Griffin 2.0 - Development & Evaluation of an Occupant Protection Platform with Active-Blast Mitigation and Crew Floor Isolation

Matthew Withun
Booz Allen Hamilton
TARDEC
Warren, MI

Patrick Griffin
TARDEC
Warren, MI

ABSTRACT

The Griffin 2.0 is a concept demonstrator that leveraged the structural design-for-blast methodologies, an Active Blast Mitigation System (ABMS), and a decoupled flooring system to demonstrate occupant survivability at large charge sizes. During a six month period, the team directed by TARDEC Ground Systems Survivability designed, fabricated, and evaluated three full scale demonstrators at elevated charge sizes. These tests included a baseline shot without countermeasures and two shots with counter measures, one at 150% MRAP Objective and one at 200% MRAP Objective. All tests were fully instrumented including ATDs and high speed video. The development process, test results, and recommended next steps will be presented.

INTRODUCTION

The original Griffin demonstrator was the result of a Broad Agency Announcement (BAA) between TARDEC and Corvid Technologies, Inc., and approximated the MATV mass, standoff, mobility, and mission capability. The focus of the BAA was to develop an occupant-centric crew cab that significantly improved blast protection over the currently fielded platforms (Kremar, 2015). The original underbody threat target was MRAP Threshold, but about a year into the program the target threat increased to MRAP Objective.

The Griffin 2.0 project picked up this demonstrator after completion of the BAA, and reengineered it to withstand a threat of 150% MRAP Objective via the integration of the Sentinal-X^{tm} Active-Blast Countermeasure System onto the reengineered demonstrator. The TARDEC Ground Systems Survivability (GSS) Exterior Blast Mitigation Team (EBMT) was tasked with leading this project, which was primarily funded by the DARPA Soldier Protection Systems (SPS) 5X+ Program. GSS contracted the Nevada Automotive Testing Center (NATC) to do the fabrication and evaluation activities (per contract W56HZV-13-D-L001-0007), who then sub-contracted Corvid Technologies (the prime contractor for the original Griffin project) to perform their engineering and risk-mitigation.

There were three Griffin 2.0 demonstrators that were ultimately fabricated and evaluated: 2A was a baseline 150% MRAP Objective evaluation *without* ABMS, and 2B was a 150% MRAP Objective evaluation *with* ABMS. Test 2C was an excursion from the original test plan in that the threat size was increased to 200% MRAP Objective, when the original test plan specified a repeat of test 2B. Due to the success of the first two tests, the test plan was revised to overmatch the Griffin structure and the ABMS system. There was a considerably amount of risk with this approach, but the justification included the facts that the necessary data was acquired in the first two tests, and that as a research organization the expectation is to push the technology to the point of failure. Reaching failure allows to understand the boundary conditions for the system and allows greater understanding of those limits.

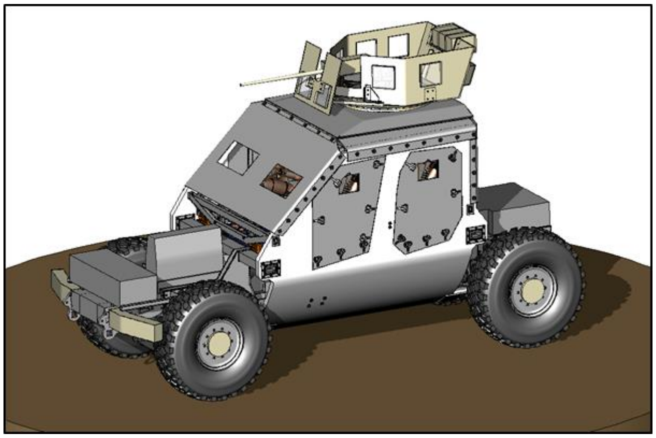

Figure 1 - Griffin Demonstrator

There was a considerable amount of engineering from the original Griffin platform that was leveraged for the Griffin 2.0 demonstrations, but the core survivability technologies that were the focus of these evaluations are as follows: 1) robust blast design methodologies, 2) a decoupled flooring system, 3) energy-absorbing seating, and 4) an active-blast mitigating system. These core technologies will be discussed further in the next sections.

