

# **PASS 2018**

## **WASHINGTON DC**

**Personal Armour Systems Symposium**

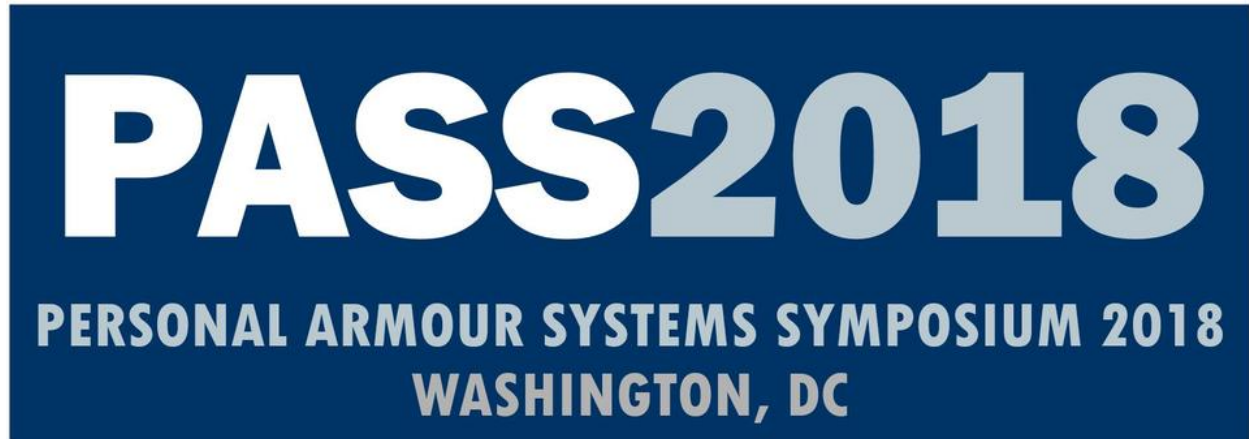


International Personal  
Armor Committee

**NIST**  
National Institute of  
Standards and Technology





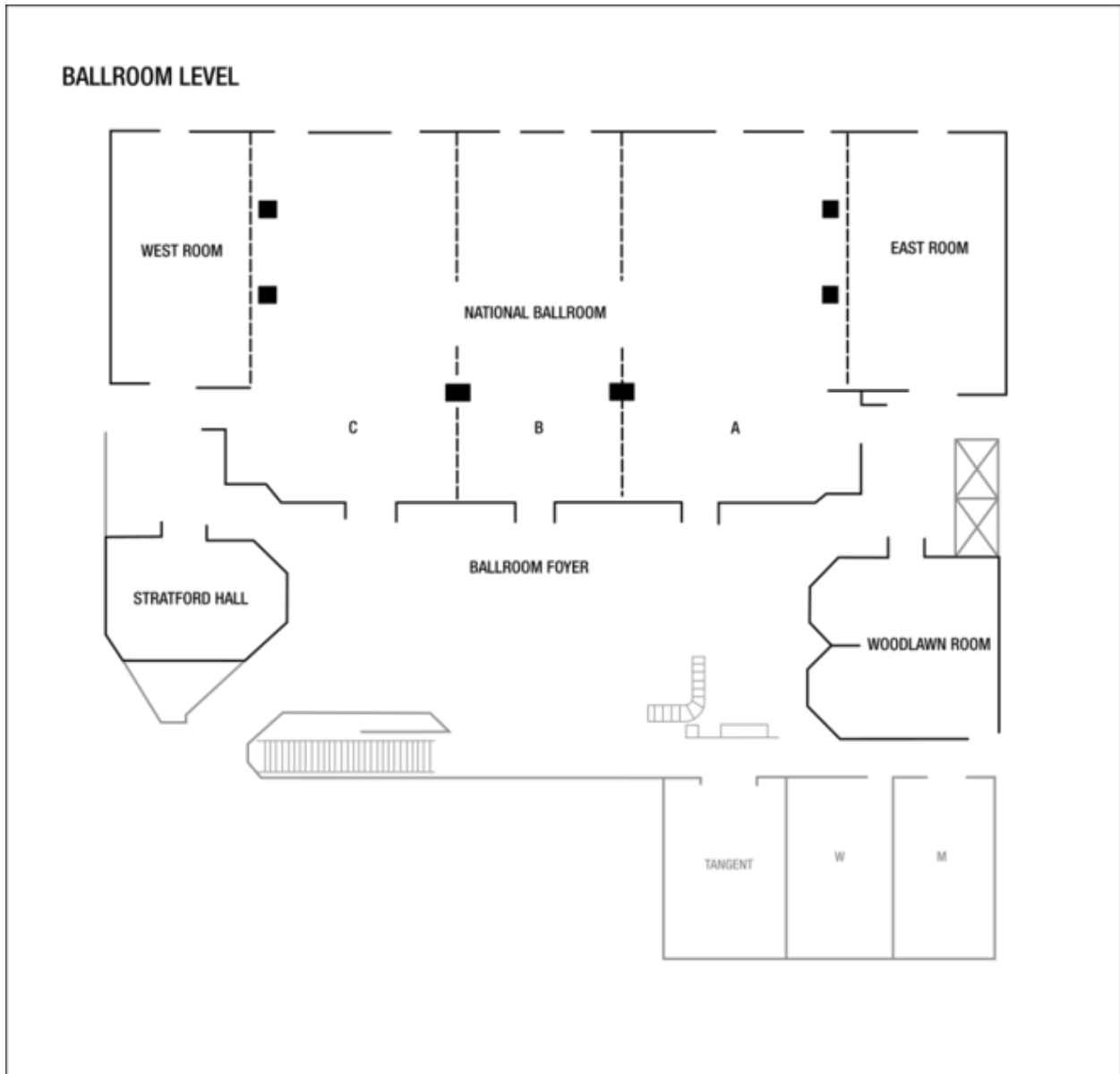


## PASS 2018

The Personal Armour Systems Symposium (PASS) is a technical conference and offers a unique opportunity for the exchange of views and experiences in the field of personal armour systems between academia, users, and manufacturers. The Symposium is focused on all aspects relating directly to personal protection, e.g., military and police body armour, helmets, and EOD protection. In conjunction with the symposium, there will be an industry exhibition area to allow the discussion, illustration, and promotion of ideas and equipment from sponsors and exhibitors.

# Symposium

The entire symposium will be held in the National Ballroom Level of the Westin Washington DC.



## **Sponsors**

IPAC and the organisers of PASS 2018 would like to extend our sincere thanks to the sponsors who have helped make this event possible.

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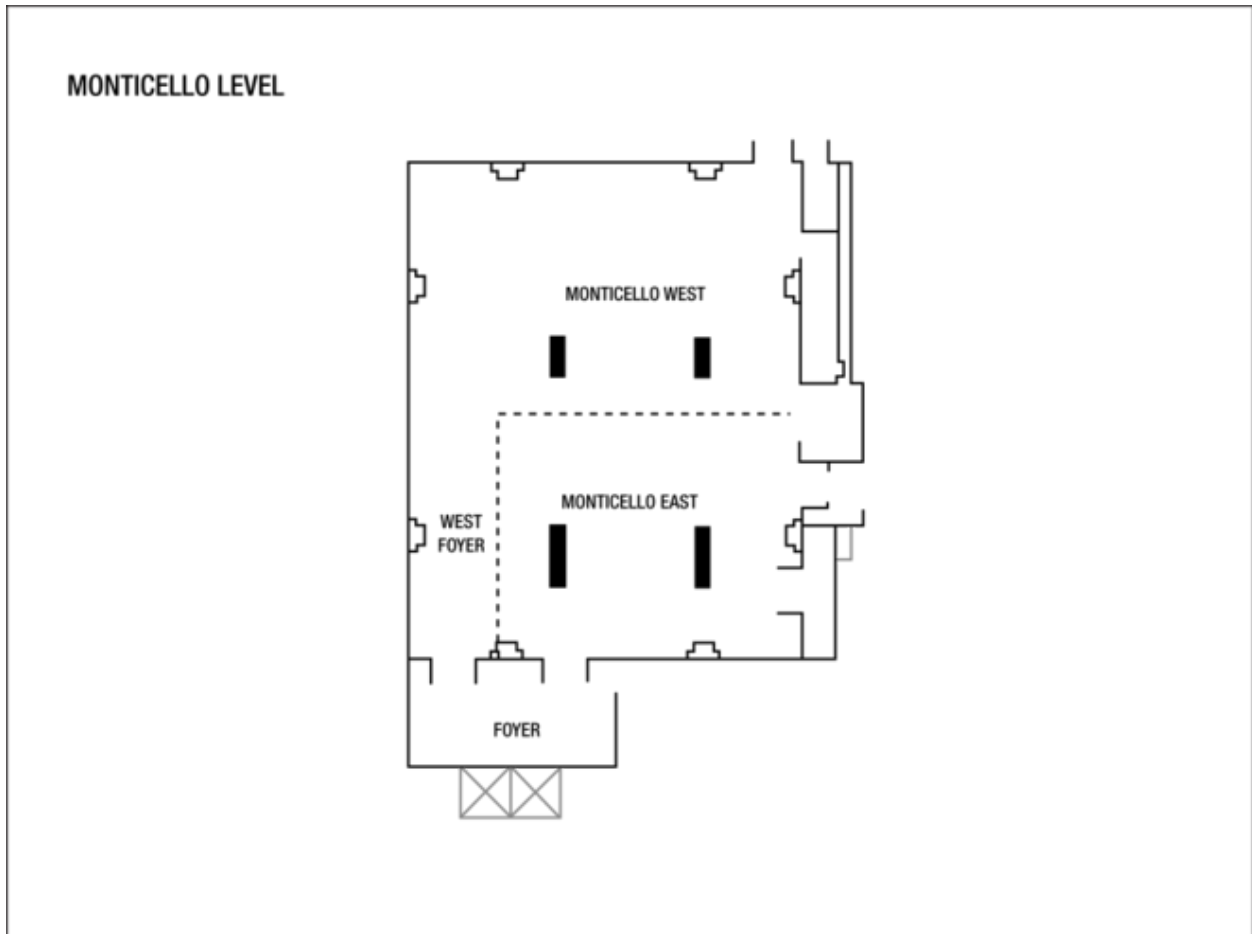
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# Exhibition

As in previous years there will be an exhibition running throughout the event on the Monticello Level of the Westin Washington DC. Exhibitors as of the date of publication are listed on the following page.



## **Exhibitors\***

TNO Defence

Sydor Technologies

Leading Technology Composites

TenCate Advanced Armor

Busch PROtective USA

Revision Military

National Technical Systems

Med-Eng (brand of Safariland group)

Source Tactical Gear

Vision Research

\*current as of date of publication, August 31, 2018



## Reception

A reception will be held on Tuesday, October 2<sup>nd</sup> at the Westin Washington, DC from 6:00 pm to 8:00 pm. Only registrants who have purchased a catering registration may attend the reception.

## Banquet

The conference banquet will be held on Thursday, October 4<sup>th</sup> at the historic Willard InterContinental Hotel, within walking distance of the conference venue, from 6:30 pm to 8:30 pm. Only registrants who have purchased a catering registration or a separate banquet ticket may attend the reception.



The Willard InterContinental Hotel  
1401 Pennsylvania Ave NW  
Washington, DC 20004

# Programme

Time	Monday October 1, 2018-Afternoon
11:00-1:00	Registration, Lunch, Exhibits
	<b>Keynotes and Invited Speakers</b> <i>Session Chairs: Amanda Forster, Janet Ward</i>
1:00-1:10	Welcome and Practical Details
1:10-1:25	Dr. Stephanie Hooker, "Welcome from NIST"
1:25-1:40	Dr. Mark Van Landingham, "Welcome from Department of Defense"
1:40-2:10	Keynote 1: Lieutenant General Paul A. Ostrowski, USA, Principal Military Deputy to the Assistant Secretary of the Army (Acquisition, Logistics and Technology) and Director of the Army Acquisition Corps
2:10-2:40	Keynote 2: Dr. Brian Holmes, National Intelligence University
2:40-3:15	Coffee break
	<b>Session 1: Standards</b> <i>Session Chairs: Kirk Rice, Phillippe Drapela</i>
3:15-3:45	Mark Greene, "The Next Revision of the NIJ Performance Standard for Ballistic Resistance of Body Armor, NIJ Standard 0101.07: Changes to Test Methods and Test Threats"
3:45-4:15	Thomas Payne, "Home Office Body Armour Standard (2017)- Scientific Rationale"
4:15-4:45	Michael Riley, "Practical Estimation of Uncertainty in Test Velocity Measurements"
4:45-5:15	Casandra Robinson, "Reducing Law Enforcement Officer Vulnerability by Closing the Gap in Body Armor Coverage and Fit"
5:15-5:45	Morgan Trexler, "Development of a Modular Load Sensing Headform"

# Programme

Time	Tuesday, October 2, 2018- Morning
8:00-8:30	Registration and Continental Breakfast
	<b>Session 2: Standards</b> <i>Moderators: Hein Jager, Peter Matic</i>
8:30-9:00	James Thomas, "Pressure Sensing in Clay: Potential New Helmet Testing Metric for Backface Impact Severity"
9:00-9:30	Matthew Bevan, "Correlation between Round Impact Energy and Displaced Clay Volume for Three Classes of Armour"
9:30-10:00	Xin-lin Gao, "Constitutive Modeling of Ballistic Roma Plastilina No. 1 Clay"
10:00-10:15	Poster Intros: Cindy Bir, Aaron Forster, Ran Tao
10:15-10:45	Coffee break/Poster Session/Exhibits
	<b>Session 3: Standards</b> <i>Session Chairs: Hein Jager, Peter Matic</i>
10:45-11:15	Mohamed Latreche, "Ballistic and Non-Ballistic Helmet Requirements and their Effect on PE Helmet Weights"
11:15-11:45	Marjolein Van Der Jagtdeutekom, "Assessment of the secondary fragments from buried explosives"
11:45-12:15	Ian Crouc, "A review of ballistic testing methodologies for Hard Armour Plates in conjunction with, and without, Soft Armour Inserts"
12:15-12:30	Poster Intros: Ashok Bhatnagar, Subramaniam Rajan, Leigh Phoenix
12:30-1:30	Lunch/Exhibits

# Programme

<b>Tuesday, October 2, 2018- Afternoon</b>	
<b>Time</b>	<b>Session 4: Armour Materials</b> <i>Session Chairs: Manon Bolduc Aaron Forster</i>
1:30-2:00	Kirk Rice, "Evaluation of Degradation Models for High Strength p-Aramid Fibers Used in Body Armour"
2:00-2:30	Naresh Bhatnagar, "Effect of matrix variation on the high strain rate performance of UHMWPE composite"
2:30-3:00	Mark Hazzard, "Finite Element Modelling of Impact on Composites made with Dyneema"
3:00-3:15	Poster Intros: Rob Kinsler, Harald Buchmann, Riyad Ratrout
3:15-3:45	Coffee break/Poster Session/Exhibits
	<b>Session 5: Armour Materials</b> <i>Session Chairs: Manon Bolduc, Aaron Forster</i>
3:45-4:15	A Ramezani, "Improvement of Ultra High Molecular Weight Polyethylene Armour Structures with Numerical Solutions"
4:15-4:45	Neelanchali Asija Bhalla, "Effect of STF packaging method on the impact resistance of UHMWPE ballistic composite"
4:45-5:15	Andrew Geltmacher, "Evaluation of Prior Dents on Ballistic Performance of High Density Polyethylene Specimens"
6:00-8:00	<b>Reception at Westin, Washington, DC</b>

# Programme

Time	Wednesday, October 3- Morning
8:00-8:30	Registration and Continental Breakfast
	<b>Session 6: Personal Armour/BABT</b> <i>Session Chairs: Frederik Coghe, Adam Fournier</i>
8:30-9:00	Justin McKee, "Finite Element Simulation to Determine the Effect of Knit Architecture on Ballistic Response"
9:00-9:30	Timothy Zhang, "Indent Depth in the clay backing for soft and hard armour"
9:30-10:00	Karin Rafaels, "Can Clay Tell Us More Than Deformation"
10:00-10:15	Poster Intros: Thuy-tien Nguyen, Karin Rafaels, Angel Miranda-Vicario
10:15-10:45	Coffee break/Poster Session/Exhibits
	<b>Session 7: Personal Armour/BABT</b> <i>Session Chairs: Frederik Coghe, Adam Fournier</i>
10:45-11:15	Kathryn Loftis, "Estimating Obliquity of Ballistic impacts from Residual Damage to Hard Armour Plates"
11:15-11:45	Anan Azevedo, "Experimental assessment of the effect of damage on the ballistic resistance of ceramic inserts"
11:45-12:15	Jason Lo, "Carbon Nanotube Reinforced Alumina"
12:15-12:30	Poster Intros: Anthony Bracq, Peter Matic, Aris Makris,
12:30-1:30	Lunch/Exhibits

# Programme

<b>Wednesday, October 3- Afternoon</b>	
<b>Time</b>	<b>Session 8: Standards</b> <i>Session Chairs: Thomas Payne, Michael Riley</i>
1:30-2:00	Manon Bolduc, "Tactical ballistic shields operational testing protocol definition"
2:00-2:30	Mark Begonia, "Influence of flexible neck on head kinematic response during military helmet impact testing"
2:30-3:00	Alan Hywel Jones, "Determination of the Cause of the Differing Ballistic Performance of 9 mm DM11 Bullets from Two Manufacturers"
3:00-3:20	Poster Intros: Courtney Cox, Joe Andrist, Aris Makris, Daniel Park
3:20-3:45	Coffee break/Poster Session/Exhibits
	<b>Session 9: Standards</b> <i>Session Chairs: Thomas Payne, Michael Riley</i>
3:45-4:15	Erik Carton, "Role of inertia in armour ceramics"
4:15-4:45	Mohamed Latreche, "Using Material Combinations to reduce the effective Risk of Penetration from High Velocity Rounds in a Helmet"
4:45-5:15	Caroline Deck, "Assessment of Behind Armour Blunt Trauma risk for a combat helmet by a combined experimental and numerical method"
5:15-5:45	Steffen Grobert, "Comparative Tests with a modified "PK17dynA" for an Integrated Assessment of Ballistic Backface Deflections on Combat Helmets "

# Programme

Time	Thursday, October 4- Morning
8:00-8:30	Registration and Continental Breakfast
	<b>Session 10: BABT</b> <i>Session Chairs: Daniel Bourget, Karin Rafaels</i>
8:30-9:00	Cyril Robbe, "Sensitivity studies of the BTTR surrogate and comparison between NLW and BABT applications"
9:00-9:30	Anthony Bracq, "Behind armor blunt trauma assessment by means of experimental and numerical approaches"
9:30-10:00	Eluned Lewis, "The virtues of VIRTUS: Development and introduction of the new VIRTUS body armour, load carriage and helmet system for UK Armed Forces personnel"
10:00-10:15	Poster Intros: Gary Tan, Yungchia Chen, Nicolas Prat
10:15-10:45	Coffee break/Poster Session/Exhibits
	<b>Session 11: Human Factors/Personal Armour</b> <i>Session Chairs: Daniel Bourget, Karin Rafaels</i>
10:45-11:15	Leonard Lombardo, "Two Sample Statistical Interference for Ballistic Limit Testing of Body Armour"
11:15-11:45	James Davis, "An analysis of the fit and function of the UK OSPREY body armour system for female users on combat operations"
11:45-12:15	Christopher Eckersley, "A Real Pain in the Neck: Design Limits on Magnitude and Location of Head Supported Mass"
12:15-12:30	PASS 2020
12:30-1:30	Lunch/Exhibits

# Programme

<b>Thursday, October 4- Afternoon</b>	
<b>Time</b>	<b>Session 12: Human Factors/Injury</b> <i>Session Chairs: Peter Knudsen, Dale Bass</i>
1:30-2:00	Aernout Oudenhuijzen, "Digital Head Avatars for combat helmet fit"
2:00-2:30	Jean-Phillippe Dionne, "Use of Hybrid III mannequins for a blast overpressure standard test methodology"
2:30-3:00	Joost Op'Teynde, "The Lessons of History: Helmets and Primary Blast"
3:00-3:30	Jean Phillippe Dionne, "Realistic bomb suit blunt impact protection vs. standards requirements"
3:30-4:00	Coffee break/Poster Session/Exhibits
	<b>Session 13: Injury</b> <i>Session Chairs: Peter Knudsen, Dale Bass</i>
4:00-4:30	Thomas O'Shaughnessy, "Influence of helmet system on blast overpressure transmission into the brain"
4:30-5:00	Vanessa Alphonse, "Effect of helmet and eyewear on headform kinematic and kinetic response to primary blast overpressure exposure"
5:00-5:30	Marina Seidl, "Investigations on projectile ricochet off body armour"
5:30-6:30	
6:30-8:30	Conference Banquet at Willard Intercontinental Hotel



# Programme

Time	Friday October 5, 2018- Morning
8:00-8:55	Continental breakfast
8:55-9:00	Welcome
	<b>Session 14: Vulnerability</b> <i>Session Chairs: Michael Maffeo, Janet Ward</i>
9:00-9:30	Sofia Hedenstierna, "Methodology for small arms vulnerability analysis of protected and unprotected man"
9:30-10:00	Sheridan Liang, "A comparison of the thoraco-abdominal anatomical data of the Visible Human Project Female to three living females"
10:00-10:45	Coffee break/Poster Session/Exhibits
	<b>Session 15: Vulnerability</b> <i>Session Chairs: Michael Maffeo, Janet Ward</i>
10:45-11:15	Mathieu Philippens, "Combat Helmet Blunt Impact Performance and Test Method and Head Injury Criteria"
11:15-11:45	Christophe Marechal, "Development of physical and numerical head substitute used for wound ballistic assessment"
11:45-12:00	Wrap Up and Adjourn
12:00-1:00	Lunch to go

# Abstracts and Presenters' Bios

## The Next Revision of the NIJ Performance Standard for Ballistic Resistance of Body Armour, NIJ Standard 0101.07: Changes to Test Methods and Test Threats

Mark E. Greene<sup>1</sup>, Jeffrey Horlick<sup>2</sup>, Daniel A. Longhurst<sup>3</sup>, Lance L. Miller<sup>3</sup>, Michael O'Shea<sup>1</sup>, David Otterson<sup>3</sup>, Casandra Robinson<sup>2</sup>, Debra A. Stoe<sup>1</sup>, and Richard A. Sundstrom<sup>3</sup>

*1National Institute of Justice, 810 7th Street NW, Washington, DC, 20531, USA, mark.greene2@usdoj.gov*

*2National Institute of Standards and Technology, 100 Bureau Drive, Gaithersburg, MD 20899, USA*

*3Leidos Innovations Corporation, 700 North Frederick Avenue, Gaithersburg, MD 20879, USA*

**Abstract.** The National Institute of Justice (NIJ) develops performance standards for the unique equipment used by law enforcement and corrections agencies to test that equipment to provide confidence that it is safe and effective. NIJ published the first performance standard for ballistic-resistant police body armour in 1972 and established body armour compliance testing several years later. Today, the NIJ Compliance Testing Program provides confidence that body armour for use by law enforcement in the United States (U.S.) meets minimum performance requirements through standardized ballistic testing to the current NIJ Standard 0101.06, *Ballistic Resistance of Body Armour*, published in 2008. NIJ is currently working on the seventh revision to this performance standard anticipated to be published in 2018 as NIJ Standard 0101.07, which will include improved test methods for female body armour and updated body armour protection levels that incorporate additional rifle threats faced by U.S. law enforcement. NIJ and the U.S. Army have been cooperating to harmonize laboratory test procedures and practices in ASTM International (ASTM). Unlike the current and previous versions of the NIJ body armour standard which have been comprehensive, standalone documents, NIJ Standard 0101.07 will incorporate by reference a suite of standardized test methods and practices developed in ASTM. Incorporation of relevant ASTM standards by reference into NIJ standards and U.S. Army requirements and testing documents affords the opportunity to harmonize laboratory test procedures and practices for both law enforcement and military ballistic-resistant armour and other ballistic-resistant equipment while allowing those end user communities ultimate control over product specifications, such as the specific threats against which their equipment must protect. NIJ has also developed a standalone specification of ballistic threats to test ballistic-resistant equipment for U.S. law enforcement applications, which will be incorporated into NIJ Standard 0101.07 for body armour as well as anticipated NIJ standards for ballistic-resistant helmets and ballistic-resistant shields.

