15547

Energy Absorber for Vehicle Occupant Safety and Survivability

David M. Fox
US Army RDECOM-TARDEC
COM: (586) 574-3844
DSN: 786-3844
Email: david.m.fox1@us.army.mil

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
27 MAR 2006	**N/A**	**-**

4. TITLE AND SUBTITLE
Energy Absorber for Vehicle Occupant Safety and Survivability

5a. CONTRACT NUMBER
5b. GRANT NUMBER
5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Fox, David M.

5d. PROJECT NUMBER
5e. TASK NUMBER
5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
USA TACOM 6501 E 11 Mile Road Warren, MI

8. PERFORMING ORGANIZATION REPORT NUMBER
15547

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)
TACOM TARDEC

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**SAR**	**17**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Motivation for vehicle upper interior impact absorber

- Interior surfaces of combat vehicles are generally relatively stiff due to armor
- Tactical vehicle body panels are becoming progressively more stiff as armor protection level increases
- Hard surfaces in vehicle interiors can pose a head injury hazard to occupants during impact events such as collisions and secondary impacts due to blast events
- Turret rings and other interior assemblies offer additional opportunities to reduce head impact severity

Motivation for vehicle upper interior impact absorber

- Soldiers wear helmets but helmets have been designed primarily for ballistic protection
- The amount of space available in helmets for blunt impact protection is significantly less than that available in vehicle interiors
- This increased space for impact attenuation treatments in vehicle interiors offers the opportunity for more effective reduction of impact severity

Motivation for vehicle upper interior impact absorber

- Impacts between the head and the upper interior components - including pillars, side rails, headers, and roofs - of civilian vehicles are the leading cause of head injury for non-ejected occupants killed in crashes
- The US National Highway Transportation Safety Administration (NHTSA) updated Federal Motor Vehicle Safety Standard (FMVSS) No. 201 to address this issue by requiring that civilian vehicles pass tests that involve the 15 mph impact between a 50^{th} percentile Hybrid III anthropometric test device head and various target locations in the vehicle upper interior
- The TACOM Tactical Vehicle Occupant Crash Protection Handbook, based on US Army Safety Center data for light tactical vehicle crash data from 1985-1997, stated that head injuries were the most frequent severe injuries in all mishap categories and suggested that the majority of these injuries resulted from head contact with interior vehicle surfaces.

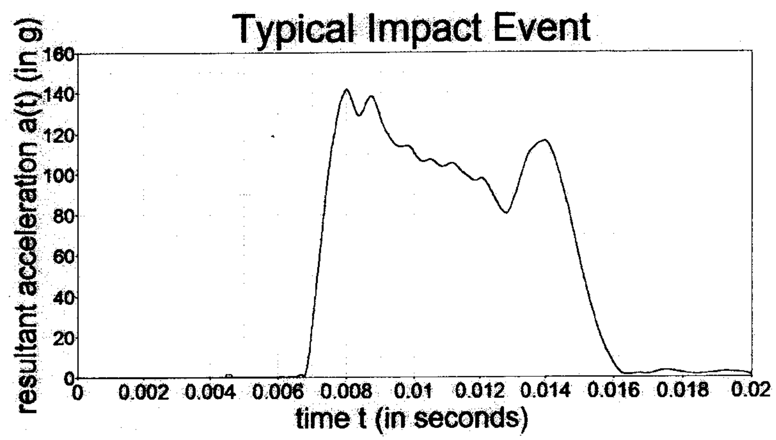
Simulation methodology

- The LS-Dyna explicit finite element solver was used to simulate impact events
- Component level impact evaluations were simulated using 15 mph initial velocity
- The impacting body was a validated finite element model of a free motion headform supplied by First Technology Safety Systems
- The free motion headform is a modified head of a 50th percentile Hybrid 3 anthropometric test device instrumented with a tri-axial accelerometer.
- The simulations were performed in order to develop impact absorbers that will, when mounted on various vehicle upper interior surfaces, enable reduced head impact severity per to the objectives and methodology of Federal Motor Vehicle Safety Standard 201U

