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Vehicle Roof Inflatable Impact Bladder (VRIIB)

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ABSTRACT

In order to reduce the frequency and severity of warfighter head, neck, and spine injuries associated with military vehicle underbody IED and AVL blasts, crash, and rollover, Hy-Tek Manufacturing Co. Inc. (HMC) has designed, fabricated, tested, and optimized its Vehicle Roof Inflatable Impact Bladder (VRIIB)**.** *Comprised of two (2) thin and impermeable airbags separated by semi-rigid force distribution plates; the VRIIB is designed to be mounted on the interior roof panel of military combat vehicles in a deflated state. During IED or AVL detonation, the VRIIB inflates by means of a COTS airbag inflator to provide a significant reduction in the rate at which a warfighter's head or neck decelerates against the rigid vehicle roof panel. The VRIIB is designed to remain inflated and functional for a protracted period of time after its initial actuation in order to protect vehicle mounted warfighters from follow-on blast related roof impacts, subsequent vehicle rollover and/or vehicle roof impacts against the ground or other structures. The stowed (uninflated) VRIIB has a thickness of only 1.0-inch and is designed to deploy by means of well-established commercial airbag collision sensor and inflator technology. When fully inflated, the VRIIB has a thickness of ~3.5-inches. The thin profile of the inflated VRIIB, along with its moderate gas inflation pressure, makes it an efficient and flexible platform for integration onto the interior surfaces of any military vehicle, especially those having an already limited space claim.*

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1. INTRODUCTION

At present, the exploitation of improvised explosive devices (IEDs) and anti-vehicle landmines (AVLs) against vehicle mounted warfighters remains a grave concern for all branches of the U.S. Military. Since the beginning of U.S. Military involvement in Iraq and Afghanistan, the use of IEDs and AVLs by enemy combatants has continued to proliferate. This proliferation is due in large part to the inexpensive and easily obtainable starting materials needed to construct IEDs and AVLs. Enemy combatants can easily multiply the lethality in an already asymmetric combat environment by utilizing caches of rocket propelled grenades (RPGs), landmines, explosive projectile warheads, and plastic explosives in combination with simple and easily fabricated pressure, trip wire, or radio frequency (RF) fuzes. When detonated, IEDs and AVLs produce a large blast pressure wave, explosively formed projectiles (EFPs), and shrapnel that can tear through the hull of combat vehicles and severely injure

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or kill vehicle mounted warfighters.

Mitigating the lethality of EFPs and shrapnel has commonly been achieved through the deployment of advanced vehicle armor that is impenetrable by these EFPs. Protecting vehicle mounted warfighters from the deadly effects of rapid acceleration/deceleration impacts caused by the expanding pressure waves produced during IED and AVL detonation is, however, another matter. When detonated alongside or beneath the hull of a military vehicle an IED or AVL produced pressure wave rapidly accelerates both the vehicle and its occupants in a vertical or oblique upward direction. The magnitude of this acceleration is so large, and occurs over such short time duration (10–30 milliseconds) that vehicle occupants can experience acceleration forces exceeding 500 G's. This value was validated by means of LS Dyna FEA simulations in which a 95th percent male HIII dummy was decelerated from ~7.0 m/s to 0.0 m/s over a 10 millisecond time interval. Under these conditions vehicle mounted warfighters often suffer acute acceleration injuries to the legs, hips, and spine as well as deceleration injuries to the head, neck and shoulders as they impact the roof panel and other interior surfaces of the vehicle. Most often, these deceleration injuries result in acute head injury, neck injury, spine injury, and sometimes death. When the upward velocity of the vehicle reaches zero, gravity then accelerates it back to the ground producing additional impact injury threats to the vehicle occupants. Under conditions where the IED or AVL blast causes the vehicle to pitch and roll, vehicle occupant's heads and necks can be subjected to repetitive high velocity and injurious impacts against the vehicle roof, doors, and side panels before the vehicle finally comes to rest [1,2,3,4,5].

