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Advancing Armor and Warfighter Protection from an Industrial Age Rut

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Advancing Armor and Warfighter Protection from an Industrial Age Rut

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> "The incompetence regarding body and vehicle armor rise almost to a level of criminal negligence."
>
> -- Hon. John Olver, Phd.

In our timeline of current military operations, we are at a shallow operational pause in major engagements. While this period should be a time for reflection, experimentation, and discovery, we have a natural urge to forget our shortfalls until crisis, mission urgency or threat capabilities leave us vulnerable to our next engagements causing uncontrolled overreaction and questionable judgements.

As an Army "Mad Scientist", I am both intellectually "mad" and emotionally "mad" about the armor/force protection topic. The time has come to move from armor solutions focused upon metallurgical and ceramic solutions, and investigate fabrics, carbons, thermoplastics, electrospray additive hybrid metals, and foams. The sewing machine and a petri dish may be just as significant as an arc welder for the future armor.

The statistics speak for themselves. As of June 5, 2015, US Service Traumatic Brain Injury Incidents since 2000 have totaled 327,299. Major limb amputations accounted for an additional 1,645 personnel. During Operation Enduring Freedom alone, the US suffered 1,401 IED fatalities. These fatalities constituted 50 – 60 percent of all losses. As of April 2015, **6,845** Americans have died in Iraq and Afghanistan and **over 900,000 Americans** have been injured in both wars.**[i]** Between one-half and two-thirds of these statistics are IED-based. My challenge to the developers of force protection is to understand ***that ballistic solutions are at best suboptimal for a blast protection problem***. With much remorse, our technical solutions remain limited, while many new materials sciences improve ballistic and blast protection, thermal isolation, and weight savings.

What About Blast?

In 2007, while working for Raytheon, a close neighbor's son suffered a "right of boom" IED experience in Iraq and to this day he has major cognitive and emotional shortfalls. I took on both a corporate and personal passion, to mitigate the effects of both acoustic and percussive blast energy. This was an effort to seek prevention solutions from IED blasts vice post trauma treatment. Pre-IED era research in blast effects remains woefully lacking and largely contains nuclear blast effects files from the 50's and 60's, documented blast events from industrial tragedy, and some limited history of Soviet exposure to IEDs in Afghanistan. Unique blast insight was discovered from IRA bombings in Northern Ireland and counter-mine capabilities developed by the South Africans which predated the MRAP. Raytheon's involvement on this idea subsided as OEF and OIF wound down and the OSHA requirements for simple soldier wearable solutions proved to be staggering. Some universal lessons I learned from research more than 10 years ago:

1. You can't shield against blast energy with dense mass. Blast is not a ballistic problem. Adding layered armor only exacerbates the problem with a longer and more resonant traveling acoustic wave against what is being protected. The up armoring of HMMWVs offered greater ballistic, kinetic and percussive protection but it also generated ballistic cabin debris and metal fragmentation while doing little for mitigating the effects of IEDs, and acoustic under/over pressure to vehicle undercarriages which remained essentially flat.[ii]

1. All large cavities generate a coup/counter coup and ductile phenomenon on acoustic wave ricochet. These include the interiors of vehicles and platforms, and more importantly the interiors of humans, namely the skull and lung cavities. Buildings with recessed windows and hallways parallel to the directivity of a likely detonation azimuth duct the energy from the source.

1. The wave duration, level of pressure, positive and negative impulse period, and cumulative number of previous exposures to blast are all contributors to TBI survival. We are poor at blast triage recognition and procedures. A collapsed lung can go undiagnosed, and bleeding from the ears, nose or eyes is not the first TBI sign.

