INTERNATIONAL BALLISTICS SOCIETY

The International Ballistics Society (IBS) promotes the science of ballistics internationally. The IBS provides for technical interchange via an International Symposium on Ballistics and provides professional development for its members by providing opportunities for publication, short courses, student programs, and other activities to promote career development.

President's Editorial

Dear Society Members,

I hope you receive this letter in good health and spirit. More than a year ago, we had to take the difficult and unique decision to postpone our International Symposium on Ballistics until May 2022. Even with the new omicron variant of COVID19, the symposium preparation for the Reno meeting in May 2022 is going forward and well. ASMI, the symposium management company, is helping with the details and will make sure that local sanitary rules are followed.

This will be a very special symposium as we all miss the personal interaction with our colleagues. The high scientific level of in-person conversations, side-bars, live presentations, questions, and papers are invaluable and help us in developing our professional careers. Please, consider seriously attending the symposium. Travel is, to say the least, inconvenient these days. But my experience with other conferences is that the scientific exchange is well worth the effort.

The first day of the symposium (Monday) we will have tutorials endorsed by the Society, an excellent opportunity for people to learn or recycle the basics in our field. The tutorials are offered as hybrid, i.e. attendance can be in-person or from a remote location. It is the first time we offer this option and hope it will be useful for our members. The plan for the rest of the symposium is "business as usual" with a reception on Monday night, sessions Tuesday through lunch on Friday, and a Gala Dinner Thursday evening. Do not forget to vote for the Board of Directors elections, either electronically or in-person at the symposium.

It is my last term as President of the Society, which is up at the end of the symposium in Reno. →

Issue #11, December 2021

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Help Needed from Members!

1. ***Recruit new members:*** spread the word and get your colleagues to join
2. ***Get involved:*** see the website for a list of committees & projects with contacts
3. ***Send or post cool photos:*** Wanted: good photos showing ballistic events in all fields

Upload photos at www.ballistics.org
As always, remember to be responsible with copyright, sensitive, or restricted information!

It has been a real pleasure to serve the Society as President starting at the Long Beach symposium in 2017. The two terms have been longer than the usual three years because of the India symposium happening half a year later to take place in November, the best time according to the organizers. Of course, the pandemic added an additional year. Important and difficult decisions were taken during these two terms so I would like to thank the Board, committee chairs, and committee members for making themselves available, and for being extremely helpful and dedicated to the Society. We are very lucky and should be very proud of having such a dedicated team of highly-skilled and knowledgeable people driving this Society. They are all selfless volunteers and an incredible asset owning the legacy of the Society that will keep it alive and dynamic for many years. I strongly suggest all members, in particular the young ones, to become more involved with the Society by participating in committees or running for the Board. It is just an incredible life learning experience, and one where you will make friends and build a network that lasts forever.

Three important decisions taken during these two terms come to my mind at this time. Two of them were central to our operations. The first one was to choose a management company for the symposium and signing with them a binding contract that limits the Society liability. The second decision was to delay the last symposium until May 2022 due to the pandemic. Both decisions were made in the best interest of the Society, from the Board's perspective, and are hopefully the right ones.

The third decision, and one that I am most proud of, is to name the student awards as Jack Riegel Student Awards in memory of our first President and founder. He was the force behind transforming the International Ballistics Committee to a formal Society and, due to his commitment to creating and building the Society, was awarded membership number 1. These awards will keep his memory and legacy for many years to come.

All this Society activity is possible thanks to the voluntary work of many people. If you want to get involved, do not hesitate letting me or any Board member know.

I hope we will see each other in Reno!

Sidney Chocron

President, International Ballistics Society

NEWS FROM THE MEMBERSHIP CHAIR

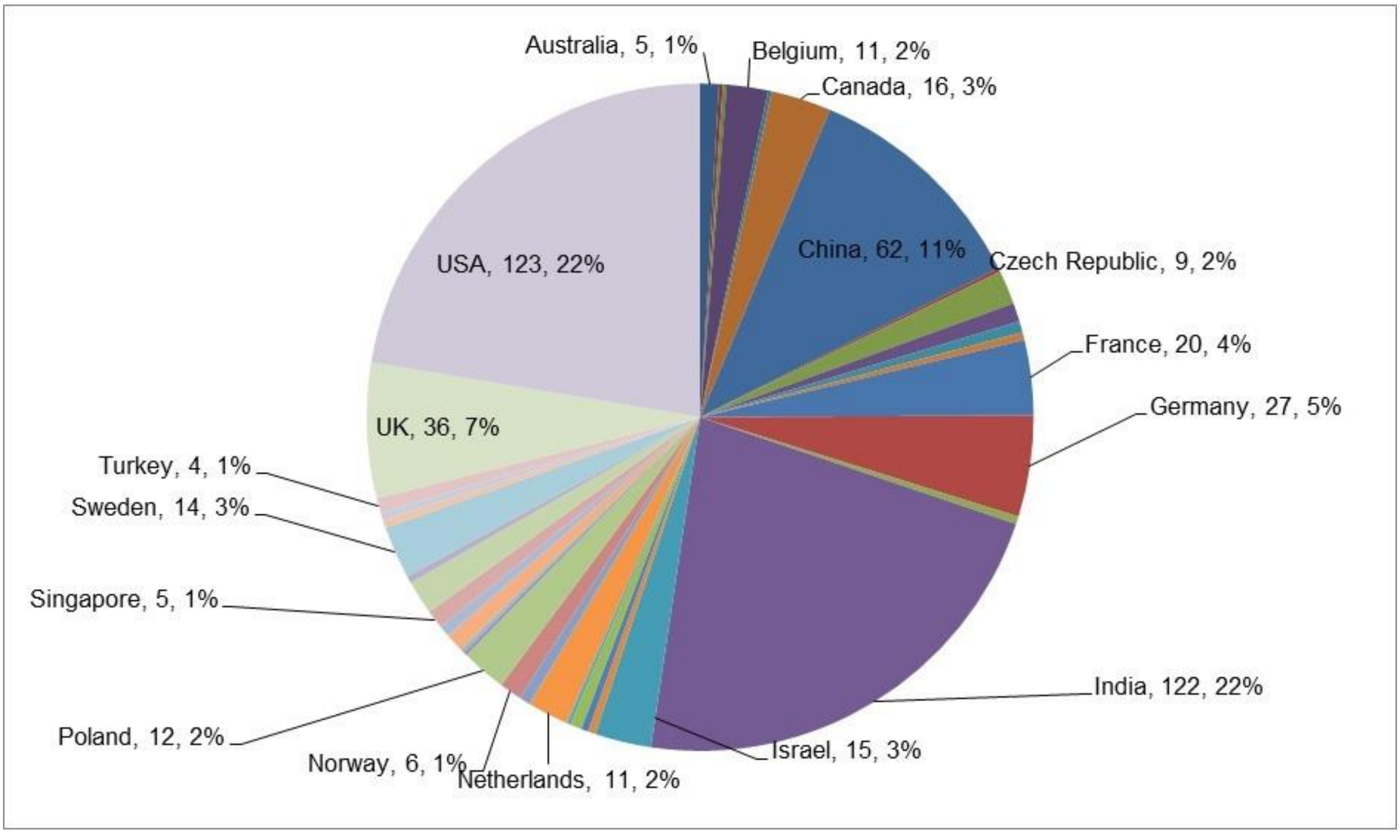
by Clive Woodley
Institute of Shock Physics, Imperial College
London, UK
Chair of the Membership Committee