### Curriculum Vitae: Mark E. Greene, Ph.D.,

Presentation 1 Monday, October 1 3:15-3:45 pm

Mark Greene is the Policy and Standards Division Director in the Office of Science and Technology at the National Institute of Justice (NIJ). His unit covers issues of technology policy, standards, and conformity assessment for equipment used by law enforcement and criminal justice practitioners and manages the NIJ Compliance Testing Program for ballistic-resistant body armor, stab-resistant body armor, and autoloading pistols for law enforcement. Previously, Mark was a program manager at NIJ where he managed research, development, test, and evaluation projects in emerging technology for criminal justice applications, such as facial recognition, video analytics, and noncontact fingerprint devices. The program also included the NIJ Sensors, Surveillance, and Biometrics Center of Excellence which focused in part on testing and evaluation of completed R&D projects supported by NIJ in biometrics, sensors, and surveillance technologies. Earlier in his career, Mark was a staff scientist at a high-tech firm that manufactured scientific instruments and was a researcher at the National Institute of Standards and Technology (NIST). He holds a Doctorate and Bachelor degree in Materials Science and Engineering and a Bachelor degree in Communications from Northwestern University.



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## Home Office Body Armour Standard (2017) – Scientific Rationale

T. Payne<sup>1</sup>, S. O'Rourke<sup>1</sup>, C. Malbon<sup>1</sup>, G. Smith<sup>1</sup>, E. Ollett<sup>1</sup>

<sup>1</sup>Home Office Centre for Applied Science and Technology, Woodcock Hill, Sandridge, St Albans, Hertfordshire, AL4 9HQ

tom.payne@homeoffice.gsi.gov.uk

**Abstract.** The Home Office Body Armour Standard (2017) provides the minimum performance requirements and test methods for the assessment of ballistic and/or stab resistant body armour intended for UK law enforcement. This standard supersedes the internationally-recognized Home Office Scientific Development Branch (HOSDB) Body Armour Standards for UK Police (2007) and includes a series of notable changes in test methods and specifications to both reflect the current requirements of UK law enforcement and provide more representative assessments. Key differences from the HOSDB (2007) standard include, but are not limited to: protection levels for ballistic, knife and spike armour; female body armour test methods; rifle plate test methods; critical perforation analysis as a quality assurance tool; and in-life monitoring.

In the development of the 2017 standard, as well as conducting internal research, the Home Office Centre for Applied Science and Technology (CAST) partnered with academic institutions and other government agencies to provide tools and evidence to support test specifications. This paper introduces each of the elements of the body armour standard and outlines the scientific rationale and evidence supporting their inclusion. Furthermore, outlined within are a series of recommendations for research to focus developments in the support of future iterations of body armour standard.

### Curriculum Vitae: Tom Payne, Ph.D.

Presentation 2 Monday, October 1 3:45-4:15 pm

Dr Tom Payne is a senior scientist at Home Office CAST, which is now integrated with the Defence Science & Technology Laboratory, and subject-matter lead on impact aspects of personal protective equipment. Dr Payne was the lead author on the Home Office Body Armour Standard (2017).

Prior to this, Dr Payne completed his PhD at Loughborough University in the field of human surrogates for personal protective equipment assessment.



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# Practical Estimation of Uncertainty in Test Velocity Measurements Using Optical Screens

Michael A. Riley<sup>1</sup>, Kirk D. Rice<sup>1</sup> and Nicholas G. Paulter<sup>1</sup>

<sup>1</sup>National Institute of Standards and Technology, 100 Bureau Dr., Mail Stop 8102, Gaithersburg, MD, 20899, USA

[michael.riley@nist.gov](mailto:michael.riley@nist.gov)

**Abstract.** The test projectile velocity is one of the critical measurements when testing armour and other protective equipment for ballistic resistance. Good laboratory practice requires estimating the uncertainty of these measurements, and understanding the sources of that uncertainty is essential to ensuring that test results are correct and repeatable. Velocity measurements, however, are particularly complicated, because they require two independent measurements: the time of flight of the projectile between two measurement planes and distance between those planes. These measurements may appear to be relatively simple to make, but nuances in how the measurements are made and small variations from ideal test conditions can significantly influence the resulting velocity measurement. In addition, the uncertainty of the velocity measurement will be dependent on both the measurement equipment and how that equipment is used. This work is focused on understanding what factors significantly influence the uncertainty of projectile velocity measurements made with commercial systems of the types that are common in test laboratories. Common sources of measurement errors are considered and their likely influence on the estimated measurement uncertainty is evaluated. The results are intended to provide laboratory personnel with a practical framework in which they can determine what factors they need to consider when assessing the uncertainty of their velocity measurements.

## Curriculum Vitae: Michael Riley, Ph.D.

Presentation 3 Monday, October 1 4:15-4:45 pm

Dr. Riley is a Research Engineer in the Security Technologies Group of the Material Measurement Laboratory at the National Institute of Standards and Technology. He leads research efforts to improve the understanding of the response of impact mitigating materials and high strength ballistic resistant materials. His work includes developing improved test methods for impact mitigating materials, which have the potential to reduce the occurrence of mild traumatic brain injuries and sporting injuries. He is also involved in the testing and modelling efforts, and the standards development process, to improve the testing and evaluation of ballistic resistant body armour and other personal protective equipment. His past research work has included experimental testing and modelling of structural systems, disaster investigation, and failure analysis of materials and systems subjected to extreme loads. Dr. Riley is a member of ASTM Committee E54 on Homeland Security Applications and a member of the NIJ Special Technical Committee that is revising the NIJ body armor standard. Dr. Riley received his Ph.D. in engineering from the State University of New York at Buffalo, where he studied earthquake engineering and structural dynamics.



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## Reducing Law Enforcement Officer Vulnerability by Closing the Gap in Body Armour Coverage and Fit

C. Robinson<sup>1</sup>, J. Horlick<sup>2</sup>

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<sup>2</sup>National Institute of Standards and Technology, 100 Bureau Drive, Gaithersburg MD 20899, USA

**Abstract.** Soft body armour is a vitally important item of personal protective equipment used by law enforcement, and proper fit and coverage are essential to that protection. A single bullet exploiting a gap in a vest that fits poorly and lacks proper coverage could have devastating results for the wearer. Federal Bureau of Investigation (FBI) Uniform Crime Reports show that, for the past 10 years, 28% of officers killed while wearing body armour were killed by bullets hitting unprotected areas of the torso. While FBI data only indicate the general area of the torso that was struck and do not indicate whether gaps in coverage were an issue, improved vest fit and coverage may provide a means to reduce that number of deaths in the future.

The authors' efforts and findings reveal a shared concern among officers and agencies regarding body armour coverage and fit. Interviews, observations, workshops, and studies involving multiple law enforcement agencies and hundreds of individual officers indicate that most officers do not understand proper coverage or how armour should fit; they are wearing vests that do not fit or cover sufficiently; and they do not know what to do if their vests fit poorly. Insufficient coverage and poor fit not only result in more exposed areas of the torso but also reduce mobility and increase discomfort, resulting in a reluctance to wear the vest.

Our findings demonstrate the need for a systematic, large-scale study to fully understand the issues with armour coverage and fit and develop solutions to this problem. This paper describes the work to date, known and suspected factors contributing to the problem, and aspects of the armour procurement process (from specification through measurement and manufacturing to delivery and officer education) that must be considered in the study. The ultimate outcome of these efforts is guidance on how officers can purchase properly fitted body armour having as much coverage as possible while ensuring maximum range of motion and mobility.

### Curriculum Vitae: Casandra Robinson

Presentation 4 Monday, October 1 4:45-5:15 pm

Casandra Robinson is a physical scientist in the National Institute of Standards and Technology (NIST) Standards Coordination Office. She is responsible for leading the development of documentary standards and coordinating with NIST technical units, other federal agencies, industry, and relevant stakeholders in the development of standards and conformity assessment systems. Prior to joining NIST in 2012, she was a Program Manager with the U.S. Department of Energy Savannah River National Laboratory. For the previous 5 years, she supported the National Institute of Justice's Standards and Testing Program with development of performance standards and conformity assessment for public safety equipment. She serves as the ASTM International Vice Chair for the E54 Committee on Homeland Security Applications and as Vice Chair for E54.04, Personal Protective Equipment Subcommittee. She also serves as the Federal co-chair for the Standards Coordination SubGroup of the InterAgency Board for Emergency Preparedness and Response. She has a Bachelor of Science in Electrical Engineering from Clemson University and a Master of Science in Industrial and Systems Engineering from the University of Alabama.



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## Development of a Modular Load-Sensing Headform

M.M. Trexler<sup>1</sup>, Q.T. Luong<sup>1</sup>, V. Alphonse<sup>1</sup>, K. Perrino<sup>1</sup>, M. Athey<sup>1</sup>, S. Storck<sup>1</sup>, J. Paulson<sup>1</sup>, C. Bradfield<sup>1</sup>, E. Gienger<sup>1</sup>, Z. Xia<sup>1</sup>, M. Bevan<sup>1</sup>, C. Carneal<sup>1</sup>, D. Colanto<sup>2</sup>, B. Fasel<sup>2</sup>

<sup>1</sup>The Johns Hopkins University Applied Physics Laboratory (JHU/APL), 11100 Johns Hopkins Rd., Laurel, MD 20723

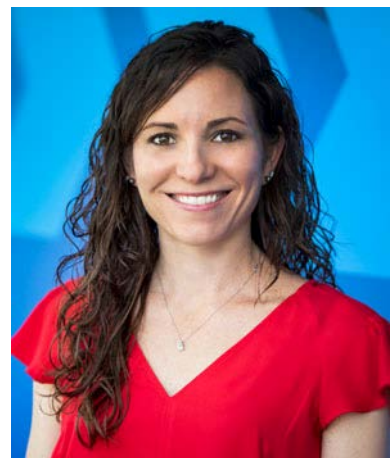
<sup>2</sup>U.S. Army Natick Soldier Research, Development, and Engineering Center, General Greene Avenue, Natick, MA, 01760, USA

**Abstract.** Limitations associated with clay-based helmet test methodologies have led to interest in developing a more advanced and user-friendly sensor-based headform. To this end, JHU/APL has developed a modular and customizable load-sensing headform. After identifying a concept that best addressed stakeholders' needs and system requirements, down selection of candidate materials and sensors, and optimization for the end-user were pursued. The headform is comprised of a single load cell surrounded by an additively manufactured polymeric head. This design supports the testing at five impact locations per current standards. The load cell, which is affixed to a stationary post, is overlaid with an impact cap of location-specific geometry, with an elastomeric skin pad that covers the impact cap. Load cell range requirements were determined via ballistic testing employing a 222 kN load cell with helmet-threat combinations of interest. Once the maximum expected load was determined for each impact location, several candidate load cells were evaluated, leading to down-selection. Impact cap size was dictated by each impact location's damage zone size, or area over which forces were distributed, which was quantified using Fujifilm PreScale. Skin pad material was down-selected based on fabrication consistency, performance, and cost. Numerous features were included to improve overall usability and reduce operational costs. The stationary post design enables use of the same load cell for all impact locations, and eliminates the need to reposition or realign between tests, regardless of impact location. Magnetic couplings used to attach the head to the post and the impact cap to load cell enable quick transitions between tests. This headform design enables rapid helmet evaluation based upon repeatable and dynamic force data, has potential for use in First Article and Lot Acceptance Testing, and can be tailored for research applications through customization of load cell arrays and varying impact cap sizes.

### Curriculum Vitae: Morgan M. Trexler, Ph.D.

Presentation 5 Monday, October 1 5:15-5:45 pm

Dr. Trexler received her Ph.D. in 2008 under the supervision of Naresh Thadhani at the Georgia Institute of Technology where she studied "Dynamic Mechanical Behaviour and High Pressure Phase Stability of a Zirconium-Based Bulk Metallic Glass and its Composite with Tungsten." Following graduate school, she joined the Johns Hopkins University Applied Physics Laboratory where she now is a Principal Staff Scientist and Supervisor of the Multifunctional Materials and Nanostructures Group within the Laboratory's Research and Exploratory Development Department. Her research is focused on a broad range of materials science and engineering topics including challenges related to biomechanics, development of novel armour materials, synthesis of nanoscale fibres, and additive manufacturing. She has over 30 journal publications and book chapters. Dr. Trexler was a recipient of the JHU/APL 2010 Invention of the Year Award, Maryland Science Center's 2014 Outstanding Young Engineer Award, and was inducted into Georgia Institute of Technology's 2015 Council of Outstanding Young Engineering Alumni.



## Notes

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## Pressure Sensing in Clay: Potential New Helmet Testing Metric for Backface Impact

J. P. Thomas<sup>1</sup>, M. H. Merrill<sup>1</sup>, C. J. Kindle<sup>2</sup>, and C. Rudolf<sup>1</sup>

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<sup>2</sup> Aerodyn Engineering Inc., 1919 South Girls School Road, Indianapolis, IN 46241 USA

**Abstract.** Helmet backface impact to the head during ballistic arrest can produce serious head injuries including brain trauma. Injury risk assessment requires quantification of the helmet-head impact characteristics. Current helmet test fixtures like the NIJ headform use ROMA Plastilina #1 (RP-1) clay to register the backface deformation (BFD) magnitude. The BFD is assumed to be correlated with head injury risk, but quantitative relations between them do not currently exist. Improvements in helmet testing are needed to: 1) quantitatively relate helmet-head interactions with blunt trauma injury risk; 2) tailor the dynamic mechanical response of the helmet test headform to match that of the human head for more realistic helmet-head interactions affecting the helmet's backface response in ballistic impact; 3) improve the precision of the helmet response data; and 4) reduce testing complexity, time, and cost. This paper will report on the development of dynamic pressure measurements in clay and silicone rubber gel under shock and ballistic impact as a potential new metric for assessing risks for head injury by helmet backface impact. Shock-tube experiments and ballistic helmet testing with sensor-modified NIJ headforms will be described. Results include an evaluation of commercial pressure sensors and instrumentation, and pressure response for applied step, shock, and ballistic impact tests. Shock pressure waves in clay/gel are amplified, dispersed, and attenuate ~10-15% over a 50 mm propagation distance. Clay/gel peak pressures for 9 mm FMJ impact on two helmet types at  $V_0 \pm 30$  m/sec ranged from ~70 kPa to 11 MPa (10-1600 psi) with sensitivity to impact velocity, helmet/pad type, backface stand-off, and sensor location/orientation relative to the headform surface and threat trajectory. Changes to shot aim and helmet mounting procedures are needed to reduce pressure/BFD measurement variations, and matched comparisons with biomedical model-testing and finite element modelling are needed to link peak pressures with head-brain injury risks.

### Curriculum Vitae: Jim Thomas, Ph.D.

Presentation 6 Tuesday, October 2 8:30-9:00 am

Dr. Jim Thomas is a Section Head in the Multifunctional Materials Branch at the Naval Research Laboratory (NRL) in Washington DC. He received his Ph.D. degree in Applied Mechanics from Lehigh University in 1989 and has been employed at NRL since 2000. He has over 25 years of R&D experience related to mechanics and materials with technical contributions in the areas of multifunctional material systems, composite armours, materials testing, additive manufacturing, and continuum mechanics and thermodynamics. He is author on more than ninety technical publications, has four patents, and serves on the Editorial Boards for the Journal of Composite Materials and Journal of Multifunctional Composites.



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## Correlation between Projectile Kinetic Energy and Displaced Clay Volume for Three Classes of Armour

M. Bevan<sup>1</sup> and Q. Luong<sup>1</sup>

<sup>1</sup>The Johns Hopkins University Applied Physics Laboratory, 11100 Johns Hopkins Road, Laurel, MD 20723, USA, [Matthew.Bevan@jhuapl.edu](mailto:Matthew.Bevan@jhuapl.edu)

**Abstract.** Data analyzed from non-penetrating ballistic tests of flat armour against a clay backing showed that the kinetic energy of the impacting round correlated well with the total volume of displaced clay. An energy-based model was created using the projectile characteristics (diameter, mass and impact velocity) and armour areal density to predict the total volume of clay displaced for the range of projectile characteristics and armour combinations tested. This correlation suggests that the maximum backface deformation (BFD) clay criterion is a measure of energy density.

The projectile and armour combinations tested were: 1) 9x19 mm NATO against 28-layer Kevlar shootpacks, 2) 7.62x39 mm and 7.62x51 mm lead-core projectiles against 14 to 16 kg/m<sup>2</sup> ultra high molecular weight polyethylene composite armour, and 3) Armour-piercing 7.62x63 mm projectiles against ceramic plate/shootpack armour. Projectile velocities ranged from 100 to 850 m/s. Drop tower and air cannon testing against clay was also conducted to compare with ballistic results.

In this model, the energy dissipated was partitioned into two components: energy dissipated in the clay and energy dissipated by the armour-projectile interaction. For the shootpack and composite armour, the clay dissipates the majority of the projectile energy. In the ceramic armour system, the armour dissipates the majority of the projectile energy.

For the range of armour and projectiles tested, these results imply for a given armour areal density, that the stiffness of the armour (varying from soft fabric to ceramic plate) does not affect the total volume of clay displaced, only the shape of deformation.

### Curriculum Vitae: Matthew G. Bevan, Ph.D.

Presentation 7 Tuesday, October 2 9:00-9:30 am

Matthew G. Bevan, Ph. D. has worked at the Johns Hopkins University – Applied Physics Laboratory since 1991 where he is Principal Professional Staff. He has lead a number of projects for the US Army to protect the soldier and improve their equipment. These projects have focused on assessment of new equipment and characterization of the performance of personnel protective equipment, including developing new test methods to assess ballistic performance of body armour and helmets. Dr. Bevan received his Ph.D in Materials Science and Engineering from the University of Maryland and his Bachelor's degree from Carnegie-Mellon University.



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## Constitutive Modelling of Ballistic Roma Plastilina No. 1 Clay

Y. Q. Li<sup>1</sup>, X.-L. Gao<sup>1</sup>, V. A. Halls<sup>2</sup>, J. Q. Zheng<sup>2</sup>

<sup>1</sup> Department of Mechanical Engineering, Southern Methodist University, Dallas, TX 75275, USA  
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<sup>2</sup> Program Executive Office – SOLDIER, U.S. Army, Fort Belvoir, VA 22060, USA

**Abstract.** Roma Plastilina No.1 (RP # 1) clay has been widely used as a backing material in ballistic tests of body armour for over 40 years. However, the constitutive behaviour of RP # 1 clay is still not well characterized. In the current paper, a new constitutive model is proposed to describe the stress-strain relation of ballistic RP # 1 clay, which accounts for the coupled effects of strain hardening, strain rate hardening and temperature softening. The model is phenomenological and can be regarded as an extended Johnson-Cook model. The model contains nine parameters, all of which are calibrated using six true stress-strain curves at two deformation temperatures and three strain rates recently obtained at the U.S. Army Research Laboratory (ARL) based on compression tests. The newly proposed constitutive model with the calibrated parameters is applied to predict six other true stress-strain curves at another two temperatures, which are compared to the experimental curves that were also generated at the ARL. The non-uniqueness of the fitting parameter values is discussed, and an error analysis is conducted. The results of the error analysis show that the new constitutive model provides a fairly accurate prediction of the stress-strain behaviour of ballistic RP # 1 clay.

### Curriculum Vitae: Xin-Lin Gao, Ph.D.

Presentation 8 Tuesday, October 2 9:30-10:00 am

Dr. Xin-Lin Gao is currently a tenured full professor of mechanical engineering and the solid mechanics and manufacturing area director at Southern Methodist University, Dallas, Texas. His other experience includes teaching at UT-Dallas for 3 years, at Texas A&M University for 7 years, and at Michigan Tech for 4 years. In addition, he was a visiting professor at University of Paris-East. He received an M.Sc. degree in Engineering Mechanics in May 1997 and a Ph.D. degree in Mechanical Engineering (with a minor in Mathematics) in May 1998, both from the University of Wisconsin-Madison. He has authored 122 journal papers, 3 book chapters, and 142 conference and other publications. His publications have received 5237 citations, with an h-index of 35 and an i10-index of 81 (Google Scholar) as of June 15, 2018. He has been a PI or Co-PI of funded research projects worth about \$10M. He has been a reviewer for 114 journals, 10 publishers and 14 funding organizations and has organized 27 symposia at major international conferences. He has been an editor/guest editor of one book and four special journal issues. He currently serves on the editorial boards of six journals. He was elected an ASME Fellow in December 2010.



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## Comparison of Various Gelatine Surrogates for Wound Track Assessment

C. Bir<sup>1</sup>, R. Villalta and M. Bodo<sup>2</sup>

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<sup>2</sup>Laboratoire Interdisciplinaire Carnot de Bourgogne UMR, CNRS 6303, Univ. Bourgogne Franche-Comte, UTBM, F-90010 Belfort, France

**Abstract.** Ordnance gelatine has been used extensively in the ballistic community for the evaluation of bullet-soft tissue interaction. Techniques for its use have been established to produce both 10% and 20% mixtures. However, this process is time consuming and requires precise techniques in order to produce a final mould that is within specifications. In addition, there is a requirement of temperature control post-production and limitation on the length of use. Therefore, several manufacturers have produced room temperature stable, pre-mixed "gelatine" that does not require a substantial amount of time to use. Although there is evidence that these new products pass the simple BB pellet calibration, it is unclear how they compare to the gold standard of ordnance gelatine in terms of live fire ammunition. A total of five (5) different types of blocks were used in this study: 10% and 20% ordnance gelatine, 10% and 20% Clear Ballistics and Perma-Gel (10%). Blocks were tested using a 9 mm and 380 Auto round fired from a universal receiver. Chronographs were placed prior to and immediately after each block tested to determine the delta-V and total energy dissipated. The blocks were examined post-test along with the high-speed video of the event. Data indicate differences in the energy dissipation throughout the block and overall fissure formation in the gelatine with higher energies and more fissure formation in the ordnance gelatine. In addition, based on the high-speed video, a secondary combustion appears to occur within the premixed gelatines.

### Curriculum Vitae: Cynthia Bir, Ph.D.

Poster 1 Tuesday, October 2 10:00-10:05 am

Dr. Cynthia A. Bir is a Professor in the Emergency Department at the Keck School of Medicine at the University of Southern California. She has extensive research experience in the area of human injury tolerances. Her research interests include sports injury biomechanics, ballistic impacts, blast injury, and forensic biomechanics. She has studied the effects of impacts to all regions of the body and is known world-wide for her work in this area. Dr. Bir currently has funding for various research efforts in the area of injury biomechanics. Investigating the effects of ballistic impacts to the human body, her research includes Behind Armor Blunt Trauma (BABT) and the assessment of personnel protective gear. She also has funding to assess stab/slash wounds to correctional officers, the effects of Tasers on vulnerable populations, and how body armour affects the core body temperature of the end users. She has been funded by the Department of Defense to study both blast neurotrauma and lower extremity injury research. Her sports related research includes the development of a new thoracic surrogate to evaluate chest protectors, a cumulative concussion model and real-time data collection of head impacts in boxing.