Head Injury Criterion (HIC)

$$HIC = \max_{t_1, t_2} \left\{ \left[\frac{\int_{t_1}^{t_2} a(\tau)\, d\tau}{(t_2 - t_1)} \right]^{2.5} (t_2 - t_1) \right\}$$

$$HIC(d) = 0.75446(HIC) + 166.4$$



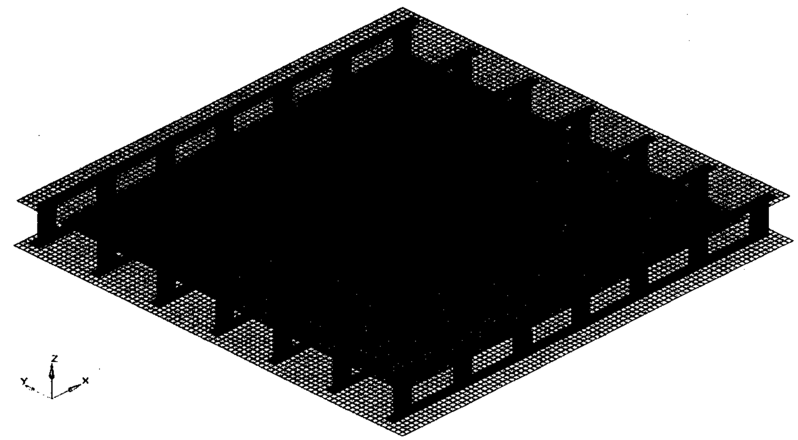
- HIC is used to estimate the severity of head impact events
- HIC(d) is a correlation between free motion headform HIC and HIC for a full 50th percentile dummy
- In the expression for HIC, a(t) is defined as the resultant acceleration as a function of time, t_1 and t_2 are any two points in time during the impact separated by not more than 36 milliseconds.
- Lower HIC is better, FMVSS 201U requires that HIC(d) be less than 1000

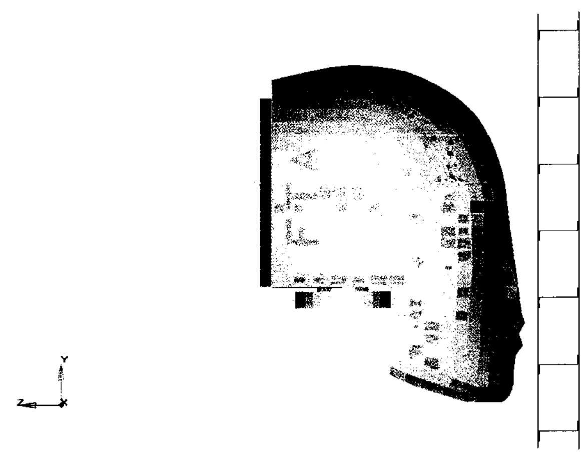
Results

- Achieved improvement in simulated head impact results via application of metal fin energy absorber
- Used appropriate levels of absorber fin spacing, package space (stopping distance), and fin thickness to significantly reduce vehicle upper interior rigid side body panel impact severity
- Investigated effect of conformation / impact angle on impact attenuation performance, achieved improved performance and robustness to conformation / angle by means of a modification to absorber fin geometry
- Reduced up-armored tactical vehicle front header impact severity by application of a metal fin absorber

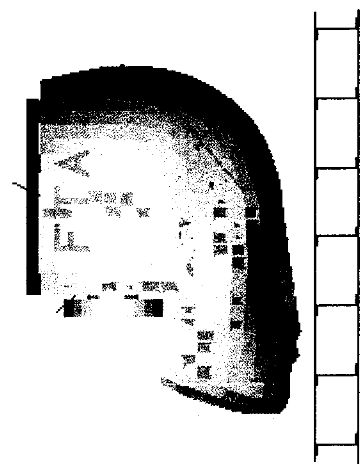
Rigid side body panel impact absorption using metal fin absorber

- A matrix of metal fins sandwiched between body panels and a metal cover transforms kinetic energy of impact to internal strain energy via plastic deformation of cover and fins
- Performance can be tuned and optimized by variation of fin spacing, crush distance, metal thickness, and metal mechanical properties
- Mechanical properties of metal do not vary significantly over the range of operating temperatures; device performance will be the same at all relevant temperatures