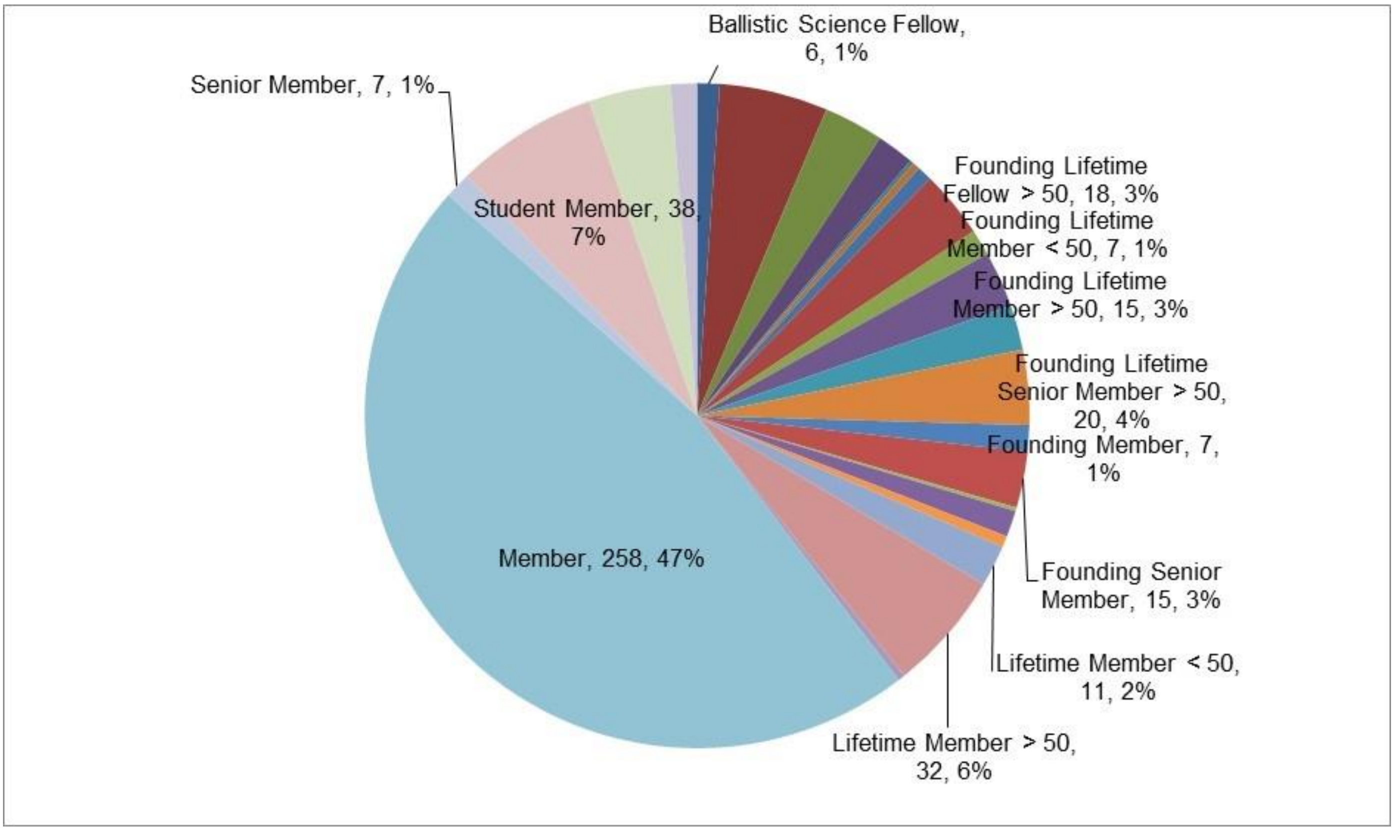
The busiest time for memberships tends to be in the few months around each International Symposium on Ballistics (ISB). New members join, members whose membership expires need to be reminded to renew and, sadly, members deciding not to renew need to have their memberships terminated. After the dust has settled, typically 3 months after the ISB, I analyse the membership, breaking it down into membership types and countries. The results from this analysis are always fascinating so I intend to share some main findings with the membership.

Currently the IBS has just over 550 members. This number has slightly increased over the last 10 years, starting at 360, after the Beijing ISB in 2010, rising to nearly 650 after the following ISB, before falling to about 550 members which has been fairly constant since 2013.

Unsurprisingly, the percentage of members from each country is heavily dependent on the location of the ISB recently held. For example, after the Beijing ISB, China represented over 50% of the membership and India (the location of the last ISB in 2019) none. Today, China has 11% of the total membership and India has 22%. Traditionally, the USA is the country with the greatest number of IBS members. The chart below indicates the current membership percentages (only countries with 4 or more members are shown).

It is very important to the IBS to retain members. Therefore, it is useful to analyse how many members fall into our main categories of lifetime membership, normal membership and student membership. It is the latter two types of members that we hope will renew after each term,





which usually lasts 18 months. The chart below breaks down the membership into various types. Note that not every membership category is indicated on the chart, such as corporate members, corporate delegates and universities. What the chart shows is that nearly 60% of the membership are members who we hope will renew next term.

Convincing term members is one of the key challenges facing the IBS. Fortunately, our retention rate approaches 60% which is good. Providing incentives to our members is very important. Examples of this are the free downloads of papers from past ISB each member gets every term. The ISB file store is a unique archive of developments in all fields of ballistics since the 1st ISB in 1974. Access to ballistics courses, particularly online, is another example of showing the importance of IBS membership. Our intention is to show to ballisticians that membership of the IBS is important for their professional development. There are also other ways membership of the IBS can help in this objective such as reviewing abstracts and papers.

If you have any questions or comments then please contact the Membership Committee Chair at membership@ballistics.org.

TRIBUTE TO ERNST ROTTENKOLBER

by Thomas Hartmann and Stefan Greulich

NUMERICS GmbH, Germany

It is with deep sadness that we announce that Ernst Rottenkolber, the founder of NUMERICS and a valued member of the International Ballistics Society has died.

Ernst first came into contact with the IBS in 1987, when he attended his first Ballistics Symposium in San Diego in 1987. From then on, he continuously contributed to the symposia. He became a lifetime member of the society and was awarded with the Neil Griffith Award in 2014. In the end he counted 22 contributions to ISB papers.

After finishing school, Ernst studied physics at the Technical University Munich, where he graduated in 1984. In the same year, Ernst joined MBB (now MBDA-TDW) where he built the foundation of his deep knowledge in warhead mechanics, blast and impact physics. Seeking new challenges, he started working at CONDAT in 1994, where he began developing his own engineering tools to facilitate his work on ballistic protection and mine blast. In 2004, he finally decided to found NUMERICS, the company he led with great passion and for which he worked 7 days a week till his early death.

He was a silent man who preferred to work in his office rather than to get on stage, but his expertise was recognized all over the world, from North America to the Far East. During his complete career he was dedicated to numerical methods supporting the development and design in defence industry. Simulation codes like SPLIT-X, PS3D or SPEED originated in his head.

To his employees, he was more than just a boss – he was the head of the NUMERICS family. He was a problem solver and a motivator, a teacher and a mentor, who always led his company with respect and appreciation towards his staff.

On September 24th, 2021 he left the office and went home for lunch, but he did not return. He died in his sleep on the couch just 5 days before his 65th birthday. He leaves a wife, a son and a grandson. He will greatly be missed!

CHOU AWARD COMMITTEE REPORT

by Paul Locking

Chair of the Chou Award Committee

As the current Chou Award Committee Chair, I'm looking for suitable candidates to come forward and apply for the 'The Rosalind & Pei Chi Chou Award'.

The Rosalind and Pei Chi Chou Award for Young Authors is given at the International Symposia on Ballistics. Its purpose is to enrich the program of the Symposia by encouraging young authors in ballistics to submit papers and attend the Symposium.

The Young Author must be 35 years of age or younger at the time of the Symposium. The paper may have multiple authors, but the Young Author must have made a major contribution to the paper. An application for the Award must accompany the paper when submitted for publication in the proceedings. To be eligible for the Award, the Young Author must register at the Symposium and must give the oral or poster presentation.

The Award selection is based solely on the written papers and judged on original contribution to the ballistic sciences. The Award consists of a plaque and a stipend. The plaque and stipend are presented by representatives from the International Ballistics Society.

The Award application form can be found in the Awards Section of the IBS website:
www.ballistics.org

JACK RIEGEL STUDENT AWARDS

Call for Contributions

by Markus Graswald

Chair of the Student Program Committee

The Jack Riegel Student Award is awarded to the best papers from students presenting their work at the ISB. This award shall motivate students attending the International Symposium on Ballistics, publishing and presenting their technical work, and interacting with technical experts and scientists from all over the world in various fields of ballistics. Students who receive this award will be granted free conference registration and travel support for attending the 32nd International Symposium on Ballistics taking place in Reno, Nevada, USA, during 9 – 13 May, 2022. Six students from Belgium, France, India, Russia, and South Africa were awarded for their scientific contributions at the 31st ISB in Hyderabad, India, in 2019.