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## New Metrologies to Assess the Dynamic Response of Soft Protective Materials used in Helmets and Pads

A. M. Forster and M. Riley

Material Measurement Laboratory, National Institute of Standards and Technology, MS 8102, 100 Bureau Dr., Gaithersburg, MD 20899  
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**Abstract.** Blunt trauma and brain injury can occur during impacts at energies and velocities below those observed in ballistic and blast events. During low to medium velocity impacts, the shell prevents helps to prevent bone fractures and the padding helps limit the maximum linear or rotational acceleration of the head. Current test methods focus on the helmet and padding as a system (pad + shell) to quantify protective levels the equipment provides for the user. System level tests involve complicated loading paths, that make it difficult to determine the performance of the padding material within the helmet system to reduce the effects of impact. This lack of information complicates the process for improving helmet materials. NIST has recently developed a set of metrologies to quantify the impact mitigating properties of soft, non-linear materials under a broad range of impact energies and loading scenarios. These measurements can provide a more complete picture of *material* performance in order to guide incorporation of new materials into the helmet or padding system. This presentation will describe these metrologies and demonstrate their usefulness on several common energy absorbing materials.

### Curriculum Vitae: Aaron M. Forster, Ph.D.

Poster 2 Tuesday, October 2 10:05-10:10 am

Dr. Aaron Forster is a Materials Research Engineer at the National Institute of Standards and Technology (NIST) in Gaithersburg, MD where he works in the Security Technologies Group. His research focuses on the effects of environmental aging on nanocomposites, semi crystalline polymers, and high strength fibres used in many protective systems. His group utilizes in-situ characterization methods to support models of mechanical and fracture properties as a function of time, length scale, and strain rate. A second research focus is the dynamic response of soft foams and elastomers for impact protection. Recently, he was a part of NIST participation in the Head Health Challenge III.



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## Thermo-Rheological Characterization on Next-Generation Backing Materials for Body Armour Testing

Ran Tao<sup>1</sup>, Aaron M. Forster<sup>1</sup>, Kirk D. Rice<sup>1</sup>, Randy A. Mrozek<sup>2</sup>, Shawn T. Cole<sup>2</sup>, Reygan M. Freeney<sup>3</sup>

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<sup>2</sup>U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, USA

<sup>3</sup>U.S. Army Aberdeen Test Center, Aberdeen Proving Ground, MD, USA

**Abstract.** The current standard backing material used for ballistic resistance testing of body armour, Roma Plastilina No. 1 (RP1), is known to exhibit complex thermomechanical behaviour under actual usage conditions. Body armour test standards that specify RP1 often establish a performance requirement for the RP1 before it can be used. To meet this requirement, RP1 most likely must be temperature conditioned. This conditioning step adds to the complexity of the test and introduces temperature-time variables into the test, which serve as incentives for finding potential alternative materials that perform similarly at room temperature. To achieve the goal of replacing the current standard backing material, the U.S. Army Research Laboratory (ARL) and U.S. Army Aberdeen Test Center (ATC) have taken the lead to develop a family of room-temperature backing materials that exhibit dynamic properties that are consistent and similar to temperature-conditioned RP1. These candidate materials, named ARTIC, have fewer components than the RP1 clay. The research at NIST focuses on rheological characterization and thermal analysis of these next-generation backing materials to understand structure-property relationships and compare to the current RP1. In this work, we show that ARTIC materials exhibit minimal temperature dependence of mechanical properties and consistent thermal properties over a wide temperature range.

### Curriculum Vitae: Ran Tao, Ph.D.

Poster 3 Tuesday, October 2 10:10-10:15 am

Dr. Tao is a guest researcher in the Security Technologies Group at the National Institute of Standards and Technology. Her current research interests include nonlinear rheology study of ballistic witness materials and performance additives utilized in personal body armour. Dr. Tao is developing rheological test protocols for stiff materials like clays. She is also interested in seeking future candidate materials as performance additives or promising fibre composite materials, in an effort to develop a more flexible and lightweight ballistic body armour system with excellent strength and energy absorbing capacity. Prior to joining NIST, Dr. Tao obtained her Ph.D. in chemical engineering in May 2015 from Texas Tech University, where she was trained to be a rheologist and a material scientist. Ran's doctoral research focused on polymer physics, rheology, structure-property relationships, and characterization of polymers and complex fluids.



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## Ballistic and Non-Ballistic Requirements and their Effects on PE Helmet Weights

**M. Latreche**, S. Samborsky, G. Czeremuszkina, Justin L'Archeveque,  
and V. Lucuta

*Revision Military Inc., 3800 Saint Patrick, Suite 200, Montréal, Québec, H4E 1A4, Canada*

**Abstract.** It is recognized that the modern helmet is not only a device designed to prevent head injury from fragments and blunt impact, but also a platform to provide the soldier with new capabilities to enhance their survivability and operational capability. The design of the modern helmet system involves multiple trade-offs, but at the heart of the system is the composite shell that requires trade-offs between weight, performance, and cost. New materials and processing techniques allow for helmets with increased ballistic protection at the same weight, or the same protection levels at reduced weight, or some combination in between. However, with the latest in materials and processing, the ballistic performance requirements may no longer be limiting the maximum weight reduction. Instead, non-ballistic requirements such as blunt impact, indentation, and compression might provide the limit on weight reduction. This paper will identify the trade-offs to be made between weight reduction and non-ballistic requirements, and verify any effect on the  $V_{50}$  performance. Flat panels, which can be correlated to helmet designs, are used for ballistic and mechanical testing to better understand how current measurements specified are affecting lightweight UHMWPE materials. For mechanical testing, established standards ASTM D790 and ASTM D5420 are utilized. All test data will be used to assess how modifying mechanical specifications can be utilized to provide further reduction in weight burden to the end user if certain additional specifications can be traded.

### **Curriculum Vitae: Mohamed Latreche, Ph.D.**

Presentation 9 Tuesday, October 2 10:45-11:15 am

Mohamed Latreche joined Revision Military as a Director of Advanced Materials Research in January 2010. Mohamed, has a PhD in Materials sciences and vacuum thin-film functional coating science and technology, he has over 18 years of experiences in research and development in industry and academia. He has worked with coatings and thin films for a wide range of applications that includes defence, microelectronics, and pharmaceutical and food packaging industries. His experience includes R&D projects management, Coordination of R&D collaborative efforts with other departments, process development and optimization, materials characterization, surface analysis, development of new testing methods. More recently, he conducted development programs on materials, components and systems for armour plates and military helmets. Mohamed holds two patents and has published numerous papers in international journals and conference proceedings.

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## Assessment of the secondary fragments from buried explosives

M.J van der Jagt-Deutekom and T.A.T. Westerhof

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marjolein.vanderjagt@tno

**Abstract.** Different test methods are used to assess the performance of personal protection equipment (PPE) against secondary debris, such as soil, grid and stones, ejected when a buried improvised explosive device (IED) detonates. However no standard scientific test and evaluation methodology exists for this type of threat. One of the reasons is the difficulty in defining the proper threat characteristics. The velocity, mass and distribution of the ejected secondary fragments resulting from a buried explosive are depending on the type, shape and mass of the explosive charge, the material type, size and the mass of the secondary fragments, the depth of burial and the distance from the explosive. This paper describes the results of an arena test series to determine the threat characteristics from a buried IED. These results consist of the secondary fragment properties (velocity, mass and distribution) and the pressure and impulse at different distances from two specified buried explosive charges buried in two soil types. This data will be used by TNO to draft a first standard test methodology.

### Curriculum Vitae: Marjolein van der Jagt-Deutekom

Presentation 10 Tuesday, October 2 11:15-11:45 am

Marjolein van der Jagt-Deutekom was educated at the Delft University of Technology, aerospace engineering, at the materials department (master thesis in 1994). Since 1997 she is working in the field ammunition effects and ballistic protection at TNO. Main part of her work is examining explosive and ammunition effects on protective materials and the effects on the protected and unprotected human.



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## A review of ballistic testing methodologies for Hard Armour Plates in conjunction with, and without, Soft Armour Inserts

Ian G Crouch<sup>1</sup>, James D Sandlin<sup>2</sup> and Deepak Ganga<sup>2</sup>

<sup>1</sup> *Armour Solutions Pty Ltd, Hollyoak House, Trentham, Victoria 3458, Australia*

<sup>2</sup> *Defence Materials Technology Centre, Hawthorn, Victoria 3122, Australia*

**Abstract:** The ballistic testing of ceramic-based, lightweight armour systems like Hard Armour Plates (HAPs) is always extremely challenging because of the brittle nature of ceramics and the limited size and reproducibility of the products in question. This paper reviews alternative methods of determining  $V_{50}$  values in situations where either military or civilian standards leverage off existing test methodologies from organisations like the National Institute of Justice (NIJ) in the USA. In particular, results of two parallel  $V_{50}$  assessments involving more than 100 Level IV HAPs, tested as Stand Alone plates, will show that a favoured method is flawed whilst an alternative approach is highly recommended, especially for inclusion in future Test Standards. This new approach is based upon recent understanding of the evolution of damage during the testing of multi-strike plates with up to six rounds. Whilst it is well recognised that shot spacing strongly influences penetration resistance, variables such as shot location and shot sequence are less well understood. This new suite of impact data is supported with high-resolution, digitized X-ray images of damaged HAPs. Two other critical aspects will also be included. First, when testing HAPs in conjunction with Soft Armour Inserts (SAIs), both the size and shape of the supporting SAI have been found to affect the ballistic performance of the total ensemble. Second, data on the decrease in ballistic performance, as the Point of Strike (PoS) approaches a free surface, will also be reported. This information provides the User with valuable data on effective coverage, which can range from 70-90% of the surface area of the HAP.

### Curriculum Vitae: Ian G. Crouch, Ph.D.

Presentation 11 Tuesday, October 2 11:45-12:15 pm

Dr Crouch has been Managing Director of Armour Solutions Pty Ltd since July 1999 after leaving Thales (then ADI Limited) where he led the Advanced Composites R&D group in Sydney, and Carrington, NSW. He obtained his BSc (Metallurgy) and PhD (Material Science) from Leeds University before working for the UK Defence Research Agency (now DSTL) for 18 years. Most of that time was spent researching the fundamentals of armour materials and developing new material systems. From 2008, until 2013, he headed the Armour Technologies division at Australian Defence Apparel (ADA) responsible for design, development and production of body armour components, especially those for the UK MoD, the Australian Defence Force and various Police Services around the world. Since 2009, he has initiated, and led, R&D programs for the Defence Materials Technology Centre, Australia, and has successfully spearheaded commercialisation of new forms of ceramic armour and body armour systems. He has recently acted as Editor, and Lead Author, of the text, "The Science of Armour Materials", published by Elsevier in October 2016, and continues to act as an armour consultant. In July 2018, he was appointed to the position of Professor, Hard Armour Protection, at RMIT University, in Melbourne.



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## Next Generation of Lightweight Materials for Military and Police Applications

**A. Bhatnagar<sup>1</sup>**, David Hurst, Greg Davis, Gary Kratzer, Dave Steenkamer, and Lori Wagner

*Honeywell International Inc. 15801 Woods Edge Road, Colonial Heights, VA, 23834 USA*

**Abstract.** Since the introduction of UHMWPE fibres, coupled with cross-ply technology and improved moulding processes<sup>1</sup>, the weight of military and police vests, breast plates, helmets and panels for military vehicles has been continuously reduced by about 1-2% per year<sup>2</sup>. After extensive research and development, new lightweight materials and laminated materials have recently been commercialized. These materials enable a major step change in reduction of the overall weight of the vests, increased ballistic performance of composite helmets, and weight reduction of stand-alone and In Conjunction (IC) breast plates.

This paper will review material development and testing phases of these new materials while keeping in mind the military and police need for reducing weight and improving protection against increased threats. Examples of vest design and moulded breast plate are presented.

### **Curriculum Vitae: Ashok Bhatnagar, Ph.D.**

Poster 4 Tuesday, October 2 12:15-12:20 pm

Dr. Ashok Bhatnagar has a Master and PhD in the area of Composite Materials. He is with Honeywell International Inc. for the last 33 years. Since 1998 he has attended and presented Papers at PASS. Dr. Bhatnagar has more than 65 ballistic Patents and edited two books title "Lightweight Ballistic Materials" first and second edition.



## Notes

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## Failure Analysis of Cross-plyed Ballistic Materials used in Law Enforcement Vests

Dr. S. D. Rajan<sup>1</sup>

<sup>1</sup>Professor, School of Sustainable Engineering and the Built Environment, Arizona State University, Tempe, AZ 85287, USA  
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**Abstract.** The objective of armour systems is to provide the requisite protection against identified threats at the lowest possible add-on weight and cost. A number of criteria must be considered when selecting materials for use in an armour system. These include the characteristics of the specific threats to be defeated, the allowable volume and weight parameters of the system, and the system cost. For example, a material that provides adequate protection against specific threats in one system configuration may become inadequate if the permissible system weight is reduced [1]. For this reason, a number of different materials have been used in armour systems. Historically, development of armour materials has been a trial and error process. Optimization of armour design with a set of available materials (or the invention of new materials) in a cost effective way is feasible only if a systematic process is followed to understand the mechanism of ballistic protection. Therefore, computer modelling of material behaviour is critical in understanding the effect of various parameters and, in turn, optimizing the material design [2, 3]. In this paper, we discuss the systematic development and use of a computer modelling system for the optimal design of personal protection systems specifically to defeat handgun bullets such as 9 mm FMJ, 357 Magnum and 44 Magnum. The design framework illustrates how accurate material and finite element (FE) models can be developed and used to simulate the deformation, damage and failure of composites under impact conditions. With increasingly sophisticated experimental and modelling techniques, it may be possible to design the next generation armour protection with minimal add-on weight and cost in a shorter design cycle time.

### Curriculum Vitae: Subramaniam Rajan, Ph.D.

Poster 5 Tuesday, October 2 12:20-12:25 pm

Subramaniam ("Subby") D. Rajan is a Professor of Civil, Aerospace and Mechanical Engineering at Arizona State University. His research interests are in the areas of computational and experimental mechanics involving basic tools such as finite element analysis, advanced experimental techniques, high-performance software development, materials development and processing, and design optimization. He has worked as a PI and co-PI on sponsored research from US government agencies such as the National Science Foundation, NASA, Federal Aviation Administration and the US Army. Over the last fifteen years he has been working to find effective solutions to ballistic and blast problems working with FAA (fabric-based engine containment system), NASA (modeling composites for impact problems) and DoD (ARO – blast mitigation, TSWG – ultra-concealable armor, SOCOM – low areal density body armor) both as a faculty member at ASU and by consulting with leading manufacturers of body and vehicular armor.



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## A numerical model of oblique impact of an RCC projectile into a flexible fibrous composite mimicking 0°/90° UD construction

S.L. Phoenix<sup>1</sup> and A. K. Yavuz<sup>2</sup>

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**Abstract.** For the past several years a group at Cornell University has been developing numerical models for ballistic impact into layered fibrous systems consisting of orthogonal, UD tapes and plain weave fabrics. The projectiles have included hard right circular cylinder (RCC) and spherical shapes, and viscoelastic interactions and slip between the projectile and target and between target yarns and layers have been modelled. Besides exploring new phenomena, these models have been useful for validating previous analytical models where various simplifying assumptions were necessary. Thus far the numerical models have had the limitation (though a computational advantage) of assuming a symmetric framework whereby numerical solution of only one quarter of the projectile and target region was necessary. Hence, only normal (perpendicular) impact could be studied. To address this limitation, attention has been devoted to modelling projectile impact into the full target plane thus making it possible to treat oblique impact at an arbitrary angle. This also makes it possible to investigate various boundary effects (clamped, free) where projectile impact occurs close to one boundary or near a corner. Such generalizations have resulted in formidable challenges arising from rapid projectile sliding on a target, and thus, it has been necessary to return to simpler discretization versions of angled impact by an RCC on a biaxial, plate-like structure. These challenges have motivated scrutiny of certain features in the results, initially suspected of being numerical artefacts, and establishing through well-understood test cases that the features observed are indeed legitimate. The most important findings involve a study that varies both angle of projectile incidence and coefficient of viscous sliding friction between an RCC projectile and fibrous target. It is shown that increasing the degree of viscous friction eventually leads to increasing fibre strain with increasing angle of incidence up to some angle where a maximum is achieved. Generally, oblique impact gives rise to important phenomena not captured by projectile impact perpendicular to the target.

### Curriculum Vitae: Stuart Leigh Phoenix, Ph.D.

Poster 6 Tuesday, October 2 12:25-12:30 pm

After receiving his Ph.D. in 1972 in Theoretical and Applied Mechanics from Cornell University, Phoenix worked for two years as a senior research associate at Fabric Research Laboratories, in Dedham, Massachusetts. He joined the Cornell faculty in 1974, where he is currently a full professor in the Sibley School of Mechanical and Aerospace Engineering. In 1983, Phoenix received the Fiber Society Award for Distinguished Achievement in Basic or Applied Fiber Science, and in 1992 he won the American Society for Testing and Materials' Harold DeWitt Smith Award for his work in the mechanics of fibrous assemblies. In 2005, he received the NASA NESC Engineering Excellence Award for his work on evaluating the reliability and remaining life of the Kevlar/epoxy composite overwrapped pressure vessels on the Shuttle, in support of its Return to Flight in 2005 after the Columbia accident. In the last 15 years he has turned much of his attention to modelling the ballistic impact response of soft body armour where he has published highly referenced papers. He also continues to do research in modelling the mechanics and reliability of composite overwrapped pressure vessels and is co-lecturer of an annual IAASS sponsored course on the topic.



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## Evaluation of Degradation Models for High Strength *p*-Aramid Fibres Used in Body Armour

K.D. Rice<sup>1</sup>, A. Engelbrecht-Wiggans<sup>2</sup>, E. Guigues<sup>1</sup>, and A.L. Forster<sup>1</sup>

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kirk.rice@nist.gov

<sup>2</sup>Theiss Research

**Abstract.** To improve the reliability and design of armour, it is imperative to understand the failure modes and the degradation rates of the materials used in armour. Despite the best efforts of manufacturers, some vulnerability of armour materials to ageing due hydrolytic or oxidative environments is expected and may result in the degradation of material properties such as tensile strength. In this work, *p*-aramid yarns from two manufacturers were exposed to environmental conditions of various fixed temperature and humidity combinations. The maximum temperature and humidity condition was 70 °C, 76 % RH, to avoid introducing degradation mechanisms unlikely to be seen in use. Tensile tests were performed on samples extracted at several different timepoints over the course of at least one year to determine degradation in ultimate tensile strength and failure strain as a function of time, temperature, and humidity. These materials were found to be generally resistant to degradation at most conditions, only showing changes of less than 10 % at the highest temperature and humidity conditions.

### Curriculum Vitae: Kirk D. Rice

Presentation 12 Tuesday, October 2 1:30-2:00 pm

Kirk Rice joined the National Institute of Standards and Technology in 1998 to lead research and standards activities related to personal protective equipment. Notable among his roles were partnering with the National Institute of Justice to provide technical research in support of the Attorney General's Body Armor Safety Initiative, which was focused on questions about the long-term performance of PBO-based body armor; drafting standards recommendations that were largely adopted in the current version of the NIJ body armor standard; and establishing a framework for developing technical standards through ASTM International, an ANSI-accredited standards developing organization. He has degrees in Chemical Engineering and Engineering Administration, and is currently a PhD student at the University of Maryland.



## Notes

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## Effect of matrix variation on the high strain rate performance of UHMWPE Composite

Hemant Chouhan<sup>1</sup>, N Asija<sup>1</sup>, A. Yadav<sup>1</sup>, A. Ahmed<sup>1</sup>, and Naresh Bhatnagar<sup>1</sup>

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**Abstract.** The compressive high strain rate behaviour of ultra-high molecular weight polyethylene (UHMWPE) fibres with two different matrix materials has been studied on split Hopkinson Pressure bar (SHPB), followed by ballistic limit ( $V_{50}$ ) determination. The composite laminates were fabricated by compression moulding and a circular specimen of desired aspect ratio  $0.5 \pm 5\%$  were produced using two matrices Kraton and polyurethane (PU) with UHMWPE fibres. High strain rate impact studies were carried out in the strain rate range of  $2100 \text{ s}^{-1}$  to  $4220 \text{ s}^{-1}$ . In general, both the composites exhibited an increase in compressive strength, which rises to over double the initial value with increasing compressive rates of loading. Kraton based composites revealed a sharp stress rise followed by strain growth at constant stress till a limiting strain. Polyurethane matrix based composite attained higher peak stress for the given incident impact energy with a continuously rising stress curve. The peak stress attained by Kraton and polyurethane matrix based composite was 457 MPa and 675 MPa, respectively. These values served as the maximum values of stress for a given composite system with the initiation of macroscopic specimen damage in the form of delamination. The  $V_{50}$  for both the composite systems with 17-grain non-deformable steel fragment simulating projectile (FSP) was determined as 528 m/s for Kraton and 536 m/s for PU based composite, respectively. The study reveals an effect of the matrix on ballistic performance of UHMWPE fibre based composites.

### Curriculum Vitae: Naresh Bhatnagar, Ph.D.

Presentation 13 Tuesday, October 2 2:00-2:30 pm

Dr. Naresh Bhatnagar completed his PhD in 1992 from IIT Bombay and worked in Industry FIAT Auto before joining academics. Being the originator of research in the area of "Machining of Composites" at IIT Bombay in the early 1990's, which is still considered relevant to the growth of future defect free reliable structural products of FRP composites be it in defense, aerospace or automotive applications. Last 20 years at IIT Delhi has also seen him venturing into multidisciplinary research cutting across departments / centers/ institute and country in areas of polymer material processing leading to products, biomedical implants, biomaterials, nano composites, microcellular injection moulding, microcellular extrusion of porous plastic sheets, bullet proof materials and new ways of testing and characterization of polymeric composites and related manufacturing technologies. He has supervised 19 PhD- 16 are ongoing, 75 Masters Thesis in variety of areas related to materials, manufacturing and medical devices. He has published 90+ International peer reviewed journals and 120+ in international/national conferences. Dr. Bhatnagar earlier also shared the responsibility of Associate Dean (Research & Development) at the Indian Institute of Technology Delhi.



**Notes**

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# Finite Element Modelling of Impact on Composites made with Dyneema®

M. Hazzard<sup>1,3</sup>, U. Heisserer<sup>1</sup>, H. van der Werff<sup>2</sup>, P. Curtis<sup>4</sup>, and S.R. Hallett<sup>3</sup>

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**Abstract.** This contribution provides a finite element methodology to capture the behaviour of Dyneema® fibre UD composites at quasi-static rates of deformation, under low velocity drop weight impact, and high velocity ballistic impact. A homogenised sub-laminate approach separated by a cohesive tied interface using fracture mechanics was employed to capture the behaviour of panels made with Dyneema® HB26. The modelling approach uses readily available material models within LS-DYNA, and validates material behaviour against experimental observations in literature. Plane-strain beam models were in good agreement with literature, providing accurate mechanisms of deformation largely controlled through Mode II cohesive zone properties and kink band formation. Ballistic impact models utilising rate effects and damage showed similar modes of deformation and failure to that observed in literature, and provide a good approximation for ballistic limit and back face deformation under 600 m/s impact speed. The mechanisms of failure in the model were also investigated, which highlight the transition zone between progressive failure on the strike face to bulge formation at the rear. A numerical study highlights the effect of varying material parameters such as fibre tensile strength, which provide benefit in terms of ballistic limit and back face deformation.

## Curriculum Vitae: Mark Hazzard, Ph.D.

Presentation 14 Tuesday, October 2 2:30-3:00 pm

Graduated with a PhD in composite materials from the University of Bristol in 2017, with focus on the impact performance of ultra-high molecular weight polyethylene fiber composites. This involved mechanical materials characterization as well as finite element modelling of high speed impact and was supported by dstl. Prior to this I completed a master's degree in aerospace engineering in 2011, also at the University of Bristol gaining broad knowledge relating to aviation and aircraft. I am currently continuing materials research within the DSM materials science center in Geleen, The Netherlands.