To mitigate frequency and severity of warfighter head, neck, and spine injuries associated with military vehicle underbody IED and AVL blasts, crash, and rollover, the U.S. Army funded Hy-Tek Manufacturing Co. Inc. (HMC) under Phase I and Phase II SBIR contracts to design, fabricate, test, and optimize its Vehicle Roof Inflatable Impact Bladder (VRIIB) design concept.

2. VRIIB DESIGN CONCEPT

The VRIIB was conceived by HMC to provide combat vehicle mounted warfighters with reliable, repeatable, and cost-effective protection against high acceleration impact injuries caused by IED and AVL detonation beneath the vehicle hull. The physics that describe high velocity bodily impacts on rigid vehicle structures such as the metal roof structure, doors and metal support beams, also defines that acute or fatal injuries are generally the result of rapid deceleration of the human body on those structures, which are without a doubt more rigid than the human body. HMC's VRIIB design concept is based upon the well-understood principle that reducing the severity of deceleration-related impact injuries requires a solution that reduces the rate at which the human body decelerates against those rigid interior vehicle surfaces. This of course is the same principle upon which the design of modern passenger vehicle air bags is based. Because passenger and commercial vehicle airbag systems typically reduce the rate of bodily deceleration over a stroke of 12 inches or more, these devices are not feasible for use within the limited space claim that exists between the helmeted head of the vehicle mounted warfighter and vehicle roof surface. VRIIB was therefore designed with two (2) low profile and pneumatically coupled airbags separated by impact force distribution plates that facilitate a prolonged rate of head and neck deceleration within the short gap between the warfighter's helmet and vehicle roof impact surface. While traditional vehicle airbags are intentionally designed to completely deflate during an impact event, VRIIB has been designed to remain inflated throughout an IED/AVL detonation event. The rationale behind this VRIIB design choice includes:

- There is insufficient space to utilize a traditional deflating vehicle airbag between the interior roof panel of a military vehicle and a vehicle occupant's head.
- Prolonged VRIIB inflation facilitates head and neck impact protection during subsequent vehicle impacts, collisions, or rollover events that may follow the initial IED/AVL detonation event.

3. VRIIB DESIGN DESCRIPTION

HMC's incrementally optimized VRIIB assembly is comprised of two (2) thin and impermeable airbags that are pneumatically coupled and inflated to a gas pressure of between 0.2 and 0.5 psi. The two adjacently layered and thin profile airbags are separated by a semi-rigid impact force distribution plate and are fitted with a second semi-rigid head impact plate that is mounted to the bottom surface (head impact surface) of the airbag assembly. A third rigid plate is fitted to the top side of the airbag assembly and used to mount the VRIIB to the vehicle interior roof. The engineered structure of the VRIIB airbags and semi-rigid force distribution plates serve to optimize VRIIB airbag pressurization and deformation when impacted by the head, shoulders, or neck of a vehicle mounted warfighter during IED or AVL detonation events. The engineered deformation of the gas inflated VRIIB assembly facilitates significant reduction in the rate at which the head and neck decelerates against the vehicle roof panel on which the VRIIB is mounted. The VRIIB airbags, impact force distribution plates, mounting plate, and all other pneumatic valves and accouterments are packaged within a low-profile collapsible containment case fabricated of high strength polymer fiber. When installed on the surface of a military vehicle roof, the stowed (uninflated) VRIIB assembly has a thickness of only approximately 1.0-inch. When inflated during an IED/AVL detonation, vehicle collision, or other impact event the VRIIB has a thickness of ~3.5-inches. The thin profile of the inflated VRIIB, along with its moderate gas inflation pressure, makes it an efficient and flexible platform for integration onto the interior surfaces of any military vehicle; especially those having an already limited space claim for the installation of critical head and body impact mitigation technology. Importantly, the VRIIB is designed to remain inflated and functional for a protracted period of time after its initial actuation in order to protect vehicle mounted warfighters from follow-on blast related roof impacts, subsequent vehicle rollover and/or vehicle roof impacts against the ground or other structures. Currently, HMC is continuing to mature VRIIB technology for rapid and logistically simple integration into a wide range of military ground vehicles including among others:

- Joint Light Tactical (JLT) Vehicles
- HMMWV (High Mobility Multi-purpose Wheeled Vehicle)
- AMPV (Armored Multiple Purpose Vehicle)
- Abrams
- Bradley Fighting Vehicle
- Stryker Vehicle
- HTV (Heavy Transport Vehicle)

4. VRIIB MODELING AND SIMULATION

HMC's approach for validating the efficacy of the VRIIB concept included evaluating the performance of the VRIIB concept using LS Dyna R10.0 Finite Element Analysis (FEA) impact simulations. HMC's advanced fidelity LS Dyna VRIIB FEA impact simulation model was comprised of a FAST Hybrid III 95th male body form (95th Male = 6'2" @ 223 lbs.) fitted with a detailed model of the Advanced Combat Helmet (ACH). This LS Dyna model included a facsimile of a 4536 kg (10,000 lb.) rigid vehicle hull, vehicle roof, vehicle seat and a 4-point seat belt restraint. The inflatable VRIIB model was fixed to the Upper Roof (UR) impact target of the vehicle roof just above the HIII 95th male body form. Each component of HMC's LS Dyna model was specifically designed to satisfy the testing procedures and requirements of FMVSS No. 201U [1]. In particular, HMC relied upon Option S6.2 (a) in FMVSS 201U which specifies: "Each vehicle when tested shall comply with specified performance requirements at all target locations when impacted by the Free Motion Head Form (FMH) at any speed up to and including 24 km/h (6.67 m/s or 15 mph)" [1]. Importantly, HMC applied the Compliance Test Execution standards in Section 12.0 of FMVSS 201U that delineates the Upper Roof (UR) target location as bounded by the Planes E, F, G, and H in Figure 12.4.2 of that FMVSS No. 201U document [1]. During these LS Dyna based VRIIB impact simulations, HMC collected head form acceleration (G's) vs. impact event time t (sec) data that was used to calculate Head Injury Criteria (HIC) values by means of the following equations that can both be found in Section 2.0 of FMVSS 201U [1].

$$HIC(d) = 0.75446 \bullet HIC36+166.41) \qquad (1)$$

Where the Free Motion Head Form HIC value is calculated in accordance with the following formula:

$$HIC = \left\{ \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)dt \right]^{2.5} (t_2 - t_1) \right\}_{max} \qquad (2)$$

The HIC(d) value of equation (1) is the weighted standardized maximum integral value of the head acceleration and is calculated using the HIC value computed in equation (2).

LS Dyna software includes an internal mathematical algorithm that calculates and returns *HIC* and *HIC(d)* values using equations (1) and (2) based upon recorded impact event head acceleration (G's) versus event time t (sec) data. That LS Dyna model is shown below in Figure 1.

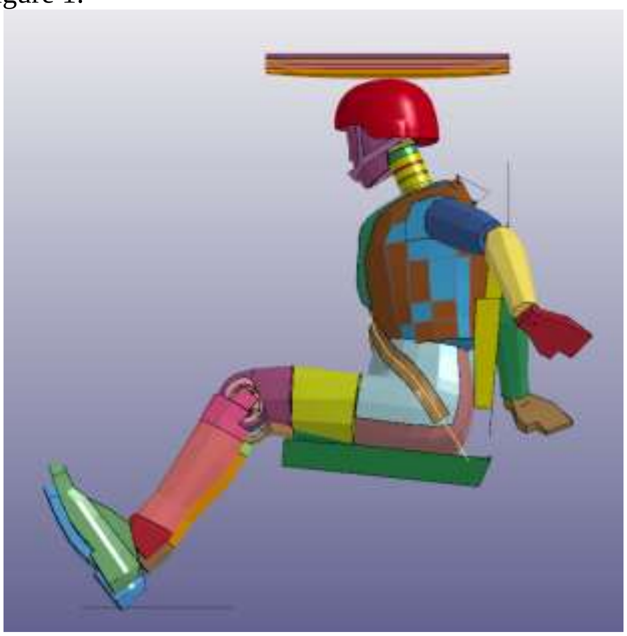

Figure 1: LS Dyna Impact Simulation Model of Fixed VRIIB and Seated Hybrid III 95th Male