So if you are a graduate or undergraduate student enrolled in an academic institution at the time of the conference we look for your paper and student award application! Please find full eligibility requirements and additional information on the Jack Riegel Student Award on the IBS website.

NOVEL EDUCATIONAL STRATEGY FOR THE SOCIETY

by Markus Graswald

Chair of the Education Committee

The Education Committee (EC) considers the continuing education of our members to be an important benefit of membership in the International Ballistics Society (IBS) and it is our goal to develop offerings that meet member needs. The novel educational strategy has been designed to pursue the Societies' objectives and enhance professional opportunities by providing an educational program on introductory and advanced levels in various delivery forms. It provides guidelines, policies, and procedures on such course programs. It may also help to increase the attractiveness of the Society through new career opportunities and other membership benefits leading eventually to more and / or longer memberships than in the past.

New aspects being considered are:

- The Education Committee has agreed a policy that places all courses under its control and direction. This policy was accepted by Board of Directors in June 2020. It places additional responsibilities on both the Education Committee and the local ISB organizer.
- Short courses during the Reno symposium in 2021 will be given in a hybrid approach to members personally attending on site and a parallel, interactive live stream to registered attendees. Recorded courses may be offered between symposia to Society members.
- The Education Committee is also pursuing the idea of a make or buy-in approach where the committee offers a number of courses they have developed as well as look to external subject-matter experts to deliver additional courses, e.g., advanced

courses on specific topics of interest. This will ensure the EC is in full control of a course so does a high standard and quality over time.

DEVELOPMENT OF NUMERICAL MODELS FOR THE BALLISTIC RESPONSE OF BUILDING MATERIALS

by C. Sauer, A. Heine, W. Riedel
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INTRODUCTION

Urban infrastructure is exposed to ammunition effects in current and future military scenarios, thus the ability to predict the response of building materials to ballistic impact events is highly desired. Reliable numerical simulations for such highly dynamic loading scenarios can constitute the basis for the assessment of weapon effects against building structures. In order to achieve the desired predictive capabilities, a constitutive model that contains all relevant physical processes needs to be combined with the appropriate specific parameters that describe the investigated material quantitatively correctly. This article shows how we combine numerical simulations with a wide range of specifically designed experiments to develop predictive numerical models for the ballistic response of building materials.

DYNAMIC EXPERIMENTS AND CORRESPONDING NUMERICAL SIMULATIONS

The basis for our approach is the application of the RHT-concrete model [1, 2], developed about 20 years ago, which is able to properly reproduce the complex phenomenology of brittle construction materials under dynamic loads in hydrocode simulations. They compute the full wave dynamics of the impact event and take care of the mechanical response of the involved materials through specific constitutive models.

Our approach for finding appropriate material parameters by a combination of experiments and numerical simulations is schematically illustrated in Figure 1. Basic material parameters are obtained by quasi-static material characterization, while dynamic properties are derived from the comparison of the results of dynamic material tests and corresponding numerical simulations. The parameter set is then finalized through the reproduction of the data from ballistic validation experiments by numerical simulations. This includes criteria like the residual velocity and depth of penetration of a projectile as well as the material damage phenomena and their extent in the target.

Developing the full parameter set of a material usually is an iterative process until all the considered results of dynamic material tests and ballistic validation experiments are properly reproduced by the final parameter set. In ballistic application experiments that constitute independent test cases, the predictive capabilities of the final parameter set for a certain range of applications are then assessed.

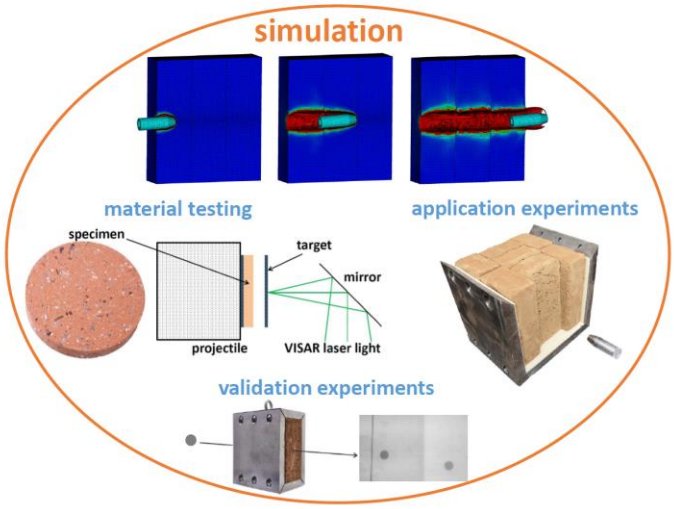

Figure 1: Schematic representation of the combination of material testing and ballistic experiments, which are all embedded in numerical simulations in order to develop predictive numerical models.

In recent years, we followed the approach presented in Figure 1 for several masonry materials. This includes an adobe material with a density of 1.8 g/cm³ [3, 4], a lightweight variant with a density of 1.2 g/cm³ [5, 6], and a fired clay masonry brick [7]. For all these materials, good predictive capabilities for projectile penetration in the investigated velocity range are found. Hence, in the studied loading range, the applied RHT-model includes the necessary mechanics, and the utilized parameter sets describe the materials quantitatively correctly.

EXAMPLE FOR THE PREDICTIVE CAPABILITIES OF THE DEVELOPED NUMERICAL MODELS

From the variety of considered application cases, a distinct example is given in Figure 2. Here, the instable penetration of a tungsten-heavy-alloy projectile due to nonzero total yaw and the resulting non-monotonic behavior of the residual velocity (dashed greed lines) is properly reproduced by the numerical model for adobe.

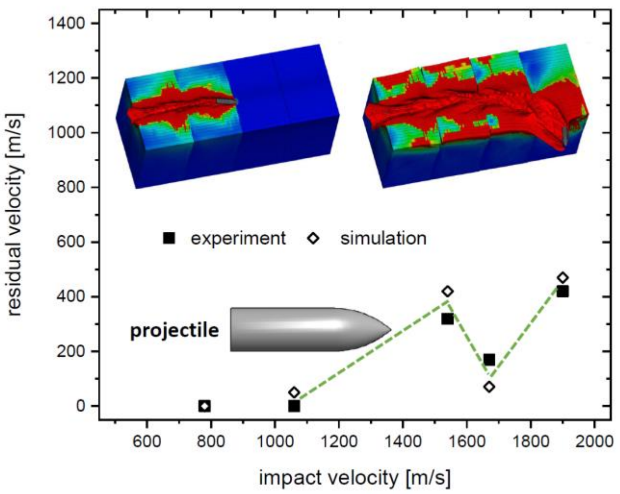

Figure 2: Example for a successful application of the material model for adobe to projectile penetration. The snap shots demonstrate the instable penetration of the depicted projectile.

Additional examples for successful applications of the numerical models for adobe [4], lightweight adobe [6], and fired clay masonry brick [7] can be found in the cited references. Current works include the investigation of fiber reinforced concrete materials into the ranges of high and ultra-high strength with respect to similar impact scenarios.

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TECHNICAL NOTES ON THE APPLICATION OF SHORT-CIRCUIT SCREENS FOR VELOCITY MEASUREMENT FOR STRUCTURAL REACTIVE MATERIALS

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INTRODUCTION

Structural Reactive Materials are a novel technology with a two-fold function. On the one hand, they have mechanical properties suitable for the replacement of structural parts in warheads. On the other hand, SRMs release additional energy upon impact into the target structure.

CHALLENGE OF SRM DIAGNOSTICS

This creates the demand for new and improved diagnostics method. Special attention has to be paid to the local blast effects, which affect the applicability of the diagnostics established for the regular characterization of fragments. This bulletin focuses on the experience with the measurement of velocities of a large set of reactive fragments created by a natural fragmentation process.

DESCRIPTION OF VELOCITY MEASUREMENT

The test involves an arrangement of two parallel velocity screens at distance of several inches. The setup to measure fragment velocities involves three different time measurements per measurement position. The casing breakup time is measured by a trigger wire at a central position on the surface of the casing. The actual measurement then takes place by the short-circuiting of the velocity screens due to the interaction during perforation of the metallic fragments. A data logger is used in order to determine the time delay from trigger wire to the velocity screen short circuit.