## Notes

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## Ballistic Limit Used Body Armour Study of Select NIJ 0101.06 Certified Armour - Levels II and IIIA

R. Kinsler

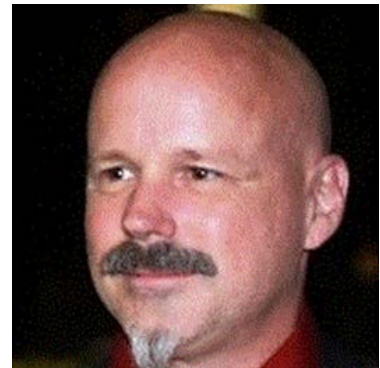
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**Abstract.** Fifty used body armour vests consisting of six (6) different models selected from more than 300 donated by law enforcement agencies around the USA were ballistically evaluated to determine if known life-cycle conditions influence the ballistic response. The down-select criteria were; vests originally certified to the NIJ 0101.06 standard, approximately five (5) years old, and provided the largest sample quantity within a specific model. Eligible models consisted of a sample quantity of at least five (5) vests allowing for a minimum of 10 12-shot tests. The models meeting the criteria originated from the eastern half of the United States. For testing, each vest was separated into front and back panels and each panel was subjected to a 12-shot  $V_{50}$  test following the up-and-down methodology. The resultant  $V_{50}$ 's with confidence intervals were determined using logistic regression. These  $V_{50}$ s were analysed with the known variables to attempt to determine which variables had the most influence on the ballistic response. As there were a limited number of vests tested, the results of this study only provide an indication of how used body armour vests may respond. Results indicate that mass, size and visual condition may influence the resultant  $V_{50}$  while none of the other known variables produced a statistically significant difference within a given model. When evaluating the published versus the resultant  $V_{50}$ 's, it appeared that some models had a slightly higher and some had a slightly lower  $V_{50}$  than the published results.

### Curriculum Vitae: Robert Kinsler

Poster 7 Tuesday, October 2 3:00-3:05 pm

Robert Kinsler is Chief of Technical Operations for HPW and is considered one of the leading national consultants in the area of PPE. Mr. Kinsler came to HP White after over 30 years with the Army Research Laboratory Survivability/Lethality Analysis Division where as Chief Analyst at the Peepsite facility, he developed new methodologies for ballistic testing of PPE. He participates actively in numerous ASTM committees and collaboration areas for testing of PPE, is a technical accreditor for ballistic laboratories for National Voluntary Laboratory Accreditation Program (NVLAP), and actively participates in the NIJ Body Armor Special Technical Committee (STC). He has presented his findings on ballistic PPE evaluation at numerous conferences to include NDIA, IDGA, and PASS.



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## A new contact free scanning procedure for personal armour

H. Buchmann<sup>1</sup>, H. Gedon<sup>2</sup> and T. Krell<sup>2</sup>

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<sup>2</sup>Bundeswehr Research Institute for Materials, Fuels and Lubricants, Institutsweg 1, D-85435 Erding, Germany

**Abstract.** Ceramic plates in personal armour are primarily built to resist ballistic load, but they are also subject to serious mechanical load during the regular service. Because of their specific construction with a ceramic plate in front and a glue fixed backing, consisting of high modulus fibres like aramid or UHMWPE in the back, the plates seem to be very stable against mechanical loading. Nevertheless due to overload the ceramic plates may crack, but not only for example by using these armour plates as a hammering device or as an off road driving support, but also during mission or regular exercises. Caused by the typical ceramic failure, occurring cracks always extend the whole thickness of the plate. Using a glued construction cracks normally show a hair crack character in the beginning, but during use with mechanical and thermal stress these cracks may open and cause a so-called ballistic hole. To avoid diversifiable risks, in consequence ballistic plates are subjected to non-destructive radiographic testing, with x-rays as the preferred method. But independent of using x-rays or alternative methods, all current procedures either need to take the ballistic plate out of the personal armour or at least to contact the plate with an electrical device or a tapping one. Using a modified RFID-technology it can be shown that it is possible to check ballistic plates in the assembled condition effectively both very cheap and very easily worldwide and without any specialized professional operator. In consequence a daily check of the personal armour can be done without the only restriction that you need an electrical source. The new technology with the technical details will be presented and also the range of the electromagnetic response of the transponders in dependence of different temperatures.

### Curriculum Vitae: Harald Buchmann

Poster 8 Tuesday, October 2 3:05-3:10 pm

Harald Buchmann is an established & internationally recognized RFID expert and with almost 25 years of experience. He holds a Master of Science in Physics and is coinventor of several patents in the field of RFID and Sensor Technology. For more than 10 years he was Managing Director for Brooks Automation in Germany and at the same time he was Director of RFID systems worldwide, the assigned market leader in this sector. Harald is now working as CTO at Xedion AG in his home country Germany.



## Notes

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## Investigating the Contribution of Different Suspension Systems to the Ballistic Protection of Combat Helmets (Peak Acceleration & Back Face Signature)

R. Ratrou1, H. Al-Ta'amneh1, M. Al Afifi2, S. Al Majali1, M. Alassi2, I. Rawashdeh1, A. Aldaradkeh1, A. Al Sardyah1 and S. Obeidat1

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<sup>2</sup>First Armour, Amman 11192, Jordan

**ABSTRACT.** Combat helmets play a vital role in protecting the soldier's life; whether by resisting the penetration of kinetic threats (Bullets, Fragmentation) or by protecting the neck and brain from the behind helmet blunt trauma (BHBT) and rapid acceleration induced upon impact. The suspension system in combat helmets consists mainly of a liner that covers the interior of the helmet shell. These pads are designed from materials that absorb and dissipate the excessive energy exerted on the neck and brain upon impact. This study was conducted to investigate the difference in performance of different suspension systems used in combat helmets and to investigate the effect of adding a suspension system on the peak acceleration and back face signature. However, this study serves more as a learning exercise for the generation of researchers to guide them through the test methods and standards that allows them to study this topic in greater depth.

Six helmets with different suspension systems were tested according to NIJ Standard 0106.01 for ballistic impact attenuation and HPW-TP-0401.01B for back face signature (BFS) against 9 x 19mm Luger FMJ copper alloy bullets. Results showed that the six designs have recorded peak accelerations of less than 400g while the helmet with the Logistic Liner had the lowest value of BFS making it the superior helmet suspension system of all six.

### Curriculum Vitae: Riyad Ali Ratrou, Ph.D.

Poster 9 Tuesday, October 2 3:10-3:15 pm

Dr. Ratrou received a Ph.D. in Mechanical Engineering/Materials in 1999. He has been employed in various roles at the Test and Evaluation Center of King Abdullah II Design and Development Bureau (KADDB) in Jordan since 2001. He is currently serving as the head of weapons, ammunition and armour testing, the head of the ballistic testing laboratory, and a certified innovation manager at KADDB.



## Notes

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# Improvement of Ultra High Molecular Weight Polyethylene Armor Structures with Numerical Simulations

Arash Ramezani and Hendrik Rothe

*Chair of Measurement and Information Technology, University of the Federal Armed Forces Hamburg, Germany, ramezani@hsu-hh.de*

**Abstract.** In the security sector, the partly insufficient safety of people and equipment due to failure of industrial components is an ongoing problem that causes great concern. Since computers and software have spread into all fields of industry, extensive efforts are currently made in order to improve the safety by applying certain numerical solutions. A fibre-reinforced composite is a promising material for ballistic protection due to its high strength, stiffness and low density. The use of ultra-high molecular weight polyethylene (UHMW-PE) composite as part of the personal armour system has the potential to provide significant weight savings or improved protection levels over traditional metallic materials. Although already used in different applications, both as spall liners and within complex multi-element/multi-material packages, there is a limited understanding of the mechanisms driving ballistic performance. Existing analysis tools do not allow a good approximation of performance, while existing numerical models are either incapable of accurately capturing the response of thick UHMW-PE composite to ballistic impact or are unsuited to model thick targets. In response, this paper aims to identify the key penetration and failure mechanisms of thick UHMW-PE composites under ballistic impact and develop analytical and numerical models that capture these mechanisms and allow accurate prediction of ballistic performance to optimize modern armour systems. An analysis methodology is proposed to model the behaviour of thick UHMW-PE composite panels under ballistic impact using inhomogeneities on the macroscale. A sub-laminate approach for discretisation of the target is proposed to overcome the problems of premature through-thickness failure in the material model. The methodology was extensively validated against existing experimental ballistic impact data and results for UHMW-PE targets. Finally, a numerical modelling methodology was developed for the analysis of thick UHMW-PE composite under ballistic impact.

## Curriculum Vitae: Arash Ramezani, Ph.D.

Presentation 15 Tuesday, October 2 3:45-4:15 pm

Arash Ramezani currently works as a research group leader in the Department of Mechanical Engineering at the University of the Federal Armed Forces in Hamburg. He has studied Applied Mathematics at the University of Bremen and the University of Queensland in Australia and received his Diploma degree in 2010. In 2015 he received his doctor's degree in engineering science. His research interests include modelling, simulation and visualization of ballistic problems. His university lectures consist of ballistics, optronics and computer science.



## Notes

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## Effect of STF packaging method on the impact resistance of UHMWPE ballistic composite

N. A. Bhalla<sup>1</sup>, H. Chouhan<sup>1</sup>, A. Ahmed<sup>1</sup>, A. Yadav<sup>1</sup> and N. Bhatnagar<sup>1</sup>

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neelanchali@gmail.com

**Abstract.** Shear thickening fluids (STFs) are a special class of field responsive non-Newtonian fluids which exhibit transition from low to high viscosity state when these are subjected to shearing deformation, particularly when the shear rate exceeds a critical value termed as the critical shear rate (CSR). Due to this unique characteristic of STFs, they are used in the development of special class of STF-treated armours called Liquid Body Armours (LBAs). These new age armours are lighter in weight and more flexible as compared to conventional heavy armours. Although, exhaustive studies are available which show the improvement in impact resistance of STF-treated high performance fabrics, but there are limited studies which explore the efficacy of STF treatment method on their ballistic performance. In this study, an attempt is made to understand this aspect. Three different methods were adopted for treating UHMWPE (Ultra High Molecular Weight Polyethylene) composite panels with STF. In the first method, extrusion foamed polymer sheets were impregnated with STF and kept between UHMWPE Gold Shield<sup>®</sup> specimens. This sandwich construction was then subjected to high strain rate testing on SHPB (Split Hopkinson Pressure Bar). In the second method, liquid STF was kept between Gold Shield<sup>®</sup> composite specimens and in the third method the UHMWPE Gold Shield<sup>®</sup> composite was itself treated with STF and then subjected to SHPB testing. The experimental strain rates attained in UHMWPE specimens during SHPB testing were of the order of 3120 to 15600 s<sup>-1</sup>. From the test results it was observed that in order to enhance the ballistic resistance, the STF must be impregnated into a ballistic material rather than keeping the STF in liquid form in a sandwich construction. Also, the impregnation of STF in a weak and fragile material like foamed polymeric sheet will further weaken the structure instead of improving its impact resistance.

### Curriculum Vitae: Neelanchali Asija Bhalla, Ph.D.

Presentation 16 Tuesday, October 2 4:15-4:45 pm

Neelanchali completed her B. Tech in Mechanical & Automation Engineering from Guru Gobind Singh Indraprastha University (GGSIPU) in 2002. Then she joined industry Ex-Instruments & Automation, an authorized channel partner of ABB Ltd, in 2002 and worked for five years in the field of industrial automation, before joining a technical institute JSSATE Noida in 2008, as a lecturer. She continued teaching till she joined M. Tech in July 2009 at GGSIPU. Subsequently, she topped M. Tech in the discipline of Nano Science & Technology to win gold medal in 2011. Thereafter, she joined Ph.D in Mechanical Engineering Department at IIT Delhi in 2011, and completed her Ph.D in 2017. Since then she has been working in the area of manufacturing and testing of ballistic composite materials under the guidance of Prof. Naresh Bhatnagar. She has authored and co-authored 11 referred international journal papers and presented 6 papers in international conferences and one paper in national conference. She has also co-authored a chapter on 'Durability of high performance ballistic composites', along with Prof. Bhatnagar.



## Notes

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## Evaluation of Prior Dents on Ballistic Performance of High Density Polyethylene Helmets

Andrew B. Geltmacher<sup>1</sup>, John J. Christopher<sup>2</sup>, John H. O'Donnell<sup>1</sup>, and Amit Bagchi<sup>1</sup>

<sup>1</sup>Naval Research Laboratory, 4555 Overlook Avenue, Washington, DC 20375 USA  
andrew.geltmacher@nrl.navy.mil

<sup>2</sup>Leidos, 11955 Freedom Drive, Reston, VA 20190 USA, currently at Aberdeen Test Center, Aberdeen Proving Grounds, MD 21005 USA

**Abstract.** The high density polyethylene (HDPE) helmets provide better resistance to penetration against higher energy ballistic impacts compared to the Aramid panels. One potential issue with HDPE is the ease of creating blunt impact damage or denting due to the increased compliance of HDPE when compared to Aramid materials. The key question is can the presence of prior dents compromise the ballistic impact protection capability of HDPE. The objective of this project is to determine the level of blunt impact damage at which the ballistic performance of HDPE is compromised. This paper addresses: a) effect of dents from blunt impacts on subsequent ballistic performance of HDPE, and the level of such damage at which ballistic performance starts to degrade for different ballistic threats; b) the effect, if any, of blunt impact damage on ballistic performance for different specimen geometries; and c) effect of indenter geometry on the subsequent ballistic performance.

A total of 73 specimens both with and without dents created by blunt impacts at multiple impact velocities and with different indenter shapes were tested for two different ballistic threats. In combination with previous first article testing on the helmets, the testing for this paper is sufficient to describe the above effects; however additional testing would be required for a complete statistical evaluation of the helmet response. The experimental data and the computer tomography based imaging data were used to assess the HDPE ballistic impact performance. The results from the different dent energies and ballistic threats show that the performance of the HDPE material is not degraded at lower dent energies or low velocity threats. However, for higher energies dents and high velocity threats, the ballistic performance of HDPE can be compromised. Additionally, the different indenter geometries produced different severity of blunt damage in the specimens. For standard blunt impact conditions, a large hemispherical indenter, which spreads out the deformation and damage, did not degrade the subsequent ballistic performance. However, a narrow cylindrical indenter, which produces localized deformation and damage, did degrade the ballistic performance of the HDPE specimens.

### Curriculum Vitae: Andrew B. Geltmacher, Ph.D.

Presentation 17 Tuesday, October 2 4:45-5:15 pm

Dr. Andrew Geltmacher received his M.S. and Ph.D. in Metals Science and Engineering from Pennsylvania State University in 1991 and 1994, respectively. He received his B.S. with high distinction and honors in Engineering Science and Mechanics from Pennsylvania State University in 1987. He joined the Naval Research Laboratory in 1994, first as a National Research Council Postdoctoral Fellow then as a contractor and finally as a government employee. His current research interests include understanding multi-threat energy dissipation mechanisms in soft armor materials, developing image-based finite element models to examine deformation and fracture of materials, and developing 3D experimental characterization techniques to examine mesoscale effects in 3D microstructures. He has co-authored over 50 refereed journal and conference publications. He is a member of TMS in the ICME and Mechanical Behavior committees.



## Notes

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# Finite Element Simulation to Determine the Effect of Knit Architecture on Ballistic Response

P. J. McKee<sup>1</sup>, and E. D. Wetzel<sup>1</sup>

<sup>1</sup>*U.S. Army Research Laboratory, Weapons and Materials Research Directorate, Aberdeen Proving Ground, MD 21005 USA  
philip.j.mckee2.civ@mail.mil*

**Abstract.** Knitted textiles are constructed from interlocking loops of yarn. Curvature in the yarn allows for bending to provide additional stretchability compared to woven textiles constructed from the same high-performance fibres. While woven textiles have been shown to have a higher ballistic performance, their lack of stretchability means they are not ideal for some specific applications such as extremity protection. The stretchability of knits allows them to move with the body to provide additional comfort and improved ballistic performance for applications where textiles made from commodity fibres would typically need to be used. However, the ballistic performance of knits has not been as well characterized as woven textiles. The goal of this work is to investigate how geometric parameters affect the response of knit textiles under ballistic loading to guide design of textiles for extremity protection. A finite element model is developed at the yarn level where the path of the yarn can be modified by input of geometric parameters. The goal of this work is to study the influence of changes to geometric parameters when a 76.2 mm single layer knit target is impacted by a 6 mm diameter spherical silica projectile. An increase in the width or height of knit loops results in an increased rate of stress propagation and a change in stretch response, which reduces the simulated maximum stress seen in the knit.

## Curriculum Vitae: P. Justin McKee

Presentation 18 Wednesday, October 3 8:30-9:00 am

P Justin McKee earned his masters in bioengineering from Clemson University in 2010. He started working at the U.S. Army Research Laboratory 2011 in the area of computational injury biomechanics. This research started with development of a human head finite element model and the implementation of a network approach to work towards understanding the effects of blast and blunt impact on the brain. In 2014 he began work to characterize knit textiles for extremity protection. This work includes experimentation as well as the development of a finite element model of a knit textile subject to ballistic loading. The goal of this effort is to evaluate and understand the factors that influence the performance of the knit to guide design of improved soft armor textiles.



## Notes

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## Indent depth and volume in the clay backing for soft and hard armour

**Timothy G Zhang**, Phillip A Jannotti, Sikhanda S Satapathy,  
Jason R Mcdonald, Brian E Schuster

*US Army Research Laboratory, Aberdeen Proving Ground, MD 21005, U.S.A.  
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**Abstract.** Ballistic impact tests were conducted on soft armour (shoot-pack) to characterize its material response. A laminate model and a yarn model were used to model the soft armour. Numerical analysis was carried out to understand the load transfer to a clay block behind the soft armour (Kevlar shoot-pack) and hard armour (Ultra-High-Molecular-Weight-Polyethylene composite). The depth, width and volume of the indentation in the clay were correlated to the impact kinetic energy for both soft and hard armours.

### **Curriculum Vitae: Timothy Zhang, Ph.D.**

Presentation 19 Wednesday, October 3 9:00-9:30 am

Timothy Zhang has Ph.D. in engineering mechanics. He was a postdoctoral scientist at Virginia Tech before he joined ARL in 2012 and worked as a Mechanical Engineer in the Weapons and Materials Research Directorate (WMRD) in the Soldier Protection Sciences Branch. He is currently working to develop numerical models to understand the ballistic/blast load transfer to the human head through helmet system.



## Notes

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## Can Clay Tell Us More Than Deformation?

K. A. Rafaels<sup>1</sup>, K. L. Loftis<sup>1</sup>, and C. A. Bir<sup>2</sup>

<sup>1</sup>United States Army Research Laboratory, 328 Hopkins Rd., APG, MD 21005, USA  
karin.a.rafaels.civ@mail.mil

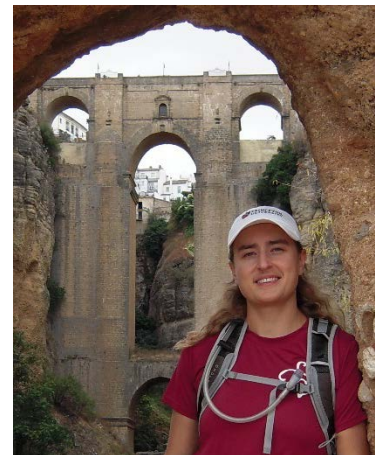
<sup>2</sup> University of Southern California, Keck School of Medicine, 1333 San Pablo Street, Los Angeles, CA 90033, USA

**Abstract.** The certification of body armour in many countries involves, in part, the evaluation of backface deformation into a clay medium. A tolerance level related to the maximum deformation in the clay is the current metric, however its relationship to injury has not been well established. This study investigates other potential metrics that can be obtained using the current clay medium to estimate the potential for injury from backface deformation. Reconstructions of several law enforcement survivor cases of behind-armour blunt trauma were performed to obtain the backface signature in clay for these events. The clay depth, volume, and an estimated Blunt Criterion (BC) were evaluated in terms of their ability to predict the corresponding injury. The estimated BC included target parameters such as chest depth, weight, areal density of armour and the contact area. Given these case studies, the BC has the best correlation with classifications of injuries with an  $R^2$  of 0.84, whereas the depth had an  $R^2$  of 0.33, and the volume was 0.11. Continued work is underway to fully understand the relationship between clay testing results and law enforcement injury cases.

### Curriculum Vitae: Karin A. Rafaels, Ph.D.

Presentation 20 Wednesday, October 3 9:00-9:30 am

Dr. Rafaels is the Team Leader for the Experimental Mechanics Team in the Soldier Protection Sciences Branch at the United States Army Research Laboratory. She has over 10 years of experience studying military injury, starting with her graduate school work at the University of Virginia's Center for Applied Biomechanics. Her research has spanned across many different models for human vulnerability, such as, biological surrogates, including animals and postmortem human subjects; mechanical surrogates, including various test devices for varying regions of the body; and mathematical models. Dr. Rafaels has numerous published papers in the field and is considered a subject matter expert in this area for the United States Army.



## Notes

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## Fragment Penetrating Injury to the Tibia

T-T. Nguyen<sup>1</sup>, D. Carpanen<sup>1</sup>, G. Tear<sup>2</sup>, D. Stinner<sup>1</sup>, J. Clasper<sup>1</sup>, W. Proud<sup>2</sup> and S. Masouros<sup>1</sup>

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<sup>2</sup>Institute of Shock Physics, Department of Physics, Imperial College London, London, United Kingdom

**Abstract.** Penetrating injuries to the extremities, especially the tibia, caused by fragments produced in explosions have been common in recent conflicts. These injuries are disabling, and involve high infection rates, slow recovery, and high risk of amputation. This study aims to develop an experimental model to identify the threshold of fragment penetrating injury through a series of tests on cadaveric ovine specimens. A 32-mm-bore gas gun was used to launch cylindrical fragment simulated projectiles (FSPs) of mass  $0.78 \pm 0.1$  g which can achieve an impact velocity up to 600 m/s. The ovine tibiae were either set in ballistic gelatin to represent the surrounding soft tissue or remained without any tissue simulant to investigate the importance of such simulant in this model. The tibiae were also either pre-compressed or suspended to reproduce differing plausible boundary conditions during gait. High-speed imaging was used to record the penetration event and calculate the velocity of the FSPs. The recovered samples underwent radiography and post-impact dissection to quantify the injury. Preliminary tests showed that  $205 \pm 10$  m/s of impact velocity can produce the same fracture patterns in the mid-diaphysis of the ovine tibia across different boundary conditions. In addition, the effect of soft tissue simulant in the outcome of injury can be considered separately. An injury risk curve for fractures classified as OTA 42-B1 type or higher was produced with the impact velocity at 50% risk to be  $147 \pm 12$  m/s. Appropriate scaling needs to be carried out in order to determine the injury risk to a human adult male.

### Curriculum Vitae: Thuy-Tien Ngoc Nguyen, Ph.D.

Poster 10 Wednesday, October 3 10:00-10:05 am

Dr. Thuy-Tien Nguyen completed her Bachelor and Master degrees in Physics at Imperial College London (London, UK) between 2008 and 2012. She then did her PhD with the Institute of Shock Physics (London, UK) on characterizing a shock tube system for various blast loading scenarios. During her studies, she participated in various teaching duties including assisting and supervising undergraduate projects, and delivering a master-level programming course. Thuy-Tien is currently a postdoctoral research associate at the Royal British Legion Centre for Blast Injury Studies at Imperial (London, UK) working on penetrating injury to long bones. Her main expertise is in developing dynamic loading platforms and techniques for investigations of primary and secondary blast injuries. She collaborates on research projects studying heterotopic ossification, blast injuries the respiratory tissues, organ injuries from blunt impact, and blast mitigating materials.