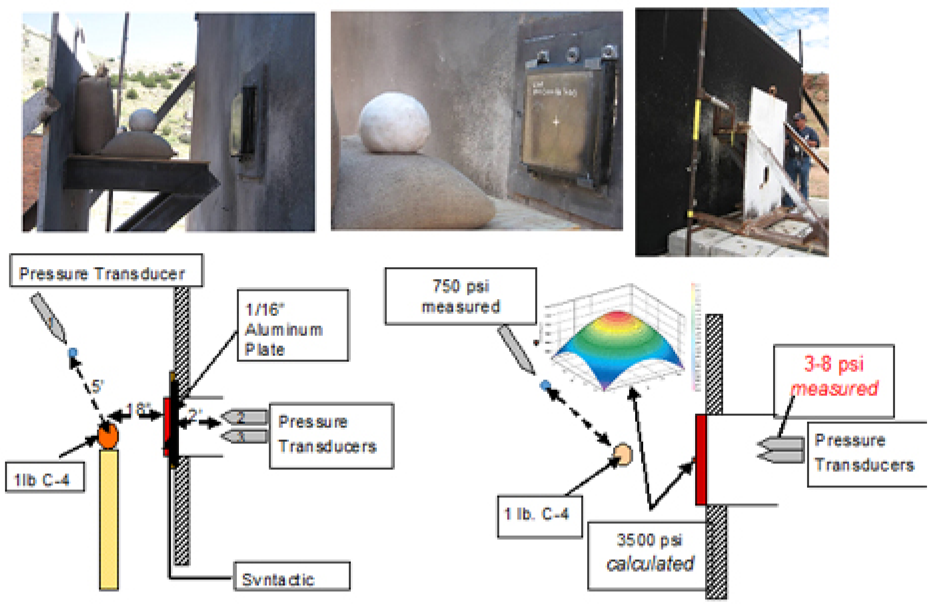
1. Blast energy can be Mach skipped/redirected or absorbed. At an angle of incidence (ideally at 42 degrees or less) with an acoustic wave, the wave will exhibit Mach skip much like a flat rock being thrown over a pond. As the angle exceeds 42 degrees, acoustic energy starts to transfer to the surface and not skip. This is the basis for MRAP V-hull design success.

Absorbing and dissipating blast is a far more dramatic event. The most resilient and effective material for blast wave mitigation is Energy Absorbing Syntactic Foam. (Figure 1)

Figure 1. Pre- and Post- Blast

Much like an executive desk swing ball set, the energy from one ball is transferred through an array of balls to the last ball on the swing. In the case of syntactic foam, microspheres of glass hold compressed nitrogen and are then tightly abutted to each other in a non-fluid resin. One cubic inch of foam can contain up to 125 x 10 exp. 6 microspheres. It is essential that the microspheres be of uniform size distribution, as uneven microsphere distributions result in blast-induced fissures, ineffective blast energy distribution, and uneven structural failure.

The syntactic microspheres transfer acoustic, blunt trauma kinetic and percussive energy radially from the highest pressure point. The blast energy distributes evenly with virtually no force moment on vector with the intended damage directions Independent blast testing results demonstrated that syntactic foam-based solutions can mitigate 95-99+ percent of a 750-3500 psi shock waves measured at 18 inches (distance from explosive materials (1 lb. of C4) against the syntactic foam armor plaque sample. *(*See Figure 2*)* Glass microspheres maintain their material integrity at temperatures up to 1472 degrees F, offer up to 43 degrees F. thermal isolation, and enjoy a 12:1 weight advantage over steel (38 lbs./ft³). Finally, syntactic foam can be layered or bonded to a base metal or ceramic frame, thus providing core structural integrity and mechanics with molded surfaces that radically mitigate blast effects. **[iii]**



Test Configuration **Test Results**

Figure 2.

While a compelling need for blast protection should now be arguably obvious, armor materials sciences have moved quickly beyond steel and ceramics. Advancements in thermoplastics, hemp, kevlar, spider silk, electrospray nano- coatings/cerments, gradient alloys, and graphene will open up new armoring concepts. These materials offer gross reductions in weight, greater flexibility and movement, conformal shaping and bonding, and superior protection.

The Old Nemeses….Ballistics

As long as threats have firearms and weapons platforms and the ability to produce shrapnel and bullet holes, the need for protecting troops from kinetic effects will not erase itself from modern warfare. This field has well defined standards such as STANAG 4569, ARL RP 89 and NIJ 0108.01 for handgun, rifle and FSP threats.

In 2006, I was witness to thermoplastic armor testing by Lucent/Bell Labs. A 1 ft. square plate weighing 17 lbs. was able to withstand 44 Magnum Gas Checked, 9 mm FMJ, 20mm/830g FSP, 0.50 caliber FSP, and 3 variations of 7.2 ball ammunition. These tests included up to 40 rounds in one spot, with bullet-on-bullet penetrations. Composite thermoplastics outperformed current technologies by an order of magnitude in addressing pounds/sq. ft. of pressure and penetration denial of ultra- high speed rounds across all tests.**[iv]**

Multilayer graphene is an anisotropic material because of its layered structure of compressed two dimensional carbon structures. Graphene absorbs huge amounts of kinetic energy, stretching into a cone at the point of impact and then spalling outwards from that point in the radial direction. Researchers at the University of Massachusetts and Rice University have demonstrated the effective use of graphene against high speed projectiles. Using laser induced gold filaments, the researchers fired micron bullets at speeds of 3000 meters per second, at 10-100 stacked sheets of graphene. Although scaling of the test is still required, initial observations conclude that graphene is roughly twice as good at absorbing impacts as Kevlar, and 10 times better than steel. **[v]**

At the University of Wollongong (Australia), researchers developed a graphene and carbon nanotube hybrid material. They added equal parts of graphene-oxide and carbon nanotubes in a polymer base. The graphene was then wet spun into fibers. The strength, toughness and resilience of this material is beyond any armor development discovered worldwide thus far and is roughly 10 times the strength of steel.