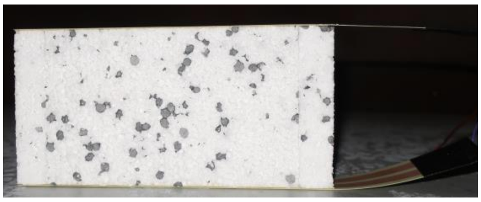

Fig. 1: Arrangement of velocity screens.

Fig. 2: Velocity screen.

The arrangement of the two velocity screens is shown in Fig. 1 while Fig. 2 shows the layout of the individual screen in order to enable short-circuit upon fragment impact.

The radial distribution of the fragment velocities is measured by a series of screens at distinct spatial positions. In total there are three measurements available per spatial position of the screen:

1. Front Screen
2. Back Screen
3. Delta Screen

Nevertheless, the screens work as a one-time method since the short-circuit can trigger only one time. Hence, the method will detect only the fastest fragments hitting the screen at first.

This is no problem for the current casing using only one type of material at the same time.

MEASUREMENT RESULTS

The results of the velocity screen measurements are shown in Fig 3 in terms of time of flight measurements related to the casing breakup. Trigger V and H describe the first screen and second screen, respectively. The time of flight measurements show the geometric arrangement related to the radial symmetric velocity distribution of the warhead casing. The corresponding fragment velocities have been validated based on simulation models. Fig 4 shows a different way of evaluating the measured time – by taking the difference between the delay times from the front and back screen. In fact, it is not possible to use this kind of evaluation method to determine the fragment velocities. In addition to negative delay times, the corresponding fragment velocities turn out the be far too high based on the expected degree of magnitude from Gurney theory.

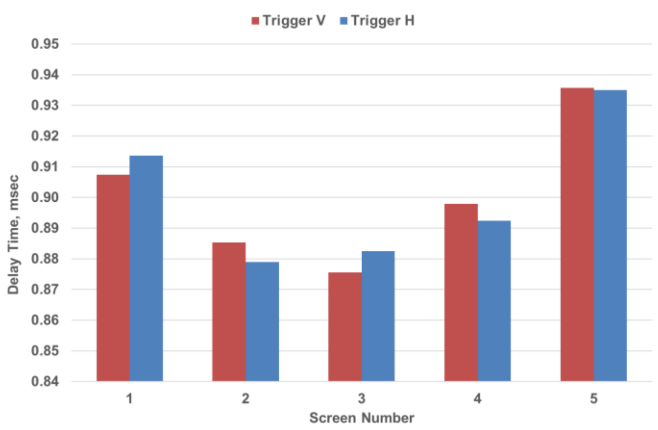

Fig. 3: Delay time from both screens related to casing breakup time.

The reason for the negative delay times for reactive fragments is not known - one explanation for this effect is possibly the fragmentation of brittle material in combination with a local blast effect upon perforating the first screen inhibiting a short-circuiting. It is not possible to measure a single fragment upon passing the screen arrangement. Measuring the time of flight of the fragment ensemble is the preferred method to determine the velocities of reactive fragments with a limited electrical conductivity.

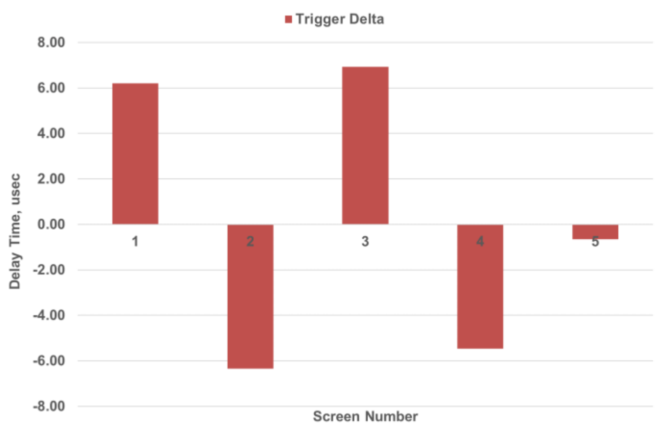

Fig. 4: Delta time from both screens related to casing breakup time.

THE INFLUENCE OF THE INTERFACE RECONSTRUCTION METHOD IN EULERIAN SIMULATIONS

by E. Barbereau
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INTRODUCTION

A major problem occurring in Eulerian simulations is interfaces tracking between materials in displacement. To solve the actualization of interface on a Eulerian mesh, several algorithms were developed to track fluid interfaces as level set methods, particle-based methods, high order monotone capturing schemes and Volume-of-Fluid methods. But VOF is one of the most widely described in literature. Indeed, VOF tracking methods are reasonably accurate, physically based, robust, low in cost, and relatively easy to implement. The first mention of the VOF method appears in 1973 in [1], but is introduced with [2]. Typically, the VOF approach presents a model based on a scalar indicator function to transport the fluid from one cell to another on a fixed computational mesh using the underlying velocity field. This function is characterized by the volume fraction C occupying one of the fluids within each cell. If a cell is completely filled with one fluid, the volume fraction takes the value of 1, and 0 if only the second fluid is present. The values between these two limits indicate the presence of the interface. In the VOF approach, the volume fraction field is the only available and required information representing the interface profile. Therefore, if the explicit location of the interface is needed, special algorithms have to be applied to attain an approximate reconstruction of the interface by exploiting the volume fraction distribution of the neighboring cells in a compact stencil. With this method, volume fractions are actualized by solving the following transport equation,

$$\frac{\partial C}{\partial t} + u.\nabla C = 0 \quad (1)$$

where $u = (u, v, w)$ denotes the fluid velocity vector, and $\nabla = (\partial/\partial x, \partial/\partial y, \partial/\partial z)$ is the gradient operator. In order to solve this equation, two categories of algorithms exist: unsplit schemes and operator split schemes. In operator splitting, the transport of the volume fraction field is realized by considering sequential updates along each direction with calculating one dimensional flux by treating only one velocity vector component in each update. This inherent feature makes operator splitting applicable only within structured mesh environments. After advancing the interface along each coordinate direction, intermediate volume fraction values are computed. As a result, three consecutive updates are required to transport the interface to the next discrete time level in three dimensions which also necessitates at least three interface reconstruction sweeps based on the corresponding intermediate volume fraction fields. Additionally, the sequence of updates in each direction must be changed in order to avoid, or at least minimize, asymmetries caused by the operator splitting. Unsplit schemes are more complex to implement as they have to respect mass conserving. To compute fluxes, in both method an interface reconstruction is needed, we present in this paper the two most used method in literature. The Simple Line Interface Calculation (SLIC) was and still is the cornerstone of the geometric interface reconstruction techniques. Here the reconstructed interface is a straight line parallel to one of the spatial directions. For the reconstruction, only the volume fraction values of the neighboring cells along a coordinate direction are taken into account in a 3 x 1 block of cells. Therefore, the interface has a different representation depending on the coordinate direction considered for the reconstruction. The piecewise linear reconstruction is nowadays the most popular approach, and the methods which fall into this category are usually referred to as Piecewise Linear Interface Calculation or Construction (PLIC) methods. In this approach, the interface is reconstructed by oblique or piecewise linear line segments (or plane segments in 3D) based on a 3 x 3 block of cells.

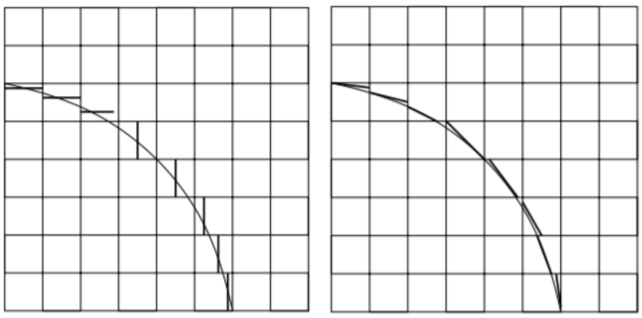

Figure 1: SLIC/PLIC comparison

INTERFACE RECONSTRUCTION

The interface reconstruction is the first step in a VOF method. In this paper only the PLIC approach recently add into the software will be detailed. The interface in each cell is approximated by a line (or a plane in three dimension). Within each cell, the interface is approximated by the equation:

$$\boldsymbol{n}.\boldsymbol{x} = n_x x + n_y y + n_z z = D \qquad (2)$$

Where $\boldsymbol{n}$ is the local surface normal, $\boldsymbol{x}$ is the position vector of a point on the interface and D is a constant which is related to the shortest distance from the origin of the cell. Essentially, the interface reconstruction involves two procedures: the determination of $\boldsymbol{n}$ and D.

