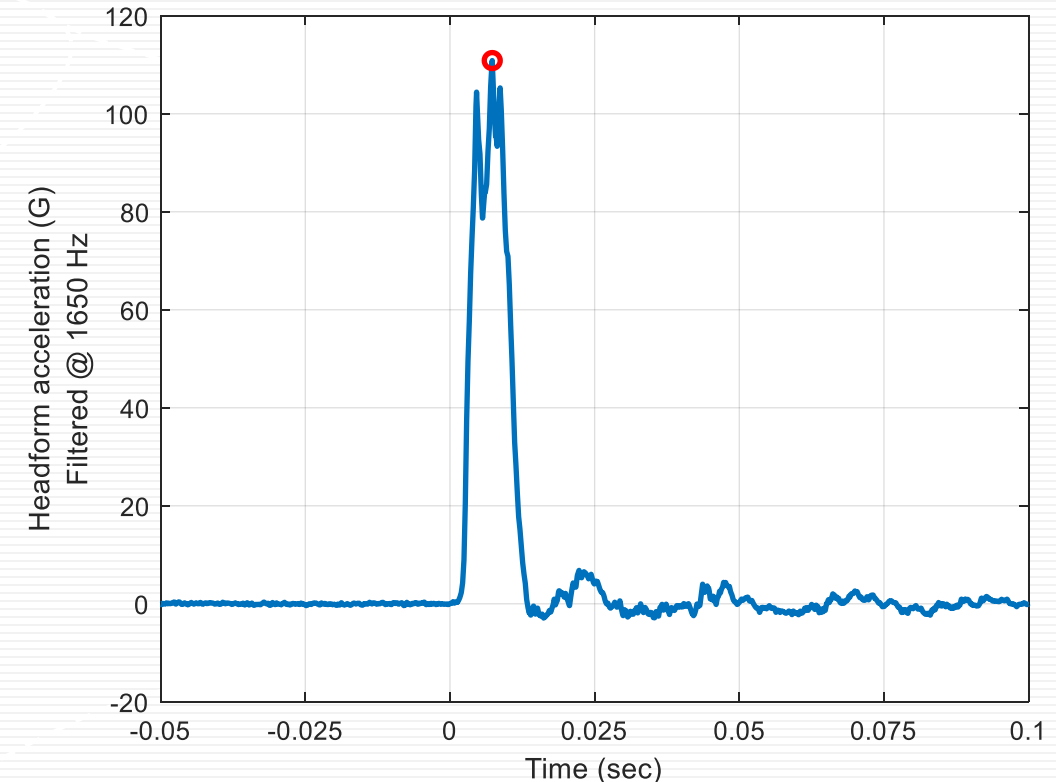
- “For Record” impacts were completed according to the HGU-56/P AIHS purchase description (Department of Defense [DoD], 1996).
- A free fall monorail drop tower conforming to Federal Motor Vehicle Safety Standard (FMVSS) 218 (Department of Transportation [DoT], 2006) was used.
- Headband impacts (front, rear, left headband, and right headband ) were conducted at an impact velocity of 19.7 feet per second (fps).
- Crown impacts were conducted at an impact velocity of 16.0 fps.
- Impact was made on a flat steel anvil at the base of the drop tower.
- Headform acceleration, impact force, and impact velocity were recorded for each drop test.