CORE TECHNOLOGIES

The key features of the Griffin demonstrator involve three technologies (floors, seats, ABMS) and one methodology (design for blast). Of these four elements, it must be emphasized that the design methodology and resultant vehicle architecture is by far the most important element of the Griffin demonstrator. Without a robust vehicle design, any technology additions will basically be compensating for the survivability performance that was “left on the table” due to a vehicle architecture that is lacking. The sections below will discuss these core elements of the Griffin demonstrator design beginning with the most important consideration – Design.

Design for Blast

There are several variables that influence the amount of impulse in an underbody event, and they include 1) threat size, 2) threat burial depth, 3) soil composition, 4) vehicle standoff, 5) hull geometry, and 6) vehicle mass. However, only items 4-6 can be influenced in the vehicle design, and the remaining are exogenous variables that are outside of our control. The blast design methodologies need to focus on these variables in order to accomplish survivability improvements.

Designing a robust vehicle structure that minimizes the potential for catastrophic failure modes, while also maximizing the length of the load paths to the occupants, can greatly improve your survivability performance… and you can essentially get this performance for free. The benefits that a vehicle platform can obtain from a well-designed vehicle architecture cannot be stressed enough. There are several considerations that should be made to accommodate underbody blast, most of which were incorporated into the Griffin vehicle architecture.

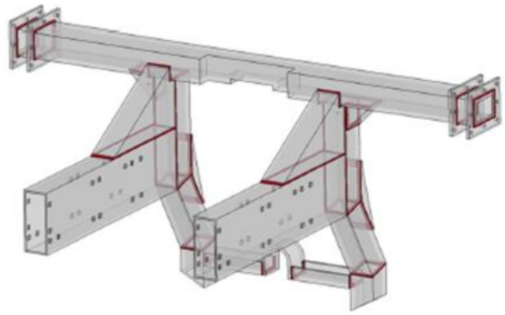

Figure 2 – Griffin Decoupled Floor

First, an effort has to be made to engage as much of the vehicle mass during a blast event as possible, since more mass will result in a lower delta-V. Poorly designed structures will have structural failure during the blast event that will result in large portions of the vehicle mass to decouple from the cab, particularly the front and rear drive-train components. This decoupled mass captures little of the impulse from the threat, which results in a reduced condition for the occupants of the vehicle. Developing robust system interfaces, such as the Griffin front/rear chassis mounts shown in the figure 2, is crucial in engaging as much of the mass as possible.

Another feature of the Griffin architecture is the continuous monocoque hull design that greatly simplifies the vehicle architecture. This type of architecture was also proven on the TARDEC CAMEL demonstrator platform that was able to survive underbody threats up to 200% MRAP Objective (Pratt & Miller Engineering, 2015).

Next a low-deformation hull needs to be utilized that will allow sufficient space for deformation. The creation of inadvertent load paths due to contact between the hull, chassis, drive-train components, and the crew cab will usually result in conditions that cannot be addressed through the addition of survivability technologies. This same space must also be free from components and structure that can create unintended consequences. Torsion bars, suspension components, drive shafts, and other typical components in legacy vehicle architecture all increase the potential for the occupant injuries.

The Griffin hull was comprised of seven 1” plates of class 2 RHA that all overlapped and reinforced each other. Directly above the blast there is a total thickness of 3” of RHA, and there is a 2” total on each side of the demonstrator. The additional thickness on the hull bottom is due to a 1” blast shield that reinforces the blast affected area of the hull.

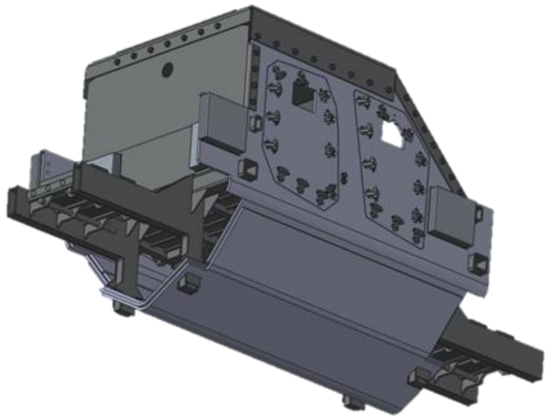

Figure 3 – Griffin Decoupled Floor

Several other important design considerations for underbody blast involves the hull geometry, namely the ground clearance and hull shaping.