## Notes

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## The Effect of Handgun Threat Flight Dynamics on Backface Deformation in Soft Armour

K. A. Rafaels<sup>1</sup>, K. L. Loftis<sup>1</sup>, R. W. Weaver<sup>2</sup>, and C. A. Bir<sup>3</sup>

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<sup>3</sup>University of Southern California, Keck School of Medicine, 1333 San Pablo Street, Los Angeles, CA 90033, USA

**Abstract.** There are several factors that contribute to the ballistic performance of body armour including the flight dynamics of the incoming round. Studies have shown that differences in the impact yaw of rifle rounds can affect the response of armour systems. The level of backface deformation behind armour is one measure of this response, but the effect of impact conditions on this measure is not fully understood. The goal of this study is to investigate the effects of velocity and yaw of two different handgun rounds on body armour as measured by the resulting backface deformation in clay. Soft armour shoot packs were used to evaluate two rounds (9 mm and 0.45 ACP), two velocity conditions and two positions within the yaw cycle. For both rounds, the degree of backface deformation was dependent on the velocity of the incoming round with an  $R^2$  of 0.61 for the 9mm and 0.84 for the 0.45 ACP, but not on the yaw angle as the  $R^2$ -value for both the 9mm and 0.45 ACP were less than 0.05. In conclusion, the yaw cycle for the 9mm or 0.45 ACP was not shown to be a factor affecting clay backface deformation.

### Curriculum Vitae: Karin A. Rafaels, Ph.D.

Poster 11 Wednesday, October 3 10:05-10:10 am

Dr. Rafaels is the Team Leader for the Experimental Mechanics Team in the Soldier Protection Sciences Branch at the United States Army Research Laboratory. She has over 10 years of experience studying military injury, starting with her graduate school work at the University of Virginia's Center for Applied Biomechanics. Her research has spanned across many different models for human vulnerability, such as, biological surrogates, including animals and postmortem human subjects; mechanical surrogates, including various test devices for varying regions of the body; and mathematical models. Dr. Rafaels has numerous published papers in the field and is considered a subject matter expert in this area for the United States Army.



## Notes

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## Experimental and numerical comparison of methods for studying the deformation of a ballistic helmet impacted with pistol ammunition

A. Miranda-Vicario<sup>1</sup>, A. Azevedo<sup>1</sup>, P. M. Bravo<sup>2</sup> and F. Coghe<sup>1</sup>

<sup>1</sup>Royal Military Academy, Department of Weapon Systems and Ballistics, Renaissance Avenue, 30, B-1000 Brussels, Belgium, [angel.miranda@dymasec.be](mailto:angel.miranda@dymasec.be)

<sup>2</sup>Universidad de Burgos, Departamento de Ingenieria Civil, Avda. Cantabria s/n, 09006 Burgos, Spain

**Abstract.** Currently, ballistic helmets are mostly designed to stop fragments from diverse explosive devices. Nowadays, new requirements have emerged for helmets, such as stopping direct impacts from rifle and pistol threats, and newest helmets are able to stop these threats. The probability of these types of impacts on helmet systems is increasing due to the changes in warfare and military operations. Although it is possible to stop these kinds of projectiles with certain helmet systems, there is a lack of studies regarding the possible injuries suffered by the user. Much of the research done in this field is at least partially based on experimental testing involving head surrogates. In this research, a comparison between the results obtained with a clay head form and a head surrogate with force sensors was done to estimate the load on the skull during a small calibre impact event. 9 x 19 mm FMJ projectiles were fired at a typical ballistic helmet to study the indentation and the force generated by the back face deformation against the two different head forms, and compared with a numerical simulation to try to establish a link between both values.

### Curriculum Vitae: Angel Miranda-Vicario

Poster 12 Wednesday, October 3 10:10-10:15 am

Angel Miranda-Vicario works as a researcher at the department of Weapon Systems & Ballistics of the Royal Military Academy, in Brussels, Belgium. His research focuses on the improvement of personal ballistic protection. For this, he conducts experimental tests for the development of a new ballistic helmet able to stop high-velocity rifle threats. Previously he has worked in an R&D department of an automotive supplier, involved in a research project on magnesium and its technical applications for the automotive industry.



## Notes

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## Estimating Obliquity of Ballistic Impacts from Residual Damage to Hard Armour Plates

K.L. Loftis<sup>1</sup>, C.H. Good<sup>2</sup>, B.E. Schuster<sup>2</sup>, P.J. Gillich<sup>2</sup>

<sup>1</sup> *United States Army Research Laboratory, Survivability/Lethality Analysis Directorate, Aberdeen Proving Ground, MD 21005, USA, kathryn.l.loftis2.civ@mail.mil*

<sup>2</sup> *United States Army Research Laboratory, Weapons and Materiel Research Directorate, Aberdeen Proving Ground, MD 21005, USA*

**Abstract.** A knowledge gap exists between hard body armour test and evaluation metrics and body armour impacts from military combat events, as different parameters are captured in each. In laboratory testing, the potential for behind armour blunt trauma (BABT) injury is assessed by measuring the backface deformation signature in clay following a controlled ballistic impact under set conditions that include known projectile, velocity, yaw, and obliquity. This contrasts with combat events where projectiles and impact conditions are generally unknown, and armour performance information arises from either complete or partial penetration of the armour or measurement of the permanent plate deformation. To reconcile the differences between test and theatre impacts, we developed a novel method to estimate obliquity from permanent damage on hard armour using computed tomography (CT) analysis. Verifying this methodology with test impacts under known conditions allows us to use this approach to study body armour impacts from theatre. To determine if obliquity could be accurately estimated from ballistic damage, ceramic plates were impacted in multiple locations at prescribed obliquities, then CT-imaged on a medical-grade scanner, and analysed using Materialise Mimics software. Obliquity estimates were conducted blindly to verify this methodology, which showed estimates having a mean difference of 5.3° from the actual test impact obliquities for impacts to the middle of the plates. Corner and edge impacts showed higher differences between the actual and estimated obliquities due to increased ceramic damage. This work now allows us to link deformation metrics between laboratory and combat events, enabling a better understanding of the impact conditions in which the plates were struck and permits more accurate re-construction of impacts of interest.

### Curriculum Vitae: Kathryn L. Loftis, PhD, CAISS

Presentation 21 Wednesday, October 3 10:45-11:15 am

Dr. Kathryn Loftis is a biomedical engineer and in this capacity serves as a researcher and analyst for the Survivability/Lethality Analysis Directorate under the United States Army Research Development, and Engineering Command. Dr. Loftis earned her Bachelor of Science in Biomedical Engineering from North Carolina State University in 2007. She received her Master of Science degree (2009) and Doctorate of Philosophy (2013) in Biomedical Engineering from the joint Center for Injury Biomechanics at Wake Forest University and Virginia Tech, with a specialty in Injury Biomechanics. Her work has included motor vehicle crash injury research, soldier survivability, and injury causation. Dr. Loftis is also a Certified Abbreviated Injury Scale Specialist (CAISS) and an active faculty member for the Association for the Advancement of Automotive Medicine (AAAM), which is a professional group that includes experts in medicine, automotive safety, and injury researchers. Her work with the military has included body armor analysis and combat data analysis in the Joint Trauma Analysis and Prevention of Injury in Combat program, which is a network of partners across the Department of Defense devoted to preventing injuries through actionable analysis of real-world data from theater.



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## Experimental assessment of the effect of damage on the ballistic resistance of ceramic inserts

A. Azevedo<sup>1</sup>, M. Vervoort<sup>1</sup> and F. Coghe<sup>1</sup>

<sup>1</sup>*Department of Weapon Systems and Ballistics, Royal Military Academy, Renaissance Avenue, 30, B-1000 Brussels, Belgium (ana.ferreira@dymasec.be)*

**Abstract.** A military bullet-resistant vest typically consists of a soft body armour base vest (offering protection against handgun threats) with an additional front and back insert made of a high-hardness ballistic ceramic tile glued to a fibre-reinforced composite backing in order to offer protection against high-velocity rifle threats. Since the introduction of these ceramic armour plates in the Belgium Army, regular X-ray tests are made to check the condition of these plates. Due to the high quantity of ceramic plates, it is however not possible to check all plates every year, as stipulated initially, and hence a risk seems to exist that a number of end-users is equipped with damaged plates. In order to assist in evaluating this risk, this research has investigated different related topics. Firstly, a study was done on how damage to the ceramic insert affects its ballistic resistance. Two different approaches were used to this purpose: a multi-hit impact test and a ballistic resistance test on pre-cracked plates. The idea of the multi-hit impact test was to quantify how much the ballistic resistance drops when the damage increases in the plate. Up to four shots were done on each plate showing that the ballistic resistance drops considerably, even after a single impact. For this reason, a second batch of experimental tests was done with pre-cracked armour plates. Ballistic tests were performed on the cracked areas and also 2cm away from the cracked areas, showing that in both cases the damage was detrimental to the ballistic resistance of the plate. In order to reconcile the lack of non-destructive inspection capability (X-rays) and the necessity to assure the integrity of the plates, a novel technique was introduced that will possibly allow to reduce the number of plates to x-ray. This novel technique consists of using a shock impact indicator as an easy and straightforward way to detect the occurrence of incidents (typically drops) that might lead to damage in the plates. It consists in placing one sticker per plate, which turns red when a potentially damaging impact occurs.

### Curriculum Vitae: Ana Ferreria Azevedo

Presentation 22 Wednesday, October 3 11:15-11:45 am

Ana Azevedo is a researcher at the department of Weapon Systems & Ballistics of the Royal Military Academy, which is located in Brussels, Belgium. She is a Mechanical Engineer and her research focuses on the optimisation of ballistic helmet designs using numerical tools. In 2013 she started a joint PhD between the Royal Military Academy in Belgium and the University of Aveiro in Portugal.



## Notes

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## Carbon Nanotube Reinforced Alumina

J. Lo<sup>1</sup>, M. Bolduc<sup>2</sup>, K. Bosnick<sup>3</sup>, D. Walsh<sup>1</sup>, R. Santos<sup>1</sup>, R. Zhang<sup>1</sup>, T. Patrie<sup>3</sup>, B. Simard<sup>4</sup>, S. Dénommée<sup>4</sup>

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<sup>2</sup>Defence Research and Development Canada (DRDC) – Valcartier Research Centre, Quebec, QC, Canada,

<sup>3</sup>NRC-Nanotechnology Research Centre, Edmonton, AB, Canada,

<sup>4</sup>NRC-Security and Disruptive Technologies Research Centre, Ottawa, ON, Canada,

**Abstract.** Alumina is a common armour ceramic used mainly for its reasonable hardness and lower cost compared to other armour ceramics such as silicon carbide and boron carbide. However, to defeat similar rounds, alumina is heavier. Therefore, to optimize the mass of the armour, the improvement of the ballistic performance of alumina is needed. In this paper, various aspects on the development of multi-walled carbon nanotube (MWCNT) reinforced alumina composites, which are meant to provide improved ballistic performance, are described. The fabrication of MWCNT reinforced alumina composites involves first the deposition of the MWCNT onto alumina powder by a catalytic chemical vapour deposition (CVD) process. The bare alumina powder is stained with iron nitrate catalyst in a slurry process, dried, and processed in the CVD reactor under ethylene at 650 °C to deposit the MWCNT onto the powder. The processing conditions are optimized so as to control the composition and the morphology of this hybrid powder, as this will affect the microstructure of the resulting composite. Second, the MWCNT coated alumina powder is hot pressed into composite tiles. In parallel, unreinforced alumina tiles fabricated with the similar hot pressing conditions as the alumina composites were also produced. Third, both alumina and alumina composite tiles were evaluated for mechanical properties. Lastly, the ballistic performance of alumina and alumina composite was assessed using the Depth of Penetration test. This was followed with an extensive failure investigation conducted on the tested tiles using scanning electron microscopy, to elucidate the impact of MWCNT addition to alumina in modifying the ballistic performance of alumina.

### Curriculum Vitae: Jason Lo, Ph.D.

Presentation 23 Wednesday, October 3 11:45-12:15 pm

Dr. Jason Lo is a principal scientist and manager of the Emerging and Defence Materials Program at CanmetMATERIALS, Natural Resources Canada. He is also an Adjunct Research Professor of McMaster University. Dr. Lo received his Ph.D. and M.Sc. degrees in Materials Science and Engineering from Cornell University, U.S.A. He holds 21 U.S. and international patents. He has published over 120 papers in the field of composites, nuclear materials, armor materials and nano materials. He had given over 100 presentations (25 were keynote and invited presentations) in conferences, edited three books and written over 100 classified and unclassified reports. Frequently, he reviews technical articles for international technical journals such as: Acta Metallurgica, Journal of Materials Science and Engineering, Scripta Metallurgica, Composite Engineering - An International Journal, Materials & Design, Journal of Science and Engineering of Composite Materials, Corrosion - Journal of Science & Engineering, Journal of Spacecraft & Rocket, and Canadian Metallurgical Quarterly. He had also served as an external examiner for M.S. and Ph.D. students from McGill University, McMaster University, University of Windsor and Carleton University. Since 1988, Dr. Lo's has been developing unique materials and fabrication methods in composites for national and international industrial clients.



## Notes

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## Risk of rib fractures assessment during kinetic energy projectile impact through experiments and modelling on a human torso FE model

A. Bracq<sup>1</sup>, R. Delille<sup>1</sup>, B. Bourel<sup>1</sup>, C. Maréchal<sup>1</sup>, G. Haugou<sup>1</sup>, F. Lauro<sup>1</sup>, S. Roth<sup>2</sup>, O. Mauzac<sup>3</sup>

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<sup>3</sup>French Ministry of the Interior, CREL/SAELSI, Place Beauveau, Paris, France

**Abstract.** The past decade has seen the rapid increase in ballistic impact studies, especially to understand the human body response, as well as to improve protective equipment. Indeed, the literature refers to severe blunt trauma caused by Less-Lethal Kinetic Energy (LLKE) projectiles but also by the body armour deformation called Behind Armour Blunt Trauma (BABT). Various materials have been employed as ballistic testing media such as ballistic gelatin and clay. Among these, a synthetic gel named SEBS is adopted by the French Ministry of the Interior as ballistic testing medium for impact interpretation. Although gel transparency provides a direct impact analysis using high-speed camera and provides information on the dynamic gel wall displacement, macroscopic data do not allow a direct evaluation of the risk of blunt trauma. Hence, the authors focus their research on the use of a biofidelic human torso finite element (FE) model named HUByx for impact modelling. The study of C. Bir about the impact of rigid LLKE projectiles on Post-Mortem Human Subjects' sternum (PMHS) are exploited by reproducing impact conditions on both a gel block and a human torso FE model. This study results in the establishment of a probability of rib fractures as a function of the viscous criterion. On the one hand, these tests are employed to validate the torso model by comparing with biomechanical corridors. On the other hand, it allows the development of a methodology to obtain the risk of skeleton injuries based solely on experimental gel block data. Indeed, a statistical approach based on twelve impact tests is employed to define a suitable transfer function between results from a gel block test and the risk of rib fractures. A perspective of this study would be to apply and extend this strategy to the study of BABT only caused by body armour deformation.

### Curriculum Vitae: Anthony Bracq

Poster 13 Wednesday, October 3 12:15-12:20 pm

Born and raised in Valenciennes, France, Anthony graduated with a MSc in mechanical engineering from the French engineering school ENSIAME with a specialty in material behavior characterization and numerical modeling. R&D projects and placements with industrial partners enforce the author's interest in the study of dynamic impacts on the human body. He is a third-year PhD student in biomechanical engineering and security studies for the French Ministry of the Interior. He is currently the author of three articles in the field of mechanical characterization and constitutive modeling of soft materials.



## Notes

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## Characterization of combat helmet design trade spaces accounting for ballistic threats, brain functional areas and injury considerations

P. Matic<sup>1</sup> and R. N. Saunders<sup>1</sup>

<sup>1</sup>Materials Science and Technology Division - Code 6300, Naval Research Laboratory, Washington DC 20375, USA, [peter.matic@nrl.navy.mil](mailto:peter.matic@nrl.navy.mil)

**Abstract.** Combat helmet design requires trade-offs between anticipated threats, helmet geometry, ballistic materials and human factors. In this paper, we add helmet trade space analysis and optimization considerations to a previously developed helmet CAD software application that integrated engineering, biomechanical and medical considerations. The software application analyses individual helmet performance protecting 104 brain points, subjected to a set of 3000 omnidirectional ballistic threats, against skull fracture and nine fundamental focal and diffuse brain injuries. Helmet performance and the ten head injuries are predicted from helmet back face deflection and motion based injury criterion, using a combination of direct calculations, first-order models and tabulated empirical data. Baseline optimization strategies are developed for an illustrative small arms operational engagement scenario. Design parameters in terms of range to the adversary, affecting ballistic projectile impact velocity, and head-to-helmet spacing, affecting helmet impact injury severity. Optimization cost factors for human factors, operational effectiveness and head injury severity and treatment costs are constructed from available data. The software executes on a desk top computer in a few minutes for one helmet configuration and a few hours for trade space mapping, identifying useful paths to optimization strategies.

### Curriculum Vitae: Peter Matic, Ph.D.

Poster 14 Wednesday, October 3 12:20-12:25 pm

Dr. Peter Matic is the Superintendent of the Materials Science and Technology Division of the Naval Research Laboratory (NRL) in Washington, DC. The Division focuses on multidisciplinary scientific discovery and technological innovation for the Navy, the Marine Corps and Department of Defense.

Dr. Matic has led or conducted programs at NRL on materials, components and systems including the biomechanics of dynamic response to blast and impact; body armor and infantry combat equipment; deformation, damage and fracture of materials and structures; mathematical and computational strategies to model complex materials and systems; integrated use of experimental data and computational simulations; and multifunctional structure-energy composite materials and components. Prior to joining NRL, Dr. Matic was a Senior Engineer at the Electric Boat Division of the General Dynamics Corporation. His work there included computational modeling and the application of material damage and fracture principles to submarine structural analyses and fabrication processes.

Dr. Matic has over 45 refereed publications, 50 conference proceedings, 70 presentations, 20 technical reports and four patents. He earned a bachelor of science in Mechanical Engineering from the Illinois Institute of Technology and a doctorate in Applied Mechanics from Lehigh University.

## Notes

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## Fragmentation testing of bomb suit using pipe bombs

J. Levine<sup>1</sup>, J.P. Dionne<sup>1</sup>, C. Hedge<sup>1</sup>, D. Bueley<sup>1</sup>, D. Acquavella<sup>2</sup> and A. Makris<sup>1</sup>

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**Abstract.** The most prevalent domestic terrorist threat in the United States is currently the pipe bomb. As such, the US Federal Bureau of Investigation (FBI) led an investigation of the performance of legacy bomb suits against representative pipe bomb threats, from both fragmentation and blast overpressure points of view, to identify any potential gaps and to assist with recommendations on standard operating procedures.

Full-scale pipe bomb blast tests were thus conducted using human surrogates donning retired legacy bomb suit ensembles. A Hybrid II mannequin instrumented with accelerometers in its head and pressure gauges at its ear and sternum was used to gather blast overpressure protection data. The mannequin was located 1 meter away from 30 cm long pipe bombs made from standardised, off-the-shelf parts, filled with approximately 670 g of one of two different smokeless powders. The pipe bombs generated a wide array of fragment sizes and velocities, as observed through high speed video.

The bomb suits were shown to provide excellent protection, whereby no complete penetrations were noted in the critical areas of the body (head, neck & torso). Numerous fragments also hit the extremities of the suit, with the vast majority being stopped within the soft ballistic protection. While quantitative results showed that no direct blastwave-induced injuries would be expected from the pipebombs, substantial blunt impacts, yet not injurious, can arise from large pipe bomb casing parts.

Finally, an attempt was made to model the smokeless powder as an explosive to drive fragment velocity and mass-distribution analyses. Using the Gurney and Mott methodologies, the velocity of the fragments and their mass-distributions were estimated

### Curriculum Vitae: Aris Makris, Ph.D.

Poster 14 Wednesday, October 3 12:25-12:30 pm

Dr. Aris Makris (Ph.D. Mechanical Engineering - McGill University) has over 30 years of expertise in the fields of shock waves, detonation, and protection technologies related to these threats. Since joining Med-Eng in 1994, Dr. Makris has led numerous R&D programs geared towards the development of highly advanced personal protective suits, helmets, footwear, hand protection and related tools, for Explosive Ordnance Disposal (EOD), Demining and soldier protection. Dr. Makris has participated in the design and prototyping of several modular components, as well as, integrated body armour solutions for dismounted soldiers. Dr. Makris holds a number of patents in personal protective armour countering the effects of IEDs.



## Notes

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## Tactical ballistic shields operational testing protocol definition

M. Bolduc<sup>1</sup>, J.S. Binette<sup>1</sup>, D. Fisher<sup>2</sup>, D. Hammond<sup>2</sup>

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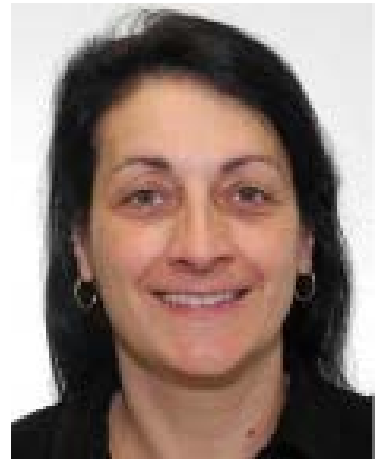
<sup>2</sup>Canadian Special Operations Forces Command (CANSOFCOM) National Defence Headquarters, Ottawa, ON, Canada

**Abstract.** CANSOFCOM has requested the assistance of DRDC to develop an operational testing protocol to evaluate tactical ballistic shields against multiple shots, from 7.62 mm unhardened steel core projectiles. This test protocol is the main core of a procurement contract for CANSOFCOM to add a new item into their personal armour equipment inventory. The test protocol addresses the level of shield protection to prevent forearm and hand bone fractures, which are as a consequence of back-face transient deformation caused by impact of the projectile. The forces associated with these impacts may result in fractures or they may result in the operator momentarily dropping the shield out of the intended position. Furthermore, this protocol addresses the requirement to use the shield as an emergency ladder. The intent of this new test protocol is to address the worst case multi-shot grouping situation. A realistic scenario representing a barricaded shooter during a hostage rescue operation was reproduced. Highly skilled marksmen were asked to shoot stationary targets using both a carbine and a pistol. The shots were fired at distances of 5, 10, and 20 m and with 2 modes of fire: single shot and full automatic burst. The results were used to define the shot-to-shot distance for perforation performance evaluation requirements. To assess the risk of fracture to the forearm and hand during ballistic impact, a force sensor was positioned in the zone of interaction between the forearm and the hand and the back-face of the shield. Data collection includes impact duration, peak force and impulse. Finally, to address the control evaluation of the 'ladder' usage, a 2-stage compression test on the handle was developed taking into consideration the requirement for the handle to support up to 113 kg in static and dynamic loading conditions. To validate the protocol, 2 models of shield designs were used. This paper describes the steps followed to develop the protocol.