Test Set-up for Crown Impact



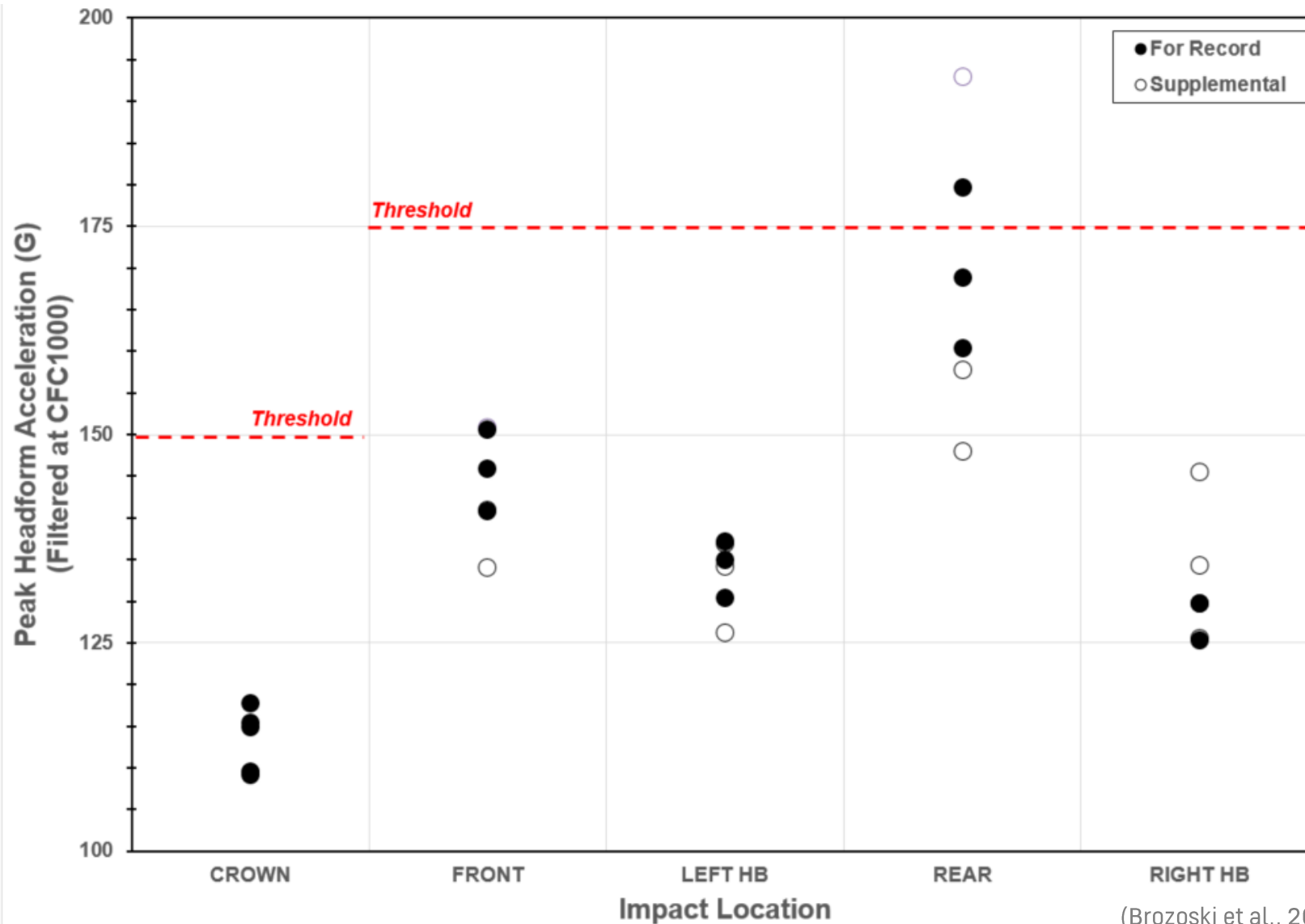
- Headform acceleration data collected during each blunt impact test were filtered according to Society of Automotive Engineers (SAE) Standard Practice J211-1 Part 1 (SAE, 1995).
- Peak headform accelerations were extracted from each filtered acceleration signal.
- Blunt impact protection was assessed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



Exemplar filtered headform acceleration time trace. Red circle indicates the peak filtered headform acceleration.