$\boldsymbol{n}$ is calculated using the data in neighboring cells. There are many algorithms to compute the local surface normal, among them are four methods frequently used: The Parker and Youngs' method [3] which is the one implemented, the least squares gradient technique [4], the Mixed Youngs-centered implementation [5] and the ELVIRA scheme [6]. All these methods aim to obtain the most accurate value of the normal from the following equation,

$$\boldsymbol{n} = -\frac{\nabla C}{|\nabla C|} \qquad (3)$$

All of these methods must overcome the discontinuity of the volume fraction field. Thus, computation of $\boldsymbol{n}$ can be complicate and expensive to obtain a truly second-order reconstruction method. The determination of D can then be expressed in general with the following equation which is the inverse problem in the forward and inverse problems method used to advect the interface.

$$D = f^{-1}(\boldsymbol{n}, C_{i,j}) \qquad (4)$$

Several approaches have been proposed for computation of D, which can be classified as analytical and iterative methods. Analytical methods are dependent to mesh dimensions and structure but computationally cheaper.

INTERFACE ADVECTION

After the orientation and location of the interface is determined, the volume fraction field is advected by the transport equation. The operator split scheme computes fluxes to solve the transport equation during a time step. Let us consider the first relation in the advection scheme and discretize it in a grid cell such as illustrated in Figure , we obtain the following equation,

$$C_{i,j}{}^{*} = C^{n}{}_{i,j} - \Delta t \left[\frac{(uC)^{n}{}_{i+\frac{1}{2},j} - (uC)^{n}{}_{i-\frac{1}{2},j}}{\Delta x_{i,j}}\right] + \Delta t F^{n}{}_{i,j}\left[\frac{u^{n}{}_{i+\frac{1}{2},j} - u^{n}{}_{i-\frac{1}{2},j}}{\Delta x_{i,j}}\right] \quad (5)$$

where $u_{i+\frac{1}{2},j}$ is the velocity component at the center of the right cell boundary. Suppose that $u_{i+\frac{1}{2},j}$ is positive and divides the cell into two parts, with areas $u_{i+\frac{1}{2},j}\Delta t\Delta y_{i,j}$ on the right and $(\Delta x_{i,j} - u_{i+\frac{1}{2},j}\Delta t)\Delta y_{i,j}$ on the left. The amount of fluid contained in $u_{i+\frac{1}{2},j}\Delta t\Delta y_{i,j}$ and illustrated as the light blue area will be advected across the right cell face during this time step. If $V^{n}{}_{i+\frac{1}{2},j}$ denotes the light blue area corresponding to the initial C^{n} field, then the approximate volume fraction at the right cell face $C^{n}{}_{i+\frac{1}{2},j}$ can be written as,

$$C^{n}{}_{i+\frac{1}{2},j} = \frac{V^{n}{}_{i+\frac{1}{2},j}}{u^{n}{}_{i+\frac{1}{2},j}\Delta t\Delta y_{i,j}} \quad (6)$$

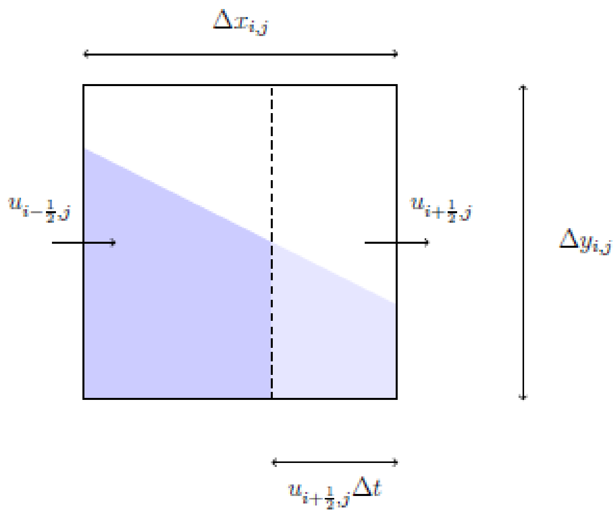

Figure 2: The amount of fluid illustrated as the light blue area crosses the right cell edge in a splitting advection.

In a VOF method, this flux can be calculated by the interface reconstructed. It is called the forward problem that can be expressed with the general equation,

$$C = f(\boldsymbol{n}, D) \quad (7)$$

This PLIC method described in this section has been developed into SPEED and is tested in the next section. The next section presents a comparison between SLIC method and PLIC method in a basic example.

MOVING CROSS TEST 2D PLANE-STRAIN

The PLIC method described above was implemented in the commercial hydrocode SPEED [8] and its performance tested against the standard SLIC method in an "academic" benchmark simulation.

In this test a water cross with a length of 30 mm, a width of 30 mm and squared branches of 10 mm by 10 mm located at (50 mm, 75 mm) inside a (100 mm, 100 mm) box with a mesh size equals to 2 mm to obtain a 50^2 grid. The cross is put in a velocity field of (v_x = 1 m/s, v_y = 1 m/s). Results for both SLIC and PLIC method are then compared at 10 ms.

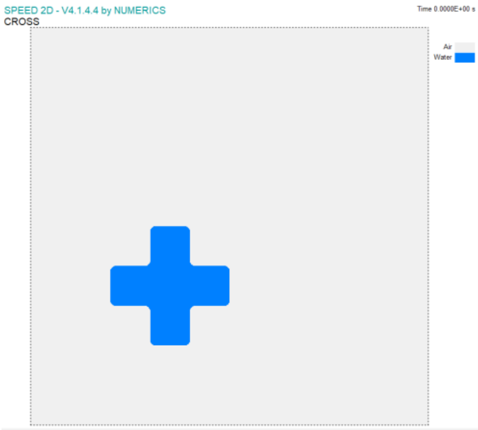

Figure 3: Initial position, velocity field (v_x = 1 m/s, v_y = 1 m/s), 50x50 grid

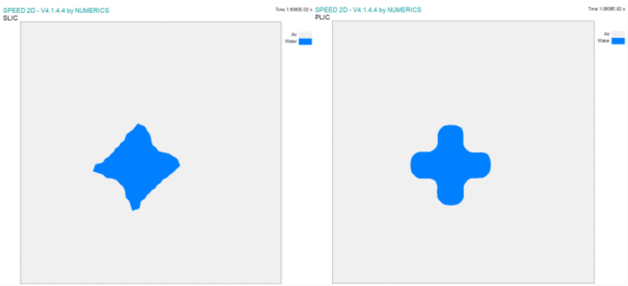

Figure 4: Comparison SLIC and PLIC results at t = 10 ms

For this first test we see the impact of the PLIC method on the cross geometry. The diffusion is deeply reduced with this piecewise interface reconstruction and the general cross geometry is more accurate with the new PLIC method.

In a second step, the geometry error and simulation time evolutions with the mesh dimensions were studied to compare SLIC and PLIC convergence.
Table 1 shows the simulation time of the water translating cross during 10 ms in the velocity field (v_x = 1 m/s, v_y = 1 m/s) for different mesh sizes.

Table 1: Simulation time for the water cross in translation

Mesh	SLIC	PLIC
64^2	< 1 min	1 min
128^2	3 min	7 min
256^2	23 min	52 min

As expected, the PLIC method has a higher computational cost (about factor 2) but both SLIC and PLIC method exhibit the same increase in simulation time with an increasing number of elements, i.e. four times the number of elements leads to four times the simulation time. Figures 5 and 6 show the final geometries of the moving cross for the different mesh sizes at 10 ms.

Figure 5: SLIC results for $64^2/128^2/256^2$ grids

Figure 6: PLIC results for $64^2/128^2/256^2$ grids

Results show good convergence with number of elements. Nevertheless, PLIC presents a low geometry error for a low number of elements.

