

Assessment of Layered Seat Cushion Configurations for Underbody Blast Protection



Katerena Sirhan, MS¹, Mark Shafer, MS², Cameron 'Dale' Bass, PhD¹

WAYNE STATE

¹ Wayne State University, Detroit, MI

² US Army DEVCOM Ground Vehicle Systems Center, Detroit Arsenal, MI

Problem Addressed

Personnel exposed to underbody blast (UBB) in vehicles have increased risk of lumbar spinal injuries owing to direct inferior to superior compression. Historically, military vehicles have been designed with limited shock or energy attenuation (EA) features¹. Recent injury epidemiology has emphasized the importance of design features that limit UBB injuries. Previous testing has evaluated polyurethane (PU) foam as an energy-absorbing (EA) material for UBB protection². However, high-density PU and other foams common for EA purposes can be uncomfortable for prolonged seating. Incorporating viscoelastic (VE) habitability foam layer over the high-density EA foam may improve occupant comfort while maintaining or enhancing protective performance. This study investigates the impact of layering VE habitability foam on top of PU foam for occupant protection against UBB events.

Methods

Testing was completed using the Sub-System Drop Tower (SSDT) at the US Army Occupant Protection Lab (OPL) at the Selfridge Air National Guard. Three foam configurations were evaluated: (1) PU foam alone, (2) PU foam layered under VE insert material A and (3) PU foam layered under VE insert material B. The thickness of all three foams varied, with a maximum combined height of 127 mm. Each foam thickness configuration was tested at four different peak platform accelerations. To simulate an UBB, a 50th percentile male Hybrid III anthropomorphic test device (ATD) was seated in an upright position on a rigid seat. PU or PU + VE inserts were layered on the seat pan.

Figure 1: SSDT ATD setup



Injury Assessments

Two injury assessment methods were applied. (1) Ortiz-Paparoni (2020)³: compression/flexion cadaveric lumbar spine injury risk function. The lumbar injury criterion (L_{ic}) risk is calculated using lumbar resultant force (F_r) and moment y (M_y).

$$k = \frac{F_r}{5824} + \frac{M_y}{1155}$$

$$L_{ic} = \frac{1}{2} + \frac{1}{2} * \operatorname{erf}\left(\frac{\ln(k) - 0.0578}{0.32148\sqrt{2}}\right)$$

(2) Enhanced Injury Assessment Reference Values (e-IARVs) established by the US Army's Occupant Centric Platform Technology-Enabled Capability Demonstration (OCP TECD) program⁴. Peak platform accelerations were selected to generate e-IARV% results within the OCP TECD e-IARV categories. Graphical comparisons of e-IARV versus peak platform acceleration were generated for each cushion configuration.