### Curriculum Vitae: Manon Bolduc

Presentation 24 Wednesday, October 3 1:30-2:00 pm

Manon Bolduc completed her MASC studies in Mechanical Engineering at the University of Sherbrooke, Quebec, Canada. In 1989, she joined the Terminal Effects Group of the Weapons Effects and Protection Section at Defence R&D Canada Valcartier. She is involved in armour materials studies, personal armour development, behind armour effects and other R&D activities. She is a member of the STANAG2920 revision committee and the International Personal Armour Committee. (



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## Influence of flexible neck on head kinematic response during military helmet impact testing

M. Begonia<sup>1</sup>, N. Yoganandan<sup>1</sup>, F. Pintar<sup>1</sup>, T. Rooks<sup>2</sup> and V. Chancey<sup>2</sup>

<sup>1</sup>Medical College of Wisconsin, Department of Neurosurgery, Milwaukee, WI, United States, mbegonia@mcw.edu

<sup>2</sup>U.S. Army Aeromedical Research Laboratory (USAARL), Injury Biomechanics Division, Fort Rucker, AL, United States

**Abstract.** The Advanced Combat Helmet (ACH) provides Soldiers with head protection against ballistic threats and blunt trauma. The ACH blunt impact performance standard is based on automotive helmet standards that assess the linear head motion associated with severe head injuries. Previous studies have shown that mild traumatic brain injury (mTBI), including diffuse brain injuries and concussion, is also linked to angular head motion. Certain helmet standards have incorporated a mechanical neck surrogate to account for rotational head kinematics. However, some standards only require a Hybrid III neck, which was designed specifically for frontal motor vehicle crashes. This study investigated the role of the neck in blunt impact performance assessments of the ACH using a pendulum-based test rig. The ACH was secured onto a National Operating Committee on Standards for Athletic Equipment (NOCSAE) head, which was attached to a Hybrid III or EuroSID 2 (ES-2) neck. The ACH was impacted at the front, side, rear, nape, and ear cup at 3.0-6.0 m/s. Head kinematics and neck kinetics were compared based on the neck, impact location, and velocity. Experimental outputs served as inputs for the Simulated Injury Monitor (SIMon) computational model to calculate the Cumulative Strain Damage Measure (CSDM). As the impact velocity increased, head kinematics increased by factors of 2.0-5.4 and neck kinetics increased by factors of 1.7-2.9 based on neck type and impact location. A higher velocity also produced higher CSDMs at different strain thresholds with CSDMs at the 10% strain threshold increasing by factors of 6.0-30 based on neck type and impact location. Head kinematics, neck kinetics, and CSDM thresholds were influenced by the dummy neck used. Incorporation of a neck surrogate in blunt impact assessments of the ACH and potentially other military helmets would enable further analysis of injury metrics that correlate to angular head motion and brain strain.

### Curriculum Vitae: Mark Begonia, Ph.D.

Presentation 25 Wednesday, October 3 2:00-2:30 pm

Mark Begonia is a postdoctoral fellow in the Department of Neurosurgery at the Medical College of Wisconsin and the Neuroscience Research Laboratories at the Zablocki VA Medical Center in Milwaukee, Wisconsin. He holds a B.S. in mechanical engineering and Ph.D. in biomedical engineering. His previous research experience includes the mechanical characterization of brain tissue; comparison of blunt and blast-related brain injury mechanisms using experimental, computational, and diffusion tensor imaging techniques; and the effects of aging on bone biomechanics. His current work focuses on the study of mild traumatic brain injury (mTBI) in military environments, which involves the evaluation of wearable head impact sensors and analysis of the brain response using finite element (FE) simulations.



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## Determination of the Cause of the Differing Ballistic Performance of 9mm DM11 Bullets from Two Manufacturers

A.H. Jones<sup>1</sup>, J. Barnes-Warden<sup>2</sup> and I. Fielden<sup>1</sup>

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<sup>2</sup>Metropolitan Police Service, Physical Protection Group, Threat Mitigation Technologies, Albany Street Police Station, NW1 4EE, United Kingdom

**Abstract.** In London, firearm threats faced by police during criminal activity include 9mm handguns and sub-machine guns. The UK Home Office body armour standards have included 9mm DM11 A1B2, manufactured originally by Dynamit Nobel under RWS branding, for over a decade. The recently published 2017 UK Home Office body armour standard continues to specify the 9mm DM11 A1B2, however, the specified manufacturer has changed to Metallwerk Eisenhütte GmbH (MEN). The DM11 A1B2 bullet comprises a copper coated steel full metal jacket with a lead core and bullets from both are specified to the same drawings and dimensional tolerances. However, during empirical testing against soft armour systems differences have been observed in the  $V_{\text{mean}}$  measured by CPA for the 2 bullets. As a result, body armour systems designed to pass the standard tests using the RWS 9mm DM11 A1B2 bullet manufactured may have a lesser safety margin when subject to impact with the equivalent MEN bullet. This paper reports on the results of an investigation into the causes of the differing performance of the two sources of 9mm DM11 A1B2 bullets. It includes a study of the metallurgy of the steel jacket, dimensional and mass comparisons and a range of high strain rate testing to compare the properties and deformation behaviour of the two bullet types. Ballistic tests have been performed to demonstrate how the difference in performance may be related to the observed differences in the steel jacket metallurgy and the resulting differing deformation behaviour. The study has shown that the root cause of the differing performance is due primarily to differences in the steel used for the jackets by the different manufacturers. This work has important consequences for the UK body armour industry and others testing with the 9mm DM11 round.

### Curriculum Vitae: Alan Hywel Jones, Ph.D.

Presentation 26 Wednesday, October 3 2:30-3:00 pm

Dr Jones is a principal research fellow at Sheffield Hallam University's Materials and Engineering Research Institute (MERI). He has degrees in Physics (BSc), Materials Characterisation (MSc) and Ceramic Composites (PhD), all from University of Warwick, UK. He has worked as a materials scientist researcher at MERI for 18 years and has worked on a wide range of materials research, including ceramic composites for armour, ballistic testing of armour systems, wear resistant materials and novel precious metal alloys. His work is funded by national and international bodies including UK MOD and the European Union. His research on ceramic armour created the spin-out company, XeraCarb, now a division of Capital Refractories Ltd, UK. He was awarded a prestigious Royal Society Industry Fellowship for this work. He has been co-chair of 2 previous PASS and regularly reviews UK research grant proposals, sits on decision panels of research councils, reviews for international journals and examines PhDs in ballistics and materials. He works with industrial partners solving materials problems using his knowledge and university facilities and has worked on more than 500 such projects. He acts as an expert witness in criminal and civil cases requiring materials expertise.



## Notes

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## Men and Women and Helmets and Necks

**Courtney A. Cox**<sup>1</sup>, Christopher P. Eckersley<sup>1</sup>, Maria A. Ortiz-Paparoni<sup>1</sup>, Allison L. Schmidt<sup>1</sup>, Jay K. Shridharani<sup>1</sup>, Robert S. Salzar<sup>2</sup>, and Cameron R. Bass<sup>1</sup>

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**Abstract.** Discussions of the desirable limits on head-supported mass such as helmets and night vision equipment often lead to the observation that the Luo women of East Africa carry loads up to 70% of their body mass balanced on the top of their heads. On the other hand, it is difficult to imagine an effective combat force carrying 50 kg on their heads. Clearly, ergonomic and mobility constraints limit the desirable head supported mass. Higher mass and unbalanced loading increase the risk of injury or fatigue; however, while there are guidelines for centre of gravity targets for men such as the USAARL curves, these have never been fully assessed for use in helmet design for women, especially with respect to acutely injurious conditions. Further, the comparative sex-based anthropometric tradeoffs of muscle area/fatigue against head supported mass are not available. Women are not small men – they are two anthropometrically and physiologically distinct populations. For example, in size matched young men and women, men have larger necks relative to head size, implying different fatigue and injury tolerance bounds for men and women, and the kinematics of head supported mass is different between men and women. This study assesses the sex-based tradeoffs for helmet design for men and women for military protective helmets based on anthropometry and a computer neck model that includes active muscle response developed at Duke University. We provide guidelines for scaling equivalent head supported mass from men to women and assess the effect of head supported mass on compressive loading. These guidelines are intended to be used in assessing mass and moment of inertia tradeoffs for fatigue and injury in helmet design.

### Curriculum Vitae: Courtney Cox

Poster 16 Wednesday, October 3 3:00-3:05 pm

Courtney Cox is a PhD candidate in the Department of Biomedical Engineering at Duke University, studying under Dr. Dale Bass. As a member of the Injury Biomechanics Laboratory, her research interests include high rate characterization of the cervical and lumbar spine, and biomechanical differences between men and women. Courtney has worked on research projects ranging from interspecies blast scaling, pediatric head/neck modelling for automotive applications, and experimental and computational underbody blast spinal response. During her tenure at Duke, she received a Whitaker International Program Summer Grant to study lumbar spine modelling at Imperial College London. Courtney has co-authored eight peer-reviewed journal and conference publications, including one first author, and has presented her work at both national and international conferences. She holds an MS in Biomedical Engineering from Duke University and a BSE concentrating in Biomedical Engineering from the Mercer University.



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## Effects of Diaphragm Material and Rupture Patterns on Downstream Shock-wave Profile in a 91 cm x 91 cm Advanced Blast Simulator

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<sup>3</sup>Oak Ridge Institute for Science and Engineering

**Abstract.** The use of explosives as weapons in recent military conflicts has created a need to better understand the injury mechanisms produced by these explosive events, specifically the overpressure generated during a blast. To effectively study this, large scale blast simulation systems have been developed, but generating pressure magnitudes similar to those observed in free-field explosive events is difficult. This function is directly linked to the diaphragm used in these systems. High speed video was employed to record diaphragm ruptures and to study the effects of membrane rupture patterns on the downstream shock profile. Diaphragm pulling, or slipping, positively correlated to higher peak overpressures and total impulses. The exact location of the rupture (right, centre, or left) had no influence on the peak pressure, positive phase duration, impulse, or planarity. The maximum achieved percentage of the diaphragm opening created from the rupture did not correlate to the downstream shock profile. However, some weak trends were observed between percent open at 1.5 ms post rupture initiation and peak overpressure, as well as impulse. Based on the configuration of the blast simulator system used in this study, diaphragm failure is a primary predictor of the shock profile at the test section. Further research, especially with different diaphragm materials and blast simulator systems, is needed to better understand the scope to which these results are applicable.

### Curriculum Vitae: Joe Andrist

Poster 17 Wednesday, October 3 3:05-3:10 pm

Joseph Andrist is an engineer at the Johns Hopkins University Applied Physics Laboratory in Laurel, MD, where he conducts research in the area of injury biomechanics. The primary focus of this research is to better understand the response of the human body, and injury mechanisms, to blast and ballistic related loading. Mr. Andrist has also worked with large and small scale blast simulators since 2008. He received an Associates degree from George Washington University in Medical Laboratory Studies in 2005.



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## Accommodating the target population of single-sized EOD helmet models through the use of a multi-fit inflatable sizing system

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**Abstract.** The fit and comfort of a helmet influences the likelihood that it will be donned by its wearer and the willingness of that wearer to continue using the helmet for the duration of the activity. Helmet fit also influences the level of protection afforded by the helmet and its ability to provide this safety function, e.g. optimized coverage. The helmet of a bomb suit ensemble presents a fit challenge because it is typically offered in only one size and is expected to accommodate a large target population due to shared equipment within a bomb squad. In previous generation helmets, this challenge was addressed through the use of foam padding of various thicknesses, used in conjunction with the helmet comfort lining, and required a user to iterate sizing options through a trial and error process putting the helmet on and off. Inspired by inflatable helmet fit liners from other activities that allow a wearer to optimize the fit while wearing the helmet (e.g. American football), an inflatable liner was developed as a retrofit option to replace legacy fit systems. Responding to an end-user need to improve the fit of fielded equipment, the US Combating Terrorism Technical Support Office (CTTSO) funded this development program including the current study to compare the fit accommodation between legacy fit systems of several helmet models and an inflatable fit system. Volunteers were recruited to subjectively assess the quality of fit using each fit system optimized to their head size and shape. It was found that a novel inflatable system consistently provided an improved fit over legacy EOD helmet systems and participants had a preference for one material type, i.e. manufacturer, over the other.

### Curriculum Vitae: Aris Makris, Ph.D.

Poster 18 Wednesday, October 3 3:10-3:15 pm

Dr. Aris Makris (Ph.D. Mechanical Engineering - McGill University) has over 30 years of expertise in the fields of shock waves, detonation, and protection technologies related to these threats. Since joining Med-Eng in 1994, Dr. Makris has led numerous R&D programs geared towards the development of highly advanced personal protective suits, helmets, footwear, hand protection and related tools, for Explosive Ordnance Disposal (EOD), Demining and soldier protection. Dr. Makris has participated in the design and prototyping of several modular components, as well as, integrated body armour solutions for dismounted soldiers. Dr. Makris holds a number of patents in personal protective armour countering the effects of IEDs.



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## Automatic Body Characteristics Estimation From Body Armored Scans for Improved Body Armor Design

B-K.D. Park<sup>1</sup>, B.D. Corner<sup>2</sup>, and M. P. Reed<sup>1</sup>

<sup>1</sup> University of Michigan Transportation Research Institute, 2901 Baxter Rd, Ann Arbor, MI, USA

keonpark@umich.edu

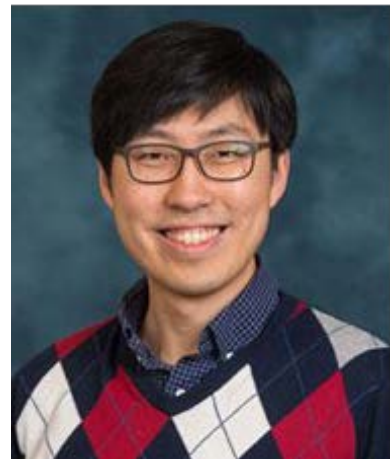
<sup>2</sup> Ground Combat Element Systems, Marine Corps Systems Command, Quantico, VA

**Abstract.** Many studies have shown that body characteristics including standard anthropometric data can be effectively captured with three-dimensional (3D) body surface scans of a minimally clad individuals, and commercial systems are available that perform these measurements. Such approaches may facilitate the design of protective body-borne equipment, including body armor design, by allowing improved sizing and fit. However, participants are generally required to change into close-fitting garb to obtain an accurate measurement of body shape, and this requires a fair amount of additional time to take scans with and without clothing and equipment conditions and raises logistical and privacy issues. In this paper, we present a rapid and automated body shape estimation method, called *inscribed fitting*, to efficiently capture estimate body characteristics for individuals wearing a wide range of ensembles, including protective equipment. For our equipped condition, we focus on scanning individuals wearing body armor and related gear. The inscribed fitting method utilizes a statistical body shape model that is based on hundreds of laser scans from minimally clad individuals with a wide range of body size and shape. The inscribed fitting method uses an iterative process to estimate the body shape underlying the body armor, based on the observation that the correct body shape can be approximated by largest feasible body shape that does not protrude through the clothed scan. The volumes between the estimated body shapes and the original armored scans are computed to analyze armor geometries relative to the body shape. The results demonstrate that body characteristics and armor fit can be estimated with good accuracy without the additional steps of scanning in a minimally clad condition and superimposing minimal and equipped scans. Our approach provides detail on armor fit and placement relative to the given body shape. Along with obtaining surface geometry, anthropometry, joint centers, and body landmarks, the inscribed scan may be linked to morphable models of internal anatomy. This paper is approved for public release: #MCSC-PRR-2353

### Curriculum Vitae: B-K. Daniel Park, PhD

Poster 19 Wednesday, October 3 3:15-3:20 pm

Dr. Park is an assistant research scientist in UMTRI's Biosciences Group. He earned his PhD, MS and BS in mechanical engineering from Hanyang University in South Korea. He joined University of Michigan Transportation Research Institute as a postdoctoral research fellow in 2013 and was promoted to a faculty position in 2015. His research interests focus on biomechanical and parametric modelling of human anatomy, which accounts for morphological variances of human body shapes and the musculoskeletal system across populations in different ages, gender, and ethnic groups. He has developed various types of statistical models that allow for predicting subject-specific shapes of bodies and bones as a function of a few predictors such as stature, body mass index, age and gender. He is also interested in multidisciplinary applications using these parametric human models, including a portable body-scanning system, markerless motion-capture system, customized protective gear design, computer-aided surgery, and advanced passenger-safety system.



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## Role of inertia in armour ceramics

E. Carton and G. Roebroeks

*TNO, Group Explosions, Ballistics and Protection, Rijswijk, The Netherlands  
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**Abstract.** At TNO a series of alternative experimental test set-ups and diagnostic tools for the ballistic behaviour of ceramic materials has been developed. Use of these methods for different ceramics, ceramic thicknesses, different projectiles at different impact velocities also including a wide range of backing materials at different thicknesses, has highlighted the large role of inertia (mass) during the projectile-target interaction process. All these experimental results can be well understood from an inertia point of view. This includes the widely accepted (increasing) order in ballistic efficiency of the most used armour ceramics when compared at equal areal density: Alumina, SiC, B<sub>4</sub>C. This role of inertia can also be derived from the early work (end sixties, early 70's) on armour ceramics by M. Wilkins. TNO has generated an engineering model for ceramic based armour (ceramic strike face with/without a backing material). It quantifies the projectile-target interaction with quite accurate calculations of the mass loss and deceleration of the projectile during the interaction with ceramic, in a time-resolved manner. Based on the understanding of the large role of inertia on ceramic armour performance and using the engineering calculation model, TNO has identified new directions for the development of advanced armour ceramics.

### **Curriculum Vitae: Erik Carton, Ph.D.**

Presentation 27 Wednesday, October 3 3:45-4:15 pm

Studied Materials Science and Engineering at Delft University of Technology. Did his PhD-study on explosive compaction of powders (1998). Became an employee at TNO since 1998 active in explosive metal working technologies, like explosion welding, hardening, cutting and forming. Since 2007 active in the Explosions, Ballistics and Protection group of TNO on projectile impact and armour concepts. Development of diagnostic tools and test methods, as well as development of engineering models of several projectile-target interactions (metals, fabrics, ceramics).



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## Using Material Combinations to reduce the effective Risk of Penetration from High Velocity Projectiles in a Helmet

**M. Latreche**, S. Samborsky, T. Moynihan, V. Lucuta, D. Puckett, J. Cattell, and G. Czeremuszkín.

*Revision Military Inc. 3800 Saint Patrick, Suite 200, Montreal, Quebec H4E 1A4 Canada*

**Abstract:** In helmet shell testing, the ballistic test protocols assume that the angle of impact dictates the effective thickness of the ballistic materials. It is generally accepted that an impact at 0 degrees obliquity presents the least thickness of material, and more oblique angles providing a greater effective depth. While the thickness, and effective thickness, of the ballistic material is directly related to protection levels in threats such as fragments, the same may not be true for high velocity rounds. There is evidence from the battlefield of helmets deflecting or stopping high velocity (HV) rounds that theoretically should have penetrated. Revision Military, as part of a Natick Soldier Research Development and Engineering Centre advanced helmet effort, hypothesized that by combining materials of different densities, the material system could be designed to capture a HV round, striking at an oblique angle or deflect it away from the user when penetration was highly likely at normal impact. The intent of the study was to verify whether material combinations could decrease the risk of a HV round penetration at oblique angles, and therefore that certain material combinations could be inherently 'less risky' than others. Evidence was collected indicating that specific material combinations that produce a predictable V50 for fragments and HV rounds can also significantly deflect HV rounds impacting at an oblique angle. The results may indicate that a battlefield risk based assessment methodology to helmet ballistic penetration could have merit after further investigation.

### **Curriculum Vitae: Mohamad Latreche, Ph.D.**

Presentation 28 Wednesday, October 3 4:15-4:45 pm

Mohamed Latreche joined Revision Military as a Director of Advanced Materials Research in January 2010. Mohamed, has a PhD in Materials sciences and vacuum thin-film functional coating science and technology, he has over 18 years of experiences in research and development in industry and academia. He has worked with coatings and thin films for a wide range of applications that includes defence, microelectronics, and pharmaceutical and food packaging industries. His experience includes R&D projects management, Coordination of R&D collaborative efforts with other departments, process development and optimization, materials characterization, surface analysis, development of new testing methods. More recently, he conducted development programs on materials, components and systems for armour plates and military helmets. Mohamed holds two patents and has published numerous papers in international journals and conference proceedings.

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## Comparative Tests with “Pk17dynA” for an Integrated Assessment of Ballistic Backface Deflections on Combat Helmets

Steffen Grobert<sup>1</sup>, Heiner Gedon<sup>2</sup>, Steffen Peldschus<sup>1</sup>, Oliver Peschel<sup>1</sup>

<sup>1</sup> Institute of Legal Medicine, Ludwig-Maximilians-University Munich, Nußbaumstraße 26, D-80336 Munich, Germany [steffen.grobert@gmail.com](mailto:steffen.grobert@gmail.com)

<sup>2</sup> Bundeswehr Research Institute for Materials, Fuels and Lubricants, Institutsweg 1, D-85435 Erding, Germany

**Abstract:** The present study continues a scientific project dealing with experimental investigations on dynamic back face deflection caused by ballistic impact on combat helmets and the effect to the human skull. Following the presented results, functional and comparative test series with the measurement system “Pk17dynA” were conducted. The present paper provides total force values determined by firing 9 mm Luger on aramid and polyethylene helmets as well as 1,1 g FSP on aramid helmets on 4 different impact locations. To compare measurement values with the commercially available BLSH, an additional test series using a modified version of the PK17dynA, including PU-cover, is presented. The Pk17dynA system delivered suitable measurement results. Differences of curve progressions are pointed out by using an improved version of the analysis software. The interpretation of the results presented in this paper reconfirmed theories regarding the differences of the material behaviour. The detected variabilities are mainly depending on the helmet type, the chosen type of ammunition and the alignment of the whole test setup. A disadvantage was the lack of precise alignment possibilities of the headform to the line of fire, which lead to additional deviations. The positive results of the comparative tests with Pk17dynA and BLSH show the suitability of the presented modified headform for potential investigations on different defined boundary layers between helmet and head.

### Curriculum Vitae: Captain Steffen Grobert

Presentation 29 Wednesday, October 3 4:45-5:15 pm

He is regular officer in the German Federal Armed Forces serving the military branch ‘Ammunition Technical Officer’ as a Captain. Mr. Grobert joined the German Forces in 1997. He had been non-commissioned officer before he changed to officer's career in 2003. From 2006 to 2010 he studied Mechanical Engineering majoring in Weapon- Ammunition Technology and Ballistics at the University of German Federal Armed Forces in Munich. His Diploma Thesis dealt with “Wound Ballistic Investigations to the Background Risk of .308 RUAG Special Operation Sub Sonic”. From 2010 to 2013 he was Commanding Officer of a German Military Training Area. Since 2013 he has been working on his thesis about “Experimental Investigations on Dynamic Back Face Deflection Caused by Ballistic Impact on Combat Helmets and the Effect to the Human Skull” as a Doctoral Student at the Institute of Legal Medicine of Ludwig-Maximilians-University of Munich. In addition to the medical parts of his studies he attended courses in Wound Ballistics and Biomechanics. Furthermore he completed a Medical Internship at the Department for General and Visceral Surgery at the Bundeswehr Hospital Berlin as well as the training ‘Combat First Responder BRAVO’ at the German Army Special Operations Training Centre in Pfullendorf Germany. Since October 2017 he has been working for the Territorial Tasks Command of the German Armed Forces at the Department for Ammunition Safety and Shooting Security in Berlin.



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## Assessment of Behind Armour Blunt Trauma risk for a combat helmet by a combined experimental and numerical method

C. Deck<sup>1</sup>, E. Van Daelen<sup>2</sup>, N. Bourdet<sup>1</sup>, **M. M.G.M. Philippens**<sup>2</sup> and R. Willinger<sup>1</sup>

<sup>1</sup>Strasbourg University, UMR 7357-CNRS, 2 rue Boussingault, 67000 Strasbourg, France

<sup>2</sup>TNO Defence Security and Safety, P.O.Box 45, 2280 AA Rijswijk, Netherlands  
mat.philippens@tno.nl

**Abstract.** The objective of this research is to develop a method to assess the skull fracture and mild traumatic brain injury risk for so called Behind Armour Blunt Trauma (BABT) using a state of the art Finite Element (FE) model of the human head for which tolerance limits for these specific injury mechanisms are available. The back face deformation, resulting from a 9 mm full metal jacket bullet, of a military combat helmet is measured experimentally in 3D by a high speed photogrammetric technique. The experimental recordings of the dynamical back face deformation (BFD) have been digitized and coupled to an existing predictive human head FE model. Head injury risk in terms of skull fracture and AIS2+ brain injury for a given dynamic BFD is assessed by numerical simulation. Moreover a numerical parametric study has been conducted, focusing on the stand-off of the helmet relatively to the head, by varying this distance from 19 mm to 24 mm. It is concluded that BABT results in serious risk on skull fracture or AIS2+ and is strongly sensitive for the helmet stand-off.