# Series 1: Small HGU-56/P AIHS with TPL<sup>®</sup> (hot conditioning)



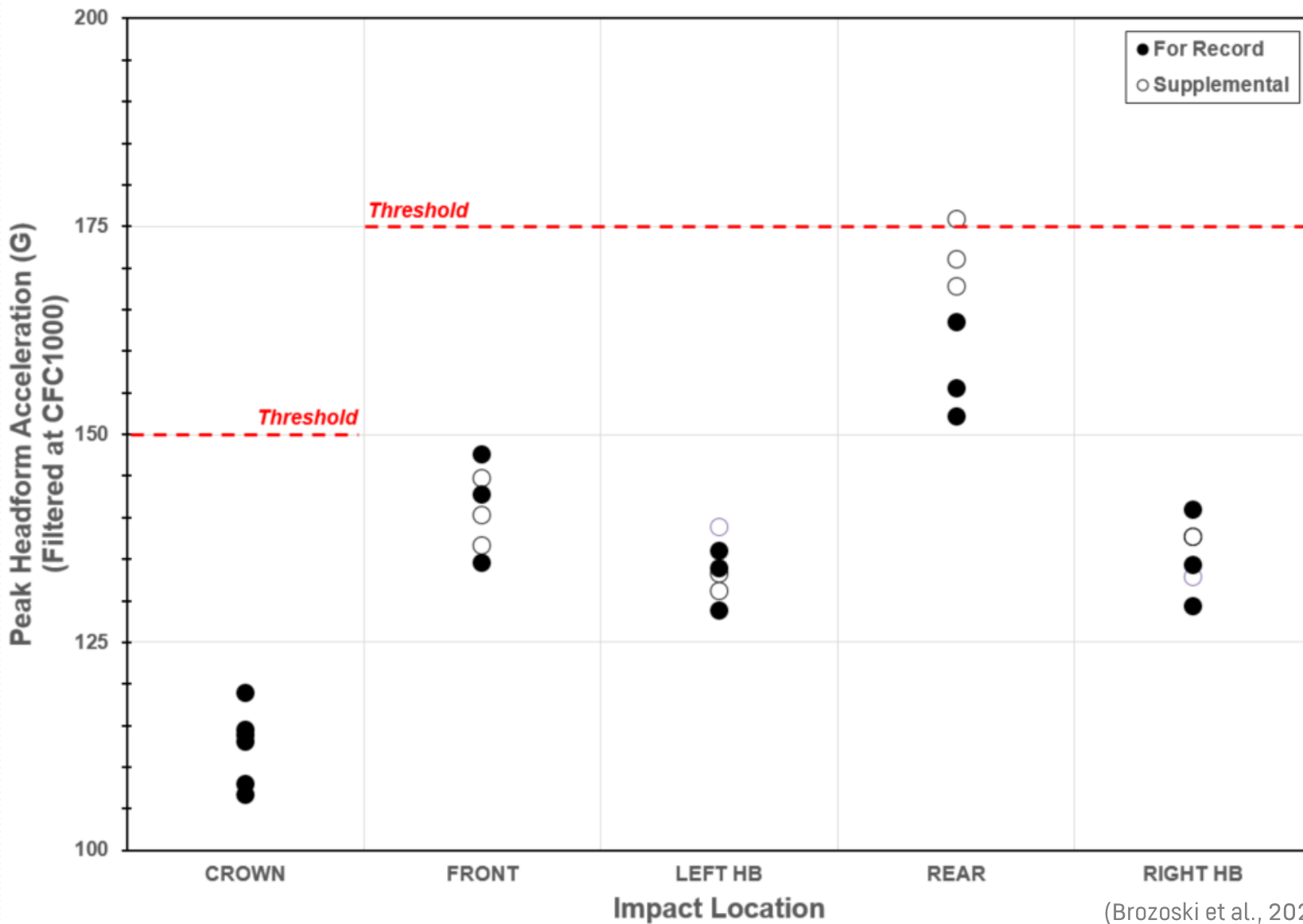
(Brozoski et al., 2020)

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.

*Note: Not all impacts are visible due to having similar peak accelerations*



# Series 1: Small HGU-56/P AIHS with SCL™ (hot conditioning)



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.