HMC's LS Dyna FEA impact simulations focused only on helmeted head form impacts on VRIIB prototype models fitted to the UR target location specified in FMVSS 201U and included gravitational forces exerted on model component masses as well as applied stress and strain effects associated with a vertical acceleration impulse sufficient to generate a minimum 6.67 m/s impact velocity. HMC applied numerous investigational boundary conditions to those LS Dyna VRIIB models including those involving a wide range impact weights, impact velocities, oblique angle head form impacts, and bladder inflation pressures (0.2 to 5.0 psi) among others. Using the head acceleration (G's) versus event time (sec) data and calculated HIC(d) values obtained from numerous VRIIB FEA impact simulations, HMC performed incremental design optimizations intended to improve VRIIB geometry, materials of fabrication, vehicle integration, reliability, and impact mitigation performance.

Through the analysis of numerous LS Dyna simulated HIII dummy head form impact events, HMC facilitated the production of an incrementally optimized VRIIB design that validated two (2) pneumatically coupled VRIIB bladders stacked vertically and separated by semi-rigid force distribution plates are capable of producing HIC(d) of only 250.7 when impacted by the helmeted head form of a seat belt restrained HIII 95th male dummy at a velocity of 6.67 m/s. Figure 2 provided below shows a plot of head acceleration (G's) versus impact event time (s) generated for a 1.75-second LS Dyna FEA impact event in which the helmeted head of the body form shown in Figure 1 impacts an inflated incrementally optimized VRIIB prototype at a velocity of ~6.67 m/s.

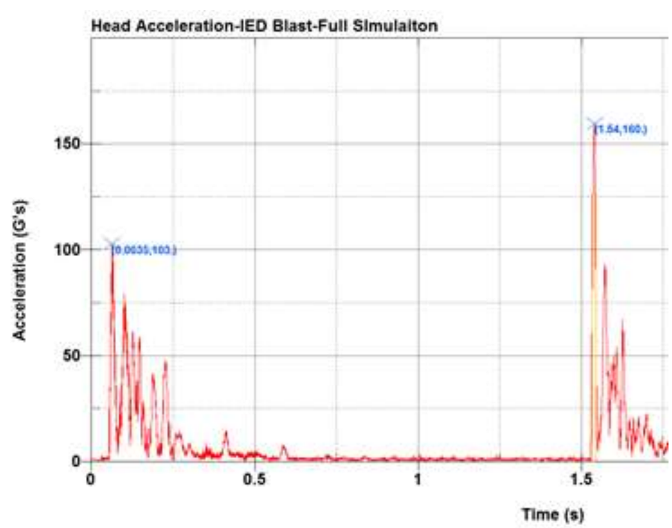

Figure 2: LS Dyna Seated Body Form Impact Simulation Results

As shown in Figure 2, there two distinct sets of head acceleration peaks corresponding to HIII head and body form strain throughout the 1.5-second vertical acceleration event. The first set of peaks represent the period during which the vertical force impulse drives the head sharply toward the chest, followed by head recoil and three separate and distinct head impacts on the inflated VRIIB. During the event period from time t = 0.0 sec to time t = 1.5 sec, the maximum head acceleration is 103 G's. The second set of peaks shown at time t = 1.6 sec to time t = 1.80 sec is the result of the HIII body form suffering whiplash from hitting the seat after it and the vehicle fall from apogee under the force of gravity, strike the ground and begin to bounce vertically upward again. These LS Dyna FEA results validated the efficacy of HMC's 2-bladder VRIIB design concept.

5. VRIIB PROTOTYPE FABRICATION

Figure 3 below shows pneumatically coupled and air impermeable VRIIB bladders fabricated by HMC.