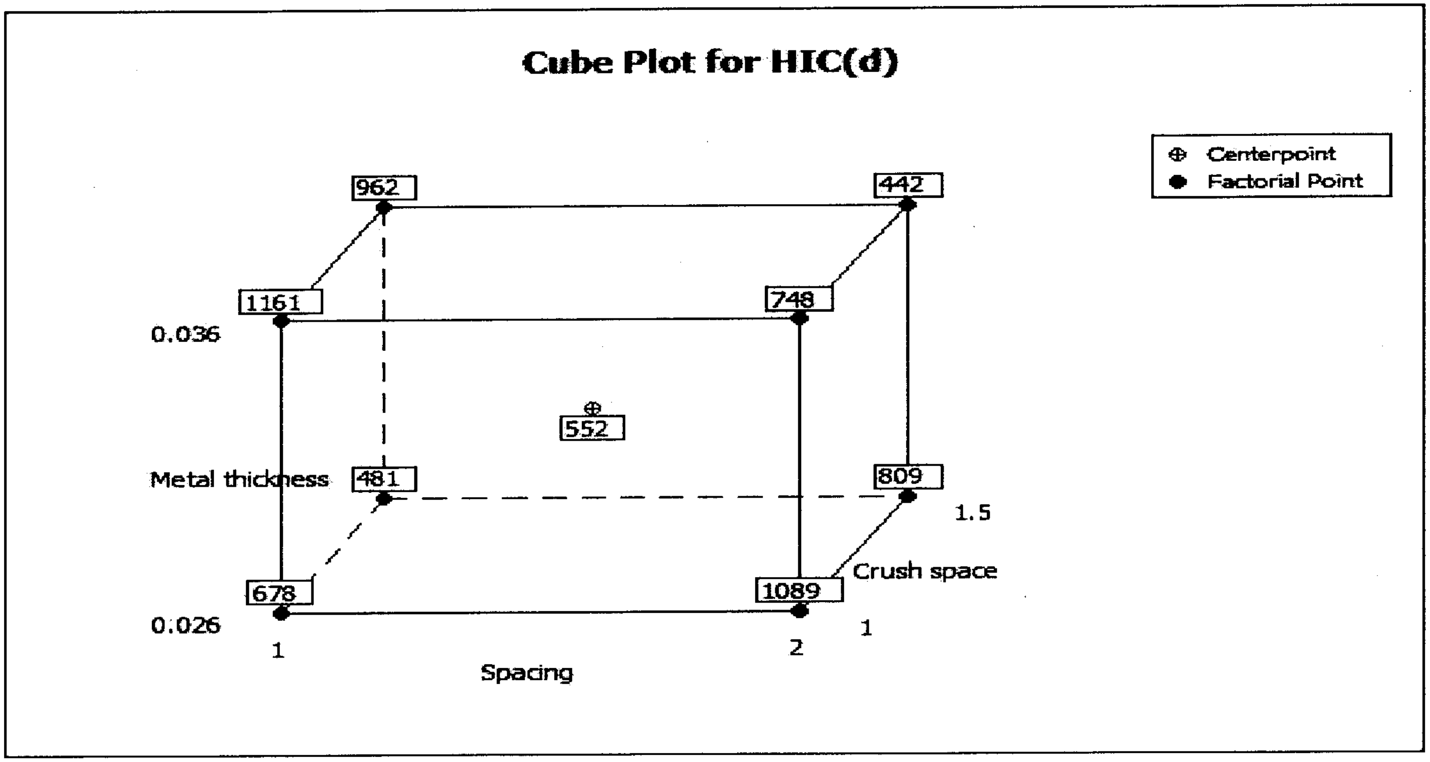
Rigid side body panel absorber



Initial factorial design investigation for side panel

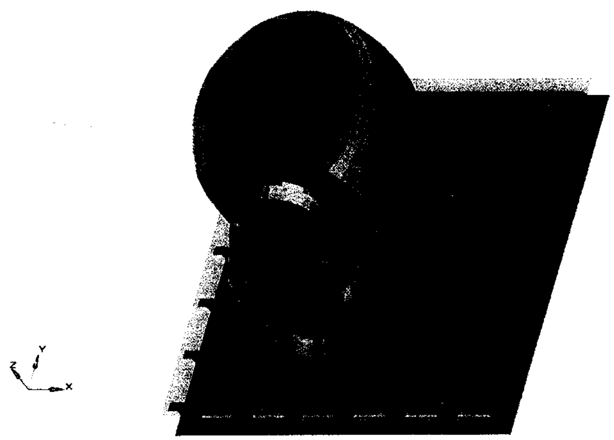
- Varied fin / cover thickness between 0.026”-0.36”
- Varied fin spacing between 1.0” and 2.0”
- Varied crush space between 1.0” and 1.5”
- Fin and cover material was mild steel
- Used 2^3 full factorial with a center point
- Objective: determine whether absorber geometry would perform acceptably given a reasonable amount of crush space