For a same number of elements, SLIC method is certainly less computational expensive but can create significant errors that the PLIC method corrects for a reasonable computational cost. This theorical example permits to understand more about improvements with the PLIC method. The next section shows a practical example which underlines the role of local interface reconstruction in parameter studies.

APPLICATION EXAMPLE: 2D AXISYMMETRIC SHAPED CHARGE JET FORMATION

In this section the application of the method to the practical problem of the simulation of a shaped charge jet formation is presented. This practical example is realized with a 2D axisymmetric model. The copper liner is a cone with a radius of 52.5 mm, a height of 105.2 mm, a thickness of 3 mm and a mass of 0.8 kg. The explosive used is 3.74 kg Octol charge with a density of 1809 kg/m³. The wave shaper is made of aluminum 6061-T6. The mesh is a 120x585 mm grid resulting in 242 190 elements. This setup is presented in the Figure 7.

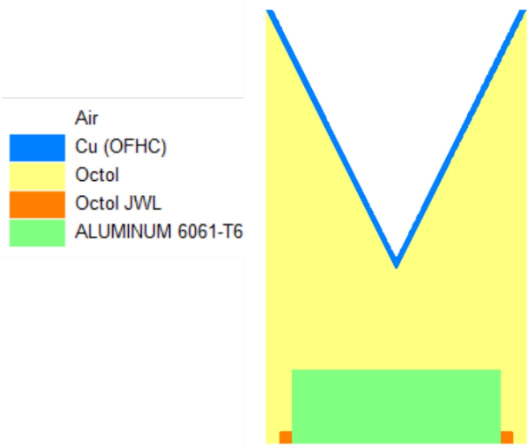

Figure 7: Shaped charge simulation model with lateral initiation

Figure 8 shows the simulation result after 60 µs (here exemplarily with the SLIC method). The (qualitative) difference between the two methods can already be seen when the jet tips are compared (Figure 9). With the PLIC method the expected continuity at jet tip is conserved and the material distribution along the jet is generally smoother than in the simulation with SLIC.

Figure 8: Shaped charge profile at t = 60 µs (SLIC method)

Figure 9: Zoom on the collapse zone of the shaped charge jet: simulation with SLIC (top) and PLIC (bottom)

The quantitative difference becomes especially obvious in the evaluation of the velocity profiles at the jet tip in Figure 10. With the SLIC method, small amounts of slower material can be observed in front of the jet, whereas the jet tip in the simulation with the PLIC method shows a continuous velocity gradient. Experimental results are not available for comparison but the simulation with PLIC seems to yield a more consistent result.

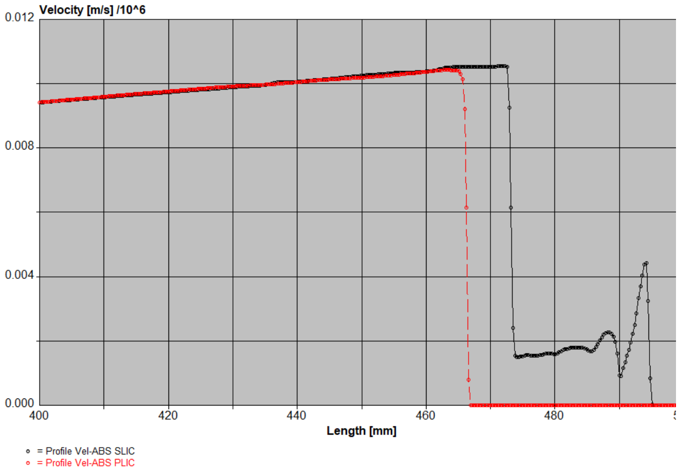

Figure 11: Comparison SLIC/PLIC of the velocity profile along the radial axe

CONCLUSION

In summary, the VOF-PLIC scheme is a volume fraction-based method to track interface. In the first test, a comparison between SLIC and PLIC method is presented with a theorical example. This comparison showed that the interface tracking with the piecewise reconstruction is more precise but also more computationally costly. However, applying the presented PLIC method to reconstruct local interfaces with piecewise lines plays noticeable role in final geometries calculation. With PLIC, the material distribution in the computational grid is improved, which eventually leads to a more precise calculation as presented in the application example. It is thus concluded that the PLIC method offers great returns on the computational investment.

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DEVELOPMENT AND TESTING OF A LARGE-AREA SKIN SIMULANT

by Amy Pullen[1], Dylan Allison[1]

[1] Defence Technology Agency, New Zealand Defence Force

INTRODUCTION

There is a requirement to simulate human skin in both wound ballistics and forensic investigations. The skin simulant should have similar mechanical properties when compared to Post-Mortem Human Subject (PMHS) skin. Previous skin simulants have included pigskin backed by 10% gelatin at 4°C [1-3] and synthetic skin simulants which have included sheet rubber, cowhide, synthetic chamois backed by gelatin, 12% gelatin, inner tubing of tyres and polydimethylsiloxane (PDMS) composite [1-5]. Furthermore, skin simulants have a significantly different performance depending on the selection of backing material and therefore it is essential to validate the skin simulant in conjunction with the intended backing material.

Traditional penetration testing is conducted on small scale, however there is an additional requirement to evaluate skin penetration in large scale arena trials. The skin simulant materials used in small scale testing may not be suitable for use in large scale trials due to cost, resources, and experimental methodology. Therefore, this study aims to identify a skin simulant and backing material that is low cost and uses materials that are readily available for use in large scale arena trials.

METHOD

A search was conducted of low cost and readily available materials used in the building, craft, and clothing industry for use as skin simulants and backing materials. Seven candidate materials were selected as skin simulants and two materials were selected as backing materials. ADOS spray adhesive was used to bond the surface material to the backing material.

Table 1: Surface and Backing materials.

Surface material
PP SMOOTH GRAIN PLEATHER, WHT, 132CH - 9349336673368
BANDERA FAUX SUEDE, SLT, 142CM – 9349336357466 (1m)
NDLE PUNCH POLY WADDIING, WHT, 75CM - 0000064178707
POLY LOW LOFT WADDING, WHT, 106CM - 0000064178686
MASONS FLOOR GUARD 1.2MX20M
EVA FOAM SHT
RUBBER SHT 1.5X1200 – P052028
Backing material
FILLER BOARD 760 X 1020MM 2100 MICRON GREY LONG GRAIN. – 15076010202100LUL
HAYDN SURFACESHIELDS 30.48X0.965M PROTECTION

The study took a three-phased approach and is detailed below. Skin penetration should be conducted using a selection of different projectile sizes. Four ball bearing sizes, each with a different sectional density, were selected as non-deforming projectiles. For a material combination to qualify as a suitable simulant, the experimental V_{50} values must be within +/- 35% of the skin simulant V_{50} validation formula "$V_{50} = 134S^{-0.35}$", with "S" denoting sectional density of the projectile [1,3].

Phase 1 - Preliminary down select – The down selection consisted of initially testing with a single projectile type, using a 4.5mm ball bearing (BB) with a sectional density of 2.1g/cm^2. V_{50} perforation results near the upper and lower V_{50} boundaries of the validation formula provided a strong indication of the materials probability of falling within the acceptance corridor when the full projectile range was tested. If <u>no</u> perforation was achieved at the lower velocity boundary and perforation <u>was</u> achieved at the higher velocity, then the skin simulant sample was considered to have passed the preliminary down select. Material combinations were also considered for elimination if other performance issues were identified during testing and analysis.

Phase 2 – Base testing process – This consisted of using an air rifle and a gas gun (Figure 1) to fire the four ball bearing types, with different sectional densities (Table 2), against all the materials which passed phase 1. The V_{50} results from each of the ball bearing and material combinations were then evaluated against the validation formula.

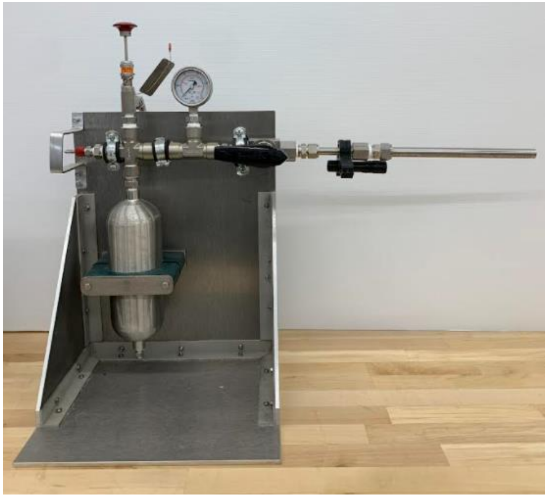

Figure 1: Compressed nitrogen gas gun.