Figure 3: Prototype VRIIB Air Bladders

As illustrated in Figure 3 the two inflatable bladders of VRIIB are positioned atop one another in the horizontal plane. During rapid inflation, the bladders are designed to inflate simultaneously by means of a pneumatic valve. The green and grey valve shown in Figure 3 is 3-D printed inflation valve used only for provisional inflation of the VRIIB bladders during HMC's in-house impact testing and performance evaluation. The VRIIB bladders shown in Figure 3 are assembled together with the two (2) semi-rigid impact force distribution plates; one positioned adjacent and parallel to the bottom most bladder and the second positioned between the two bladders. Along with a vehicle roof mounting plate, this layered assembly is packaged within a collapsible case constructed of a high strength and elastic polymer fabric comprised of 90% nylon and 10% spandex. This fabric readily stretches without tearing to allow the VRIIB assembly to readily expand during inflation and properly deform during head/neck impact events. A photograph of HMC's most current VRIIB prototype is shown below in Figure 4 in its fully inflated (~0.3 psi) state.

Figure 4: VRIIB Prototype (Inflated)

The rigid vehicle roof mounting plate and semi-rigid force distribution plates comprising the VRIIB prototype of Figure 4 are mechanically connected by means of Kevlar threading so as to limit the thickness of the inflated VRIIB to only 3.5 inches at the operational inflation pressure of 0.2-0.3 psi. To reduce force impulse transmission between the helmeted head of the vehicle mounted warfighter and inflated VRIIB assembly, the VRIIB case is also covered with a ¼ inch thick foam sheet that compresses to 25% when exposed to 11psi.

6. VRIIB TESTING AND EVALUATION

The VRIIB prototype shown in Figure 4 was subjected to comprehensive impact testing by means of HMC's in-house drop tower, impact testing at the U.S. Army's Occupant Protection Laboratory at Selfridge ANGB, and live-fire blast testing at Ft. Polk, LA. During in-house drop tower impact testing conducted by HMC, the VRIIB prototype shown in Figure 4 was subjected to weighted head form impacts at a range of velocities satisfying Option S6.2 (a) criteria cited in FMVSS No. 201U, namely: "Each vehicle when tested shall comply with specified performance requirements at all target locations when impacted by the Free Motion Head Form (FMH) at any speed up to and including 24 km/h (6.67 m/s)" [1]. Furthermore, HMC's drop tower test apparatus was configured to provide the best possible simulation of Compliance Test Execution standards in

Section 12.0 of FMVSS 201U that delineate the Upper Roof (UR) target location. During its first test regime, the VRIIB was inflated to a pressure of 0.2 psi and impacted by a 32-lbs. head form traveling at velocities ranging from ~4.0m/s (9mph) to ~6.65 m/s (14.9 mph).The purpose of this testing regime was to evaluate the performance of VRIIB when consistently inflated to 0.2 psi and impacted by a weighted head form traveling over a range of possible impact velocities. The 4.0 – 6.7 m/s velocity range was selected because it satisfies the Option S6.2 (a) testing criteria cited above. It is important to note that HMC's in-house drop tower was not capable of generating 6.67 m/s impact velocity because of its limited height above floor level. The maximum impact velocity achieved was 6.65 m/s. The results of seven (7) consecutive impact tests conducted by HMC using the VRIIB prototype in this manner are provided below in Table 1 and Figure 5.

Table 1: In-House Drop Tower Test Results

Trial	Impact Velocity	Peak Accel.	HIC	HIC(d)
#	(m/s)	(g)	-	
1	3.97	30.5	46	201
2	4.60	41.0	81	228
3	5.12	43.6	115	253
4	5.63	58.7	166	292
5	6.10	73.0	215	329
6	6.42	138.7	377	451
7	6.65	94.3	296	390