The vehicle ground clearance was be influenced by the chassis and suspension design, but should not be driven by those factors using design-for-blast methodologies. Ideally you would want to specify a minimum clearance necessary to meet the survivability objectives and then develop the chassis and suspension to accommodate that criteria.

Hull shaping can have a dramatic influence on underbody blast performance, particularly when the hull/ground angles are in excess of 30°. Hull shaping is particularly important in lighter vehicle platforms as you have more influence over the impulse delivered to those vehicles as opposed to heavy combat platforms where impulse loading may be a secondary concern to excessive deformation and structural failure.

Finally, minimizing the joints, welds, and fasteners, particularly in the blast affected areas, will reduce the potential for failures in the vehicle structure. Where fasteners or joints are needed, they must be designed in such a way that the stresses on them are minimized during an underbody blast event. One of the features of the Griffin that was particularly successful in this regard was the design of the front/rear modules that are shown integrated to the Griffin chassis in figure 3. These components effectively replaced the full chassis that was in the legacy MATV architecture that the Griffin is based on, and they have very simple and robust interfaces with the cab that are designed to withstand the extreme vertical loading that is experienced during and underbody blast event.

Decoupled Flooring System

Blast related injuries to the lower extremities of soldiers has been a difficult issue to address with many of the legacy platforms that are in the field today. The use of blast mats in these vehicles provide considerable improvements, but there are issues with the integration of these mats that often resulted in them being discarded or damaged. Another technology that is beneficial, if utilized, is the use of footrests that isolate the soldier’s feet and legs from the flooring system. The problem with this is that the utilization rate of these footrests is not sufficient to address the problem. The rationale was that there was a secondary issues with comfort and accommodation that caused the Soldiers not to use the footrest. Neither blast mats nor foot rests addressed the problem directly, but instead focused on the symptoms of the issue. The fundamental problem that needed to be addressed is that the floors were directly coupled to the vehicle structure, and often were integral to the structure itself. This resulted in a short robust load-path that transferred a large portion of the blast loads directly into the floor and into the lower extremities of anyone in contact with the floor.

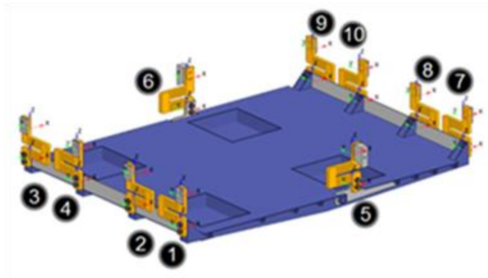

Figure 4 – Griffin Decoupled Floor

To address the fundamental issue, first we needed to decouple the floor from the vehicle structure. This in itself can provide significant benefits to the occupants. The Griffin demonstrator integrated decoupling devices in the form of ten deformable stainless steel brackets (figure 4) that also allowed the flooring system to stroke downward up to 6". There have been studies that show even small stroke floors, with as little as 1" travel, can provide benefits over just the decoupling itself if the vehicle cannot accommodate large stroke floors like the Griffin (Pratt & Miller Engineering, 2015).

One of the features of the flooring systems featured was the integration of blast mats into recessed tubs (figure 4 and 5) in the flooring system. Although blast mats have limited value as a stand-alone solution for lower leg injuries, they do provide benefits as a component in a decoupled flooring system as they mitigate much of the high-frequency energy that floors can experience, as well as providing additional energy absorption above what the floor EA mechanisms provide. Integration of the blast mats into a decoupled flooring system can often be accomplished without affecting the packaging space in the vehicle, as the decoupled flooring systems are typically thick enough to allow for a recessed tub without penalty.

Energy-Absorbing Seating

EA seating has become a standard addition to any ground vehicle platform since the modernization of the MRAP, Stryker, and Bradley platforms. Modern seating systems can accommodate a delta-V input of up to 8m/s without occupant injury, and there are systems under development that have the potential to take that value up to 12m/s. In addition, most modern blast seats also have the ability to reset during the return-to-ground phase of the blast event so that they have the full stroke-available for the slam-down.

The Griffin demonstrator utilized the Jankel BLASTech^{tm} mark 2.5 seating systems in all four occupant locations, which were all instrumented with 50th percentile ATD. This decision was based upon a precedent from the MATV platform, which was the basis for many of the decisions that drove the design and engineering of the Griffin demonstrator.