### Curriculum Vitae: Mathieu Philippens

Presentation 30 Wednesday, October 3 5:15-5:45 pm

Ir. Mathieu M.G.M. Philippens (MSc) graduated as Mechanical Engineer at the Technical University Eindhoven (NL)/Bioengineering Centre Strathclyde University Glasgow (Scotland). Since 1986 working on development of human surrogates to assess injury risk and effectiveness of protection measures for occupants of road vehicles, water-, air- and spacecraft, with focus on biofidelity of crash test dummies. More recent his research has extended into the military field contributing to research on injury risk mitigation for military vehicle occupants as well as for personal protective equipment for blast, ballistic and blunt threats leading to blast-tbi, babt and blunt trauma. He developed a vivid network within the international biomechanics, biomedical and neuro-trauma community and is member of several international working groups and review committees.



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## Sensitivity studies of the BTTR surrogate and comparison between NLW and BABT applications

Cyril Robbe<sup>1</sup>, Nestor Nsiampa<sup>1</sup>, and Alexandre Papy<sup>1</sup>

<sup>1</sup>Royal Military Academy – Department of Weapons Systems and Ballistics - 30 avenue de la Renaissance, 1000 Brussels, Belgium (cyril.robbe@rma.ac.be)

**Abstract.** The study of the Behind Armour Blunt Trauma (BABT) is quite similar to the study of the impact of a Kinetic Energy Non-Lethal Weapon (KENLW). One can find in the literature several attempts to compare both phenomena. For KENLW applications, the method to assess the thoracic impact consists in measuring the  $(VC)_{max}$ , which is a well-established injury criterion that could also be applicable to BABT studies. The proposed article will further investigate the suitability of the Blunt Trauma Torso Rig (BTTR) to study both domains. The BTTR consists of measuring the back-face displacement of a soft biofidelic membrane, ultimately computing the  $(VC)_{max}$  criterion. It has been validated for rigid KENLW projectiles. Four steps are followed in this article. Firstly, sensitivity studies are carried out concerning the location of the impact of a KENLW projectile, the location of measurement, the angle of impact and the local curvature of the membrane. Secondly, validation of the BTTR laser based displacement measurement is performed by using high-speed camera and comparing both measurements when undergoing a KENLW projectile impact. Thirdly, results of KENLW impacts are presented and an appropriate scaling coefficient is determined. Fourthly, BABT impacts of 9mm parabellum projectiles and 7.62x51mm NATO projectiles impacting the BTTR protected by an adequate body armour are presented and are compared to KENLW loadings. Conclusions and perspectives are then drawn.

### Curriculum Vitae: Cyril Robbe, Ph.D.

Presentation 31 Thursday, October 4 8:30-9:00 am

Cyril Robbe is a mechanical engineer specialized in ballistics. He's currently working as a researcher and part-time associate professor in ballistics in the Royal Military Academy of Belgium, Weapon Systems and Ballistics department since 2009. The field of his study is the experimental evaluation of kinetic energy non-lethal weapons. His PhD topic was: "*the experimental evaluation of the thoracic impact of non-lethal projectile*", accomplished in 2013, at the Royal Military academy of Belgium, in partnership with the University of Liege (ULg) in Belgium. He's currently member of the NATO group: Land Capability group – Dismounted Soldier – Non Lethal Capabilities Sub group – Non-Lethal Kinetic Energy – Team of Expert (LCG-DSS-NLCSG-NLKE-TOE), leading the topic concerning the standardization of the evaluation of kinetic energy non lethal weapon thoracic impact.



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## Behind armour blunt trauma assessment by means of experimental and numerical approaches

A. Bracq<sup>1</sup>, R. Delille<sup>1</sup>, B. Bourel<sup>1</sup>, C. Maréchal<sup>1</sup>, G. Haugou<sup>1</sup>, F. Lauro<sup>1</sup>, S. Roth<sup>2</sup>, O. Mauzac<sup>3</sup>

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<sup>2</sup>University of Bourgogne Franche-Comté, UTBM, Interdisciplinary Carnot laboratory of Bourgogne UMR CNRS 6303, 90010 Belfort, France

<sup>3</sup>French Ministry of the Interior, CREL/SAELSI, Place Beauveau, Paris, France

**Abstract.** The risk of Behind Armour Blunt Trauma (BABT) has become a primary concern for the law enforcement officers, soldiers and armour manufacturers. Indeed, the need for body armour weight reduction and the enhancement of projectile efficiency may result in a higher body armour deformation and therefore, an increasing risk of blunt trauma. This study focuses on the soft body armour deformation where blunt trauma is supposed to be mainly due to the dynamic deformation of the protective equipment. Indeed, for the velocity range considered, it is assumed that trauma linked to shock waves may be neglected. The transparent synthetic gel SEBS is employed by the French Ministry of the Interior to capture the dynamic deformation of the body armour and interpret the impact scenario. In order to replicate impact conditions on a biofidelic human torso Finite Element (FE) model, it is necessary to develop a procedure for the modelling of various projectiles and soft body armours. Indeed, the complex material behaviour of the projectile and the body armour during dynamic loading makes difficult the numerical study. Firstly, the experimental backface deformation is exploited to build the geometry of an equivalent rigid projectile. Secondly, an inverse iterative approach using both experimental and numerical model of the gel block leads to the identification of the body armour material model. The maximum backface deflection is used as objectives to reach in the identification procedure, along with the shape of the deformation. This method is validated by comparing experimental tests with different projectiles and body armours with their corresponding FE modelling.

Then, the impact conditions are replicated on the torso model and the viscous criterion is calculated. Finally, a previous study about the risk of rib fractures evaluation during the impact of less-lethal kinetic energy projectiles is applied and extended for body armour assessment.

### Curriculum Vitae: Anthony Bracq

Presentation 32 Thursday, October 4 9:00-9:30 am

Born and raised in Valenciennes, France, Anthony graduated with a MSc in mechanical engineering from the French engineering school ENSIAME with a specialty in material behavior characterization and numerical modeling. R&D projects and placements with industrial partners enforce the author's interest in the study of dynamic impacts on the human body. He is a third-year PhD student in biomechanical engineering and security studies for the French Ministry of the Interior. He is currently the author of three articles in the field of mechanical characterization and constitutive modeling of soft materials.



## Notes

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## The virtues of VIRTUS: Development and introduction of the new VIRTUS body armour, load carriage and helmet system for UK Armed Forces personnel.

E.A. Lewis and B. Clarke

*Defence Equipment and Support (DE&S), Ministry of Defence (MoD), Abbey Wood, Bristol BS34 8JH United Kingdom. Barbara.Clarke340@mod.gov.uk*

**Abstract.** In 2015, the UK Ministry of Defence introduced a new, improved, integrated body armour, load carriage and helmet system to UK Armed Forces personnel called VIRTUS. Building on lessons from previous combat operations in Iraq and Afghanistan, VIRTUS evolved from the OSPREY body armour system that was developed and procured through an Urgent Operational Requirement (UOR). The OSPREY body armour system was continually modified and improved throughout its service life in response to medical evidence and user feedback. This resulted in piecemeal acquisition of components to enhance the coverage and protection; that whilst fully integrated with the OSPREY system, were not fully optimised. Whereas, VIRTUS was procured as a system; and includes a torso sub-system and a head sub-system. The VIRTUS torso sub-system is lighter, less bulky and more streamlined than OSPREY. VIRTUS has a novel sizing and fitting regimen based on medical coverage and anthropometric data and incorporates an innovative weight distribution system, a quick release function and utilises OSPREY plates. Currently, Defence Equipment and Support is in the process of procuring new lighter-weight, anthropometrically optimised plates, which will significantly reduce the mass of the plate, particularly for the smallest users. The VIRTUS head sub-system includes a helmet, mandible guard and visor which all integrate with the VIRTUS torso sub-system. The helmet was designed using medical coverage requirements and utilises lightweight innovative materials, making it lighter than the UK in-service MK7 combat helmet. This paper will provide the opportunity to describe the recent developments in personal body armour and load carriage systems procured and fielded to U.K. Armed Forces personnel. The paper will also describe the development of the technical and medical requirements as well as the innovative elements of the VIRTUS system itself.

### Curriculum Vitae: Barbara Clark

Presentation 33 Thursday, October 4 9:30-10:00 am

Mrs Barbara Clarke has worked in the area of personal protection since 2001. Barbara is the Technical Manager with Soldier Training and Special Projects (STSP) for the UK MoD's VIRTUS body armour and load carriage system, based at Defence Equipment and Support (DE&S) in Bristol, UK. Barbara was responsible for leading all technical aspects of the VIRTUS project such as the integrated test and evaluation plan (ITEAP), the Human Factors Integration (HFI) trials, coordination of the materials testing and collating user feedback. She also manages the technical aspects of in-service equipment such as Personal Load Carriage Equipment (PLCE), Chemical Biological Radiological and Nuclear (CBRN) Clothing, Enhanced Combat Body Armour (ECBA) & OSPREY Body Armour; managing all aspects of post design modifications and upgrades, maintenance of technical specifications, and reviewing technical data sheets and test reports to ensure compliance.



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## Computational analysis of performance of combat helmet to mitigate blast induced traumatic brain injury

X. G. Tan<sup>1</sup>, R. N. Saunders<sup>1</sup> and A. Bagchi<sup>1</sup>

<sup>1</sup>*U.S. Naval Research Laboratory, Multifunctional Materials Branch, Washington, DC, USA, [gary.tan@nrl.navy.mil](mailto:gary.tan@nrl.navy.mil)*

**Abstract.** Current understanding of blast wave transmission and mechanism of primary traumatic brain injury (TBI) and the role of helmet is incomplete thus limiting the development of protection measures. We explore the helmet configuration to investigate blast induced brain biomechanics and understand the role of helmet by utilizing an integrated experimental and computational method. Experimental shock tube tests of the head surrogate provide benchmark quality data and were used for the validation of computational models. The full-scale computational head-neck model with a combat helmet provides physical quantities such as acceleration, pressure, stress, strain, and energy thus provides a more complete understanding of conditions that may contribute to the TBI. This paper will discuss possible pathways of blast energy transmission to the brain and the effectiveness of helmet systems under the blast loads. The anatomically accurate finite element (FE) head model was applied to investigate the influence of helmet configuration and suspension pads. The blast wave loading on the helmet and head was generated by simulating a free-field explosion in the shock tube, via a two-phase computational fluid dynamics (CFD) formulation. By employing the Eulerian-Lagrangian fluid structure interaction (FSI) approach we solved the coupled problem of helmet and head dynamics exposed to the blast. Response metrics including head acceleration and intracranial pressure (ICP) were used to assess the protection performance of helmet while comparing with the unprotected head. The main contribution was the elucidation of blast wave brain injury pathways, including wave focusing in ocular cavities and the back of head under the helmet, the effect of neck, and the pressure entering the brain through the helmet and head. The helmet and suspension were seen to significantly affect the ICP results and energy transmission. These findings can be used to design future helmets including helmet shape, suspension system, and eye protection.

### Curriculum Vitae: X. Gary Tan, Ph.D.

Poster 20 Thursday, October 4 10:00-10:05 am

Dr. X. Gary Tan is the Mechanical Engineer at the U.S. Naval Research Laboratory. Prior to that he was the Technical Fellow at the CFD Research Corporation. His primary areas of research are computational solid mechanics, computational fluid dynamics, and fluid-structure interaction. The solid-shell element formulation he developed was implemented in commercial software ESI CFD-ACE+ and ABAQUS and used worldwide. He is the main developer of the multi-physics solver CFD-ACE+ and CoBi. CoBi has been used in many DoD and NASA laboratories. He has extensive modelling experience on applications related to blast, blunt, and ballistic induced traumatic brain injury, helmet design, hearing protection, and inflatable aerodynamic decelerator and many others. He holds a Ph.D. degree in Mechanical Engineer from the University of Florida.



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## Shockwave pressure transmission through the ear canal with hearing protection

Y. Chen<sup>1</sup>, A. Bagchi<sup>1</sup>, G.H. Kamimori<sup>2</sup> and T.J. O'Shaughnessy<sup>1</sup>

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<sup>2</sup>*Walter Reed Army Institute of Research, 503 Robert Grant Ave, 2W97, Silver Spring, MD 20910*

**Abstract.** There have been a large number of studies relating blast overpressure exposure to hearing loss and the determination of the effectiveness of various forms of hearing protection to mitigate this loss. However, less effort has been focused on measuring overpressure penetration into the middle ear, particularly outside of standard auditory frequencies. Repeated exposure to low level overpressure events leads to complaints of dizziness and nausea in some people. One hypothesis is that overpressure penetration into the middle ear is directly affecting the vestibular organs. To determine overpressure penetration into the ear, we developed a human head surrogate with an anatomically accurate ear and ear canal. Pressure sensors of varying capabilities were placed at the location of the ear drum and the head and eye sockets filled with a tissue simulant gel. The surrogate was placed near various breaching situations to determine the portion of pressure, compared to free field, entering the ear canal and impinging on the eardrum. The surrogate was also used in conjunction with a shock tube to determine the effect of directionality on the pressure transmission to the eardrum. The presence of hearing protection not only decreased the peak amplitude of pressures into the ear but also changed the frequency spectrum from the pressures as measured at the eardrum. External versus internal pressures were compared to determine what portion of external pressure actually transmits into the ear canal and into auditory organs with and without the hearing protection.

### Curriculum Vitae: YungChia Chen, Ph.D.

Poster 21 Thursday, October 4 10:05-10:10 am

Dr. YungChia Chen received her PhD in Bioengineering from University of Pennsylvania where she conducted research on the effect of cellular signalling on traumatic brain injury outcomes. Prior to that she received her BS in Mechanical Engineering from the University of Maryland, Baltimore County and her MSE from Johns Hopkins University. She was an American Society for Engineering Education Post-doctoral Fellow studying blastwave transmission into the brain and changes to neuronal function post blast exposure and is currently continuing this work at the Naval Research Laboratory.



## Notes

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## Physical, clinical and numerical approaches of the risks for a dismounted soldier facing IED explosion

NJ. Prat<sup>1</sup>, S. De Mezzo<sup>2</sup>, C. Mano<sup>3</sup>, P. May<sup>1</sup>, W. Menini<sup>4</sup>, L. Ehrhardt<sup>2</sup>, J. Mosnier<sup>1</sup> and P. Magnan<sup>2</sup>

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**Abstract.** Combat suits including ballistic proof vests and combat helmets have considerably been improved over the last decades to protect soldiers from bullets and shrapnel. However, explosion of charges most often improvised especially in urban areas or confined spaces, causes new patterns of blast-related injuries in dismounted soldiers and interaction between blast overpressure and ballistic protections brings new avenues of research. Under specific conditions, a possible amplification of the pressure behind the soft layers of ballistic protection cannot be excluded, causing more internal injuries than in unprotected soldier. Additional hard plate seems to locally prevent the injuries but restricts mobility of the soldier. To clarify these phenomena, a new French program on blast interaction with dismounted soldier has been ran. The aims are to investigate physically, clinically and numerically the risks of physiological dysfunctions and life threatening injuries during primary blast exposure, to later gain understanding on the cascade of events in protected or not conditions.

This paper describes the specific experimental setup, putting together anthropomorphic instrumented dummies and monitored anaesthetized swine. Correlations between physical parameters of the loading and levels of injury are investigated. The threat sizing (height of burst, mass and distances), the positioning of the biological reactor are discussed and the first trends are given.

On unprotected animals, an average side-on pressure of 450 kPa and 2.25 ms positive phase duration induces diffuse hematoma of the right exposed lung with an increase of the ratio lung/body weights by 41%. Moreover, numerous intestinal hematomas are noticed with possible multiple sites of intestinal wall rupture. No immediate signs of a tangible effect of primary blast on haemostasis are observed. Current and next objectives will be an assessment of different ballistic protection levels both on dummies and animals.

### Curriculum Vitae: LCL Nicolas J. Prat, MD, Ph.D.

Poster 22 Thursday, October 4 10:10-10:15 am

LCL Nicolas PRAT is currently appointed to the French Armed Forces Institute of Biomedical Research (IRBA, France) in the combat casualties research Unit. He graduated at the University of Lyon in 2005. From 2005 to 2007, he served in the "Gendarmerie" (French Military Police) as a general practitioner. In 2007, he passed the National Military Competitive Exam of Research, and since then, he has coped with both his military fellowship in Integrated physiology (until 2013) and a PhD in physiology (until 2011). He got the research certification in May 2013. In this field of competence, he has worked on numerous traumatic injury research themes including wound ballistics, personal armor systems, hemorrhage control, thoracic trauma and emergency surgery. LCL Prat holds different academic diplomas and post-graduated courses focused on traumatic injuries: wound ballistics (2003), catastrophic medicine (2003), forensic sciences (2004), biomechanics engineering (2004), forensic medicine (2008), PHTLS and ATLS courses (2009-2010). In addition, he is an Instructor and the National Educator for ATLS. He teaches also Combat Casualty Care Skills to military physicians and nurses who are being deployed. He spent 3 years as an exchange officer at the US Army Institute of Surgical Research (2012-2014).



**Notes**

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## Two-Sample Statistical Inference for Ballistic Limit Testing of Body Armour

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**Abstract.** Ballistic limit testing is a type of sensitivity testing where the velocity at which a kinetic energy threat impacts an armour sample is varied and the binary penetration result (partial or complete) is recorded. The data is then analysed to estimate the probability of penetration as a function of threat velocity assuming some probability distribution using a generalized linear model. As the body armour community continues to develop lighter armour solutions, it is desirable to know if the protection afforded by these lighter systems remains comparable to the protection provided by legacy systems. Typical protection levels of interest include the  $V_{50}$  (velocity at which there is a 50% probability of complete penetration) and the  $V_{10}$  (velocity at which there is a 10% probability of complete penetration). Traditional model-building strategies involve likelihood ratio tests on the linear parameters of the model and do not directly test for differences in the protection levels of interest. These statistical tests can be adapted, however, to test for significant differences in the  $V_{50}$  or in an extreme quantile, such as the  $V_{10}$ . Lastly, since proper test planning involves sample size determination, it will be shown how Monte Carlo simulations can be used to estimate power for a given sample size and test method. Power tables are provided for various sample sizes using both the Neyman-D-optimal and c-optimal test methods for the probit link function.

L. Lombardo

Presentation 34 Thursday, October 4 10:45-11:15 am

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## An analysis of the fit and function of the UK OSPREY body armour system for female users on combat operations

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**Abstract.** In 2016, the ban on women in ground close combat roles throughout the UK's Armed Forces was lifted. In anticipation of this, work has been on-going to prepare future ballistic protection programmes for a potential increase in the number of female users. A human factors study on the fit and function of the OSPREY body armour system was therefore carried out with female users whilst on combat operations. A questionnaire was designed and provided to 150 female users of OSPREY body armour to complete whilst on combat operations in Afghanistan. The questionnaire asked the users to rate the comfort of their OSPREY body armour along with their ability to carry out basic tasks. It also asked for other background data such as size of body armour worn and bra size to supplement the quality of the data. The questionnaire responses were analysed and the results demonstrated that survey participants reported various types of discomfort when wearing their OSPREY body armour, with 135 instances of discomfort experienced in the hip region, for example. Challenges were also reported in the respondent's ability to carry out basic movements, with the tasks being rated on a Likert scale as difficult or very difficult by between 29% and 59% of respondents. In addition, a restriction in ability to access to personal equipment worn on the person (including pouches, trouser pockets) was commented on by 39% of respondents. The analysis demonstrated that female users reported challenges relating to the fit and function of their body armour. Using data from this work, current and future programmes can address some of these challenges by optimising the fit of body armour for all users. The VIRTUS body armour system for UK Armed Forces Personnel has already addressed some of the reported issues and further work is on-going.

### Curriculum Vitae: James Davis

Presentation 35 Thursday, October 4 11:15-11:45 am

James joined the UK MoD in 2014 on the Defence Engineering and Science Graduate scheme and has been working on projects in the area of personal protection for the past year. James currently works in the Technology Office in Defence Equipment and Support, where he has worked on projects including the Army Warfighting Experiment, the female fit of current Body Armour systems and Additive Manufacturing. He has a Master of Engineering in Mechanical Engineering.



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## A Real Pain in the Neck: Design Limits on Magnitude and Location of Head Supported Mass

C. P. Eckersley<sup>1,2</sup>, C. A. Cox<sup>2</sup>, M. A. Ortiz-Paparoni<sup>2</sup>, R. H. Lutz<sup>3</sup>, T. C. Sell<sup>4</sup>, C. R. Bass<sup>2</sup>

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**Abstract.** Head supported mass, including helmets, night vision, communications, and other attachments, is a two-edged sword. Though such technologies generally increase soldier survivability, there are functional occupational limits to how much mass may be borne effectively and safely. The chronic effects of an increased head supported mass include acute and degenerative cervical spine injuries. To understand the role this increased mass plays in chronic cervical spine injuries, the sensitivity of intervertebral stresses to the location and magnitude of the head supported mass was assessed using the Duke University Human and Neck Model (DUHNM). The DUHNM is a hybrid multibody and finite element model equipped with active musculature and anatomically accurate stiffness of spinal units and has been validated against human response in the mid-sagittal plane for neck tension, compression, flexion, and extension. The region of interest included head supported mass from 0 to 5 kg at locations 0-100 mm from the head centre of gravity in the vertical and horizontal directions. Simulations include the effects of running (~1 g-1 Hz sinusoidal input), jumping from low height (4 g-100 ms half sine input), and parachute drops (~10 g-50 ms half sine input) on maximum neck forces and moments. Extreme scenarios show increasing mass as well as the distance anterior the centre of gravity increase the maximum moment and force in the neck by nearly an order of magnitude. It has been shown that tensed cervical muscular alone can reach 40-45 percent of compressive neck tolerances. Incorporating both repeated impact response from occupational loads (jumping, waling, etc.) and increased head supported mass can increase the compressive loads beyond muscular response. Based on these simulations, we provide initial contours for design guidance envelopes for head supported mass and centre of gravity location in terms of career longevity and assumed occupational scenarios for head supported mass under repeated impact loading.

### Curriculum Vitae: Christopher Eckersley

Presentation 36 Thursday, October 4 11:45-12:15 pm

Christopher Eckersley is a second year PhD student in Biomedical Engineering at Duke University, studying under Dr. Dale Bass in the Injury Biomechanics Laboratory. He graduated from Duke University in 2016 with a Bachelor's of Science in Biomedical and Mechanical Engineering where he was a Pratt Undergraduate Research Fellow. His research interests include mechanisms of brain injury following blunt trauma, and the role of cervical musculature on head kinematics. Christopher has been working in the Injury Biomechanics lab since 2014 on projects such as: impact attenuation of baseball catcher masks, the roll of neck musculature on blunt impact head kinematics, the impact of concussion on oculomotor function, and blast physics behind military combat helmets. Christopher has one lead author publication and another one in review and has given 3 podium presentations and 3 poster presentations at both national and international conferences.