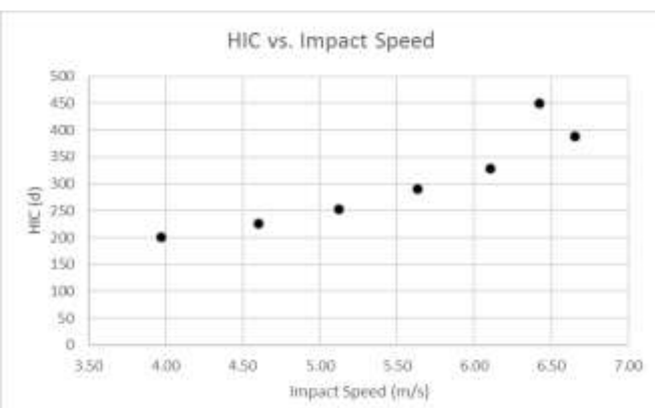

Figure 5: VRIIB Testing HIC(d) Results

As Table 1 and Figure 5 impact testing results illustrate however, at an impact velocity of 3.97m/s (~9mph) VRIIB limited peak head form acceleration and HIC(d) values of 30.5g and 201 respectively. As HMC incrementally increased the height of the drop test and consequently the impact velocity, the peak head acceleration and HIC values increased proportionally. As shown in Table 1 and Figure 5, drop test no. 6, performed at a head form impact velocity of 6.42 m/s, produced peak head acceleration and HIC(d) values of 138.7G's and 451 respectively. During impact test no. 7, performed at a head form impact velocity 6.65 m/s, peak head acceleration was recorded at 94.3G's and HIC(d) reached a maximum value of 390. HMC believes this unexpected reduction in G's and HIC(d) may have been caused by an initial VRIIB bladder pressure of slightly greater than 0.2 psi. Nonetheless, all seven in-house drop tower tests validated reliable and repeatable VRIIB impact mitigation performance over a large range of impact velocities. A second series of in-house VRIIB drop tests were conducted to evaluate impact mitigation performance over a wide range of head form weight. During this testing the inflated VRIIB was impacted at a maximum velocity of ~6.65 m/s (~14.9 mph) using head form weights ranging from 12.5-lbs to 63.5-lbs in accordance with the best possible simulation of FMVSS No. 201U test procedures. The results of those VRIIB prototype impact tests are provided below in Figure 6 and Figure 7.

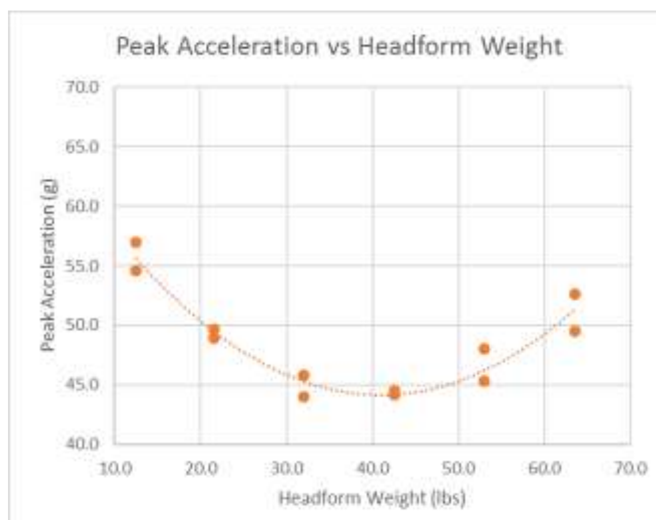

Figure 6: In-House Testing HIC(d) Results

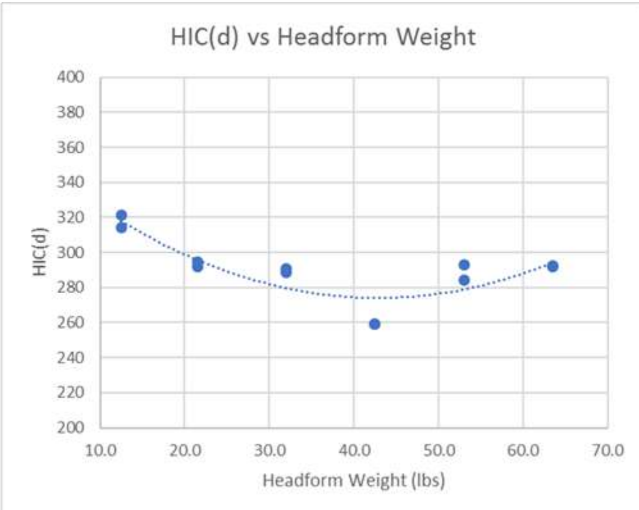

Figure 7: In-House Testing Peak Acceleration Results

As Figures 6 and 7 illustrate, VRIIB returned peak acceleration of less than 60 G's and peak HIC(d) of less than 325.0 for each head form weight tested. Importantly, there is only moderate deviation in measured G's and calculated HIC(d) values as a function of head form weight. These results are indicative that VRIIB is capable of facilitating a reduction in the rate of head deceleration across a wide range of impact weight sufficient to satisfy U.S Army performance thresholds.