Figure 5 – Occupant/Seating Configuration

The Jankel seats are floor-mounted, which since the floor system also has an EA mechanism integrated into it, creates a condition where you have two EA mechanisms in series that have been independently develop to improve occupant survivability. Given the success of recent flooring systems in platforms, such as the TARDEC CAMEL demonstrator, it can be expected that future vehicle platforms will have similar systems. The development of flooring systems and seating systems in such an architecture should be combined so that the performance can be optimized. In practice, vehicle platforms that utilize both decoupled flooring systems and energy-absorbing seating should consider these a single-subsystem that should be designed and engineered together instead of developed as individual technologies.

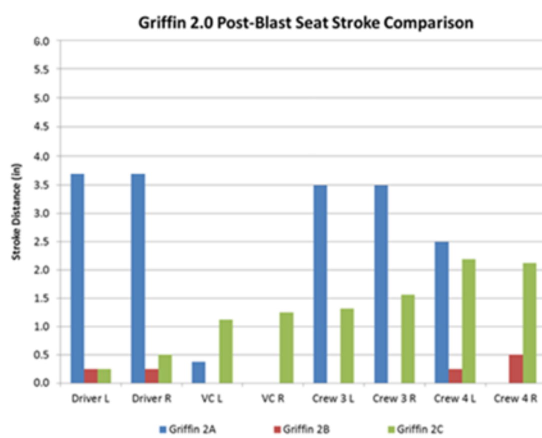

Figure 6 – Seat Stroke

As seen in figure 6, all three of the evaluations fell short of utilizing the full 6” stroke of these seating systems, as evidence by the white space that is visible above the bars. In particular, the combination of the decoupled flooring system and the ABMS system in event 2B (red bars in figure 5) resulted in seating inputs that were barely enough to trigger the seating EA mechanisms. Had the trigger threshold been set to match the expected inputs, as well as altering the EA mechanisms to have a less aggressive performance curve, the survivability data as presented later in the paper could have been improved considerably.

Active-Blast Mitigation System

Isaac Newton's First Law states the following: *An object in motion continues in motion with the same speed and in the same direction unless acted upon by an unbalanced force.* In the case of an underbody blast, the detonation results in a force on the vehicle (via the blast wave and the discharged soil) that imparts upward momentum to the vehicle mass. Once the momentum has transferred from the blast to the vehicle, the only opposing force on the system is gravity. For an MRAP Objective sized shot, the force of gravity would probably result in the vehicle returning to ground after about 1.5 seconds. In this simplified model, the ABMS provides an unbalanced force, as described above, which opposes the force from the underbody blast. The ABMS is effectively a counter-impulse technology.

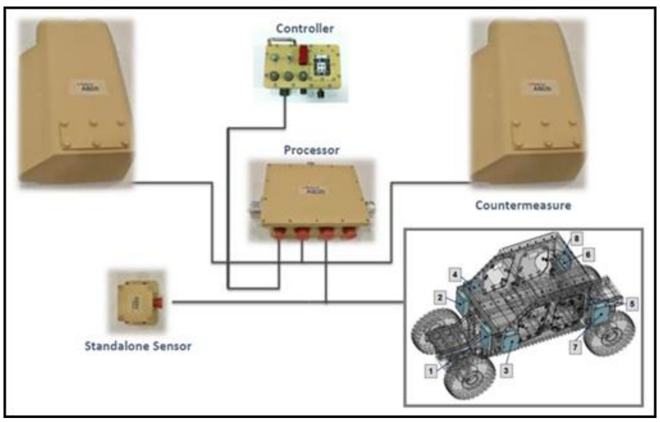

Figure 7 – ABMS Sentinal System Components

A critical component to the ABMS sub-system is the blast-sensing technology. This technology detects an underbody event, differentiates this event from other possible events, and deploys the countermeasures in a sufficient time-frame to reduce the loads that are imparted into the vehicle occupants via the vehicle structure, flooring system, and seating systems. This blast sensing system utilizes accelerometers to detect the event and an algorithm that currently uses two criteria to differentiate a blast event from the other possible events. Note: This blast detection methodology is the product of, and proprietary to, TenCate. The first criteria is an acceleration threshold that arms the system. The second is a velocity threshold that triggers the countermeasures. Acceleration and velocity thresholds must be exceeded in order to activate the countermeasures. Those thresholds were developed to ensure smaller underbody events that would not significantly impact the vertical global momentum of the vehicle, such as hand grenades or anti-personnel mines, did not trigger the ABMS.