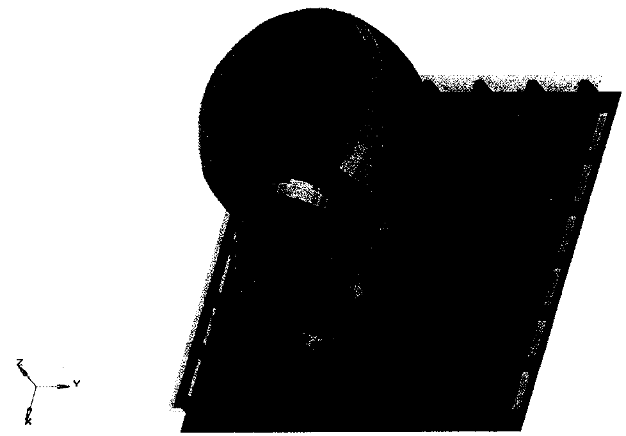
Results of initial factorial design investigation for side panel



Conclusion: Reasonable levels of HIC(d) can likely be achieved by the absorber with reasonable levels of crush space, for example, 678 HIC(d) with 1″ of crush space

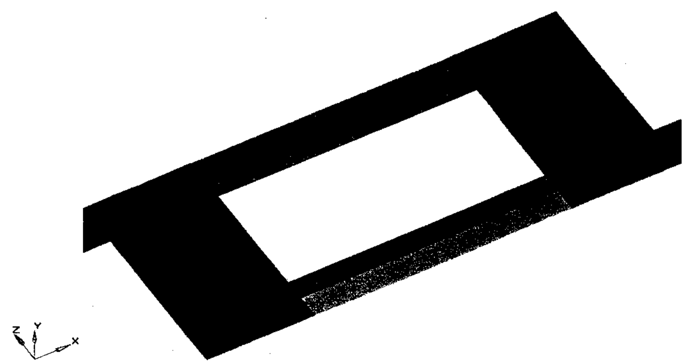
Effect of 90° rotation on impact results

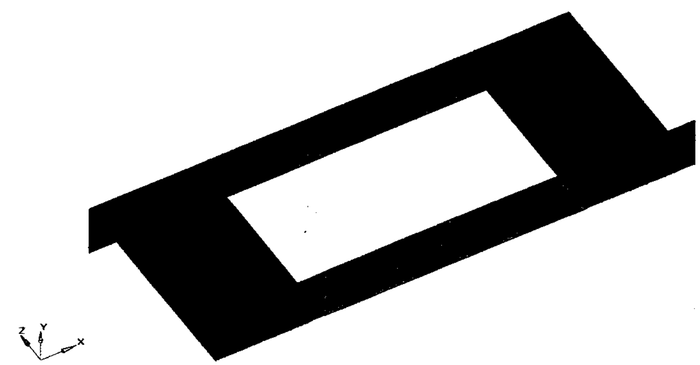




- The effect of fin conformation on HIC(d) was evaluated for an absorber with 0.026” fin/cover thickness, 1.2” fin spacing, and 1” of crush space
- When the fin orientation was rotated by 90°, HIC(d) increased from 669 (for the case on the left), to 767 (for the case on the right)

Effect of modified fin geometry





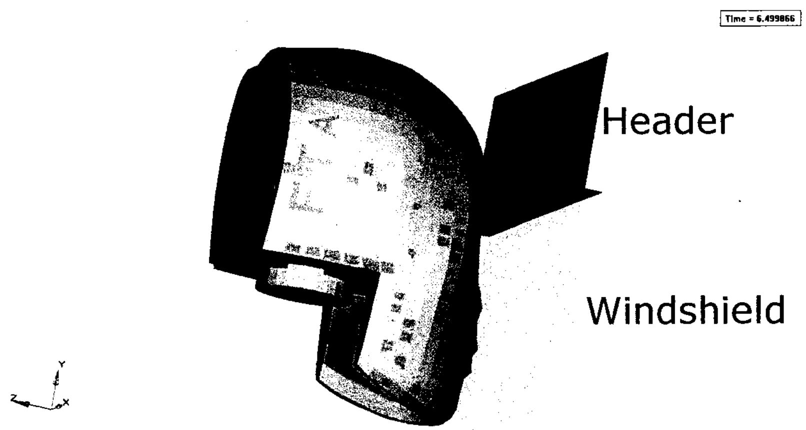
- Several modifications were made in attempts to reduce response variation when conformation varied by 90°
- Removal of cross-tie on top and bottom web (tan structures) between fins (blue structures) resulted in a reduction of mean and maximum HIC(d)
- The modification also reduced the dispersion of HIC(d) results between the 0° and 90° fin conformations
- For the case cited in the previous slide, simulations using original geometry produced HIC(d) of 669 and 767 for 0° and 90° conformations, respectively; simulations with the improved fin geometry produced HIC(d) of 658 and 662, respectively