Such discovery also introduces other side benefits. Graphene is conductive. Either as a stand-alone, or as a carbon nanotube additive, one has the ability to use armor as a means of low voltage power energy distribution and embedded sensors. Additionally, layered carbons and graphite are the basis for warfighter protection against chemical and biological threats. Further research should be devoted to not only composite, hybrid armors, but also their ability to transfer energy, isolate heat or cold, and protect against CBRNE environments.

BioSteel is the trademark name of protein based fiber made from spider silk. Through a proprietary process transgenetic goats at Utah State University produce this silk from their milk. Currently there are 30 goats in this experimental project. Spider silk is 5-7 times stronger than steel if compared for the same weight, and 3 times stronger than Kevlar, the silks stretch to 20 times their unaltered length without deforming. It should be noted that spider silk has superior tensile strength above all other materials cited in this paper. Despite being a protein, spider silk exhibits great strength (the weight a material can bear) and toughness (the amount of kinetic energy it can absorb without breaking).**[vi]** In recent tests, 10 layers of woven spider silk were successful in stopping most small arms munitions. The US Navy is contracted with Utah State to develop a super “Velcro-like” fastening silk that attaches to surfaces under water.**[vii]**

This paper is a “Mad Scientist calling” to develop armor solutions that offer both ballistic and blast protection. Anything less than this calling is a disservice to warfighters and their families. Central to this premise is the need for smart designs, smart sandwich materials, nano factory and bonding techniques and clever concepts of operations.

First and foremost, for the individual soldier, it is of paramount necessity to protect the brain and primary organs not only for ballistics, but also blast. A 3/8 inch molded syntactic foam helmet liner would significantly reduce head trauma and theoretically mitigate TBI and PTSD effects. This thickness allows for protection without neck fatigue against an optimal resin and microsphere mix while still providing significant protection to the brain. Ballistic helmet protection designers should consider bonded Kevlar and graphene/carbon nanotube hybrid surfaces for the syntactic foam architecture. It is also important to consider armor protection for the ear canal as it is a major blast ductile channel to the brain. Face and eye protection require us to rethink history. Knights wore armor with angular faceplates to prevent arrow, lance and sword penetration. Future helmets should consider face plates that can Mach skip blast energy and ricochet ballistics from the facial area. The eye sockets, nose and throat also become ductile to blast energy and need shielding.

The lungs and chest cavity require blast and ballistic protection as well. Flak and ballistic protection vests are of little consequence to advanced blast environments and high velocity projectiles. Future new materials designs can stop small and long rifle arms, as well as shrapnel and blast effects. In addition, syntactic foam dampens kinetic shock energy prevalent when stopping a high velocity round.

Vehicles also require new armor concepts against evolving threats, new munitions, and lingering and continued IED threats. Such capabilities can be attained in lightweight form factors with the materials explained within this article, and the need for improved armor airlift, CBRNE protection, EMI and EW protection and platform energy efficiencies. “More steel” is not a good future solution.

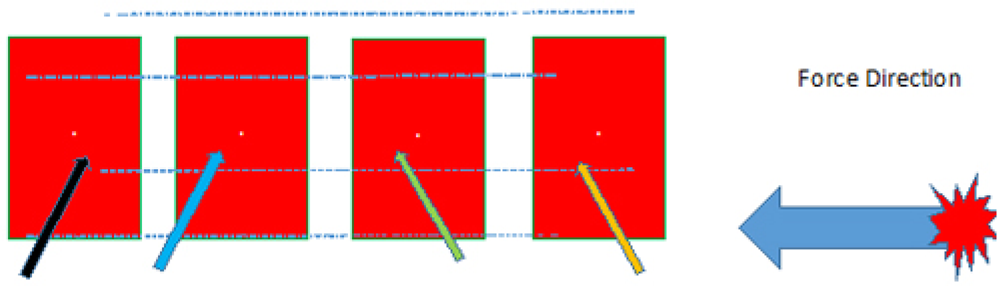


Figure 3.-***S*yntactic Foam -- Steel/Ceramics -- Graphene/Carbon Nanotubes -- Themoplastics**

Figure 3 illustrates my contention that light armor structures can be “up armored” or “new armored” with disruptive materials. Core structural integrity, drive trains, and major sub-assemblies are still best served with metals and ceramics. Having said that, the use of electrospray techniques to additively manufacture armor and ceramic plating is key. Electrospray deposition permits bonding and structural cohesion at the molecular level. Metals and ceramic nano-cerments can be made with hybrid properties, superior thermal, stress/strain and tensile strength, and perfectly reproduced shapes. Lining an armor chassis with replaceable flat and conformal syntactic foam panels would be prudent for blast protection. Additionally, such panels would deter interior steel spalling on ballistic impact, absorb blunt kinetic energy (collision and blunt shock from projectile impact), and isolate heat and vibration.