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## Digital Head Avatars for combat helmet fit

A.J.K. Oudenhuijzen<sup>1</sup> and F.B. ter Haar<sup>2</sup>

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**Abstract.** Today's combat helmet is becoming more than only a means to protect the warriors head. It is more and more used as a platform for sensors and has to integrate with other protection devices. As such, the combat helmet is becoming an integrated system with higher demands on combat helmet fit and stability. Combat helmet fit is usually tested in time consuming field trials. This paper describes a study on the use of digital head avatars for combat helmet fit testing in the quest for less time demanding trials. A family of seven digital head avatars with various head dimensions was selected from our database of 3D whole body scans of the Dutch Military Forces. Multiple head dimensions were used to select these seven head avatars which were then printed in 3D. Different helmet configurations were placed onto the digital head avatars as well physically on a set of subjects (male, n = 29) with comparable head dimensions, following the manufacturers guidelines. Each subject and head avatar were scanned with and without the helmet. After digitizing these helmet configurations, the orientation and position of each helmet was analysed using 3D CAD. The results revealed that the helmet orientation and position was the same for the real subjects and for the digital head avatars. Hence, the use of helmet fit testing on digital head avatars has been validated, which opens the path to use digital head avatars for combat helmet fit testing. Currently this method is applied in the replacement of the Dutch combat helmet. A family of high resolution Digital Head Avatars (DHAs) was constructed using the 3D head scans from subjects. The family of seven DHAs represent 95% of the Dutch soldier population. These DHAs are used to analyse each helmet fit in a digital manner. Thus, it partly replaces field trials with the focus on helmet fit, other aspects such as thermal comfort, pressure points, compatibility with government furnished equipment still has to be evaluated in field trials.

### Curriculum Vitae: Aernout Johan Korneel Oudenhuijzen

Presentation 37 Thursday, October 4 1:30-2:00 pm

Aernout Oudenhuijzen studied Industrial Design at the Technical University. Aernout has the strength to oversee a wide range of technical issues in Soldier Systems and has the capability to generalize these as a human factors system integrator. Aernout has been working in the field of the physical Soldier Burden, as a member of the NATO CSO working group RTG238 as well as the NATO NAAG Land Capability Group for Dismounted Soldier Systems. A central pillar in Aernout's expertise is 3D anthropometry, physical ergonomics and vehicle ergonomics. Aernout has been working in this field, for TNO, since 1994. In the paper, a study is described on how 3D printed heads can be used for fit testing on combat helmets.



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## Use of Hybrid III mannequins for a blast overpressure standard test methodology

J.P. Dionne, J. Levine, and A. Makris

<sup>1</sup>Med-Eng, 2400 St. Laurent Boulevard, Ottawa, ON, Canada, K1G 6C4  
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**Abstract.** The currently released version of the NIJ standard for public safety bomb suits (NIJ 0117.01) only includes a qualitative blast overpressure assessment (bomb suit integrity), without any quantitative measurement. NIJ's rationale for the omission of quantitative requirements is that at the time of publishing the standard, research and data related to the effects of blast overpressure was limited. However, end users identify this as major gap, and as such an ASTM working group (WK57359) is developing a quantitative blast overpressure standard, to be used as a complement to the NIJ 0117.01. One of the challenges faced in the development of this ASTM standard is the selection of a human test surrogate. A test surrogate for a standardized test methodology should be readily available by any test laboratory, have a realistic human shape for appropriate donning of the bomb suit and helmet, allow for standard instrumentation, survive a large number of blasts, be configurable in different positions (e.g. standing, kneeling), and provide repeatable data. Ideally, the test surrogate should also provide quantitative data that can be correlated to blast injury. In the context of the development of this ASTM standard, the current paper investigates the appropriateness of the Hybrid III mannequin for blast overpressure testing of bomb suits. Based on historical data collected through bomb suit testing, it is concluded that despite the indirect link between Hybrid III data and potential for blast injury, this mannequin is suitable towards a quantitative blast overpressure standard. Suggestions are provided in terms of the minimum number of tests to be conducted to achieve some minimal statistical significance for bomb suit blast overpressure performance, in the view of costs associated with blast testing of such expensive personal protective equipment, and the inherent variability of blast.

### Curriculum Vitae: Jean-Phillippe Dionne, Ph.D.

Presentation 38 Thursday, October 4 2:00-2:30 pm

Dr. Dionne holds a Ph.D. in Mechanical Engineering from McGill University (Montreal, Canada) with more than 20 years expertise in the fields of numerical simulations of detonations, blast waves and combustion. Since joining Med-Eng in 2000, he has been involved in numerous projects including explosive tests on demining and bomb disposal personal protective equipment, performance testing of personal cooling systems, and blast mitigation seats. He has devised injury working charts for EOD technicians and has investigated the effect of confinement. Dr. Dionne manages a small group of R&D engineers and technologists dedicated to research on personal protective equipment, protective materials (soft, rigid and transparent armour), blast mitigation seats, and blast dosimetry sensors. He has contributed to the development of standard test methodologies for personal cooling systems (ASTM F23 Committee), blunt impact protection (Canadian Standards Association) as well as Public Safety Bomb Suits (US National Institute of Justice). He is currently involved in the ASTM W57359 working group on the development of a standardized test method for bomb suit overpressure evaluation. During the 2004 Personal Armour Systems Symposium, taking place in The Hague, Netherlands, Dr. Dionne received the Young Talent Award, recognizing his contribution in personal protection against blast.



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## The Lessons of History: Helmets and Primary Blast

J. Op 't Eynde<sup>1,2</sup>, A. W. Yu<sup>2</sup>, C. P. Eckersley<sup>2</sup> and C. R. Bass<sup>2</sup>

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**Abstract.** Since World War I, helmets have been used to protect the head in warfare. They have been designed primarily for protection against artillery shrapnel. More recently, helmet requirements have included ballistic and blunt trauma protection, but neurotrauma from primary blast has not been a key concern in helmet design. This study compares the blast protective effect of historical (WWI) and current combat helmets, against each other and the 'no helmet' case, for realistic shock wave impingement on the helmet crown. Helmets included WWI helmets from the UK/US (Brodie), France (Adrian), Germany (Stahlhelm), and a current US combat helmet (ACH). Helmets were mounted on a Hybrid III® (Humanetics) dummy head and neck and faced towards the ground with a cylindrical blast tube (30.5 cm diameter) aligned along the crown of the head to simulate an overhead blast. Primary blast waves of different magnitudes were generated. Peak reflected overpressure at the open end of the blast tube was compared to peak reflected overpressure at the crown of the head. A general linear model was used to assess the effect of helmet type and tube pressure on the resultant crown pressure response. The interaction between helmet type and tube pressure was found to have a significant effect on the outcome. 'No helmet' and the Adrian helmet were each found to be statistically significantly different from all other helmets. The peak crown pressure was lowest in the Adrian helmet and highest in the 'no helmet' case. The Stahlhelm, Brodie, and ACH were not found to be statistically different from each other. The study demonstrates that both the historical and current helmets have some primary blast protective capabilities, and that simple design features may improve this capability for future helmet systems.

### Curriculum Vitae: Joost Op't Eynde

Presentation 39 Thursday, October 4 2:30-3:00 pm

Joost Op 't Eynde is a PhD student in Biomedical Engineering at Duke University, working with advisor Dr. Dale Bass in the Injury Biomechanics Laboratory. He graduated from Duke University with a Master of Science in Biomedical Engineering in 2016. During this degree, he was a fellow of the Belgian American Educational Foundation. Joost obtained his Bachelor of Science in Engineering from the Catholic University of Leuven, in Belgium, his country of origin. He majored in mechanical and electrical engineering. Research interests include head and spinal injury biomechanics, joint biomechanics, and blast injury biomechanics. Some of his research projects are: detecting orthopaedic failures using acoustic emissions, characterizing the effects of helmets on blast wave protection, designing an eye tracking headset and analysing tracking data for aiding concussion assessments, and viscoelastic modelling of cervical spinal ligament behaviour.



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## Realistic helmet blunt impact protection vs. standards requirements

J. Levine, J.P. Dionne, D. Bueley and A. Makris

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**Abstract.** While bomb suits typically focus on blast overpressure and fragmentation protection, head and spine impact protection are essential to protect from falls and blunt impacts against rigid surfaces after a blast. As such, the Public Safety Bomb Suit Standard from the US National Institute of Justice (NIJ-0117.01) includes head and spine impact protection requirements based on drop tower test methodologies. However, drop towers do not necessarily appropriately replicate typical blunt impacts from blast, and as such, the current study was aimed at evaluating the protection provided by bomb suit helmets in more representative scenarios involving anthropomorphic mannequins. More specifically, Hybrid III mannequin free falls were investigated, to generate two types of representative impacts, for comparison with the drop tower tests. Impact velocities were selected based on the NIJ Standard as well as human surrogates propelled by the force of a blast. The present study concluded that the impact energy levels from the existing drop-tower based head protection standard requirements are significantly higher than realistic EOD threats. This study highlights the fact that standards requirements must only be perceived as minimum requirements for head protection, keeping in mind that realistic incidents are likely to yield much more severe impacts for which a higher level of protection may be required.

### Curriculum Vitae: Jean-Phillippe Dionne, Ph.D.

Presentation 40 Thursday, October 4 3:00-3:30 pm

Dr. Dionne holds a Ph.D. in Mechanical Engineering from McGill University (Montreal, Canada) with more than 20 years expertise in the fields of numerical simulations of detonations, blast waves and combustion. Since joining Med-Eng in 2000, he has been involved in numerous projects including explosive tests on demining and bomb disposal personal protective equipment, performance testing of personal cooling systems, and blast mitigation seats. He has devised injury working charts for EOD technicians and has investigated the effect of confinement. Dr. Dionne manages a small group of R&D engineers and technologists dedicated to research on personal protective equipment, protective materials (soft, rigid and transparent armour), blast mitigation seats, and blast dosimetry sensors. He has contributed to the development of standard test methodologies for personal cooling systems (ASTM F23 Committee), blunt impact protection (Canadian Standards Association) as well as Public Safety Bomb Suits (US National Institute of Justice). He is currently involved in the ASTM W57359 working group on the development of a standardized test method for bomb suit overpressure evaluation. During the 2004 Personal Armour Systems Symposium, taking place in The Hague, Netherlands, Dr. Dionne received the Young Talent Award, recognizing his contribution in personal protection against blast.



## Notes

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## Influence of helmet system on blast overpressure transmission into the brain

T.J. O'Shaughnessy<sup>1</sup>, Y. Chen<sup>1</sup>, D.M. Horner<sup>2</sup>, M.J. Doherty<sup>1</sup>, G.H. Kamimori<sup>3</sup> and A. Bagchi<sup>1</sup>

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**Abstract.** Exposure to blast overpressures is a reality of the modern military experience, whether it be on the battlefield or during training. While exposures during training are controlled and maintained within safety standards, there is still concern over the effects of repeated exposure, even to these low-level overpressures. While quantifying the overpressure of a blast event in air is relatively straight forward, the challenge is to determine the amount of energy that penetrates into the brain, potentially causing damage. To this end, we have constructed several gel-based brain surrogates with integral pressure sensors and accelerometers and mounted these 'brains' within surrogate heads. During several military training exercises, these surrogate systems were exposed to different levels of blast overpressure from low (considered safe) through high (expected to produce significant injury). Pressures within the brain were measured both with and without helmets present. At low overpressures, the pressure measured under the helmet was close to the reflected pressure measured at the eye. As the overpressure exposures increased, however, the under helmet pressure relative to the eye measurements decreased. The presence of a helmet resulted in a 20-60% increase in measured brain pressures relative to no helmet. The extent of the increase depended on the size of the peak overpressure at the eye. It is clear that the interaction of blast overpressure events with the human head, brain, and armour systems is complex and likely varies depending on the blast magnitude.

### Curriculum Vitae: Thomas J. O'Shaughnessy, Ph.D.

Presentation 41 Thursday, October 4 4:00-4:30 pm

Dr. Thomas O'Shaughnessy received his M.S. and Ph.D. in Biomedical Engineering from the University of Virginia in 1992 and 1997, respectively. He received his B.S. in Biomedical Engineering from the Johns Hopkins University in 1990. He joined the Naval Research Laboratory in 2001, first as a National Research Council Postdoctoral Fellow then as a government employee in 2004. His research interests include electrophysiology, neuroscience, neurodegenerative diseases, and diseases of the ion channels. His current research interests include understanding the effects of blast pressures on neuronal cells, with an aim towards understanding the mechanisms behind mild traumatic brain. Additionally, his present work focuses on the relationship between blast forces, personnel protective equipment, and biology. He has co-authored over 30 refereed journal and conference publications.



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## Effect of Helmet and Eyewear on Headform Kinematic Response to Primary Blast Overpressure Exposure

V. Alphonse<sup>1</sup>, C. Carneal<sup>1</sup>, Q. Luong<sup>1</sup>, J. Clark<sup>1</sup>, J. Andrist<sup>1</sup>, K. Townsend<sup>1</sup>, M. Maffeo<sup>2</sup>, M. Carboni<sup>2</sup>, and J. Cyganik<sup>2,3</sup>

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**Abstract.** The Blast Overpressure Simulation System (BOSS), a passive diaphragm-driven Advanced Blast Simulator at the Johns Hopkins University Applied Physics Laboratory has been used to establish requirements for a standardized test methodology for headborne protective equipment. An advanced instrumented headform mounted on a Hybrid III neck was fitted with and without a helmet and/or eyewear and was tested inside the BOSS in four orientations with respect to the propagation of the shock wave (forward, rearward, inclined, side) to model various operational scenarios. Overpressure was measured along the walls of the BOSS as well as on the surface of the headform at 18 locations. Data from an accelerometer and angular rate sensor inside the headform, combined with high speed video of each event, was recorded to quantify the kinematic response of the head/neck. Characteristic shock wave metrics including peak overpressure magnitude, positive phase duration, and positive phase impulse were calculated for each sensor location for every test. The addition of the helmet altered the overpressure response recorded by the sensors compared to the bare headform by itself; the significance of these changes relied largely on sensor location and headform orientation. Generally, positive phase duration remained statistically similar; however, peak overpressure and positive phase impulse were statistically different for the bare and helmeted headform for some sensor locations and headform orientations. The data reported herein indicates the addition of a helmet affects the characteristic metrics that may be used to evaluate personal protective equipment and that the orientation of the headform affects many of the changes in these metrics. In the absence of well-understood pressure-related injury criteria to interpret the significance of these changes, it is recommended that testing of personal protective equipment includes multiple test conditions and orientations to establish a standard test methodology.

### Curriculum Vitae: Vanessa Alphonse, Ph.D.

Presentation 42 Thursday, October 4 4:30-5:00 pm

Dr. Alphonse is a Biomedical Engineer employed at the Johns Hopkins University Applied Physics Laboratory (JHU/APL) where she conducts experiments related to injury biomechanics. Specifically, she strives to understand the response of the human body to dynamic events such as ballistic and blast loading, with a focus on warfighter protection. She holds Bachelor of Science degrees in Biomedical Engineering and Mechanical Engineering from Rensselaer Polytechnic Institute and Master of Science/Doctor of Philosophy degrees from Virginia Tech.



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## Investigations on projectile ricochet off helmets

M. Seidl

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**Abstract.** The ricochet effect is a threat and ballistic protection. A ricochet occurs when the projectile rebounds off a surface and deflects from its original trajectory after striking the target at an obliquity angle. Such deflected projectiles are known to be a potential threat. However, projectile deflection means avoidance of penetration through the target. This study discusses the ricochet effect off body armour, particularly helmets, to avoid penetration and increase survivability. The complex helmet surface poses challenges to determining impact conditions, such as the obliquity angle of a projectile. These imprecise initial conditions result in limitation of measurement precision during experiments. Numerical simulations — defined in the explicit Lagrangian solver in the commercial LS-DYNA program — are used to accompany the experimental data and support a better interpretation of the obtained results.

### **Curriculum Vitae: Marina Seidl, Ph.D.**

Presentation 43 Thursday, October 4 5:00-5:30 pm

Marina Seidl studied Mechatronics at the Munich University of Applied Sciences. During her studies, she went for one semester to Melbourne, Australia, where she passed exams in Electrical and Mechanical Engineering. In fulfillment of her theses, she worked on a project at Cranfield University, England. The project was a numerical study on a Continuously Variable Transmission (CVT).

She continued her work at Cranfield University as a PhD student on the topic: Modelling gas flows in a single stage nitrogen gun using FSI (Fluid Structure Interaction). After her PhD, she continued in a Postdoc position at Lille University in France. She worked on FSI and SPH coupling with Lagrangian environment, studying ricochet phenomenon off water.

Since 2016, she works at the French-German research institute of Saint-Louis (ISL) on oblique high velocity impact on structures, with focus on the ricochet phenomenon particularly on composite materials.



## Notes

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# Methodology for small arms vulnerability analysis of protected and unprotected man

S. Hedenstierna<sup>1</sup>, M. Hartmann<sup>1</sup> and Peter Alvå<sup>1</sup>

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**Abstract.** In order to evaluate the vulnerability of the protected and unprotected man for different small arms systems there is a need for a lethality and survivability analysis tool that consider hit probability, penetration of body armour and wound ballistics. Many nations have their own tool for vulnerability analysis, often developed for fragments with straight wound paths and not for tumbling projectiles. A methodology has been developed that combines algorithms in the Swedish vulnerability/lethality (V/L) assessment tool AVAL with vulnerability computations from the ComputerMan code developed by ARL in USA, and a newly developed model for projectile tumbling. This new methodology can be used to analyse the vulnerability of soldiers with or without modern body armour, subjected to small arms projectiles. The tumbling model describes how the projectile's projected area changes as the projectile tumbles in the body. The model is empirical with input from experimental data of projectile interaction with gelatine. It gives the depth where the tumbling starts (neck length) and tumbling velocity as primary parameters of the wounding potential. The vulnerability is computed with the tumbling model in a call routine to ComputerMan. The tissue wound models and incapacitation computations are used as they are described in the ComputerMan 1994 version. The body armour penetration is computed with AVAL. In cases when the projectile fragments during perforation of the body armour, AVAL also computes the residual velocities, directions and masses of the fragments, which are then provided as input to the vulnerability computations in ComputerMan. The results from ComputerMan are returned to AVAL for further assessments and graphical presentation. In a scenario context a tactical hit point distribution computation can be included in the analysis, shifting the focus from vulnerability to lethality and survivability.

## Curriculum Vitae: Sofia Hedenstierna, Ph.D.

Presentation 44 Friday, October 5 9:00-9:30 am

Sofia Hedenstierna is working as Deputy Research Director at the Swedish Defence Research Agency, FOI since 2009. Sofia received her PhD degree in biomechanics in 2008 from the Royal Institute of Technology in Stockholm. Her main research focus at FOI is questions related to human vulnerability, personal protective equipment and small arms lethality. The work is often conducted in close collaboration with the Swedish Armed Forces and FMV.



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## A pilot study comparing the thoraco-abdominal anatomical data of the Visible Human Project Female to three living females

S. Laing and M. Jaffrey

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**Abstract.** Several human computational models have been developed to assess anatomical vulnerability to ballistic threats, particularly for the thoraco-abdominal region. The internal anatomy of such models is typically based on that of a single male individual, and this is often the Visible Human Project (VHP) dataset. The degree to which the positions and dimensions of the internal organs and anatomical structures within such models are representative of those of a broader population, such as male soldiers, has seldom been assessed. Further, when females are the population of interest, the use of the female VHP female data set (n=1 cadaver) might seem more appropriate. However, the age (59 years) and various anthropometry measurements of this individual are not representative of a typical female soldier, suggesting the representativeness of this data to a broader female military population for the purposes of predicting internal anatomical positions may also be questionable. This pilot study compared the external anthropometry and relevant internal thoraco-abdominal anatomical positions and dimensions of the VHP female with a small group of three living females (aged 27-31 years). Magnetic resonance imaging (MRI) of three living females was performed using conventional recumbent MRI and anatomical structure positions and dimensions were derived from these images, as well as from the images of the VHP female. The effect of breathing on the dimensions and positions of organs and structures of the three living females was also investigated. A larger cohort of living females is required to develop a suitably representative data set for application to a broader female military population.

### Curriculum Vitae: Sheridan Laing

Presentation 45 Friday, October 5 9:30-10:00 am

Sheridan Laing holds a Bachelor of Engineering (Biomedical) and is currently completing a PhD in Biomechanics at the University of Melbourne. Since joining DST in 2012, Sheridan's work has concentrated on the analysis of traumatic injuries and human vulnerability, providing injury biomechanics support to the Australian Army in the assessment of soldier systems in dismounted and mounted environments.



## Notes

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## Combat helmet blunt impact performance and test method and injury criteria.

M.Philippens<sup>1</sup>

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**Abstract.** Head injury criteria commonly used for the assessment blunt impact protection are applied for combat helmet. Impact velocities and the expected injury severity are compared for operational conditions. The only proposed requirement applied until now is a maximum of 150 g for a guided headform drop tests. However, this exceeds the concussion tolerance of the Abbreviated Injury Scale injury severity score 2 (AIS2) for humans. A series of free fall drop tests in line with the United Nations Economic Commission regulation 22.05 (ECE 22.05) helmet standard shows that peak g and the Head Injury Criterion (HIC) are close to or above the AIS3 injury severity. Application of a Finite Element (FE) head model with non-isotropic characteristics, includes tolerances for diffuse axonal injury and skull fracture confirms the HIC based conclusion. Tests according to a standard for industrial safety show results close or just over the 5 kilonewton (kN) skull base force. It is suggested that blunt impact performance should be addressed more strictly in future combat helmet design to come more in line with operational conditions and military requirements. Especially FE models and rotational acceleration based criteria provide better resolution for the military operational conditions and requirements.

### Curriculum Vitae: Mathieu Philippens

Presentation 46 Friday, October 5 10:45-11:15 am

Ir. Mathieu M.G.M. Philippens (MSc) graduated as Mechanical Engineer at the Technical University Eindhoven (NL)/Bioengineering Centre Strathclyde University Glasgow (Scotland). Since 1986 working on development of human surrogates to assess injury risk and effectiveness of protection measures for occupants of road vehicles, water-, air- and spacecraft, with focus on biofidelity of crash test dummies. More recent his research has extended into the military field contributing to research on injury risk mitigation for military vehicle occupants as well as for personal protective equipment for blast, ballistic and blunt threats leading to blast-tbi, babbt and blunt trauma. He developed a vivid network within the international biomechanics, biomedical and neuro-trauma community and is member of several international working groups and review committees.



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## Development of physical and numerical head substitute used for wound ballistic assessment

C. Marechal<sup>1</sup>, R. Delille<sup>1</sup>, M. Karkar<sup>1</sup>, F. Bresson<sup>2</sup>, G. Haugou<sup>1</sup> and T. Colard<sup>3</sup>

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**Abstract.** The field of wound ballistics is as old as the use of firearms on the battlefield. Since the 19th century researchers have worked to understand the interaction between projectiles and the human body. We propose here to study and design simultaneously a material and a numerical model of the human head for ballistics experiments. The dummy head should give quantitative predictions about ballistic wounds whenever a real head suffers injury under the same experimental conditions. The application fields are war surgery, protection against ballistic threats and forensic science. The experimental range will first be limited to handgun. The construction of a dummy head is the main goal of this study. To achieve it we will rely on the knowledge acquired by mechanical characterization of parts of the human head (skull, brain and skin). The physical study will be coupled to a numerical study of the proposed structure. A numerical dummy head would provide a powerful alternative to ballistic experiments. Coupled with the knowledge gained on stiff targets, it could fully simulate rather complex cases as those encountered in the surgical and forensic fields. The simultaneous development of a physical and a numerical model is a strong scientific choice. We believe that it will prove its value to the specialists involved in the field of wound ballistics.

### Curriculum Vitae: Christophe Marechal, Ph.D.

Presentation 47 Friday, October 5 11:15-11:45 am

Christophe Marechal received a Master in mechanical engineering in 1997 from Valenciennes University, and a Ph.D. in 2001 also from Valenciennes University. His Ph.D. thesis was entitled "Optimisation par la Méthode des Eléments Finis du formage robotisé du verre". Since 2003, he has been an Assistant professor in Technological Institute of Valenciennes University and LAMIH laboratory of Valenciennes University. Since 2006 he has been the manager of ballistic experimentation and numerical simulation for biological application in the LAMIH laboratory. Since 2011, he has been the scientific coordinator of the "Subtitete" project funded by the French National Research Agency. His current research interests are experimental protocols and numerical models to simulate and understand human head and thoracic behaviour during ballistic solicitations.