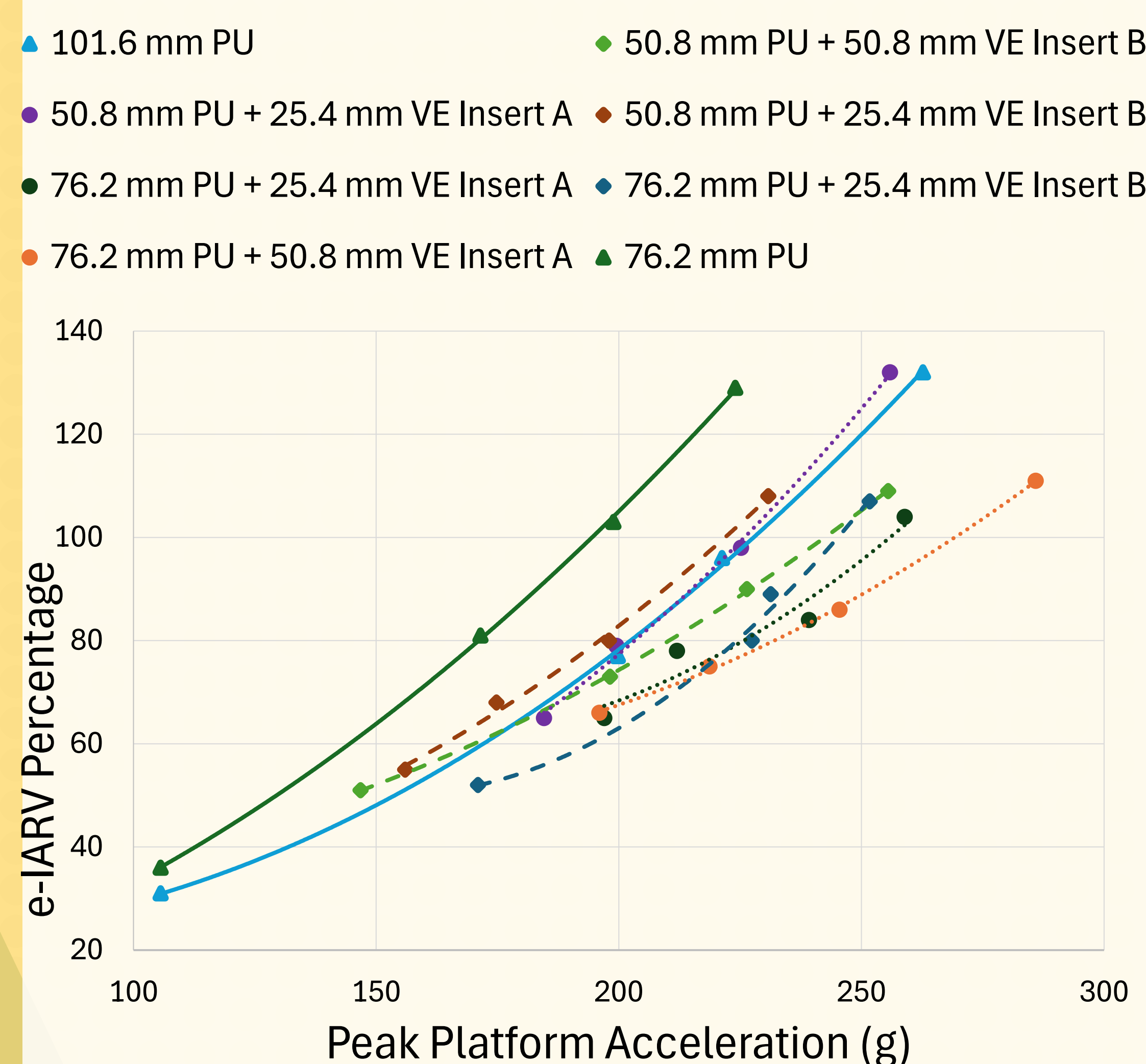
Table 1: e-IARV Categories

	e-IARV Percentage
Good	Less than 75%
Acceptable	75% to 99%
Not Acceptable	≥ 100 %

Results

A regression analysis was completed for e-IARV vs L_{ic} resulting in a r-squared value of 95.83% meaning the two injury assessments are well correlated. e-IARV percentages and L_{ic} were graphed against peak platform acceleration for a visual representation of the impact of the VE foam.

Figure 2: e-IARV Percentage vs Peak Platform Acceleration



A general linear model was created using L_{ic} vs peak platform acceleration using Minitab.

Results (Con.)

Using 101.6 mm PU as the baseline, four of the seven cushion types were significantly different ($p < .001$). Three of the four had coefficient values corresponding to better performance compared to the baseline (negative Coef).

Table 2: Coefficients L_{ic}

Cushion Type	Coef	P-Value
50.8 mm PU + 25.4 mm VE Insert A	0.03	0.26
50.8 mm PU + 25.4 mm VE Insert B	0.03	0.34
50.8 mm PU + 50.8 mm VE Insert B	-0.04	0.18
76.2 mm PU	0.26	0.00
76.2 mm PU + 25.4 mm VE Insert A	-0.12	0.00
76.2 mm PU + 25.4 mm VE Insert B	-0.11	0.00
76.2 mm PU + 50.8 mm VE Insert A	-0.16	0.00

The model was repeated for e-IARV vs peak platform acceleration and produced similar results.

Limitations / Future Work

It is important to note that L_{ic} was developed using the Post Mortem Human Subjects (PMHS) biomechanical response. Evaluating the data using L_{ic} may not be appropriate. It is also to be noted that these results are for the 50th percentile male. Future work includes testing the 5th female and 95th male.

Conclusion

Underbody Blast simulations were completed using a rigid seat on a SSDT and instrumented 50th percentile Hybrid III male ATD seated on PU and/or viscoelastic foam. The resulting lumbar response data corresponded to e-IARV percentage and L_{ic} methodologies. While both metrics were created using different data methods, the results remain consistent across both. The four PU/VE thickness combinations outperformed the PU foam only counterpart confirming that VE foam is a viable EA cushioning solution. This methodology can be used to determine the appropriate combination of EA and VE foam thickness for protection against UBB events.

References

¹Cheng et al. 2010, ²Capouellez et al. 2015, ³Ortiz-Paperoni et al. 2020, ⁴Wodzinski et al. 2017

Acknowledgements

•US Army DEVCOM Ground Vehicle Systems Center, Occupant Protection Team and Lab
•Wayne State University, Biomedical Engineering Department