Another critical component to the system is the countermeasures. The system integrates its countermeasures on the exterior side walls of a vehicle. Preferably, the countermeasures would be mounted near the most rigid portion of the structure (usually near the A, B, or C pillars if on a tactical wheeled vehicle). The countermeasures are ejectable-mass systems that launch material that is similar to steel bird-shot in order to generate a recoil counter-force that is imparted to the vehicle.

ABMS technology has been tested extensively by the US Army TARDEC. Each component was evaluated to ensure that the trigger timing, counterforce, and autonomous features of the system were effective. Once the components were verified, the technology was integrated on various prototypes and subjected to underbody blast testing. The system has been integrated and tested on vehicles that vary in weight from 18,000 pounds to 90,000 pounds. Structurally, the system has been tested on both aluminum and steel structures in order to analyze the amount of strain the countermeasures imparted. Each test produced similar results involving strain, global vertical lift, and ATD injury risks. Vehicle jump height was effectively reduced by 45-60% from the baseline, where the baseline tests were the same test asset and test parameters without the ABMS active. In the evaluations where ATDs were utilized, crew AIS injuries were reduced anywhere from 75% to 100%. Vehicle deformation was not negatively impacted due to the ABMS integration, as the evaluations showed minimal additional impact to the vehicle structure.

PERFORMANCE

For each Griffin evaluation, there are approximately 360 data channels that were available to use in the post-event analysis. With that being said, provided here are some of the pertinent values and analysis that represent the performance of the Griffin system. The jump height of the demonstrators can be used as an estimate of both ΔV and Impulse per the following:

$$Impulse\ (J) = Mass\ (m)\ x\ Change\ in\ Velocity\ (\Delta V)$$

$$J = m\ x\ \Delta V$$

$$Displacement\ (X) = \int V dt$$

Figure 8: ΔV Reduction in vehicle structure

The jump height is directly related to ΔV, as it is the integral of the global velocity that the Griffin experienced during the evaluations. Since the initial upward velocity of the Griffin was zero ($V_0 = 0$), the ΔV for static blast test is effectively the same as the peak global velocity.

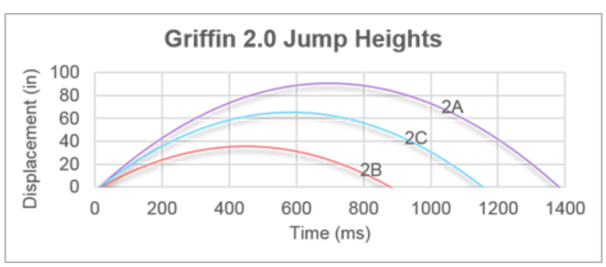

Figure 9 - Griffin jump heights derived from video analysis

The jump heights that were measured via high-speed video cameras for the three Griffin evaluations yielded the results shown in figure 8. The actual jumps heights for the three evaluations were 90 inches, 36 inches, and 65 inches, respectively. The reduction of jump height between events 2A and 2B indicate that event 2B had 60% less impulse than the baseline event, and the only difference between these tests was the integration of the ABMS system.

In addition to high speed video, there were also several hard-mounted and LOFFI-mounted accelerometers that were analyzed to assess performance. Similar to the high-speed video analysis, these accelerometers also show a significant reduction in the impulse of the vehicle (figure 9) which amounts to about an 80% reduction. Although the high-speed video is probably a better indicator of global motion and impulse than the velocity trace, they both indicate that a substantial counter-impulse was delivered to the vehicle system by the ABMS technology.

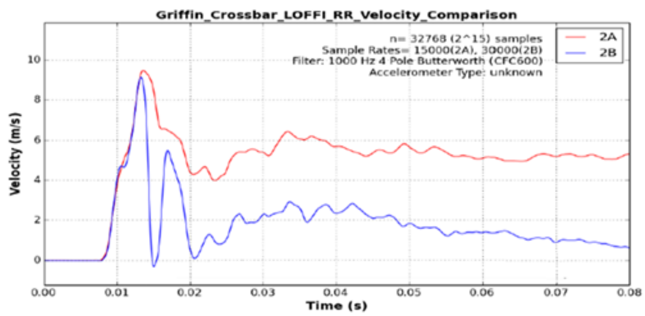

Figure 10 – ΔV Reduction in vehicle structure

Lastly, and most importantly for the evaluations, the specific survivability of these demonstrators were assessed using four 50th percentile ATDs in each of the three evaluations. Each ATD has over 80 channels of data that are used to assess survivability performance, but there are a few key channels that we tend to focus on as generic performance indicators and they are lower tibia axial compressive forces (TAC), pelvic vertical acceleration (PVA), and lumbar spine axial compression (LSAC) forces. Comparison of event 2B to the baseline (2A) yields the following percentage improvements:

- Driver TAC – 43%,
- Driver PVA – 42%
- Driver LSAC – 12%
- Cmdr TAC – 37%
- Cmdr PVA – 56%
- Cmdr LSAC – 26%
- Crew3 TAC – 32%
- Crew3 PVA – 23%
- Crew3 LSAC – 36%
- Crew4 TAC – 46%
- Crew4 PVA – 40%
- Crew4 LSAC – 15%

Comparison of event 2C (200% MRAP Objective ABMS) to either the baseline or event 2B would not yield much insight as the threat size did not remain constant between them. For that reason, comparative values for event 2C are not summarized here.

In addition to the comparison between events, the stand-alone survivability of all three Griffin evaluations resulted in 100% of the ATD data channels remaining below injury threshold values, as shown in figure 10. The table on the left shows the upper body data and the table on the right shows the corresponding lower body data. The three color coded columns are events 2A, 2B, and 2C respectively. This graphic shows that there are no red cells which would indicate an occupant injury.

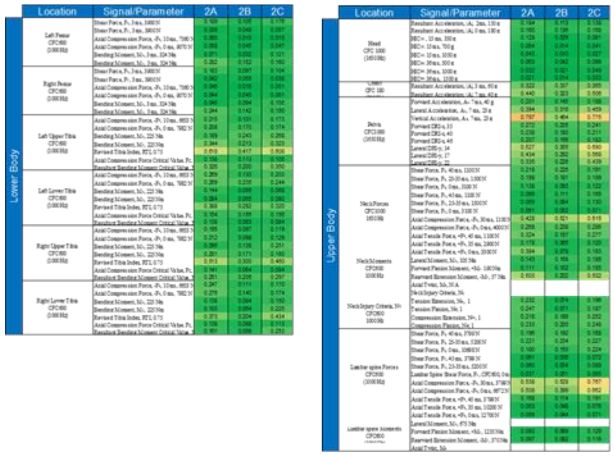

Figure 11 – ATD Summary of 2A, 2B, and 2C Tests

A full summary of the ATD results is included in the GVSS briefing that will be presented at this year's conference.

SUMMARY

Three Griffin 2.0 demonstrators were fabricated and evaluated: a baseline 150% MRAP Objective evaluation without ABMS, a 150% MRAP Objective evaluation with ABMS, and an excursion from the original test plan with an increase in threat size to 200% MRAP Objective. The intent of these evaluations was to quantify the occupant survivability enhancements during a blast event with an ABMS and decoupled floor technology integration. Overall, the ABMS and decoupled floor technology integration reduced the amount of global impulse delivered to the vehicle from the blast. Between the two 150% MRAP Objective threat evaluations, the reduction in global impulse significantly mitigated occupant injury numbers. As for the test utilizing the 200% MRAP Objective threat, the occupant injury numbers were similar to the baseline 150% MRAP Objective threat event. An integration of an ABMS and a decoupled floor demonstrated an increase in overall occupant survivability installed within a rigid vehicle structure. The next steps would be to study this technology integrated to a legacy Army ground vehicle and obtain Army Fuze Safety Review Board (AFSRB) and Army Insensitive Munitions Board (AIMB) safety certifications. TARDEC is seeking PM partners to assist in these endeavors.

REFERENCES

Hodges, K. (2016). *Griffin 2.0 Final Report (W56HZV-13-D-L001-0007).* Silver Springs: Nevada Automotive Testing Center (NATC).

Kremar, J. (2015). *Griffin Final Report (W56HZV-12-C-0317).* Mooresville: Corvid Technologies, Inc.

Pratt & Miller Engineering. (2015). *Occupant Centric Platform Technology Enabled Capabilities Demonstration.* Warren: DTIC.