Skin simulant and backing material candidates which produced V_{50} test results within the margin of error corridor (between upper and lower limit) for all the non-deforming projectiles were consider having passed phase 2 testing.

Table 2: Sectional densities evaluated.

Non-deforming projectiles		
BB diameter (cm)	Mass (g)	Sectional density (g/cm^2)
0.45	0.34	2.1
0.6	0.88	3.1
0.87	2.71	4.5
1.27	8.36	6.6

Phase 3 – Final testing process – This consisted of re-testing material combinations which passed phase 2 an additional 4 times to provide statistical robustness and to identify any variation in material properties.

RESULTS

Phase 1 - Preliminary down select - Nine material combinations passed the initial down selection on phase 1. However, only three material combinations were brought forward from phase 1 for further evaluation (see table 3 and 4). The six other material combinations were eliminated for the following reasons *:

a. Poor material stiffness.
b. Inconsistency in material uniformity.
c. Difficulty in indicating penetration or perforation due to colour.
d. Failed V_{50}.

Table 3: Filler board backing material results.

Material and Filler board backing		
Surface Material	Pass/Fail (V_{50})	Selected
PP SMOOTH GRAIN PLEATHER	Pass	Yes
BANDERA FAUX SUEDE	Pass	Yes
NDLE PUNCH POLY WADDIING	Pass	No (b,c)*
POLY LOW LOFT WADDING	Pass	No (b,c)*
MASONS FLOOR	Pass	Yes
RUBBER SHT	Fail	No (d)*
EVA FOAM SHT	Pass	No (c)*

Table 4: Haydn surface shield backing material.

Material and Haydn Surface shields backing		
Surface Material	Pass/Fail (V_{50})	Selected
PP SMOOTH GRAIN PLEATHER	Pass	No (a)*
BANDERA FAUX SUEDE	Pass	No (a)*
NDLE PUNCH POLY WADDIING	Fail	No (d)*
POLY LOW LOFT WADDING	Fail	No (d)*
MASONS FLOOR	Pass	No (a)*
RUBBER SHT	Fail	No (d)*
EVA FOAM SHT	Fail	No (d)*

Phase 2 – Base testing process – From the three materials which were brought forward from phase 1 only one material combination passed this phase by performing within its V_{50} corridor across each of the sectional densities.

Table 5: Phase 2 Test results

Material Combination	Pass/Fail (V_{50})	Selected
PP SMOOTH GRAIN PLEATHER + FILLER BOARD	Fail	No (failed V_{50} for 6.6g/cm² sectional density)
BANDERA FAUX SUEDE + FILLER BOARD	Pass	Yes
MASONS FLOOR + FILLER BOARD	Fail	No (failed 4.5g/cm² and 6.6g/cm² sectional densities)

Phase 3 – Final confirmation testing - The BANDERA FAUX SUEDE WITH FILLER BOARD backing was brought forward for additional V_{50} confirmation testing.

All five test results for the four sectional densities were compiled to provide an overall average result (Figure 2).

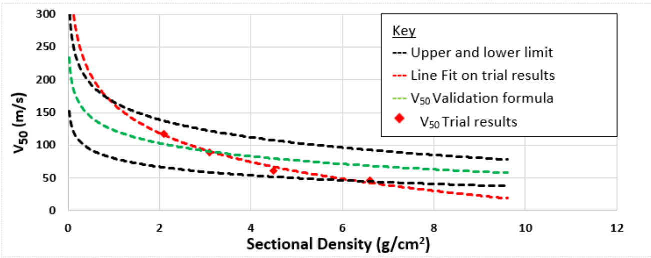

Figure 2: Phase 3 BANDERA FAUX SUEDE/FILLER BOARD results.

DISCUSSION

The 3-phase test methodology significantly shortened the testing time and complexity of the large area skin simulant evaluation.

ADOS spray adhesive increases the rigidity of the large-area skin simulants through bonding of the front face to the backing material.

Based on the test result, BANDERA FAUX SUEDE skin simulant, with filler board backing, performed well against the 4 sectional densities. However, if sectional densities less than 1g/cm² or greater than 6.6g/cm² were to be used then the performance of the skin simulant is predicted to fall outside the upper and lower limits of the validation formula corridor.

To maintain consistent mechanical properties, it is critical that the BANDERA FAUX SUEDE material combination is only used when moisture free.

In addition to fragment penetration damage, blast test trials generate pressure waves which can cause significant damage to the large-area skin simulant panels. This can be mitigated by increasing the stand-off distance.

Due to potential variability between material batches a skin simulant should undergo a single stage batch validation test before use to confirm that its performance matches that of the current approved material.

CONCLUSIONS

BANDERA FAUX SUEDE WITH FILLER BOARD BACKING performs to the required standard and is suitable for use in a large-scale arena trials to identify the likelihood of skin perforation from fragmentation.

ACKNOWLEDGMENT

Research funded by the Defence Technology Agency, New Zealand Defence Force.

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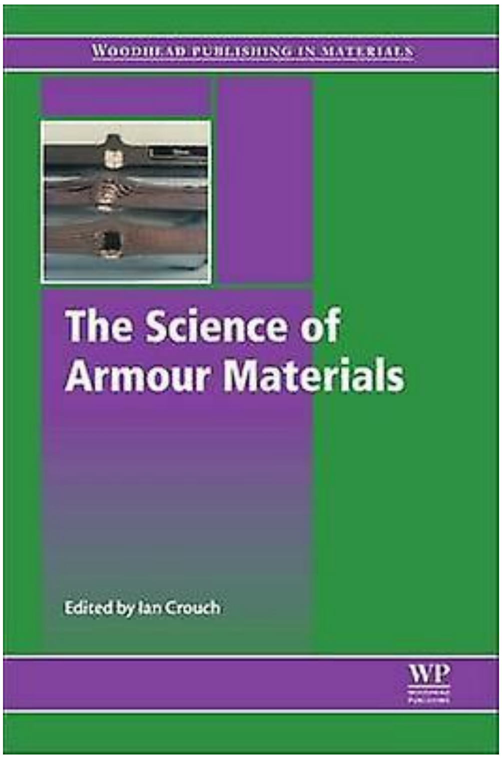
BOOK REVIEW

by T. Hartmann
NUMERICS GmbH, Germany

In this issue we present a book for those seeking a compact overview over armor materials and their terminal ballistics behavior:



EDITOR: **Ian G. Crouch**

PUBLISHER: **Woodhead Publishing, Cambridge UK**

PAGES: **715**

FORMAT: **Hardback, eBook**

ISBN: **9780081010020**

The book at hand was published in 2017 and was written during the editor's time working at the RMIT university in Victory, Australia.

Having passed an introduction, a foreword, a preface and a forethought, the book offers a comprehensive overview over the most important armor materials like steel, light alloys (Al, Ti and Mg), laminates, polymers and FRP (with a separate chapter on fibers and textiles) and glass / ceramics.

In the first chapter, the "general framework" is defined, i.e. all issues like the operational environment, basics of armor design, but also physical effects, etc. are addressed. Thereby, the all topics are kept on a descriptive level avoiding any mathematics and just explaining the respective effects and phenomena. Even the 16 pages long section on "Penetration mechanics and failure modes" goes without a single equation!

Before you stop reading: mathematics and physics, respectively, are covered later in the book. The previous statement was meant in a positive way: how the topics are described just by words and figures is very comprehensive and will provide a certain basic understanding especially for all who are new to the topic (and for those who are allergic to mathematics).

In the following chapters, for each material a brief history is provided and the typical material properties and classifications are described. Specific protective effects and related failure modes are explained. A series of application examples and experimental tests are provided and the advantages and disadvantages of the specific materials are discussed. This gives the reader a good understanding of the strengths and weaknesses of different materials and their possible applications.