7. U.S. Army VRIIB Testing and Evaluation

The impact mitigation performance of the VRIIB prototype shown in Figure 4 was also evaluated through impact testing performed at Selfridge ANGB facilities located in Harrison Township, MI and live-fire blast testing performed at Fort Polk, LA by U.S. Army personnel. It is important to note that while HMC's LS Dyna testing was performed using a model of the HIII 95th male head form, U.S. Army testing was conducted using a 50th male head form in accordance with U.S. Department of Transportation National Highway Traffic Safety Administration's laboratory test procedure FMVSS 201U. Figure 8 below shows an inflated VRIIB prototype mounted to Selfridge ANGB test equipment just prior to head form impact.

Figure 8: VRIIB Vertically Mounted to Test Assembly at Selfridge ANGB Occupant Protection Laboratory

A summary of Selfridge ANGB impact test results for each of three (3) VRIIB prototypes evaluated is shown below in Table 2.

Table 2: Summary of FMVSS 201 U Impact Testing Results Conducted at Selfridge ANGB Occupant Protection Laboratory

Impact Velocity (m/s)	Bladder Pressure (psi)	HIC(d)	Peak Accel. (g)
7.58	0.2	427	105
6.86	0.3	332	69.7
6.94	0.5	426	79.9

As Table 2 shows, the head form impact on VRIIB assembly no. 1 produced a peak acceleration of 105G's and a HIC(d) of 427 at a VRIIB bladder inflation pressure of 0.2 psi. Notably, the velocity of the 10-lb head form used during this test was approximately 7.58 m/s. VRIIB assembly no. 2 produced a peak acceleration of 69.7G's and a HIC(d) of 332 at an inflation pressure of 0.3 psi while VRIIB assembly no. 3 returned a peak acceleration value of 79.9 G's and a HIC(d) of 426 at an inflation pressure of 0.5psi. These impact testing results are essentially identical to those recorded during HMC's in-house impact testing of an identical VRIIB prototype.

HMC fabricated six (6) additional VRIIB prototypes for evaluation during live fire testing performed by U.S. Army at Fort Polk, LA. During that testing two identical VRIIB prototypes were installed into the test asset for performance evaluation during each of three (3) individual blast test events. About 24 hours before each test, HMC inflated the VRIIB assemblies using ~25g of argon gas; pressurizing the VRIIB to ~0.25psi. A photograph of the inflated VRIIB, circled in white, after installation on the test asset roof panel is provided below in Figure 9.

Figure 9: VRIIB Installed on Test Asset Roof

A summary of the percentage of the allowable limits of both head acceleration and HIC(d) values collected from the Hybrid III dummy seated in Position 04 (Pos04) beneath VRIIB during each of the three (3) blast tests is shown below in Table 3.

Table 3: Peak Acceleration and HIC Values from Pos04 Hybrid III Dummy

Blast Test No.	HIC(d) (% of Limit)	Acceleration (% of Limit)
1	24.0%	5.6%
2	23.9%	4.3%
3	25.2%	10.6%

As Table 3 illustrates, the Pos04 Hybrid III dummy seated below VRIIB during each of the three live fire blast events returned peak acceleration values of between 4.3% and 10.6% of the maximum allowable limit and HIC(d) values of between 23.9% and 25.2% of the maximum allowable limit.. A summary of the neck force and moment data collected from the Hybrid III dummy in Pos04 are provided below in Tables 4 – 6.