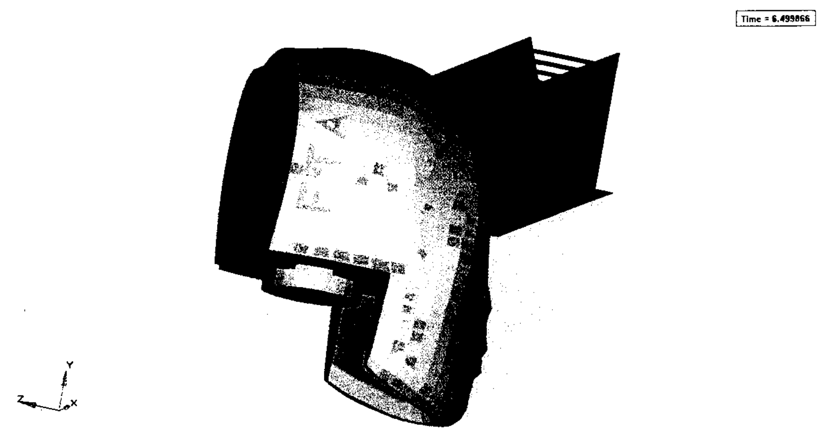
Effect of modified fin geometry

Geometry	Original	New	New
Conformation	0°	0°	90°
Mean HIC(d)	742	656	654
Min HIC(d)	669	607	630
Max HIC(d)	895	733	684
HIC(d) range	226	126	54

- A 9 run, 2 level, 3 factor designed experiment with one center point was conducted on the original geometry and the original fin conformation to investigate the effect of varying fin spacing, cover sheet thickness, and fin/web thickness
- When the experiment was repeated with the new geometry – at both the 0° and 90° conformations – the new geometry exhibited a reduction in mean HIC(d) and an apparent improvement in HIC(d) robustness relative to variation of geometry parameters

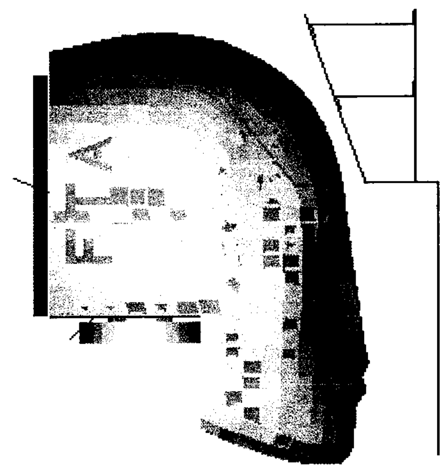
Reduction of severity of front header/windshield impact





- Impact simulations were performed on a rigid up-armored tactical vehicle header/windshield system
- Baseline HIC(d) was in excess of 7000,
- Several metal fin absorber designs for the windshield header were simulated
- One design reduced impact severity to about 860 - an acceptable level – by means of metal fin absorber affixed to the front header
- The crush space at the bottom of this absorber (intrusion into passenger compartment) was a little bit less than 1"; at the top, a little bit less than 2.25"
- There is opportunity for further optimization of this design

Front header / windshield absorber



Conclusions and recommendations

- Simulation results for rigid upper interior panels and front headers with metal fin absorbers suggest it is possible to provide significant soldier head impact protection for rigid body panels using relatively minimal amounts of vehicle interior package space
- Component and vehicle level physical tests of prototypes would provide a suitable means for validation of the finite element models
- Correlated finite element models could be used to develop and optimize designs for various locations in various vehicles
- Application of energy absorbers to vehicle rigid interior surfaces would save soldiers' lives during impact events that result from vehicle collisions, from vehicle rollovers, and from secondary impacts due to blasts