Two chapters of the book then deal with analytical and numerical modeling. Starting with the different phases of a penetration event and hydrodynamic theory, different empirical (e.g. THOR) and analytical models for metal targets but also for other materials are presented. This also covers the modeling of failure in the respective materials. Even though the chapter on analytical modeling cannot cover all model approaches, it gives some details on the most important models. On the first view, empirical equations / models thereby seem to be slightly over-represented regarding their usually either narrow range of application or low accuracy. However, they can provide means for a rapid estimation and thus still have practical relevance.

The chapter on numerical modeling gives an introduction to hydrocodes and describes the most popular constitutive models for volumetric material behavior and for strength and damage (with a certain focus on the LS-Dyna software). Also here, mathematical descriptions are reduced to a minimum emphasizing the introductory character of the book.

Typically, material models become popular when a large number of parameter sets for different materials is published. It is thus not surprising that only the well-known models like Johnson-Cook are presented. Less well-known but upcoming (and probably more favorable) models like e.g. the Xue-Wierzbicki damage model are left out. However, a series of material parameter sets for the described models is provided in tables (presumably due to the fact that LS-Dyna does not include a material library).

Another two chapters regard high-dynamic material and ballistic testing, where the latter mainly provides guidelines and specific recommendations for different testing aspects. For the material testing different test methods and test setups ranging from low velocity drop-weight tests to hypervelocity impact tests with a gas gun or Split-Hopkinson Pressure Bar (SHPB) tests are described and discussed. The respective instrumentation and the results gained from the tests are explained.

Finally, an outlook on future trend in armor materials and armor systems is given.

On the book cover, it is claimed that: ”This book provides a cross-disciplinary approach that brings together expertise in material science and defence engineering, […]”. After studying the book, I can confirm this statement. In summary, the book provides a broad overview over the complete field of armor science. It is very comprehensible with many illustrations and test results supporting the various descriptions and statements.

However, in contrast to the book cover, I would not rate it as suitable for practically everybody. It seems ideal as an introduction for people who are new in the field of armor materials (no matter if they are postgraduates or senior managers), whereas engineers and scientists already working in this field for some time will probably find just a few new aspects.

DID YOU KNOW…?

…that The Halifax Explosion in 1917 was the largest accidental human-made explosion releasing the equivalent energy of roughly 2.9 kilotons of TNT (12 TJ)?

The Halifax Explosion was a disaster that occurred in Halifax, Nova Scotia, Canada, on the morning of 6 December 1917. The SS Mont-Blanc, a French cargo ship fully loaded with the explosives TNT and picric acid, the highly flammable fuel benzol and guncotton, collided with the Norwegian vessel SS Imo in the Narrows, a strait connecting the upper Halifax Harbour to Bedford Basin. A fire on board the Mont-Blanc led to a massive explosion that devastated the Richmond district of Halifax. Every building within a 2.6-kilometre (1.6 mi) radius, over 12,000 in total, was destroyed or badly damaged. Hundreds of people who had been watching the fire from their homes were blinded when the blast wave shattered the windows in front of them. A part of the anchor hit the ground more than 4 km away on the far side of Northwest Arm and a gun barrel landed in Dartmouth more than 5 km from the harbour. The explosion caused a tsunami that washed up as high as 18 meters above the harbour's high-water mark on the Halifax side. The tsunami even lifted Imo onto the Dartmouth shore. Approximately 2,000 people were killed, largely in Halifax and Dartmouth, by the blast, debris, fires, or collapsed buildings, and an estimated 9,000 others were injured.

View across the devastated neighbourhood of Richmond in Halifax (Reference no.: NSARM / negative: DNDHfxExplosion-2)

The Norwegian steamship Imo (ex. Runic (I), 1889) aground on Dartmouth shore (Reference no.: NSARM / negative: N-138)

The disaster had a word-wide impact and many safety-related changes were made after the Halifax Explosion, including new rules for storage of hazardous materials and harbour navigation.

32ND INTERNATIONAL SYMPOSIUM ON BALLISTICS

RENO, NEVADA MAY 2022

The International Symposium on Ballistics (ISB) traditionally allows exposure to the most current state-of-the-art technology in ballistics, provides opportunities for interactions with some of the world's leading experts in the field of ballistics technology and offers the chance to present, exhibit and share scientific research and development with international group of professionals.

The International Symposium on Ballistics brings together experts to promote and facilitate the exchange of technical information; establish standards; effect coordination of research, exploratory development, and advanced development programs in the fields of External and Internal Ballistics, Launch Dynamics, Terminal Ballistics, Vulnerability and Survivability, Explosion Mechanics, and Emerging Technologies (Directed Energy and Hypersonics); and accomplish problem solving in areas of joint interest.

The society encourages the presentation of a wide range of papers at the ISB, from work in progress through to high quality scientific papers. This is an exciting opportunity to learn and share with others in the field.

As the venue for the upcoming 32nd International Symposium on Ballistics, the Board of Directors has selected Reno, Nevada, USA. The ISB will take place May 9-13, 2022.

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For more information on sponsorships, exhibiting, and attending contact Clay Tyeryar at ctyeryar@asmii.net or +1 (703) 533-0251.

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IMPORTANT DATES

Full paper submission is due on 30 January 2022. Please follow the paper guidelines and upload your contribution together with the form to release your copyright to the International Ballistics Society.

Please note that you will need the proposal ID number provided in the acceptance notification to successfully upload your paper! Further, the "Upload link" (also provided in the acceptance notification) must be used to upload your paper and copyright release form.

Early registration will end on 01 February and regular registration will be possible thru 15 April 2022.

TUTORIAL PROGRAM PLANNED FOR RENO

by Markus Graswald,
Chair Education Committee

Tutorial courses were and will remain an integral part of each International Symposium on Ballistics. Based on calls in 2020 and 2021, we received broad interests and various course proposals by world-known experts in their respective fields. The Education Committee had to make hard decisions for providing a well-balanced set of introductory courses. So, we happily announce offering the following four short courses at the upcoming 32nd ISB in Reno, Nevada, USA, in 2022:

- TB101: Introduction to Terminal Ballistics by Dr James Walker, SwRI, USA
- EB101: Introduction to Exterior Ballistics by Dr. Pierre Wey, ISL, France
- EM101: Introduction to Explosion Mechanics by Dr Meir Mayseless, Retired, Israel
- IB101: Introduction to Interior Ballistics and the Propellant Charge Design Process by Dr. Sebastian Wurster, Fraunhofer ICT, Germany

These courses will be organized by the Education Committee and facilitated by ASMI. We pursue a hybrid approach for members personally attending on-site and a parallel, interactive live stream to registered attendees. You will find further details on these courses and lecturers on our IBS website. Course registration can be made either during registration for the conference or on-site in Reno.

We look forward to your feedback and any questions you may have through sending an email to education@ballistics.org.

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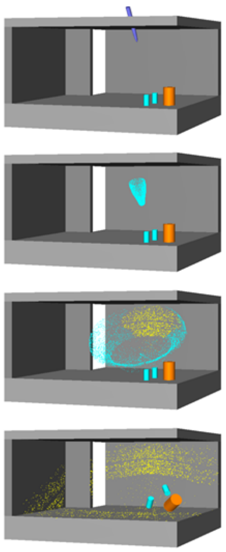

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中国兵工学会

China Ordnance Society

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The purpose of the China Ordnance Society is to serve the defense construction and economic development by organizing science and technology workers and to promote and develop scientific ideas and disciplines. Its main task is to organize academic exchange, publish academic periodicals, promote the development of science and technology, propagate scientific information and popularize scientific knowledge.

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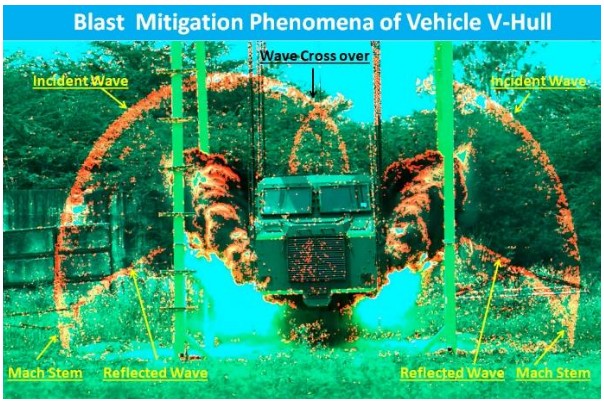

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