Table 4: Pos 04 Maximum Neck Forces and Moments for Blast Test #1

50th Percentile Male Hybrid III	
Sensor:	**% of Limit**
Shear Force:	11.69%
Compression Force:	4.86%
Tensile Force:	12.38%
Lateral Moment:	6.57%
Flexion Moment:	5.68%
Extension Moment:	11.15%

Table 5: Pos 04 Maximum Neck Forces and Moments for Blast Test #2

50th Percentile Male Hybrid III	
Sensor:	**% of Limit**
Shear Force:	4.68%
Compression Force:	5.04%
Tensile Force:	13.45%
Lateral Moment:	6.34%
Flexion Moment:	8.21%
Extension Moment:	8.20%

Table 6: Pos 04 Maximum Neck Forces and Moments for Blast Test #3

50th Percentile Male Hybrid III	
Sensor:	**% of Limit**
Shear Force:	9.27%
Compression Force:	12.58%
Tensile Force:	33.55%
Lateral Moment:	14.63%
Flexion Moment:	14.00%
Extension Moment:	16.54%

The x and y-direction shear force plots furnished to HMC and represented in the tables above indicated that the maximum shear force on the VRIIB protected Hybrid III dummy during all blasts was approximately 11.7% of the allowable limit for the 50th percentile male Hybrid III. The highest compression force and tensile force recorded during blast testing were 12.58% and 33.55% of their respective allowable limits while the maximum lateral neck moment was 14.63% of the allowable maximum value. The maximum flexion moment value recorded was just 14.00% of the allowable limit, while the maximum extension moment recorded was only 16.54% of the maximum allowable limit. An example of the chalk markings left by helmet shell impact on VRIIB units installed on the test asset roof is shown below in Figure 10.

Figure 10: Chalk Marks on VRIIB Surface After Helmet Shell Impact – Blast Test #3

8. FUTURE VRIIB DEVELOPMENT

HMC's recent success validating the performance of the VRIIB prototype is indicative that significant improvement in the protection of vehicle mounted warfighters can be achieved through follow-on VRIIB design optimization and inflator integration. HMC has already initiated technical discussions with AmSafe Inc. to develop and produce a VRIIB specific inflator system. This partnership will commence during additional VRIIB development and optimization to be performed under a U.S. Army funded Sequential Phase II SBIR contract that has already been awarded to HMC for that purpose. Once matured and subjected to comprehensive testing and evaluation by U.S. Army and others, HMC estimates the cost of deployable VRIIB units for deployment in military vehicles will be comparable to currently available commercial vehicle systems. Traditional airbag systems generally have a replacement cost of between $1000 and $1500 each. HMC estimates that a new 24" x 24" VRIIB airbag assembly will be priced similarly once efficient mass fabrication processes are in place. It should be noted however, that not every VRIIB assembly will need to be replaced after each IED/AVL related deployment. Most VRIIB components, if undamaged, can be immediately converted back into the stowed configuration or refurbished in the field as necessary.

A distinct advantage of the militarized VRIIB system detailed herein is that it requires a small volume of inflation gas for inflation to its optimal working pressure. A 24" x 24" VRIIB unit requires only 25g of N_2 gas for inflation to 0.2-0.3 psi to provide reliable and repeatable impact protection performance. Deployment of compressed gas VRIIB inflators will of course also eliminate the need for dangerous azide based pyrotechnic gas generators often used to inflate commercial vehicle airbags. 25 grams of N_2 gas, for example, can be safely stored within a small pressurized cylinder like that shown below in Figure 11.

Figure 11: 25 Gram N_2 Gas Cylinder for VRIIB Inflation

While additional engineering, testing, optimization, and inflator integration work is required to fully mature VRIIB into a TRL-6 certified product, HMC is confident that certification will stimulate rapid transition of VRIIB technology for use in myriad other military and commercial applications. Promising applications for VRIIB technology include military airdrop operations, helicopter crash protection, law enforcement vehicle impact protection, recreational off-road vehicle impact protection, and protection for occupants of industrial vehicles and heavy construction/earthmoving equipment among others. HMC's and Army's testing of the Phase II VRIIB prototype validated that the device, even in its currently emergent form, is wholly capable of satisfying U.S. Army's vehicle mounted warfighter protection requirements. When fully developed for deployment within military ground vehicles, VRIIB design variants will then be far easier to transition for use in other important military and commercial applications. When fully developed and made available for application transition, VRIIB technology will provide a reliable, repeatable, and cost-effective vehicle passenger safety solution.

9. REFERENCES

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