Coating a steel or ceramic face with a Graphene-Oxide/Carbon Nanotube mix provides elasticity and when layered offers, more than ten times the strength of steel with limited penetrability and a fraction of the weight of steel or ceramic equivalents. It is important to stress that this carbon envelope recipe can provide a conductive layer within the armor for distributed sensing, electronic signature change, and chemical/biological protection. Additional work is in progress on the use of graphene substrates for scalable battery power. This Eboxx™ capability will permit conformal armor to act as a significant power source with current capabilities scaling to primary power for electric vehicles.**[viii]**

Finally, a dense thermoplastic external face has proven itself against small arms and FSP. Thermoplastic armor also provides protection from the elements and a safe, yet rigid surface for external mounts and troop support. It is my contention that a hybrid armor construct similar to Figure 3 provides up to 10 times the protection over equivalent dense steel and/or ceramic architectures, at less than 1/6 of the weight and 1/3 of the cost of existing heavy armor solutions. Additionally, the suggested armor concept introduces an attempt at blast mitigation to save the lives of our troops in a “left of boom” solution.

The use of advanced materials is not without commercial synergy. For instance, the use of syntactic foam as a helmet liner and perhaps a protective cover, in theory would enormously reduce blunt head trauma and concussion. Helmet inserts may literally “explode” if blunt kinetic energy exceeds a certain psi, but that is small consequence to hospitalization or long term brain damage.

Similarly, syntactic foam bumpers on vehicles would mitigate the force moment of mass that is going through a vehicle on impact and convert that energy to microspheres distributing energy around the vehicle. Likewise, Jersey walls, road signs, lamp posts and other infrastructure would benefit from such a material. Since resins can be colorized throughout, scratches and dings would go largely unnoticed. Syntactic foams could also be made with similar strength to steel at 1/12 the weight without suffering fatigue, rusting or other decay.

Finally, air cargo safety could greatly be enhanced by implementing syntactic containers. Such containers would be more affordable and less weight than aluminum, and would have the ability to contain a blast or fire. Such containers would also support EOD/bomb disposal scenarios and could likely be carried and emplaced by an unmanned ground vehicle.

Armoring the future requires the Army to look beyond the arc wielder and the ceramic mold, and perhaps embrace the petri dish, the sewing machine and the nano-factory/ electrospray system. A renaissance era is before us in materials science, manufacturing and understanding threats. We cannot coddle the past and hope everything will be OK. New materials offer greater performance, reduced costs, greater mobility, and greater mitigation of threat effects. At the end of the day, it’s not just about saving lives…it’s about saving lives and bringing our warfighters back home intact.

End Notes

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About the Author

Frank Prautzsch

In his current role as President of Velocity Technology Partners LLC, Mr. Prautzsch (LTC, Ret. Signal Corps) is recognized as a technology and business leader known for exposing or crafting innovative technology solutions for the DoD, SOF, DHS and Intelligence community. His focus is upon innovation and not invention. His waking moments are spent in the process of identifying and contriving use cases for global commercial technologies that the government is unaware of, or at best has yet to assume a use case for that could support their needs. Prior to his own consulting program, Mr. Prautzsch served as the Sr. VP for Government Programs for ORBCOMM, the Director of the Raytheon Rapid Initiatives Group (RIG), and Director of Army Requirements for Hughes Space and Communications Company

While on active duty in the US Army, Mr. Prautzsch held a variety of Command, Staff, and Engineering positions. He served on numerous Joint Task Force, Army, and contingency missions across all operational environments and was instrumental in defining many of the Army's MILSATCOM concepts of operations and doctrine used today. He was the Secretary of the Army's selection to Lead the DoD MILSATCOM Architecture under the DoD Space Architect. During this process, he was instrumental in formulating a $42B investment plan for wideband, protected and narrowband communications for the Nation.

Mr. Prautzsch holds a Bachelor of Science in Engineering from the United States Military Academy at West Point, is a distinguished graduate of the Marine Corps Signal Advanced Course, Army Airborne School, Ranger School, and Command and General Staff College. He attended Raytheon's University of Chicago Business Development School, and is Six Sigma qualified. He also holds a Master of Science Degree from Naval Postgraduate School in Monterey, California with a degree in Systems Technology (C3) and Space.

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