*Note: Not all impacts are visible due to having similar peak accelerations*

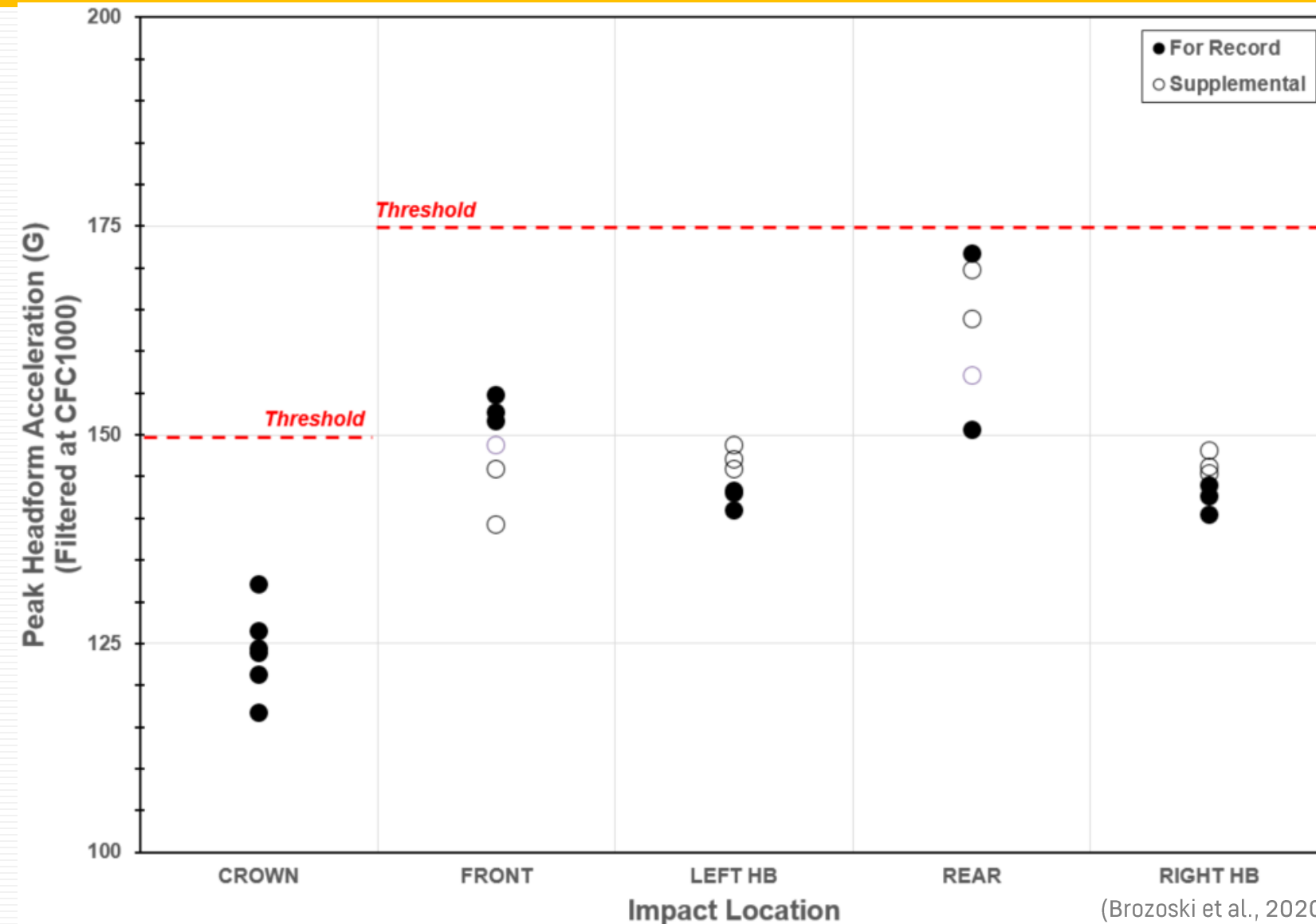
(Brozoski et al., 2020)



- 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 ( $p < 0.05$ ).
- The two-way ANOVA tested for the equality of the mean peak headform acceleration for each liner type and impact site.
- The ANOVA results were used to determine which modified liner would be used for Series 2.
  - Only the rear impact location showed a significant difference between the mean peak headform accelerations measured with the TPL<sup>®</sup> versus the SCL<sup>™</sup> ( $p=0.006$ )
  - The TPL<sup>®</sup> was chosen for ambient blunt impact evaluation for Series 2.



# Series 2: Small HGU-56/P AIHS with TPL<sup>®</sup> (ambient conditioning)



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.

*Note: Not all impacts are visible due to having similar peak accelerations*

(Brozoski et al., 2020)



# Discussion



- Removing the two inner-most layers of thermoplastic material from TPLs<sup>®</sup> and SCLs<sup>™</sup> did not adversely affect the impact protection provided by the HGU-56/P AIHS.
- HGU-56/P AIHS size small modified TPL<sup>®</sup> and SCL<sup>™</sup> helmet liners were shown to meet the blunt impact requirements outlined in the HGU-56/P AIHS purchase description (DoD, 1996).
  - Three rear impacts (one “For Record” and two “Supplemental”) on HGU-56/P AIHSs with modified liners conditioned at 122° F resulted in a peak headform acceleration above the specified pass-fail criterion (DoD, 1996).
  - Results of all rear impacts indicate that the one “For Record” peak headform acceleration exceeding 175 Gs may be an outlier, as other previously-damaged (“supplemental” impacts) helmets fitted with modified TPLs<sup>®</sup> were shown to provide the required level of impact protection.



# Conclusions



- Per current fitting guidance, a four-layer TPL® or SCL™ is required to be worn in the HGU-56/P AIHS (DA, 1996).
- Removing the two inner-most layers of thermoplastic material from TPLs® and SCLs™ did not adversely affect the impact protection provided by the HGU-56/P AIHS.
- Currently, such advanced liner removal or modifications should only be made by trained USAARL PROFIT Program technicians.



# Questions



For details, see Brozoski, F. T., Ganz, G., Sous, S., Gomez, J., & Logsdon, K. (2020). *Assessment of HGU-56/P aircrew integrated helmet System (AIHS) blunt impact protection after liner modifications* (USAARL-TECH-FR--2020-018). U.S. Army Aeromedical Research Laboratory.





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